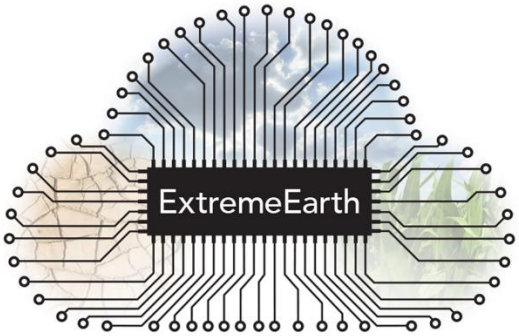
ExtremeEarth Preparatory Project

ExtremeEarth-PP



No.*	Participant organisation name	Short	Country
1 (Co)	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS	ECMWF	INT/ UK
2	UNIVERSITY OF OXFORD	UOXF	UK
3	MAX-PLANCK-GESELLSCHAFT	MPG	DE
4	FORSCHUNGSZENTRUM JUELICH GMBH	FZJ	DE
5	ETH ZUERICH	ETHZ	CH
6	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	CNRS	FR
7	FONDAZIONE CENTRO EURO-MEDITERRANEOSUI CAMBIAMENTI CLIMATICI	CMCC	IT
8	STICHTING NETHERLANDS ESCIENCE CENTER	NLeSC	NL
9	STICHTING DELTARES	Deltares	NL
10	DANMARKS TEKNISKE UNIVERSITET	DTU	DK
11	JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION	JRC	INT/ BE
12	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	BSC	ES
13	STICHTING INTERNATIONAL RED CROSS RED CRESCENT CENTRE ON CLIMATE CHANGE AND DISASTER PREPAREDNESS	RedC	NL
14	UNITED KINGDOM RESEARCH AND INNOVATION	UKRI	UK
15	UNIVERSITEIT UTRECHT	UUT	NL
16	METEO-FRANCE	MF	FR
17	ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA	INGV	IT
18	HELSINGIN YLIOPISTO	UHELS	FI

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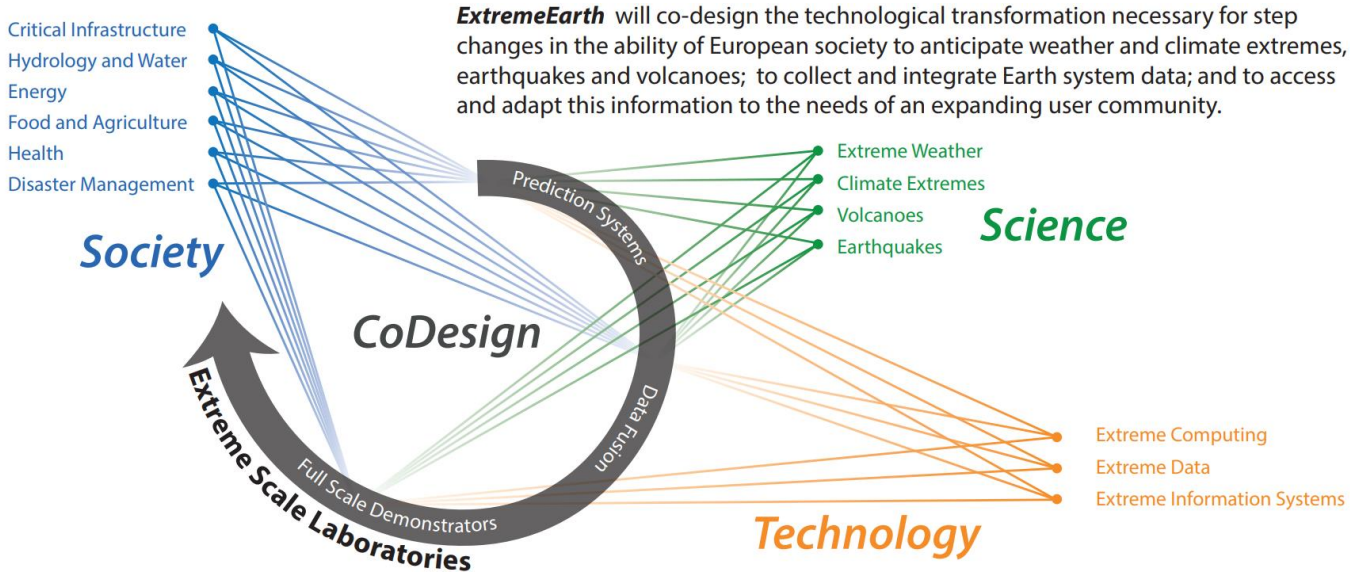


Figure 1: Basic elements of the ExtremeEarth vision of dissolving boundaries between Science, Society and Technology to advance society's capacity to anticipate Earth extremes.

1.1 Vision and unifying goal

1.1.1 The need for *ExtremeEarth*

Europe and Europeans are impacted by natural hazards, even when these events play out far away. Prior to 1990, losses from natural disasters worldwide were estimated to never have exceeded €100 billion in a single year. Since 2005, losses from natural disasters exceeded €200 billion in four different years. Alone in 2017, natural disasters caused €300 billion in losses, only 2005 was costlier. These disasters are manifestations of extreme events in the Earth system. Meteorological and hydrological extremes — from winds and rain — are typically responsible for the greatest losses. Not only hurricanes, but also winter storms, the strongest of which — like Kyrill in 2007 — can inflict damages greater than €5 billion[1]. Damages from widespread flooding in Europe can exceed €10 billion in a bad year, as was the case in 2002 and again in 2013[2]. Extremes in air-pollution have a staggering effect, as measured by foreshortened lives[3]. Heat-waves, droughts, and fires are examples of climatic extremes associated with global costs near €100 billion annually. The 2003 European heat wave and drought affected over 100 million EU citizens with a cost of at least €10 billion and a death toll exceeding 70,000[4]. Extreme conditions across the northern hemisphere this past summer are playing havoc with societies across three continents. Within the solid Earth, extremes – particularly earthquakes – are responsible for commensurate losses. The 1999 Izmit earthquake (Turkey) measured 7.6 on the Richter scale and killed 17,000 people, while in L'Aquila a moderate 5.9 magnitude quake killed more than 300 people and destroyed much of the city. Volcanic eruptions menace large urban areas (e.g., Naples with 3 million people at risk from Vesuvius and Campi Flegre in Europe) and even small distant volcanoes can prove enormously disruptive to commerce, e.g., the 2010 Ejafjallajökull eruption, which shut down air traffic operations over central-northern Europe for several days.

European exposure to extremes is compounded by large shifts in populations and infrastructure, and — as Ejafjallajökull showed — increasing connectivity in economies and infrastructure. The same technologies that

[1] https://public.wmo.int/en/media/press-release/joint-press-release-wmocreducl-atlas-of-mortality-and-economic-losses-from
[2] https://www.munichre.com/en/media-relations/publications/press-releases/2013/2013-07-09-press-release/index.html
[3] https://www.mpg.de/12118117/air-pollution-cause-of-death
[4] Robine et al., 2008: Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies, 331 (2), 171–178.

enable this connectivity create possibilities for reducing vulnerabilities it would otherwise imply. *ExtremeEarth* will capitalise on these to transform the technological infrastructure underpinning the prediction of weather and climate extremes, earthquakes and volcanoes, and how their impacts are assessed and communicated (see Fig. 1).

Technology developed by *ExtremeEarth* will: (i) enable a new class of models to provide a suitable and science-driven foundation for anticipating extremes; (ii) create the capacity to assimilate new or previously un-usable data streams to document precursors and consequences of extremes; (iii) reinvent the value chain (linking predictions to impacts) by developing the tools and syntax to intuitively expose information about the past and future of the Earth system to the full ingenuity of disparate actors and socio-economic sectors. In doing so *ExtremeEarth* will build upon and strengthen European excellence in geosciences, support European institutions, and launch a new wave of innovation at the intersection of the geo and information sciences.

In giving society the tools to meaningfully anticipate future extremes and turn the tide on growing cost (in lives and money) of natural disasters, *ExtremeEarth* will materially improve the well-being of everyone.

1.1.2 The science case

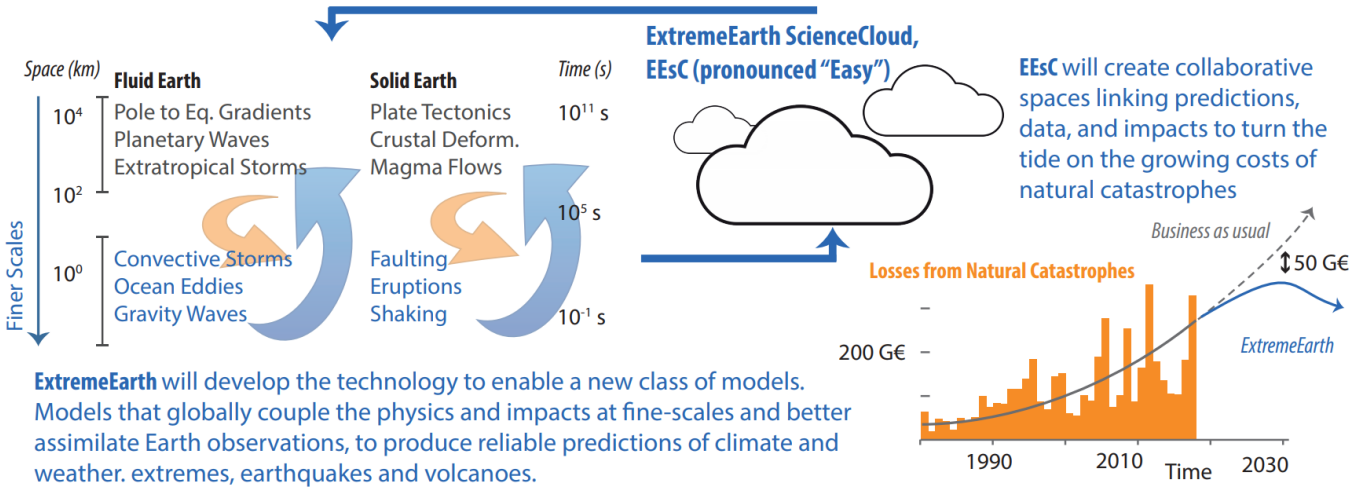


Figure 2: ExtremeEarth will re-invent the value chain through the ExtremeEarth science Cloud, EEsC (pronounced "Easy").

Decades of advances in high-performance computing (HPC) have brought us to a threshold. It is now possible to conceive of new classes of models[5], ones much better grounded in the laws of physics, providing less biased, more reliable, and hence useful, predictions and assessments of extremes. To operationally realize the potential of these models requires, however, at least a 1000-fold increase in the computational capacity realized by our most performant prediction systems[6]. For operational models of the global atmosphere and ocean, a factor of 1000 means that it becomes possible, for the first time, to replace crude statistical models of crucial climate processes (called 'parameterisations') by an explicit representation of these processes, one grounded in fundamental physics[7]. This would enable weather forecasts and climate projections by models that directly simulate the transient dynamics of crucial small (km) scale processes — ocean eddies, precipitating deep convection, gravity waves, ice fracture, the interaction of flows with local orography and bathymetry — whose detailed interaction with global circulation systems preconditions most weather and climate extremes[8]. Given the extent to which the current, and inadequate, representation of such processes limits our present ability to usefully anticipate future changes in climate and weather, such a development will be a game changer[9] (as illustrated in Fig. 2).

For models of the solid Earth, a 1000-fold increase in computational capacity would allow models of the solid Earth to break free from a dependence on statistical and piecemeal modelling approaches[10][11]. Only on this scale of computation is it possible to encapsulate advances in understanding of rupture phenomena, magma flow, and wave propagation in heterogeneous media and integrate it with large-scale models of the solid Earth. Multi-scale and multi-physics models expressing these couplings will enable predictions of the spatial and temporal distribution of earthquakes, their initiation and rupture and the resultant seismic shaking at frequencies most relevant for the built environment. Applied to volcanic eruptions, this computational capacity will lead to the first systems capable of predicting the initiation of an eruption, the space-time evolution of the eruption dynamics, and its remote impacts.

[5] Bony et al., 2015: Clouds, circulation and climate sensitivity. Nature Geoscience, 8, 261–268.
[6] Bauer et al., 2015: The quiet revolution of numerical weather prediction. Nature, doi:10.1038/nature14956.
[7] Stevens and Bony, 2013: What Are Climate Models Missing? Science, 340(6136), 1053–1054.
[8] Zhang et al., 2003: Effects of moist convection on mesoscale predictability. Journal of the Atmospheric Sciences, 60, 1173-1185,
[9] Shepherd, 2014: Atmospheric circulation as a source of uncertainty in climate change projections, Nature Geoscience, 7, 703-708.
[10] Giardini et al., 2014: Mapping Europe's seismic hazard. EOS, 95(29), www.efehr.org.
[11] Selva et al., 2012: Operational eruption forecasting at high-risk volcanoes: the case of Campi Flegrei, Naples. Journal of Applied Volcanology, 1: 5. https://doi.org/10.1186/2191-5040-1-5.

By creating models that can efficiently, consistently, and physically link small-scale and local processes to global circulation, fault, or large-scale magma systems, new horizons in high-end data analysis and data assimilation[12] are also opened. For instance, physical models integrating earthquake dynamics on complex fault geometries with real-time data assimilation from near-fault observatories will be constructed, to identify possible precursors and to map the initiation and evolution of rupture. Similarly, physical models of the coupled dynamics in volcanic sub-domains will be integrated with automatic signal detection from massive analysis of data from multi-parametric volcano monitoring systems to resolve the deep volcano dynamics and anticipate eruptions.

Across both fluid and solid Earth, the limitations in the physics of existing models render enormous amounts of information as unusable. Better, more physically based models that explicitly represent the scale at which diverse, heterogeneous, and increasingly unconventional observing systems collect their data, make it possible to assimilate the information. In addition, and not to be underestimated, the computational advances underpinning advances in the quality of models will enable ensemble approaches[13]. This, in itself, opens up new possibilities in data assimilation as well as quantification of uncertainties in a probabilistic framework.

1.1.3 The technology case

In the past, achieving a factor of 1000 in computational and data handling throughput for real-world applications has taken 20 years, and was mostly produced by computer chip advancement alone. In the absence of considerable effort, and nearing the end of Moore's law[14], a factor of 1000 is unachievable — even if one were willing to wait 20 years. Just as technology evolves to a point where breakthroughs come into focus, its development shifts course in ways that (almost cruelly) threaten to keep them out of reach — at least for those pursuing business as usual. Changing how we compute and deal with data, and dispensing with business as usual, is at the heart of *ExtremeEarth*.

To expand the throughput of the currently most performant systems by a factor of 1000 will require a radical re-design of current software frameworks and hardware systems. A full integration of computing, data and connectivity is envisaged, one where HPC and cloud technology will converge, around institutional, industrial as well as transnational, initiatives such as the European Open Science Cloud (EOSC) and EuroHPC[15]. To meet that challenge *ExtremeEarth* will adopt a contemporary approach to software ingesting components that are widely supported in the information and communications technology (ICT) industry and that are part of the main roadmaps of digital technology development. In this way, *ExtremeEarth* will bring a new quality to the European HPC programme, one that is fundamentally different from the prestige driven, exa-scale computing developments in East Asia and the USA, and that is more likely to succeed.

ExtremeEarth will be application driven. Only a new system design at exa-scale for computing, data handling and user-connectivity can achieve this aim. The system will capitalise on joint HPC and cloud technologies to develop optimised hardware-software linkages[16] that achieve the required throughput for real world applications, thus achieving the *ExtremeEarth* science objectives and making a new way of working possible for all users. The application-driven approach proposed by *ExtremeEarth* can only be made to happen by a concerted effort with substantial and sustained funding – and it requires a focused science-technology co-design and co-development over a long (10 year) timescale. Furthermore, this must take place in ways that integrate input from diverse communities to produce systems that effectively address their needs, yet remain agile enough to allow efficient adaptation to changing computational architectures in the future.

Data handling in *ExtremeEarth* represents a similarly extreme challenge in terms of both data volume and diversity. Current technologies and workflows dealing with the kind of data *ExtremeEarth* envisages are either unavailable or very limited in their scope and flexibility. *ExtremeEarth* must therefore also embark on the co-design of information and communication technology solutions for the efficient and timely handling of diverse data being produced by high-definition models and observational sensor networks at rates far in exceedance of what could be accommodated by incremental advances to existing systems.

To fully exploit this model-data fusion *ExtremeEarth* introduces the idea of the *ExtremeEarth* science-Cloud (EEsC, pronounced "easy"). EEsC will take full advantage of modern software and communication technologies and exploit extreme-scale computing and big data capabilities to unburden users and communities from excessive technological challenges. EEsC will develop and provide the programming interface for users to interact and even steer high-definition Earth-system simulations, observational data, applications and analysis systems. This capability goes well beyond current cloud technologies. *ExtremeEarth* will thus re-invent value chains as a

[12] Data assimilation techniques combine models with observations through complex mathematical algorithms for producing a physically consistent estimate of the state of a physical system at a given time. This state estimate is used, among others, for forecast initialisation.
[13] Ensembles of model predictions help characterize the prediction uncertainty arising from inaccuracies in initial state and models.
[14] Khan et al., 2018: Science and research policy at the end Moore's law. Nature Electronics, 1, 14–21.
[15] https://ec.europa.eu/digital-single-market/en/eurohpc-joint-undertaking
[16] Schulthess, 2015: Programming revisited. Nature Physics, 11, 369–373.

collaborative space, one which allows for interactions between domain scientists and application communities at all levels. EEsC will be the ultimate technological and scientific game changer as it requires ground-breaking developments in extreme computing and data technology to provide a radically different way for scientists and users to interact with simulations and data.

1.1.4 The business case

By bringing together fluid and solid Earth physical sciences, and by interconnecting physical sciences with impact sciences, *ExtremeEarth* will achieve a significant economy of scale. This arises from the development of a common infrastructure that can most effectively predict and prepare for the effects of extremes across all Earth-system components, and that creates a generic technological foundation to allow models, observations, computing and data logistics to provide the best possible information in support of decision-making.

To maximize its economy of scale, *ExtremeEarth* technologies will be co-designed with users of data related to weather and climate, earthquake and volcano extremes. Within *ExtremeEarth* these 'impact communities' will work with scientists and technologists to develop *ExtremeEarth* application demonstrators, for six specific sectors: (i) *Critical Infrastructures*, will focus on the catastrophic consequence of extremes, also for the built environment; (ii) *Energy*, to provide seamless prediction capability of energy-relevant variables at the site of vulnerable energy assets as well as along the grid; (iii) *Hydrology & Water*, to provide consistent global probabilistic hydrological modelling at fine resolution, with an explicit treatment of water scarcity and drought; (iv) *Food & Agriculture*, to provide accurate information on food scarcity induced by extremes globally, at sub-plot scale in ways that also address correlated risks; (v) *Health* including *Air Quality*, to link environmental predictions with real-time information on the state of society, to identify at-risk regions; and (vi) *Emergency and Disaster Management*, to provide an improved capacity to predict the impending occurrence of disastrous events, map their evolution and consequences in real time, and thereby better target first responders and disaster aftermath management.

Although a major focus of *ExtremeEarth* will be on extremes over Europe, many of the models developed under *ExtremeEarth* will be global in domain and therefore capable of simulating and predicting extremes in other parts of the world. For example, the African continent experiences some of the most severe and long-term extremes of drought, with devastating consequences. Working with the international development agencies and others, *ExtremeEarth* will work to ensure that its new simulation and prediction capabilities can help African society become more resilient, helping to reduce the social upheavals of the past.

Demonstrators will exhibit the realisation of the *ExtremeEarth* ***Key Objectives*** through ***Key Technologies*** at full scale for the above applications. In achieving these demonstrators, *ExtremeEarth* will enhance European competitiveness in at least three ways: (i) by improving predictions, data services and their link to impacted sectors, *ExtremeEarth* will strength its partner institutions, e.g., European, public and private, providers of services on behalf of citizens; (ii) through application-driven, end-to-end, co-design and co-development *ExtremeEarth* will enhance European competitiveness in HPC and advanced ICT; (iii) through its introduction of EEsC, the project will spawn new user communities in areas that have not yet realized the potential of such information.

Together these efforts will turn the tide on rising costs from natural disasters. Given trends over the past 20 years, this would imply global cost savings of over €50 billion annually[17] by the time *ExtremeEarth* is completed.

1.1.5 Specific actions and roadmap

In the following, a brief description is given of how to arrive at a complete design of the candidate Flagship activity *ExtremeEarth* within the *ExtremeEarth-Preparatory Project (PP)*. Due to the complexity of the project, the engagement with existing communities and programmes to define both domain specific and cross-domain developments is crucial.

Selected specific steps to be undertaken by *ExtremeEarth-PP* are:

1. The establishment of the *ExtremeEarth* governance and control structure, the assignment of roles and responsibilities to the *ExtremeEarth-PP* partners, and the definition of interfaces with all stakeholders from the wider science and technology communities, industry, service infrastructures, the European Commission, and the public.
2. The definition of the *ExtremeEarth* strategic science and technology roadmaps, which break down the ***Key Objectives*** and ***Key Technologies*** (Section 1.3) into a development roadmap, identifying the streams of existing and novel science and technology research that need ingestion into *ExtremeEarth*. These roadmaps will include the definition of success metrics (Key Performance Indicators, KPI) across the range of component developments and full systems (demonstrators), and an initial identification of alternative development scenarios for high-risk elements. This will be covered in a risk management plan.

[17] Based on an estimated average annual cost of natural catastrophes of €500 billion globally and €10 billion in Europe, and the assumption that 10% could be saved by a better predictive capacity and improved information services by 2030.

3. The definition of the *ExtremeEarth* industrial and societal impact roadmaps, which lay out the approach for maximizing impact across Europe's services and commercial enterprises as defined in Section 2.1. This will be performed in close collaboration with all stakeholders throughout *ExtremeEarth-PP*.
4. The definition of Extreme Scale Laboratories within which science-technology co-design and co-development converges around the centres of gravity of different impact sectors, and for which the *ExtremeEarth* demonstrators will be developed. The definition of an Extreme Scale Laboratory will also be advised by *ExtremeEarth* stakeholders to achieve commitment, ensure that technology developments take into account the existing industrial roadmaps, and foster uptake by stakeholders.
5. The definition of a collaboration strategy between the potential *ExtremeEarth* partners and collaborators based on excellence and including sectors crucial for verifying the *ExtremeEarth* impact (Section 2.1). An important component in this step is the coordination with existing advanced technology developments that *ExtremeEarth* will depend on.
6. The definition of a co-funding strategy through consultation with national and international, public and private entities following the establishment of the science-technology roadmaps. Co-funding risks will be covered in the risk management plan.
7. The definition of a strategy for public engagement, dissemination and communication that ensures that *ExtremeEarth* will receive the appropriate public and political support given its impact on policy-making, society, economy, industry, and for each European citizen.
8. The definition of an agenda for education that will spawn new branches of academic excellence at the interface between Earth-system science and applications, and between science and technology, in particular including all relevant aspects of computational science.

The *ExtremeEarth-PP* consortium has the scientific, technological and management competence to realize this approach and prepare an ambitious yet feasible Flagship project. ECMWF has an outstanding track record as a project coordinator across the board from research and innovation, coordination and support to service actions.

The *ExtremeEarth-PP* partners were also selected to act as gateways to access much broader communities, thus multiplying the project's effectiveness. All possible collaboration channels – electronic means, dedicated workshops, sessions embedded in community workshops and conferences, town-hall meetings and public events – will be used in this preparatory project. The main formal interface with stakeholders during *ExtremeEarth-PP* will be Screening Workshops at the beginning of the project and Consolidation Workshops near project completion. These workshops will be highly visible events that will require substantial preparation.

1.1.5.1 Engaging with science and technology communities

The collaboration with the scientific community within *ExtremeEarth-PP* will be organized along and across science areas while emphasizing the two novelties of *ExtremeEarth*: (i) science-technology co-design; and (ii) full science-impact and user integration, enabled by EEsC. For the first, the challenge will be to work with practitioners (operational centres, research institutes from solid- and fluid-Earth sciences) to map their requirements for extremes prediction onto domain-specific methodologies that best exploit future technologies in high-performance, cloud and edge computing, domain-specific integrated information systems, big data analytics and artificial intelligence (AI). For the second, the challenge will be to encapsulate as much sector-specific science as possible into the full prediction system infrastructure. These new areas need a high degree of interaction with existing activities in the community throughout *ExtremeEarth-PP*, to be managed by the project partners.

A survey of existing science and technology research infrastructures, programmes and projects will establish the baseline of the research roadmap identifying the game-changing requirements and success metrics for each application area. This will form the vision for the specific *ExtremeEarth* organisation of research in concert with the existing infrastructures that produces the best cost-benefit ratio for common investments. This vision will also benefit from the leadership in research and innovation of the *ExtremeEarth* community (major research institutes and operational centres) as well as coordination and support actions governed by the EC's Research, Climate Action, Connect, Environment directorates. International (non-European) expertise will also be consulted.

The interface with the European Strategy Forum on Research Infrastructures (ESFRI) will be defined within the planning horizon of the existing ESFRI roadmap recognizing that *ExtremeEarth-PP* is mobilizing the research community already utilizing European infrastructures, e.g., the Integrated Carbon Observation System (ICOS), the Aerosols, Clouds and Trace gases Research Infrastructure (ACTRIS), the In-service Aircraft for a Global Observing System (IAGOS), the European Multidisciplinary Seafloor and water-column Observatory (EMSO), the Long-Term Ecosystem Research (LTER) and the Analysis and Experimentation on Ecosystem (AnaEE). The involvement of the European Plate Observing System (EPOS) and ICOS will eventually allow operational services to access observational data and to develop new data products for risk mitigation and geo-hazard assessment. Collaboration with pan-European e-infrastructures will provide a collaborative framework to develop a virtual

research environment for scientific computation and to foster procurement policies for computational resources. Pan-European frameworks such as the European Open Science Cloud (EOSC) and the European Data Infrastructures (EDI) will provide the opportunity to further implement the computational capacity of involved scientific teams.

The science-technology co-design and the full science-impact integration sit at the heart of *ExtremeEarth* and require entirely new infrastructures[18]. These will be developed in what we call the Extreme Scale Laboratories, which will be defined around selected *ExtremeEarth* co-design topics. The definition and assignment of these laboratories to existing institutes, their organizational form and their matrix management between vertical science centres and horizontal co-design and application centres is one of the main tasks of the *ExtremeEarth-PP*, and touches on many of the steps outlined above.

1.1.5.2 Involving stakeholders

ExtremeEarth will rely on partners and stakeholders who actively participate in co-development, in defining the framework and focus of the project and who ensure that the expected impacts are actually achievable. *ExtremeEarth-PP* will lay out the approach for partnership and collaboration management, which also has implications on future co-funding. The present *ExtremeEarth-PP* consortium has already started to engage with potential partners and stakeholders through an endorsement process[19], which introduces an early forum helping to shape the actual collaboration during the *ExtremeEarth-PP* already now. The science-technology community covered by the *ExtremeEarth* scope forms the core of partners.

A large group of stakeholders of *ExtremeEarth-PP* will be European providers of services on behalf of citizens – both institutionally and commercially funded – that ingest, extend and enhance, and further disseminate Earth-system information. This group of stakeholders will employ the novel capabilities that *ExtremeEarth* will develop, and drive future requirements and the ability to adapt to fundamentally new systems. ECMWF's function as the host of two and contributing to other Copernicus services implies that the future needs of these services (and their stakeholders) will be reflected in the Flagship roadmap. Apart from Copernicus, examples of service-type stakeholders are meteorological, hydrological, oceanographic, seismological and geological services at national and regional level, as well as civil and environmental protection agencies, but also commercial providers for energy generation and distribution, water services, farming industry, and infrastructure companies.

Another large stakeholder group comprises Earth observation data providers, for example national and international space agencies (e.g. Centre National d'Etudes Spatiales, CNES; Deutsches Zentrum für Luft- und Raumfahrt, DLR; European Space Agency, ESA; European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT), ground-based network providers and ESFRIs, companies running commodity-based or specialized networks, but also governing bodies which supervise and coordinate international programmes for facilitating global access to data such as the World Meteorological Organization (WMO), the Food and Agriculture Organization (FAO), the World Bank, the Group on Earth Observation (GEO/GEOSS), the Global Disaster Alert and Coordination System (GDACS), the Federation of Digital Seismographic Networks (FDSN) and others.

A very important stakeholder group comprises private companies, which exploit Earth-system information for specific applications and markets through value adding, for example reinsurance companies, urban design and investment and consultancy firms. For this sector, *ExtremeEarth* offers substantial growth potential that is complementary to the institutionally funded services. Note that more information on our engagement with industry and businesses is provided in the next section.

The involvement of all groups will be crucial for defining the *ExtremeEarth* full-scale end-to-end demonstrators as these are key project deliverables that will qualitatively enhance the capabilities of these stakeholders. *ExtremeEarth-PP* will develop a stakeholder map in the early stage of the project and produce a model for continually operating feedback loops between stakeholders and the project. The project has dedicated work packages on socio-economic impacts, which will deal with this aspect.

ExtremeEarth will lay the foundation for future European research infrastructures in digital technologies and their applications. In this regard, a core novelty is EEsC, which will pioneer an interactive configuration of science and technology components given specific user needs. Both existing and new user groups will be strongly involved in *ExtremeEarth-PP*. The success metric will be the value generated for European citizens benefiting from decision support systems for coping with extremes in the Earth system that are more accurate and reliable than available today and that can optimally be adapted to specific use profiles, thus reducing loss of human lives and reducing costs of society from weather and climate extremes, earthquakes and volcanoes.

Throughout the *ExtremeEarth-PP*, stakeholders will be involved in the design of the Flagship project through the Screening and Consolidation workshops, the roadmap developments and consultations, and in the co-design

[18] http://www.exascale.org/bdec/sites/www.org.bdec/files/whitepapers/bdec_pathways.pdf
[19] www.extremeearth.eu

elements of its vision. Stakeholders will be treated as equal, non-funded partners that ensure full community support of the final outcomes of the project.

1.1.5.3 Involving industry and businesses

The co-design focus of *ExtremeEarth* requires a new approach for engaging with the digital technology industry. Regarding HPC, the timing of other European infrastructure programmes supporting HPC development (in particular the EuroHPC Joint Undertaking) are important as their coordination with *ExtremeEarth* will offer the best return on investment for both general purpose and domain specific computing. *ExtremeEarth-PP* will develop the corresponding roadmap for an application-driven design of extreme computing, as described above, that will serve as a template for many other domains, which involve large computing and data handling problems, such as material sciences and fluid-dynamics based engineering, and that also have many industrial applications.

The ultimate goal is to prepare the ground for a community-driven approach[20] that is believed to be both more appropriate and more successful to address the basic problem of two paradigm splits: the compute/data-software-ecosystem split and the wide-area-data-logistics split. This needs new standards that will govern the interoperability between data and compute, based on a new, common and open Distributed Services Platform (DSP), that offers programmable access to shared processing, storage and communication resources, and that can serve as a universal foundation for the component interoperability that novel services and *ExtremeEarth* applications will require.

While HPC represents a comparably small market share for the computing industry, it has a strong foothold in Europe with world leading companies for hardware systems and software. The co-design of HPC system components and of system configurations with future architectures targeting grand science and societal challenges offers significant momentum to engage with the HPC industry, also because *ExtremeEarth* moves well beyond centralized and into distributed (cloud, fog and edge) computing. An important element here is software co-design where *ExtremeEarth* promises entirely new interactive workflows for running tailored simulations and extracting user specific information efficiently from vast amounts of primary data. The benefits of these developments go well beyond *ExtremeEarth* offering an extended basis for future collaboration with industry. *ExtremeEarth-PP* will define the roadmap and operation modus for its engagement with the HPC industry through dedicated working groups that will be supported by the existing public-private partnership framework agent, the European Technology Platform for HPC, ETP4HPC[21]. The Strategic Research Agenda (SRA) of the ETP4HPC and its reflection in FET-HPC funded projects offers a unique opportunity to draw wide-reaching project expertise into *ExtremeEarth*. This includes most major computing and data hardware and software technology companies in Europe and abroad, many of which are also members of the ETP4HPC (see also Sections 1.3.4 and 1.3.5).

With regard to application sectors, *ExtremeEarth* will provide major industrial sectors dealing with infrastructures, water, energy, transport and agriculture with the necessary tools to plan and prepare for a changing world as well as greatly improve the capability of using operational forecasts on time scales from minutes to decades. Europe is facing major challenges in the coming decades, such as switching to renewable energy, securing future food production and maintaining food distribution chains. *ExtremeEarth-PP* will engage with these and other industrial sectors throughout the project to prepare novel on-demand services for optimizing the production line as well as increasing resilience against extreme events.

1.1.5.4 Obtaining public support

Obtaining widespread recognition and support for *ExtremeEarth* will be a key element of *ExtremeEarth-PP*. The consortium has already garnered endorsement[19] from numerous national, European and international institutes and organisations, research networks and infrastructures, projects, industrial sectors and local/regional authorities.

During *ExtremeEarth-PP* this engagement activity will be further extended moving from endorsements to commitments. These will be critical for securing co-funding for the Flagship project. Another important element for securing co-funding will be to push the goals of *ExtremeEarth* into future national and international funding programmes. For this purpose, the *ExtremeEarth-PP* will exploit its partners' links to national governments, and develop a professional communication and public support strategy. This strategy will seek to make clear to the public what the benefits will be of realising the *ExtremeEarth* Flagship project, on a European, national, regional as well as personal level. The communication activities will include highly visible press releases throughout the duration of *ExtremeEarth-PP* to reach a wider audience. In addition, attendance of conferences with *ExtremeEarth-PP* stands will be realised to reach the scientific and industrial communities and garner their support. EU member state support will be achieved through regular policy updates, outlining how the proposed roadmap of *ExtremeEarth* will impact national and European policy making.

The most important vehicle to obtain public support is to produce a transparent roadmap for realizing the *ExtremeEarth* project with clear goals and well-documented progress, and with wide and profound public visibility

[20] Hagel and Brown, 2017: Shaping strategies for the IOT. Computer, 50(8):64–68.

[21] http://www.etp4hpc.eu, ECMWF is a full member.

to ensure that EU Member States can support and benefit from the project throughout its lifetime and beyond.

1.2 Relation to the work programme

The *ExtremeEarth-PP* proposal addresses the main area '(3) Energy, Environment and Climate change' of the FETFLAG-01-2018 call with a particular focus on sub-area 'Earth, Climate Change and Natural Resources'. Its vision is to revolutionize Europe's capability to monitor and predict environmental extremes and their impacts on society through the imaginative integration of extreme-scale computing and a novel information-demand-driven paradigm for Earth-system data processing, including the real-time exploitation of pervasive environmental data.

ExtremeEarth-PP is fully compliant with the call text and addresses this sub-area as a whole: *'High-precision modelling and simulation'* capabilities sit at the core of *ExtremeEarth-PP* for realizing step-change advances in predictive skill, and with a focus on *'natural hazards'*. The *'new technologies and approaches'* in *ExtremeEarth-PP* include *'data integration'* and focus on the development of domain-specific, extreme-scale computing, data handling and logistics, and integrated information systems. *ExtremeEarth-PP* further aims to realize the full value chain of science-to-impact prediction, thus *'helping to manage/mitigate … impacts on human activity and natural resources'*. *ExtremeEarth-PP* fully integrates impact sectors referred to as *'agriculture'* and *'energy'* in the call text but also water (highly relevant for *'protecting natural ecosystems'*) and disaster management including the effects of telluric events. Thus, the project creates an explicit connection between high-definition Earth-system models, the reliable prediction of extreme events, and the management of natural resources in a highly complex natural system altered by significant human influence.

As a whole, *ExtremeEarth-PP* also addresses the Work Programme's general goals. The core partners represent world leading expertise in their respective fields and their approach has a strong multi-disciplinary basis.

1.3 Objectives

To turn the tide on the rising costs from natural disasters *ExtremeEarth* will, with its partners, deliver the science and technology necessary for a step-change in the prediction and assessment of extremes in weather and climate, earthquakes and volcanoes. In this section, we formulate the science and technology case in terms of ***Key Objective***s (1.3.1), and ***Key Technologies*** (1.3.2).

The KPIs add specificity to the objectives/technologies and measure progress relative to the state-of-the-art. This is illustrated in Fig. 3 with reference to the overall approach shown in Fig. 1.

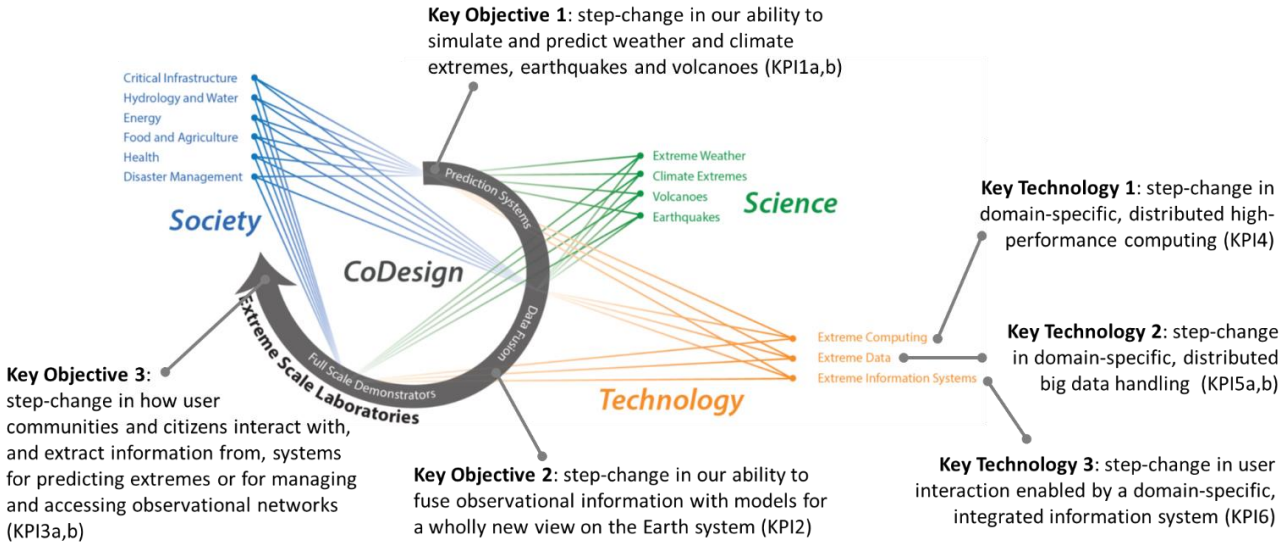


Figure 3: The mapping of Key Objectives and Key Technologies on the ExtremeEarth workflow vision introduced in Fig. 1.

1.3.1 New science capabilities

Key Objective 1: Enable a step-change in our ability to simulate and predict weather and climate extremes, earthquakes and volcanoes.

Two KPIs, one each for the fluid- and solid-Earth components, will measure progress toward this objective:

- **KPI1a**: weather and climate models that are "indistinguishable" from observations (at near-grid and larger scales) with a global throughput of 5 simulated years per day (SYPD) at 1 km horizontal resolution;
- **KPI1b**: unified geo-prediction systems to predict the spatial and temporal distribution of earthquakes at regional scale and seismic shaking at 10 Hz, and to assess eruption scenarios.

Turing-tested[22] weather and climate models operating on 1 km-scale global grids with a simulation throughput of 5 SYPD have been chosen as the KPI (KPI1a) for two main reasons. The first reason is that models of this quality, while not solving every problem, circumvent some of the most important long-standing ones. The step-change in accuracy they will bring to predictions of extremes is necessary to drive impact models to the level required for designing effective adaptation and mitigation measures for disaster risk reduction and preparedness. The second reason is that simulation systems capable of this throughput pace a wide range of additional but related applications. These include regional downscaling and process studies on 10 m to 100 m grids, the use of very large ensembles at coarser (3-5 km) resolution for data assimilation, and because it means that yet coarser (5 km) resolution models —which would have a throughput of 30 SYPD, but still be storm resolving — become suited for multi-centennial scale applications.

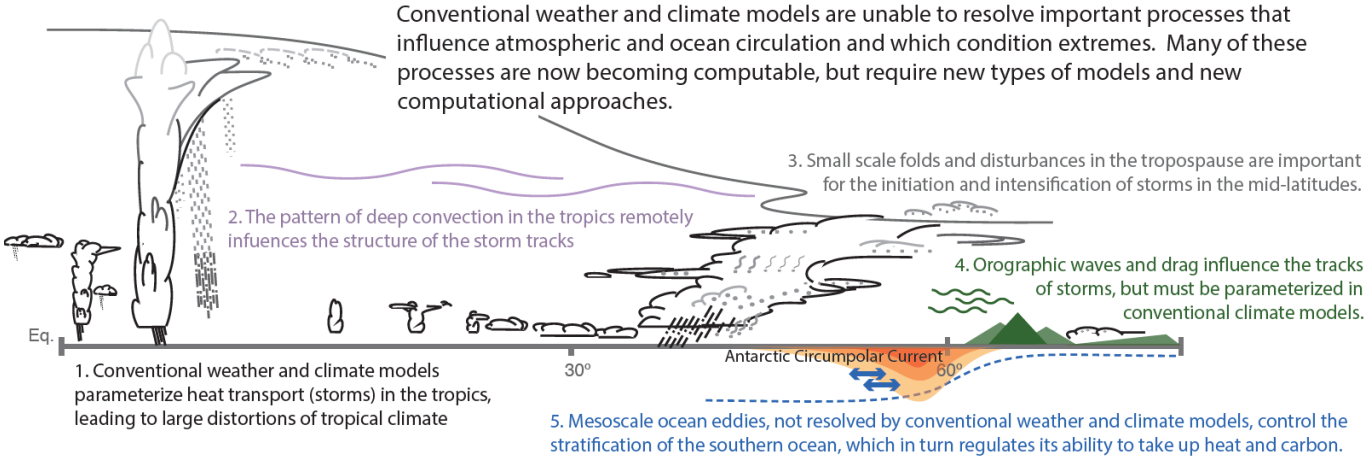


Figure 4: Illustration of small-scale processes and their effect on "fluid-Earth" extremes, that ExtremeEarth technologies will help resolve.

The expectation that weather and climate models operating on a grid scale of 1 km, compared to the 10-100 km scale at which numerical weather prediction and climate models currently operate, will deliver a step-change in accuracy arises from decades of experience with regional scale models operating on that scale[23]. At 1 km, important processes responsible for shaping the atmospheric circulation, and the transformations of energy that drive and accompany it, can be resolved rather than parameterized — models become simpler and more faithful to basic physics. As illustrated in Fig. 4, 1 km models largely resolve atmospheric moist convection, momentum transport and mixing associated with gravity waves and the interaction of winds and currents with fine-scale topography and bathymetry, the dynamics of tropopause disturbances that are the seeds of extra-tropical storms, fracture processes in ice-sheets, and the ocean equivalent of weather, meso-scale eddies and current systems, which determine how the ocean circulates heat and trace elements. Although some processes, such as cloud microphysical, land-surface and turbulent mixing processes, will remain unresolved, these will interact with circulation systems in a natural and observable way, creating the expectation that their effect on the resolved scales can be better represented. In short, at 1 km many problems are solved, and those that are not become solvable. This logic applies equally to limited-area models that need to operate at scales of 100 m or better, and for which small-scale orography, shallow clouds, turbulence and urban effects will become resolved.

KPI1b emphasizes the development of unified geo-prediction systems, one for predictions of seismic shaking leading to earthquakes, another for evaluating volcanic eruption scenarios. As is the case for the proposed step-change in weather and climate models these geo-prediction systems propose to leverage computational gains to develop and integrate more physical representations of sub-systems across a wide range of scales, and to better link their resultant behaviour to measurement networks and impacts.

[22] Alan Turing introduced the idea of artificial intelligence being indistinguishable from human intelligence by the ability of computers to converse with humans in ways that to a passive observer were indistinguishable from human-human conversations. For models of the Earth system the Turing test refers to models whose output are indistinguishable from observations at the scale of the output. See also Palmer, 2016: A personal perspective on modelling the climate system. Proc. Roy. Soc. A, doi: 10.1098/rspa.2015.0772.

[23] Guichard and Couvreux, 2017: A short review of numerical cloud- resolving models. Tellus A, 69, doi:10.1080/16000870.2017.1373578

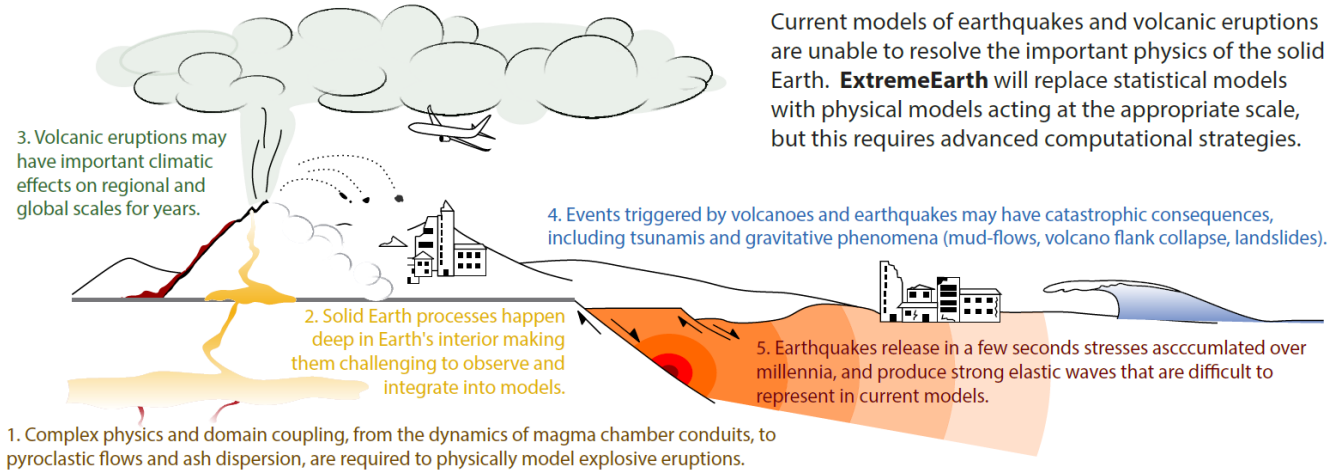


Figure 5: Illustration of small-scale processes and their effect on "solid-Earth" extremes, that ExtremeEarth technologies will help resolve.

For seismic models, this implies the integration of models of fault interactions, crustal deformation and earthquake occurrence on variable scales (see Fig. 5). To simulate shaking, methodologies for representing full-waveform simulations in complex heterogeneous media will be developed – accounting for the geological and sedimentary structures observed at the Earth's surface and in the upper crust and for the interactions between the seismic wave field and surface structures, like buildings at the scale of a city. Extending these methodologies to reach the 10 Hz frequency-goal makes them relevant for the resonance of shallow sediment basins and buildings. The resulting unified prediction system shall characterize and forecast future earthquake occurrence — on time scales of hours to centuries, and on spatial scales ranging from the activation of single fault to regional Euro-Mediterranean scale activity — and measure their impact through the generation of synthetic seismograms in a site-specific manner[24].

A unified volcano simulator will, for the first time, explicitly represent the interplay of the totality of volcanic subsystems, from the deep regions of magma storage into the atmosphere. This includes a representation of the fully coupled dynamics of the underground magma chambers and dykes/conduits, the confining rock systems, the aquifers and geothermal systems, the atmospheric ash dispersion, the lava flows and pyroclastic density currents at the Earth's surface (see Fig. 5). The simulator will define a new international reference[25] and provide internally consistent prediction scenarios of volcanic eruptions, linking all the required data and components, e.g. the dynamic state of magma below the volcano to observations from multi-parametric monitoring networks.

The science objectives related to fluid and solid Earth, although measured by different KPI, are linked because both require substantial investments in new technologies including both software and hardware[26], and thus share commonalities in the co-design required to reach their objectives. Both fluid and solid Earth pose problems in continuum mechanics, and their impacts and data needs are referenced to specific places and times on, or near, Earth's surface (geo-specific). The radical reformulation of all layers between mathematical kernels, numerical and multi-scale physics methods, observational and model data handling in data assimilation, and workflows argues for domain-specific approaches to obtain the necessary computational speed-up factors. But to attain, at the same time, a critical mass of effort and ensure agility in the approaches requires a careful and sufficiently broad definition of one's domain. *ExtremeEarth's* approach to meeting this challenge is thus to link, through a single objective (***Key Objective 1***) the co-design of the solid- and fluid-Earth applications and the common Key Technologies.

Key Objective 2: A step-change in our ability to fuse observational information with models for a wholly new view on the Earth system.

The KPI for this objective is:

- **KPI2:** the amount and type of new observations that *ExtremeEarth* enables for use in initializing, driving and evaluating the prediction systems described in ***Key Objective 1***.

At present, most systems for generating observationally constrained trajectories of the Earth system are tailored to specific applications and apply very strict observation selection criteria for targeting the most valuable information. Despite the fact that atmospheric data assimilation is most advanced in Earth science, in state-of-the-art systems only 5% of the available data is used. At the same time new sources of data, often from unconventional sources, are growing. Limitations in the scale and fidelity of existing models is one of the main reasons hindering a more

[24] Quinay and Ichimura, 2016: An improved fault-to-site analysis tool towards fully HPC-enhanced physics-based urban area response estimation. Journal of Earthquake and Tsunami, 10, https://doi.org/10.1142/S1793431116400182

[25] http://www.globalvolcanomodel.org/

[26] Mitchell et al., 2012: Infrastructure strategy for the European Earth System Modelling community 2012-2022. ENES Rep. Ser. 1, 33 pp.

effective uptake of data, another is that data analysis and assimilation methods are presently limited by computational and data logistic capacity. These limitations are even more pronounced when it comes to prediction systems for earthquakes and volcanoes, where many of the tools are in an earlier stage of development. Together these issues motivate the idea to measure the progress toward ***Key Objective 2*** by measuring (i.e., **KPI2**) the amount of new data that *ExtremeEarth* allows us to assimilate**.**

In collaboration with observational data providers, *ExtremeEarth* will fundamentally revise the information extraction from the growing fleet of satellites, reference stations and surface networks covering atmosphere, land surfaces and oceans, near-fault observatories and deep-underground networks, and the vast information potentially available from commodity devices such as mobile phones and sensors onboard cars, commercial aircraft and ships. Along with the investment in a new class of models for weather and climate, earthquakes, and volcanoes, *ExtremeEarth* will advance data fusion and AI-methodologies for creating a complete four-dimensional view of the Earth. As an example, by integrating the newest earthquake dynamics knowledge with real-time assimilation of multi-scale and multi-parameter data from satellites, near-fault observatories, deep underground laboratories, GEO supersites, and ionospheric anomalies it may be possible to identify earthquake precursors and develop a new operational capacity to map the initiation and evolution of earthquake rupture[27]. By producing a better match with observations, the new class of models being developed for ***Key Objective 1*** will allow more observational information to be assimilated and help catalyse yet better predictions.

To meet ***Key Objective 2*** requires very high-resolution, fully coupled, non-linear algorithms and AI-technologies that can be flexibly tied together with a new generation of Earth-system prediction models, that can be run on computers as efficiently as the forecasts themselves and that can simulate on the scale of the observations. These systems also need to include a full characterization of uncertainties. *ExtremeEarth* will develop the necessary techniques for scalable methods with a throughput of hundreds of billions of observations per day.

Key Objective 3: A step-change in how user communities and citizens interact with, and extract information from, systems for predicting extremes or for managing and accessing observational networks.

There are two KPIs for this objective:

- **KPI3a**: the ability of users to interactively manage and interact with upstream Earth-system predictions, according to their needs, and to access fine-scale information, also from observations, in an open and flexible way.
- **KPI3b**: the readiness of full-scale 'Demonstrators' that stream Earth-system prediction and observational information (***Key Objective 1-2***) into impact and risk models as part of the critical production path.

To achieve its objective *ExtremeEarth* will, through EEsC, provide a comprehensive application programming interface to extreme-scale computing applications, namely ***Key Technology 3***. EEsC will allow users to discover and extract information from prediction systems at full scale — something not presently possible. Going one step forward, EEsC will allow users to actively shape these prediction systems — reconfiguring the "value chain" as a collaborative space. Opening up the prediction systems to the creative potential of its users will accelerate the uptake of information by existing communities and create opportunities for innovation by new application communities. *ExtremeEarth*'s progress toward this goal will be measured by **KPI3a**.

To appreciate how this vision departs from the present state of the art, consider that at present, only parts of (linear) value chains are implemented in service-type infrastructures, and they operate at fine scales only for selected areas and sectors. Copernicus services for Climate Change, Atmospheric Monitoring and Emergency Response include global-to-regional downscaling and interfaces of weather and climate information to atmospheric composition/air quality/flood prediction/renewable energy segments but are based on simplified models with an inadequate focus on extremes, especially those associated with volcanoes. Likewise, the assessment of seismic risk is based on information that is provided piecemeal, often by models not well suited to purpose, but for which better alternatives do not exist. Most importantly, the sequential nature of existing systems leads to information bottlenecks, and hence links to informed decision-making by commercial, civil protection and disaster relief sectors are grossly underdeveloped and new value is slow to be realized. The information bottlenecks are amplified by technological bottlenecks in computing, data and workflow management.

If the proof is in the pudding, **KPI3b** is about tasting the pudding. Full-scale 'Demonstrators' will be built with and for six key impact sectors (as identified in Section 1.1.4) to demonstrate the added value brought by the new class of prediction systems — for weather and climate extremes, earthquakes and volcanoes — both in terms of their predictions and in terms of the additional observations they can assimilate. Demonstrators will vary in complexity and combine knowledge across sectors. They will be co-designed with the respective science and impact communities in organizational units we call Extreme Scale Laboratories. The step from extremes to impacts (many

[27] Di Toro et al., 2011: Fault lubrication during earthquakes. Nature, 471, 494–498.

of which take the form of natural hazards) will be explicitly built into the software framework, and include feedback loops whereby user-specific risk reduction scenarios can be evaluated by reconfiguring the upstream components. Further impact model configurations can be built in analogy to these select demonstrators, which will serve novel communities as trial-balloons for their own future impact model development.

ExtremeEarth makes the crucial step of linking impact with risk prediction capability that requires precise information on exposure and vulnerability. As these are highly end-user driven, the ability to dynamically shape and structure the information that a new class of km-scale ensemble prediction systems will provide will greatly improve decision making on all time-scales, and help turn the tide on the rising costs from natural disasters.

1.3.2 New technology

The main technological aim is to develop extreme-scale computing, data handling and interactive workflow capabilities (e.g., as illustrated in Fig. 6) to fulfil the grand science objectives outlined in Section 1.3.1. These technologies will drive digital technology and European roadmaps on scientific and technological research and development for decades to come.

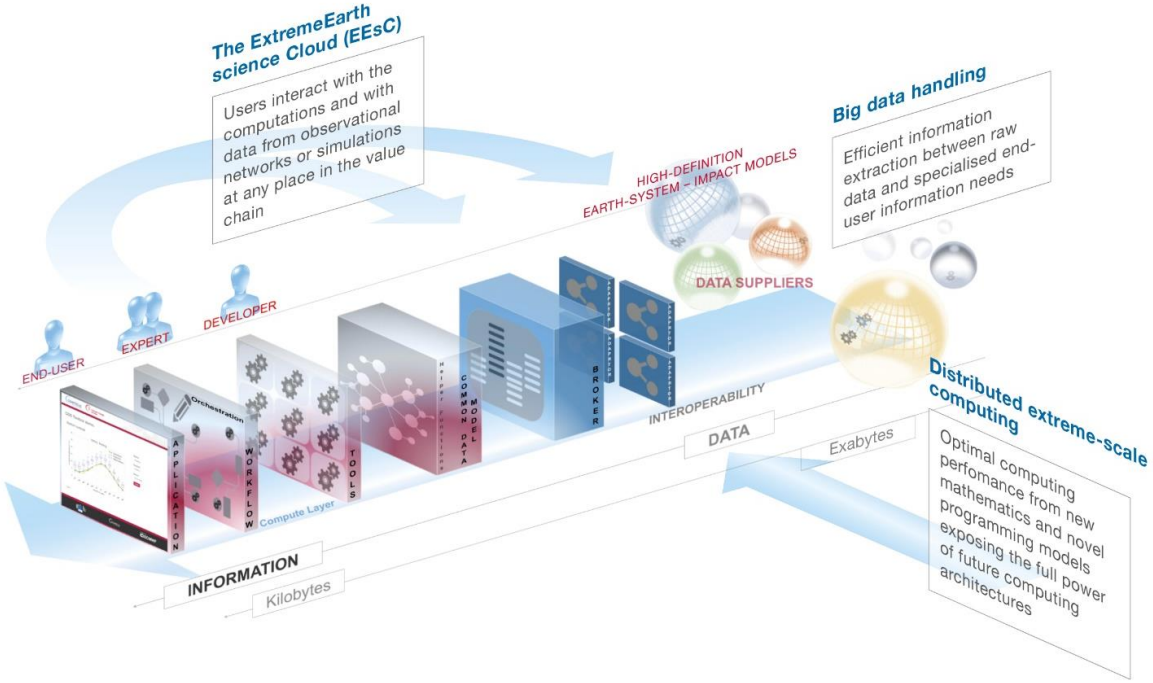


Figure 6: ExtremeEarth's vision for transforming the present value chain into collaborative spaces.

Key Technology 1: A step-change in domain-specific, distributed high-performance computing realising our ambition for the simulation and prediction of Earth-system extremes.

The KPI for this technology is:

- **KPI4**: the ability to run service-like, end-to-end fluid and solid Earth simulations at full scale with the required computational speed (***Key Objective 1***) and with electric energy footprints that are similar as today. Progress will be fully demonstrated on domain-specific, extreme-scale computing systems benefiting from the full range of *ExtremeEarth* hardware-software co-design.

ExtremeEarth will implement and demonstrate a new hardware and software system design that is optimized for the full workflow range - from physical models to application sectors. The codes will not be single simulation models any more, but rather a full framework of science-technology solutions in which Earth-science prediction systems will be developed and implemented for European needs, and impact models from different application sectors will be fully integrated.

The state of the art builds upon numerical codes that have developed over decades, adjusting incrementally to changing hardware technologies. More recent developments have ported selected model kernels to new processor types showing the direction of where to seek enhanced performance and lower energy footprints[28]. However, for reaching the scientific goals of *ExtremeEarth* much enhanced algorithmic flexibility and hardware portability are needed: Algorithmic flexibility to explore the best trade-off between accuracy and computational speed, and

[28] Fuhrer et al., 2017: Near-global climate simulation at 1 km resolution: establishing a performance baseline on 4’888 GPUs with COSMO 5.0. *Geosci. Model Dev. Discuss*. https://doi.org/10.5194/gmd-2017-230.

hardware portability to achieve the best trade-off between different types of specialised hardware components[29]. This needs a full co-design of numerical Earth-system science codes, software stacks and workflows.

This technology objective comprises both hardware and software development, because both need to be fundamentally re-designed together to achieve the required performance gains and ensure inter-operability. These will be realized in several stages to be defined in detail by the *ExtremeEarth-PP* science-technology roadmaps.

The initial stage will focus on hardware components that are available on the market. Current bottlenecks are communication memory usage, cache efficiency, code vectorization and data transfer. Special-purpose accelerators with a memory system that is designed to support the low-arithmetic-density motifs of Earth-system modelling codes will be considered. Options are special-purpose processors (Application-Specific Integrated Circuits, ASIC) that are co-designed with a backend implementation of the numerical tools in the software framework. *ExtremeEarth* will also use the latest insights into applied mathematics to advance software whereby compute-intensive kernels may be replaced by modules trained by deep-learning algorithms for processes that are still not resolved at the scales envisioned for *ExtremeEarth*. The project will make AI-methods a special focus point for the Extreme Scale Laboratories.

In the next stage, Earth-system model redesign will separate canonical components of the Earth-system models that manage distributed data on grids and perform basic numerical operations from back-ends that map specific functions onto particular processor and communication architectures. The approach will be similar to that used by popular machine learning frameworks[30] that enable data scientists to implement deep neural network models and benefit from highly optimized back-ends[31] that themselves map onto specialized architectures. The Earth-system scientists would work in a software environment, in which they can refine models, access data to perform analysis on the fly and steer simulations. These are radically new concepts and the fundamental libraries will be implemented step by step in the current frameworks. This new approach will allow scalable mapping onto general-purpose supercomputing architectures of the time, allowing European Earth-system modellers to use pre-exa-scale and exa-scale (EuroHPC) supercomputers that will be available during the ramp-up phase of the Flagship project.

In the final stage of the Flagship project, full advantage from emerging digital technologies will be taken benefiting from the full algorithmic and hardware flexibility of the code re-design. The software framework will be mature enough to run full-scale simulations and workflows on entirely new hardware technologies, measured by **KPI4**.

Key Technology 2: A step-change in domain-specific, distributed big data handling realising our ambition for the simulation and prediction of Earth-system extremes, and for exploring the full range of information from simulations and observations.

There are two KPIs for this technology:

- **KPI5a:** the ability to realise ***Key Objective 1*** including all necessary output data handling and storage across all Earth-system simulation applications.
- **KPI5b**: the ability to fuse simulations with observations within exa-scale workflows (***Key Objective 2***).

ExtremeEarth will co-design scalable and interoperable data workflows and the tools to manage them. It will make Earth-system data and workflows Findable, Accessible, Interoperable and Re-usable (FAIR[32]). A new information-demand-driven paradigm will be established, which will allow European scientists, stakeholders, and citizens to find, generate, and access relevant Earth system information as easily as we navigate roads today. This includes both full-scale simulation output and billions of observations per day.

ExtremeEarth will deal with and enable user friendly access to high-volume and high-quality data, e.g. from satellites, measurement stations and derived environmental data sets as well as disparate sensor data (e.g. cell phones or from internet-of-things (IoT) networks in cities). Data will be made available in integrated storage solutions providing seamless access to central, cloud or edge based computing. Delivering data to end users will be realized in real time, employing in-transit analysis by developing and implementing today's and tomorrow's cloud technologies (e.g. blob-file systems, object stores, data lakes). These technologies will be integrated with extreme-scale computing towards the vision of EEsC (***Key Technology 3***), a user-friendly, fully interactive computing, data access, integration and visualization service. At the end of the project, any user in the value chain can access simulations, deploy simulations and access sensor data, and analyse and visualise the data in a streamed approach.

Current European initiatives around Earth-system data primarily focus on harmonization and improved handling of data from government sources (e.g. the Infrastructure for Spatial Information in Europe, INSPIRE) and research

[29] Lawrence et al., 2018: Crossing the Chasm: How to develop weather and climate models for next generation computers? Geosci. Model Dev. Discuss, 11, 1799-1821.
[30] https://keras.io/
[31] https://www.tensorflow.org/
[32] Wilkinson et al., 2016: The FAIR Guiding Principles for scientific data management and stewardship. Nature Scientific Data, 3, 160018.

infrastructures (e.g. ESFRIs and also developing the EOSC). Much of the on-going work is targeting data discovery and semantic interoperability, while there is little effort to integrate these topics with high-performance throughput of extreme data volumes. *ExtremeEarth* will fill this gap. Selected use cases with various stakeholders will serve as starting points for analysing and generalizing common data management workflows and to improve them from a co-design perspective. *ExtremeEarth* will focus on the technical aspects of data management (including performance, latency, resilience, timeliness, security, discoverability). Other aspects (legal issues; licensing; General Data Protection Regulation, GPDR; business models; etc.) will be dealt with in collaboration with existing and emerging infrastructures (EOSC, ESFRIs, GEOSS, Copernicus Services etc.).

The vast amount of information that will be generated in *ExtremeEarth* requires a fundamental re-thinking of current data handling strategies and connectivity[33]. Future HPC hardware will very likely consist of multi-layered storage architectures, and the classical Portable Operating System Interface (POSIX) file systems will be replaced by other concepts such as object stores and array databases. These changes must be integrated in numerical model code along with the many other infrastructure changes that will be required to run these models efficiently on future hardware. During a simulation, the data will be available in real time to scientists and can be confronted interactively with observations from sensor networks. By fully exposing the model state to data services and through adoption of modern software concepts such as asynchronous scheduling and co-routines, the model system can be influenced at runtime, for example to start a regional ensemble simulation upon identification of specific weather phenomena, or to activate online visualization streams and pull in additional data for cross-checking and validation when a seismic crisis is evolving and potentially escalating to a major earthquake.

Emerging technology trends suggest that the boundaries between dedicated HPC systems and large-scale clouds converge. In terms of Earth-system data, large companies such as Google, Amazon, IBM or Microsoft, together with space agencies are pushing the frontier with cloud-based web services. These services also host large and rich datasets that have been underused. Tying numerical Earth-science simulations closer to cloud-like data services through *ExtremeEarth* offers the opportunity to achieve much greater consistency in model and data workflows, and – in turn – to develop standards and tools for managing and using these workflows for the benefit of the wider community. *ExtremeEarth-PP* will develop work, governance, and business plans with major industry stakeholders to achieve optimal workflow integration and create a new generation of software tools, which will radically improve discovery, access, and use of Earth-system data for everyone.

Key Technology 3: A step-change in user interaction enabled by a domain-specific, integrated information system towards the *ExtremeEarth* science Cloud (EEsC).

The KPI for this technology is:

- **KPI6**: the ability to realise ***Key Objective 3*** with a set of full-scale, end-to-end demonstrators on dedicated, interactive platforms designed to maximize throughput of computing and data handling from integrating ***Key Technology 1*** and ***Key Technology 2***.

Key Technology 3 makes available both simulations as well as observational data in real time through the EEsC framework. EEsC provides interactive workflow management for exploiting the data and for tailoring the model and observational data configuration to their specific needs. This will allow the *ExtremeEarth* user communities to apply data analytics techniques to exploit diverse information streams bridging between scientific data and user-relevant value, to optimally combine simulations and observations, and to configure the optimum mix between existing data and on-request simulations through a software interface that is highly flexible and interactive.

Presently, models and application communities work within well defined boundaries. Scientists develop and run models using monopolised computational infrastructure, and the output is used by application communities with little expertise in scientific data analysis and little influence on the set-up of the simulations upstream. EEsC will allow *ExtremeEarth* users to explore the entire range of Earth-system and impact models, as well as observational data streams. Beyond data access, the key new asset is the programmability of the data-generating workflow by a broad user community. *ExtremeEarth* will enable the linkage of models and data, users and applications, at the point of computation. This is radically different from today's approach of unidirectional streaming of information from fundamental Earth sciences to selected applications. To this end, the workflows will not be linear anymore but user-defined loops of information.

Based on the availability of ***Key Technologies 1-2***, a modular workflow concept needs to be implemented that enables users to deploy and steer Earth-system simulations on extreme-scale computing facilities, deploy sectoral impact models and assess the results and interact with observational data in real time. The workflow requires well defined and open interfaces, centralised metadata frameworks for simulations and observations, a common strategy for simulation check-pointing enabling simulation restarts, access to object-based data stores for model fields and

[33] Overpeck et al., 2011: Climate data challenges in the 21st century. Science, 331, 700-702.

observations, efficient and resilient access to centralized and distributed computing and data management facilities and new diagnostic capabilities for verifying the correctness of the results. This new role for users will need a substantial investment in training and education so that the *ExtremeEarth* capabilities can be effectively used by as many communities as possible.

1.3.3 Time and cooperation among disciplines required to meet objectives

ExtremeEarth's central insight is that its ***Key Objectives*** can only be realized through application-driven co-design delivering the enabling ***Key Technologies***. This involves the commitment and "buy-in" of a large part of the community working on weather and climate extremes and geo-hazards. Moreover, as the ***Key Objectives*** are not independent from one another, and the communities required to achieve them have diverse disciplinary backgrounds and organizational cultures, they must be addressed in an integrated fashion. This requires a scale of effort and degree of persistence that only a Flagship-scale project can provide.

It will take about ten years to enable a new generation of physics based ultra-high-resolution weather, climate and earthquake models to fully exploit extreme computing and data management. Typically, this is also the time needed to develop new prediction models from pure scientific principles including the uncertainty quantification in a consistent probabilistic framework. However, given the demanding performance requirements (at least a factor of 1000 for computing speed, hundreds of billions of observations per day[34]) changes to existing modelling infrastructures will be much more drastic, including innovations that exploit hardware-specific performance in a flexible and portable way. For exploiting the full computational performance of novel hardware architectures, at processor, component and system level, the entire software stack needs to be reconfigured. However, as the simulation models themselves are only one element in the production chain, radically new ways of dealing with critical aspects such as observational data handling, data analytics and reduction, data assimilation, and data intensive model-application workflows also need to be implemented. Further, the introduction of deep learning and AI methods to better link users to models and data, and to make full use of performance gains from new hardware, imply a long-term development effort whose fruits will be demonstrated in the Extreme Scale Laboratories.

There is no question that a radical reformulation of Earth-system prediction capabilities, their realization through novel computing and data handling technologies, and the maturation of a fundamentally different service provision quality level by a fully integrated and on-demand operating workflow with EEsC requires substantial and concerted resources to deliver in ten years what is unachievable from any other type of support. The full roadmap for the collaboration among applied and computational science expertise across the above described software framework and hardware topics will be defined in *ExtremeEarth-PP*, along with the multi-disciplinary collaboration framework necessary to achieve the *ExtremeEarth's* Flagship ***Key Objectives***.

1.3.4 European research excellence and industrial capabilities

The *ExtremeEarth-PP* consortium springs from a nexus of world-renowned European research organisations – for solid Earth, weather, climate, and computational science; world leading institutional facilities and European Research Infrastructures – for weather prediction, earthquake science, HPC, and data management; and strong and interlinked application communities – in both the public and private sectors. Our excellence is exemplified by ECMWF, the coordinating organisation, and the acknowledged world-leader in numerical weather prediction. ECMWF embodies the *ExtremeEarth* concept of joining scientific expertise around a dedicated HPC infrastructure to serve society through its member institutions. Many other partners represent access ports to significant research and technology infrastructures, including the Max-Planck and Helmholtz Societies in Germany, the French CNRS and Météo-France, the Italian INGV and CMCC, the Spanish BSC, top-ranking universities and institutes in the Netherlands, UK, Scandinavia, and Switzerland, as well as international organisations with JRC and the Red Cross.

The *ExtremeEarth-PP* consortium is very well connected both across and outside of Europe, through strong researcher networks built from a history of coordinated modelling (e.g. the European Network for Earth-system Modelling, ENES[35]) and observing activities, common service provision and joint infrastructure management which directly feed into industrial capabilities and opportunities. These connections have been fused through a history of strong and strategic national and European Commission funding – through Framework and Infrastructure Programmes – as well as support from space agencies (ESA, EUMETSAT) and services, such as the European Commission's Copernicus programme.

ExtremeEarth has strong links to leading hardware and software companies (e.g. Atos/Bull, ARM, and US/Asian companies, and through ETP4HPC), and the technologies it will develop aim to spawn European technology leadership in science areas where Europe is already world leading. The EuroHPC Joint Undertaking will deliver general-purpose exa-scale computing and data facilities, which are the fundament of the capabilities developed in *ExtremeEarth*. We will return the investment by extending it further towards application-driven hardware and

[34] Kulmalla, 2018: Build a global Earth observatory. Nature, doi:10.1038/d41586-017-08967-y.
[35] European Network for Earth System modelling, https://enes.org.

software design. The already strong European software development industries will have a competitive advantage by co-designing the frameworks. This feeds into the applications as well. Europe has a thriving consulting industry with global impact to which *ExtremeEarth* partners have strong links already (e.g. Arcadis). Also, reinsurance industries including the Willis group provide strong support and we have links to both Munich Re and Swiss Re. Given the substantial level of existing collaboration towards common goals in the *ExtremeEarth* community, there is enormous potential for success at a time when break-through science and service capabilities are needed. The wide-ranging support for *ExtremeEarth* throughout science, technology, services and industry is expressed in over 100 letters of support (see Sections 4 and 5), also comprising a large fraction of stakeholders.

1.3.5 Interface with existing national, European and international activities

ExtremeEarth will not and cannot take on activities that presently are, or in the future can, be filled by its constituent partners. Rather, it aims to give its partners new tools, to enable them to provide services, create value, and open economic sectors that would be inconceivable and inaccessible without a coordinated approach, i.e., without a Flagship. Only through the co-design of its ***Key Technologies*** can *ExtremeEarth* ensure that the important scientific, technical, institutional and cultural bottlenecks are identified and resolved, and thereby ensure that *ExtremeEarth* technologies are actually used by the communities for whom they were developed. In the mature fields that *ExtremeEarth* targets this would not be possible without a Flagship, as it requires a change in the way of working for an entire sector. This is something that cannot be achieved on the scale of national programmes.

The *ExtremeEarth* technology-for-modelling focus is built around strong European activities in the development of domain-specific hardware-software capabilities, through INFRAEDI (e.g. ESiWACE-1&2, HIDALGO and ChEESE centres of excellence) as well as FET-HPC projects (ESCAPE-1&2, NextGenIO, EuroEXA, MAESTRO, EPiGRAM-HS, LEXIS) and INFRAIA e-infrastructures (IS-ENES projects). These provide a foundation of research into numerical methods, programming models, workflow and application design for EuroHPC infrastructures and complement national initiatives pioneering technology development in support of advanced computing (e.g., PASC and HP2C in Switzerland, HD(CP)^2 in Germany) and H2020 projects supporting collaborative scientific research (e.g. PRIMAVERA, CRESCENDO, IMPREX, ANYWHERE, EUCP). Together with EuroHPC these links provide a strong technological backdrop and high degree of readiness for *ExtremeEarth's* technological leap.

The *ExtremeEarth* technology-for-data focus is likewise rooted in strong European infrastructure projects, in particular the major ESFRI infrastructures such as EPOS, EMSO, ACTRIS, ICOS, Euro-Argo, LTER, AnaEE as well as efforts such as the Partnership for Advanced Computing in Europe (PRACE), the pan-European research and education network that interconnects Europe's National Research and Education Networks (GEANT), European Data Infrastructure (EUDAT) and EOSC (the European Open Science Cloud). Also at European scale, links to ESA and EUMETSAT, the Copernicus services for climate change, atmospheric monitoring (both hosted by ECMWF), marine environment monitoring, land monitoring and emergency management services (European and Global Flood Awareness Systems, EFAS/GloFAS, supported by ECMWF) represent large-scale efforts to centralize European capabilities. The data focus is further strengthened through partnerships with national and international organisations, in particular to the WMO through its Global Atmospheric Watch (GAW), World Climate and Weather Research Programmes (WCRP, WWRP).

The *ExtremeEarth* science-to-impact focus is also built on a well-developed European service provision infrastructure that comprises national hydro-meteorological, telluric prediction and civil protection services. *ExtremeEarth* is thus well placed to provide the prediction and technology capabilities that these service infrastructures require in the coming decades, doing so will allow Europe to exploit novel technologies to expose the information content of a new generation of models and observations.

In terms of computing infrastructure, the Contractual Public-Private Partnership (cPPP) for HPC between the European Commission and ETP4HPC offers a forum for collaborating with the HPC industry and policy makers in accordance with the European HPC strategy development. The same applies to other entities such as the Big Data Value Association (BDVA), and the key concerted European efforts on super-computing, data networks and data infrastructures, e.g., PRACE, GEANT, and EUDAT. These are already involved in *ExtremeEarth* planning efforts, and links will be integrated and extended during the *ExtremeEarth-PP*.

2 Impact

2.1 Expected Impacts

2.1.1 Science and technology breakthrough

ExtremeEarth will enable a break-through in our ability to simulate and predict weather and climate extremes, volcanoes and earthquakes, and in how users interact with this information. The break-through will be made manifest through science-technology solutions delivering levels of predictive accuracy with real value for a society

grappling with their consequences. For the first time, reliable, impact-oriented forecasts will become available at scales that are relevant for decision-making in countries, regions, cities, coast-lines and large, medium, and small businesses. These predictions will be supported by a much-advanced capability to exploit observational information from existing and yet unused observatories and sensors.

ExtremeEarth strongly deviates from the traditional impact assessment approach, in which individual, disconnected communities operate downstream of the Earth-science modelling community, and use selected outputs as inputs to their own risk models. *ExtremeEarth* will implement a fully integrated science-impact value cycle (Fig. 1) allowing users to extract information from Earth system models and observations within time critical decision-making paths. Users will be able to interact at all stages with data and simulations on the desired level of complexity. These capabilities define the three *ExtremeEarth* Key Objectives.

These Key Objectives can only be realized by a substantial investment in technology that is co-developed with end users. Again, *ExtremeEarth* deviates from traditional thinking by focusing on geo-specific rather than general-purpose technologies. This is necessitated by computational requirements, as realizing the desired scientific advances is way beyond what will be achievable from a general-purpose approach. Here, software development is crucial. *ExtremeEarth* is proposing an investment into three Key Technologies: distributed extreme-scale computing, big data handling and an integrated information system. *ExtremeEarth* will hide the scientific and technological complexity (as much as possible) from the user, and still enable the user to employ the best science and impact models running on the best technological solutions.

2.1.2 Socio-economic benefits

While short-term forecasts of weather have improved significantly over recent decades, an ability to anticipate weather extremes on longer time-scales has not advanced apace, and predictions of volcanoes and earthquakes, or projections of climate extremes remain in a more primitive state. This contributes to European vulnerability and the high costs of natural disasters. First, many damages occur because current forecasting systems do not predict the precise location and actual impacts of extreme events with sufficient reliability and lead time to allow for proactive management. Second, poor models of long-term disaster risk result in damages that could have been avoided through targeted investments in safe buildings and infrastructure. The value of early and better information about the vulnerability of the built environment to present-day extremes and how these may change as a result of development trajectories on the one hand, or of a changing climate on the other hand. This will allow to optimize the long-term socio-economic trajectories and avoid the cost of inappropriate actions[36].

For example, all future protection strategies against earthquake and volcanic eruption impacts require a drastic improvement of our ability of predicting location, timing and extension of the next events. While the location of active volcanoes in Europe is known, the ability of anticipating specific extremes with improved precision and time will enable to calibrate mitigation measures such as evacuations, air-space protection and recovery. For earthquakes the overall knowledge is more scant as damaging earthquakes can take place anywhere in Europe, and catastrophic earthquakes can affect large parts of the Euro-Mediterranean region. Moving from the present-day assessment of hazard to time-dependent hazard will enable society to prioritize retrofitting measures and strengthening of all exposed infrastructures. The capacity of releasing accurate early warnings while the extreme event unfolds will drive rapid reaction and intervention measures. The detection of precursors or the preparation phase of an impending major earthquake would then open opportunities for a different strategy of rapid intervention.

When planning for the coming decades, governments and private sector companies need detailed projections on (i) the expected socio-economic impacts of extremes; (ii) adaptation measures to reduce damage, and (iii) their cost. Cutting-edge modelling capabilities for both solid and fluid Earth developed in *ExtremeEarth* will provide this information at the required resolution and accuracy, enabling substantial progress in enhancing the resilience of European society and its investments.

ExtremeEarth will contribute to both short-term preparedness as well as long-term resilience building. For short-term warnings, *ExtremeEarth* will enable forecasts of the socio-economic impact of extremes (for instance real-time shake maps from earthquakes, or flood scenarios) with sufficient location and information detail, so that crisis managers can tailor their preparations to manage evacuations, protect critical infrastructure, deliver medical support, water and relief to the areas that need it most, especially to prepare before the disaster happens. Current early warnings have reduced the number of casualties by thousands around the globe and the economic benefits of early warning systems run into many billion €[37] – with potential for improvement again in the billion €.

With sufficient lead-time, vulnerable people can be evacuated and assets can be moved while stockpiles of relief supplies can be assembled already in advance of the event, further reducing the number of casualties and the recovery time after the actual event and increasing the resilience. This contributes to the Priorities for Action of the

[36] https://www.ncbi.nlm.nih.gov/pubmed/26438286
[37] http://www.unisdr.org/files/3612_GlobalSurveyofEarlyWarningSystems.pdf

Sendai Framework for Disaster Risk Reduction[38], its proposed implementation in the Global Risk Assessment Framework (GRAF) and the European Commission action plan[39] - including the priorities on understanding all dimensions of risk, strengthening disaster risk governance, investing in disaster risk reduction for resilience, and enhancing disaster preparedness for effective response. *ExtremeEarth* will provide timely and accurate Earth-system information that is prerequisite to the proposed pan-European disaster risk prevention framework and response mechanisms to be developed under the ambitious European Scale rescEU framework[40].

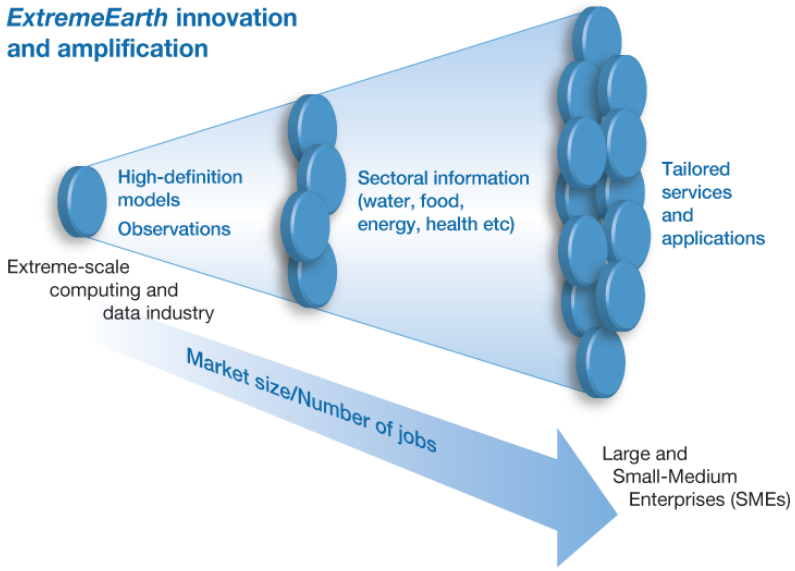
In addition, the Earth-system technology concepts of *ExtremeEarth* will allow for a comprehensive assessment of the benefits of proposed measures to adapt to climate change or manage development. With such information, *ExtremeEarth* will strengthen the EU leadership in a highly connected, global community to evolve towards a sustainable and resilient global economy by providing the capabilities for a more science-based planning. Among other things, such actions will, for instance, allow *ExtremeEarth* to help its partners contribute to initiatives such as the five-year global stocktaking assessment of the Paris climate agreement to provide contributions to the Intergovernmental Panel on Climate Change (IPCC), and contribute to good practice on greenhouse gas and climate impact reporting under the United Nations Framework Convention on Climate Change (UNFCCC).

ExtremeEarth-PP will allow assessing the quantitative socio-economic impact potential together with relevant stakeholders in a dedicated work package (WP4-5) to provide estimates of the return on investments. The preparatory project engages stakeholders from industry, government, and civil society to design how these groups will collaborate with modellers during the *ExtremeEarth* project, ensuring that users will co-design tools for accessing and visualizing Earth-system information.

2.1.3 Industrial support and European competitiveness

The race for leadership in HPC systems is driven both by the need to address societal and scientific grand challenges more effectively, such as preventing large-scale catastrophes, and by the needs of industry to innovate products and services. The industrial landscape continues to undergo dramatic changes following the digital revolution including the adaptation to robotics, AI, and big-data analytics techniques.

ExtremeEarth will be both a beneficiary of the changing digital environment and a contributor to on-going change. *ExtremeEarth's* initial industrial impact provides a boost to a relatively small, but quintessential European HPC industry. To this end, *ExtremeEarth* will provide a competitive advantage for the market of HPC systems specifically developed for environmental forecasting centres, including the combination of HPC, modern sensor technology, new visualisation technology and big data. Beyond HPC, the full integration of computing, data and cloud technologies is already on the horizon, but *ExtremeEarth* is much larger in scale, and it takes a crucial application perspective not seen by current major commercial cloud providers. This will result in a major competitive advantage to applying generic technology in other sectors. It will further boost a growing market of larger technologically advanced industries working in applications of high definition forecasts, e.g. in the food and energy sectors (e.g. Bayer Crop science and Arcadis)[19]. EEsC will give the technologically advanced industries much greater access to accurate assessments of natural hazards and their impacts, and serve as a platform for innovation more broadly (as illustrated in Fig. 7).



The impact of *ExtremeEarth* ranges from extreme-scale data and computing industry to consultancy and tailored services by public and private institutions. Products are developed for adaptation and mitigation options along the entire nexus of critical infrastructures – energy – hydrology & water – food & agriculture – health & air quality – emergency & disaster management. *ExtremeEarth* stimulates large and small-medium enterprises in this entire range. It develops software to enable the delivery of tailored services, but will not provide services. It replaces the traditional cumbersome chain of data from Earth-system sciences to services with a new infrastructure - EEsC. Through EEsC, *ExtremeEarth* will give European industry a huge competitive advantage, and will be instrumental in the Single Digital Market.

Figure 7: The amplifying effect of ExtremeEarth's technological developments.

[38] http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf
[39] https://ec.europa.eu/echo/news/european-commission-launches-sendai-action-plan-disaster-risk-reduction_en
[40] https://ec.europa.eu/echo/news/resceu_en

Many of the benefits from *ExtremeEarth* will be felt by changes to the services delivered by its partners. Researchers currently target their scientific expertise to inform the society as to potential hazards, e.g., from climate change or volcanoes. The capabilities *ExtremeEarth* will develop will move away from more assessment-focused research outputs towards research that allows the fruits of this research to be easily transformed into actual services. The co-design process ensures that this capacity will be developed in collaboration with scientists, applied research institutes, Small and Medium-Sized Enterprises (SME) and engineering companies alike, who can each test their innovations on the platforms that *ExtremeEarth* will develop.

ExtremeEarth is a game-changer that will enhance the competitiveness of all European agencies and agents involved in, or touched by, environmental extremes, to combine exposure and vulnerability information with weather, climate and geo-hazard information, identifying hotspots of risk that require pro-active investment. We are only beginning to comprehend the opportunities afforded by this investment, but *ExtremeEarth-PP* will specifically flesh out scenarios and trajectories in this impact area by reducing risk, developing industry and sparking off new applications and services. Some examples for the opportunities of such services are listed below.

2.1.3.1 Risk reduction

Advanced Earth-system prediction and observation capabilities (***Key Objectives 1-3*** enabled by ***Key Technologies 1-3***) will allow for making comprehensive assessments of the form and frequency of weather and climate extremes, earthquakes and volcanoes. This will provide governments and businesses with information on the potential impacts (***Key Objective 3***) on their investments, infrastructure, production and distribution facilities, now and for the coming decades. For both fluid- and solid-Earth "seamless" forecasting systems will also allow for accurate and high-resolution early warning systems, allowing civil society to mobilize quickly to protect the most vulnerable before extreme events happen.

Inventories assembled by the re-insurance industry concluded that there are substantial disaster coverage gaps ("only a third of worldwide economic damage is covered by insurance"[41]) and governments often have to intervene as the insurer of last resort. Better *projections* of extremes enabled by *ExtremeEarth* through ***Key Objectives 1-3*** will lead to improved early warning services, to save lives and property. More comprehensive probabilistic modelling of risk will also allow for risk reduction. This will lead to more affordable pricing of insurances, loans and guarantees, as well as reduced costs for governmental support.

Today, annualized damages of 1-12% of the Gross Domestic Product (GDP) result from existing climate risks, which – based on the projection of future economic development and analysis of three climate scenarios – are likely to rise to up to 19% of GDP by 2030[42]. Depending on the region, up to 80% of this increase is driven by economic development in hazard-prone areas such as (mega) cities in coastal regions. Risks from volcanoes and earthquakes are more difficult to quantify. There is significant potential for cost-effective adaptation measures: Up to 60% of the projected increases in damages can be averted - a strong case for preventive action[43]. Therefore, the financial sector has strong interest in more precise assessment of physical risks (from the impact of extremes implied by long-term climate change projections, let alone additional information about vulnerability to solid-Earth extremes) for sovereigns and corporates as requested by the Financial Stability Boards' (FSB) Task Force for Climate-related Disclosure (TFCD)[44] (***Key Objective 1***).

Key Objective 1 and ***3***, namely the capabilities for simulating and predicting extremes and their impacts, makes it possible to better account for the effects of both development and climate changes when assessing risk. To this end, *ExtremeEarth* will reduce the uncertainty around such assessments. It is estimated that a 5% increase in the accuracy of natural hazard risk assessment in Europe would free up € 1 billion annually. This would enable the financial sector to provide more risk-bearing capital, better diversify risk and hence help to close the disaster-finance-gap.

ExtremeEarth provides to enterprises the capabilities to map the information needed to actively manage and mitigate disasters, including the disruptions to global supply chains (***Key Objectives 1-2***). European businesses will be able to use forecasts of extreme events to minimize risk for their operations, such as airlines choosing to re-route flights and avoid costly weather or volcanic ashes cancellations, and to target mitigating measures to protect critical infrastructures against accidental release of toxins, in line with the European Seveso-III Directive (2012/18/EU). For extremes and hazards affecting human health, *ExtremeEarth* makes it possible to trigger targeted health protection investments locally and at much larger lead times. Similarly, it will provide the basis for novel approaches to pre-emptively manage air quality and to better protect highly vulnerable communities[45].

[41] http://media.swissre.com/documents/sigma2_2017_en.pdf
[42] Bresch, 2016: Shaping Climate Resilient Development – Economics of Climate Adaptation. In Salzmann, Huggel, Nussbaumer, Ziervogel (Eds): Climate Change Adaptation Strategies – An Upstream-downstream Perspective. Springer New York.
[43] https://www.ethz.ch/content/dam/ethz/special-interest/usys/ied/wcr-dam/documents/Economics_of_Climate_Adaptation_ECA.pdf
[44] www.fsb-tcfd.org
[45] Im et al., 2017: Deadly heat waves projected in the densely populated agricultural regions of South Asia. Sci. Adv., 3:e1603322.

Finally, impact-modelling services may be developed to estimate the potential effects of natural disasters on national security concerns including migration (***Key Objective 3***). This is critical for the European economy, which needs to account for risk in economic strategies and investment decisions on a global scale.

2.1.3.2 Economy

From the increased predictive capability at very high resolution of the Earth-system (***Key Objective 1*** enabled by ***Key Technologies 1-2***), *ExtremeEarth* will strongly support the transition of the energy sector towards a competitive low carbon EU-economy. More reliable weather predictions will support operations by seamlessly monitoring and predicting energy variables (e.g., wind, sunshine) at various temporal and spatial scales for demand and production forecasting. This will help to optimize the mix of renewable resources, and reduce fossil fuel use. Better assessment of possible impacts from weather and climate extremes, earthquakes and volcanoes will also help minimize the vulnerability of energy distribution networks.

Better (and more localized) information about weather and climate extremes, earthquakes and volcanoes is pivotal for investment decisions by identifying beneficial locations for large scale solar, wind and water production plants including energy storage and distribution. With ***Key Technology* 3**, *ExtremeEarth* will enable industry to assess the impact of weather and climate variability, shake-potential or volcanic activity on energy saving and distribution strategies, and enable informed decisions on energy saving investments. This will help deriving recommendations for the improvement of regulatory monitoring protocols also supporting public engagement.

A further economic benefit targeted by ***Key Objective 1***, one that strongly benefits from *ExtremeEarth*'s link between solid and fluid Earth, will be the control of induced seismicity by underground exploration technologies, which in recent years has grown in importance[46]. Induced seismicity severely limits our ability to explore for and extract traditional and new renewable geo-resources (ground-water extraction and waste-water injection, conventional and unconventional oil and gas, deep hydro- and geothermal energy, gas and CO_2 storage). *ExtremeEarth* will create the knowledge to validate protocols and procedures, and provide a computational platform integrating experimental, modelling and monitoring technologies, with the goal to enable the energy transition to renewable geo-energy technologies. These efforts will further allow *ExtremeEarth* to support the knowledge generation required to implement CO_2 geological sequestration while controlling induced seismicity (***Key Objective 1***) and to help assess the Earth-system's response to geo-engineering scenarios (***Key Objective 1***)[47].

ExtremeEarth will facilitate development in novel areas of climate and weather services through the availability of data and forecasts whose precision and accuracy brings real value to the anticipation of extremes (***Key Objectives 1, 3)***. For example, the tourism sector will be able to improve operational planning and adaptive measures to minimize damages from extreme weather events, volcanoes and earthquakes.

ExtremeEarth will benefit the agriculture and food sectors by supporting strategic decision-making aimed to select the best agro-ecological zones for investments in sustainable production (***Key Objective 3***, ***Key Technologies 1-3***). *ExtremeEarth* will help to transform Europe's future Common Agricultural Policy (CAP) consolidating the European Union as the global leader in sustainable farming and food provision. This can include improvements to harvest bulletins, which currently provide only limited end-of-season skill in production forecasts. *ExtremeEarth* will underpin future global investments in agricultural research and development – amounting to € 55 billion in 2011[48], with an increased share of private investments in recent years due to advances in genomics, analytical capacity, technology, computation, and logistics. Farms are evolving towards high-tech and information intensive systems. *ExtremeEarth* will facilitate the needed information systems allowing farmers to take better in-season management decisions, plant breeders to develop the next generations of crop varieties, agro-businesses to plan and optimize production and distribution systems post-2030, and policy to invest and support in resilient agronomic production with a higher degree of efficacy and reduced costs (***Key Objectives 1*** and ***3***, ***Key Technologies 2-3)***. Such agricultural research and development investment strategies could boost total factor productivity to 2%, which can lower world prices of cereals and meat by as much as 17% and 15%[49]. With 570 million farms around the world, *ExtremeEarth* can benefit the full variety of farming systems, including the 90% that are family-run, yet produce 80% of the world's food and are critical for local food provision[50].

ExtremeEarth-PP will estimate the potential impact on the individual business sectors together with relevant stakeholders in a dedicated work package to provide estimates of the return on investments.

2.1.4 Impact on research infrastructures

Through a complete redesign of the modelling, data handling, and computing capabilities in Earth-system science,

[46] Giardini, 2009: Geothermal quake risks must be faced, Opinion. Nature, 462, 848-849, doi: 10.1038/462848a.
[47] European Academies Science Advisory Council, Negative emission technologies: what role in meeting Paris Agreement targets, EASACpolicy Report 35, Feb 2018, ISBN: 978-3-8047-3841-6.
[48] https://www.pwc.co.uk/sustainability-climate-change/assets/fsb-task-force-ag-food-forestry.pdf
[49] http://www.ifpri.org/publication/2015-annual-report
[50] http://www.fao.org/docrep/017/i1688e/i1688e.pdf

ExtremeEarth will provide two critical missing elements for research today: (i) the integration of the full value chain into a seamless prediction system, and (ii) solving 1000-fold larger computing tasks at operational production speed than expected in 2020. The impact on science and service would be immediate: *ExtremeEarth* will be a role-model demonstrator for the European Data Infrastructure within PRACE, GEANT and EUDAT.

ExtremeEarth will design extreme-scale computing and data systems to solve very ambitious problems in Earth-system sciences. Linking solid and fluid Earth in this effort increases the chance that the algorithmic motifs and data flow problems may also be exported to other domains. For instance, the partial differential equations with complex parametrised models that themselves are represented by differential equations appear in many areas of computational science, such as in material sciences and fluid dynamics in engineering. We push the envelope for a number of reasons: the scientific challenges are real and have economic consequences, the assimilation of vast amounts of observational data in the models is unparalleled in other fields, the diversity of downstream applications is large and the necessity to change the workflow will have consequences for many domains. Computational chemistry and life sciences face similar multi-scale modelling, workflow and data integration challenges. Life sciences face similar challenges for data integration. Thus, the technologies necessary to support *ExtremeEarth's* computing and data needs will almost certainly find application in other domains.

ExtremeEarth will offer and coordinate a unique exchange platform, which makes available technological advances to the wider research and education community. This includes HPC software and hardware technology that enables users to deal with very large simulation problems, novel software developments with code that can be run on various HPC architectures, advanced mathematical and algorithmic techniques including AI, and efficient and application oriented workflows.

ExtremeEarth will facilitate big data handling from both models and observations thanks to a shared expertise in ICT technologies. This will provide a unique knowledge-base for European observational research infrastructures in Earth-system science, such as EPOS for geo-hazards, ICOS, IAGOS, ACTRIS for the atmosphere, Euro-Argo and EMOS for the oceans, as well as for leading entities such as IS-ENES for climate and ECMWF for weather prediction. This will also foster open and easy access to the vast Earth-system data archives.

The exploitation of national, European (EC, EUMETSAT, ESA) and international Earth observation satellite programmes will be fostered by *ExtremeEarth* through optimized data workflows, much enhanced information extraction, and information in support of future observing system design. This will influence the innovation cycle of satellite technology but also trigger new developments in the value adding business sectors. In concert with existing research monitoring networks such as ICOS, Terrestrial Environmental Observatories (TERENO), LTER, *ExtremeEarth* will trigger the development and use of low-cost innovative sensors in commodity devices, drones and other monitoring devices will be provided by specialised manufacturers to respond to the requirements of the new generation of simulators.

Ensuring institutional commitments and a coordinated development path over a period of 10+ years for a project with this level of ambition is a complex challenge, comparable to the large international high-energy physics endeavours. By meeting this challenge, *ExtremeEarth* is expected to become a similar attractor and focal point for the entire Earth-science community with numerous subsequent research and development spin-offs.

ExtremeEarth-PP will assess the impact on national and European research infrastructures together with relevant stakeholders in a dedicated work package. Here, *ExtremeEarth-PP* will join forces with other programmes (i.e. Joint Programming Initiatives, JPI, like JPI Urban Europe, JPI-Climate. JPI-Agriculture, Food Security and Climate Change and JPI-Water) as well as insurance and reinsurance industry to design the tools required for a comprehensive and accurate risk assessment, with a particular focus on extreme events and their impacts.

2.1.5 Initiation and training of a new generation of researchers

ExtremeEarth will create a new generation of multi-disciplinary scientists better prepared to face the future environmental challenges than we are today, as *ExtremeEarth* will bring the Earth- and impact science communities together with the HPC community and with service providers operating with different constraints and incentives than scientists. In this way, *ExtremeEarth* dissolves disciplinary borders separating technology from science from society (Fig. 1). *ExtremeEarth* will invest substantially in creating an education and training programme at the interface between these disciplines, and with a particular focus on gender balance.

Proposed instruments include new curricula at universities associated with *ExtremeEarth* individual proposals for the European Research Council's synergy and the proof-of-concept grants, the Erasmus programme and Marie Sklodowska-Curie actions, "Summer schools" at universities and research institutes, an industry fellowship programme across employment sectors, secondments of early-career researchers to industry and civil society partners, dual bachelor and master courses on applied mathematics and informatics taught by partners from both research and industry, domain-specific collaboration with a focus on entrepreneurship including – as part of the Climate Knowledge and Innovation Community (Climate-KIC) – the solid Earth community, the energy innovation

community, and the (re)insurance sector, customized education portals for partner institutes, and simulation laboratories at partner institutions. The details of this programme will be defined during *ExtremeEarth-PP*.

2.2 Measures to maximise impacts

2.2.1 Dissemination and exploitation of results

2.2.1.1 Dissemination activities

As the ultimate goal of *ExtremeEarth-PP* is to provide a blueprint for an FET Flagship initiative, the expected results comprise plans and roadmaps towards a consolidated effort to improve Europe's capabilities to simulate and predict extremes in the Earth system as well as a mobilisation of the community (including research, industry, policy makers, and other stakeholders).

Dissemination of results will be realised through a targeted effort addressing the different stakeholder groups. These efforts include:

- organisation of Screening and Consolidation Workshops that will involve stakeholders already at an early stage in the project ensuring visibility and near the end of the project to confirm stakeholder engagement and commitment, respectively;
- promotion at conferences including dedicated sessions, panel discussions and conference stands to disseminate the project philosophy, garner support and disseminate plans and roadmaps;
- progress and result updates on the *ExtremeEarth* as well as partner and stakeholder websites;
- further dissemination through mailing lists, newsletters, popular articles and press releases.

Scientific publications underpinning the roadmaps and plans will be published in relevant journals and conferences. After the end of *ExtremeEarth-PP*, public results will be available via the *ExtremeEarth* project website, which will be accessible for five years after the end of the project.

2.2.1.2 Exploitation activities

Exploitation activities will be geared towards the establishment of *ExtremeEarth* as a consolidated, multi-partner European effort, including expanding the political and societal support for the project. The exploitation activities will therefore include interactions with all stakeholders to further motivate the realisation of the project and its translation into the research agendas of national and international programmes and industrial development roadmaps to prepare the envisioned co-funding model.

2.2.1.3 Research data

ExtremeEarth will allow to exploit high-volume and high-quality data from model simulations (source code, inputs, outputs and checkpoints), satellites, measurement stations and derived environmental data sets as well as data from cell phones and other non-conventional (edge) data sources. The data will be stored using existing data standards of the scientific community, for example, WMO standards for model data and observations as well as NetCDF. This data is of high value for many potential users at research institutions, for climate services and operational forecast centres as well as for industrial and finance applications. The data will also be a versatile resource for education and public engagement. It is very difficult to predict the exact data that will eventually be requested by the large number of potential users. This is particularly true for ground-breaking applications in the field of AI or those originating from SMEs with specific requirements. EEsC will therefore be designed to establish a transparent and easy workflow to allow all user groups to access data that is generated by *ExtremeEarth* while hiding technical details and technology challenges from the user.

ExtremeEarth will establish a database for all participants and users that will keep track of all data that is generated under *ExtremeEarth*, and is FAIR. A standard to label data correctly will be established and communicated within the consortium to make sure that data can eventually be exploited by all users. The labelling information will include details on how the data was generated, what data format was used when generating the data, whether the data is confidential, where the data can be found and accessed, who is responsible for the data, whether the data may be polluted (for example when generated while debugging the model) and the duration for which the data should be stored. An expiration date for all data is required since an exponential increase of storage volume cannot be tolerated in the future. However, the expiration date can be set to infinity (for example for observations) and changed at any time. On the other end, users from both within and outside of the consortium will be able to send requests to EEsC about data that they require via a webpage. Users can specify the type of data (for example observations or model output of a specific model or re-analysis), the dimensions and resolution in space and time, the parameters and model fields, and the number of ensemble members that are required. EEsC will generate a list of suggestions for data that is accessible to the specific user as well as details on how to access the data. It will also provide suggestions how to generate data that is missing, for example by interpolation from grids with different shape or resolution or via a re-submission of model simulations from checkpoints or re-analysis data sets. A cost estimate for the generation of new data will be provided.

ExtremeEarth will curate data within EEsC. The overall data volume will be reduced as much as possible through

the opportunity to share data between users, the data expiration date and the capability to re-generate data from model check-points. All publications that are generated under *ExtremeEarth* will provide a unique identifier that can be used on EEsC homepage to get immediate access to the specific data sets that were used for the publication.

ExtremeEarth-PP will prepare the *ExtremeEarth* approach to research data in its data management activities that will also cover data-curation for the time when the project is finished.

2.2.1.4 Knowledge management and IPR

IPR issues will be handled according to the H2020 Model Grant Agreement as well as the Consortium Agreement (based on the commonly used DESCA template) covering the *ExtremeEarth-PP* project. It is not expected that IPR protection measures (patents, trademarks, etc.) will be required for the results of the preparatory action, as these mainly comprise roadmaps and plans.

The scientific publications resulting from the preparatory action will be open access (either green or gold) and thus available to the wider public.

2.2.2 Communication of results

Communicating effectively and efficiently in *ExtremeEarth-PP* is an important factor in preparing the *ExtremeEarth* Flagship. It will help the project to reach the right (wider) audience with the right message (Tab. 1).

ExtremeEarth-PP communication activities will address the interaction with current stakeholders and promote the project to potential new stakeholders and the general public. The *ExtremeEarth* website will be the main repository for the project documentation and related news.

Project description, news items, listing of main events (particularly the workshops organised by *ExtremeEarth-PP*), and the description of results will all be covered through the *ExtremeEarth-PP* website. The website will be maintained by ECMWF with input from the consortium partners.

Defining the target audience is important to produce the impact outside *ExtremeEarth-PP* and tailor the information provided accordingly. The target audiences identified for *ExtremeEarth-PP* include (local, regional, national) governments, industry, agencies and technology providers, science and research communities, etc.

ExtremeEarth-PP will utilise expert communicators through the ECMWF communications department with support from external contractors on the communication as well as dissemination aspects to ensure a high visibility of the project in the community and wider audience, promoting the added value of this European collaboration and the need for an *ExtremeEarth* FET Flagship.

Table 1: Communication targets.

Target audience	**Communication Means**	**Responsibility**
Governments, Agencies, EU member states (incl. policy makers)	Workshops and resulting reports; Road Maps; Policy briefs/ Press releases; Project news/ Newsletters; Tailored updates on the results; *ExtremeEarth* website.	ECMWF with support from all partners
Scientific community	Peer-reviewed scientific papers; Workshops and resulting reports; Conferences; Road Maps; Project news/ Newsletters; *ExtremeEarth* website.	All partners
Industry and Technology providers	Targeted publication material; Link with relevant H2020 and other initiatives; Representation at relevant conferences and fairs; Project news/ Newsletters.	All partners
General public	General Information Material; *ExtremeEarth* website; Project news/ Newsletters; Dissemination Material; Press releases.	ECMWF with support from all partners

3 Implementation

3.1 Objectives

ExtremeEarth-PP aims to provide a trustable basis for the implementation of the *ExtremeEarth* Flagship project. 'Trustable' means that the Flagship's ambitious vision will be underpinned by a traceable implementation plan that takes along the complex collaboration between science disciplines, key enabling technologies, societal impact areas, industrial and commercial partners, national and international administrations, and policy makers. The Flagship implementation plan will be defined such that stakeholders will be able to ingest the *ExtremeEarth* outcomes in their respective short and long-term planning and that sustainable structural changes can be realised with sufficient lead time, and maximum benefit and cost effectiveness.

The overarching objective of *ExtremeEarth-PP* is the definition of the highly ambitious 10-year *ExtremeEarth* project to deliver the methods required for a step-change in predictive capabilities for

Earth-system extremes, allowing scientists to understand the drivers of extremes, to translate understanding into simulation accuracy, and equip application communities to anticipate their impact. This will be enabled by developing the technologies for the required 1000-fold increase in computational capacity and data handling, by fundamentally redesigning workflows to dynamically expose the full information content of a new generation of models and data to users, thus becoming an engine for European innovation across a broad range of sectors.

At the end of *ExtremeEarth-PP*, all organisational structures, project governance, independent control mechanisms, the partner and stakeholder engagement framework forming the unique *ExtremeEarth* community, draft budget including a co-funding model and schedule, and project management, communication and dissemination tools are expected to be ready for implementing the visionary *ExtremeEarth* programme within a minimum spin-up period.

The **specific objectives** of *ExtremeEarth-PP* are:

1. Define the **top-level, strategic framework** of the *ExtremeEarth* project between initiation and conclusion, and the roadmap for achieving its overarching goals.
2. Develop the draft **research programme** for the *ExtremeEarth* science disciplines, exploiting common methodologies and maximising connectivity, following the general science strategy.
3. Develop the draft **technology programme** to realize the scientific strategy and implementation plan.
4. Develop the multi-disciplinary and cross-sectorial plan for structuring the relationships between the science-technology co-development of *ExtremeEarth* and **European industry and societal services**.
5. Develop the concept of **Extreme Scale Laboratories** around which the key components of the science-technology co-design and co-development will be formed.
6. Define a roadmap for the **management of partnership** in ***ExtremeEarth*** that realises the scientific and technological ambitions.
7. Define a **governance and project control model** that assigns clear responsibilities for the development of the cross-disciplinary *ExtremeEarth* actors.
8. Define plans for **communication and dissemination**, and a draft *ExtremeEarth* **education programme**.
9. Define a **draft budget** for *ExtremeEarth* and a **co-funding model**.

The following sub-sections describe how the specific objectives will be achieved in *ExtremeEarth-PP*, and how its work packages will jointly produce the main cornerstones for the *ExtremeEarth* **Flagship Implementation Plan**.

3.2 Concept and Approach

3.2.1 General concept and approach

ExtremeEarth-PP is aiming to realize its objectives within eight work packages (see Figure 8). They comprise of the main technical work packages (WP2-3), the interaction with commercial and societal impact generators through industry and services (WP4-5), the definition of Extreme Scale Laboratories where the fundamental co-design efforts are located (WP6), and the set-up of partnership and collaboration as well as Flagship coordination (WP7-8). The CSA coordination work package (WP1) manages the preparatory action, establishes its governance, activates its formal management instruments, and defines a high-level strategic framework. The coordination work package also supports the technical work packages to start their work and guarantees coherence across WP2-7 with respect to science, technology, policy and finance during the project. WP8 concludes the preparatory action by converging the main deliverables from the other work packages into the Flagship Implementation Plan.

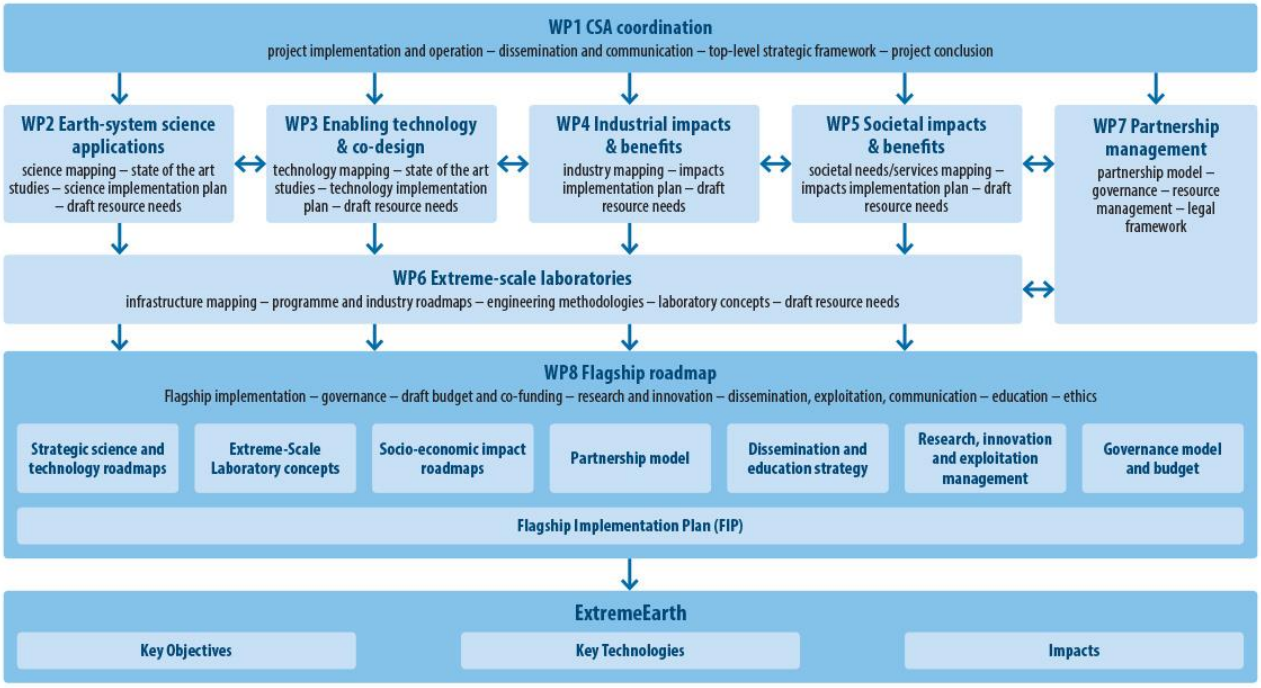


Figure 8: PERT chart of ExtremeEarth-PP showing the main work packages and the key deliverables towards implementing ExtremeEarth and its Key Objectives (Section 1.3.1), Key Technologies (Section 1.3.2) and realising its Impacts (Section 2.1).

Selected key elements of the Flagship Implementation Plan are:

- **Strategic science and technology roadmaps** - delivered by **WP2** and **WP3**: The science and technology roadmaps break down the goals defined as Key Objectives and Key Technologies (Section 1.3) into a development roadmap, identifying the streams of existing and novel science and technology research that will create novel science-technology interface disciplines in *ExtremeEarth*. The roadmaps will also include a definition of success metrics (Key Performance Indicators, KPIs) across the range of prediction system components, full-scale Demonstrators as well as new Key Technologies. An initial identification of alternative development scenarios for high-risk elements will be provided. These will become part of the *ExtremeEarth-PP* risk management plan. The science-technology roadmaps will define requirements for the Extreme Scale Laboratories and receive input from the socio-economic impact roadmaps.
- **Socio-economic impacts roadmaps** - delivered by **WP4** and **WP5**: *ExtremeEarth* will foster smart, sustainable and innovation-led socio-economic growth. The socio-economic impacts roadmaps will ensure that the science-technology roadmaps evolve into measurable and achievable goals for socio-economic impacts. This includes an assessment of the business-readiness of the European research, technology and impact sectors for structural changes to be delivered by the project. The impacts will target industry, national governments, national, international and supranational organisations, and the society as a whole through the implementation of science/technology-industry and science/technology-society relationships during *ExtremeEarth-PP*. The socio-economic impact roadmaps aim to establish these relationships by providing the critical mass to existing collaborations, by spawning new collaborations across different sectors and by creating a virtuous system capable to convert innovation into lasting economic growth and societal benefits.
- **Extreme-scale laboratory concepts** - delivered by **WP6**: *ExtremeEarth's* co-design based research and development will be established by Extreme Scale Laboratories that fuse the expertise of physical science, the wide range of applications, software development across all levels of the stack, and domain specific hardware. The Extreme Scale Laboratories will deliver a concept for a European network of competence centres that coordinate the research on the development streams identified in the science and technology roadmaps by exploiting the existing distribution of expertise in Europe and by creating new nuclei of advanced research in selected regions, which require added impetus. The laboratories will take specialised developments to the level of full-sized demonstrators.
- **Partnership strategy** - delivered by **WP7**: The partnership strategy defines the collaboration between *ExtremeEarth-PP* and potential *ExtremeEarth* partners and stakeholders based on excellence and those sectors crucial for delivering the proposed research and development as formulated in the science-technology and socio-economic impact roadmaps. An important component in this step is the coordination with existing advanced technology developments and the Extreme Scale Laboratories that *ExtremeEarth* will create. In addition, the partnership strategy will include the planning of cost-effective resource management in the

project.

- **Governance model and Flagship organisation** - delivered by **WP8**: The governance model establishes a concept for the *ExtremeEarth* governance and control structure and the definition of interfaces with the wider science and technology community, stakeholders and service infrastructures, the European Commission, and the public. In its first pillar, the governance model will ensure that the *ExtremeEarth* management is tightly connected to the science community through independent review bodies carrying forth the Implementation Plan in a flexible and cost-effective way. The delegation of authority to thematic sectors and the Extreme Scale Laboratories will receive special attention in the governance model as it represents the core of the cross-disciplinary management effort. The governance model will define roles and responsibilities of the initial partners in the early ramp-up phase, and foster the liaison with the European Commission. The approach to procuring and awarding research funds and controlling projects throughout the lifetime of *ExtremeEarth* and the interaction with the European Commission will form the second pillar of the governance model. The Flagship organisation includes the management of risks and ethics.
- **Draft budget and co-funding approach** - delivered by WP8: The budget estimate will be drawn from input of all work packages and consolidated near the end of the project, with a particular focus on the ramp-up phase of the Flagship ensuring that *ExtremeEarth* is budgeted at start time and can be implemented without delay. Through its wide stakeholder map ranging from Earth-system science research infrastructures and environmental services to application oriented industrial sectors, *ExtremeEarth* will have a similarly wide range of sources for co-funding that will be mobilised in *ExtremeEarth-PP*.
- **Dissemination and exploitation, communication, education** - delivered by **WP8**: The dissemination and exploitation of outcomes of *ExtremeEarth* form an important contribution to the success of the project ensuring a transparent management of methodologies and technologies across *ExtremeEarth* and in the information management with external stakeholders. Transparent information management is also key for obtaining co-funding from stakeholders. Together with the communication and education strategy, they ensure the long-lasting impact of *ExtremeEarth* on European society and industry.

The Flagship Implementation Plan will be the main deliverable of *ExtremeEarth-PP* and provide the blueprint of the *ExtremeEarth* Flagship project. It will follow best practices of implementation planning.

Due to the magnitude and length of the Flagship project and its aim to realize ambitious research enabled by novel technologies, the Implementation Plan will include a detailed risk assessment plan and risk mitigation measures to make sure that *ExtremeEarth* can be realized with full control over project deviations at all times. It will also include a special section on the ramp-up phase of the Flagship project, in which the actions initiated in the preparatory action are transitioned into the large-scale Flagship framework. This step is important for providing the project stakeholders with planning security for their respective contribution to the effort.

Since the development of the main elements of the Implementation Plan in the above list require substantial community input and interaction, stakeholder workshops will be organised in support of thematic areas such as science and technology, partnerships and co-funding, and Flagship governance and coordination. At the beginning of the project, a *Screening Workshop* (in WP1) will define the initial design of the Flagship and will set up the partner networks (both *ExtremeEarth-PP* and external). Near the end of the project a *Consolidation Workshop* (in WP8) will review the work completed in the individual work packages and prepare the integrated blueprint of the Flagship and its Implementation Plan. This means that *ExtremeEarth-PP* will actively involve stakeholders throughout the project.

Depending on the guidance given by the European Commission and the future evolution of the Flagship concept under Horizon Europe, potentially towards so-called Missions, *ExtremeEarth-PP* can take into account alternative implementation options for *ExtremeEarth*. This flexibility is included in WP1.

3.2.2 Domain-specific concept and approach

To prepare for the *ExtremeEarth* Flagship project that will allow achieving the Key Objectives by realizing Key Technologies as described in Section 1.3 *ExtremeEarth-PP* will establish a common scientific-technological framework. Enabling a step-change in our ability to simulate and predict extreme events will require a significant modernization of Earth-system science applications (WP2). Based on an assessment of the science and technology states-of-art and of future needs for achieving the Key Objectives critical areas for investments in new scientific methodologies and applications will be identified. During the Flagship project, these investments will be made long-term and thus need to be carefully aligned with future technology roadmaps, which are assessed in WP3. With application requirements pushing technology to its limits, WP3 will be responsible for enabling co-design with relevant technology providers.

ExtremeEarth-PP will furthermore establish a unified science-application framework to maximise socio-economic impact. We aim for a multi-disciplinary and cross-sectorial engagement with European industry. Within work

package WP4 existing industrial stakeholders and relations with them will be compiled. Models for engaging with new industrial stakeholders, which will benefit from the step-change prediction capabilities and which will share developments of the Key Technologies and their derivatives, will be developed. Similarly, a strategy for a long-term and sustainable cooperation with societal service stakeholders, e.g. in the areas of civil protection, water, energy and food provision, health protection and risk management, will be formulated (WP5).

ExtremeEarth-PP will continuously interact and cooperate with all relevant European and international services and industries as well as governmental (environmental and civil protection) agencies, the geothermal, solar and wind energy sectors, airlines and jet engine producers, food companies, insurances and re-insurances, and critical infrastructures (cities, airports, harbours, nuclear reactors, large factories) that are exposed to natural risks and require specific, highly accurate, and highly refined information.

A key element of *ExtremeEarth-PP*'s strategy is the establishment of Extreme Scale Laboratories (WP6). *ExtremeEarth* tackles grand socio-economic challenges with a new level of science-technology co-design. Co-design can only be effective if separate communities are able to converge their excellence into novel methodologies and technologies, and engage with the wider stakeholder ecosystem such that their applications can exploit the *ExtremeEarth* capabilities throughout Europe. The Extreme Scale Laboratories will serve as catalysts for co-design and produce real-world demonstrators at full scale where different methodologies and technologies are integrated, tested, validated and new capabilities are demonstrated. To achieve the Key Objectives the ability to integrate diverse modelling and observational data integration components, and to connect data analysis and forecast information with societal vulnerabilities, industry supply chains, and development planning will be crucial, and prototypically realised within these Labs. One example is the demonstration of the capability to predict how extreme winds may impact the design of offshore wind farms as well as how winds will distribute volcanic ash following an eruption, or the ability to predict landslides caused by earthquakes or by extreme rainfall within the same methodological and technical framework. In this context, uncertainty modelling for extremes prediction and mitigation will be crucial throughout the science-application dependencies.

When establishing the methodological-technological framework as well as the science-application framework, *ExtremeEarth-PP* will carefully monitor opportunities for engaging with relevant research initiatives in EU member states (and associated countries), industry and interdisciplinary research communities and other initiatives at European level. This concerns in particular the following areas:

- HPC and other IT technologies: The scientific disciplines that are converging in *ExtremeEarth* share methodologies that require extreme-scale computing and data handling capability. Close collaboration in all areas covered by the ETP4HPC Strategic Research Agenda (SRA), namely mathematics and algorithms, computing system architecture (including I/O and storage), system software and management, programming environment, workflows, is essential for *ExtremeEarth-PP*. We plan to expand links and engagement in various development projects driven by DG CNECT.
- HPC and data infrastructures: To prepare for leveraging Europe's future exa-scale capabilities and contribute to the enablement of a post exa-scale infrastructure, *ExtremeEarth-PP* will engage with relevant organisations like EuroHPC and PRACE.
- Science: *ExtremeEarth-PP* will engage with EC-RTD projects on generic Earth-system model and prediction systems, data assimilation and impact modelling. Along with the European Commission programmes, national research infrastructures in EU member states will be consulted. Synergies between industry and science in the development of training courses for research staff will be established. There will be a focus on the creation of targeted cooperations between science and SMEs.
- Policy-making: Within *ExtremeEarth-PP* we will explore how *ExtremeEarth* can engage with and create impact on important international policy making processes. For example, *ExtremeEarth* will help to realign and strengthen European participation in the IPCC process advising governments on climate change science and impacts, thereby contributing significantly to the realisation of the Paris Agreement process and its stock-taking mechanism that is at the heart of the agreement. *ExtremeEarth-PP* also aims for raising European visibility in a number of domain specific programmes of the WMO (WCRP, WWRP, Future Earth), but also be relevant for other international organizations and their programmes (WHO, UNEP, UNDP).
- Services: *ExtremeEarth-PP* will engage with Copernicus (C3S, CAMS, CMEMS, CLMS, CEMS) and national services to ensure that their future requirements will be fulfilled by *ExtremeEarth.*

3.3 Work Plan

Section 3.3.1 shows the list of work packages and the GANTT-chart of work package / task timings and deliverable due dates, followed by the detailed work package descriptions in Section 3.3.2, and the list of deliverables and milestones in Section 3.3.3.

3.3.1 GANTT Chart and Work Packages

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
WP1 CSA Project Coordination												
Task 1.1 Project implementation and operation	D1.1											
Task 1.2 Project dissemination and communication	D1.2											
Task 1.3 Top-level strategic framework		D1.3										
Task 1.4 Project conclusion												
WP2 Earth-system Science Applications												
Task 2.1 Science-application mapping						D2.1						
Task 2.2 State of the art studies						D2.2						
Task 2.3 Specific science strategy and implementation plan											D2.3	
Task 2.4 Draft resource plan											D2.4	
WP3 Enabling Technology and Co-design												
Task 3.1 Science-technology mapping						D3.1						
Task 3.2 State of the art studies						D3.2						
Task 3.3 Specific technology strategy and implementation plan											D3.3	
Task 3.4 Draft resource plan											D3.4	
WP4 Industrial Impacts and Benefits												
Task 4.1 Industry relationships mapping						D4.1						
Task 4.2. Industrial impact implementation plan											D4.2	
Task 4.3 Draft resource plan											D4.3	
WP5 Societal Impacts and Benefits												
Task 5.1 Societal needs and services mapping						D5.1						
Task 5.2 Societal service impact implementation plan											D5.2	
Task 5.3 Draft resource plan											D5.3	
WP6 Extreme-Scale Laboratories												
Task 6.1 Infrastructure and capability mapping						D6.1						
Task 6.2 Programmatic environment and industrial roadmaps						D6.2						
Task 6.3 Software and infrastructure engineering methodologies											D6.3	
Task 6.4 Extreme-scale laboratory concepts												
Task 6.5 Draft resource plan											D6.4	
WP7 Partnership Management												
Task 7.1 Partnership model						D7.1						
Task 7.2 Partnership governance and management											D7.2	
Task 7.3 Resource management											D7.3	
Task 7.4 Legal partnership framework											D7.4	
WP8 Flagship Implementation Roadmap												
Task 8.1 Flagship governance											D8.1	
Task 8.2 Draft budget and co-funding model											D8.2	
Task 8.3 Research, innovation and exploitation management											D8.3	
Task 8.4 Ethics management												
Task 8.5 Dissemination and communication strategy											D8.4	
Task 8.6 Education programme											D8.5	
Task 8.7 Flagship implementation												D8.6
Project Milestones	*MS1*	*MS2*				*MS3*					*MS4*	*MS5*

Work package No	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End Month
WP1	CSA Project Coordination	01	ECMWF	4	1	12
WP2	Earth-system Science Applications	06	CNRS	8	1	11
WP3	Enabling Technology and Co-design	05	ETHZ	8	1	11
WP4	Industrial Impacts and Benefits	04	FZJ	6	1	11
WP5	Societal Impacts and Benefits	17	INGV	6	1	11
WP6	Extreme Scale Laboratories	08	NLeSC	8	1	11
WP7	Partnership Management	18	UHELS	5	1	11
WP8	Flagship Implementation Roadmap	01	ECMWF	8	1	12
				53		

3.3.2 Work Package Descriptions

Work package number	1		**Lead beneficiary**	ECMWF
Work package title	CSA Project Coordination			
Participant number	01	05	**Total**	

Short name of participant	ECMWF	FZJ		
Person months per participant:	2	2	**4**	
Start month	1		**End month**	12

Objectives

This work package will establish and carry out the project management of *ExtremeEarth-PP and* prepare the initial-stage strategic planning. To help set up the large technical (WP2, 3, 6) and impact (WP4, 5) work packages, WP1 will define the strategic framework of the *ExtremeEarth* project between initiation and conclusion, the general roadmap for achieving its overarching science-technology goals, and the transition of its ambitious research project structure into an operational framework in collaboration with national, European and international partners, and with an adequate funding support. The details of these themes will be developed and delivered in WP2-6. WP1 will also draft the initial approach for the partnership (WP7) and organisational model (WP8) within *ExtremeEarth*, and between the *ExtremeEarth-PP* project governance and the European Commission. The Screening Workshop will be organized by WP1 in support of the initial-stage strategic planning.

WP1 realises Objectives 1 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP1 will be led by ECMWF and co-led by FZJ.

Task 1.1 Project implementation and operation (Lead: ECMWF)

T1.1 will initiate and implement the CSA *ExtremeEarth-PP*, form its governance structure and (quality) control mechanisms, including the establishment of the External Advisory Board. The task will set up the comprehensive meeting and workshop schedule for the duration of the project and define the rules and guidelines for the project reporting and internal communication procedures. T1.1 will also provide the financial management for the CSA and ensure a smooth project execution, and it will establish and maintain the risk management process (D1.1). Lastly, T1.1 will manage the interface with the European Commission and all reporting duties through the *ExtremeEarth-PP* Project Office.

Task 1.2 Project dissemination and communication (Lead: FZJ)

T1.2 will develop the approach to dissemination and communication of the results of *ExtremeEarth-PP*. This task will take into account the comparably short project duration in which a very large group of partners and (scientific, technological, political, industrial, public) stakeholders need to be reached, and the communication with the European Commission will be handled. A dissemination and communication plan will be provided near the beginning of the project (D1.2), which will be managed and completed by this task for the remainder of the project duration. This task is crucial for elevating *ExtremeEarth* to the necessary level of public perception. In support of the other work packages, the task will be in charge of disseminating the results of the Screening (T1.3) and Consolidation (T8.7) Workshops that will be the key interaction platforms for the *ExtremeEarth-PP* consortium and all stakeholder groups.

Task 1.3 Top-level strategic framework (Co-lead: ECMWF, FZJ)

T1.3 will define a top-level strategy that helps to initiate the other work packages and provide a consistent first-order sketch of the *ExtremeEarth* Flagship (D1.3). D1.3 will be based on the first of two dedicated *ExtremeEarth-PP* workshops - the Screening Workshop. This workshop will assign an entire week to the key *ExtremeEarth-PP* cross-sectional topics:

- the unified scientific methodological framework reaching across different disciplines of Earth sciences - together with stakeholders from academia and national/international research programmes and infrastructures**,**
- the integration of Earth-system applications into a unified, interactive framework to maximise societal and industrial impact - together with stakeholders from services, industry and national/international technology programmes,
- the science-technology co-design and its manifestation in Extreme Scale Laboratories - together with stakeholders from academia, national/international research programmes and infrastructures**,** industry and national/international technology programmes,
- the open and transparent partnership management - together with potential stakeholders from all *ExtremeEarth* areas of science, technology and impact.

The Screening and Consolidation Workshops will be complemented by focused workshops in each work package.

The output from T1.3 will be the starting point for Tasks T2.1-8.1 and defines the overall research strategy for the science-technology co-design stream across applications and enabling technologies in collaboration with WP2 and WP3, and their translation into Extreme Scale Laboratories in WP6. The task will set up the work streams on socio-economic impacts managed by WP4-5 and concepts for the Flagship governance, and the partner and coordination strategy in collaboration with WP7-8. A roadmap for the realistic planning of the ambitious top-level co-design and collaboration targets will be defined that the other work packages can take over and evolve in a consistent and synchronized way.

In case, the European Commission alters their strategic approach to realize ambitious, visionary and multi-disciplinary research initiatives from Flagships to other concepts, for example more mission-oriented research and innovation projects, T1.3 will adapt the top-level strategic framework accordingly such that the scientific-technological, impact and project organisational work packages of *ExtremeEarth-PP* will meet the changed requirements.

Task 1.4 Project conclusion (Lead: ECMWF)

T1.4 will conclude the project, produce the final *ExtremeEarth-PP* final report, prepare and carry out the final presentation, and the interaction and communication with the European Commission.

Deliverables (brief description and month of delivery)

D1.1 Risk and Quality Management Plan (M1)

D1.2 Dissemination and communication plan (M1)

D1.3 Top-level strategic framework (M2)

Partner Roles	
ECMWF	Co-lead WP1 and lead tasks T1.1 and T1.4, co-lead task T1.3, provide deliverables D1.1 and D1.3
FZJ	Co-lead WP1 and lead task T1.2, co-lead task T1.3, provide deliverable D1.2
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	2		**Lead beneficiary**		CNRS
Work package title	Earth-system Science Applications				
Participant number	06	03	05	**Total**	
Short name of participant	CNRS	MPG	ETHZ		
Person months per participant:	4	2	2	**8**	
Start month	1			**End month**	11

Objectives

This work package will develop the research programme for the *ExtremeEarth* science disciplines both individually and in the value-chain logic, following the general science strategy (from WP1, T1.3). The work package will establish how to realise the three Key Objectives of *ExtremeEarth.* The output will feed into the science-technology strategy and implementation plan that will be finalised in WP8. WP2 will be based on an assessment of current capabilities, the definition of science goals for achieving break-through extremes prediction capabilities and the requirements on co-development of technology together with WP3. WP2 will focus specifically on the development of common methodologies between the different *ExtremeEarth* science disciplines. It will cover all science areas concerned, from Earth-system science disciplines to the range of application areas (***Key Objective 3***). WP2 will thus address the Key Objectives of *ExtremeEarth* together and their demonstration in WP6. The work package will provide detailed targets, success metrics, milestones and deliverables, a draft assessment of research partnership requirements, and draft resource requirements (for WP7 and WP8).

WP2 realises Objective 2 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP2 will be led by CNRS and co-led by MPG and ETHZ.

Task 2.1 Science-application mapping (Lead: CNRS)

Based on the general science strategy and science-technology targets defined in T1.3, this task will prepare a detailed mapping of the general strategy into the *ExtremeEarth* Earth-system science disciplines (weather and

climate, earthquakes and volcanoes) and their societal applications (hydrology and water, energy, food and agriculture, atmospheric composition, environmental risk management) in D2.1. T2.1 will define the path towards achieving ***Key Objectives 1***, ***2*** and ***3*** throughout the Flagship project lifetime. T2.1 will set a specific focus on the interfaces between the different Earth-system science methodologies and between the physical and societal application areas because these form key innovation areas of *ExtremeEarth* (e.g. ***Key Objective 3***). The requirements from the application areas will be contributed by WP4 and WP5.

The task will organise the work distribution through working groups defined at the Screening workshop (T1.3) for completing the detailed strategy exploiting the wide range of expertise of the *ExtremeEarth-PP* project partners, and it will define the interface and requirements for the technology tasks covered in WP3. Output will be a new layer for the top-level science strategy and roadmap defined in T1.3 that is specified for each application individually and collectively for both Earth-system science applications and science-technology.

Task 2.2 State of the art studies (Lead: MPG)

T2.2 will provide a comprehensive assessment of scientific research landscape and needs across the *ExtremeEarth* science domains and application areas. Specifically, it will identify commonalities and differences in computational and data handling bottlenecks in the science domains and the elements of a common syntax through which application areas attempt to access information from prediction systems. This is to quantify the step-change between the ambition defined in T2.1 and the status quo. The assessment includes a description of the current landscape and strengths of the European research communities (to feed into WP7), the identification of critical areas where substantial investments are expected to provide significant benefit for extremes prediction and where connections need to be strengthened between science disciplines and between science and enabling technology. This assessment will include a quantitative estimate of which potential advances would be achievable with existing support, i.e. without *ExtremeEarth*, and which advances will require substantial investments. In collaboration with WP3, detailed requirement profiles for critical mass investments in research areas will be defined, which will be taken up for the specific plans in T2.3. T2.2 will also contribute to the definition of the Extreme Scale Laboratories (WP6).

Task 2.3 Specific science strategy and implementation plan (Lead: CNRS)

Based on the results of T2.2 and governed by T2.1, T2.3 will spell out the detailed scientific strategy for each *ExtremeEarth* science discipline (D2.3) and, as a whole, for realising the three Key Objectives of *ExtremeEarth*. The science strategy will be complemented by a detailed implementation plan per science discipline. The *ExtremeEarth* value chains across science disciplines will be defined in detail including feedbacks. In collaboration with WP3, options for common methodology and technology developments across science disciplines will be assessed.

The detailed implementation plans will be translated into measurable targets, deliverables and milestones - employing the KPI of the Key Objectives. The success metrics for individual science disciplines, across-discipline value chains, and science-technology co-developments will be defined. The latter will be done in collaboration with WP3 and WP6. Critical breaking points and risks for achieving individual targets and for realizing the project objectives will be identified and integrated in the risk management plan developed in WP8.

The output from T2.3 will form the main science strategy contribution to the Implementation Plan assembled in WP8. The implementation plan will be defined in collaboration with the approaches for maximizing socio-economic impacts performed in WP4-5.

Task 2.4 Draft resource plan (Lead: ETHZ)

Based on the detailed implementation plan from T2.3, a draft budget timeline will be produced (D2.4). Options for efficiency gains will be presented, taking into account existing funding structures but also priorities for investment will be included given the risk assessment performed in T2.3. T2.4 will provide input for the overall budget and the co-funding model managed in WP8 (T8.2).

Deliverables (brief description and month of delivery)

D2.1 Extended science strategy and roadmap, and definition of important interface areas for exploiting synergies (M6)

D2.2 Report on state of the art and critical break-through development needs (M6)

D2.3 Specific science strategy and implementation plan including detailed science targets, Flagship deliverables and milestones (M11)

D2.4 Draft resource plan and funding priorities (M11)

Partner Roles

CNRS	Co-lead WP2 and lead tasks T2.1 and T2.3, provide deliverables D2.1 and D2.3
MPG	Co-lead WP2 and lead task T2.2, provide deliverable D2.2
ETH	Co-lead WP2 and lead task T2.4, provide deliverable D2.4
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	3		**Lead beneficiary**		ETHZ
Work package title	Enabling Technology and Co-design				
Participant number	05	07	15	**Total**	
Short name of participant	ETHZ	CMCC	UUT		
Person months per participant:	4	2	2	**8**	
Start month	1			**End month**	11

Objectives

This work package will develop the novel technologies required to realize the scientific strategy and implementation plan defined in WP2. In collaboration with WP2, the output will feed into the science-technology strategy and implementation plan that will be finalised in WP8. The approach is based on the co-design concept requiring a tightly controlled, iterative loop between science and technology with a view to create interactive work environments employing the full range of future technologies for achieving the science goals with optimal technical performance. The work package will plan this element of the *ExtremeEarth* project along three axes of technology, namely high-performance computing, big data handling and integrated, interactive workflows, which form the Key Technologies of *ExtremeEarth*. WP3 will provide the technological guidance for the Extreme Scale Laboratories defined in WP6. The work package will provide detailed targets, success metrics, milestones and deliverables, a draft assessment of technology partnership requirements, and draft resource requirements (for WP7 and WP8).

WP3 realises Objective 3 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP3 will be led by ETHZ and co-led by CMCC and UUT.

Task 3.1 Science-technology mapping (Lead: CMCC)

Based on the general science strategy and top-level science-technology targets defined in T1.3, this task will prepare a detailed match-up of the science implementation plan into the *ExtremeEarth* set of Key Technologies, namely high-performance computing, big data handling and interactive workflow technologies including both software and hardware components. T3.1 will define the path towards realizing these technologies so that the scientific ambitions of the project can be realized. The requirements from the application areas will be contributed by WP4 and WP5.

The task will organise the work distribution for completing the detailed strategy exploiting the wide range of expertise of the *ExtremeEarth-PP* project partners, and it will define the interface and requirements for the science tasks covered in WP2. Output will be a new layer for the top-level strategy and roadmap defined in T1.3 that is specified for each application individually and collectively for both Earth-system science applications and science-technology. The task will also provide input for the foundation of the Extreme Scale Laboratories defined in WP6.

Task 3.2 State of the art studies (Lead: UUT)

T3.2 will provide a comprehensive assessment of technologies suitable for supporting the *ExtremeEarth* Earth-system science areas - individually and as value chains including feedbacks (D3.2). This is to quantify the step-change between the ambition defined in T2.1 and the status quo. The assessment includes the identification of critical technology areas where substantial investments for achieving science-technology advances are expected, leading to significant benefit for extremes prediction (D3.2), that cannot be achieved with incremental progress and the existing disconnect between science disciplines and between science and enabling technology. This assessment will include a quantitative estimate of which potential advances would be achievable with status quo support, i.e. without *ExtremeEarth*, and which advances will require substantial investments. In collaboration with WP2, detailed requirement profiles for critical mass investments in research areas will be defined, which will be taken up for the specific plans in T3.3.

Task 3.3 Specific technology strategy and implementation plan (Lead: ETHZ)

Based on the results of T3.2 and governed by T3.1, T3.3 will develop the specific technology strategy for each *ExtremeEarth* science discipline and the value chains (D3.3). The technology strategy will be complemented by a detailed implementation plan per technology category including technology co-dependencies. In collaboration with WP2, options for common technology developments across science disciplines will be assessed. T3.3 will also support the definition of the Extreme Scale Laboratories defined in WP4.

The detailed implementation plans will be translated into measurable targets, deliverables and milestones - employing the KPIs of the Key Technologies. The success metrics for individual technologies with a focus on science-technology co-developments will be defined. The latter will be done in collaboration with WP2. Critical breaking points and risks for achieving individual targets and for realizing the project objectives will be identified and integrated in the risk management plan managed in WP8.

The output from T3.3 will form the main technology strategy contribution to the Flagship Implementation Plan assembled in WP8. The implementation plan will be defined in collaboration with the approaches for maximizing socio-economic impacts performed in WP4-5.

Task 3.4 Draft resource plan (Lead: ETHZ)

Based on the detailed implementation plan from T3.3, a draft budget timeline will be produced (D3.4). Options for efficiency gains will be presented taking into account existing funding structures and technology infrastructure programmes, but also priorities for investment will be included given the risk assessment performed in T3.4. T3.4 will provide input for the overall budget and the co-funding model managed in WP8 (T8.2).

Deliverables (brief description and month of delivery)

D3.1 Extended technology strategy and roadmap, and definition of important interface areas for exploiting synergies (M6)

D3.2 Report on state of the art and critical break-through development needs (M6)

D3.3 Specific technology strategy and implementation plan including detailed technology targets, Flagship deliverables and milestones (M11)

D3.4 Draft resource plan and funding priorities (M11)

Partner Roles	
ETHZ	Co-lead WP3 and lead tasks T3.3 and T3.4, provide deliverables D3.3 and D3.4
CMCC	Co-lead WP3 and lead task T3.1, provide deliverable D3.1
UUT	Co-lead WP3 and lead task T3.2, provide deliverable D3.2
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	4		**Lead beneficiary**		FZJ
Work package title	Industrial Impacts and Benefits				
Participant number	04	10	14	**Total**	
Short name of participant	FZJ	DTU	UKRI		
Person months per participant:	4	1	1	**6**	
Start month	1			**End month**	11

Objectives

This work package will develop a multi-disciplinary and cross-sectorial plan to maximise the impact of *ExtremeEarth* on European industry. It will define the strategy for a long-term and sustainable cooperation with industrial stakeholders in Earth-system science and link to technology developments covered by this project. It will reach across the entire breadth of impact areas, for example, high-performance, edge and cloud computing, geo-information and prediction value adding, geothermal energy, airlines and aviation, renewable energy and water, food and agriculture, insurance and reinsurance. The work will additionally address the importance of Earth-system science for all sectors, today and in the future, as well as a sector's ability to accommodate changes identified via *ExtremeEarth.* Thus, WP4 will advise WP2 and WP3 and contribute to WP6. The industrial impacts planning in WP4 will also account for the programme and compliance requirements of national governments, international entities and at EU-level, all of which will require development of public-private partnerships designed

to catalyse and promote novel methodologies and technologies.

Based on the assessment of existing industry partnerships requirements and a thorough analysis of gaps and opportunities, the work package will provide an implementation plan feeding into the Flagship Implementation Plan (WP8) including detailed targets, success metrics, milestones and deliverables. WP4 will also draft industry partnership models and resource requirements contributing to WP7 and WP8.

WP4 contributes the industry element of Objective 4 in *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP4 will be led by FZJ and co-led by UKRI and DTU.

Task 4.1 Industry relationships mapping (Lead: DTU)

T4.1 will create a comprehensive database of all activities that support and define *ExtremeEarth* industry relationships at national, EU and international (extra-European) level (D4.1). The database elements will include the domain-specific technological areas of cooperation, the involved industrial sectors, existing spin-off and start-up activities as well as patents, adopted funding schemes and partnership models, time frames for the cooperation, and monetary turn-over and employment profiles. The database will allow *ExtremeEarth* partners to assess growth potential in structurally less developed parts of the European Union. It will also allow collaboration with international partners (e.g. from highly developed countries including the US, Japan and China, and from emerging countries like India). It is thus expected that a full picture of the status of *ExtremeEarth* relevant industry activity. T2.1 and T3.1 (science-application and science-technology mapping) will provide input on *ExtremeEarth* specific requirements for T4.1.

Task 4.2. Industrial impact implementation plan (Lead: FZJ)

The industrial implementation plan (D4.2) will be developed in partnership with industrial and governmental stakeholders. It will take into account existing activities (T4.1), identify approaches to strengthen underdeveloped areas and propose new ways of collaboration. T4.2 will rely on input from T2.3 (specific science strategy and implementation plan) and T3.3 (specific technology strategy and implementation plan), and tightly collaborate with the definition of Extreme Scale Laboratories performed in T6.4, as they require close interaction with industry. T4.2 will collaborate with T5.2 on commercial services for the provision of societal benefits.

The implementation plan will include the high degree of flexibility and risk analysis necessary to account for the evolution of science-technology developments, in a rapidly evolving industrial ecosystem that will be expected during the implementation of *ExtremeEarth*. The plan will describe the areas of interaction, the industries involved, the partnership model and strategy (from WP7), the funding scheme including participation of industry to costs, as well as risks (WP8). The aim will be a focus on fast and effective cooperation during the early implementation of *ExtremeEarth*. The output from T4.2 will form the industry contribution to the Flagship Implementation Plan managed by T8.7.

Task 4.3 Draft resource plan (Lead: UKRI)

Building on T4.2, T4.3 will define an overall draft resource plan for the implementation of *ExtremeEarth*-industry relationships, including co-funding from the participating industries and from national governments and international programmes. It will incorporate the overall EU-level industry-partnership approach. The resource plan will be undertaken according to principles and guidelines provided by WP7 and with guidance from the coordination WP1, and will feed into Task 8.2 (Draft Budget and Co-funding Model) defining the overall draft budget and co-funding model.

Deliverables (brief description and month of delivery)

D4.1 Existing industry relationship and benefit analysis (M6)

D4.2 Industrial impacts implementation plan (M11)

D4.3 Proposal resource plan (M11)

Partner Roles	
FJZ	Co-lead WP4 and lead task T4.2, provide deliverables D4.2
UKRI	Co-lead WP4 and lead task T4.3, provide deliverable D4.3
DTU	Co-lead WP4 and lead task T4.1, provide deliverable D4.1
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	5	Lead beneficiary		INGV
Work package title	Societal Impacts and Benefits			
Participant number	17	11	13	Total
Short name of participant	INGV	JRC	RedC	
Person months per participant:	4	1	1	6
Start month	1		End month	11

Objectives

This work package will develop a multi-disciplinary and cross-sectorial plan for maximising the impact of *ExtremeEarth* on European society. It will define the strategy for a long-term and sustainable cooperation with societal service stakeholders in Earth-system science and technology developments realised by this project reaching across the entire breadth of impact areas such as civil protection, water, energy and food provision, health protection and risk management. The societal impacts planning in WP6 will also account for the programmatic requirements and constraints presented by national governments and international entities, and EU-level service oriented programmes designed to catalyse funding and promote novel methodologies and technologies. Thus, WP5 will advise WP2 and WP3 and contribute to WP6.

Based on the assessment of existing societal partnerships requirements and a thorough analysis of gaps and opportunities, the work package will provide an implementation plan feeding into the Flagship Implementation Plan (WP8) including detailed targets, success metrics, milestones and deliverables, based on the assessment of existing service partnership requirements and a thorough analysis of gaps and opportunities. WP6 will also draft new service partnership models and resource requirements contributing to WP7 and WP8.

WP5 realises the societal element of Objective 4 in *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP5 will be led by INGV and co-led by RedC and JRC.

Task 5.1 Societal needs and services mapping (Lead: JRC)

T5.1 will perform a comprehensive assessment of the societal needs for the management and adaptation to cope with the impacts of environmental extremes based on the vast amount of information available from existing national and international programmes that assess risk and impacts of extreme natural events both within and outside of Europe. T5.1 will also map what exists in terms of national and international programs that would benefit from the availability of the detailed information provided by *ExtremeEarth*. There are several efforts currently existing in this respect that are based on community efforts to provide a world-wide high-resolution information on exposure and vulnerabilities. The level of detail of the information provided by *ExtremeEarth* has to be matched with a comparable level of detail in vulnerabilities and exposure to make risk assessment and adaptation meaningful and effective. Mapping the existing programs and data availability and gap-analysis of data needs to make use of the future *ExtremeEarth* outcomes is of primary importance. The information gathered will inform the work in Task 5.2 and assist defining the implementation plan. Within this data, T5.1 will focus on (a) where the *ExtremeEarth* break-through science-technology developments will be most effective, (b) what information not strictly relating or produced by *ExtremeEarth* has to be gathered to make those development societally relevant (c) closing the gap between the provision of Earth-system science information and its translation into actionable information by governments and civil-protection agencies, (d) how impacts are created at community and individual-citizen level for protecting lives and property, (e) make the development of scenario analysis and planning more reliable and feasible. T5.1 will include input from the science-application value-chain mapping exercise performed in T2.1. The entire assessment in T5.1 (D5.1) will provide the basis for defining the stakeholders of societal benefits of the *ExtremeEarth* capabilities and for defining the implementation plan that evolves the existing service infrastructure (T5.2) and maximises societal benefits.

Task 5.2 Societal service impact implementation plan (Lead: INGV)

The evolution of the existing national and international service infrastructure into a system optimised for realising the benefits of *ExtremeEarth* for protecting society requires the investment into an effective and flexible cooperation. T5.2 will provide the implementation plan (D5.2) for the collaboration with existing service infrastructures at international, national, community, and citizen level that includes continuous feedback mechanisms for monitoring the societal impact of the *ExtremeEarth* contribution, and that allows a flexible adaptation of science-technology developments for impact optimisation. The implementation plan will include a roadmap for service evolution and recommendations targeted at the key stakeholders in charge of service

infrastructures.

Based on the needs mapping from T5.1, this implementation plan will focus on areas where breakthroughs require large-scale coordination and collaboration. For example, *ExtremeEarth-PP* will investigate what break-through results could exist if public actors could directly interrogate earth system data as it is generated.

To develop this implementation plan, *ExtremeEarth-PP* will consult with a full range service provider and governmental stakeholders across *ExtremeEarth* application areas. This will include direct one-to-one consultations with specific sectorial actors, as well as group consultations during government meetings (e.g., public safety decision makers), industry conferences, and international development gatherings. *ExtremeEarth-PP* will implement simulation and visioning exercises with small groups of collaborators, based on methods used in business strategic planning processes; and will evaluate the potential and strategic roadmap for developing EU-level science-technology response plans to manage Earth extremes in Europe and abroad. These discussions will take into account already existing activities (T5.1), identify approaches to strengthen currently underdeveloped areas and propose new ways of collaboration. T5.2 will rely on the science-technology implementation plans defined in T2.3 and T3.3 as much as they require close interaction with service providers. T5.2 will collaborate with T4.2 on commercial services.

The implementation plan will include a high degree of flexibility necessary to account for the risks connected with science-technology developments, and to account for the evolving service landscape during the implementation of *ExtremeEarth*. The plan will describe the areas of interaction, the involved services, the partnership model and strategy (from WP7), the funding scheme including participation of services and governments to the foreseen costs as well as risks (WP8) with a focus on a fast and effective start of the cooperation during the implementation of *ExtremeEarth*. The output from T5.2 will form the societal contribution to the Flagship Implementation Plan managed by T8.7.

Task 5.3 Draft resource plan (Lead: RedC)

Building on T5.2, T5.3 will define an overall draft resource plan for the implementation of the *ExtremeEarth*-services relationships, including co-funding from committed independent organisations, local communities, national governments and international programmes, and taking into account the overall EU-level service-partnership approach. The resource plan will be realized according to principles and guidelines provided by WP7 and with guidance from the coordination WP1, and will feed into Task 8.2 defining the overall draft budget and co-funding model.

Deliverables (brief description and month of delivery)

D5.1 Societal needs and existing services impact analysis (M6)

D5.3 Societal impacts implementation plan (M11)

D5.4 Draft resource plan (M11)

Partner Roles	
INGV	Co-lead WP5 and lead task T4.2, provide deliverables D4.2
JRC	Co-lead WP5 and lead task T4.1, provide deliverable D4.1
RedC	Co-lead WP5 and lead task T4.3, provide deliverable D4.3
	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	6		**Lead beneficiary**		NLeSC
Work package title	Extreme Scale Laboratories				
Participant number	08	12	14	**Total**	
Short name of participant	NLeSC	BSC	UKRI		
Person months per participant:	4	2	2	**8**	
Start month	1			**End month**	11

Objectives

This work package will develop the concept of Extreme Scale Laboratories where science-technology co-design will be exploited. Within these laboratories, software platforms are developed exploiting domain-specific hardware that are used for the demonstrators of *ExtremeEarth.* Options for the concept of laboratories, ranging from virtual

and distributed to institutional and centralized laboratories, will be explored. The output from WP2-WP5, where the landscaping and road-mapping from scientific, technological, industrial and service user-perspectives is carried out, will feed into the laboratory design that will be finalized in WP8.

Extreme Scale Laboratories will generate new workflows with extreme-scale data handling and computing capabilities at their core. They will include access to significant infrastructures for high-performance, cloud and edge computing, big data handling and storage, workflow and user interface design as well as access to data from the Earth science and application areas (with WP2-3). The work package will deliver concepts of future European infrastructures leading multi-national research for co-design, and a collaboration plan for existing national and European infrastructure programmes as well as with industrial providers (with WP4-5). This will enable the development of the key *ExtremeEarth* software platforms, including EEsC. The work package will provide these concepts including targets, milestones and deliverables, a draft assessment of partnership requirements (for WP7), and draft resource requirements (for WP8).

WP6 realises Objective 5 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP6 will be led by NLeSC and co-led by BSC and UKRI.

Task 6.1 Infrastructure and capability mapping (Lead: BSC)

Based on the general science strategy and science-technology targets defined in T1.3 and in tight collaboration with WP2 and WP3 where the co-design framework is framed (T2.3 and T3.3), this task will provide the baseline upon which the collaborative, virtual and co-located research, data and compute infrastructures will be planned and built (D6.1). This includes an assessment of how much of the infrastructure needs to be centralized vs distributed and define the technological implications, how much needs to be specifically dedicated to Earth-system science vs drawn from general-purpose resources, and how software and hardware development will be synchronised. It includes the data infrastructure required to establish the pipelines where data from large observational programmes are integrated with the extreme-scale simulations, which *ExtremeEarth* will create. The task will provide a comprehensive map of all relevant research infrastructures (both national and international) and centres of excellence. The outputs will be merged with those from T6.2 and T6.3 to provide a roadmap for the *ExtremeEarth* Extreme Scale Laboratories drafted in T6.4.

Task 6.2 Programmatic environment and industrial roadmaps (Lead: BSC)

T6.2 will provide a comprehensive assessment (D6.2) of the existing national, European and wider international technology infrastructure ecosystem and associated programmatic environment components identified in T6.1 (spanning HPC, big data and connections to data sources, including observing systems). It will enable a solid assessment of how and where *ExtremeEarth* can facilitate, coordinate and promote the required extreme-scale technologies across Europe in order to deliver the overall *ExtremeEarth* objectives. The assessment will be complemented by available technology roadmaps from industry and large technology providers (with WP3 and WP4). Both assessments will incorporate the partnership design concepts elaborated in WP7. T6.2 will identify synergies and provide a gap/overlap-analysis and will include an assignment of priorities to gaps and options to exploit synergies.

Task 6.3 Software and infrastructure engineering methodologies (Lead: UKRI)

A well-defined approach to software and infrastructure engineering is required in order to reach *ExtremeEarth*'s key technological goals (domain-specific distributed extreme-scale computing, domain-specific big data handling, domain-specific integrated information system, big data analytics and emerging AI-technologies) for the broad and diverse set of science domains that will be involved in this Flagship project. Based on results from WP2-4 as well as T6.1 and T6.2, different approaches to software and infrastructure engineering will be analysed and assessed. On this basis, a concept and recommendations for its implementation will be formulated in support of T6.4.

Task 6.4 Extreme Scale Laboratory concepts (Lead: NLeSC)

Based on the results of T6.1, T6.2 and T6.3, T6.4 will develop options for laboratories where software platforms for generating the demonstrators will be developed (D6.3). The laboratories implement, test and demonstrate the key *ExtremeEarth* Key Technologies, namely high-performance, cloud and edge computing, AI, big data handling and storage, analytics, workflow and user interface design with a special focus on EEsC, and the access to data from the core science and application areas in *ExtremeEarth* (e.g. large observing systems and natural laboratories). All of this must address not only the science and technology options, but also stakeholder participation in order to maximize industrial and societal benefits (with WP4-5). These concepts will include a draft cost-benefit analysis comparing these options, and a risk-analysis with reference to the overall *ExtremeEarth* objectives. The concepts will include recommendations for how to transition the existing national and international resources into the new *ExtremeEarth* concepts, and formulate recommendations for the future evolution of national and European

technology funding programmes. The concepts will specifically lay out the opportunities for collaboration with industry and produce options for new economic growth and social impact. T6.4 will tightly communicate with WP7 on the *ExtremeEarth* partnership coordination.

These detailed concepts will be translated into targets, deliverables and milestones. Critical breaking points and risks for achieving individual targets and for realizing the project objectives will be identified and integrated in the risk management plan set up in WP8. The output from T6.4 will form an important contribution to the Flagship Implementation Plan assembled in WP8. The implementation plan will be defined in collaboration with the approaches for maximising industrial impacts performed in WP6.

A core element of the laboratory concepts and their implementation plan of T6.4 will be the definition of *ExtremeEarth* demonstrators that will serve as proofs-of-concept for the new capabilities at full scale - from science to application and employing the entire science-technology co-design framework. The success of the demonstrators will be measured by the Key Performance Indicators of the *ExtremeEarth* Key Technologies.

Task 6.5 Draft resource plan (Lead: NLeSC)

Based on the detailed concept plan from T6.4, a draft budget will be produced (D6.4) for the available concepts. The budget estimates will highlight sources of uncertainty due to unknown or uncertain information, the availability and training of skilled human resources, about the future of existing funding structures and technology infrastructure programme. T6.5 will provide input for the overall budget and the co-funding model managed in WP8.

Deliverables (brief description and month of delivery)

D6.1 Baseline technology infrastructure framework (M6)

D6.2 Assessment of programmatic environment and industrial roadmaps (M6)

D6.3 Extreme-scale laboratory concepts including specific targets, deliverables and milestones (M11)

D6.4 Draft resource plan and funding uncertainties (M11)

Partner Roles	
NLeSC	Co-lead WP6 and lead tasks T6.4 and T6.5, provide deliverables D6.3 and D6.4
BSC	Co-lead WP6 and lead tasks T6.1 and T6.2, provide deliverables D6.1 and D6.2
UKRI	Co-lead WP6 and lead task T6.3
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	7		**Lead beneficiary**		UHELS
Work package title	Partnership Management				
Participant number	18	10	16	**Total**	
Short name of participant	UHELS	DELTARES	MF		
Person months per participant:	3	1	1	**5**	
Start month	1			**End month**	11

Objectives

This work package will develop a plan for the management of partnership in *ExtremeEarth*, which is an essential part of the Flagship Implementation Plan finalised by WP8. In the first step, a tiered partnership model will be developed that defines roles and responsibilities for the project combining the requirements for stability, sustainability and flexibility. Specific partnership management and governance plans will be set up for the science community, industry, national administrations and agencies, and the international (non-European) community. Since these partnerships will be dynamically evolving throughout the duration of *ExtremeEarth*, flexible mechanisms providing the highest level of transparency will be targeted. This will be tightly coordinated with WP8 due to the dependence on the planning and coordination of funding, innovation, dissemination and exploitation, and education. This work package will also contribute to the definition of external, project-independent advisory and control panels, and it will receive input from WP4-5 for the definition of the industry and societal service partnerships.

WP7 realises Objective 6 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

WP7 will be led by UHELS and co-led by DELTARES and MF.

Task 7.1 Partnership model (Lead: UHELS)

T7.1 will develop the basic partnership concept for *ExtremeEarth* that aims to deliver sufficient stability and sustainability to ensure that the *ExtremeEarth* strategic objectives will be achieved throughout the lifetime of the project, but that also embeds sufficient flexibility as well so that the project can respond with agility to changes of external constraints, to project-internal evolution and unforeseen developments (both positive and negative) that are important to cope with for completing a successful project.

It is anticipated that the partnership model will comprise of several tiers such as strategic core partners, funded research and technology partners, non-funded associated partners, and general stakeholders and interest groups. These layers would allow exploiting the benefits from different layers of interaction between parties - coalescence, collaboration, cooperation and competition. Partner groups such as research groups and projects, research facilities, infrastructures and services, operational entities, national and international administrations, and commercial companies and education facilities etc. will be considered. T7.1 will deliver a proposal for partnership in *ExtremeEarth* (D7.1) based on an assessment of the experience from similar large-scale projects such as FET-Flagships, Copernicus services and commercial companies that operate at the interface between science and technology, and that include public-private partnership elements. The latter will be defined in collaboration with WP4-5.

The Extreme Scale Laboratories (WP6) will occupy a dedicated tier as they represent the *ExtremeEarth* specific, multi-partner platforms for realizing co-design.

Task 7.2 Partnership governance and management (Lead: DELTARES)

T7.2 will provide the governance and management needed to realize the partnership approach defined in T7.1 (D7.2). The partnership governance will be coordinated with the definition of the overall project governance performed in T8.1. Partnership specific governance is required for the management of flexible partnership through independent review, participation in and delegation of decision-making, contracting and procurement mechanisms, engagement and raising-of-interest programmes and others. Formal project management options will be explored to achieve the best compromise between freedom of research and result-driven developments. Together with T6.4 and T8.3 the management of research itself and the transition of research to demonstrators and, eventually, operational services for society will be included.

Task 7.3 Resource management (Lead: MF)

Resource management requires a separate task (T7.3) as *ExtremeEarth* will be a very large project that aims to create new centres of gravity for novel research and technological developments in existing structures but also aims to create new hot-spots in areas where European expertise is missing. This needs a substantial investment to create a critical mass. The technological focus of the project is on both software and hardware development. For hardware there are existing HPC infrastructures that will undergo substantial revision in the forthcoming 5-10 years, also because of a significant investment by the European Commission and individual countries (e.g. EuroHPC). The cost-effective integration of *ExtremeEarth* in this ecosystem is important, as is the identification of void areas where *ExtremeEarth* domain-specific resources need to be created. Once established, these resources need to be dynamically managed across the project. The same applies to software developments, for which distributed, shared and centralized resources will be explored. The concept of Extreme Scale Laboratories developed in WP6 embodies this approach and T7.3 will develop the plan for the most effective management of this area (D7.3).

Task 7.4 Legal partnership framework (Lead: UHELS)

Partnership management requires a consistent and reliable legal framework for both funded and non-funded contributions. T7.4 will define this legal framework in agreement with EU legislation and best practices adopted by existing large-scale projects like FET-Flagships and Copernicus (D7.4). The framework will include all levels of partnership as defined in T7.1, and cover formal project partnership, sub-contracting, procurement, the handling of intellectual property rights etc. T7.4 will exploit the legal expertise available to those *ExtremeEarth-PP*-partners, which are involved in similarly sized projects.

Deliverables (brief description and month of delivery)

D7.1 Draft partnership model (M6)

D7.2 Governance and management tools for partnership handling (M11)

D7.3 Plan for technological resource management across project (M11)

D7.4 Legal partnership framework (M11)

Partner Roles	
UHELS	Co-lead WP7 and lead tasks T7.1 and T7.4, provide deliverables D7.1 and D7.4
DELTARES	Co-lead WP7 and lead task T7.2, provide deliverable D7.2
MF	Co-lead WP7 and lead task T7.3, provide deliverable D7.3
	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external stakeholders

Work package number	8		**Lead beneficiary**		ECMWF
Work package title	Flagship Implementation Roadmap				
Participant number	01	02	17	**Total**	
Short name of participant	ECMWF	UOXF	INGV		
Person months per participant:	4	2	2	**8**	
Start month	1			**End month**	12

Objectives

This work package will draft the roadmap for the implementation of the *ExtremeEarth* Flagship as a Flagship Implementation Plan.

In particular, it will propose a governance model that is lightweight but effective, and that involves a sufficient level of community involvement and independent advice on all key aspects of the project, namely research, technology, policies, finances and legal affairs, and the coordination of the project with the European Commission. Further, the work package will draft the budget with input from WP1-7, and develop a co-funding model including a risk assessment. The management of research and innovation across the project elements and throughout the project lifetime will be established. The work package will also present concepts for the dissemination of project results, a communication strategy, an approach to ethics-related questions implied by the *ExtremeEarth* capabilities, and an educational programme closely related to the main strands of the *ExtremeEarth* research.

The Flagship Implementation Plan will assess and finalize the science, technology, societal and industrial impacts implementation plans from WP2-WP5, the Extreme Scale Laboratory concepts from WP6, the partnership management from WP7, and the above models for governance, budget and co-funding, research and innovation management, dissemination, communication and education into the Implementation Plan following a second iteration with the *ExtremeEarth* community through the Consolidation Workshop.

WP8 realises Objectives 7-9 of *ExtremeEarth-PP*.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

Work package 8 will be led by ECMWF and co-led by UOXF and INGV.

Task 8.1 Flagship governance (Lead: ECMWF)

In T8.1, structure and elements of the *ExtremeEarth* governance will be laid out (D8.1). In a first step, the existing Flagship projects will be assessed and 'lessons learnt' will be assembled to derive options that have worked in the past given the significant challenges associated with managing such a large project. Based on these options the governance form that is most suitable for the *ExtremeEarth* profile of activities, its specific configuration of research and technology development and its stakeholder profile encompassing physical sciences and science applications with high societal relevance will be assembled. The structure will aim to maximize transparency and be set up so that the *ExtremeEarth* community will be able to shape the project throughout its lifetime. At the same time, review mechanisms for achieving the highest level of scientific excellence and partnership models (WP7) supporting industry and service involvement (WP4-5) and realising true co-design will be proposed (informed by T8.4 on ethics management). As *ExtremeEarth* aims to deliver new capabilities crucial for political decision-making at national and international level to deal responsibly with Earth-system extremes, an interface dedicated to national and international administrations will be set up. A risk assessment and management plan will be drafted with input from WP1-7.

Task 8.2 Draft budget and co-funding model (Lead: INGV)

With input from WP2-7 (D2.4, D3.4, D4.3, D5.3, D6.4, D7.3), T8.2 will configure a draft budget and budget management plan for the Flagship project (D8.2). This budget will be specified with enhanced detail for the ramp-

up phase of the project in the first years. The budget will include priorities by assigning thresholds to specific milestones that are considered crucial for the overall success of the project, and for which sufficient funding must be obtained. The task will also provide a risk assessment and a proposal for mitigation measures.

T8.2 will include a co-funding strategy that will identify the potential funding sources suitable for the *ExtremeEarth* stakeholder profile taking into account existing national and international programmes, and industrial contributions. Options for creating new governmental programmes will be developed. The technology development aspects of *ExtremeEarth* will require a dialogue with commercial computing technology providers for co-funding co-design - similar to existing Horizon-2020 projects, but elevated to a domain-specific, higher and more sustained level. As there is substantial economic power behind the *ExtremeEarth* application domains, such as energy, water, food/agriculture, and risk management, an important element of the co-funding strategy will be the access to key European companies operating in these sectors. A first step in this direction has been made already through the *ExtremeEarth-PP* endorsement action.

Task 8.3 Research, innovation and exploitation management (Lead: UOXF)

T8.3 will provide a methodology for governing the research and development efforts in *ExtremeEarth* and for formulating the impact on research infrastructures, operational service provision and commercial exploitation of *ExtremeEarth* products and knowledge (D8.3). The project combines large individual research areas with currently separate communities aiming to explore common and multiple purpose developments of Key Technologies (methodologies, software, hardware, services) and T8.3 will strengthen the interfaces between physical and applied science. The task will assess gaps and weaknesses of the current situation and propose specific actions to strengthen shared developments.

As *ExtremeEarth* also covers many thematic areas benefiting from physical and technological developments (energy, water, food/agriculture, risk management) there is significant room for the transition of *ExtremeEarth* products to very well developed industrial sectors in Europe but also potential for entirely new exploitation areas at the interface between science and technology and between prediction and impact areas. T8.3 will directly interact with the European stakeholders to explore options for *ExtremeEarth* product uptake (with WP4-5). The research management strategy delivered by this task (and informed by the T8.4 on ethics management to achieve Responsible Research and Innovation) will feed into the transition to innovation and exploitation beyond.

Task 8.4 Ethics management (Lead: INGV)

ExtremeEarth does not work with animals or human subjects, thus does not raise traditional research ethics issues. The project may raise data protection issues that will be duly considered. However, a success of the project will raise highly significant ethical issues. The outputs of the simulation can affect national and international policy and collaboration. Ownership of outputs can be financially and politically invaluable. Most of these ethical issues are unlikely to occur during the initial research phase, but the consortium recognises the need to reflect on them early and continuously. T8.4 will therefore develop an ethics management approach that aims to integrate ethical reflection into the project governance to ensure research process and outcomes are developed responsibly.

This approach is multi-dimensional and focuses on various areas, including: Foresight Ethics (identifying the potential impact of the tools and methods developed by *ExtremeEarth* and their use), Governance Ethics (how to ethically manage the governance including partnership evolution), Stakeholder Ethics (the ethical approach to engagement with stakeholders outside of the partnerships), Data ethics (in case of personal data - e.g. mobile phone data).

The guidelines will define how *ExtremeEarth* will address these issues, based on existing ethics approaches (e.g. within Consortium Partners and other Flagship/ large-scale research pogrammes) and will provide the structure for ethics management in the flagship.

As ethics is a cross-cutting topic, the task will contribute both to D8.1 (on Governance Ethics) and D8.3 (on the remaining issues).

Task 8.5 Dissemination and communication strategy (Lead: INGV)

T8.5 will define the strategy for disseminating the results of *ExtremeEarth* to its vast stakeholder community (D8.4), and to ensure a swift and cost-effective uptake into research, operations, services and policy-making. The stages of the implementation roadmap will take into account the key known milestones at which Earth-system extremes related decision-making at national and international level requires input from excellent science. In collaboration with the European Commission, a Flagship promotion plan will be defined that supports the entire programme and ensures visibility of this substantial investment in Europe and internationally.

Part of the communication strategy will be the preparation of several layers of information complexity depending on the targeted audience, as well as a detailed plan for which communication media to employ so that *ExtremeEarth* stakeholders and the public will receive a precisely defined level of information at the right time

through well-chosen channels. An important component of this strategy will be the selection of recipients. T8.5 will draft a contact management plan that can be activated as soon as the project starts. The strategy will be completed by a schedule for conference, workshop and meeting attendance featuring *ExtremeEarth* as well as dedicated *ExtremeEarth* event organisation.

Task 8.6 Education programme (Lead: UOXF)

T8.6 will plan the education programme (D8.5) of *ExtremeEarth* that will be entirely built on on-line resources and that will exploit the large group of university and research facility partner competence in *ExtremeEarth*. The emphasis will be to fill the current voids in the educational sector at the interface between physical and applied sciences and between science and technology developments with a special focus on computational science and software development. This sector will become increasingly important in Earth sciences but also other domains, and young European scientists will be at the forefront of this development due to the outstanding educational opportunities provided by *ExtremeEarth*.

In collaboration with the technical and impact work packages WP2-WP6, T8.5 will set out an assessment of the existing opportunities that the *ExtremeEarth* educational programme will complement, define goals and modern teaching concepts, propose the technical infrastructure to use, and include a non-academic teaching programme for the general public. An early-career scientist programme will be developed that allows young scientists to assume responsibility in *ExtremeEarth* and for nurturing the next generation of top-level scientists required in the later stages of the project and beyond.

Task 8.7 Flagship implementation (Lead: ECMWF)

T8.7 will coordinate the integration of the main outcomes of *ExtremeEarth-PP* into the ultimate deliverable, the Flagship Implementation Plan (D8.6). This deliverable will be based on the work performed in WP1-8, in particular:

- the initial, top-level strategy framework (D1.3),
- the specific science strategy and implementation plan (D2.3),
- the specific technology strategy and implementation plan (D3.3),
- the industrial impacts implementation plan (D4.2),
- the societal impacts implementation plan (D5.2),
- the realisation of the science-technology co-design through Extreme-Scale Laboratory concepts (D6.4),
- the partnership management concept (7.2-7.4),
- the revised output from the previous tasks in WP8, namely D8.1-8.6, following a critical review by the community.

At the beginning of this task, the Consolidation Workshop will evaluate the above list of deliverables together with the *ExtremeEarth-PP* consortium and with potential stakeholders from all *ExtremeEarth* areas of science, technology and impacts already consulted in the Screening Workshop. This ensures that the Flagship Implementation Plan reflects the community-wide requirements for achieving the break-through capabilities encapsulated in the *ExtremeEarth* Key Objectives enabled by Key Technologies, that *ExtremeEarth* receives full support from those stakeholders that are critical for the success of *ExtremeEarth*, and that *ExtremeEarth* reflects the European Commission's vision for the future shape of the Flagship programme and how to realise mission-oriented research and innovation in the European Union.

Deliverables (brief description and month of delivery)

D8.1 Flagship governance model (M11)

D8.2 Draft budget and co-funding model (M11)

D8.3 Ethics, Research, innovation and exploitation management strategy (M11)

D8.4 Dissemination and communication strategy (M11)

D8.5 Education programme (M11)

D8.6 Flagship Implementation Plan (M12)

Partner Roles	
ECMWF	Co-lead WP8 and lead tasks T8.1 and T8.7, provide deliverables D8.1 and D8.6
UOXF	Co-lead WP8 and lead tasks T8.3 and T8.6, provide deliverables D8.3 and D8.5
INGV	Co-lead WP8 and lead tasks T8.2, T8.4 and T8.5, provide deliverables D8.2 and D8.4
All partners	The work package will be managed in collaboration with all *ExtremeEarth-PP* partners and external

	stakeholders

3.3.3 List of deliverables and milestones

Deliverable (number)	Deliverable name	WP number	Short name of lead participant	Type	Dissemination level	Delivery date
D1.1	Risk and Quality Management Plan	1	ECMWF	R	CO	M1
D1.2	Dissemination and communication plan	1	ECMWF	R	PU	M2
D1.3	Top-level strategic framework	1	FZJ	R	PU	M3
D2.1	Extended science strategy and roadmap, and definition of important interface areas for exploiting synergies	1	CNRS	R	PU	M6
D2.2	Report on state of the art & critical break-through development needs	2	MPG	R	PU	M6
D2.3	Specific science strategy and implementation plan including detailed science targets, Flagship deliverables and milestones	2	CNRS	R	PU	M11
D2.4	Draft resource plan and funding priorities	2	ETHZ	R	PU	M11
D3.1	Extended technology strategy and roadmap, and definition of important interface areas for exploiting synergies	3	CMCC	R	PU	M6
D3.2	Report on state of the art & critical break-through development needs	3	UUT	R	PU	M6
D3.3	Specific technology strategy and implementation plan including detailed technology targets, Flagship deliverables and milestones	3	ETHZ	R	PU	M11
D3.4	Draft resource plan and funding priorities	3	ETHZ	R	PU	M11
D4.1	Existing industry relationship and benefit analysis	4	DTU	R	PU	M6
D4.2	Industrial impacts implementation plan	4	FZJ	R	PU	M11
D4.3	Proposal resource plan	4	UKRI	R	PU	M11
D5.1	Societal needs and existing services impact analysis	5	JRC	R	PU	M6
D5.2	Societal impacts implementation plan	5	INGV	R	PU	M11
D5.3	Draft resource plan	5	RedC	R	PU	M11
D6.1	Baseline technology infrastructure framework	6	BSC	R	PU	M6
D6.2	Assessment of programmatic environment & industrial roadmaps	6	BSC	R	PU	M6
D6.3	Extreme-scale laboratory concepts including specific targets, deliverables and milestones	6	NLeSC	R	PU	M11
D6.4	Draft resource plan and funding uncertainties	6	NLeSC	R	PU	M11
D7.1	Draft partnership model	7	UHELS	R	PU	M6
D7.2	Governance and management tools for partnership handling	7	Deltares	R	PU	M6
D7.3	Plan for technological resource management across project	7	MF	R	PU	M11
D7.4	Legal partnership framework	7	UHELS	R	PU	M11
D8.1	Flagship governance model	8	ECMWF	R	PU	M11
D8.2	Draft budget and co-funding model	8	INGV	R	PU	M11
D8.3	Ethics, Research, innovation & exploitation management strategy	8	UOXF	R	PU	M11
D8.4	Dissemination and communication strategy	8	INGV	R	PU	M11
D8.5	Education programme	8	UOXF	R	PU	M11
D8.6	Flagship Implementation Plan	8	ECMWF	R	PU	M12

Milestone number	Milestone name	Related work package(s)	Due date	Means of verification
MS1	CSA initiation	WP1	M1	D1.1, D1.2 submitted
MS2	Top-level Strategic Framework	WP1	M2	D1.3 submitted
MS3	Interim Plans and Roadmaps	WP2-7	M6	Dx.1 and Dx.2 deliverables submitted
MS4	Flagship Implementation Plan inputs	WP2-8	M11	Dx.3 and Dx.4 deliverables submitted
MS5	Flagship Implementation Plan finalised	WP8	M12	D8.6 submitted

3.4 Management structures and procedures

3.4.1 Project Organisation

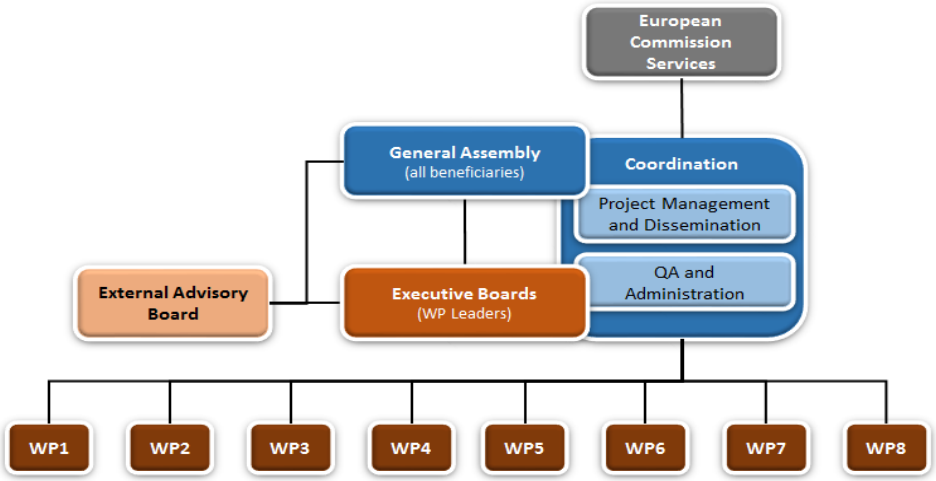


Figure 9: ExtremeEarth-PP Coordinating and Supporting Action (CSA) management structure.

The efficiency of project management and project coordination will be ensured using a sound organisational structure, clearly assigning responsibilities to the different participants of the project. This organisational structure will be supported by project management methods relying on the latest communication and collaboration technologies. Project management and coordination will be provided by ECMWF who is leading both management (WP1) and the Flagship roadmap (WP8) work packages. ECMWF will organise the necessary General Assembly meetings liaise between the project consortium and the European Commission and provide the financial administration.

The management structure adopted for the CSA is shown in Fig. 9. The planned structure and roles in *ExtremeEarth-PP* are described below.

The **General Assembly** is the decision-making body of the project. The GA is chaired by the project coordinator and consists of one representative from each partner. It will meet twice (at the beginning of and six months into the project). Additional meetings will be arranged if needed. It will be responsible, amongst others, for the monitoring of the project's progress and costs as well as the revision of the project plan in response to unforeseen problems and conflict resolution.

The **Executive Board** will be the supervisory body ensuring successful execution of the project, and will be accountable to the GA. The board will be chaired by the Project Coordinator. Its members will be the WP leaders (or their designated representatives). The board will convene monthly through online and/or physical meetings. Responsibilities of the Executive Board include the monitoring of the effective and efficient implementation of the project and the provision of suggestions for modifications to the work plan.

The **External Advisory Board** needs to comprise world-renowned experts representing the different sectors and application areas of the *ExtremeEarth* Flagship. The focus will be on expertise in science, technology, policy, finance, stakeholder engagement and education. It will operate mostly remotely in virtual joint sessions exploiting teleconference facilities and/or use email based interaction. It will meet at least three times in the project lifespan (at the beginning, mid-way through and at the end) to be agreed by its members and project coordination. External Advisory Board members will be identified and invited at the start of the project (WP1) and elect a chair.

The **Project Coordinator** is responsible for the evaluation of project progress, the handling of results and information to be protected, the day-by-day legal, contractual, ethical, financial and administrative management of the project, the relationship with EU officers, the management of the partnership, co-ordination, monitoring and supervision of the overall technical work, resolution of technical issues, and project risk management. The *ExtremeEarth-PP* Project Coordinator will be Dr Peter Bauer (ECMWF).

The **Project Manager** is responsible for the efficient administration of the project and works together with the Project Coordinator, work package leaders and the representatives of each beneficiary. The main tasks are to establish the necessary infrastructure for the project administration, handle project administration in terms of project progress monitoring and reporting, and provide support to the project meetings. The *ExtremeEarth-PP* Project Manager will be Dr Daniel Thiemert (ECMWF).

Work Package Leaders (supported by task leaders) are responsible for the co-ordination and supervision of the work related to their assigned work package, including the organisation of work by some or all of the participants in the work package. Work Package Leaders will review the results of the work carried out in each WP, confirming

the suitability of the next stages in the project plan and identifying possible problems, ensure the timely delivery of the agreed work package deliverables to high standards, participate in the project's review meetings and assembling the WP's contributions to the periodic/final reports. The affiliations of the Work Package Leaders (and task leaders) have been identified in the WP-tables.

3.4.2 Project management procedures

Project management activities will be based on the following procedures, which will be agreed among project partners and detailed in the project quality plan, according to ISO-9001:2000 directives:

- detailed project planning;
- project monitoring and controlling process;
- project deliverable reviews and validation;
- risk and problem management;
- communication management.

Project monitoring and control: Project monitoring and controlling processes allow for the planning, tracing and monitoring of work progress and other events that impact the project. The main formal occasions for project control will be project progress meetings (e.g. of the Executive Board, Work Packages and the General Assembly).

Risk management: Risk management aims to minimise factors that can be detrimental to project objectives. Risk management will be performed at all levels and adopt a uniform and systematic approach across project teams to:

- identify and evaluate risks;
- define and plan proactive and efficient actions for risk reduction;
- start, perform and control planned mitigation activities;
- document progress of risk management activities, and evaluating their results with continuity in order to implement corrections.

The duty of risk management will be shared by project partners and the Project Coordinator with support of the Project Manager according to their responsibility level. They will trace identified risks in the risk-management report, which describes risk probability, seriousness in terms of impacts and costs, mitigation strategy, risk monitoring activities and plans of mitigation activities.

A specific procedure will be defined for risk escalation from the Project Team up to General Assembly level. The initial list of *ExtremeEarth-PP* implementation risks is shown in Tab. 2.

Table 2: Critical risks for implementation.

Description of risk (indicate level of likelihood: Low/Medium/High)	**WP(s) involved**	**Proposed risk-mitigation measures**
Limited European Commission funding available for the CSA (low)	All	Consortium Partners have recognised the importance of the *ExtremeEarth* initiative and have committed significant in-kind contributions to ensure the successful completion of the CSA
Lack of community awareness and involvement (medium)	All	*ExtremeEarth-PP* foresees dedicated workshops and substantial outreach activities and has already collected around 100 endorsements from the relevant stakeholders
Change of Flagship Concept (high)	All	A task has been defined to monitor the foreseen concepts in Horizon Europe and provide
Too large outreach dimension, not being able to reach all communities (medium)	All	*ExtremeEarth-PP* will rely on digital outreach technologies to ensure maximum visibility, including online attendance of workshops and respective feedback provision
Limited time available to establish options for co-funding (high)	All	Early engagement with key industrial and governmental stakeholders responsible for institutional and national funding

Problem resolution: The aim of problem resolution is to guarantee project objectives are achieved, and to protect the project's quality, timing and budget against the impact of negative events. Problems may occur during all project phases and activities. They will be analysed and managed inside the related project team. In case that they cannot be resolved or entail risks for the whole project, they will be escalated to the Project Coordinator and the General Assembly (including online meetings to resolve issues).

All problems will be included in the problem management reports at both Work Package Leader and Project Manager level. The report will include problem description and classification, problem status, problem resolution

activities and their costs and results.

3.5 Consortium as a whole

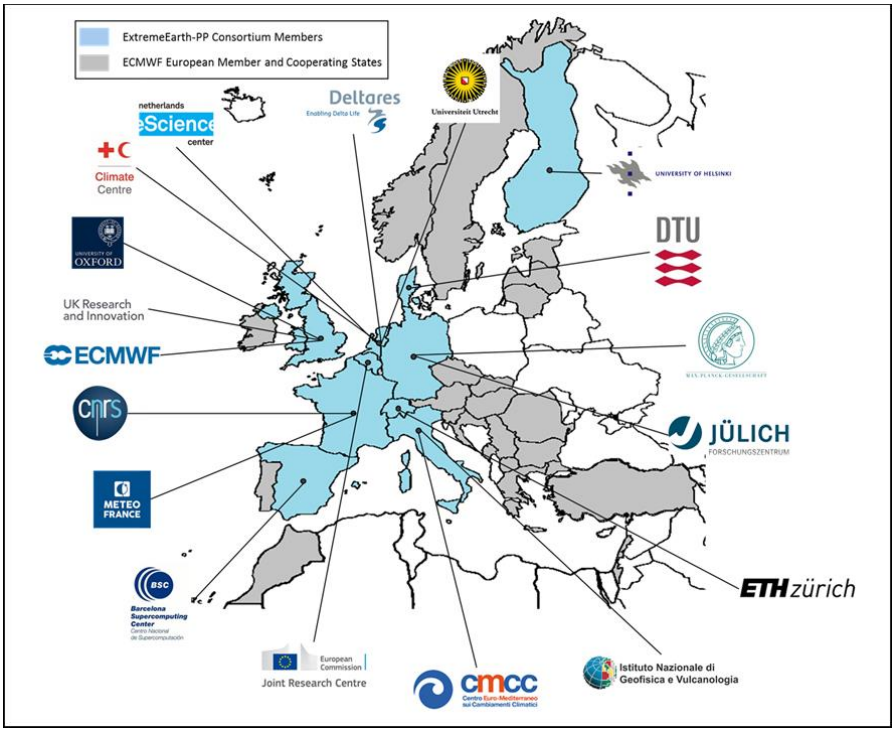


Figure 10: Geographical distribution of the ExtremeEarth-PP consortium and of the coordinator's Member and Cooperating States.

The *ExtremeEarth-PP* consortium is comprised of 18 partners from 9 European countries (Netherlands, Finland, Denmark, Spain, United Kingdom[51], Germany, France, Switzerland, Italy). The project is coordinated by ECMWF, an independent International Organisation of European Interest that is supported by 34 Member and Cooperating states. The geographical distribution of both *ExtremeEarth-PP* partners and ECMWF Member and Cooperating states is shown in Figure 10.

Several partners in the *ExtremeEarth-PP* consortium act on behalf of large umbrella organisations, which enable the project to benefit from intellectual resources and support that reach far beyond those of the 18 formal partners:

- ECMWF's status as an international organisation ensures the support of *ExtremeEarth-PP* by its Member States represented by the national meteorological-hydrological services in Europe. ECMWF has substantial experience and an outstanding track-record of managing large externally funded research projects and Coordination and Support Actions throughout the portfolio of topics covered by the EC's RTD and FET programmes. ECMWF acts as the trusted entity of the European Commission in its Copernicus Programme by hosting the Copernicus Climate Change Service and the Copernicus Atmospheric Monitoring Service. ECMWF also contributes capabilities (model output and computing) to the Copernicus Emergency Management Service with the European Flood Awareness System (EFAS) and the European Forest Fire Information System (EFFIS). The support of its Member States is further manifested by Meteo-France (MF) as a separate partner of *ExtremeEarth-PP* contributing a particular focus on regional meteorological and climatological applications, a strong competence in high-performance computing, and close links to socio-economic stakeholders benefiting from weather and climate prediction.
- The German Max-Planck Society (MPS) funds world-leading researchers to direct individual Max-Planck Institutes (MPIs). In *ExtremeEarth-PP*, the MPI for Meteorology in Hamburg, the MPI for Chemistry in Mainz and the MPI for Biogeochemistry in Jena are the leading contributors to the project in the field of physical processes in the climate system and climate modelling, biogeochemical cycles in the Earth system as well as research on chemical processes in the atmosphere and the observation of atmospheric constituents. Closely associated funded by the Max-Planck Society (and the Helmholtz Society, see below) is also the Deutsches Klimarechenzentrum (DKRZ) the national centre for climate data and computing in Germany and which coordinates the H2020 Center of Excellence in Simulation of Weather and Climate (ESiWACE).
- The Forschungszentrum Juelich (FZJ) represents the access point to Germany's largest research organisation, the Helmholtz Association, with an annual budget of 4 billion Euros and access to substantial infrastructures, including high-performance computing facilities. Via FZJ, the project is supported by the Alfred Wegener

[51] The Consortium is fully aware of the current Brexit negotiations and can mitigate any results accordingly.

Institute Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven, the GEOMAR Helmholtz Centre for Ocean Research in Kiel, the GFZ German Research Centre for Geosciences in Potsdam, the German Research Centre for Environmental Health in Munich (HMGU), the Helmholtz-Centre Geesthacht - Centre for Materials and Coastal Research GmbH, the Helmholtz-Centre for Environmental Research (UFZ) in Leipzig, and the Karlsruhe Institute of Technology (KIT). Together these members of the Helmholtz Association cover all aspects of Earth-system science, modelling and observation as well as high-performance computing and data handling.

- The Eidgenoessische Technische Hochschule in Zuerich (ETHZ), Switzerland, is one of the leading universities in Europe and contributes expertise in the areas of climate modelling, solid Earth science, risk assessment and management, and high-performance computing to *ExtremeEarth-PP* with members from the Institutes of Earth Science, Atmospheric and Climate Science, Environmental System Science and Theoretical Physics.
- The Centre National de la Recherche Scientifique (CNRS) is the largest fundamental research organisation in Europe. It is represented in *ExtremeEarth-PP* with experts from the Institut Pierre-Simon Laplace (CNRS-IPSL) for climate modelling, the Institut de Physique du Globe de Paris (CNRS-IPGP) for seismology and volcanoes and Observatoire des Sciences de l'Univers de Grenoble (CNRS-OSUG) for observations in both domains. It will associate experts in HPC and ICT technologies through its large collaborative network.
- The Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) is a national Italian foundation studying the climate system and its interactions with society and the environment in support of sustainable growth, environmental protection, and to develop science-driven adaptation and mitigation policies in a changing climate. It has seven member organisations, namely the Italian National Institute of Geophysics and Volcanology (INGV), the University of Salento, the Italian Aerospace Research Center (CIRA S.c.p.a), the Ca' Foscari University of Venice, the University of Tuscia, the University of Sassari, and the Politecnico di Milano.
- The Italian National Institute of Geophysics and Volcanology (INGV) is the European largest single research Institute on Earthquake and Volcanoes, also hosting Environment-related research, and works in close cooperation with the Civil Protection Department by running the national seismic network and the volcano observatory network in Italy, providing 24h volcano and earthquake surveillance as well as seismic and volcanic hazard evaluations and forecasts. INGV has a long record of participation to, and coordination of European projects, and currently hosts the EPOS (ESFRI) ERIC. INGV is also renowned as the international reference for numerical investigation and impact modelling of volcanic processes and hazards.
- The Joint Research Centre (JRC) is a Directorate General of the European Commission (EC) that also hosts the Copernicus Emergency Management Service. It will coordinate all activities related to the modelling and stakeholder engagement with respect to the food and agriculture sector in *ExtremeEarth-PP*. JRC as a whole covers many more thematic areas related to the project, which are accessible to *ExtremeEarth-PP* through JRC's partnership in the project.
- The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC-CNS) was established in 2005 and is a key element of and coordinates the Spanish Supercomputing Network. The Earth Science and the Compute Science Institutes will be contributing most directly to *ExtremeEarth-PP* with expertise on Earth-system modelling and all aspects of high-performance and big data handling.
- The UK Research and Innovation (UKRI) brings together seven UK Research Councils (AHRC, BBSRC, EPSRC, ESRC, MRC, NERC, STFC) plus Innovate UK and Research England. For *ExtremeEarth-PP*, the British Geological Survey (BGS) and National Centre for Atmospheric Science (NCAS) will support data science systems and innovation pathways, Earth-system and weather system modelling, observation and high-performance computing.
- The Netherlands eScience Center (NLeSC) contributes expertise on the development and application of research software and digital methodologies. It performs collaborative scientific projects with both academia, public and private partners to enable and accelerate research across science and technology domains.
- The Red Cross Red Crescent Climate Centre (RedC) supports the Red Cross and Red Crescent Movement and its partners in reducing the impacts of climate change and extreme weather events on vulnerable people. In *ExtremeEarth-PP*, RedC will assume a leading role in the assessment of societal needs regarding extreme events, feeding into the co-design of *ExtremeEarth* science and technology research to best serve these needs.
- Deltares represents the flooding, water management and subsoil sectors in *ExtremeEarth-PP*. Deltares executes projects for the Dutch national and regional government and waterboards, the European Union, supra-national organizations, private engineering companies and consultants.
- The consortium includes selected, top-ranked European universities providing access to world-leading

scientific excellence on predictability and dynamics of weather and climate (Department of Physics, University of Oxford, UOXF), on energy analytics and markets (Centre for Electric Power and Energy, Danish Technical University, DTU), on seismic events and the Earth's interior at all scales (Earth Science Department, University of Utrecht, UUT), and on atmospheric composition and its interaction with climate (Institute for Atmospheric and Earth System Research, University Helsinki, UHELS).

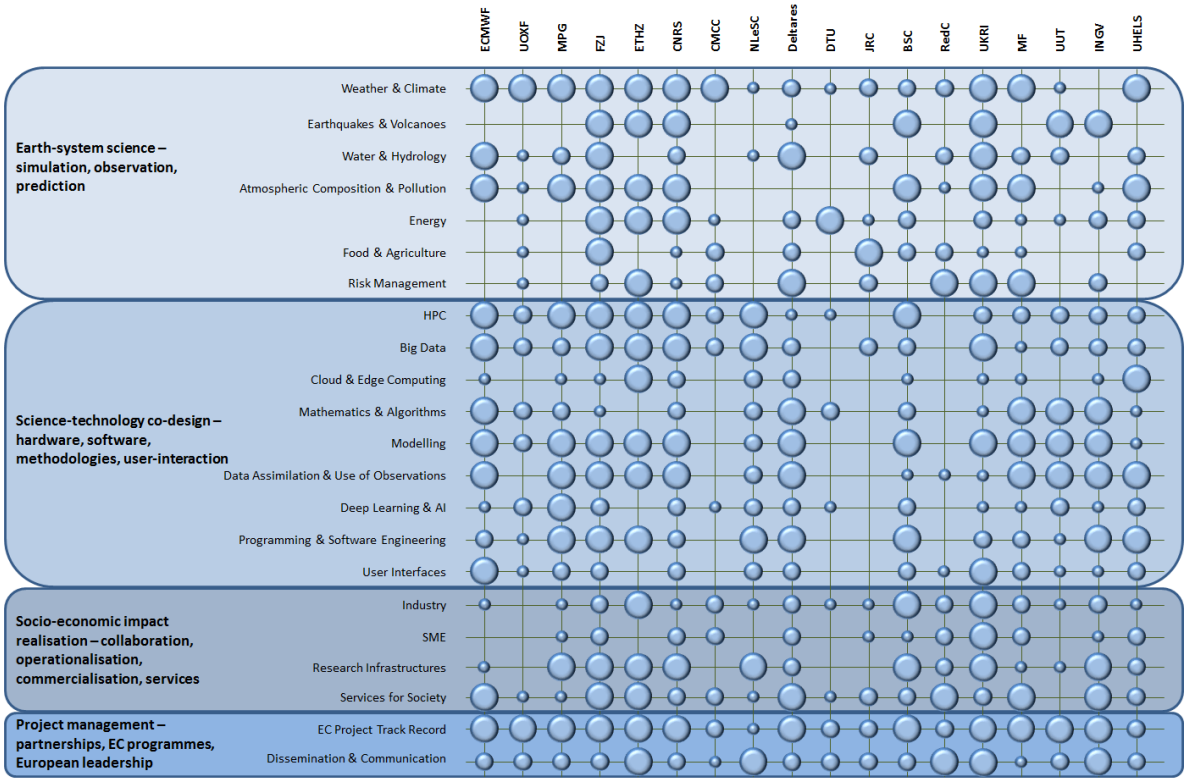


Figure 11: ExtremeEarth-PP partner competencies relevant for this project.

Our partnership presents a well-balanced mixture of research organisations, end-user representatives and international organisations. All partners have extensive experience in collaborative research at European level and have previously been engaged in projects throughout the European Commission Framework Programmes with outstanding track records. Figure 11 shows the excellent coverage of competencies relevant for *ExtremeEarth-PP* across the project's core partners and associated institutes.

Beyond formal partnership, the *ExtremeEarth-PP* consortium has a very large network of supporting and partnering organisations. This support is documented by the large number of support, commitment and endorsement letters that are attached to this proposal and accessible on the *ExtremeEarth* website. The supporting stakeholders cover national governmental institutes, civic institutions, universities, international organisations, research networks and research projects related to the *ExtremeEarth-PP* range of topics, as well as industrial companies throughout the technology and application sectors addressed by *ExtremeEarth*.

The *ExtremeEarth-PP* partnership competencies are translated into responsibilities for the individual work packages through the assignment of additional (one to two) co-leads:

- WP1 - CSA Project Coordination: ECMWF and FZJ
- WP2 - Earth-system Science Applications: CNRS, ETHZ and MPG
- WP3 - Enabling Technology and Co-design: ETHZ, CMCC and UUT
- WP4 - Industrial Impacts and Benefits: FZJ, UKRI and DTU
- WP5 - Societal Impacts and Benefits: INGV, RedC and JRC
- WP6 - Extreme Scale Laboratories: NLeSC, BSC and UKRI
- WP7 - Partnership Management: UHELS, MF and Deltares
- WP8 - Flagship Implementation Roadmap: ECMWF, UOXF and INGV

Co-leads assume responsibility for the individual tasks within their respective work package. All partners are, however, committed to contribute to many of the tasks, across the entirety of the project, even if the limited funding is reserved for those leading the task. Given the tight timeline, how much needs to be accomplished, and the limited funding that is available, this approach was chosen for *ExtremeEarth-PP* to help keep the focus on delivering the tasks and to avoid splitting responsibility across too many partners.

4 Members of the Consortium

4.1 Participants

4.1.1 European Centre for Medium-Range Weather Forecasts

4.1.1.1 Brief description of organisation

European Centre for Medium-Range Weather Forecasts (ECMWF) is the world-leading centre for medium-range global weather forecasts. It is both a research institute and a 24/7 operational service, producing and disseminating numerical weather predictions to its member states, research partners and commercial customers. The super-computer facility (and associated data archive) at ECMWF is one of the largest of its type in Europe. Apart from medium-range high resolution forecasts, ECMWF also provides extended-range (46 days) and seasonal (7 months) forecasts as well as meteorological and oceanographic reanalysis. The organisation was established in 1975 and now employs around 350 staff from more than 30 countries. ECMWF is one of the six members of the Co-ordinated Organisations, which also include the North Atlantic Treaty Organisation (NATO), the Council of Europe (CoE), the European Space Agency (ESA), the Organisation for Economic Co-operation and Development (OECD), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). On behalf of the European Commission ECMWF hosts the Copernicus Climate Change (C3S) and Atmospheric Monitoring Services (CAMS).

4.1.1.2 Excellence

ECMWF has over 40 years of experience in global weather forecasting using supercomputers. The centre has delivered operational forecasts since 1979 and is today recognised as the leading institute in global weather forecasts. The success of ECMWF can to a large extent be contributed to its close collaboration between scientists and technical personnel from both earth system sciences (meteorology, oceanography, atmospheric chemistry, climatology, hydrology etc.) and numerical and computational sciences. High-performance computing has been an integral part of ECMWF's science strategy since its foundation. Recently, the research areas of scalability and numerical efficiency have been given much enhanced focus to maintain the lead in the development and delivery of global meteorological forecasts, given that maintaining computational capacity requires significant investments in all areas of code development and hardware-software co-design. ECMWF has assumed a leading role in bringing together applied and computational sciences, it is a member of the ETP4HPC that liaising between the community and the EC, and is leading and partnering in several H2020 projects (ESCAPE, ESCAPE-2, ESiWACE, EuroEXA, NextGenIO, MAESTRO, EPiGRAM-HS) dedicated to advancing prediction through an investment in computing.

4.1.1.3 Personnel

Dr Peter Bauer (M) joined ECWMF in January 2000. Before becoming Deputy Director of Research at ECMWF, he headed the Model Division that comprises the physical and numerical aspects of numerical weather prediction and the Satellite Section. Prior to his employment with ECMWF, he was leading a DLR research team on satellite meteorology in Germany, and was affiliated with NOAA, NASA and CETP as a visiting scientist. His background covers physical modelling, data assimilation and satellite remote sensing. He is the author and co-author of over 100 peer-reviewed scientific journal papers, and his publications have an h-index of 43. He is a member of several scientific advisory committees at national and international level and has extensive experience with managing international research projects. At ECMWF, his current duties also include the management of the Scalability Programme. He coordinates the ESCAPE and ESCAPE-2 projects and co-coordinates the ESiWACE centre of excellence.

Selected publications:

- **Bauer**, P., A.J. Thorpe, and G. Brunet, 2015: Numerical weather prediction - A quiet revolution, *Nature*, 525, 47-55, doi:10.1038/nature14956.
- Schulthess, T., P. **Bauer**, O. Fuhrer, T. Hoefler, C. Schaer, and N.P. Wedi, 2018: Reflecting on the goal and baseline for "ExascaleComputing:" a roadmap based on weather and climate simulations. *IEEE Computing in Science and Engineering*, accepted.
- Lawrence, B.N., M. Rezny, R. Budich, P. **Bauer**, J. Behrens, M. Carter, W. Deconinck, R. Ford, C. Maynard, S. Mullerworth, C. Osuna, A. Porter, K. Serradell, S. Valcke, N. Wedi, and S. Wilson, 2017: Crossing the Chasm: How to develop weather and climate models for next generation computers? *Geophys. Model Dev*., 11, 1799-1821, https://doi.org/10.5194/gmd-11-1799-2018.
- Deconinck, W., P. **Bauer**, M. Diamantakis, M. Hamrud, C. Kuehnlein, P. Maciel, G. Mengaldo, T. Quintino, B. Raoult, P. K. Smolarkiewicz, and N. P. Wedi, 2017: Atlas: A library for numerical weather prediction and climate modelling, *Computer Physics Developments*, https://doi.org/10.1016/j.cpc.2017.07.006
- **Bauer**, P. and T. Jung, 2016: Editorial for the Quarterly Journal's special issue on Polar Prediction. *Quarterly Journal of the Royal Meteorological Society*, 142, 537-538.

Dr Daniel Thiemert (M) joined ECMWF in 2015 as Project Manager in the Research Department. Before joining ECMWF, he was working for the University of Reading as Senior Researcher and Project Manager, being responsible for the management and coordinator of large scale European and national projects in intelligent systems. He obtained his masters in computer science from the Anhalt University of Applied Sciences, Germany, and his PhD in Computer Science from the University of Reading, UK. At ECMWF he is responsible for the project management of the EU-funded FET-HPC project ESCAPE, ESCAPE-2 and CHE, as well as for managing externally funded project acquisition.

Dr Fredrik Wetterhall (M) joined ECMWF as a researcher in 2011, coming from the Swedish Meteorological, Hydrological Institute (SMHI). Fredrik has a PhD in Hydrology from Uppsala University, and has over 15 years of experience in hydrological modelling and forecasting. He is currently working as a Senior Researcher within the Environmental Forecasts team at ECMWF who is responsible for the computational part of the Copernicus-funded European Flood Awareness System (EFAS) as well as is Global equivalent (GloFAS). Fredrik is leading the development of several components of the system and is very active in the international community, acting as co-chair of the Hydrological Ensemble Forecast Experiment (HEPEX). He has the author or co-author of over 50 peer-reviewed publications and has an H-index of 22.

Selected publications:

- Maraun, D, **Wetterhall**, et al., Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user, *Reviews of Geophysics 48(3)*, doi:10.1029/2009RG000314, 2010.
- **Wetterhall**, F, Winsemius,, HC, Dutra, E, Werner, M, Seasonal predictions of agro-meteorological drought indicators for the Limpopo basin, *Hydrology and Earth System Sciences (19)*, 2577–2586, 2015.
- Pappenberger, F, Cloke, HL, Parker, DJ, **Wetterhall**, F, The monetary benefit of early flood warnings in Europe, *Environmental Science & Policy (51)*, 278-291, 2015.
- **Wetterhall**, F., Graham, LP, Andreasson, J, Rosberg, J., Using ensemble climate projections to assess probabilistic hydrological change in the Nordic region, *Natural Hazards and Earth System Sciences* (11), 2295–2306., 2011
- **Wetterhall**, F, and Di Giuseppe, F, The benefit of seamless forecasts for hydrological predictions over Europe, *Hydrology and Earth System Sciences, 2*, 3409-3420, 2018.

Dr Peter Düben (M) is a Royal Society University Research Fellow with ECMWF as his host organisation. Peter is working on the use of reduced numerical precision arithmetic, deep learning and uncertainty quantification in weather and climate simulations. He is currently developing a single precision version of the Integrated Forecast System at ECMWF that allows to reduce runtime of forecast simulations by 40% while keeping meteorological quality of forecasts at a level that is almost indistinguishable compared to double precision simulations. Peter wrote his PhD thesis at the Max Planck Institute for Meteorology in Hamburg on the development of dynamical cores for Earth System models and worked for several years as Postdoc with Tim Palmer at the University of Oxford before joining ECMWF in October 2016.

Selected publications:

- **Düben**, P. D. and Bauer, P., Challenges and design choices for global weather and climate models based on machine learning, Geoscientific Model Development Discussions, 2018
- **Düben**, P.D. and Dawson, A., An approach to secure weather and climate models against hardware faults. JAMES (9), 2017
- **Düben**, P.D., Subramanian, A., Dawson, A., Palmer, T.N., A study of reduced precision to make superparametrisation more competitive using a hardware emulator in the OpenIFS model, JAMES (9), 2017
- **Düben**, P.D. and Dolaptchiev, S.I, Rounding errors may be beneficial for simulations of atmospheric flow: Results from the forced 1D Burgers equation, Theoretical and Computational Fluid Dynamics (29), 2015
- **Düben**, P.D., Russell,F.P., Niu, X., Luk, W., Palmer, T.N., On the use of programmable hardware and reduced numerical precision in earth-system modeling, JAMES (7), 2015

4.1.2 University of Oxford

4.1.2.1 Brief description of organisation

University of Oxford (UU) is a world-leading university, and the involvement in this consortium is through the sub-department of Atmospheric, Oceanic and Planetary Physics (AOPP), within the Department of Physics. AOPP has a long and distinguished history in numerous aspects of atmosphere, ocean and planetary sciences. In addition, UU has a range of world-leading departments whose work will be relevant to ExtremeEarth-PP: E.g. Mathematics and Computer Science for the development of high resolution models, and the Institute for New Economic Thinking and the Oxford Martin School, for realising many of the key socio-economic benefits that will accrue from this new generation of model.

4.1.2.2 Excellence

AOPP through Tim Palmer pioneered the development of probabilistic ensemble forecasting, which provides an essential methodology for producing integrations of high resolution models in ExtremeEarth. Tim also pioneered the development of stochastic parametrisation as the means to represent model uncertainty in ensemble

integrations. Although the development of 1km global models will remove the need for some key parametrisation, others (e.g. sub-cloud turbulence) will need to continue to be used and developed in ExtremeEarth. As a corollary of stochastic parametrisation, it is now possible to run models at single or even half precision, and exploring the extent to which this is possible in ExtremeEarth will be an essential aspect of the problem of scalability and computational efficiency. These types of application will be important in ExtremeEarth.

4.1.2.3 Personnel

Tim Palmer (M) is an expert on the predictability and dynamics of the climate system and a Royal Society Research Professor. He is the winner of top prizes of American and European Meteorological Societies, including the Dirac Gold Medal of Institute of Physics, Gerbier-Mumm Prize of WMO and Richardson Prize of EGU. He is the member of several learned societies around the world. Tim was previously Division Head at ECMWF and coordinator of two EU Climate Framework Projects. Head of WCRP CLIVAR International Scientific Steering Committee. British and Irish nationality.

Selected publications:

- **Palmer**, T.N., 2011: A CERN for climate change, Physics World, Vol. 24, Issue. 3, 14-15
- **Palmer**, T.N. (2014). Climate forecasting: build high-resolution global climate models. *Nature*, *515*(7527), 338-339. doi:10.1038/515338a
- **Palmer**, T. N. (2016). A personal perspective on modelling the climate system. *Proceedings. Mathematical, physical, and engineering sciences / the Royal Society*, *472*(2188), 20150772.
- **Palmer**, T. N. (2014). More reliable forecasts with less precise computations: a fast-track route to cloud-resolved weather and climate simulators? *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, *372*(2018), 20130391. doi:10.1098/rsta.2013.0391

4.1.3 Max Planck Institute

The Max Planck Society (MPG), established in 1948, is Germany's most successful research organization. The 83 Max Planck Institutes and facilities conduct basic research in the service of the public in the natural sciences, life sciences, social sciences, and the humanities. Max Planck Institutes focus on research fields that are particularly innovative, or that are especially demanding in terms of funding or time requirements. Max Planck Institute is represented through four institutes.

4.1.3.1 Max Planck Institute for Meteorology

4.1.3.1.1 Brief description of organisation

The Max Planck Institute for Meteorology (MPI-M) develops and uses Earth System Models and critical observations to support its overall mission: to understand Earth's changing climate. Research activities within the MPI-M are centred in three departments: atmosphere, land and ocean in the earth system. The institute also hosts independent research groups focused on stratosphere, and climate and turbulent mixing processes in the earth system. The International Max Planck Research School on Earth System Modelling – jointly run by the MPI-M and the Universität Hamburg – manages the institute's contribution to doctoral training. To satisfy the extensive computational needs of MPI-M, the institute built strategic partnership with the German Climate Computing Centre (DKRZ), the German collaborator of the Earth System Grid Federation (ESGF). MPG is the major shareholder of the DKRZ. MPI-M maintains a close cooperation with the German weather Service DWD (Deutscher Wetterdienst) for the development of the comprehensive modelling framework ICON (ICOsahedral Nonhydrostatic) for numerical weather prediction, climate simulation and process studies.

4.1.3.1.2 Excellence

MPI-M develops the ICON based Earth System Model ICON-ESM and uses it to understand and project climate dynamics, in particular under anthropogenic forcings. ICON-ESM will be used in the sixth phase (CMIP6) in concerted action with world leading climate centres, including European groups involved in ExtremeEarth, and projects like ESiWACE or IS-ENES. A strength of the MPI-M team is the access to the knowledge from MPI-Ms fundamental science departments land, ocean, and atmosphere on linking processes and feedbacks in the Earth System, supported by its Scientific Computing Laboratory. MPI-M utilizes in-house expertise on software infrastructure development (a group led by B. Stevens) and on ocean model development (led by P. Korn within the ocean department, led by J. Marotzke). The extensive computational needs of MPI-M are satisfied by the German Climate Computing Centre (DKRZ), which the MPS is a shareholder of.

4.1.3.1.3 Personnel

Bjorn B. Stevens (M) is a director at the Max-Planck-Institute for Meteorology where he leads the Atmosphere in the Earth System Department and is a professor at the University of Hamburg. Prior to moving to Hamburg Dr. Stevens was a full professor of Dynamic Meteorology at the University of California of Los Angeles. He received a PhD in Atmospheric Science in 1996 from the Colorado State University and holds a Bachelor and Masters of Science in Electrical Engineering from Iowa State University. Prof. Stevens' research blends modeling, theory and

field work to help articulate the role of aerosols, clouds and atmospheric convection in the climate system. He has made pioneering contributions to both understanding and modelling of mixing and microphysical processes and their impact on the structure and organization of clouds. Likewise, his contribution to an understanding of how clouds respond to warming, and how radiative forcing responds to aerosol perturbations, has proven fundamental to the present comprehension of the susceptibility of Earth's climate to perturbations. Prof. Stevens served as a lead-author of Chapter 7, "Cloud and Aerosols" for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). He is the lead principal investigator for the HD(CP)2 project, High Definition Clouds and Precipitation for Climate Prediction, a national project supported by the Germany Ministry of Education and Research. He serves on several international advisory boards, has served as editor of leading journals in his field and has been honored by a number of awards, and fellowships.

Selected publications:

- **Stevens,** B., S. C. Sherwood, S. Bony, M. J. Webb, 2016: Prospects for narrowing bounds on earth's equilibrium climate sensitivity. Earth's Future. doi: 10.1002/2016EF000376.
- **Stevens,** B., 2015: Rethinking the lower bound on aerosol radiative forcing. Journal of Climate, 28, 4794-4819. doi:10.1175/JCLI-D-14-00656.1.
- Bony, S., B. **Stevens,** et al., 2015: Clouds, circulation and climate sensitivity. Nature Geoscience, 261. doi:10.1038/ngeo2398.
- Mauritsen, T., B. **Stevens,** 2015: Missing iris effect as a possible cause of muted hydrological change and high climate sensitivity in models. Nature Geoscience, 8, 346-351. doi:10.1038/ngeo2414.
- **Stevens,** B., S. Bony, 2013: Water in the atmosphere. Physics Today, 66(6), 29-34. doi: 10.1063/PT.3.2009.

Jochem Marotzke (M) is the Managing Director of the Max Planck Institute for Meteorology. He studied physics at the universities of Bonn, Copenhagen and Kiel and received his doctorate in physical oceanography in 1990. From 1990 to 1992 he worked as Post-doctoral Associate at the Massachusetts Institute of Technology and became Assistant Professor in 1992, then Associate Professor in 1997. From 1999 to 2003 he was Professor of physical oceanography at the Southampton Oceanography Center, UK, after which he was appointed Director at the Max Planck Institute for Meteorology in Hamburg. Since 2006 he has also been Honorary Professor at the University of Hamburg. In 2007 he became a member of the German Academy of Sciences Leopoldina. Jochem Marotzke received the European Geosciences Union's Fritjof Nansen Medal in 2009 and was elected a member of the German Academy of Engineering Sciences (acatech) in 2017. In the IPCC's Fifth Assessment Report published in 2013, he was one of the two Co-ordinating Lead Authors of the chapter "Evaluation of climate models". In the current IPCC's Sixth Assessment Report, he is the Coordinating Lead Author of chapter 4: "Future global climate: scenario-based projections and near-term information".

Selected publications

- Hedemann, C., T. Mauritsen, J. Jungclaus, and J. **Marotzke,** 2017: The subtle origins of surface-warming hiatuses. Nature Climate Change, 7, 336-339
- **Marotzke,** J., W. A. Müller, F. S. E. Vamborg, P. Becker, U. Cubasch, H. Feldmann, F. Kaspar, C. Kottmeier, C. Marini, I. Polkova, K. Prömmel, H. W. Rust, D. Stammer, U. Ulbrich, C. Kadow, A. Köhl, J. Kröger, T. Kruschke, J. G. Pinto, H. Pohlmann, M. Reyers, M. Schröder, F. Sienz, C. Timmreck, and M. Ziese, 2016: MiKlip: A national research project on decadal climate prediction. Bulletin of the American Meteorological Society, 97, 2379-2394.
- **Marotzke,** J., and P. M. Forster, 2015: Forcing, feedback and internal variability in global temperature trends. Nature, 517, 565-570.
- Flato, G., J. **Marotzke,** B. Abiodun, P. Braconnot, S. C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason, and M. Rummukainen, 2013: Evaluation of Climate Models. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, Eds., Cambridge University Press, 741-866.
- Matei, D., J. Baehr, J. H. Jungclaus, H. Haak, W. A. Müller, and J. **Marotzke,** 2012: Multiyear prediction of monthly mean Atlantic Meridional Overturning Circulation at 26.5ºN. Science, 335, 76-79.

Cathy Hohenegger (F) is a scientist working at the Max-Planck-Institute for Meteorology in the Department "Atmosphere in the Earth System" and leading a research group on "Precipitating Convection" since 2011. Prior to moving to Hamburg, she was a visiting scientist at the University of Washington in Seattle funded by a fellowship of the Swiss National Science Foundation for advanced researchers. She received a PhD in Atmospheric Science in 2007 from ETH Zurich and holds a diploma (master equivalent, with distinction) in Earth Sciences from ETH Zurich as well. Dr Hohenegger's research focuses on moist convection and is geared towards understanding the factors controlling the lifecycle of convection and the role of convection in the climate system. She has made fundamental contributions to our understanding of the interactions between soil moisture and precipitation. Her research also highlighted the key role of circulations, in particular circulations confined in the boundary layer, in controlling the lifecycle of convection, in contrast to a more traditional view of convection based on instability and moistening. Given the multi-scale nature of moist convection, Dr Hohenegger has been using for her research models across spatial and temporal scales, has pioneered the use of convection-permitting models for climate simulations, and has also developed model parameterizations. Since 2011, Dr Hohenegger has been leading one of the five groups of the Hans-Ertel Centre for Weather Research (HErZ), a 12-year program of the German Weather

Service funded by the German government to support basic research and improve education in meteorology. She is the speaker of HErZ for his 2nd phase (2015-2018). She is also leading one of the five subprojects of the HD(CP)2 project, and has been organizing workshops, summer schools and sessions at conferences on topics related to her research.

Selected publications:

- **Hohenegger,** C. and B. Stevens, 2018: The role of the permanent wilting point in controlling the spatial distribution of precipitation. *Proc. Natl. Acad. Sci.*, doi:10.1073/pnas.1718842115
- Rieck M., C. **Hohenegger** and P. Gentine, 2015: The effect of moist convection on thermally induced mesoscale circulations. *Quart. J. Roy. Meteor. Soc.*, **141**, 2418-2428, doi:10.1002/qj.2532
- **Hohenegger** C. and B. Stevens, 2013: Preconditioning deep convection with cumulus congestus. *J. Atmos. Sci*., **70**, 448-464, doi:http://dx.doi.org/10.1175/JAS-D-12-089.1
- **Hohenegger** C., P. Brockhaus, C. S. Bretherton, and C. Schär, 2009: The soil-moisture precipitation feedback in simulations with explicit and parameterized convection. *J. Climate*, **22**, 5003-5020, doi:http://dx.doi.org/10.1175/2009JCLI2604.1
- **Hohenegger** C., P. Brockhaus, and C. Schär, 2008: Towards climate simulations at cloud-resolving scales. *Meteor. Z.*, **17**, 383-394, doi:10.1127/0941-2948/2008/0303

4.1.3.2 Max Planck Institute for Chemistry

4.1.3.2.1 Brief description of organisation

The Max Planck Institute for Chemistry (MPI-C) is one of the two oldest institutes of the MPG. The institute has four departments: Atmospheric Chemistry, Climate Geochemistry, Multiphase Chemistry, and Particle Chemistry and additional research groups. Current research aims at an integral understanding of chemical processes in the Earth system, particularly in the atmosphere and biosphere. Investigations address a wide range of interactions between air, water, soil, life and climate in the course of Earth history up to today´s human-driven epoch, the Anthropocene.

4.1.3.2.2 Excellence

The focus of MPI-C lay on atmospheric chemistry, air quality and climate modelling, spreading of vector borne diseases, public health impacts; hot weather extremes and dust storms in the Mediterranean, Middle East and North Africa (MENA) region.

4.1.3.2.3 Personnel

Jos Lelieveld (M) is the Director of MPI-C. Jos received a PhD from the Faculty of Physics and Astronomy at Utrecht University (1990). He worked at Stockholm University (1991) and the University of California, San Diego (1992), and became a Professor and the chair of the Air Quality Department at Wageningen University in 1993, in 1995 he received the Professorship in Atmospheric Physics and Chemistry at Utrecht University. In 2000, he was appointed as a Director at the Max Planck Institute for Chemistry in Mainz. Since January 2008 he is also a Professor at the Cyprus Institute and leads the Atmospheric and Climate Modeling group of the EEWRC (Energy, Environment and Water Research Center). Jos published over 400 peer-reviewed articles of which many are highly cited. He is a member of the German national academy of sciences Leopoldina, of international committees and societies, and received international distinctions. His key expertise applicable to ExtremeEarth-PP includes atmospheric chemistry, air quality and climate modelling, and public health impacts.

Selected publications:

- **Lelieveld**, J., T. M. Butler, J. N. Crowley, T. J. Dillon, H. Fischer, L. Ganzeveld, H. Harder, M. G. Lawrence, M. Martinez, D. Taraborrelli, and J. Williams, Atmospheric oxidation capacity sustained by a forest, Nature, 452, 737-740, 2008.
- Montzka, S., M. Krol, E. Dlugokencky, B. Hall, P. Jöckel, and J. **Lelieveld**, Small inter-annual variability of global atmospheric hydroxyl, Science, 331, 67-69, 2011.
- **Lelieveld**, J., J.S. Evans, M. Fnais, D. Giannadaki, and A. Pozzer, The contribution of outdoor air pollution sources to premature mortality on a global scale, Nature, 525, 367-371, 2015.
- **Lelieveld**, J., Y. Proestos, M. Tanarhte, M.S. Fnais, E. Tyrlis, and G. Zittis, Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century, Clim. Change, 137, 245-260, 2016.
- **Lelieveld**, J., E. Bourtsoukidis, C. Brühl, H. Fischer, H. Fuchs, H. Harder, A. Hofzumahaus, F. Holland, A. Pozzer, H. Schlager, J. Williams, A. Zahn, and H. Ziereis, The South Asian monsoon – pollution pump and purifier, Science, 361, 270-273, 2018.

Benedikt Steil (M) is research scientist at the MPI-C, Atmospheric Chemistry Department, WG Prof. Lelieveld, since 2000. He received his M.Sc. in Physics from the Gutenberg University Mainz in 1990. During 1991-2000 he worked as research associate at the MPI for Chemistry and MPI for Meteorology, and in 1998 he received his Ph.D. in Physics from the University of Hamburg, Geoscience Faculty. His research interests cover tropospheric and stratospheric chemistry, aerosols, radiation, satellite data, trends in atmospheric chemistry and climate, high resolution simulations, paleo-chemistry and paleo-climate, and earth system model development. He has contributed to EU and national projects in Germany on atmospheric chemistry and climate modelling, and software development on new computer architectures. He has coordinated working groups in national projects on paleo-chemistry (PalMod) and software development (Scales).

Selected publications:

- Abdelkader, M.; Metzger, S.; **Steil**, B.; Klingmüller, K.; Tost, H.; Pozzer, A.; Stenchikov, G.; Barrie, L.; Lelieveld, J.: Sensitivity of transatlantic dust transport to chemical aging and related atmospheric processes. Atmospheric Chemistry and Physics 17 (6), pp. 3799 - 3821 (2017)
- Elshorbany, Y. F.; Crutzen, P. J.; **Steil**, B.; Pozzer, A.; Tost, H.; Lelieveld, J.: Global and regional impacts of HONO on the chemical composition of clouds and aerosols. Atmospheric Chemistry and Physics 14 (3), pp. 1167 - 1184 (2014)
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- Butchart, N.; Cionni, I.; Eyring, V.; Shepherd, T. G.; Waugh, D. W.; Akiyoshi, H.; Austin, J.; Brühl, C.; Chipperfield, M. P.; Cordero, E. et al.: Chemistry-Climate Model Simulations of Twenty-First Century Stratospheric Climate and Circulation Changes. Journal of Climate 23 (20), pp. 5349 - 5374 (2010)

Andrea Pozzer (M) is group leader at the MPI-C in Mainz. He graduated in Physics at the University of Padua in Italy (2003) and obtained his PhD at the University of Mainz (2007). After 3 years as associated research scientist at the Cyprus Institute in the Energy, Environment and Water Research Centre, he joined the International Center for Theoretical Physics (ICTP) in Trieste (Italy). Since July 2012 he is group leader at the MPI for Chemistry, coordinating the atmospheric and climate modelling group of the Atmospheric Chemistry Department.

Selected publications:

- **Pozzer**, A., Tsimpidi, A. P., Karydis, V. A., de Meij, A., and Lelieveld, J.:"Impact of agricultural emission reductions on fine-particulate matter and public health", Atmos. Chem. Phys., 17, 12813-12826, https://doi.org/10.5194/acp-17-12813-2017, 2017
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- Cabrera-Perez, D., Taraborrelli, D., Sander, R., and **Pozzer**, A. "Global atmospheric budget of simple monocyclic aromatic compounds", Atmos. Chem. Phys.,16, 6931-6947, doi:10.5194/acp-16-6931-2016, 2016
- Jöckel, P., Tost, H., **Pozzer**, A., Kunze, M., Kirner, O., Brenninkmeijer, C. A. M.,Brinkop, S., Cai, D. S., Dyroff, C., Eckstein, J., Frank, F., Garny, H., Gottschaldt,K.-D., Graf, P., Grewe, V., Kerkweg, A., Kern, B., Matthes, S., Mertens, M.,Meul, S., Neumaier, M., Nützel, M., Oberländer-Hayn, S., Ruhnke, R., Runde,T., Sander, R., Scharffe, D., and Zahn, A.: "Earth System Chemistry integrated Modelling (ESCiMo) with the Modular Earth Submodel System (MESSy) version2.51", Geosci. Model Dev., 9, 1153-1200, doi:10.5194/gmd-9-1153-2016, 2016.
- **Pozzer**, A., de Meij, A., Pringle, K.J., Tost, H., Doering, U.M., van Aardenne,J., and Lelieveld, J.: "Distributions and regional budgets of aerosols and their precursors simulated with the EMAC chemistry-climate model", Atmos. Chem. Phys., 12, 961-987, doi:10.5194/acp-12-961-2012, 2012.

4.1.3.3 Max Planck Institute for Biogeochemistry

4.1.3.3.1 Brief description of organisation

The Max-Planck-Institute for Biogeochemistry (MPI-BGC) is a research institute of the German Max-Planck Society and was founded in 1997 and currently has 200 employees from more than 20 countries. The research mission of the MPI-BGC is the investigation of the global biogeochemical cycles and their interaction with the climate system. and has an annual budget turnover of around 15 million €, with an average of 20% from competitive third-party funding. The researchers at the institute have published on average more than 160 papers a year in the last five years, in highly respected peer-reviewed journals (e.g. including 25 papers in Nature, Science, PNAS). In a MPG evaluation of publication citations (2013), MPI-BGC was attributed an "outstanding publication record". Not only does the institute have an outstanding international reputation for its research success but it has a strong commitment to higher education and scientific training, housing 44 Ph.D. students from 13 countries and operating the International Max Planck Research School for Global Biogeochemical Cycles in cooperation with the Friedrich Schiller University Jena.

4.1.3.3.2 Excellence

MPI-BGC has gained a large portfolio of expertise, such as applied earth observation, numerical modelling, computational statistics, machine learning, and model-data integration as well as eddy covariance, ecosystem physiological and soil ecological methods. One important emphasis is "data-driven Earth System science", where knowledge and predictions are derived from in-situ and remotely sensed data streams via machine learning (including deep learning) approaches. For instance, the MPI-BGC has estimated global fields of biosphere-atmosphere exchange of carbon dioxide, water and energy so far at up to 5 km resolution and up to half-hourly purely from observations. Effects of the water cycle and of extreme climate events on the biosphere and the carbon cycle have been determined globally in this context and remain areas of active research. The MPI-BGC is one of the pivotal European research institutions in its field, and as such was co-ordinating the CARBOEUROPE-IP project (FP6) and the FP7 projects CarboSchools, CARBO-Extreme and IGAS, and is currently leading the project BACI (Horizon 2020). Moreover, the institute is strongly involved in more than ten collaborative EU projects, co-leads international collaborative efforts such as FLUXNET/FLUXCOM, and regular contractor of the European Space Agency.

4.1.3.3.3 Personnel

Markus Reichstein (M) is a director at Max-Planck-Institute for Biogeochemistry where he leads the Biogeochemical Integration Department. He also is Professor for Global Geoecology at the FSU Jena, and Director at the Michael-Stifel-Center Jena for Data-driven and Simulation Science in Jena. Markus Reichstein was born in Kiel, Germany, in 1972. He received the Diploma degree in Landscape/Geo-Ecology from the University of Münster with minors in Botany, Chemistry, and Mathematics/Computer Science. He pursued a PhD in Bayreuth at the Department of Plant Ecology and received the doctorate with distinction in natural sciences in 2001. His main research interests include ecosystem physiology, carbon and water cycles and their interactions from ecosystem to globe, the impact of climate variability on the carbon cycle and the role of the soil in the Earth System. He and his research group tackle these topics by combining experimental, ground- and satellite-based observations with data-driven and process-oriented models in a model-data integration approach and have published more than 120 peer reviewed articles. In 2013 he received the German Max-Planck Research Prize by the Alexander von Humboldt foundation, one of the highest scientific prizes in Germany, and the Piers Sellers Award 2018 by the American Geophysical Union. He has been involved in several international research projects (e.g. CARBOEUROPE-IP, CARBOAFRICA, COMBINE) and has been coordinating the EU-project CARBO-Extreme as well as the ERC project QUASOM on soils carbon and water cycling. Moreover, together with D. Papale and D. Baldocchi, he is leading the current FLUXNET data synthesis activity which brings together to world-wide eddy-covariance observations for an improved understanding of ecosystem and eventually earth system functioning. Markus Reichstein has been part of the iLEAPS/IGBP Scientific Steering Committee, lead author of the IPCC special report on Climate Extremes (SREX), Working group I, and member of the Thuringian panel on climate change, and leading the Future Earth Cluster “Extreme Events from climate to society” and the current Knowledge Action Network activity "Extreme Events and Emergent Risks". He serves on the Editorial board of Agricultural and Forest Meteorology, Global Change Biology and Carbon Management.

Miguel Mahecha (M) is the leader of the Global Empirical Inference group at the Max Planck Institute for Biogeochemistry. He studied geoecology at the Universities of Bayreuth and Exeter (until 2006) and received a PhD from the ETH Zurich (2009). For his work on data driven ecosystem research he was awarded with the Bernd-Rendel Prize for young geoscientists (DFG); the thesis on "Ecosystem-atmosphere exchanges on multiple time scales" was awarded with the Medal of the ETH Zurich. Today, his main scholarly interests are to achieve a better understanding of the role of terrestrial ecosystems in global biogeochemical cycles and the climate system, and the challenges of the human-environmental dynamics during extreme events. Miguel was amongst the founding members of the German Center for Integrative Biodiversity Research (iDiv) and the Michael Stifel Centre for Data Driven and Simulation Science (MSCJ). He can refer to more than 60 articles in scientific journals, including high profile publications in Science, Nature, and related journals. Currently, Miguel Mahecha is the coordinator of the H2020 project BACI (http://www.baci-h2020.eu/), and of the ESA project "Earth System Data Lab" (https://www.earthsystemdatalab.net/). He serves in Scientific Steering Committee of iLEAPS/FutureEarth, participates in the writing team of the emerging Future Earth Knowledge Action Network activity "Extreme Events and Emergent Risks", and is a SSC member in the BELSPO project "ECOPROHET". He is also a founding member of "PEACE - platform for Ecological Analyses on Colombian Ecosystems".

Martin Jung (M) Martin Jung is the leader of the Global Diagnostic Modelling group at the Max Planck Institute for Biogeochemistry. He got his PhD in carbon cycle modelling at the University of Hamburg. Martin is PI of the FLUXCOM initiative and leads the WP in EU-Projects (CLIMAFRICA, BACI / H2020). He got expertise in the synthesis of carbon and water flux data, combined with machine learning and remote sensing information (diagnostic ecosystem modelling). As an expert in carbon-water cycle interactions he has published multiple articles in high-impact journals (Nature, Science, PNAS) and is member of the CMIP6-C4MIP scientific steering committee.

Selected team publications:

- Flach, M. et al. Multivariate anomaly detection for Earth observations: a comparison of algorithms and feature extraction techniques. Earth System Dynamics 8, 677 - 696, doi:10.5194/esd-8-677-2017 (2017).
- Forkel, M. et al. Enhanced seasonal CO2 exchange caused by amplified plant productivity in northern ecosystems. Science 351, 696 - 699, doi:10.1126/science.aac4971 (2016).
- **Reichstein**, M. et al. Climate extremes and the carbon cycle. Nature 500, 287 - 295, doi:10.1038/nature12350 (2013).
- Bodesheim, P., **Jung**, M., Gans, F., Mahecha, M. D. & Reichstein, M. Upscaled diurnal cycles of land–atmosphere fluxes: a new global half-hourly data product. Earth Syst. Sci. Data 10, 1327-1365, doi:10.5194/essd-10-1327-2018 (2018).
- **Jung**, M. et al. Compensatory water effects link yearly global land CO2 sink changes to temperature. Nature 541, 516 - 520, doi:10.1038/nature20780 (2017).

4.1.3.4 Deutsches Klima Rechenzentrum

4.1.3.4.1 Brief Description of the Organisation

DKRZ, the German Climate Computing Centre (DKRZ), is a national service provider which constitutes an outstanding research infrastructure for model-based simulations of global and regional climate and the investigation of the processes in the climate system. DKRZ's principal objectives are provision of adequate computer performance, data management, and service and support to use these tools efficiently. DKRZ is a non-profit and non-commercial limited company with four shareholders. MPG holds 55% of the shares of DKRZ.

4.1.3.4.2 Excellence

DKRZ operates one of the largest supercomputers in Germany and provides its more than 1000 scientific users with the technical infrastructure needed for the processing and analysis of huge amounts of data from climate simulations. This also includes training and support for related application software and data processing issues. DKRZ participates in many national and international projects aiming to improve the infrastructure for climate modelling. Through its research group on scientific computing DKRZ is linked to the Department of Informatics of the University of Hamburg. DKRZ is also co-ordinating (led by Joachim Biercamp) the H2020 Center of Excellence in Simulation of Weather and Climate in Europe, ESiWACE.

4.1.3.4.3 Personnel

Joachim Biercamp (M) holds a PhD in Physical Oceanography and has long-standing experience in supporting data intensive climate simulations. He is leading the Application department of DKRZ. His responsibilities include the organization of user support and the interaction with DKRZ's user group and scientific steering committee. He coordinated the procurement and benchmarking of the previous three generations of DKRZ super computers (NEC SX6, IBM Power6, bullx), all ranked within the TOP 35 of the TOP500 list. Joachim is involved in several national and international projects dealing with infrastructure for climate modeling. He is member of the steering committees of two large German framework projects: HD(CP)^2, which is aiming at development and operation of a cloud resolving version of the ICON model, and PALMOD, which is setting up Earth System Models to understand climate system dynamics and variability during the last glacial cycle. He is the coordinator of ESiWACE and of ESiWACE-2 (which is currently in grant preparation phase.)

4.1.4 Helmholtz Association of German Research Centres as represented by Forschungszentrum Jülich

The Helmholtz Association is the scientific organisation in Germany with the overall aim to "solving the grand challenges of science, society and industry". In ExtremeEarth-PP, Helmholz Association is represented by Forschungszentrum Jülich, but below we list all the Helmholz organisations that are participating in the proposal.

4.1.4.1 Forschungszentrum Jülich

4.1.4.1.1 Brief description of organisation

Forschungszentrum Jülich (FZJ) pursues cutting-edge interdisciplinary research on pressing issues facing society today. With its competence in multi-disciplinary numerical simulation science and information technology, and fundamental research in Earth system sciences, material sciences, physics, nanotechnology, biosciences and brain research, Jülich is developing the basis for the key technologies of tomorrow. In this way, Forschungszentrum Jülich helps to solve the grand challenges facing society in the fields of energy and the environment, information and the brain, and bio-economy. Forschungszentrum Jülich is also breaking new ground in the form of strategic partnerships with universities, among which the Geoverbund which is the geoscientific network of the Aachen-Bonn-Cologne/Jülich area, and industry in Germany and abroad. With more than 5,900 employees, Jülich – a member of the Helmholtz Association – is one of the largest interdisciplinary research centres in Europe. Four institutes of Jülich will be involved in ExtremeEarth-PP: the Jülich Supercomputing Centre (JSC), the Institute for Bio- and Geosciences 3 (IBG-3), the Institute for Energy and Climate Research – Troposphere (IEK-8), and the Institute for Energy and Climate Research – Stratosphere (IEK-7).

4.1.4.1.2 Excellence

JSC is a world leading provider of supercomputing capacity and federated data systems. It is continuously expanding its capacities for data processing and analysis. JSC promotes the principle of co-design, i.e. the development of new technologies, methods, and algorithms in close collaboration with domain scientists and driven by high-end demands from scientific communities. IBG-3 develops and runs a fully coupled terrestrial system model on HPC systems. The terrestrial system model couples in a physically consistent manner water, energy, and matter fluxes in the groundwater, soil, vegetation and atmosphere spatially resolved at the European continental scale. The atmospheric institutes IEK-7 and IEK-8 focus on atmospheric physics and chemistry of the stratosphere and troposphere, respectively. They develop and use global and regional atmospheric models for air quality and atmospheric dynamics analysis and forecasts with high resolution. The Jülich institutes are engaged in major international research activities (e.g. IPCC, WMO/UNEP, TOAR), and provide important elements of international

environmental services (e.g. IAGOS, LTER, CAMS, TERENO, ICOS).

4.1.4.1.3 Personnel

Prof. Harald Bolt (M) is a member of the scientific board of FZJ. In his scientific research, Harald Bolt has largely been concerned with materials science. For example, he developed materials and coatings that help to confine the hot plasma in fusion devices like ITER and he also investigated the interactions of these materials with the fusion plasma. In the European Union's 6th Framework Programme, he coordinated one of the largest research projects in the materials sector, the EU ExtreMat Project (New Materials for Extreme Environments) with 37 partner institutions in 13 European countries. He is involved in various international committees on which he holds many positions, including chairman of an EU committee for the implementation of energy materials research in Horizon 2020, member of the ESFRI committee on European infrastructures for energy research, member of the Advisory Group on Energy for the EU Directorates-General for Research as well as Transport and Energy (RP7), and member of the supervisory board of the European fusion agency "Fusion for Energy". He is also a member of several scientific societies and of the Berlin-Brandenburg Academy of Sciences as well as of the German National Academy of Science and Engineering (acatech).

Selected publications:

- Herrmann, A; Schmid, K; Balden, M; **Bolt**, H, Interfacial optimization of tungsten fibre-reinforced copper for high-temperature heat sink material for fusion application JOURNAL OF NUCLEAR MATERIALS, 386: 453-456 APR 30 2009
- Koch, F; Koppl, S; **Bolt**, H, Self passivating W-based alloys as plasma-facing material, JOURNAL OF NUCLEAR MATERIALS, 386: 572-574 APR 30 2009
- Brendel, A; Paffenholz, V; Kock, T; **Bolt**, H, Mechanical properties of SiC long fibre reinforced copper, JOURNAL OF NUCLEAR MATERIALS, 386: 837-840 APR 30 2009
- Koeck, T; Herrmann, A; Brendel, A; **Bolt**, H, Influence of different deposition parameters on the performance of a Ti-Ta-C interface layer in SiC-fiber reinforced copper matrix composites, ADVANCED MATERIALS RESEARCH, 59: 138-142 2009
- Paffenholz, V; Lindig, S; Brendel, A; **Bolt**, H, Synthesis and analysis of the thermal behavior of SiC-fibre reinforced copper matrix composites as heat sink material, ADVANCED MATERIALS RESEARCH, 59: 153-157 2009

Prof. Astrid Kiendler-Scharr (F) is director at the Troposphere Institute, IEK-8 and W3 professor for physics at Cologne University. Work at IEK-8 focusses on process level understanding of reactive trace species in the atmosphere and related effects on air quality and climate. Prof. Kiendler-Scharr is an expert in aerosol processes, focusing on atmosphere biosphere interactions. She is lead author of the IPCC AR6, chapter 6. She also represents the expertise of colleagues at IEK-8: Domenico Taraborrelli, Vlassis Karydis, and Hendrik Elbern. She and her team will contribute to high resolution regional and continental scale simulations of atmospheric composition and pollution, utilizing data assimilation to link observations with simulations.

Selected publications:

- **Kiendler-Scharr**, A. A. Mensah, E. Friese, D. Topping, E. Nemitz, A. S. H. Prevot, M. Äijälä, J. Allan, F. Canonaco, M. Canagaratna, S. Carbone, M. Crippa, M. Dall Osto, D. A. Day, P. De Carlo, C. F. Di Marco, H. Elbern, A. Eriksson, E. Freney, L. Hao, H. Herrmann,L. Hildebrandt, R. Hillamo, J. L. Jimenez, A. Laaksonen, G. McFiggans, C. Mohr, C. O'Dowd, R. Otjes, J. Ovadnevaite, S. N. Pandis, L. Poulain, P. Schlag, K. Sellegri, E. Swietlicki, P. Tiitta, A. Vermeulen, A. Wahner, D. Worsnop, and H.-C. Wu, Ubiquity of organic nitrates from nighttime chemistry in the European submicron aerosol, *Geophys. Res. Lett.*,43, 7735–7744, 2016
- Karydis, V. A., Tsimpidi, A. P., Pozzer, A., Astitha, M., and Lelieveld, J.: Effects of mineral dust on global atmospheric nitrate concentrations, *Atmos. Chem. Phys*., 16, 1491-1509, https://doi.org/10.5194/acp-16-1491-2016, 2016.
- Fountoukis, A.G. Megaritis, K. Skyllakou, P.E. Charalampidis, C. Pilinis, H.A.C. Denier van der Gon, M. Crippa, F. Canonaco, A.S.H. Prévôt, J. D. Allan, L. Poulain, T. Petäjä, P. Tiitta, S. Carbone, **A. Kiendler-Scharr**, E. Nemitz, C. O'Dowd, E. Swietlicki and S.N. Pandis, Organic aerosol concentration and composition over Europe: Insights from comparison of regional model predictions with aerosol mass spectrometer factor analysis, *Atmos. Chem. Phys.*,14, 9061-9076, 2014
- Taraborrelli D., M. G. Lawrence, J. N. Crowley, T. J. Dillon, S. Gromov, C. B. M. Groß, L. Vereecken, and J. Lelieveld, Hydroxyl radical buffered by isoprene oxidation over tropical forests, *Nature Geoscience*, volume 5, pages 190 – 193, 2012
- N. M. Donahue, K. M. Henry, Th. F. Mentel, **A. Kiendler-Scharr**, C. Spindler, B. Bohn, T. Brauers, H.-P. Dorn, H. Fuchs, R. Tillmann, A. Wahner, H. Saathoff, K.-H. Naumann, O. Möhler, T. Leisner, L. Müller, M.-C. Reinnig, T. Hoffmann, K. Salo, M. Hallquist, M. Frosch, M. Bilde, T. Tritscher, P. Barmet, A. P. Praplan, P. F. DeCarlo, J. Dommen, A. S. H. Prévôt, U. Baltensperger, Aging of biogenic secondary organic aerosol via gas-phase OH radical reactions, *Proceedings of the National Academy of Sciences*, 109 (34), 13503-13508, 2012

Martin Schultz (M) is a group leader on earth system data exploration and lecturer in meteorology at the University of Bonn. He is listed a highly-cited researcher and has recently been awarded an Advanced ERC Grant to develop Deep Learning methods for the analysis of air quality and meteorological data. Dr. Schultz is pioneering data-intensive end-to-end use cases of Earth System science applications. He will be involved in developing the technology case with a special focus on the technology strategy and extreme-scale laboratory concepts. He will act as liaison with the JSC co-design activities on software and infrastructure engineering methodologies.

Selected publications:

- **Schultz, M. G.**, Stadtler, S., Schröder, S., Taraborrelli, D., Franco, B., Krefting, J., Henrot, A., Ferrachat, S., Lohmann, U., Neubauer, D., Siegenthaler-Le Drian, C., Wahl, S., Kokkola, H., Kühn, T., Rast, S., Schmidt, H., Stier, P., Kinnison, D., Tyndall, G. S., Orlando, J.

J., and Wespes, C.: The chemistry–climate model ECHAM6.3-HAM2.3-MOZ1.0, Geosci. Model Dev., 11, 1695-1723, https://doi.org/10.5194/gmd-11-1695-2018, 2018.
- **Schultz, M.G.** et al. , (2017). Tropospheric Ozone Assessment Report: Database and Metrics Data of Global Surface Ozone Observations. Elem Sci Anth . 5, p. 58. DOI: http://doi.org/10.1525/elementa.244
- Lyapina, O., **Schultz, M. G.**, and Hense, A.: Cluster analysis of European surface ozone observations for evaluation of MACC reanalysis data, Atmos. Chem. Phys., 16, 6863-6881, https://doi.org/10.5194/acp-16-6863-2016, 2016.
- Flemming, J., Huijnen, V., Arteta, J., Bechtold, P., Beljaars, A., Blechschmidt, A.-M., Diamantakis, M., Engelen, R. J., Gaudel, A., Inness, A., Jones, L., Josse, B., Katragkou, E., Marecal, V., Peuch, V.-H., Richter, A., **Schultz, M. G.**, Stein, O., and Tsikerdekis, A.: Tropospheric chemistry in the Integrated Forecasting System of ECMWF, Geosci. Model Dev., 8, 975-1003, https://doi.org/10.5194/gmd-8-975-2015, 2015.
- Inness, A., Baier, F., Benedetti, A., Bouarar, I., Chabrillat, S., Clark, H., Clerbaux, C., Coheur, P., Engelen, R. J., Errera, Q., Flemming, J., George, M., Granier, C., Hadji-Lazaro, J., Huijnen, V., Hurtmans, D., Jones, L., Kaiser, J. W., Kapsomenakis, J., Lefever, K., Leitão, J., Razinger, M., Richter, A., **Schultz, M. G.**, Simmons, A. J., Suttie, M., Stein, O., Thépaut, J.-N., Thouret, V., Vrekoussis, M., Zerefos, C., and the MACC team: The MACC reanalysis: an 8 yr data set of atmospheric composition, Atmos. Chem. Phys., 13, 4073-4109, https://doi.org/10.5194/acp-13-4073-2013, 2013.

Jan Vanderborght (M) is director at the Agrosphere Institute, IBG-3 and professor for soil physics at the KU Leuven (Belgium). A the IBG-3, he is heading the research field modelling terrestrial systems and is representing also the expertise of colleagues at IBG-3: Stefan Kollet, Harrie-Jan Hendricks-Franssen, and Harry Vereecken. He is member of the international soil modelling consortium (ISMC), member of scientific review panels in Belgium and France and awardee of the Kirkham Award of the Soil Science Society of America. His field of expertise is soil hydrology, soil-vegetation-atmosphere-transfer models, and soil sensing. He and his team will be involved in the application of the fully coupled terrestrial system model TerrSysMP for high resolution regional and continental scale simulations using exascale computing that will consistently link (groundwater)hydrology, vegetation dynamics and atmospheric processes and that will link observations with simulations using data assimilation.

Selected publications:

- J. Keune, M. Sulis, S. Kollet, S. Siebert and Y. Wada. Human Water Use Impacts on the Strength of the Continental Sink for Atmospheric Water. Geophysical Research Letters, 45,(9), 4068-4076, (2018).
- S.J. Kollet, R.M. Maxwell, C.S. Woodward, S. Smith, **J. Vanderborght**, H. Vereecken and C. Simmer. Proof of concept of regional scale hydrologic simulations at hydrologic resolution utilizing massively parallel computer resources. *Water Resources Research*, 46, W04201, (2010).
- W. Kurtz, G.W. He, S.J. Kollet, R.M. Maxwell, H. Vereecken and H.J.H. Franssen. TerrSysMP-PDAF version 1.0): a modular high-performance data assimilation framework for an integrated land surface-subsurface model. Geoscientific Model Development, 9,(4), 1341-1360, (2016).
- **J. Vanderborght**, T. Fetzer, K. Mosthaf, K.M. Smits and R. Helmig. Heat and water transport in soils and across the soil-atmosphere interface: 1. Theory and different model concepts. Water Resources Research, 53,(2), 1057-1079, (2017).
- H. Vereecken, A. Schnepf, J.W. Hopmans, M. Javaux, D. Or, T. Roose, **J. Vanderborght**, M.H. Young, W. Amelung, M. Aitkenhead, S.D. Allison, S. Assouline, P. Baveye, M. Berli, N. Brüggemann, P. Finke, M. Flury, T. Gaiser, G. Govers, T. Ghezzehei, P. Hallett, H.J. Hendricks Franssen, J. Heppell, R. Horn, J.A. Huisman, D. Jacques, F. Jonard, S. Kollet, F. Lafolie, K. Lamorski, D. Leitner, A. McBratney, B. Minasny, C. Montzka, W. Nowak, Y. Pachepsky, J. Padarian, N. Romano, K. Roth, Y. Rothfuss, E.C. Rowe, A. Schwen, J. Šimůnek, A. Tiktak, J. Van Dam, S.E.A.T.M. van der Zee, H.J. Vogel, J.A. Vrugt, T. Wöhling and I.M. Young. Modeling Soil Processes: Review, Key Challenges, and New Perspectives. Vadose Zone Journal, 15,(5)(2016).

4.1.4.2 Alfred Wegener institute

4.1.4.2.1 Brief description of organisation

The Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) is one of the world´s leading polar and marine research organisations, which provides cutting-edge research in geosciences, climate sciences and biosciences by combining observational and modelling approaches. AWI conducts multidisciplinary research in the Arctic and Antarctic, and contributes to our understanding of the role of the polar regions in the Earth system. AWI is a member of the Helmholtz Association of German Research Centres (HGF). It has an annual budget of more than 100 million Euros and a staff of more than 1000 employees. Furthermore, AWI coordinates polar research in Germany and beyond. Furthermore, it provides infrastructure, equipment and logistics to the German and international polar research communities. AWI keeps the German federal government updated on its research results and provides advice for the development of environmental policies. AWI has also extensive strategic partnerships with leading national and international institutions and coordinates numerous national and international large-scale projects. The AWI is an associate of the German Climate Computing Centre (DKRZ) and has access to a dedicated ESM partition at Jülich Supercomputing Centre.

4.1.4.2.2 Excellence

Modelling constitutes an important element of AWI's research program, ranging from process modelling over regional modelling to global climate and paleoclimate simulations. AWI actively contributes to new technologies in model development. AWI scientists have developed the first mature global sea ice-ocean model formulated on unstructured meshes (Finite Element Sea Ice-Ocean Model, FESOM), which, in a coupled version, will contribute to CMIP6. FESOM research explores next-generation dynamical cores and considers aspects such as scalability on extreme scale high-performance computers. Furthermore, AWI actively develops sea ice, biogeochemistry and ice

sheet models. Running model systems at extremely high spatial resolutions to represent multi-scale aspects and increase the realism of models is a central element of AWI's modelling strategy. Thus, AWI's modelling activities contribute to the development of highly scalable Earth system models that can be run at horizontal resolutions capable of explicitly representing critical processes. AWI also has extensive experience in coordinating large-scale modelling projects such as *Advances Earth System Modelling Capacity* funded by the Helmholtz Association.

4.1.4.2.3 Personnel

Thomas Jung (M) is head of the Climate Dynamics section at AWI, where he is leading the climate modelling and prediction activities with a specific focus on the development and application of high-resolution climate models formulated on unstructured meshes. He coordinates various national and international modelling projects including, WMO's Polar Prediction Project, the Horizon2020 project APPLICATE and the ESM project of the Helmholtz Association. Furthermore, he serves of various committees including the scientific advisory committee (chair) of the German Weather Service and the John von Neumann Institute for Computing. Prof Jung will be involved in the general coordination and in the development of next-generation models for the ocean and cryosphere in an Earth system model context.

Selected publications:

- Sein, D., N.V. Koldunov, S. Danilov, Q. Wang, D. Sidorenko, I. Fast, T. Rackow, W. Cabos and **T. Jung**, 2017: Ocean modeling on a mesh with resolution following the local Rossby radius. *J. Adv. EarthSys. Model.*, 9, 2601–2614.
- **Jung, T.** , N. Gordon, P. Bauer, D. Bromwich, M. Chevallier, J. Day, J. Dawson, F. Doblas-Reyes, C. Fairall, H. Goessling, M. Holland, J. Inoue, T. Iversen, S. Klebe, P. Lemke, M. Losch, A. Makshtas, B. Mills, P. Nurmi, D. Perovich, P. Reid, I. Renfrew, G. Smith, G. Svensson, M. Tolstykh and Q. Yang, 2016: Advancing polar prediction capabilities on daily to seasonal time scales , Bulletin of the American Meteorological Society, 97, 1631–1647.
- Wang, Q., S. Danilov, D. Sidorenko, R. Timmermann, C. Wekerle, X. Wang, **T. Jung**, and J. Schröter, 2014: The Finite Element Sea ice-Ocean Model (FESOM): Formulation of an unstructured-mesh ocean general circulation model. *Geosci. Mod. Dev*., 6, 3893—3976.
- Kinter, J. et al., 2013: Revolutionizing climate modelling-Project Athena: A multi-institutional, international collaboration. *Bull. Amer. Meteor. Soc*., 94, 231—245, DOI: 10.1175/BAMS-D-11-00043.1.
- **Jung, T.**, M. Miller, T. Palmer, P. Towers, N. Wedi, D. Achuthavarier, J. Adams, E. Altshuler, B. Cash, J. Kinter III, L. Marx, C. Stan and K. Hodges, 2012: High-resolution global climate simulations with the ECMWF model in Project Athena: Experimental design, model climate and seasonal forecast skill. J. Climate, 25, 3155—3172.

Angelika Humbert (F) is leading the ice modelling and remote sensing groups at AWI. Her expertise is modelling of glacier dynamics in Greenland and Antarctica, ranging from projections of contribution of ice sheets to sea level rise to process modelling. She is leading the efforts speeding up of full Stokes ice models on unstructured adaptive grids to enhance capability of ice sheet models to capture acceleration. She was leading the topic cryosphere in the HGF Alliance Remote Sensing and Earth System Dynamics, is head of 'Remote sensing of Arctic surfaces' in the EU ERA Planet project iCUPE, member of mission advisory group for Sentinel Extension Mission. Furthermore, she is strongly involved in combining remote sensing of ice sheets with modelling. In AWI's research program PACES-II she leads the work package 'Ice sheet dynamics and mass balance' Within the next research program of Helmholtz Earth and Environment Topic 2 'Ocean and cryosphere in climate' she will lead the 'Advanced Research Technologies of Tomorrow', representing modelling.

Selected publications:

- Bondzio, J. H., M. Morlighem, H. Seroussi, T. Kleiner, M. Rückamp, J. Mouginot, T. Moon, E. Y. Larour, and **A. Humbert** (2017), The mechanisms behind Jakobshavn Isbræ's acceleration and mass loss: A 3-D thermomechanical model study, Geophys. Res. Lett., 44, doi:10.1002/2017GL073309.
- Goelzer, H., Nowicki, S., Edwards, T., Beckley, M., Abe-Ouchi, A., Aschwanden, A., Calov, R., Gagliardini, O., Gillet-Chaulet, F., Golledge, N. R., Gregory, J., Greve, R., **Humbert, A.**, Huybrechts, P., Kennedy, J. H., Larour, E., Lipscomb, W. H., Le clec'h, S., Lee, V., Morlighem, M., Pattyn, F., Payne, A. J., Rodehacke, C., Rückamp, M., Saito, F., Schlegel, N., Seroussi, H., Shepherd, A., Sun, S., van de Wal, R., and Ziemen, F. A.: Design and results of the ice sheet model initialisation experiments initMIP-Greenland: an ISMIP6 intercomparison, The Cryosphere, 12, 1433-1460, https://doi.org/10.5194/tc-12-1433-2018, 2018
- N. Wilkens, J. Behrens, T. Kleiner, D. Rippin, M. Rückamp, and **A. Humbert** (2015): Thermal structure and basal sliding parametrisation at Pine Island Glacier – a 3-D full-Stokes model study. The Cryosphere, 9, 675–690, doi:10.5194/tc-9-675-2015
- Kleiner, T., Rückamp, M. , Bondzio, J. H. and **Humbert, A.** (2015): Enthalpy benchmark experiments for numerical ice sheet models , The Cryosphere, 9 (1), pp. 217-228 . doi: 10.5194/tc-9-217-2015

Sergey Danilov (M) is a world-leading expert in the development of sea ice-ocean models on unstructured meshes. In the context of ExtremeEarth-PP he will be providing expertise in high-resolution sea ice-ocean modelling and in the scalability of dynamical cores on unstructured meshes.

Selected publications:

- Wang, Q., C. Wekerle, **S. Danilov**, X. Wang, X. and T. Jung, 2018: A 4.5 km resolution Arctic Ocean simulation with the global multi-resolution model FESOM1.4 , Geosci. Model Dev., 11 , 1229–1255.
- **Danilov, S**., D. Sidorenko, Q. Wang and T. Jung, 2017: The Finite-volumE Sea ice–Ocean Model (FESOM2). *Geosci. Mod. Dev*., 10, 765–789.
- **Danilov, S**., Q. Wang, R. Timmermann, N. Iakovlev, D. Sidorenko, M. Kimmritz, T. Jung and J. Schröter, 2015: Finite-Element Sea Ice Model (FESIM), version 2 , *Geosci. Model Dev*., 8 , 1747–1761.

- Wang, Q., **S. Danilov**, D. Sidorenko, R. Timmermann, C. Wekerle, X. Wang, T. Jung, and J. Schröter, 2014: The Finite Element Sea ice-Ocean Model (FESOM): Formulation of an unstructured-mesh ocean general circulation model. *Geosci. Mod. Dev*., 6, 3893–3976.
- **Danilov, S.**, 2013: Ocean modeling on unstructured meshes , Ocean Modelling, 69, 195–210.

4.1.4.3 GEOMAR

4.1.4.3.1 Brief description of organisation

GEOMAR is among the largest non-university research institutions in the field of marine sciences in Germany (1000 staff, incl. 450 experienced scientists and about 200 doctoral candidates), and a member of the Helmholtz Association, Germany's largest non-university scientific organisation. The centre's mandate is the inter- and multidisciplinary investigation of all relevant aspects of modern marine sciences, from seafloor geology through physical, chemical and biological oceanography to marine meteorology. Research is conducted worldwide in all oceans and adjacent seas. The main research topics are grouped in four divisions: ocean circulation and climate dynamics, marine biogeochemistry, marine ecology, and dynamics of the ocean floor. GEOMAR cooperates closely with national and international research institutions and with many SMEs active in marine technology and science. The scientific breadth and the state-of-the-art infrastructure, particularly adapted for deployments in the open ocean and the deep sea, gives GEOMAR a unique profile and a central collaborative role within the German and international marine science community. This observational infrastructure is tightly integrated with GEOMAR's earth system modelling capacities. Research in all four divisions includes scientific computing activities and GEOMAR formulated an ocean system modelling strategy to coordinate and integrate these activities. GEOMAR is contributing this expertise as partner in major earth system modelling projects like PALMOD funded by German Federal Ministry of Education and Science (BMBF) to understand climate system dynamics during the last glacial cycle and ESM, which brings together eight Helmholtz Research Centres to develop a comprehensive earth system modelling capacity.

4.1.4.3.2 Excellence

The ocean covers more than 70% of Earth's surface and more than 40% of the global population lives near the ocean. It exerts a major influence on climate and its densely populated coasts are exposed to marine hazards such as landslides, earthquakes, tsunamis and a rising sea-level. This illustrates the clear need for a strong ocean science component in the comprehensive assessment of geo-extremes envisioned by the ExtremeEarth initiative. GEOMAR investigates the physical, chemical, biological, and geological processes in the ocean and their interaction with the seafloor and the atmosphere. Research at GEOMAR combines theoretical concepts, observations and numerical modelling and their joint synthesis. To follow this comprehensive approach several research groups at the centre employ methodologies that can be summarized as high-end scientific computing. We will bring this expertise in ocean and climate modelling, with emphasis on the sub-mesoscale to mesoscale ocean dynamics to ExtremeEarth-PP.

4.1.4.3.3 Personnel

Lars Rüpke (M) is a professor for Seafloor Modelling at GEOMAR and the Christian-Albrechts University Kiel since 2007. After receiving his PhD from GEOMAR and Kiel University in 2004, he joined the Norwegian Centre of Excellence "Physics of Geological Processes" at the University of Oslo, Norway, where he became senior scientist and leader of the geodynamics group. His key expertise is in scientific computing applied to the evolution of the ocean floor and its role in the earth system. Examples of his interdisciplinary work include feedbacks between sea level changes and volcanism, gas hydrate dynamics in a warming ocean, and biogeochemical exchange at deep-sea hydrothermal systems. He is a co-PI of the "Future Ocean" cluster of excellence at Kiel University, which brings together a large interdisciplinary team to work on solution-oriented research questions regarding the sustainable use of the ocean. Since 2018 he is the chair of the GEOMAR Scientific Council and from 2014-2017 was the deputy head of research division 4 "Dynamics of the Ocean Floor". He has published 38 peer-reviewed papers, which have received a total of 1565 citations; his h-factor is 17.

Selected publications:

- Elger, J., C. Berndt, L. **Rüpke**, S. Krastel, F. Gross, W. H. Geissler (2018): Submarine slope failure due to pipe structure formation. Nature Communications, http://dx.doi.org/10.1038/s41467-018-03176-1
- Hasenclever J, Knorr G, **Rüpke** LH, Köhler P, Morgan JP, Garofalo K, Barker S, Lohmann G, Hall I (2017): Sea level fall during glaciation stabilized atmospheric CO_2 by enhanced volcanic degassing, Nature Communications, doi:10.1038/ncomms15867
- **Rüpke** LH and Hasenclever J (2017): Global rates of mantle serpentinization and H_2 production at oceanic transform faults in 3-D geodynamic models, GRL, DOI: 10.1002/2017GL072893
- Kretschmer K., Biastoch A., **Rüpke** LH., Burwicz E. (2015): Modeling the fate of methane hydrates under global warming, Global Biogeochemical Cycles, 29, doi:10.1002/2014GB005011
- Biastoch, A., Treude T., **Rüpke** LH., Riebesell U., Roth C., Burwicz EB., Park W., Latif M., Böning C., Madec G., Wallmann K. (2011): Rising Arctic Ocean temperatures cause gas hydrate destabilization and ocean acidification, Geophysical Research Letters, 38, L08602, doi:10.1029/2011GL047222

Arne Biastoch (M) leads an ocean modelling group at GEOMAR and is adjunct professor for physical

oceanography at the Christian-Albrechts University Kiel. Before joining GEOMAR (and its predecessor organisations), he worked at the Scripps Institution of Oceanography, La Jolla, U.S.A. Prof. Biastoch has extensive experience in modelling the large-scale circulation of the ocean, with emphasis on mesoscale processes. His main interests are studying the Atlantic Ocean circulation variability, the dynamics in the Agulhas system and their combined effects on the meridional overturning circulation and climate. He also works with strongly interdisciplinary foci, e.g. on the role of seafloor warming on the fate of Arctic gas hydrates or on simulating the dispersal of organisms using Lagrangian frameworks. In 2014-2017 he was chair of the GEOMAR Scientific Council and member of the Consultatory Board of Directors, 2010-2012 co-chair of the SCOR Working Group No. 136 „Climatic Importance of the Greater Agulhas System". He has participated in numerous national and international research projects and is member of the Kiel Cluster of Excellence "Future Ocean". Prof. Biastoch is the (co)-author of a total of 92 publications in the peer-reviewed literature and has a h-index of 28.

Selected publications:

- **Biastoch, A.**, C. W. Böning, F. U. Schwarzkopf, and J. R. E. Lutjeharms, 2009: Increase in Agulhas leakage due to poleward shift in the southern hemisphere westerlies, *Nature*, 462, 495-498, doi: 10.1038/nature08519.
- **Biastoch, A.**, J. V. Durgadoo, A. K. Morrison, E. van Sebille, W. Weijer, S. M. Griffies, 2015: Atlantic Multi-decadal Oscillation covaries with Agulhas leakage, *Nat. Commun.*, 6:10082, doi: 10.1038/ncomms10082.
- **Biastoch, A.**, T. Treude, **L. H. Rüpke**, U. Riebesell, C. Roth, E. B. Burwicz, W. Park, C. W. Böning, M. Latif, G. Madec, and K. Wallmann, 2011: Rising Arctic Ocean temperatures cause gas hydrate destabilization and ocean acidification, *Geophys. Res. Lett.*, 38, L08602, doi: 10.1029/2011GL047222.
- **Biastoch, A.**, C. W. Böning, J. Getzlaff, J.-M. Molines, and G. Madec, 2008: Mechanisms of interannual - decadal variability in the meridional overturning circulation of the mid-latitude North Atlantic Ocean, *J. Climate*, 21, 6599-6615, doi: 10.1175/2008JCLI2404.1.
- Böning, C. W., E. Behrens, **A. Biastoch**, K. Getzlaff, and J. L. Bamber, 2016: Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean, *Nat. Geosci.*, 9, 523-527, doi: 10.1038/ngeo2740.

Katja Matthes (F) is head of the research department “Ocean circulation and climate change” as well as head of “Physics of the Atmosphere” group at GEOMAR and full professor for atmospheric physics at the Christian-Albrechts-Universität (CAU) in Kiel. Before joining GEOMAR she had an International Outgoing Marie Curie Fellowship of the European Commission and spent three years as a Postdoc at the National Center for Atmospheric Research (NCAR) in Boulder/CO. She then headed a Helmholtz-Young Investigator Group at the Helmholtz Center Potsdam, the German Research Center for Geosciences (GFZ) combined with an associate professorship at the Free University of Berlin before joining GEOMAR and CAU in 2012. Prof. Matthes has extensive experience in modelling the large-scale circulation of the atmosphere and is particularly interested in the role of the upper atmosphere (stratosphere) on the troposphere and the ocean. Her main interests are the understanding of natural climate variability such as from solar variability, from the sub-seasonal to the (multi-) decadal timescales and the importance of atmospheric chemistry for this. She leads an international model comparison project on solar influence under the World Climate Research Programme (WCRP) SPARC-SOLARIS/HEPPA, is responsible for the solar forcing of the Coupled Model Intercomparison (CMIP) exercise of the WCRP and has participated in numerous national and international research projects, is member of the Kiel Cluster of Excellence "Future Ocean" and Co-PI of the Future Ocean Sustainability Cluster proposal. Prof. Matthes is the (co)-author of a total of 65 publications in the peer-reviewed literature and has a h-index of 19.

Selected publications:

- Kemena TP, **Matthes K**, Martin T, Wahl S, Oschlies A (2017) Atmospheric feedbacks in North Africa from an irrigated, afforested Sahara. Climate Dynamics: 1-21, doi: 10.1007/s00382-017-3890-8.
- **Matthes K**, Funke B, et al. (2017) Solar forcing for CMIP6 (v3.2). Geoscientific Model Development 10: 2247-2302, doi: 10.5 194/gmd-10-2247-2017.
- Wang W, **Matthes K**, Omrani N-E, Latif M (2016) Decadal variability of the tropical tropopause temperature and its relation to the Pacific Decadal Oscillation. Nature Scientific Reports 6: 29537, doi: 10.1038/srep29537.
- Thiéblemont R, **Matthes K**, Omrani N-E, Kodera K, Hansen F (2015) Solar forcing synchronizes decadal North Atlantic climate variability. Nature Communications 6: 8268, doi: 10.1038/ncomms9268.
- **Matthes K**, Kuroda Y, Kodera K, Langematz U (2006) Transfer of the solar signal from the stratosphere to the troposphere: Northern winter. Journal of Geophysical Research 111, D06108, doi: 10.1029/2005JD006283

4.1.4.4 German Research Centre for Geosciences

4.1.4.4.1 Brief description of organisation

German Research Centre for Geosciences (GFZ) was founded in 1992 as the national research institution for geosciences in Germany and is *ab initio* member of the Helmholtz Association of National Research Centres. With currently 1,261 employees including 505 scientists and more than 200 doctoral candidates, GFZ combines all solid earth science fields including geodesy, geology, geophysics, mineralogy, palaeontology and geochemistry, in a multidisciplinary scientific and technical environment. The centre is built up by six departments: geodesy, geophysics, geochemistry, geomaterials, geoarchives, and geotechnologies. The departments constitute the hotbed for a very large range of new methodologies, models, architectures, software and instrumentation, coming with many new standards of worldwide impact. Research at GFZ is accomplished using a broad spectrum of methods

and techniques, such as satellite geodesy and remote sensing, geophysical deep and shallow sounding, scientific drilling, experiments under in-situ conditions and modelling of geo-processes. GFZ is providing the empirical basement and the information infrastructure with core data services for large scale and supra-national geoscientific projects. This is accomplished by means of large scale monitoring and sounding infrastructures, e.g. seismological and GPS networks, satellites like the ongoing satellite missions CHAMP and GRACE, magnetic or gravimetric observatories, as well as unique active experiments, the global seismological network GEOFON (since 1992), the International Continental Scientific Drilling Program (ICDP), and many others. As a member of the Open Geospatial Consortium (OGC) and OASIS (Organization for the Advancement of Structured Information Standards) GFZ supports the further development and application of standards and best practices for the data and information management in geosciences. GFZ has a relevant experience in coordinating and participating to international projects and was involved in 57 FP6 and FP7 projects, of which 13 projects are coordinated by GFZ. Currently, the GFZ is involved in 42 EU projects, of which 11 are coordinated by the GFZ.

4.1.4.4.2 Excellence

GFZ has the high-end infrastructure, equipment and broad expertise, which enable to significantly drive and influence the future developments in the research field of geo-hazards planned within ExtremeEarth. The GFZ data Science expertise will strongly contribute to ExtremeEarth-PP by enhancing knowledge extraction from geodata generated either by multi-parametric observations (terrestrial, airborne, and satellite), by simulation models, by experiments, by historical archives, or by citizen scientists. GFZ is developing new strategies in seismic data analytics, novel approaches to explore and analyse the output from complex, multi-run simulations, and the analysis of very large and heterogeneous satellite data. GFZ is involved in key international and international projects relevant to ExtremeEarth: Digital Earth (HGF), Future Earth, EPOS, EUDAT, SERA, IGS, ICGEM, IERS, Sentinel, Copernicus, World Stress Map, GeoMultiSens. GFZ maintains massive scientific infrastructure and platforms which are highly relevant for ExtremeEarth, including observatories, a modular earth science infrastructure and the Earth System Knowledge Platform.

4.1.4.4.3 Personnel

Cotton, Fabrice (M) has a PhD in Geophysics (Grenoble-I University, 1995). She is currently head of Section 2.6 “Seismic Hazard and Stress Field”, at GFZ. She also holds a W3 professor in Geophysics at the University of Potsdam and is on the Global Earthquake Model Science Board chair. Previously she held the position as professor at Grenoble-I University (2001-2014). She was researcher at the seismic hazard team of the French Nuclear Safety Agency (1996-2001). Outstanding awards: Gauss lecture (EGU 2017), Helmholtz Association Recruitment Initiative Professorship (2014), Kyoto University invited Professor (2013), University Grenoble-I medal (2008), Institut Universitaire de France junior fellow (2006). Her key expertise and research interests are in earthquake source studies, engineering seismology (ground-motion prediction models, probabilistic seismic hazard assessment), high consequences low probabilities hazard assessment (e.g. critical facilities) and neural networks.

Selected publications:

- Bora, S. S., **Cotton**, F., Scherbaum, F., Edwards, B., Traversa, P. (2017) Stochastic source, path and site attenuation parameters and associated variabilities for shallow crustal European earthquakes. Bulletin of Earthquake Engineering 15(11): 4531-4561.
- **Cotton**, F., Archuleta, R., Causse, M. (2013) What is Sigma of the Stress Drop? Seismological Research Letters 84(1): 42-48.
- **Cotton**, F., Campillo, M. (1995) Frequency domain inversion of strong motions: Application to the 1992 Landers earthquake. Journal of Geophysical Research: Solid Earth 100(B3): 3961-3975.
- **Cotton**, F., Scherbaum, F., Bommer, J. J., Bungum, H. (2006) Criteria for selecting and adjusting ground-motion models for specific target regions: Application to Central Europe and rock sites. Journal of Seismology 10(2): 137-156.
- Kotha, S. R., Bindi, D., **Cotton**, F. (2017) From Ergodic to Region- and Site-Specific Probabilistic Seismic Hazard Assessment: Method Development and Application at European and Middle Eastern Sites. Earthquake Spectra 33(4):

Tilmann, Frederik (M) has a PhD in Geophysics from University of Cambridge, U.K. (1999) and is currently head of section 2.4 “Seismology”, GFZ (since 2010) and professor in Seismology (W2) at Freie Universität Berlin (since 2010). Previous positions include Feodor-Lynen scholar, New Mexico State University, Las Cruces, New Mexico (1999-2000), Assistant Professor (C1), GEOMAR, Centre for Marine Geosciences of the Christian-Albrechts University Kiel (2000-2003), University Lecturer, Department of Earth Science, University of Cambridge (2003-2010) & Staff Fellow at Trinity Hall College (2007-2010), Community: ORFEUS ExeCom; ITU/WMO/Unesco Joint Task Force on SMART cables; editorial board “Surveys in Geophysics”. His key expertise and research interests are: seismological investigations into subduction and collision zone processes, crustal and lithosphere scale inversions from surface waves and ambient noise data, receiver functions, body waves, seismic anisotropy, shear wave splitting and big data analysis.

Selected publications:

- Kufner, S.-K., Schurr, B., Sippl, C., Yuan, X., Ratschbacher, L., Akbar, A. s. M., Ischuk, A., Murodkulov, S., Schneider, F. M., Mechie, J., **Tilmann**, F. (2016) Deep India meets deep Asia: Lithospheric indentation, delamination and break-off under Pamir and Hindu Kush (Central Asia). Earth and Planetary Science Letters 435: 171-184.

- Schurr, B., Asch, G., Hainzl, S., Bedford, J., Hoechner, A., Palo, M., Wang, R., Moreno, M., Bartsch, M., Zhang, Y., Oncken, O., **Tilmann**, F., Dahm, T., Victor, P., Barrientos, S., Vilotte, J.-P. (2014): Gradual unlocking of plate boundary controlled initiation of the 2014 Iquique earthquake. Nature, 512: 299-302.
- **Tilmann**, F., Zhang, Y., Moreno, M., Saul, J., Eckelmann, F., Palo, M., Deng, Z., Babeyko, A., Chen, K., Baez, J. C., Schurr, B., Wang, R., Dahm, T. (2016) The 2015 Illapel earthquake, central Chile: a type case for a characteristic earthquake? Geophysical Research Letters 43(2): 574-583.
- **Tilmann**, F.; Craig, T. J.; Grevemeyer, I.; Suwargadi, B.; Kopp, H.; Flueh, W. (2010): The updip seismic/aseismic transition of the Sumatra megathrust illuminated by aftershocks of the 2004 Aceh-Andaman and 2005 Nias events. Geophysical Journal International 181(3): 1261-1274.
- **Tilmann**, F.; Ni, J. and INDEPTH III seismic team (2003): Seismic imaging of the downwelling Indian lithosphere beneath Central Tibet. Science 300(5624): 1424-1427.

Rivalta, Eleonora (F) has a PhD in physics from University of Bologna (2002). She is currentlya senior scientist. Previously she has worked in Hamburg, Leeds and Bologna. She has been awarded the ERC Starting Grant. Her key expertise and research interests are: pre-eruptive volcano physics (mechanics of magma propagation), volcano seismicity and deformation, modelling of volcanic and seismic sources, interaction of tectonics and magmatism, forecasting of pre-eruptive magma pathways.

Selected publications:

- Cattania, C., **Rivalta**, E., Hainzl, S., Passarelli, L., Aoki, Y. (2017) A nonplanar slow rupture episode during the 2000 Miyakejima dike intrusion. Journal of Geophysical Research 122(3): 2054-2068.
- Corbi, F., **Rivalta**, E., Pinel, V., Maccaferri, F., Bagnardi, M., Acocella, V. (2015): How caldera collapse shapes the shallow emplacement and transfer of magma in active volcanoes. Earth and Planetary Science Letters 431: 287-293., 1433-1453.
- Maccaferri, F., **Rivalta**, E., Keir, D., Acocella, V. (2014) Off-rift volcanism in rift zones determined by crustal unloading. Nature Geoscience 7: 297-300.
- **Rivalta**, E., Segall, P. (2008) Magma compressibility and the missing source for some dike intrusions. Geophysical Research Letters 35: L04306.
- **Rivalta**, E., Taisne, B., Bunger, A. P., Katz, R. F. (2015) A review of mechanical models of dike propagation: Schools of thought, results and future directions. Tectonophysics 638: 1-42.

4.1.4.5 German Research Center for Environmental Health

4.1.4.5.1 Brief description of organisation

Helmholtz Zentrum München is the German Research Center for Environmental Health (HMGU). It investigates important common diseases which develop from the interaction of lifestyle, environmental factors and personal genetic background, focusing particularly on diabetes mellitus, allergies and chronic lung diseases. Helmholtz Zentrum München is a research institution of the Federal Republic of Germany and the Free State of Bavaria. It is a member of the Helmholtz Association of German Research Centers. The expertise of Helmholtz Zentrum München ranges from biomedicine to research on ecosystems and the preservation of the natural foundations of human life. Chronic and complex diseases at the interface of health and environment are investigated aiming to promote the application of future medicine and to develop new, personalized approaches of prevention, diagnosis and therapy. HMGU prioritizes excellent basic research, internationally used experimental platforms, core facilities, clinical cooperation groups and centers for translational medicine. This targeted process requires the expertise and collaboration of many different specialists and offers the fellow a wide field of interdisciplinary and multidisciplinary cooperation in ground-breaking research areas. HMGU plant science aims to understand on a molecular level the interplay between biotic and abiotic stress responses with plant health and productivity and to devise strategies how genetics and beneficial microbes can be used to mitigate adverse effects of pollution, nutrient deprivation and climate stress. It is organised in a department structure with J. Durner being the head. Currently the HMGU is composed of 40 independent scientific institutes and research units and employs approximately 2000 people of 50 different nationalities.

4.1.4.5.2 Excellence

The Institute of Biochemical Plant Pathology has a great expertise in climate change impact on crops. Environmental Simulation allows for highly sophisticated climate controlled chambers and a greenhouse environment. Recent installations of unique plant phenotyping facilities to monitor the effects of abiotic stress with or without biotic interactors will further expand the competence in selecting plants for the future. The institute Plant Genomes and Systems Biology has been involved in the development and implementation of plant genome oriented bioinformatics since the inception of the field. The research focus is on evolutionary aspects in plant breeding for highly relevant crop species, which are dissected in world-leading manner using big data management and bioinformatics. The basis for speed breeding is developed via the in-depth analysis of highly complex genomes, such as barley or wheat in international collaborations. The expertise of both institutes combined allows the assessment of future challenges in plant breeding such as climate change.

4.1.4.5.3 Personnel

Klaus Mayer (M) is the Head of the Plant Genome and Systems Biology research group; Helmholtz Center Munich (since 2014). Before, the was the Head of the Plant Genome Analysis research group; Helmholtz Center

Munich (2003-2014) and Head of the Genome Analysis of Plant Systems research group; Helmholtz Center Munich and Max Planck Institute for Biochemistry, Martinsried (1999-2003). He was a Postdoctoral research fellow; Max Planck Institute for Biochemistry, Martinsried (1997-1999) and did his Doctorate for his work on plant developmental biology, University of Tübingen (1994-1997). His key expertise include applied bioinformatics, plant genomics, molecular- and systems biology.

Selected publications:

- Pfeifer, M. et al., Analysis of the bread wheat grain transcriptome reveals complex genome interplay in a hexaploid cereal. Science 345 (6194), 1250091 (2014)
- Wang, M. et al., The genome sequence of African rice (Oryza glaberrima) and evidence for independent domestication. Nature Genetics 46(9), 982-988. (2014)
- Brenchley, R. et al., Analysis of the bread wheat genome using whole genome shotgun sequencing. Nature 491, 705-710 (2012)

Jörg Durner (M) holds the Chair of Biochemical Plant Pathology (Center of Life and Food Sciences, Weihenstephan) and is the director of the institute of the same name at Helmholtz Zentrum München. He furthermore is the head of the Department of Environmental Sciences at the Helmholtz Zentrum München. After studying biology and completing his doctorate at the University of Konstanz, Prof. Durner was a research associate at the Waksman Institute of Rutgers University (NJ, USA) from 1994 to 1998. He qualified as a lecturer in physiology and biochemistry of plants at the University of Konstanz in 1999. Prof. Durner is an environmental researcher at the Helmholtz Association's research center in Munich. Key expertise: natural defense mechanisms and the growth and health of plants in response to environmental cues. The focus of the research is on understanding the molecular mechanisms of signal transduction cascades, especially redox signals like nitric oxide (NO). In recent years, the interest in allergies caused by plants and in phenotyping agriculturally relevant crop species with state-of-the-art technology.

Selected publications:

- Bourdais et al., Large-scale phenomics identifies primary and fine-tuning roles for CRKs in responses related to oxidative stress. PLoS Genet. 11:e1005373 (2015)
- Gaupels, F. et al., Systemic induction of NO-, redox-, and cGMP signaling in the pumpkin extrafascicular phloem upon local leaf wounding. Front. Plant Sci. 7:154 (2016)
- Zhao, F. et al., Pollen of common ragweed (*Ambrosia artemisiifolia L.*): Illumina-based de novo sequencing and differential transcript expression upon elevated NO_2/O_3. Environ. Pollut. 224, 503-514 (2017)
- Georgii, E. et al., Relationships between drought, heat and air humidity responses revealed by transcriptome-metabolome co-analysis, BMC Plant Biol. 17:120 (2017)

4.1.4.6 Geesthacht Zentrum für Material- und Küstenforschung

4.1.4.6.1 Brief description of organisation

The Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH (HZG) is one of 18 members of the Helmholtz Association of German Research Centres. HZG is in Geesthacht near Hamburg with branches in Teltow near Berlin and in Hamburg, with a total staff of approximately 950 employees, including more than 650 scientists, engineers and technicians. The main HZG research areas cover materials science with foci on advanced engineering materials, research with neutrons and synchrotron radiation and regenerative medicine, as well as environmental research focussing on marine, coastal and polar systems including climate services; all these are closely embedded in research fields of the Helmholtz Association. The national federal and states governments provide about 78% of HZG's annual budget (118 million Euro in 2016), while 22% are generated via additional income such as EU and national research projects, contract research, and licensing of HZG patents for products and processes. High-level training and education for e.g. students, PhD-students, and post-docs play an important role at HZG and are provided by numerous of its institute and department leaders, several of which being part-time affiliated to universities. HZG has gained experience for years and has cultivated a successful tradition in both the co-ordination of and participation in different types of EU projects. Since the year 2000, researchers at HZG have coordinated some 45, and have participated in more than 150 EU projects co-financed by the European Commission, mainly through FP5, FP6, FP7 and Horizon 2020 framework programs.

4.1.4.6.2 Excellence

HZG provides key expertise in the field of hydrodynamic-, biogeochemical- and biological modelling at high spatial and temporal resolution. We furthermore develop and apply multi-compartment pollutant models. Our modelling expertise cover atmosphere, coastal ocean and estuaries with a particular focus on coupled systems and multi-compartments. Information needs are central for many actors in the context of climate change. The HZG scientific organizational entity GERICS (Climate Service Center Germany) develops and operates climate services at the interface between society and science. The main objective is to enable decision makers to better cope with the impacts, risks, and opportunities expected from climate change, and to establish links between the science community and societal actors involved. The current priority sectors are water, energy, ecosystems, and the cross-sectoral field of urban areas.

4.1.4.6.3 Personnel

Daniela Jacob (F) is director of GERICS, HZG and visiting professor at Leuphana University, Faculty of Sustainability, Lüneburg, Germany. Her main research fields and areas of interest are regional climate modelling and the hydrological cycle. She was one of the leading authors of the IPCC AR 5 (WG II). Currently, she is one of the coordinating lead authors of the IPCC Special Report on the impacts of global warming of 1.5°C. Daniela Jacob is member of several committees, Ex-officio member of the 'Earth League', an international alliance of prominent scientists from world class research institutions and Editor-in-Chief of Journal "Climate Services", a new scientific Journal she co-founded with Elsevier.

Selected publications:

- **Jacob**, D.; Kotova, L.; Teichmann, C.; Sobolowski, S.P.; Vautard, R.; Donnelly, C.; Koutroulis, A.G.; Grillakis, M.G.; Tsanis, I.K.; Damm, A.; Sakalli, A.; Vliet, M.T.H.van: Climate impacts in Europe under +1.5°C global warming. In: Earth's Future [Online Ressource]. Vol. 6 (2018) 2, 264 - 285. (DOI: /10.1002/2017EF000710)
- Sieck, K., **Jacob**, D. (2016): Influence of the Boundary Forcing on the Internal Variability of a Regional Climate Model. AJCC 5, 373-382
- **Jacob**, D. et al. EURO-CORDEX (2014): New high-resolution climate change projections for European impact research. Reg Environ Change 14, 563-578
- **Jacob**, D. et al. (2012): Assessing the Transferability of the Regional Climate Model REMO to Different Coordinated Regional Climate Downscaling Experiment (CORDEX) Regions. Atmosphere 3,181-199

Corinna Schrum (F) is director of the Institute of Coastal Research, HZG and professor in system analysis and modelling at University of Hamburg, Germany. Schrum´s primary research during the past 25 years focused on the understanding, observing and modeling the functioning of regional marine systems and their coupled interactions with atmosphere and marine biosphere. Prof. Schrum is actively contributing to international working group (ICES, SCOR) and has led and coordinated many national and international research projects during the past decades.

Selected publications:

- Chust G, Allen J, Bopp L, **Schrum** C, et al. (2014) Biomass changes and trophic amplification of plankton in a warmer ocean. Global Change Biology 20(7), 2124–2139.
- Daewel, U and **Schrum**, C, (2013). Simulating long-term dynamics of the coupled North and Baltic Sea ecosystem with ECOSMO II: model description and validation. Journal of Marine Systems. http://dx.doi.org/10.1016/j.marsys.2013.03.008.
- Daewel, U. and **Schrum**, C. (2017). Low frequency variability in North Sea and Baltic Sea identified through simulations with the 3-d coupled physical-biogeochemical model ECOSMO, Earth Syst. Dynam., doi:10.5194/esd-2017-36, 2017.
- **Schrum**, C, Lowe, J, Meier, M., Iris Grabeman, Jason Holt, Moritz Mathis, Thomas Pohlmann, Morten Skogen, Andreas Sterl, Sarah Wakelin. Projected Change - North Sea and interface regions. Chapter 6, NOSCCA- North Sea Climate Change Assessment, Ed. M. Quante & F. Colijn, 175-217, Springer **http://link.springer.com/chapter/10.1007/978-3-319-39745-0_6** .
- Jason Holt, Corinna **Schrum**, Heather Cannaby, Ute Daewel, Icarus Allen, Yuri Artioli, Laurent Bopp, Momme Butenschon, Bettina Fach, James Harle, Dhanya Pushpadas, Baris Salihoglu, Sarah Wakelin (2016). Potential impacts of climate change on the primary production of regional seas: a comparative analysis of five European seas. Progress in Oceanography 140. 91-115. **10.1016/j.pocean.2015.11.004**

Ralf Weisse (M) is a senior research scientist and head of the Coastal Climate Department at HZG. His research interests comprise all aspects of marine climate and marine climate change and variability, in particular wind storms, wind generated waves, storm surges and regional mean sea level. He is a member of the Baltic Earth Science Steering Group where he coordinates a working group on Understanding Sea Level Dynamics in the Baltic Sea Region. He currently coordinates the research project EXTREMENESS (Extreme North Sea Storm Surges and Their Consequences).

Selected publications:

- **Weisse**, R., Weidemann, H. 2017: Baltic Sea extreme sea levels 1948-2011: Contributions from atmospheric forcing. Procedia IUTAM, 25, 65-69, doi: 10.1016/j.piutam.2017.09.010.
- Feser, F., Barcikowska, M., Krueger, O., Schenk, F., **Weisse**, R., Xia, L. 2015: Storminess over the North Atlantic and northwestern Europe - A review. Q.J.R. Meteorol. Soc, 141, 350-382, doi: 10.1002/qj.2364.
- Grabemann, I., Groll, N., Möller, J., **Weisse**, R. 2015: Climate change impact on North Sea wave conditions. A consistent analysis of ten projections. Ocean Dynamics, 65, 255-267, doi: 10.1007/s10236-014-0800-z.
- **Weisse**, R., Bellafiore, D., Menéndez, M., Méndez, F., Nicholls, R.J., Umgiesser, G., Willems, P. 2014: Changing extreme sea levels along European coasts. Coastal Engineering, 87, 4-14, doi: 10.1016/j.coastaleng.2013.10.017.
- **Weisse**, R., von Storch, H. 2010: Marine Climate and Climate Change. Berlin, Heidelberg: Springer Berlin Heidelberg, doi: 10.1007/978-3-540-68491-6

4.1.4.7 Karlsruhe Institute of Technology (KIT)

4.1.4.7.1 Brief description of organisation

Karlsruhe Institute of Technology (KIT) creates and imparts knowledge for society and the environment. From fundamental research to application, it excels in a broad range of disciplines, and makes significant contributions to the global challenges of humankind in the fields of energy, mobility, and information. With about 9,300 employees, and 26,000 students, KIT offers research-based study programs to prepare its students for responsible positions in

society, industry, and science. Its innovation efforts build a bridge between important scientific findings and their application for the benefit of society, economic prosperity, and the preservation of our natural foundations of life. Having positioned itself as The Research University in the Helmholtz Association, KIT has made its objective to harness its potential and synergies at the national and international level for excellent research, teaching, and innovation. The direction for the future development of KIT is laid down in the KIT 2025 Umbrella Strategy, issued in 2015. KIT combines the potential and assets of a university and of a national research center. The nationwide unique institution was founded in 2009 following the institutional strategy within the Excellence Initiative by merging its long-established and well-respected precursor institutions, i.e. the University of Karlsruhe and the Karlsruhe Research Center. The former was a state institution and the latter was a national, mostly federal institution; hence the making of KIT represented a pioneering step in Germany's scientific landscape. Originating from one of the oldest Polytechnical Schools (founded in 1825), the University of Karlsruhe developed into a modern location of research, education, and innovation. The Karlsruhe Research Center was founded in 1956 as a Nuclear Reactor Construction and Operation Company; during the 1990´s it was transformed into a multidisciplinary large-scale research center of the Helmholtz Association.

4.1.4.7.2 Excellence

KIT addresses the improvement of regional and global projections of climate, water availability and climate effects on the biosphere, the forecast of extreme weather events, air quality, as well as the evolution of the ozone layer. In collaboration with national and international partners, KIT investigates questions of immediate relevance to society in the context of increasing demands for risk assessment related to climate and atmospheric change. Central research themes include (i) clouds and weather research (interactions between aerosols/clouds and weather or climate), (ii) land surface processes in the climate system (interaction and feedback between soil, vegetation, the atmosphere, and land use change), (iii) tropospheric trace substances and regulating chemical processes (dynamics and long-term trends), (iv) composition and dynamics of the upper troposphere and middle atmosphere (chemical and physical processes crucial for the climate system). This research combines observational and modelling approaches from regional to global scales.

4.1.4.7.3 Personnel

Christoph Kottmeier (M) is a senior research scientist and head of the Department Tropospheric Research at the Institute of Meteorology and Climate Research of KIT. His research interests comprise Atmospheric physics, meteorology, dynamics and turbulence, regional modelling as well as observational techniques. He is a member of Center for Disaster Management and Risk Reduction Technology at KIT.

Selected publications:

- **Kottmeier, C.** et al. (2016): New perspectives on interdisciplinary Earth science at the Dead Sea: The DESERVE project, Science of the Total Environment 544, 1045-1058. DOI: 10.1016/j.scitotenv.2015.12.003
- Drobinski, P. et al. (2014): HyMeX: A 10-year multidisciplinary program on the mediterranean water cycle, Bulletin of the American Meteorological Society 95, 1063-1082. DOI: 10.1175/BAMS-D-12-00242.1
- Marotzke, J. et al. (2016): MiKlip: A National Research Project on Decadal Climate Prediction, Bulletin of the American Meteorological Society 97 (12), 2379-2394. DOI: 10.1175/BAMS-D-15-00184.1
- Kalthoff, N. et al. (2013): KITcube - A mobile observation platform for convection studies deployed during HyMeX, Meteorologische Zeitschrift 22 (6), 633-647. DOI 10.1127/0941-2948/2013/0542
- Weimer, M. et al. (2016): A new estimator of heat periods for decadal climate predictions - A complex network approach, Nonlinear processes in geophysics 23 (4), 307-317. DOI: 10.5194/npg-23-307-2016

Johannes Orphal (M) is head of the Department of Atmospheric Trace Substances and Remote-Sensing at the Institute of Meteorology and Climate Research, KIT. His recent research topics comprise Atmospheric remote senisng, optical technologies, meteorology, high-resolution molecular spectroscopy. Since 2012 he is Scientific Spokesman of the Programme "Atmosphere and Climate", funded by the Helmholtz Association of National Research Centers HGF (Germany).

Selected publications:

- **Orphal, J.** et al. (2016): Absorption cross-sections of ozone in the ultraviolet and visible spectral regions - Status report 2015, Journal of Molecular Spectroscopy 327, 105-121
- Butz, A. et al. (2015): Geostationary Emission Explorer for Europe (G3E): mission concept and initial performance assessment, Atmospheric Measurement Techniques 8, 4719-4734
- Riese, M. et al. (2014): Gimballed Limb Observer for Radiance Imaging of the Atmosphere (GLORIA): scientific objectives, Atmospheric Measurement Techniques 7, 1915-1928
- Hache, E. et al. (2014): The added value of a geostationary thermal infrared and visible instrument to monitor ozone for air quality, Atmospheric Measurement Techniques 7, 2185-2201
- Rothman, L.S. et al. (2013): The HITRAN 2012 molecular spectroscopic database, journal of Quantitative Spectroscopy and Radiative Transfer 130, 4-50

Hans Peter Schmid (M) is head of Institute of Meteorology and Climate Research - Atmospheric Environmental Research where he leads the research group *"Biosphere-Atmosphere Exchange Processes over Complex Terrain"*.

His research focus lies on biosphere-atmosphere exchange over fragmented landscapes (observation and modelling).

Selected publications:

- Wolf, B. et al. (2016): The ScaleX campaign: scale-crossing land-surface and boundary layer processes in the TERENO-preAlpine observatory (in press), In: Bulletin of the American Meteorological Society. DOI: 10.1175/BAMS-D-15-00277.1
- Zeeman et al. (2017): Reduced snow cover affects productivity of upland temperate grasslands, Agricultural and Forest Meteorology 232, 514-526. DOI: 10.1016/j.agrformet.2016.09.002
- Hommeltenberg, J. et al. (2014): Can a bog drained for forestry be a stronger carbon sink than a natural bog forest?, Biogeosciences 11 (13), 3477-3493. DOI: 10.5194/bg-11-3477-2014
- Keenan, T.F. et al. (2014): Net carbon uptake has increased through warming-induced changes in temperate forest phenology, Nature Climate Change 4 (7), 598-604. DOI: 10.1038/nclimate2253
- Keenan, T.F. et al. (2013): Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise, Nature 499 (7458), 324-327. DOI: 10.1038/nature12291

4.1.4.8 Helmholtz Centre for Environmental Research

4.1.4.8.1 Brief description of organisation

The Helmholtz Centre for Environmental Research (UFZ), Germany, was established in 1991 as the first and only centre in the Helmholtz Association of National Research Centres to be exclusively devoted to environmental research in a great variety of fields. It currently employs around 1,100 people. Founded in response to the severe pollution prevailing in Central Germany, the UFZ has become a world-wide acknowledged centre of expertise in the remediation and re-naturation of contaminated landscapes, as well as the preservation of biodiversity and natural landscapes. Today, the UFZ is one of the world's leading research centres in the field of environmental research, enjoying high social recognition. It demonstrates ways in which a sustainable use of our natural resource base is possible for the benefit of both humankind and the environment. The UFZ has extensive competences in integrated environmental research as the disciplinary borders between the natural-, engineering- and social sciences need to be overcome in dealing with complex environmental issues. It boasts innovative scientific infrastructures and nurtures indispensable national and international cooperation, enabling problem solving at the highest level. As a reliable partner, the UFZ supports the political arena, the economy and the public to better understand the consequences of human actions on the environment and to develop options for social decision-making processes. UFZ is and was participating in 91 Projects funded within FP7 and Horizon 2020, 33 of them coordinated by UFZ (collaborative and individual projects). UFZ is or was the host for 3 ERC grants, 2 Starting Grants and 1 Advanced Grant, and has coordinated 3 ITNs. Since 2014 the UFZ is leading the European Topic Centre on Inland, coastal and marine waters funded by the European Environment Agency (EEA).

4.1.4.8.2 Excellence

The UFZ has more than 15 years of experience in the development of "so-called" smart models with a focus on terrestrial hydro systems, biodiversity and ecosystem functions as well as complex geosystems. The UFZ has extensive experience in the theoretical conceptualisation, the mathematical formulation, the numerical coding, the professional software development and maintenance, the operation of multi-site international user-groups as well as the dissemination of the results in these fields. Numerous high-level publications (see below) proof the high scientific quality of the work carried out.

4.1.4.8.3 Personnel

Sabine Ettinger (F) is the head of strategic Research Unit "Smart Models & Monitoring". Research interests include multiplicity of interacting change processes on different scales; developing predictive regional models for water-, energy- and material flows, biodiversity or eco- system functions; smart model driven monitoring and data science. As head of the department of Computational Hydrosystems she is working on development, validation and integration of hydrologic models; improved predictability of smart hydrologic models; data assimilation into hydrologic and land surface models and subsurface hydrology. Other research interests and expertise are: design and creation of geographically distributed multiscale terrestrial systems models; modelling flow and transport processes in surface- and subsurface hydrology; multiscale and stochastic modelling; scaling water and matter fluxes from pore scales to mesoscales (complexity reduction) and geostatistics, parameter uncertainty and estimation.

Selected publications:

- Baroni, G., Zink, M., Kumar, R., Samaniego, L., **Attinger, S**., (2017): Effects of uncertainty in soil properties on simulated hydrological states and fluxes at different spatio-temporal scales, Hydrol. Earth Syst. Sci. 21 (5), 2301 – 2320
- Heße, F., Zink, M., Kumar, R., Samaniego, L., **Attinger, S.**, (2017): Spatially distributed characterization of soil-moisture dynamics using travel-time distributions, *Hydrol. Earth Syst. Sci.***21** (1), 549 – 570
- Samaniego, L., Kumar, R., Thober, S., Rakovec, O., Zink, M., Wanders, N., Eisner, S., Müller Schmied, H., Sutanudjaja, E.H., Warrach-Sagi, K., **Attinger, S**., (2017): Toward seamless hydrologic predictions across spatial scales Hydrol. Earth Syst. Sci. 21 (9), 4323 - 4346

- Rakovec, O., Kumar, R., **Attinger, S.**, Samaniego, L., (2016): Improving the realism of hydrologic model functioning through multivariate parameter estimation *Water Resour. Res.***52** (10), 7779 – 7792
- Kumar, R., Musuuza, J.L., Van Loon, A.F., Teuling, A.J., Barthel, R., Ten Broek, J., Mai, J., Samaniego, L., **Attinger, S.**, (2015): Multiscale evaluation of the Standardized Precipitation Index as a groundwater drought indicator, *Hydrol. Earth Syst. Sci. Diss.***12** (8), 7405 – 7436

Luis Eduardo Samaniego-Eguiguren (M) is the deputy Head, Department Computational Hydrosystems and works with the administration and strategic planning for the department. He is involved in scientific project coordination and writing project proposals (e.g., H2020, Belmont Forum); PI in the Water Scarcity Integrated project (UFZ). Development of an impact assessment model chain for semi-arid regions in Europe and Latin-America; PI in Cosmic Ray Probe verification (TERENO observatories, Germany); PI in the Helmholtz Earth Dynamics Alliance (Soil moisture assimilation). He is the chief developer of the hydrologic model (mHM) and a work package lead in the Coperncius-project EDgE. His main research interest is in hydrologic modelling (development of mHM, www.ufz.de/mhm) which includes development of a robust multiscale parameterization scheme for mHM, development of soil moisture droughts, land surface model parameterization and multisite weather generators. Other research interests are: land-vegetation-atmospheric interactions, modelling and forecasting of droughts and floods, multiscale parameterization of land surface and hydrologic models, parameter estimation and uncertainty analysis, assimilation of remotely sensed products into mHM, stochastic hydrology, precipitation downscaling, and geostatistics.

Selected publications:

- **Samaniego, L.**, Thober, S., Kumar, R., Wanders, N., Rakovec, O., Pan, M., Zink, M., Sheffield, J., Wood, E.F., Marx, A., (2018): Anthropogenic warming exacerbates European soil moisture droughts, *Nat. Clim. Chang.***8** (5), 421 – 426
- **Samaniego, L.,** Kumar, R., Breuer, L., Chamorro, A., Flörke, M., Pechlivanidis, I.G., Schäfer, D., Shah, H., Vetter, T., Wortmann, M., Zeng, X., (2017): Propagation of forcing and model uncertainties on to hydrological drought characteristics in a multi-model century-long experiment in large river basins. Clim. Change 141 (3), 435 – 449
- **Samaniego, L**., Kumar, R., Thober, S., Rakovec, O., Zink, M., Wanders, N., Eisner, S., Müller Schmied, H., Sutanudjaja, E.H., Warrach-Sagi, K., Attinger, S., (2017): Toward seamless hydrologic predictions across spatial scales Hydrol. Earth Syst. Sci. 21 (9), 4323 - 4346
- Rakovec, O., Kumar, R., Mai, J., Cuntz, M., Thober, S., Zink, M., Attinger, S., Schäfer, D., Schrön, M., **Samaniego, L.,** (2016): Multiscale and multivariate evaluation of water fluxes and states over European river basins J. Hydrometeorol. 17 (1), 287 – 307
- Thober, S., Kumar, R., Sheffield, J., Mai, J., Schäfer, D., **Samaniego, L.**, (2015): Seasonal soil moisture drought prediction over Europe using the North American Multi-Model Ensemble (NMME). *J. Hydrometeorol.***16** (6), 2329 - 23

Andreas Marx (M) is the head of the Climate Office for Central Germany. He is working on: science-policy interface and is since 2009 Member of the Working Group "Climate Change" at the Ministry of Farming and Environment in Saxony-Anhalt which leads the Development and Update of the Adaptation Strategy for Saxony-Anhalt. He is a topic speaker to the Helmholtz Climate Initiative REKLIM (Regional climate change) for TP4 “The Land Surface in the Climate System”. He was the project Manager for Task “Climate Change Indicators’ 2011-2018 in the European Environmental Agency ETC/CCA (European Topic Centre on Climate Change, Impacts, Vulnerability and Adaptation). He is a partner in the Helmholtz Regional Climate Offices Network and works with the German Drought Monitor (online information platform, www.ufz.de/droughtmonitor). His research interests include: regional climate change, impact analysis, and adaptation; science-policy interface; hydrological modelling; NWP and flood forecasting and precipitation fields and radar rainfall estimation.

Selected publications:

- L. Samaniego, S. Thober, R. Kumar, N. Wanders, O. Rakovec, M. Pan, M. Zink, J. Sheffield, E. F. Wood, and **A. Marx** (2018): Anthropogenic warming exacerbates European soil moisture droughts. Nature Climate Change, accepted, DOI: 10.1038/s41558-018-0138-5
- **Marx, A**., Kumar, R., Thober, S., Zink, M., Wanders, N., Wood, E. F., Ming, P., Sheffield, J., and Samaniego, L. (2018): Climate change alters low flows in Europe under a global warming of 1.5, 2, and 3 degrees, Hydrol. Earth Syst. Sci., 22, 1017-1032, https://doi.org/10.5194/hess-2017-485
- Thober, S., Kumar, R., Wanders, N., **Marx, A**., Pan, M., Rakovec, O., Samaniego, L., Sheffield, J., Wood, E. F., and Zink, M. (2018): Multi-model ensemble projections of European river floods and high flows at 1.5, 2, and 3 degree global warming, Environmental Research Letters, 13(1), pp. 1–22, https://doi.org/10.1088/1748-9326/aa9e35.
- Füssel, H. M., Jol, A., **Marx, A**., Hilden, M. (edts., 2017): Climate change, impacts and vulnerability in Europe 2016. EEA Report 01/2017. online available under http://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016
- Zink M , Samaniego L, Kumar R, Thober S, Mai J, Schaefer D and **Marx A** (2016) The German drought monitor, Environmental Research Letters, accepted: 08 June 2016

4.1.5 Eidgenössische Technische Hochschule Zürich

4.1.5.1 Brief description of organisation

Eidgenössische Technische Hochschule Zürich (ETHZ) is an institution of the Swiss Confederation dedicated to higher learning and research with core areas being engineering, natural sciences, architecture and mathematics.

Together with EPFL and four research institutes, it forms the federally directed ETH domain. Founded in 1855, ETH Zurich today has over 20'000 students from over 120 countries, including 4'000 doctoral students and 530 professors. ETH Zurich appears at the top of international rankings as one of the best universities in the world (7th in QS ranking 2018, 1st in Earth & Marine Sciences for 2015-2018).

4.1.5.2 Excellence

The results and innovations produced by ETH researchers are channeled into some of Switzerland's most high-tech sectors: from computer science, through to micro- and nanotechnology and cutting-edge medicine. Every year ETH registers around 90 patents and 200 inventions. Since 1996, the university has produced a total of 382 commercial spin-offs. ETH also has an excellent reputation in scientific circles, with 21 Nobel laureates having studied, taught or researched at ETH. In earth and marine sciences, ETH Zurich holds the first position in the QS World University Rankings for several years now, including 2018. ETH professorships involved in the ExtremeEarth-PP are in Seismology and Geodynamics, Atmospheric Physics, Weather and Climate Risks, and Computational Physics. ETH also operates the Swiss National Supercomputing Center of relevance to this proposal.

4.1.5.3 Personnel

Domenico Giardini (M) is Professor of Seismology and Geodynamics at ETH Zurich since 1997. He obtained his doctorate in 1987 from the University of Bologna, and was postdoctoral fellow at Harvard University, researcher at the National Institute of Geophysics in Rome and Associate Professor of Seismology at the University of Rome III. He was the Director of the Swiss Seismological Service until 2011 and President of the Italian National Institute of Geophysics and Volcanology (2011-2012). He was director of the European Seismological Commission (ESC), Chairman of the International Federation of Digital Seismic Networks and President of the International Association of Seismology and Physics of the Earth's Interior (IASPEI). He chaired the Seismic Risk Section of the Italian High Risks Commission and was a member of the Nuclear Earthquake Safety Review Commission of Switzerland. He leads the Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE). He has extensive experience in coordinating large European projects (SHARE, NERIES, STREST, NERA, SERA) and was the initiator of the ESFRI EPOS (European Plate Observing System) infrastructure. He leads the Swiss participation in the ESA LISA mission (Laser Interferometer Space Antenna) and NASA InSight mission to Mars. His research spanned deep earthquakes, earth free oscillations, structure of the earth's mantle and core, source inversion, waveform modelling in complex media, seismic hazard and risk assessment, planetary seismology, induced seismicity and geo-energies.

Selected publications:

- D. **Giardini**, L. Danciu, M. Erdik, K. Şeşetyan, M. B. Demircioğlu, S. Akkar, L. Gülen & M. Zare, Seismic hazard map of the Middle East, *Bull. Earthquake Engineering*, 16: 3567, https://doi.org/10.1007/s10518-018-0347-3, 2018.
- Mignan, A., Danciu, L. & **Giardini**, Considering large earthquake clustering in seismic risk analysis, *D. Nat Hazards*, 91(Suppl 1): 149. https://doi.org/10.1007/s11069-016-2549-9, 2018.
- P. Galvez, L. Dalguer, J.P. Ampuero and D. **Giardini**: Rupture Reactivation during the 2011 M-w 9.0 Tohoku Earthquake: Dynamic Rupture and Ground-Motion Simulations. *Bull. Seismol. Soc. America*, 106, 819-831, https://doi.org/10.1785/0120150153, 2016.
- D. **Giardini**, J. Wössner & L. Danciu, Mapping Europe's seismic hazard, *EOS Transactions*, 95, 261-262,https://doi.org/10.1002/2014EO290001, 2014.
- D. Giardini, Geothermal quake risks must be faced, Opinion, *Nature*, 462, 848-849, https://doi.org/10.1038/462848a, 2009.

Thomas Schulthess (M) is Professor of Computational Physics at ETH Zurich and Director of the Swiss National Supercomputing Center (CSC) since 2008. He studied physics at ETH Zurich and earned his doctorate in 1994 with a thesis on surface physics, in which he combined experiment and supercomputing-based simulations. He subsequently continued his research in the USA, working on the DARPA-funded spintronics project and spending more than 10 years at Oak Ridge National Laboratory (ORNL), from where he returned to Switzerland in 2008. Thomas led the teams that won the ACM Gordon Bell Prizes in 2008 and 2009 with the first production-level applications sustaining a petaflop on ORNL's first peta-scale supercomputers. In the past 10 years, as director of CSCS that hosts the operational weather forecasting systems of MeteoSwiss, Thomas took interest in developing software systems for weather and climate simulations, as wells a design of computing systems for numerical weather prediction. Under his leadership, CSCS was the first center in Europe that deployed a productive GPU-accelerated supercomputing system in 2013, and co-designed with Cray, NVIDIA and MeteoSwiss the first GPU-based weather forecasting system that has been deployed in 2015, and since spring 2016 is running MeteoSwiss' new COSMO-NEXT model at 1km horizontal resolution. For this work CSCS and MeteoSwiss received the 2016 Swiss ICT Award for Outstanding IT-Based Projects and Services.

Selected publications:

- Fuhrer, O.; Osuna, C.; Lapillonne, X.; Gysi, T.; Cumming, B.; Bianco, M.; Arteaga, A.; **Schulthess, T. C.**; *Towards a performance portable, architecture agnostic implementation strategy for weather and climate models*, Supercomputing Frontiers and Innovations, **1**, no. 1, 2014 (see superfri.org).
- **Schulthess, T. C.**; *Programming revisited*, Nature Physics, **11**, 369-373, 2015.

- Gysi, T; Osuna, C.; Fuhrer, O.; Bianco, M.; and **Schulthess, T. C.**; *STELLA: a domain-specific tool for structured grid methods in weather and climate models*, Proceedings of the 2015 ACM/IEEE International Conference on High Performance Computing, Networking, Storage and Analysis, 41, 2015.
- Martinasso, M., Kwasniewski, G., Alam, S. R., **Schulthess, T. C.**, Hoefler, T.; A PCIe congestion-aware performance model for densely populated accelerator servers; Proceedings of the 2016 ACM/IEEE International Conference for High Performance Computing, Networking, Storage and Analysis, 1-10, 2016.
- Fuhrer, O.; Chadha, T.; Hoefler, T; Kwasniewski, G.; Lapillonne, X.; Leutwyler, D.; Lüthi, D.; Osuna, C.; Schär, C.; **Schulthess, T. C.**; and Vogt, H.; *Near-global climate simulation at 1 km resolution: establishing a performance baseline on 4888 GPUs with COSMO 5.0*, Geosci. Model Dev., 11, 1665-1681, 2018. https://doi.org/10.5194/gmd-11-1665-2018.

Ulrike Lohmann (F) is Professor of Atmospheric Physics at ETH Zurich since 2004. She obtained her PhD in climate modeling from the Max Planck Institute for Meteorology in Hamburg, Germany in 1996 and did her post-doctoral research at the Canadian Centre for Climate Modelling and Analysis before moving to Dalhousie University in Halifax, Nova Scotia as an Assistant and Associate Professor in 1997. She was a lead author for the Fourth and Fifth Assessment Reports of the Intergovernmental Panel for Climate Change (IPCC). She was awarded the Canada Research Chair in 2002, the AMS Henry G. Houghton Award in 2007, is a fellow of the American Geophysical Union and the German Academy of Sciences Leopoldina and will become an honorary doctorate of Stockholm University in September 2018. Her research focuses on the role of aerosol particles and clouds in the climate system with focus on clouds containing ice and aerosol radiative forcing. She combines laboratory work, field measurements, satellite data and numerically modelling. Relevant to this proposal is her work on the simulation of weather extremes in the form of tropical cyclones which require high resolution climate models as well as her work on climate engineering with its possible side effects.

Selected publications:

- Kübbeler, M., U. **Lohmann** and J. Feichter, Effects of stratospheric sulfate aerosol geo-engineering on cirrus clouds, Geophys. Res. Lett., 39, L23803, doi.org/10.1029/2012GL053797, 2012.
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- Gasparini, B., Münch, S., Poncet, L., Feldmann, M., and **Lohmann**, U., Is increasing ice crystal sedimentation velocity in geoengineering simulations a good proxy for cirrus cloud seeding?, Atmos. Chem. Phys., 17, 4871-4885, doi.org/10.5194/acp-17-4871-2017, 2017.
- **Lohmann**, U. and B. Gasparini, A cirrus cloud climate dial?, Science 357, 248-249, doi.org/10.1126/science.aan3325, 2017.

David N. Bresch (M) is Professor for Weather and Climate Risks at ETH Zürich and MeteoSwiss since 2016. He obtained his PhD in physics from ETH Zurich, Switzerland. Between 2000 and 2016, his roles were at Swiss Re including Head Business Development, Global Head Sustainability, Head Atmospheric Perils Group and as Chief modeler for natural catastrophe risk assessment. In 1998-1999 he was Research Associate at Massachusetts Institute of Technology, MIT, Cambridge, USA. He is Member of the Swiss UNFCCC delegation (2009-2012 and 2015), member of the Private Sector Advisory Group (PSAG) of the UN Green Climate Fund (GCF) (2014-2016). His research focuses on the impacts of weather and climate on socio-economic systems. Combining numerical (open-source) modelling of weather and climate risks with the engagement of decision makers and end-users, his research aims to explore ways to strengthen their resilience and create a shared understanding of their weather and climate susceptibility. Such an integrated view along the chain of impacts also opens new perspectives and approaches to the treatment of uncertainty in decision-making. He has conducted many case studies across the globe, applying a worldwide consistent, yet locally specific methodology to strengthen climate resilience while integrating adaptation with economic development and sustainable growth.

Selected publications:

- Zscheischler, J., Westra, S., van den Hurk, B., Ward, P. J., Pitman, A., AghaKouchak, A., **Bresch**, D. N., Leonard, M., Wahl, T., Zhang, X., Seneviratne, S., 2018: Future climate risk: The challenge of compound events. Nature Climate Change, 8, 469–477. https://doi.org/10.1038/s41558-018-0156-3.
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- Gettelman, A., **Bresch**, D. N., Chen, C. C., Truesdale, J. E., Bacmeister, J. T., 2017: Projections of future tropical cyclone damage with a high-resolution global climate model. Climatic Change, 146, 3–4, pp 575–585. https://doi.org/10.1007/s10584-017-1902-7.
- Welker, C., Martius, O., Stucki, P., **Bresch**, D. N., Dierer, S., & Brönnimann, S., 2015: Modelling economic losses of historic and present-day high-impact winter storms in Switzerland. Tellus A 2016, 68, 29546, http://dx.doi.org/10.3402/tellusa.v68.29546.
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Kauzar Saleh (F) is project manager at ETH since 2016. She received her PhD in physics from the University of Valencia and INRA-Bordeaux (2006) for her work on remote sensing of soil moisture in the frame of ESA's SMOS mission. After being research associate at the University of Cambridge, UK (2006-2010, COSPAR medal in 2008), she moved to Spain to take up a permanent position at CDTI (Ministry of Economy, 2010-2016) as national delegate to ESA and other European scientific infrastructures in the fields of physics and astronomy (ESO, FAIR,

XFEL). She is currently the manager of the H2020 INFRAIA SERA project in seismology and earthquake engineering, member of the EPOS (European Plate Observing System) project development board, as well as responsible of the elaboration of the EPOS Thematic Core Services financial framework.

Nicolas Gruber (M) has been Full Professor of Environmental Physics at the Department of Environmental Sciences at ETH Zurich since July 2006. After his Matura in 1989, he was among the first students to enter the new Environmental Sciences degree program at ETH Zurich. As part of his undergraduate studies, he spent one year at the Scripps Institution of Oceanography, La Jolla, California, where he worked with the late Charles D. Keeling, sparking his interests in the human perturbation of the global carbon cycle. After earning his diploma degree in 1993, Dr. Gruber went to the University of Bern for his Ph.D. studies, which he completed in 1997. He then worked for three years as a postdoctoral researcher at Princeton University. In 2000, he joined the Department of Atmospheric and Oceanic Sciences and the Institute of Geophysics and Planetary Physics at the University of California, Los Angeles, first as an assistant professor, and from 2005 until 2007 as a tenured associate professor. In 2006, he was appointed as a full professor at ETH Zurich. His research interests are biogeochemical cycles on regional to global scales and on timescales from months to millennia, with a focus on the interaction of these cycles with Earth's climate system. His goal is to better understand the physical, chemical and biological processes that control these cycles and to be able to make predictions for the future, especially regarding the potential feedbacks between the global carbon cycle and a changing climate. His primary research tools are the interpretation and analysis of observational data coupled with the use of models ranging in complexity from simple box models to general circulation models.

4.1.6 Centre national de la recherche scientifique

The National Centre for Scientific Research (CNRS) is a public organization under the responsibility of the French Ministry of Education and Research. CNRS encompasses all scientific domains. It is involved in ExtremeEarth-PP through the Institut Pierre-Simon Laplace (CNRS-IPSL) for climate modelling, the Institut de Physique du Globe de Paris (CNRS-IPGP) and Observatoire des Sciences de l'Univers de Grenoble (CNRS-OSUG) for observations. CNRS will link with its institutional partners from other research organisations and Universities, it will involve the Commissariat à l'Energie Atomique et aux Energies Renouveables (CEA) as a third party.

4.1.6.1 Institut Pierre Simon Laplace

4.1.6.1.1 Brief description of organisation

Institut Pierre Simon Laplace (CNRS-IPSL) is a research and training institute that brings together 9 research laboratories located in Paris area whose research topics concern climate and the global environment. The main objectives of IPSL are (i) to understand climate processes and the underlying dynamical, chemical and biological mechanisms, (ii) to understand the natural and anthropogenically-driven climate variability on a large range of space and time scales, and (iii) to apply skills and tools on the terrestrial environments to explore other planets, (iv) to quantify and understand GHG anthropogenic emissions and natural sinks based on observations and data assimilation. The IPSL laboratories have set up a range common services and major scientific projects to serve its scientific strategy through (i) a Climate Modelling Centre which develops a numerical model of the Earth system and contributes to the national CLIMERI-France climate modelling infrastructure, (ii) a computing and data centre that provides IPSL teams with easy access to computing, observational and modelling data, (iii) several observation, monitoring (e.g., stratospheric ozone, greenhouse gases, carbon fluxes in the ocean and atmosphere) and modelling (ocean and air pollution) services as well as of a ground-based instrumental site for atmospheric measurements, (iv) thematic groups (e.g. on regional climate impacts, air quality, climate services, mathematical and statistical tools in geosciences etc.). CNRS-IPSL will work in ExtremeEarth-PP in close collaboration with Maison de la Simulation (MdS) which is a joint institute between CEA, CNRS, University of Paris-Sud and University of Versailles-Saint Quentin whose aim is to support and stimulate the scientific community in order to get the best out of supercomputers. MdS develops strong synergies between engineers and researchers from various fields, necessary for the important scientific breakthroughs expected from HPC to materialize. MdS focuses on developing transverse fields (i.e. applied mathematics, computer sciences, software engineering…) that can provide new methodologies and basic building blocks for other application fields and on codes co-development with scientific communities.

4.1.6.1.2 Excellence

Within its Climate Modelling Centre, IPSL is hosting a collaborative effort to develop a comprehensive Earth's climate system model, study the natural variability of climate, its past, current and future changes, and the anthropogenic influences on it. IPSL is also strongly involved in the European ocean platform NEMO. Special emphasis has been placed on high-resolution modelling with a new highly-scalable atmospheric dynamical core (DYNAMICO), high-resolution versions of the oceanic model, and sophisticated scalable I/O servers (XIOS). IPSL collaborates with the Maison de la simulation which coordinates the Center of Excellence EoCOE. Other strengths

of CNRS-IPSL in the context of ExtremeEarth lie in the coordination of key observational networks, its multi-petascale data management capability, the convergence of data management coming from observations and models, the emergence of new machine learning and IA techniques in Earth System modelling and observations, co-design of prototype climate services to enhance the data value chain. IPSL will also bring expertise in tailoring climate information for the energy sector. CNRS-IPSL plays a key contribution to European research infrastructures collecting high accuracy atmospheric data for GHG fluxes and reactive gases / aerosols (ICOS, ACTRIS), in the COPERNICUS Atmospheric core service for GHGs and in the design of the European CO_2 Sentinel operational observing system for anthropogenic GHG emissions.

4.1.6.1.3 Personnel

Joussaume Sylvie (F), CNRS senior scientist, expert in climate modelling, has a long experience in scientific coordination as ex director of the CNRS National Institute for Earth Sciences and Astronomy, Chair of ENES Scientific Board, Coordinator of IS-ENES infrastructure projects, Member of the JPI Climate governing board. Will contribute to coordinate with the ENES community network, the ClimatEurope network and JPI Climate. Is involved in the Copernicus project CRECP to prepare a roadmap for climate projections. She will co-lead WP2 and will collaborate with other WPs.

Boucher Olivier (M), CNRS senior scientist, expert in climate modelling and director of the IPSL climate modelling centre. He has a strong experience in Earth System Modelling with a focus on biogeochemical cycles. He will contribute to the concept of the flagship in liaison with other scientists and engineers from the IPSL climate modelling centre. He will contribute to WP2 and WP4.

Robert Vautard (M), CNRS senior scientist, expert on climate extremes, attribution of climate change and services for energy. He was the coordinator of the CLIM4ENERGY C3S project on climate services for the Energy sector within Copernicus, is involved in CRECP and EUPHEME and in charge of the case study on wind power in the EUCP project. Will contribute to linking with the Energy sector and on climate extremes. He will contribute to WP2, WP4 and WP5.

Venkatramani Balaji (M), is visiting IPSL Laboratory on climate and Environment (2019-2022) as a recipient of the national fellowship “make our Planet great again” at CEA. He works at the Cooperative Institute for Modeling the Earth System (CIMES) at Princeton University, affiliated to NOAA Geophysical Fluid Dynamics Laboratory (GFDL), and has a strong expertise at the interface between climate modelling, HPC and data engineering. he will contribute to WP2, WP3, WP6 and WP8.

Meurdesoif Yann (M, engineer at CEA within the LSCE joint unit, has a strong expertise in HPC. He has developed the parallel versions of several components of the IPSL Earth system model and is responsible at IPSL for the development of IO server XIOS. He will contribute to WP3 and WP6.

Philippe Ciais (M), Senior scientist at CEA, expert on the carbon cycle with established collaboration with corporate partners and director of the national Convergence Institute CLAND (impacts and GHG mitigation in agriculture & forestry). Will contribute to linking with the ICOS research infrastructure atmospheric GHG observations and the development of high resolution tracer transport models applicable to the assimilation of in situ and satellite data for quantifying anthropogenic emissions and natural sinks in support of the Paris Agreement on Climate.He will contribute to WP2 and WP4.

Denvil Sébastien (M), senior research engineer at CNRS within the IPSL research federation. Working with and contributing to build e-infrastructure for 15+ years he has a strong expertise in HPC and HTC workflows, cloud and big data handling and storage. He is one of the CMIP & CORDEX data infrastructure principal investigator. He is coordinating and contributing COPERNICUS services in charge to deliver global and regional climate model data to the Copernicus Climate Data Store. He will contribute to WP3 and WP6.

Edouard Audit (M), senior scientist at CEA, director of the Maison de la Simulation supporting computational science and coordinator of the Energy Oriented Center of Excellence (EoCoE). he will contribute to WP3 and WP6.

Selected team publications

- **V. Balaji**, E. Maisonnave, N. Zadeh, B. N. Lawrence, J. Biercamp, U. Fladrich, G. Aloisio, R. Benson, A. Caubel, J. Durachta, M.-A. Foujols, G. Lister, S. Mocavero, S. Underwood, and G. Wright, “CPMIP: measurements of real computational performance of Earth system models in CMIP6”, Geoscientific Model Development, vol. 10, no. 1, pp. 19–34, 2017.
- **V. Balaji**, “Climate Computing: The State of Play,” Comput. Sci. Eng., vol. 17, no. 6, pp. 9–13, 2015.
- Gaitan, Carlos F., **Venkatramani Balaji**, and Berrien Moore III. "Can we obtain viable alternatives to Manning’s equation using genetic programming?." Artificial Intelligence Research 5.2 (2016): 92**.**
- **Ciais, P**., et al. (2005), Europe-wide reduction in primary productivity caused by the heat and drought in 2003, Nature, 437(7058), 529-533.
- **Ciais, P**., et al. (2013), Attributing the increase in atmospheric CO2 to emitters and absorbers, *Nature Climate Change*, *3*(10), 926-930.
- Dubos, T., Dubey, S., Tort, M., Mittal, R., **Meurdesoif, Y.,** and Hourdin, F.: DYNAMICO-1.0, an icosahedral hydrostatic dynamical core designed for consistency and versatility, Geosci. Model Dev., 8, 3131-3150, https://doi.org/10.5194/gmd-8-3131-2015, 2015.

- **Vautard R.,** F. Thais, I. Tobin, F.-M. Bréon, J.-G. Devezeaux de Lavergne, A. Colette, P. Yiou, and P. M. Ruti, 2014 : Regional climate model simulations indicate limited climatic impacts by operational and planned European wind farms, Nature Communications, doi:10.1038/ncomms4196
- Tobin, I., Greuell W., Jerez S., Ludwig F., **Vautard R.,** van Vliet M.T.H., and Bréon F.-M., 2018: Vulnerabilities and resilience of European power generation to 1.5°C, 2°C and 3°C warming, Environ. Res. Lett., 13 044024.
- Benedetti, A., J. S. Reid, A. Baklanov, S. Basart, **O. Boucher**, I. M. Brooks, M. Brooks, P. R. Colarco, E. Cievas, A. da Silva, F. Di Giuseppe, J. Escribano, J. Flemming, N. Huneeus, O. Jorba, S. Kazadzis, S. Kinne, P. Knippertz, P. Laj, J. H. Marsham, L. Menut, L. Mona, T. Popp, P. K. Quinn, S. Rémy, T.T. Sekiyama, T. Tanaka, E. Terradellas, and A. Wiedensohler, Status and future of Numerical Atmospheric Aerosol Prediction with a focus on data requirements, *Atmospheric Chemistry and Physics*, submitted, 2018.
- Asrar, G., S. Bony, **O. Boucher**, A. Busalacchi, A. Cazenave, M. Dowell, G. Flato, E. Källén, T. Nakajima, A. Ratier, R. Saunders, J. Slingo, B.-J. Sohn, J. Schmetz, B. Stevens, P. Zhang, and F. Zwiers, Climate Symposium 2014: Findings and Recommendations, *Bulletin of the American Meteorological Society*, 96, ES145-ES147, 10.1175/BAMS-D-15-00003.1, 2015.
- Wang, R., S. Tao, Y. Balkanski, P. Ciais**, O. Boucher**, J. Liu, S. Piao, H. Shen, M. R. Vuolo, M. Valari, H. Chen, Y. Chen, A. Cozic, Y. Huang, B. Li, W. Li, G. Shen, B. Wang, and Y. Zhang, Exposure to ambient black carbon derived from a new inventory and high-resolution model, *Proc. Natl. Acad. Sci.*, doi:10.1073/pnas.1318763111, 2014.
- Mitchell J, Budich R, **Joussaume** S, Lawrence B and Marotzke J (2012), "Infrastructure strategy for the European Earth System Modelling community 2012-2022", ENES Report Series 1, 33 pp. doi.org/10.5285ca90b281d6ff4cffb9a9bbdeb5fa63f3
- **Joussaume S.,** Lawrence B., Guglielmo F., Update of the ENES infrastructure strategy 2012-2022, ENES Report Series 2, 20 pp, 2017. **https://portal.enes.org/community/about-enes/the-future-of-enes/ENES_strategy_update_2017.pdf**

4.1.6.2 Institut de Physique du Globe de Paris

4.1.6.2.1 Brief description of organisation

The Institut de Physique du Globe de Paris (CNRS-IPGP) is a world-leading higher education and research institution in major fields of Earth, Planetary and Environmental Sciences, and in added applications of societal and economical interest such as the physics-based monitoring and prevention of geo-hazards and environmental changes, the exploration of new energy resources. It is associated with the CNRS and a component of the COMUE (community of universities and institutions) Paris Sorbonne Cité. The IPGP has specific missions in observation of Earth and environmental systems and geo-hazards (seismic, volcanic, environmental) monitoring with national observatories (metropolitan and overseas) and worldwide geophysics networks for which it has the responsibility in seismology, volcanology, magnetism, and environmental sciences. The IPGP, in collaboration with the Centre National d'Etudes Spatiales (CNES) and the European Space Agency (ESA), is also in charge of the conception and the scientific exploitation of spatial missions. The IPGP offers several Masters degrees and is responsible for a Doctoral school in close collaboration with the Université Paris-Diderot and the École Normale Supérieure Paris. The Institute offers also advanced course in exploration and monitoring geophysics that benefits from strong partnerships with several industrial partners (CGG Veritas, Schlumberger, Shell, Total).

4.1.6.2.2 Excellence

The flexible structure of IPGP allows front-end interdisciplinary research addressing challenging research and technological issues in the study of Earth and Planetary systems and in physics-based geo-hazards monitoring, combining multi-source observation (land, sea, space), experimentation, computational modelling, together with advanced statistical data analysis. In particular, the strength of IPGP in the context of ExtremeEarth lies in its expertise in the development of innovative data-intensive methods and services for: the statistical analysis of multi-source data; the modelling and the numerical simulation of multi-scale and multi-physics natural systems, combining high-end probabilistic data assimilation, inference and imaging methods with recent machine learning and AI techniques; the detection and the restoration of transient events (tectonic, volcanic, environmental). The Institute hosts and provide powerful federated resources and services for multi-source FAIR data archiving and curation, high-performance computing and statistical data analysis, together with next-generation experimental facilities.

4.1.6.2.3 Personnel

Michel Diament (M): Professor at IPGP, he currently leads the French national data and services centre for satellite and in-situ data for the Solid Earth (ForM@Ter). He is involved in the ESFRI project EPOS-IP. His research interests range from marine geosciences, applied geophysics, volcanology, tectonics and geodynamics. His main tool is gravimetry and microgravimetry. He has co-authored about 115 peer-reviewed publications and a geophysics textbook (h-index 30). He supervised or co-advised 28 PhD students and 6 post-docs from France, Brazil, Cameroon, Chili, India, Indonesia, Russia and Tunisia. He has been deputy director for Solid Earth and director in charge of the CNRS-INSU, member of the Earth Science Advisory Committee (ESAC) of the European Space Agency, member and chair (2015) of the IODP-ECORD Council. He has been serving or chairing a number of scientific committees in French research organizations (CNES, CNRS-INSU, IFREMER, ORSTOM/IRD...). He was also in charge of the French-Indonesian scientific cooperation program on geological risks from 1997 to 2002. He is corresponding member of the "Bureau des Longitudes".

Jean-Pierre Vilotte (M): IPGP professor, he is the scientific director of the High-Performance and Data analysis facility (S_CAPAD). He is Scientific Deputy at the French CNRS-INSU for computing and information

technology. In 2015, he was awarded Fellow of the American Geophysical Union. He has a long-established expertise in mathematical and computational geophysics, at the interface between geophysics, mathematics, statistical physics, mechanics and computational and data sciences. His research mainly focuses in geodynamics, rock mechanics, earthquake seismology and seismic source processes, high-performance wave propagation and dynamic earthquake source numerical modelling, seismic imaging, and statistical seismic signal analysis. He has advised 22 PhDs and 10 international Postdocs and authored more than 80 peer-reviewed (h-index 32) papers, including 5 Science and Nature papers. He has served in a number of national and international scientific committees (e.g. CNRS, IRD, ANR, DOE, OECD, Belmont Forum). He was the scientific PI of the FP7-Infrastructure project VERCE (2011-2015). He is involved in the ESFRI project EPOS-IP, the BDEC international initiative, the European EXDCI project and the e-Infrastructure and Data Management informative action of the Belmont Forum. He is also part of the External Advisory board of the H2020-Infrasupp project AENEAS for SKA. He will contribute in coordinating the solid Earth data and computing infrastructures and in Earthquake seismology, data-intensive statistical analysis and physics modelling. He will contribute to ExtremeEarth-PP in his capacity to accelerate the convergence between HPC, HAD and data logistics for numerical modelling, data-intensive data analytics and assimilation in earthquake seismology and solid earth sciences.

Gauthier Hulot (M): CNRS senior scientist, he is currently Deputy Director for Science and Space at IPGP. His research mainly focuses on the investigation of the main field produced within the Earth's core, and deals with the issue of converting all types of data (satellite, historical, archeo-magnetic, and paleo-magnetic data) into information about the past and present behavior of the main field, which he then interprets in terms of core dynamical processes. This has led him to develop on many different issues, such as potential theory, deterministic and statistical geomagnetic field modeling and interpretation, core surface flow modeling and interpretation, length of day variation investigation, and more recently, dynamo simulations, with special emphasis on dynamos predictability. He authored more than 96 peer-reviewed papers (h-index: 33) and book chapters. He works on many satellite projects, including the ESA Swarm project (launched on November 22, 2013), where he leads the French contribution, investigating the lithospheric and ionospheric magnetic sources. This very successful mission also demonstrated the potential of an innovative absolute vector magnetometer built by CEA-Leti that G. Hulot proposes to adopt for a nanosatellite concept (NanoMagSat) currently under phase 0+ within the CNES. He also takes an active role in teaching and promoting French and International Science through national and international committees, as well as meeting organization, most recently as Chair of the SEDI commission of IUGG and Chair of Division I of IAGA, and as a member of the executive council of the INTERMAGNET network of ground magnetic observatories, which the NanoMagSat concept aims at expanding to space. As Deputy Director of IPGP for Science and Space, he will contribute to ExtremeEarth-PP, in his capacity to plan and coordinate IPGP contributions and partnerships.

Anne Le Friant (F): 43 years old, CNRS senior scientist at IPGP, she is Deputy Director for the Observatories at IPGP. She has a strong expertise in geology, volcanology and marine geophysics. She has 20 years of experiences in volcanic island construction and destruction processes with focus on volcanic island slope instability and associated hazards (landslides and tsunamis) where she has numerical simulation experience. She developed the international IODP "lesser Antilles" drilling proposal that was implemented with great success. She was co-chief of the IODP 340 Expedition (10 M€) offshore Lesser Antilles volcanoes that led to revisit concepts about mass wasting on submarine island flanks around the world. The societal impact of her results is quite important, due to the implications on tsunamis hazards. She authored 47 publications (h-index: 17). She was leading the volcanology team at IPGP from 2011 to 2015, and supervising 4 PhD and 6 masters students, and advising 3 postdocs. She has been appointed as a member of several national committees (French cruise planning, Scientific Advisory board of IPGP, the inter-government group for tsunami alert, CSS1 Committee at IRD….). She is also member of the European Magellan + Committee and represents France in ESSAC which is the scientific committee of ECORD (European Consortium for Ocean Research Drilling). She is actively involved in outreach activities including in schools, to raise the public interest. She received the "Chevalier de l'ordre du Mérite" award from the Ministry of Research in 2014. She will contribute to ExtremeEarth-PP in her capacity for the volcanology science applications and observatories.

Claudio Satriano (M): 39 years old, IPGP assistant professor, he is the scientific director of the IPGP multi-source data centre. He received a Master degree in Physics (2002) from University of Naples, Italy and a PhD in Geophysics (2006) from University of Bologna, Italy. He has a long-established experience in the study of seismic source processes (rupture, nucleation, fault transients), natural and anthropogenic seismicity, using advanced signal analysis methodologies. He has authored 26 peer-reviewed publications and book chapters (h-index: 13). He has a strong expertise in scientific software development, and contributed to several high-profile seismological open source software projects, like ObsPy, NonLinLoc and Earthworm. He will contribute in FAIR data management and curation services and software development. He will bring also his expertise in earthquake and induced seismicity monitoring and modeling. He will contribute to ExtremeEarth-PP in his capacity for multi-type data

logistics and management, data centers, and statistical data analytics in earthquake seismology.

Geneviève Moguilny (F): CNRS senior research engineer, she is the technical director of the High-performance Computing and Data Analysis facility (S-CAPAD) at IPGP. She has a long-established expertise in the development of data-intensive high-performance and cloud computing platforms, including virtualisation technology, and contributed to several European infrastructure projects such as EGEE, VERCE, EGI, and EGI-Engage where she was actively involved in the EPOS Competence Centre. She will bring her expertise in data-intensive computing and analysis platforms and services, together parallel distributed-data storage technologies. She will contribute to ExtremeEarth-PP in her capacity to develop data and computing infrastructures.

Constantza Pardo (F): CNRS senior research engineer, she is the technical director of the IPGP data centre. She has a long-established expertise in multi-source data management and curation, together with open data and metadata standards and services for data access and exploration. She is involved in the European EPOS and French RESIF core services development, the GEOSCOPE global seismic network data management and more recently in the management and curation of the data from the SEIS instrument of the Mars Insight mission, developed in collaboration between IPGP and CNES. She will bring expertise in FAIR multi-source data management and curation platforms. She will contribute to ExtremeEarth-PP in her capacity in multi-type data centers and data management.

Selected team publications:

- Andre, J.C, Antoniu, G., Asch, M., Badia Sala, R., Beck, M., Beckman, P., Bidot, T., Bodin, F., Capello, E., Choudary, A., de Supinski, B., Deelman, E., Dongarra, J., Dubey, A., Fox, G., Fu, H., Girona, S., Groop, W., Heroux, M., Ishikawa, Y., Keahey, K., Keyes, D., Kramer, W., Lavignon, J.-F., Lu, Y., Matsuoka, S., Mohr, B., Moore, T., Reed, D., Requena, S., Saltz, J., Schultess, T., Stevens, R., Swany, M., Szalay, A., Tang, W., Varoquaux, G., **Vilotte**, J.-P., Wisniewski, R., XU, Z., Zacharov, I. *Big Data and Extreme-scale Computing: Pathway to convergence*, BDEC report, Ed. M. Asch and T. Moore, Tech Report No. ICL-UT-17-08, 2017, **http://www.exascale.org/bdec/sites/www.exascale.org.bdec/files/whitepapers/bdec2017pathways.pdf**
- Atkinson, M., Carpene, M., Casarotti, E., Claus, S., Filgueira Vicente, R., Frank, A., Galea, M., Garth, T., Gemuend, A., Igel, H., Klampanos, I., Krause, A., Krischer, L., Hoon Leong, S., Magnoni, F., Matser, J., Michelini, M., Rietbrock, A., Schwichtenberg, H., Spinuso, S., **Vilotte**, J.-P.. *VERCE delivers a productive e-Science environment for seismology research*, 224–236. IEEE, 2015, doi: 10.1109/eScience.2015.38.
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- **Hulot**, G., Lhuillier, F., Aubert J., *Earth's dynamo limit of predictability,* Geophys. Res. Lett., 37, L06305, 2010, doi:10.1029/2009GL041869.
- Lebas, E., Le **Friant**, A., Deplus, C., de Voogd, B.. *Understanding the evolution of an oceanic intraplate volcano from seismic reflection data: A new model for La Réunion, Indian Ocean*. Journal of Geophysical Research – Solid Earth, doi.1002/2017JB014959, in press, online 24 January 2018.
- Le **Friant**, A., Ishizuka, O. , Boudon, G. , Palmer, M.R. , Talling, P. , Villemant, B. , Adachi, T., Aljahdali, M., Breitkreuz, C., Brunet, M., Caron, B., Coussens, M., Deplus, C., Endo, D., Feuillet, N., Fraas, A.J., Fujinawa, A., Hart, M. B., Hatfield, R.G., Hornbach, M., Jutzeler, M., Kataoka, K. S., Komorowski, J-C., Lebas, E., Lafuerza, S., Maeno, F., Manga, M., Martínez-Colón, M., McCanta, M., Morgan, S., Saito, T., Slagle, A., Sparks, S., Stinton, A., Stroncik, N., Subramanyam, K. S.V., Tamura, Y., Trofimovs, J., Voight, B., Wall-Palmer, D., Wang, F., Watt, S.F.L. *Submarine record of volcanic island construction and collapse in the Lesser Antilles arc: First scientific drilling of submarine volcanic island landslides by IODP Expedition 340*. Geochem., Geophys., Geosyst, 16, 2, 420-442, 2015, doi:10.1002/2014GC005652.
- Morzfeld, M., Fournier, A., **Hulot**, G., *Coarse predictions of dipole reversals by low-dimensional modelling and data assimilation*, Phys. Earth Planet. Int., 262, 8-27, 2017, doi: 10.1016/j.pepi.2016.10.007.
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- Poiata, N., **Satriano**, C., Vilotte, J.P., Bernard, P., Obara, K. Multiband array detection and location of seismic sources recorded by dense seismic networks. *Geophys. J. Int.*, 205(3), 1548–1573, 2016, doi: 10.1093/gji/ggw071.
- **Satriano**, C., Dionicio, V., Miyake, H., Uchida, N., Vilotte, J.-P., Bernard. *Structural and thermal control of seismic activity and megathrust rupture dynamics in subduction zones: Lessons from the Mw 9.0, 2011 Tohoku earthquake*, Earth Planet. Sci. Lett., 403, 2014, 287-298, doi 10.1016/j.epsl.2014.06.037.
- Shapiro, N.M., Droznin, D.V., Droznina, S. Ya.., Senyukov, S.L., Gusev, A.A., Gordeev, E.I. Deep and shallow long-period volcanic seismicity linked by fluid-pressur transfer. *Nature Geosciences*, 2017, doi:10.1038/ngeo2952.
- Schurr, B., Asch, G., Hainzl, S., Bedford, B., Hoechner, A., Palo, M., Wang, R., Moreno, M., Bartsch, M., Zhang, Y., Oncken, O., Tilmann, F., Dahm, T., Victor, P., Barrientos, S.,**Vilotte**, J.-P. *Gradual unlocking of plate boundary controlled initiation of the 2014 Iquique earthquake*. Nature, 512 (7514): 299–302, 2014, doi: 10.1038/nature13681.
- Seydoux, L., Shapiro, N.M., de Rosny, J., Brenguier, L., Landès, M. *Detecting seismic activity with a covariance matrix analysis of data recorded on seismic arrays*, Geophys. J. Int., 204, 3, 1430-1442, 2016, doi: 10.1093/gji/ggv531.

4.1.6.3 Observatoire des Sciences de l'Univers de Grenoble

4.1.6.3.1 Brief description of organisation

Observatoire des Sciences de l'Univers de Grenoble (CNRS-OSUG) is a federative institute for coordination of Earth Science at the University of Grenoble-Alpes. It will involve IGE (Institut des Géosciences pour l'Environnement) and ISTerre (Institut des Sciences de la Terre) as members of OSUG.

4.1.6.3.2 Excellence

IGE conducts research on climate, the water cycle, cryosphere and natural and anthropized environments with the aims to better understand the processes that govern the various geophysical compartments (ocean, atmosphere physics and chemistry, cryosphere, watersheds, critical zone), their interactions and responses to human pressures, and the processes of adaptation and resilience of societies. ISTerre conducts research dedicated to Solid Earth and Environmental Sciences, with one of the ISTerre teams being a world leader on processing and modelling of massive data sets in seismology. A dedicated team is working on imaging volcanoes and their evolution in time, while another team specialises in Space observations of Earth deformation. Other research subjects of ISTerre include seismic hazard & risk, and long-term observation and monitoring of landslides. ISTerre will collaborate with the Laboratory on Magmas and Volcanoes (LMV) based in Clermont-Ferrand.

4.1.6.3.3 Personnel

Paolo Laj (M), senior scientist at Université-Grenoble-Alpes (Physicien),works at OSUG-IGE. He has been involved in the development of ACTRIS RI since more than 15 years, and he is part of the coordination team. He is involved in Earth Observation projects such as ERA-PLANET and is co-coordinator of the ENVRIplus cluster of Research Infrastructures. He is the chair of the WMO-GAW SAG aerosol and serves in the scientific advisory panel of GEO-6.

Selected publications:

- Pandolfi, M., et al., A European aerosol phenomenology – 6: scattering properties of atmospheric aerosol particles from 28 ACTRIS sites, Atmos. Chem. Phys., 18, 7877-7911, https://doi.org/10.5194/acp-18-7877-2018, 2018.
- Lim, S., et al., Sulfate alters aerosol absorption properties in East Asian outflow, Scientific Reports, 8, 5172 (2018) doi:10.1038/s41598-018-23021-1
- M. Dall'Osto, et al., Novel insights on new particle formation derived from a pan-european observing system, Scientific Reports, 8, 1482 (2018) doi:10.1038/s41598-017-17343-9

Helle Pedersen (F), senior seismologist at Université-Grenoble-Alpes (Physicienne), specialises in the seismic imaging of the Earth at scales ranging to surface to the core. She is part of the world leading team of ISTerre on massive data processing and modeling in seismology. She leads the French scientific participation in EPOS (European Plate Observing System, to become an ERIC at the end of 2018), and is a member of the EPOS Project Development Board through her role as a chair of the EPOS Services Coordination Board. She is presently the Chair of the Management Board of ORFEUS - EIDA (European Integrated Data Archive, in charge of distribution of waveform seismic data i Europe). She directed RESIF, the main French contribution to EPOS, from its creation in 2008 until 2017. She was leading Governance and legal activities, and participated in the financial WP in EPOS-PP (also led by CNRS), and is presently strongly involved in the CNRS-led governance and legal activities in EPOS-IP.

Selected publications:

- Poli P., Campillo, M., **Pedersen**, H. A., and the POLENET/LAPNET Working Group, 2012. Body wave imaging of the Earth's mantle discontinuities from ambient seismic noise, Science, 338 no 6110, 1063-1065 DOI : 10.1126/science.1228194.
- Lyu, C., **Pedersen**, H. A., Paul, A., Zhao, L., Solarino, S., and the CIFALPS Working Group, 2017. Shear wave velocities in the upper mantle of the Western Alps: new constraints using array analysis of seismic surface waves, Geophys. J. Int., 210 (1), 321-331, doi: 10.1093/gji/ggx166.
- Lecocq, Th., Longuevergne, L., **Pedersen**, H. A., Brenguier, F., Stammler, K., 2017. Long-term monitoring of subsurface water storage at basin scale: 30 years continuous observation with seismic noise, Nature Scientific Reports, Nature Publishing Group, 7, Art. n°14241.
- Eeken, T. , Goes, S., **Pedersen**, H.A., Arndt, N., Bouilhol ; P., 2018. Seismic evidence for depth-dependent metasomatism in cratons, Earth Planet. Sci. Lett., 491, 148-159.
- **Pedersen**, H. A. and Colombi, A., 2018. Body waves from a single source area observed in noise correlations at arrival times of reflections from the 410 discontinuity, Geophys. J. Int., **https://doi.org/10.1093/gji/ggy191**.

Raphaël Paris (M), 41 years old, CNRS scientist. He is Head of the team « Volcanology » at LMV-OPGC (Clermont-Ferrand). He as a 20-years' experience on volcanology and tsunami, and most particularly on volcano flank instability and tsunami generated by volcanic eruptions. This experience has been acquired through different ANR and European projects (e.g. ASTARTE FP7 ENV.2013.6.4-3). He has authored 58 peer-reviewed publications (h-index: 26, 2300 cites in Google Scholar). He was awarded the CNRS Bronze Medal in 2009 and the EGU Plinius Medal in 2011. He will contribute to ExtremeEarth-PP on the links with activities related to EPOS (European Plate Observing System), GVM (Global Volcano Model), and GTM (Global Tsunami Model) at LMV-OPGC.

Selected publications:

- **Paris**, R., Coello Bravo, J.J., Martín González M.E., Kelfoun, K., Nauret, F., 2017. Explosive eruption, flank collapse and megatsunami at Tenerife ca. 170 ka. Nature Communications 8, 15246.
- Grezio A., Babeyko, M. A. Baptista, J. Behrens, A. Costa, G. Davies, E. L. Geist, S. Glimsdal, F. I. Gonzàlez, J. Griffin, C. B. Harbitz, R. J. LeVeque, S. Lorito, F. Lövholt, R. Omira, C. Mueller, R. **Paris**, T. Parsons, J. Polet, W. Power, J. Selva, M. B. Sörensen, H. K. Thio, 2018. Probabilistic Tsunami Hazard Analysis (PTHA): multiple sources and global applications. Reviews of Geophysics 55, 1158-1198.

4.1.7 Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici

4.1.7.1 Brief description of organisation

The Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (Fondazione CMCC) is a non-profit research institution. CMCC's mission is to investigate and model our climate system and its interactions with society to provide reliable, rigorous, and timely scientific results, which will in turn stimulate sustainable growth, protect the environment, and develop science driven adaptation and mitigation policies in a changing climate. CMCC collaborates with experienced scientists, economists, and technicians, which work together to provide full analyses of climate impacts on various systems such as agriculture, ecosystems, coasts, water resources, health, and economics. CMCC also supports policymakers in setting and assessing costs, mitigation, and adaptation policies. CMCC benefits from the extensive applied research experience of its members and institutional partners: Istituto Nazionale di Geofisica e Vulcanologia (INGV); Università del Salento; Centro Italiano di Ricerche Aerospaziali (CIRA S.c.p.a.); Università Ca' Foscari Venezia; Università di Sassari, Università della Tuscia, Politecnico di Milano, Resources for the Future.

4.1.7.2 Excellence

CMCC research activities are distributed among nine research divisions that share different knowledge and skills in the field of climate science: Advanced Scientific Computing (ASC) Division; Climate Simulation and Prediction (CSP) Division; Economic analysis of Climate Impacts and Policy (ECIP) Division; Sustainable Earth Modeling Economics (SEME), Impacts on Agriculture, Forests and Ecosystem Services (IAFES) Division; Ocean modeling and Data Assimilation (ODA) Division; Ocean Predictions and Applications (OPA) Division; Risk Assessment and Adaptation Strategies (RAAS) Division; Regional Models and geo-Hydrological Impacts (REHMI) Division.

4.1.7.3 Personnel

Antonio Navarra (M) graduated in Physics in Bologna in 1980 and returned to Italy in 1986, after getting a Ph.D. at the Geophysical Fluid Dynamics Laboratory at Princeton University. He is President of the Euro-Mediterranean Centre on Climate Change Foundation and Dirigente di Ricerca at the National Institute of Geophysics and Volcanology (INGV), where he carries out his activity in the field of the climate simulation with general circulation numerical models. The scientific interests of Dr. Navarra focus on the investigation of the dynamical mechanisms which control climate on the global scale, particularly regarding the natural climate variability of the atmosphere-ocean system on interannual, decadal and centennial scales. The general aim is to understand and document the main modes of climate variability on interannual and decadal scales (teleconnections) by means of statistical methods, numerical simulations and simplified models. These studies are the natural complement of the second activity field, which concerns the simulation and the evaluation of the climate changes using scenarios of the future climate. Dr. Navarra is also teaching in the PhD Program on "Science and Management of Climate Science" at Universita‟ Ca‟ Foscari, Venice. He is the author of several books and articles of general interest and contributes to national newspapers.

Simona Masina (F), Ph.D. Princeton University, Director of the Ocean Modelling and Data Assimilation Division of the Euro-Mediterranean Centre on Climate Change Foundation and Senior Researcher at the National Institute of Geophysics and Volcanology. Her scientific interests focus on the understanding of the ocean role in the global climatic system. She has more than 20 years of experience in global ocean modelling and ocean data assimilation. In 2014, she coordinated the first PRACE project awarded to CMCC to set up the basis of a NEMO based high-resolution ocean forecasting system which is now operational at CMCC. She has been involved in several EU projects (among the latest MyOcean and CRESCENDO) and more recently in the COPERNICUS Marine Environment Monitoring Service (CMEMS) and Climate Change Service (C3S) for the provision of NEMO based global ocean reanalyses. She is author of more than 100 scientific papers in refereed journals. She teaches the course "Ocean Dynamics" at the Università di Venezia Ca' Foscari, in the "Science and Management of Climate Change" Ph.D. Programme and is member of the Faculty Board since 2006. She is member of the CLIVAR Panel on Ocean Model Development and representative at the "Commissione Oceanografica Italiana" (Italian IOC-UNESCO).

Silvio Gualdi (M) is a Senior Scientist at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and at the Euro-Mediterranean Centre on Climate Change Foundation, where he leads the "Climate Simulations and

Predictions" Division (CSP). He holds a Masters degree in Physics from the University of Modena (Italy) and a PhD in Geophysics from the University of Hamburg (Germany) and has more than 20 years of experience in climate modelling and simulations. During this period, he has contributed to the development of a several climate models (e.g., SINTEX, CMCC-Med), and has performed a number of climate scenario simulations and projections (CMIP3, CMIP5). During the past 12 years, he has been partner in several international projects, such as, the EU-Project SINTEX, DEMETER (INGV principal investigator), ENSEMBLES (INGV principal investigator and WP leader), CIRCE (WP leader) and COMBINE (WP leader). He is Member of the International Scientific Steering Committee of HyMex (Hydrological Cycle in the Mediterranean Experiment),member of the MedCLIVAR Programme. Along with other colleagues, he has received the Norbert Gerbier- MUMM International Award for 2006. Since February 2008, he has been the convener of the AW4 session "Large scale air-sea interaction processes and their influence on the Euro-Mediterranean climate" at the Annual Meeting of the European Meteorological Society (EMS). Since 2007, he has been a teacher of "Climate Dynamics" for the "Science and Management of the Climate Change" Doctorate Programme of the Cà Foscari University of Venice. Furthermore, he has been the co-tutor of several PhD and Degree thesis at the University of Bologna. He is author of more than 60 peer-reviewed publications.

Giovanni Aloisio (M). He is full professor of Information Processing Systems at the Dept. of Innovation Engineering of the University of Salento, Lecce, Italy, where he leads the HPC laboratory. Former director of the Scientific Computing and Operations (SCO) Division at Euro-Mediterranean Centre on Climate Change Foundation, he is now the Director of the CMCC Supercomputing Center and a member of the Strategic Council. His expertise concerns high performance computing, grid & cloud computing and distributed data management. He was strongly involved in EU grid projects such as GridLab, EGEE, IS-ENES1, EUBrazilCC, ISENES2, CLIP-C and the G8 ExArch. As CMCC, he is also the coordinator of the OFIDIA2 (Operational FIre Danger preventIon plAtform) project in the context of Interreg V-A Greece Italy Programme 2014-2020 and he is currently coordinating the CMCC activities in the ESiWACE project. He has been in charge of the EU-FP7 EESI (European Exascale Software Initiative) project for ENES as well as the EU-FP7 EESI 2 project for the University of Salento (as PRACE Third Party). In both cases, he has also chaired the WCES (Weather, Climate and solid Earth Sciences) European Working Group. He is a member of the ENES HPC Task Force and one of the key experts of the IESP project (International Exascale Software Project), whose main goal is the definition of the roadmap for a common, open source software infrastructure for scientific computing at exascale. He is the author of more than 100 papers in referred journals on high performance computing, grid computing and distributed data management.

Sandro Fiore (M) Ph.D., Director of the Advanced Scientific Computing (ASC) Division of the Euro-Mediterranean Centre on Climate Change Foundation. His research activities focus on parallel and distributed computing, in particular on scientific data management, big data, data analysis, mining and high-performance data analytics. He has been Visiting Scientist at Lawrence Livermore National Laboratory (LLNL) working at PCMDI in the context of the Earth System Grid Federation (ESGF). Since 2004, he has been involved in several national and international projects, such as: EGI-InSPIRE, IS-ENES, EUBRAZILCC, ExArch, ORIENTGATE, TESSA, OFIDIA, CLIP-C, INDIGO-DataCloud, EUBra-BIGSEA and ESIWACE, working on data management topics. Since 2010, he has been the Principal Investigator of the Ophidia project, a research project on high performance data analytics, mining, and diagnostics for eScience. He is the author and co-author of more than 60 papers in refereed books/journals/proceedings on parallel and distributed computing and holds a patent on data management. He is the editor of the book "Grid and Cloud Database Management" (Springer, 2011). He is an ACM Member.

Selected team publications:

- Iovino, D., S. Masina, A. Storto, A. Cipollone, and V.N. Stepanov, (2016). A 1/16° eddying simulation of the global NEMOv3.4 sea ice-ocean system. Geosci. Model Dev., Volume: 9, Issue: 8, 2665-2684 - doi:10.5194/gmd-2015-268.
- Epicoco, I., Mocavero, S., Macchia, F., Vichi, M., Lovato, T., Masina, S., & Aloisio, G. (2016). Performance and results of the high-resolution biogeochemical model PELAGOS025 v1.0 within NEMO v3.4, Geosci. Model Dev., Vol 9, Issue 6, 2115-2128, doi:10.5194/gmd-9-2115-2016.
- Jack J. Dongarra, Peter H. Beckman, Terry Moore, Patrick Aerts, Giovanni Aloisio, Jean-Claude Andre, David Barkai, Jean-Yves Berthou, Taisuke Boku, Bertrand Braunschweig, Franck Cappello, Barbara M. Chapman, Xuebin Chi, Alok N. Choudhary, Sudip S. Dosanjh, Thom H. Dunning, Sandro Fiore, Al Geist, Bill Gropp, Robert J. Harrison, Mark Hereld, Michael A. Heroux, Adolfy Hoisie, Koh Hotta, Zhong Jin, Yutaka Ishikawa, Fred Johnson, Sanjay Kale, Richard Kenway, David E. Keyes, Bill Kramer, Jesús Labarta, Alain Lichnewsky, Thomas Lippert, Bob Lucas, Barney Maccabe, Satoshi Matsuoka, Paul Messina, Peter Michielse, Bernd Mohr, Matthias S. Müller, Wolfgang E. Nagel, Hiroshi Nakashima, Michael E. Papka, Daniel A. Reed, Mitsuhisa Sato, Edward Seidel, John Shalf, David Skinner, Marc Snir, Thomas L. Sterling, Rick Stevens, Fred Streitz, Bob Sugar, Shinji Sumimoto, William M. Tang, John Taylor, Rajeev Thakur, Anne E. Trefethen, Mateo Valero, Aad van der Steen, Jeffrey S. Vetter, Peg Williams, Robert W. Wisniewski, Katherine A. Yelick: The International Exascale Software Project roadmap. IJHPCA 25(1): 3-60 (2011).
- Sandro Fiore, Marcin Plóciennik, Charles M. Doutriaux, Cosimo Palazzo, J. Boutte, Tomasz Zok, Donatello Elia, Michal Owsiak, Alessandro D'Anca, Z. Shaheen, Riccardo Bruno, Marco Fargetta, Miguel Caballer, Germán Moltó, Ignacio Blanquer, Roberto Barbera, Mário David, Giacinto Donvito, Dean N. Williams, V. Anantharaj, Davide Salomoni, Giovanni Aloisio: Distributed and cloud-based multi-model analytics experiments on large volumes of climate change data in the earth system grid federation eco-system. BigData 2016: 2911-2918.

- Epicoco I, Mocavero S, Porter A R, Pickles S M, Ashworth M, Aloisio G (2017). Hybridisation strategies and data structures for the NEMO ocean model, IJHPCA Volume 25, doi:10.1177/1094342016684930
- Luca Cinquini, Daniel Crichton, Chris Mattmann, John Harney, Galen Shipman, Feiyi Wang, Rachana Ananthakrishnan, Neill Miller, Sebastian Denvil, Mark Morgan, Zed Pobre, Gavin M. Bell, Charles Doutriaux, Robert Drach, Dean Williams, Philip Kershaw, Stephen Pascoe, Estanislao Gonzalez, Sandro Fiore, Roland Schweitzer, The Earth System Grid Federation: An open infrastructure for access to distributed geospatial data, Future Generation Computer Systems, Volume 36, 2014, Pages 400-417, ISSN 0167-739X, https://doi.org/10.1016/j.future.2013.07.002.

4.1.8 Netherlands eScience Center

4.1.8.1 Brief description of organisation

The Netherlands eScience Center (NLeSC www.esciencecenter.nl) is an expertise center on the development and application of research software and digital methodologies. It performs collaborative scientific projects with both academia, public and private partners to enable and accelerate research across domains. NLeSC has expertise in data handling, big data analytics and efficient computing. It works on the interface of e-infrastructure (computing, data) and domain sciences varying from climate science, astronomy, chemistry to humanities amongst others. In weather, climate and earth sciences the expertise of NLeSC is in efficient computing of large and complex codes on heterogeneous (including accelerated) hardware, multiscale coupled modelling and the combination of disparate compute resources as well as in visualization of large data sets. NLeSC coordinates the platform for national and European e-Science activities. NLeSC maintains a Research Software Directory containing tools, interfaces, and libraries to deal with and extract information from large amounts of (distributed) data, requiring large computing infrastructures, high-speed networks, and high-resolution visualization equipment. NLeSC has a staff of about 60, including 50 eScience Research Engineers from varying background, including computer science, applied mathematics and climate science.

4.1.8.2 Excellence

NLeSC has expertise in modern research software technologies. It specializes in applying research software to domains including earth sciences. Hence it works on the interface of computer and data science and domain science and enables and accelerates science with digital technologies. In more detail, the expertise are on research software development for workflows, generic libraries, interfaces for coupling multiscale numerical models. Also, the data handling expertise of NLeSC will be very relevant to ExtremeEarth. NLeSC has worked on accessibility of distributed climate data (e.g. as part of the EUCP project), on streamed data from radioastronomy (LOFAR) and on data from sensors (IoT data from traffic). Moreover, it has expertise in coordinating large research communities and projects.

4.1.8.3 Personnel

Wilco Hazeleger (M) serves as Director of the Netherlands eScience Center since July 2014. He also holds a chair in Climate Dynamics at Wageningen University. Prof. Hazeleger has a background in meteorology and physical oceanography. He obtained his PhD in 1999 from Utrecht University in physical oceanography. After his PhD he went to Columbia University (NY, USA) to study decadal variability in El Nino Southern Oscillation. From 2002 until 2014 he worked at KNMI, first as researcher and later as division head in global and regional climate research. In 2014 he was acting director of the Climate and Seismology department of KNMI. He initiated and led the EC-Earth consortium, a consortium of over 20 partners from 14 European countries that co-developed the EC-Earth global model which is now one of the leading climate models, based on ECMWFs forecast system. His work includes studies on coupled climate variability, predictability beyond the seasonal time scales, climate change and climate adaptation and decision making. Since joining the eScience Center he broadened his scope to data and computational sciences. He served on many committees, including scientific advisory committees of ECMWF, the UK Met Office Hadley Center and the Swedish eScience Center.

Selected publications:

- Rasmijn, L., G. vd Schrier, A. Sterl, J. Barkmeijer and W. **Hazeleger**, 2018: Future equivalent of 2010 Russian heatwave intensified by weakening soil moisture constraints. *Nature Climate Change*, doi:10.1038/s41558-018-0114-0.
- Haarsma, R.J. et al., 2016: High Resolution Model Intercomparison Project (HighResMIP). *Geosc. Model Dev.*, 9, 4185-4208
- **Hazeleger**, W. et al, 2015: Tales of Future Weather. *Nature Climate Change*, 5, 107-114
- **Hazeleger** W., and Co-authors, 2012: EC-Earth V2.2: description and validation of a new seamless Earth system prediction model. *Climate Dynamics*, 39, 2611-2629, doi:10.1007/s00382-011-1228-5
- Haarsma, R.H., W. **Hazeleger** and co-authors, 2013: More hurricanes to hit Western Europe due to global warming. *Geoph. Res. Lett.* doi:10.1002/grl.50360

Rob V. van Nieuwpoort (M), is professor of Efficient Computing for eScience at the University of Amsterdam and Director of Technology at the Netherlands eScience Center. His research interests include high performance computing, parallel and distributed algorithms, multi- and many-core computing, and the application of this technology in all scientific disciplines, particularly radio astronomy. The focus of his PhD research (1998-2003)

was on "Efficient Java-Centric Grid Computing". He has designed and implemented the Ibis, Satin, and JavaGAT systems (the latter is now standardized in OGF as SAGA) and worked on the EU FP5 GridLab project, and the Dutch Virtual Labs for eScience project. From 2009 to 2012 he was a researcher at ASTRON, the Netherlands Institute for Radio Astronomy, where he designed and developed software for the real-time data processing of the LOFAR software telescope, the largest radio telescope in the world, and for LOFARs successor, the exascale SKA telescope. His recent research focuses on auto-tuning and the use of many-core architectures such as GPUs for radio astronomy. In 2011, as assistant professor at VU University Amsterdam, he initiated the first CUDA Teaching Center in the Netherlands. In the EU PROCESS project, and in the European Open Science Cloud, he is currently investigating novel exascale software infrastructure and programming model.

Selected publications:

- M. P. van Haarlem, …, **R.V. van Nieuwpoort** et al.: LOFAR: The LOw-Frequency ARray**,**Astronomy and Astrophysics 556, 2013. DOI: 10.1051/0004-6361/201220873.
- **Rob V. van Nieuwpoort**, Jason Maassen, Gosia Wrzesinska, Rutger Hofman, Ceriel Jacobs, Thilo Kielmann, Henri E. Bal: Ibis: a Flexible and Efficient Java-based Grid Programming Environment, Concurrency & Computation: Practice & Experience. Volume 17, No. 7-8, pp. 1079-1107, 2005. DOI 10.1002/cpe.860.
- Alessio Sclocco, Joeri van Leeuwen, Henri E. Bal, **Rob V. van Nieuwpoort**: Real-Time Dedispersion for Fast Radio Transient Surveys, using Auto Tuning on Many-Core Accelerators**.,** Astronomy and Computing, Volume 14, January 2016, pages 1-7, DOI:10.1016/j.ascom.2016.01.001.
- P. Chris Broekema, **Rob V. van Nieuwpoort** and Henri E. Bal: The Square Kilometre Array Science Data Processor Preliminary Compute Platform Design**,** Journal of Instrumentation, Volume 10, July 2015. DOI:10.1088/1748-0221/10/07/C07004.
- **Rob V. van Nieuwpoort**, Gosia Wrzesinska, Ceriel J.H. Jacobs and Henri E.Bal: Satin: a High-Level and Efficient Grid Programming Model**,** ACM Transactions on Programming Languages and Systems (TOPLAS), Volume 32 Issue 3, ACM Press New York, NY, USA, 2010. DOI: 10.1145/1709093.1709096.

Jason Maassen (M) is Technology Lead at the Netherlands eScience Center. He is involved in many of the projects at the center that apply parallel and distributed programming to scientific applications, ranging from high resolution climate modeling to digital forensics. In addition, he guides internal software development at the center and scouts for new software technology that can be used in projects. In 2003 he obtained his PhD from VU University Amsterdam in Computer Science. Since then he has participated in many research projects, such as EU FP5 GridLab, the Dutch Virtual Labs for eScience, StarPlane, PROMM-GRID, and COMMIT, where he has worked on a range of topics related to large scale distributed computing. In these projects, he has developed a monitoring system for a world-wide Grid, robust communication libraries, programming models for computing on heterogeneous distributed systems, and several eScience applications that use dynamically allocatable optical networks. In the EU PROCESS project, he is currently investigating software infrastucture to support exascale applications.

Selected publications:

- J. **Maassen**, B. van Werkhoven, M. van Meersbergen, H.E. Bal, M. Kliphuis, S.E. Brunnabend, H.A. Dijkstra, G. van Malenstein, M. de Vos, S. Kuijpers, S. Boele, J. Wolfrat, N. Hill, D. Wallom, C. Grimm, D. Kranzlmüller, D. Ganpathi, S. Jha, Y.E. Khamra, F.O. Bryan, B. Kirtman, F.J. Seinstra, "On the complexities of utilizing large-scale lightpath-connected distributed cyberinfrastructure". Concurrency Computat.: Pract. Exper., 29: e3853, 2017. doi: 10.1002/cpe.3853.
- B. van Werkhoven, J. **Maassen**, M. Kliphuis, H.A. Dijkstra, S.E. Brunnabend, M. van Meersbergen, F.J. Seinstra, H.E. and Bal. "A distributed computing approach to improve the performance of the Parallel Ocean Program (v2.1)", Geosci. Model Dev., 7, 267-281, 2014. doi: 10.5194/gmd-7-267-2014
- H. E. Bal, J. **Maassen**, R. van Nieuwpoort, N. Drost, R. Kemp, T. van Kessel, N. Palmer, G. Wrzesinska, T. Kielmann, K. van Reeuwijk, F.J. Seinstra, C. Jacobs, C. Verstoep, "Real-World Distributed Computing with Ibis," in Computer, vol. 43, no. 8, pp. 54-62, Aug. 2010. doi: 10.1109/MC.2010.184
- J. **Maassen** and H. E. Bal. “Smartsockets: solving the connectivity problems in grid computing.” Proceedings of the 16th international symposium on High performance distributed computing, Monterey, California (HPDC'07), USA, pp. 1-10, 2007. doi: 10.1145/1272366.1272368
- G. Wrzesinska, J. **Maassen**, H.E. Bal. "Self-adaptive applications on the grid", Proceedings of the 12th ACM SIGPLAN symposium on Principles and practice of parallel programming, San Jose, California, USA, pp. 121-129, 2007, doi: 10.1145/1229428.1229449

4.1.9 DELTARES

4.1.9.1 Brief description of organisation

Deltares is an independent institute for applied research on floods, water management and the subsoil, located in The Netherlands. Our mission is to develop, acquire, apply and disseminate integral, multidisciplinary knowledge and knowledge products related to living and working in delta areas. With a turnover of about 105 Million Euros, and a staff of about 800, of which 20% are PhDs, Deltares executes projects for the Dutch national and regional government and waterboards, the European Union, supra-national organizations and donor such as the World Bank and Regional Development Banks, as well as a diversity of clients abroad and at home such as private engineering companies and consultants, NGO’s, port authorities, flood management authorities and foreign governments. About 30% of our funding is acquired abroad. All projects, whether financed privately, publicly or from strategic research

budgets, contribute to the expansion and consolidation of our knowledge base. Most of our knowledge on the coastal and inland river and flood plain system dynamics is cast in numerical software, data products and tools, most of which are either open-source or free-ware. We firmly believe that we can only expand our knowledge through openness and transparency. Deltares plays an active role in research and innovation networks with the goal of creating societal value, by supporting and speeding up innovation. Within the EU research arena Deltares has extensive experience as both research partner and project coordinator. Relevant EU research projects which Deltares has recently led are Earth2Observe, DEWFORA, GLOWASIS, and RISC-KIT. Furthermore, Deltares participate(d)s in IMPREX, EUCP, MARS, GRACeFUL, INFORM, FAST, RASOR, RISES, REFRESH, REFORM, BASE, EFFS and many others. Stichting Deltares may apply employees of a Linked Third Party in this project. Delta Innovation B.V. (PIC 998285201) is a full daughter of Stichting Deltares. New Deltares employees are granted a 2-year contract with Delta Innovation B.V. The employees of Delta Innovation B.V. work as employees of Stichting Deltares under the Deltares CAO (Collectieve Arbeids Overeenkomst = Collective Labor Contract) and are seconded to Stichting Deltares in full.

4.1.9.2 Excellence

Deltares main expertise is the understanding of the response of coastal and inland systems due to flooding and droughts. This system understanding has developed into expert knowledge on the effectivity and suitability of mitigating measures, in order to balance flood protection and natural values and into expertise on stakeholder engagement We have cast our physical knowledge into world leading physics-based numerical software and data products**.** Modelling and developing software used for flood and water management constitutes an important element of Deltares activities. This software is applied world-wide to support decision making in water and flood risk management as well as for climate adaptation. Deltares developed the flood forecasting software, Delft-FEWS, that connects meteorological and hydrological observations and numerical weather predictions to hydrological models. Delft-FEWS is a.o. applied in the UK, Switzerland, USA, Australia and recently in China. With the sum of all these systems, the Deltares supports the protection of about 30% of the global economy from floods. The Deltares Delft3D modelling suite provides all functionality for integrated, (flow, sediment, waterquality, ecology) 3D hydrodynamical modelling. It is used world wide in coastal and estuarine areas. Together with the Google Earth Engine group, Deltares is now successfully connecting large data sets, numerical modelling and HP computing by providing global to local scalable products for coastal and water management. With respect to software and data development Deltares applies a strong open source policy.

4.1.9.3 Personnel

Frederiek Sperna Weiland (F) is currently co-leading the research programme on modelling the impact of extreme inland and coastal flood events. She will be involved in the preparatory actions for the co-creation of the continental- scale coastal, surface, and ground water models. She has co-led the EU FP7 project eartH2Observe. This project as well as her other work focusses on the application of global hydrological models, climate as well as satellite data for regional to local scale water management applications. In projects all over the world she works on the translation of scientific data into locally relevant indicators.

Selected publications:

- Schellekens, J., Dutra, E., Martínez-de la Torre, A., Balsamo, G., van Dijk, A., **Sperna Weiland, F.,** Minvielle, M., Calvet, J.-C., Decharme, B., Eisner, S., Fink, G., Flörke, M., Peßenteiner, S., van Beek, R., Polcher, J., Beck, H., Orth, R., Calton, B., Burke, S., Dorigo, W., and Weedon, G. P.: A global water resources ensemble of hydrological models: the eartH2Observe Tier-1 dataset, Earth Syst. Sci. Data, 9, 389-413, https://doi.org/10.5194/essd-9-389-2017, 2017.
- **Sperna Weiland, F.C.** , J.A. Vrugt, R.L.P.H. van Beek, A.H. Weerts, and M.F.P. Bierkens (2015), Significant uncertainty in global scale hydrological modeling from precipitation data errors, Journal of Hydrology, 529 (3), 1095-1115, doi:10.1016/j.jhydrol.2015.08.061.
- **Sperna Weiland, F. C.,** van Beek, L. P. H., Kwadijk, J. C. J., and Bierkens, M. F. P.: Global patterns of change in discharge regimes for 2100, Hydrol. Earth Syst. Sci., 16, 1047-1062, https://doi.org/10.5194/hess-16-1047-2012, 2012
- Ward P, J., Jongman B, **Sperna Weiland F.**, Bouwman A, van Beek R, Bierkens MFP, Ligtvoet W, Winsemius HC (2013) Assessing 397 flood risk at the global scale: model setup, results, and sensitivity. Environmental Research Letters 8:044019.

Heleen Vreugdenhil (F) has a joint appointment at Deltares and TU-Delft on topics to increase sustainability in river management and port planning. She studies the role of pilot projects in innovation processes and advices on the design to become more effectively. She combines Natural Resources Management (e.g. rivers, coasts, sustainable cities, ocean space) and Political Science questions related to innovation and learning through pilot projects, social uncertainties, (public) participation, long term policy making and scenario development.

Selected publications:

- **Vreugdenhil,** H.S.I., Taljaard, S., Slinger, J.H. (2012).Diffusion of pilot projects: the next step in policy transitions. *International Journal for Sustainable Development* 15 (1-2), pp. 148-172
- **Vreugdenhil**, H.S.I., Slinger, J.H., Thissen, W.A.H., Ker Rault, P.A (2010) Pilot projects in Water Management. *Ecology and Society* 15 (3) article 13

- **Vreugdenhil**, H.S.I., Slinger, J.H., Kater, E. (2010) The influence of scale preferences on the design of an innovation in Dutch river management. *Environmental Management* 46(1) pp 29-43

Marc Bierkens (M) has a joint appointment at Deltares and Utrecht University. His work comprises integrated modelling of soil-water-vegetation dynamics, data-assimilation methods for operational water management and global scale hydrological modelling in relation to climate change and water availability. He is a fellow of the American Geophysical Union. He is also a member of the European Geosciences Union and the International Association of Hydrological Sciences and is associate editor for Water Resources Research.

Selected publications:

- de Graaf, Inge E.M., van Beek, Rens L.P.H., Gleeson, Tom, Moosdorf, Nils, Schmitz, Oliver, Sutanudjaja, Edwin H. & **Bierkens, Marc F.P.** (01.04.2017). A global-scale two-layer transient groundwater model - Development and application to groundwater depletion. *Advances in Water Resources*, 102, (pp. 53-67) (15 p.)
- **Bierkens, Marc** F P, Bell, Victoria A., Burek, Peter, Chaney, Nathaniel, Condon, Laura E., David, Cédric H., de Roo, Ad, Döll, Petra, Drost, Niels, Famiglietti, James S., Flörke, Martina, Gochis, David J., Houser, Paul, Hut, Rolf, Keune, Jessica, Kollet, Stefan, Maxwell, Reed M., Reager, John T., Samaniego, Luis, Sudicky, Edward, Sutanudjaja, Edwin H., van de Giesen, Nick, Winsemius, Hessel & Wood, Eric F. (01.01.2015). Hyper-resolution global hydrological modelling - What is next?: "Everywhere and locally relevant" M. F. P. Bierkens et al. Invited Commentary. *Hydrological Processes*, 29 (2), (pp. 310-320) (11 p.).
- **Bierkens, Marc F. P. (**2015). Global hydrology 2015: State, trends, and directions. *Water Resources Research*, 51 (7), (pp. 4923-4947).
- Gleeson, Tom, Wada, Yoshihide, **Bierkens, Marc** F. P. & Van Beek, Ludovicus P. H. (09.08.2012). Water balance of global aquifers revealed by groundwater footprint. *Nature*, 488 (7410), (pp. 197-200) (4 p.).

4.1.10 Danmarks Tekniske Universitet

4.1.10.1 Brief description of organisation

Danmarks Tekniske Universitet (DTU) is an internationally-leading university in the areas of engineering science and technology. DTU is known for its business-oriented approach, its focus on sustainability, and its modern and attractive study environment. Furthermore, DTU is dedicated to benefiting society and to cultivating, and advancing the natural and technical sciences to serve as a driver for development in the commercial and public sectors. Leiden University Ranking (2016) places DTU as number 66 in the world, and in collaboration with industry DTU is ranked as number 6 in the world. The SJTU Academic Ranking of World Universities consistently places DTU within the top 10 universities in the world and number one among the European universities in the category 'Energy Science and Engineering'. DTU has approximately 11000 students of which 2000 graduated in 2016; 1700 scientific staff and 1200 PhD students (2016). DTU offers 11 B.Eng. programs, 14 B.Sc. programs, and 27 M.Sc. programs – including programmes in Wind Energy and Sustainable Energy Engineering. The main departments involved, i.e. DTU Department of Electrical Engineering and Department of Wind Energy have a strong profile from basic research, teaching and commercial activities related to various aspects at the interface between energy and meteorology e.g., forecasting, measurements, markets, system integration, markets, etc. DTU coordinates and participates in many National and EU projects in Energy Science and Engineering, while it was deemed the most active institution in Europe in the field of Smart Grid.

4.1.10.2 Excellence

DTU developed the first operationally running wind power forecasting system at utilities, (Prediktor) in 1993 (then as Risø National Laboratory, now DTU Wind Energy) and the Wind Power Prediction Tool "WPPT" in 1994 (DTU IMM, now DTU Compute; WPPT is also further developed at DTU Elektro). Since then, several departments at DTU have researched and developed weather dependencies in power systems for operation and planning. DTU also was lead or WP lead on many national, Nordic and European research projects (ANEMOS, POW'WOW, Anemos.PLUS, SafeWind, Efp-Vindmøllepark Produktionsprediktor, PSO-Ensemble, PSO Intelligent Prognosis Systems, Nordic IceWind, EERA-IRP, …) since the 90ies. DTU also developed energy system models and feeds meteorological expertise and model results to ENTSO-E for use in their Ten Year Network Development Plan. DTU is today seen as a world-leading institution when it comes to renewable energy and to understanding the evolution of the interface between weather and climate systems with the energy systems.

4.1.10.3 Personnel

Pierre Pinson (M) is a Professor at the Centre for Electric Power and Energy (CEE) of the Technical university of Denmark (DTU, Dept. of Electrical Engineering), also heading a group focusing on Energy Analytics & Markets. He holds a M.Sc. In Applied Mathematics from INSA Toulouse and a Ph.D. In Energy Engineering from Ecole de Mines de Paris (France). He acts (or has acted) as an Editor for the IEEE Transactions on Power Systems, the International Journal of Forecasting and Wind Energy. His main research interests are centered around the proposal and application of mathematical methods for electricity markets and power systems operation, including forecasting. He has published extensively (>100 articles) in some of the leading journals in Meteorology, Energy Engineering, Statistics and Operations Research. He has been a visiting researcher at the University of Oxford (Mathematical Institute) and the University of Washington in Seattle (Dpt. of Statistics), as well as a scientist at the

European Center for Medium-range Weather Forecasts (ECMWF, UK) and a visiting professor at Ecole Normale Superieure (Rennes, France). In 2019, he will be a Simons fellow at the Isaac Newton Institute, Cambridge University, UK. He is leading several initiatives aiming to profundly rethink our relationship to energy in view of the transition towards renewable-based energy systems driven by weather and climate.

Selected publications:

- J.M. Morales, A. Conejo, H. Madsen, P. **Pinson**, M. Zugno (2014). Integrating Renewables in Electricity Markets: Operational Problems. Springer Verlag
- T. Hong, P. **Pinson**, S. Fan (2014). Global Energy Forecasting Competition 2012 (GEFCom2012). International Journal of Forecasting 30(2): 357-363
- T.V. Jensen, P. **Pinson** (2017). RE-Europe: a large-scale dataset for a future renewable-energy based European power system. Nature, Scientific Data 4: 170175
- P. **Pinson** (2012). Adaptive calibration of (u, v)-wind ensemble forecasts. Quarterly Journal of the Royal Meteorological Society 138(666): 1273–1284
- P. **Pinson** (2013). Wind energy: Forecasting challenges for its optimal management. Statistical Science 28(4): 564–585

Gregor Giebel (M) is a Senior Scientist at DTU Wind Energy. During the last 20 years, his main field was wind power forecasting, with additional topics like offshore wind cluster design, use of drones in wind power and most recently, wind farm control being prominent side topics. He holds a Dr degree from Oldenburg University and is educated as physicist from TU München, both Germany. He is the Operating Agent of the IEA Wind Task 36 on Wind Power Forecasting, and leads a global group of about 250 stakeholders from weather services, forecast vendors and end users. He has broad experience in running research projects from national, Nordic and European projects. His (Google based) h-index is 31. Among his publications, the report on the state of the art in forecasting has been cited over 750 times. He also works as an international consultant for power system operators and public agencies, most recently in South Africa and Ukraine.

Selected publications:

- **Giebel**, G., J. Cline, H. Frank, W. Shaw, P. Pinson, B.-M. Hodge, G. Kariniotakis, J. Madsen, C. Möhrlen: Wind power forecasting: IEA Wind Task 36 & future research issues. In: Journal of Physics: Conference Series (Online), Vol. 753, No. 3, 032042, 2016.
- Draxl, C., A.N. Hahmann, A.P. Diaz, G. **Giebel**: Evaluating winds and vertical wind shear from Weather Research and Forecasting model forecasts using seven planetary boundary layer schemes. Wind Energy 17(1), pp. 39-55, 2014
- Badger, J., H. Frank, A.N. Hahmann, and G. **Giebel**: Wind-Climate Estimation Based on Mesoscale and Microscale Modeling: Statistical-Dynamical Downscaling for Wind Energy Applications. Journal of Applied Meteorology and Climatology 53(8), p. 1901-1919, 2014
- Ranaboldo, M., G. **Giebel**, B. Codina: Implementation of a Model Output Statistics based on meteorological variable screening for short-term wind power forecast. Wind Energy 16(6), pp. 811-826, 2013
- **Giebel**, G., R. Brownsword, G. Kariniotakis, M. Denhard, C. Draxl: The State-Of-The-Art in Short-Term Prediction of Wind Power. A Literature Overview, 2nd Edition. Report for the ANEMOS.plus and SafeWind projects, 110 pp., 384 references, Risø DTU, Roskilde, 2011

4.1.11 Joint Research Centre

4.1.11.1 Brief description of organisation

The Joint Research Centre (JRC) is a Directorate General of the European Commission (EC), and spread over six sites in five different countries. The JRC employs about 3000 researchers and support staff, organized in 7 directorates. As the EC's science and knowledge service, JRC supports EU policies with independent scientific evidence throughout the whole policy cycle. JRC scientific role includes research and anticipation of emerging issues that need to be addressed at EU level. In addition to conducting own research, JRC collaborates with over a thousand organisations worldwide in a variety of fields. Policies themes supported by JRC relevant for this call include, environment and climate change, food and nutrition security, disaster risk management, immigration, and multi-sectoral, economic analysis, and the Copernicus services.

4.1.11.2 Excellence

JRC will bring in its extensive research in cross-sectorial impact and adaptation modelling, using advanced bias-correction methods. JRC's work has been at the core of several Copernicus services. In the consortium, JRC has expertise in agriculture, hydrology, blue and green economy, disaster risk management and will bring in EU and international policy aspects. JRC provides seasonal agricultural forecast to the European Union and climate impact simulations for Europe. JRC provides early warning and support to provide information on food crises or natural disasters throughout the world. It hosts the European Commissions new Knowledge Centre on food security, the Disaster Risk Management Knowledge Centre and manages and further develops the Copernicus Emergency Management Service.

4.1.11.3 Personnel

Frank Dentener (M) works since 25 years in the field of atmospheric pollution, climate change and agriculture. Frank is senior expert at the European Commission's Joint Research Centre. He completed a Ph.D. in Physics with

Nobel prize-laureate Paul Crutzen. He is member of the International Commission on Atmospheric Chemistry and Global Pollution, co-chair of WMO's Scientific Advisory Group on near-real-time applications, and co-chair of the UNECE's Task Force Hemispheric Transport Air Pollution. He has been lecturing at the Universities of Wageningen, Utrecht and the ETH Zurich. He was a member of the JRC's Scientific Committee from 2014-2016, and is currently member of the Scientific Advisory Board of the JPI FACCE (agriculture and climate change). He has (co-) authored more than 170 peer-reviewed publications and 3 IPCC reports, and will be lead author in the IPCC AR6 report. His H-factor 72, and is a Thomson-Reuters highly cited scientist. He is an expert in atmospheric chemistry-land interactions, including ozone impacts on agriculture, climate change and agriculture mitigation and adaptation.

Selected publications:

- G.Mills, G., K.Sharps, D. Simpson, H.Pleijel, M.Broberg, J.Uddling, F.Jaramillo, W.J. Davies, F.**Dentener**, Maurits Van den Berg, M.Agrawal, S.B. Agrawal, E.A. Ainsworth, P. Büker, L.Emberson, Z. Feng, H. Harmens, F. Hayes, K. Kobayashi, E.Paoletti, R.Van Dingenen , Ozone pollution will compromise efforts to increase global wheat production, DOI: 10.1111/gcb.14157, Glob Change Biol. 1–15, 2018
- Zampieri, Matteo; Ceglar, Andrej; **Dentener**, Frank; Toreti, Andrea, Understanding and reproducing regional diversity of climate impacts on wheat yields: current approaches, challenges and data driven limitations, Environ. Res. Lett.13, 2018.
- Hartmann, D. L., A. M. G. Klein Tank, M. Rusticucci, L. V. Alexander, S. Brönnimann, Y. Charabi, F. J. **Dentener**, E. J. Dlugokencky, D. R. Easterling, A. Kaplan, B. J. Soden, P. W. Thorne, M. Wild and P. M. Zhai, 2013: Observations: Atmosphere and Surface. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.
- Stefano Galmarini, Andrea Toreti, Grigory Nikulin, Nathalie de Noblet-Ducoudré, Alex Cannon, Frank **Dentener**, S. Mcginnis, Efisio solazzo, Ole Christensen, Harilaos Loukos, F.J. Doblas-Reyes, Alessandro Dosio, José Manuel Gutiérrez, Douglas Maraun, M Zampieri, Andrej Ceglar, E. Sanchez, A. Maiorano, Mathieu Vrac, Angelo Riccio, Adjusting Climate Model Bias for Agricultural Impact Assessment: how to cut the mustard? Submitted to climate services, 2018.

Marijn van der Velde (M) research in the last 15 years has focussed on the management and interactions of agriculture and natural resources under increasing societal demands and climate change, including extreme events. His H-factor is 33. He was a NOAA Climate and Global Change Postdoctoral Fellow at Columbia University, New York, USA, and he was leading a group modelling agri-environmental systems at the International Institute for Applied Systems Analysis (IIASA, Austria). He is active in the H2020 project LandSense, and a member of the Scientific Advisory Board of the H2020 ANTARES teaming project aiming to establish a European Centre of Excellence for Advanced Technologies in Sustainable Agriculture and Food Security in Serbia. His current work focusses on climate change impacts on agriculture, improving the quality of crop yield and production forecasts, and investigating the potential of novel (crowd-sourced) data-streams to provide relevant in-situ data on land use and land cover.

Selected publications:

- J. Balkovič, R. Skalský, C. Folberth, N. Khabarov, E. Schmid, M. Madaras, M. Obersteiner and **M. van der Velde**, 2018. Impacts and uncertainties of +2°C of climate change and soil degradation on European crop calorie supply. *Earth's Future,* doi:10.1002/2017EF000629.
- T. Ben-Ari, J. Boe, P. Ciais, R. Lecerf**, M. van der Velde** and Makowski, D., 2018. Causes and implications of the unforeseen 2016 extreme yield loss in the breadbasket of France. *Nature Communications, 9,* Article number 1627, doi:10.1038/s41467-018-04087-x.
- C. Folberth, R. Skalský, E. Moltchanova, L.B. Azevedo, J. Balkovič, M. Obersteiner and **M. van der Velde**, 2016. Uncertainty in soil data can outweigh climate impact signals in global crop yield simulations. *Nature Communications,* 7, doi:10.1038/ncomms11872.
- **M. van der Velde**, C. Folberth, J. Balkovič, P. Ciais, S. Fritz, I. Janssens, M. Obersteiner, L. See, R. Skalský, W. Xiong, and J Peñuelas, 2014. African crop yield reductions due to increasingly unbalanced Nitrogen and Phosphorus consumption. *Global Change Biology,* doi:10.1111/gcb.12481.

Peter Salamon (M) graduated as an M.Sc. in Applied Environmental Geoscience in 2001 at the Eberhard-Karls Universität in Tübingen (Germany). After working two years for an international environmental consulting company in Frankfurt (Germany) as a Project Manager, he started in 2003 his doctorate studies at the Polytechnic University of Valencia (Spain), where he received a Ph.D. in Hydraulic and Environmental Engineering in 2006. At the end of 2006 Peter joined the Joint Research Centre of the European Commission as a scientific project manager where his main tasks are to provide policy support in flood risk management at European and global level. During his research activities and professional career, he has gained experience in hydrology, numerical modeling, flood risk and hazard mapping, assessing the effects of climate change on natural disasters, uncertainty estimation as well as operational flood forecasting systems. His H-factor is 17. He has (co-) authored more than 40 peer-reviewed publications. He has been in the advisory board of numerous international research projects and is currently chair of the Global Flood Partnership Steering Committee. He is currently managing the Copernicus Emergency Management Service with a specific focus on the European and Global Flood Awareness Systems.

Selected publications:

- Alfieri, L., Bisselink, B., Dottori, F., Naumann, G., de Roo, A., **Salamon**, P., Wyser, K., Feyen, L. Global projections of river flood risk in a warmer world. (2017) Earth's Future, 5 (2), pp. 171-182.
- Dottori, F., **Salamon**, P., Bianchi, A., Alfieri, L., Hirpa, F.A., Feyen, L. Development and evaluation of a framework for global flood hazard mapping (2016) Advances in Water Resources, 94, pp. 87-102.
- Alfieri, L., Feyen, L., **Salamon**, P., Thielen, J., Bianchi, A., Dottori, F., Burek, P. Modelling the socio-economic impact of river floods in Europe (2016) Natural Hazards and Earth System Sciences, 16 (6), pp. 1401-1411.
- Ward, P.J., Jongman, B., **Salamon**, P., Simpson, A., Bates, P., De Groeve, T., Muis, S., De Perez, E.C., Rudari, R., Trigg, M.A., Winsemius, H.C. Usefulness and limitations of global flood risk models (2015) Nature Climate Change, 5 (8), pp. 712-715.

Andrea Toreti (M) is a senior scientist of the European Commission Joint Research Centre. He graduated in Mathematics at the University of Rome 'La Sapienza' and got a Ph.D. in Climate Sciences at the University of Bern. He was scientific researcher at the Italian Institute for Environmental Protection and Research, post-doc scientific researcher at the University of Bern and Ass. Professor at the University of Giessen. He is an expert on: climate dynamics; climate extremes, climate variability, climate change and impacts on agriculture; seasonal-to-decadal prediction; statistical climatology. He has been involved in several FP6, FP7, Life and H2020 projects and he is a member of the MedCLIVAR and MEDECC steering committees. In 2011, he was awarded by the European Science Foundation-MedCLIVAR for his important contribution on the understanding of climate extremes in the Mediterranean region. He has co-authored more than 40 peer-reviewed publications.

Selected publications:

- Ceglar, A. **Toreti**, C. Prodhomme, M. Zampieri, M. Turco, F.J. Doblas-Reyes. 2018. Land-surface initialisation improves seasonal climate prediction skill for maize yield forecast. Scientific Report 8, 1322
- **Toreti**, P. Giannakaki, O. Martius. 2016. Precipitation extremes in the Mediterranean region and associated upper-level synoptic-scale flow structures. Climate Dynamics, 925-1941.
- **Toreti** and P. Naveau. 2015. On the evaluation of climate model simulated precipitation extremes. Environmental Research Letters 10, 014012.
- **Toreti** et al. 2013. Projections of global changes in precipitation extremes from CMIP5 models. Geophysical Research Letters 40, 4887-4892

Thomas Diehl (M) has 20 years of experience in the field of climate modeling. He is an expert in the use of high-performance computing facilities to run complex climate simulations, and has in-depth experience with both fully coupled Earth System Models, Land Models, and CTMs. Currently, he conducts research to advance the understanding of climate change impacts on Arctic and Boreal terrestrial ecosystems and permafrost thawing, and potential feedback of ecosystem and soil processes to global warming. Prior to his current role at JRC, he worked at the NASA Goddard Space Flight Center (USA) and the Max Planck Institute for Meteorology (Germany), where he focused on aerosol research, the compilation of emission inventories, atmospheric chemistry modeling, and Earth System model development. He has chaired the group on User Requirements for a Copernicus Polar Mission.

Alessandro Dosio (M) is an expert in regional climate change modelling and its linkage to impact models. He is active in the World Climate Research Programme such as the Coordinated Regional climate Downscaling Experiment (CORDEX) aimed at producing high resolution climate change projections for all the land areas of the world (focusing primarily on Africa and Europe) by means of downscaling the IPCC AR5 CMIP5 Global Circulation Models. He is responsible for delivering 'tailor-made' climate change projections to a range of JRC users for the assessment of the impact of climate change on several sectors (floods, forest fires, agriculture).

- **Dosio** A., H-J Panitz: Dynamically downscaling of CMPI5 CGMs over CORDEX-Africa with COSMO-CLM: analysis of the climate change signal and differences with the driving GCMs, *Clim. Dyn. 2018.*
- **Dosio**, A., & Paruolo, P. (2011) Bias correction of the ENSEMBLES high-resolution climate change projections for use by impact models: Evaluation on the present climate. *Journal of Geophysical Research D: Atmospheres*, 116(16), DOI: 10.1029/2011JD015934.

4.1.12 Barcelona Supercomputing Center

4.1.12.1 Brief description of organisation

The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC-CNS) was established in 2005 and is a key element of and coordinates the Spanish Supercomputing Network, which is the main framework for granting competitive HPC time to Spanish research institutions. Furthermore, BSC is one of seven hosting nodes in France, Germany, Switzerland, Italy and Spain that form the core of the Partnership for Advanced Computing in Europe (PRACE) network. PRACE provides competitive computing time on world-class supercomputers to researchers in the 25 European member countries.

4.1.12.2 Excellence

The Center houses Mare Nostrum 4, one of the most powerful supercomputers in Europe with 48,128 cores and 11.15 Pflops capacity. The mission of BSC is to research, develop and manage information technologies to facilitate scientific progress. BSC combines HPC service provision, and R&D into both computer and computational science (life, earth and engineering sciences) under one roof and currently has over 450 staff from

44 countries. BSC has collaborated with industry since its creation and participates in various bilateral joint research centers with companies such as IBM, Microsoft, Intel, NVIDIA and Spanish oil company Repsol. The Center has been extremely active in the EC Framework Programs and has participated in over 100 projects funded by it. BSC is a founding member of HiPEAC, the ETP4HPC and other international fora.

4.1.12.3 Personnel

Francisco Doblas-Reyes (M) obtained a PhD Universidad Complutense de Madrid (Spain) in 1992. He is an ICREA research professor and leads ES-BSC, a Department hosts that hosts more than 70 engineers, physicists, mathematicians and social scientists who try to bring the latest developments in supercomputing and data analysis to provide the best information and services on climate and air quality.

Albert Soret (M) holds a PhD in Environmental Engineering from the Polytechnic University of Catalonia (Barcelona). He is head of the Services group at ES-BSC. The group tries to bring the latest developments in earth sciences to society to advance sustainable development in key sectors such as energy, urban development, infrastructure, transport, health, and agriculture and water management.

Kim Serradell Maronda (M) is currently managing the Computational Earth Sciences group at ES-BSC. He is responsible of supervising the operational runs of the NMMB/BSC-CTM model and CALIOPE Air Quality System at BSC. His activity focuses in deploying different earth system models (dust transport, climate or weather forecast) required by the department in a wide range of HPC architectures.

Selected team publications:

- Tintó, O., M.C. Acosta. M. Castrillo, A. Cortes, A. Sanchez, K. Serradell and F.J. **Doblas-Reyes** (2017). Optimizing domain decomposition in an ocean model: the case of NEMO. Procedia of Computer Sciences, 108, 776-785, doi:10.1016/j.procs.2017.05.257.
- Ceglar, A., A. Toreti, C. Prodhomme, M. Zampieri, M. Turco and F.J. **Doblas-Reyes** (2018). Land-surface initialisation improves seasonal climate prediction skill for maize yield forecast. Scientific Reports, 8, doi:10.1038/s41598-018-19586-6.
- Lledó, Ll., O. Bellprat, F.J. **Doblas-Reyes** and A. Soret (2018). Investigating the effects of Pacific sea surface temperatures on the wind drought of 2015 over the United States. Journal of Geophysical Research Atmospheres, doi: 10.1029/2017JD028019.
- Badia, A., O. Jorba, A. Voulgarakis, D. Dabdub, C. Pérez García-Pando, A. Hilboll, M. Gonçalves and Z. Janjic (2017). Description and evaluation of the Multiscale Online Nonhydrostatic AtmospheRe CHemistry model (NMMB-MONARCH) version 1.0: gas-phase chemistry at global scale. Geoscientific Model Development, 10, 609-638, doi:10.5194/gmd-10-609-2017.
- Caron, L.-P., L. Hermanson, A. Dobbin, J. Imbers, L. Lledó and G.A. Vecchi (2017). How skilful are the multi-annual forecasts of Atlantic hurricane activity? Bulletin of the American Meteorological Society, doi:10.1175/BAMS-D-17-0025.1
- Christel, I., D. Hemment, D. Bojovic, F. Cucchiettia, L. Calvoa, M. Stefaner and C. Buontempo (2017). Introducing design in the development of effective climate services. Climate Services, doi:10.1016/j.cliser.2017.06.002.
- Di Tomaso, E., N.A.J. Schutgens, O. Jorba, and C. Pérez García-Pando (2017). Assimilation of MODIS Dark Target and Deep Blue observations in the dust aerosol component of NMMB-MONARCH version 1.0. Geosci. Model Dev., 10, 1107-1129, https://doi.org/10.5194/gmd-10-1107-2017.
- Guevara, M., López-Aparicio, S., Cuvelier, C., Tarrason, L., Clappier, A., Thunis, P. (2017). A benchmarking tool to screen and compare bottom-up and top-down atmospheric emission inventories. Air Quality, Atmosphere & Health, 10, 627-642, doi:10.1007/s11869-016-0456-6.
- Lawrence, B. N., M. Rezny, R. Budich, P. Bauer, J. Behrens, M. Carter, W. Deconinck, R. Ford, C. Maynard, S. Mullerworth, C. Osuna, A. Porter, K. Serradell, S. Valcke, N. Wedi and S. Wilson (2017). Crossing the Chasm: How to develop weather and climate models for next generation computers?, Geoscientific Model Development Discussion, doi:10.5194/gmd-2017-186.
- Bellprat, O. and F.J. **Doblas-Reyes** (2016). Attribution of extreme weather and climate events overestimated by unreliable climate simulations. Geophysical Research Letters, 43, 2158-2164, doi:10.1002/2015GL067189.
- Massonnet, F., O. Bellprat, V. Guemas and F. J. **Doblas-Reyes** (2016). Using climate models to estimate the quality of global observational data sets. Science, 6311, 452-455, doi:10.1126/science.aaf6369.
- Prodhomme, C., L. Batté, F. Massonnet, P. Davini, O. Bellprat, V. Guemas, and F.J**. Doblas-Reyes** (2016). Benefits of increasing the model resolution for the seasonal forecast quality in EC-Earth. Journal of Climate, 29, 9141-9162, doi:10.1175/JCLI-D-16-0117.1

4.1.13 Red Cross Red Crescent Climate Centre

4.1.13.1 Brief description of organisation

The Red Cross Red Crescent Climate Centre (RedC) supports the Red Cross and Red Crescent Movement and its partners in reducing the impacts of climate change and extreme weather events on vulnerable people. The Climate Centre works at the interface of science, policy and practice, shaping research and international policy discussions on climate risk management. On the ground, they provide practical support to Red Cross Red Crescent Societies in 191 countries, collaborating with governments, multilaterals, universities and civil society.

4.1.13.2 Excellence

The Climate Centre is pioneering a climate risk management strategy called Forecast-based Financing, which ensures humanitarian funding is available when there is a weather or climate forecast of a potential disaster. The Climate Centre has supported the launch of a new international fund for forecast-based action, and is developing programmes in more than 20 countries to automatically trigger humanitarian action when forecasts indicate high risk of extreme events. Positively received at the Third UN World Conference on Disaster Risk Reduction and

multiple Conference of Parties to the United Nations Convention on Climate Change, the humanitarian sector has pledged to rapidly scale up its work on Forecast-based Financing during the World Humanitarian Summit in 2016. The Climate Centre also supports the humanitarian and development sectors to address long term climate risk management, holding international roles as knowledge manager in the Building Resilience for Climate Extremes and Disasters (BRACED) programme, and climate risk partner in the Partners for Resilience Programme. This work includes the development of shock-responsive social protection systems, Reality of Resilience work around learning from climate extremes; a Climate and Weather Information Helpdesk; and facilitation of dialogue among scientists and disaster managers.

4.1.13.3 Personnel

Erin Coughlan de Perez (F) is the manager of the climate science team at RedC, where she researches the physical science of and adaptation to extreme events. Recent projects under Erin's leadership emphasize the use of short-term climate and weather information to establish Forecast-based Financing systems for the long term. Erin will be involved in developing the Societal Impacts work package, with a focus on climate risk management in health, disasters, food security, and shelter.

Selected publications:

- **Coughlan de Perez**, E., Stephens, E., Bischiniotis, K., van Aalst, M., van den Hurk, B., Mason, S., Nissan, H. and Pappenberger, F. (2017). Should seasonal rainfall forecasts be used for flood preparedness? Hydrology and Earth System Sciences. ISSN 1027-5606 (In Press)
- Nissan H., Burkart K., **Coughlan de Perez** E,, van Aalst M, Mason S. (2017). Defining and Predicting Heat Waves in Bangladesh. *J Appl Meteorol Climatol*. 2653-2670. doi:10.1175/JAMC-D-17-0035.1.
- **Coughlan de Perez** E., van den Hurk B., van Aalst M., et al. (2016). Action-based flood forecasting for triggering humanitarian action. *Hydrol Earth Syst Sci*. 2016:3549-3560. doi:10.5194/hess-20-3549-2016.
- **Coughlan de Perez** E., and Mason S. (2014). Climate Information for Humanitarian Agencies: Some Basic Principles. *Earth Perspectives* 1 (1): 11. doi:10.1186/2194-6434-1-11.
- **Coughlan de Perez**, E, Monasso F, van Aalst M, and Suarez P. 2014. Science to Prevent Disasters. *Nature Geoscience* 7: 78–79. doi:10.1038/ngeo2081.

Maarten K. van Aalst (M) is the Director at RedC; his research and applied work has emphasized climate risk management, adaptation, loss and damage, attribution of extremes and science-based communication and decision-making. He is a member of the UN Secretary-General's *A2R* Leadership Group and advisor on climate risk management to the World Bank and African Development Bank. He will be involved in the mobilization of risk management stakeholders to co-design ExtremeEarth-PP outputs.

Selected publications:

- Field, C.B., V.R. Barros, K.J. Mach, M.D. Mastrandrea, M. **van Aalst**, et al. (2014) Technical summary. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC [Field, C.B., et al. (eds.)]. Cambridge University Press.
- Costella, C., Jaime, C., Arrighi, J., de Perez, E. C., Suarez, P., & **van Aalst**, M. (2017). Scalable and Sustainable: How to Build Anticipatory Capacity into Social Protection Systems. IDS Bulletin, 48(4).
- Suarez, P., & **van Aalst,** M. K. (2017). Geoengineering: A humanitarian concern. Earth's Future, 5(2), 183-195.
- IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 3-21.
- Ward, P.J., Jongman B., Salamon P., Simpson A., Bates P., De Groeve T., Muis S., Coughlan de Perez E., Rudari R., Trigg M., Winsemius H. (2015). Usefulness and Limitations of Global Flood Risk Models. *Nature Climate Change* 5 (8). Nature Publishing Group: 712–15. doi:10.1038/nclimate2742

4.1.14 UK Research and Innovation

4.1.14.1 Brief description of organisation

The British Geological Survey (BGS) and National Centre for Atmospheric Science are component organisations of UK Research and Innovation (UKRI) which brings together seven UK Research Councils (AHRC, BBSRC, EPSRC, ESRC, MRC, NERC, STFC) plus Innovate UK and Research England. UK Research and Innovation ensures the UK maintains its world-leading position in research and innovation. The Natural Environment Research Council (NERC) includes several research centres that will participate in the consortium. These include: The British Geological Survey (BGS, participant John Ludden) the National Centre for Atmospheric sciences (participant Stephen Mobbs); the Centre for Environment and Hydrology (CEH), the National Oceanographic Centre (NOC) and the National Centre for Earth Observation (NCEO), the British Antarctic Survey: These NERC Research Centres share a common data sharing system via NERC. All are publicly-funded organisations responsible for advising the UK government on all aspects of geosciences, as well as providing impartial geological advice to industry, academia and the public. They are UK's premier providers of objective and authoritative

geoscientific and environmental data.

4.1.14.2 Excellence

NERC research centre partners bring access to the entire UK environmental data systems, including links with global programmes in the areas of geoscience environmental science including meteorology. All seven NERC centres run data services that link to a common platform and UK based supercomputing and super-data-cluster hubs, such as JASMIN.

4.1.14.3 Personnel

John Ludden (M) is Executive Director of the British Geological Survey. Previously Director of the Earth Sciences Division at the French National Centre for Scientific Research (CNRS). Prof. Ludden has long been active in European and international geoscience, amongst other responsibilities serving as President of the European Geosciences Union from 2005 to 2007 and as the President of EuroGeoSurveys. He brings extensive links in the European geoscience realm.

Selected publications:

- **Ludden**, John; Peach, Denis; Flight, Dee. 2015 Geochemically based solutions for urban society: London, a case study. *Elements*, 11 (4). 253-258. https://doi.org/10.2113/gselements.11.4.253
- Lambert, Ian; Durrheim, Ray; Godoy, Marcio; Kota, Mxolisi; Lehy, Pat; **Ludden**, John; Nickless, Edmund; Oberhaesli, Roland; Anjian, Wang; Williams, Neil. 2013 Resourcing future generations: a proposed new IUGS initiative. *Episodes*, 36 (2). 4, pp.
- **Ludden**, John. 2009 Subduction fluxes through geologic time. *Applied Geochemistry*, 24 (6). 1052-1057. https://doi.org/10.1016/j.apgeochem.2009.02.015
- **Ludden**, John. 2009 Surveying the future : applied geoscience for our changing Earth. *Geoscientist*, 19 (1). 4.
- Stephenson, Michael; Hough, Edward; Riley, Nicholas; **Ludden**, John. *Why is shale gas on the UK energy agenda now?* 27 June 2013, http://www.youtube.com/watch?v=8XOzANhTZLo [Output (Electronic)]

Stephen Mobbs (M) is Director of the National Centre for Atmospheric Science (NCAS). Prof. Mobbs has extensive experience managing and undertaking research an innovation in weather science, atmospheric observations and modelling the atmosphere and related coupled components of the Earth system. NCAS has research programmes in climate, weather and air quality science.

Selected publications:

- Gadian, A., Blyth, A., Bruyere, C., Burton, R., Done, J., Groves, J., Holland, G., **Mobbs**, DS., Thielen-del Pozo, J., Tye, M., Warner, J., 2018, A case study of possible future summer convective precipitation over the UK and Europe from a regional climate projection. *International Journal of Climatology*, 38, 2314-2324, doi: 10.1002/joc.5336
- Lee, J., **Mobbs**, S., Wellpott, A., Allen, G., Bauguitte, S., Burton, R., Camilli, R., Coe, H., Fisher, R., Freance, J., Gallagher, M., Hopkins, J., Lanoiselle, M., Lewis, A., Lowry, D., Nisbet, E., Purvis, R., O'Shea, S., Pyle, J., Ryerson, T., 2018. Flow rate and source reservoir identification from airborne chemical sampling of the uncontrolled Elgin platform gas release. *Atmospheric Measurement Techniques*, 11, 1725-1739. doi: 10.5194/amt-11-1725-2018.
- Burton, R., Dudhia, J., Gadian, A., **Mobbs**, S., 2017. The use of a numerical weather prediction model to simulate the release of a dense gas with an application to the Lake Nyos disaster of 1986. *Meteorological Applications*, 24, 43-51, doi: 10.1002/met.1603.
- Armstrong, A., Burton, R., Lee, S., **Mobbs**, S., Ostle, N., Smith, V., Waldron, S., Whitaker, J., 2016. Ground-level climate at a peatland wind farm in Scotland is affected by wind turbine operation. *Environmental Research Letters*, 11, doi: 10.1088/1748-9326/11/4/044024
- Smith, V., **Mobbs**, S., Burton, R., Hobby, M., Aoshima, F., Wulfmeyer, V., DiGirolamo, P., 2015. The role of orography in the regeneration of convection: A case study from the convective and orographically-induced precipitation study. *Meteorologische Zeitschrift*, 24, 83-97, doi: 10.1127/metz/2014/0418.

Bryan Lawrence (M) is the NCAS Director for Models and Data. He is responsible for the NCAS provisions of environmental data services, including curation, archival and analysis services. He pioneered the development of the JASMIN super-data-cluster facility providing high level data analysis tools in close proximity to the storage of PByte-scale data storage. Professor Lawrence has extensive expertise and experience in environmental data analytics and HPC applications.

Selected publications:

- **Lawrence**, B.N. et al. 2018. Crossing the chasm: how to develop weather and climate models for next generation computers?, *Geoscientific Model Development*, 11, 1799-1821.
- Balaji, V., Maisonnave, E., Zadeh, N., **Lawrence**, B.N. 2017. CPMIP: measurements of real computational performance of Earth system models in CMIP6, *Geosci. Model Dev*., 10, 19–34.
- Eyring, V., Gleckler, P.J., Heinze, C., Stouffer, R.J., Taylor, K.E., Balaji, V., Guilyardi, E., Joussaume, S., Kindermann, S., **Lawrence**, B.N., Meehl, G.A., Righi, M., Williams, D.N. 2016. Towards improved and more routine Earth system model evaluation in CMIP. *Earth System Dynamics*, 7, 813-830.
- **Lawrence**, B., Jones, C., Matthews, B., Pepler, S., Callaghan, S. 2011. Citation and peer review of data: Moving towards formal data publication. *International Journal of Digital Curation*, 6, 4-36.
- Mizielinski, M.S., Roberts, M.J., Vidale, P.L., Schiemann, R., Demory, M., Strachan, J., Edwards, T., Stephens, A., **Lawrence**, B.N., Pritchard, M., Chiu, P., Iwi, A., Churchill, J., del Cano Novales, C., Kettleborough, J., Roseblade, W., Selwood, P., Foster, M., Glover, M., Malcolm, A. 2014. High resolution global climate modelling; the UPSCALE project, a large simulation campaign Geoscientific Model Development, 7, 1629-1640.

Michelle Bentham (F) is Head of Partnerships and Innovation for the British Geological Survey. She develops

strategic partnerships that bring together business, government and civil society with BGS scientists to address the challenges and opportunities of managing the environment. She also works to develop opportunities to innovate for UK business and societal wellbeing. Michelle has a background in energy geoscience with a focus on carbon capture and storage (CCS).

Laura Platt (F) is the Science Grants Coordinator for UKRI-BGS covering pre-award support and funding landscape understanding across BGS. She has enhanced knowledge of UK, EU and International research funding schemes. She has previously worked as a Research Scientist in both academia and industry addressing clean energy solutions.

4.1.15 Universiteit Utrech

4.1.15.1 Brief description of organisation

The Department of Earth Sciences at the Universiteit Utrech (UUT) is the largest academic Earth Sciences institute in the Netherlands, and among the larger ones in Europe. Its staff of about 200 researchers and PhD students has created an international centre of excellence in scientific research and research training that actively contributes to addressing the challenges we face in developing a modern, sustainable society. In the latest Dutch research review (www.qanu.nl), the Department has been described as a gem in scientific world of the Netherlands. In international Earth Science rankings over recent years, the Department is consistently found among the top in Europe. In seismology, the Department is world-leading with contributions in computational techniques, data assimilation and data mining. The Department of Earth Sciences at the University of Utrecht studies the system Earth and other planets and contributes to answers on socio-economic questions concerning natural resources (water, energy, raw materials), the terrestrial environment (including remediation of pollutions), natural hazards (such as earthquakes, volcanic eruptions, and floods), and the use of terrestrial space (specifically near surface and underground space). Our research programmes integrate the principles and methods of physics, chemistry, geology, biology, mathematics, and computational sciences. We specifically develop new scientific hypotheses, methods of data analyses, and experimental and observational techniques that enable us to reconstruct and predict the interactive behaviour of the solid Earth, the biosphere, the hydrosphere, and the atmosphere, on scales ranging from seconds to billions of years, and from nanometers to the entire globe.

4.1.15.2 Excellence

The seismology group at Utrecht University studies seismic events and the Earth's interior at all scales. We extract information from earthquakes or seismic noise recorded at global and regional seismic networks to produce three-dimensional models of the Earth's interior and/or the physics of the seismic source, mostly using super-computing. We developed many state-of-the-art tools for full waveform inversion and earthquake forecasting. Much of our work is methodological, with special emphasis on uncertainty analysis and data assimilation. We contributed community tools to the efficient calculation of the Hessian using higher order adjoints, mathematical up-scaling in full waveform inversion, and recently introduced machine learning techniques in seismology. Using machine learning, we showed that it is possible to invert chaotic flow systems and booked first success in quantitative forecasting of earthquakes.

4.1.15.3 Personnel

Jeannot Trampert (M) joined the University of Utrecht in 1996, where since 2015 he is Head of Department of Earth Sciences. His expertise is in seismic wave propagation, inverse theory, data processing and machine learning. He is a (co-)author of over 100 research papers and has an H-index of 42 (Scopus). He received the 'Grand Prix des Sciences Geologiques' in Luxembourg and is an elected member of Academia Europaea and the Royal Netherlands Academy of Arts and Sciences. He received several prestigious personal grants, most recently a Top-subsidy from the Dutch Science Foundation and an ERC Advanced Grant.

Selected publications:

- Kaeufl P., Valentine A.P., **Trampert** J., 2016. Probabilistic point source inversion of strong-motion data in 3-D media using pattern recognition—a case study for the 2008 Mw 5.4 Chino Hills earthquake, Geophys. Res. Lett., 43, doi:10.1002/2016GL069887.
- Kaeufl P., Valentine A.P., de Wit R.W.L., **Trampert** J., 2016. Solving probabilistic inverse problems rapidly with prior samples, Geophys. J. Int., 205, 1710–1728.
- Rickers F., Fichtner A., **Trampert** J., 2013. The Iceland - Jan Mayen plume system and its impact on mantle dynamics in the North Atlantic region: Evidence from full waveform inversion, Earth Planet. Sci. Lett., 367, 39-51.
- Fichtner A., **Trampert** J., 2011. Resolution analysis in full waveform inversion, Geophys. J. Int., 187, 1604-1624.
- **Trampert** J., Deschamps F., Resovsky J., Yuen D., 2004. Probabilistic tomography maps chemical heterogeneities throughout the lower mantle, Science, 306, 853-856.

4.1.16 Météo-France

4.1.16.1 Brief description of organisation

Météo-France is the French national meteorological service. With around 3000 permanent staff, it provides a full range of weather and climate related services, from free forecasts and weather alerts for all citizens to bespoke products for professional clients. It is the acknowledged weather service provider of several French government organizations such as air traffic control, civil security, armed forces wherever they operate, etc. Météo-France maintains a 24h/7d watch of weather evolution, supported by its dual polarization Doppler radar network and other observation systems as well as direct reception of data from many satellite instruments. Météo-France is heavily involved in the main satellites programmes of EUMETSAT, CNES and Earth observations missions of ESA, NASA and other space agencies worldwide. France is a founding member state of ECMWF and is represented at ECMWF Council by Météo-France. Moreover, somewhat uniquely amongst ECMWF member states, Météo-France co-develops and shares the global forecasting system computer code suite. Together with about 25 national weather services from Europe (including Turkey) and North-Africa, Météo-France has co-developed limited area, very high scale options of that same code suite. As a result, Météo-France produces its own global and local short-range forecasts and relies on ECMWF for medium and long range. Météo-France also operates a full climate modelling system and is a contributor to IPCC assessment reports. Its derived seasonal forecast suite as well as its atmospheric composition models enable it to contribute to the C3S and CAMS Copernicus services. Météo-France also operates large catchments hydrological models, wave, sea-level and drift models as well as a complete mountain weather forecast suite. To run these services, Météo-France operates one of the most powerful computer centres in France: when last upgraded in 2016, Météo-France appeared to be 2nd French overall, and 10th weather or climate worldwide, computing centre.

4.1.16.2 Excellence

Météo-France has expertise in optimising the use of a high-performance computer through suitable algorithmic approaches for both weather forecasting and climate studies, actual operational experience with kilometric scale data assimilation and atmospheric and surface modelling, deriving and providing services from such short-range forecasts, preparing, running global and regional climate simulations and scenarios, scientifically exploiting and deriving climate services from them. The limited area kilometric scale know-how is being extended to local climate projections. The global weather forecast, seasonal forecast and high-resolution local systems all exist in ensemble form. Météo-France has also been pioneering the use of ensembles in variational data assimilation. Perhaps most relevant to ExtremeEarth, Météo-France has a long experience of software co-development: it has developed a set of physical parameterizations for representing surface and atmospheric processes at kilometric scales in close cooperation with the French and European scientific atmospheric research community. It is running a dynamical core fit for the same scales co-developed with several European national meteorological services, all this in a framework shared with ECMWF.

4.1.16.3 Personnel

David Salas y Melia (M) is head of Météo-France's research group in charge of climate and atmospheric composition modelling. He has more than 20 years of experience in sea ice and coupled climate modelling, with a particular interest in the Arctic climate system and sea level changes. David Salas y Mélia is the author of the sea ice model (Gelato) included in the Atmosphere-Ocean General Circulation Model CNRM-CM and the Earth System Model CNRM-ESM developed by Météo-France in collaboration with CERFACS (Toulouse). He is currently member of the NEMO-Sea Ice Working Group, which is in charge of coordinating the development of the new unified sea ice model within the NEMO ocean model. He used to be member of the scientific committee on French national supercomputing (2007-2015) and is currently the co-director of the French national research infrastructure on climate modelling CLIMERI-France. He has coordinated Météo-France's contributions to the successive phases of the Coupled Model Intercomparison Project (CMIP) since 2003. He is the author or co-author of about 50 peer-reviewed articles. David Salas y Mélia is member of the Editorial Board of the French journal 'La Météorologie'. He often contributes to outreach actions about global climate change and polar regions (grand public scientific journals, books, web-sites, grand public conferences…), and gives various courses on climate change.

Selected publications:

- Ramos Buarque, S. and **Salas y Melia**, D.(2018): Link between the Surface Mass Balance of the Greenland Ice Sheet and the North Atlantic Oscillation under preindustrial and last interglacial climates: a study with a Coupled Global Circulation Model, Clim. Past Discuss., https://doi.org/10.5194/cp-2018-12, in review.
- Séférian, R., C. Delire, B. Decharme, A. Voldoire, D. **Salas y Mélia**, M., Chevallier, D. Saint-Martin, O. Aumont, J.-C. Calvet, D. Carrer, H. Douville, L. Franchistéguy, E. Joetzjer, and S. Sénési (2016). Development and evaluation of CNRM Earth system model – CNRM-ESM1, Geosci. Model Dev., 9, 1423-1453, DOI:10.5194/gmd-9-1423-2016.
- Wang, Q., Mehmet Ilicak, Rüdiger Gerdes, Helge Drange, and 35 co-authors including D. **Salas y Mélia** (2016). An assessment of the Arctic Ocean in a suite of interannual CORE-II simulations. Part I: Sea ice and solid freshwater. Ocean Modelling, 99, 110-132.

- Voldoire, A., E. Sanchez-Gomez, D**. Salas y Mélia**, B. Decharme, C. Cassou, S.Sénési, S. Valcke, I. Beau, A. Alias, M. Chevallier, and 16 co-authors (2013). The CNRM-CM5.1 global climate model : description and basic evaluation , Clim. Dyn., 40(9-10): 2091-2121, DOI:10.1007/s00382-011-1259-y
- **Salas y Mélia**, D. (2002): A global coupled sea ice-ocean model. Ocean Modelling 4, 137-172.

Alain Joly (M) is head of the data assimilation and numerical weather prediction (NWP) research group at Météo-France. He has experience in atmospheric research activities, NWP and computing, weather forecasting, education. Part of his PhD work has been done at the Dept. of Meteorology, Reading University. A. Joly is the author and co-author of more than 30 peer-reviewed scientific journal papers, and has supervised or co-supervised about 10 PhDs. He has been the project manager of the Fronts and Atlantic Storm-Track Experiment (FASTEX), a large international field experiment that has been a step change in observing and understanding the life-cycle of mid-latitude storms from one side of the ocean to the other. As part of this role, A. Joly has coordinated the FP4 EC project that supported the field experiment itself. A. Joly initiated and managed the actual development of the limited-area model called ALADIN. This project had two features: (1) in terms of software, the model is an option fully embedded into the shared ECMWF IFS code; (2) in terms of personpower, the work has been performed with a mixed group of scientists from Météo-France as well as from central and eastern European countries, and later joined by others from Europe and North-Africa. The vision of the "political" and scientific manager, Dr. J.F. Geleyn, was to enable the participating countries to gain the ability to fully master operating their own version of the model, so that the state-of-the-art high-resolution modelling software that is still being produced cooperatively is truly co-owned by the Aladin partners.

Selected publications:

- Termonia, P., Fischer, C., Bazile, E., Bouyssel, F., Brozková, R., Bénard, P., Bochenek, B., Degrauwe, D., Derkova, M., El Khatib, R., Hamdi, R., Masek, J., Pottier, P., Pristov, N., Seity, Y., Smolíková, P., Spaniel, O., Tudor, M., Wang, Y., Wittmann, C., and **Joly**, A., 2018 : The ALADIN System and its Canonical Model Configurations AROME CY41T1 and ALARO CY40T1, Geosci. Model Dev. Discuss, 11, 257–281, 2018, https://doi.org/10.5194/gmd-11-257-2018
- **Joly** A., 2015 : Synoptic meteorology, Extratropical cyclones. In Encyclopedia of atmospheric sciences, second edition, G. North, F. Zhang and J. Pyle editors, collection Major Reference Works, Elsevier, pages 304–336, http ://dx.doi.org/10.1016/B978-0-12-382225-3.00128-6.
- Descamps L., C. Labadie, A. **Joly**, E. Bazile, Ph. Arbogast and P. Cébron, 2015 : PEARP, the Météo-France short-range ensemble prediction system, Quart. J. Roy. Meteor. Soc.,141, 1671–1685, DOI :10.1002/qj.2469.
- Nuissier 0., B. **Joly**, A. Joly, V. Ducrocq, 2011 : A statistical downscaling to identify the large scale circulation patterns associated with heavy precipitation events over southern France. Quart. J. Roy. Meteor. Soc., 137, (660), 1812–1827. DOI :10.1002/qj.866
- **Joly**, A. and P. Santurette, 2001: Turning dynamical ideas into forecast practice, chapter 8, pages 83–105. in Meteorology at the Millenium, R.P. Pearce Ed, Academic Press, 2001; vol. 83 in International Geophysics Series.

4.1.17 Istituto Nazionale Geofisica e Vulcanologia

4.1.17.1 Brief description of organisation

Istituto Nazionale Geofisica e Vulcanologia (INGV-IT) INGV is the largest Italian research institute dedicated to the Earth Sciences, and with about 1000 employees, it is among the largest ones in Europe. The headquarters are in Rome, and several branches are spread over the territory (Milan, Pisa, Bologna, Naples, Palermo, and Catania, plus many other smaller centers and observatories). The mission of INGV includes the study, monitoring and surveillance of geophysical phenomena and their relationship with the environment. INGV is also the reference scientific institution for the Italian Government in the field of geo-hazards, and operates in close synergy with the Italian civil protection authorities at national and local level. To these aims, INGV runs monitoring networks, computational centers, laboratories, and national observatories, and provides data and research in the fields of seismology, volcanology, geodesy, geochemistry, and marine and atmospheric sciences. The Centro Allerta Tsunami (CAT) at INGV is the National Tsunami Warning Centre and a Tsunami Service Provider for the Mediterranean in the framework of the North-eastern Atlantic and Mediterranean Tsunami Warning System coordinated by IOC/UNESCO. The INGV 24/7 national seismic, volcanic and tsunami surveillance services are based on a dense multi-parametric network of monitoring instruments. At European level, INGV hosts the headquarters of two major ESFRI Research Infrastructures: the Coordination Office (ECO) of the European Plate Observing System (EPOS) and the Legal Head Office of the European Multidisciplinary Seafloor Water Column Observatory (EMSO). INGV also manages the two GEO volcano Supersites Mt. Etna and Campi Flegrei/Vesuvius. The scientific organization of INGV involves three departments: Earthquakes, Volcanoes and Environment.

4.1.17.2 Excellence

INGV is internationally recognised as a leading Institute in Solid Earth Geophysics. Founded in 2001, it gathers previous major research Institutes with international re-known expertise and experience, including the Vesuvius Observatory which dates to 1848 and was the first volcano observatory in the world. INGV coordinates or coordinated tens of European projects, including the two major ESFRI Infrastructures EPOS and EMSO, and participates or participated as a major partner to more than hundred others. The INGV Volcano Dynamics

Computational Centre located in Pisa is the world leader in advanced numerical simulations of volcanic processes occurring from the deep regions of the volcanic systems all along the volcano flanks and into the atmosphere. Other important computational centres are located in Rome (mainly for seismicity and tsunami dynamics), Naples and Catania (volcano dynamics), and Bologna (seismicity and volcanoes).

4.1.17.3 Personnel

Paolo Papale (M) is the Director of Research at INGV (Pisa), currently Chair of the Earth and Cosmic Sciences section of the Academia Europaea. Director of the Volcanoes Division of INGV (2013-2016), Head of the Volcanic Hazards Centre of INGV (2016), President of the Geochemistry, Mineralogy, Petrology and Volcanology (GMPV) Division and Council Member of the European Geosciences Union (EGU) (2007-2011), Head of the National Volcanic Hazard Projects (2005-2010). Coordinator of the EU FP7 MC-ITN Project NEMOH, PI and/or WP leader in many other EU Projects. Main field of expertise is volcano physics and dynamics, and numerical modelling and simulation of magmatic and volcanic processes, for which I am Research Director at the Volcano Dynamics Computational Centre of INGV in Pisa. Author of 70+ international publications with h-factor 28 and about 2800 citations.

Selected publications:

- **Papale**, P. Global time-size distribution of volcanic eruptions on Earth. Nature Scientific Reports *8:6838* | DOI:10.1038/s41598-018-25286-y (2018).
- Garg, D., Longo, A., **Papale**, P. Computation of compressible and incompressible flows with a space-time stabilized finite element method. Computers and Mathematics with Applications 75, 4272-4285 (2018).
- **Papale**, P., Montagna, C.P., Longo, A. Pressure evolution in shallow magma chambers upon buoyancy-driven replenishment. Geochemistry, Geophysics, Geosystems 18, 1214-1224 (2017).
- Rutherford, M.J., **Papale**, P. Origin of basalt fire-fountain eruptions on Earth versus the moon. Geology 37, 219-222 (2009).
- **Papale**, P. Strain-induced magma fragmentation in volcanic conduits. Nature 397, 425-428 (1999).

Massimo Cocco (M) is the Director of Research at INGV (Rome). He has been the coordinator of the EPOS Preparatory Phase project and he is presently coordinating the EPOS Implementation Phase project (European Plate Observing System). The EPOS mission is the long-term integration of research infrastructures for solid Earth Science (www.epos-eu.org). His research interests are focused on the physics of earthquakes and faults. More specifically, his work deals with earthquake dynamics and fault interaction, seismicity patterns and fault frictional properties. He is interested in both theoretical studies and observational research. He has interests in all aspects of the mechanics of earthquake and faulting from observations of natural faults through geophysical and geological measurements to experimental faults at the laboratory scale. Author of more than 115 papers on International Scientific Journals. H index = 41.

Selected publications:

- Miller, S.A., C. Collettini, L. Chiaraluce, M. **Cocco**, M. Barchi and M. Kaus (2004). Aftershocks driven by a high pressure CO2 source at depth, Nature, 427.
- Di Toro G, R. Han, T Hirose, N. De Paola, S. Nielsen, K. Mizoguchi, F. Ferri,1 M. **Cocco**, T. Shimamoto (2011) Fault lubrication during earthquakes, Nature, 471, 494–498 (24 March 2011), doi:10.1038/nature09838
- **Cocco** M., Cultrera G., Amato A., Braun T., Cerase A, et al. (2015). In: Geoethics - The Role and Responsibility of Geoscientists. Geological Society London Special Publications 419(1):13 · July 2015 DOI: 10.1144/SP419.13
- **Cocco** M., Tinti E., Cirella A. (2016). On the scale dependence of earthquake stress drop. Journal of Seismology 20 (3) July 2016, DOI 10.1007/s10950-016-9594-4
- Tinti E., Scognamiglio L., Michelini A., **Massimo C.** (2016). Slip heterogeneity and directivity of the ML 6.0, 2016, Amatrice earthquake estimated with rapid finite-fault inversion. Geophysical Research Letters, Volume 43, Issue 20, 28 October 2016 DOI: 10.1002/2016GL071263

Antonio Costa (M) is a researcher at INGV (Bologna). Expert Advisor on Volcanic Hazards for the International Atomic Energy Agency, Asian Nuclear Safety Network, and Italian Civil Protection Department; Scientific Coordinator of the INGV Research Project *Premiale* funded by the Italian Ministry of Education and University (MIUR) Ash-RESILIENCE (2018-2020); Member of the Deep Carbon Observatory (DCO) Task Force 2020 for determining the future of DCO beyond the end of the decadal program and secure DCO's legacies (2016-2018); International Association for Volcanology and Chemistry of the Earth's Interior (IAVCEI) Wager Medalist (2013); Coordinator of the International Eruption Column Model Inter-comparison Study endorsed by the IAVCEI Commission on Tephra Hazard Modelling (2013-2016); WP leader in many other EU and National Projects. His main research interests are coupled fluid-rock dynamics of magmatic and volcanic processes; physical properties of magma; fluid flows in hydrothermal systems; volcanic plume dynamics; tephra dispersal and atmospheric transport of volcanic ash; atmospheric dispersion of volcanic and hydrothermal gases; volcanic lakes; lava flow models; volcanic hazards and risk assessment. Author of 90+ international publications with h-factor 30 and more than 2500 citations.

Selected publications:

- **Costa** A., Suzuki Y.J., Koyaguchi T. (2018) Understanding the plume dynamics of explosive super-eruptions, Nature Comm., 9, 654, doi:10.1038/s41467-018-02901-0
- Chiodini G., Paonita A., Aiuppa A., **Costa** A., Caliro S., De Martino P., Acocella V., Vandemeulebrouck J. (2016) Magmas near the critical degassing pressure drive volcanic unrest towards a critical state, Nature Comm., 7, 13712, doi:10.1038/ncomms13712
- **Costa** A. et al. (2016) Results of the eruption column model inter-comparison study, J. Volcanol. Geotherm. Res., 326, 2-25, doi:10.1016/j.jvolgeores.2016.01.017
- **Costa** A. (2006) Permeability-porosity relationship: a re-examination of the Kozeny-Carman equation based on fractal pore-space geometry, Geophys. Res. Lett., 33, L02318, doi: 10.1029/2005GL025134
- **Costa** A., Macedonio G., Folch A. (2006) A three-dimensional Eulerian model for transport and deposition of volcanic ashes, Earth Planet. Sci. Lett., 241, 634/647, doi:10.1016/j.epsl.2005.11.019

Stefano Lorito (M) is a researcher at INGV (Rome). Member of the INGV coordinating body for the Italian National Tsunami Warning Centre (Centro Allerta Tsunami, CAT); Officer elect (Vice-chair) of ICG-NEAMTWS. INGV PI or WP leader in several EU and National Projects related to tsunami hazard and warning (e.g. RITMARE, ASTARTE, TSUMAPS-NEAM) and within the INGV Agreement with Civil Protection for tsunami hazard and warning. He collaborated in the PTHA for UN-ISDR GAR15 and is involved in the construction of the Global Tsunami Model (GTM). He holds a Degree in Physics and a PhD in Geophysics. His research is focused on Seismic source; tsunami hazard; tsunami warning. Seismologist and tsunamist on shift, and Tsunami Warning Duty Officer on call. He is frequently Editor and Reviewer for International Scientific Journals, Scientific Committee Member and Session Convener for International Conferences, Supervisor for PhD Students and Post-docs, Evaluator for National and International Projects.

Selected publications:

- Grezio, A., Babeyko, A., Baptista, M. A., Behrens, J., Costa, A., Davies, G., Geist, E., Glimsdal, S., Gonzalez, F., Griffin, J., Harbitz, C.B., Leveque, R., **Lorito**, S., Løvholt, F., Omira, R., Mueller, C., Paris, R., Parsons, T., Polet, J., Power, W., Selva. J., Sørensen, M., and Thio, H. K. (2017). Probabilistic tsunami Hazard Analysis: Multiple sources and global applications. Reviews of Geophysics, 55, 1158-1198, doi:10.1002/2017RG000579
- **Lorito**, S., Selva, J., Basili, R., Romano, F., Tiberti, M. M., & Piatanesi, A. (2015). Probabilistic hazard for seismically induced tsunamis: Accuracy and feasibility of inundation maps. Geophysical Journal International, 200(1), 574–588. https://doi.org/10.1093/gji/ggu408
- **Lorito**, S., Romano, F., & Lay, T. (2016). Tsunamigenic earthquakes (2004–2013): Source processes from data inversion. In R. Meyers (Ed.), Encyclopedia of complexity and systems science. New York: Springer Science+Business Media New York 2015. https://doi.org/10.1007/978-3-642-27737-5641-1
- Romano F., E. Trasatti, S. **Lorito**, C. Piromallo, A. Piatanesi, Y. Ito, D. Zhao, K. Hirata, P. Lanucara, and M. Cocco (2014). Structural control on the Tohoku earthquake rupture process investigated by 3D FEM, tsunami and geodetic data. Nature Scientific Reports 4, Article number: 5631 doi:10.1038/srep05631
- **Lorito**, S., F. Romano, S. Atzori, X. Tong, A. Avallone, J. McCloskey, M. Cocco, E. Boschi, and A. Piatanesi (2011), Limited overlap between the seismic gap and coseismic slip of the great 2010 Chile earthquake, Nature Geoscience, 4, 1073, doi:10.1038/NGEO1073

Giovanni Macedonio (M) is a director of Research at INGV (Napoli). Director of the Osservatorio Vesuviano, INGV, (2001-2007), Head of the Volcanic Hazards Centre of INGV (since 2017), Editor of the EGU Journal "Natural Hazards and Earth System Sciences" (since 2000). Member of the Inter-Active Preparatory Council (IAPC) of the EU-EPOS Project. Expertise in volcano physics and dynamics, volcano monitoring data analysis, numerical modeling of volcanic processes, computer science. Author of 65+ international publications with h-factor 30 and about 2500 citations.

Selected publications:

- Costa, A.; Folch, A.; **Macedonio**, G., Quantifying volcanic ash dispersal and impact of the Campanian Ignimbrite super-eruption, Geophysical Research Letters, 39, 2012, doi:10.1029/2012gl051605
- Folch, A.; Costa, A.; **Macedonio**, G., FALL3D: A computational model for transport and deposition of volcanic ash, Computers & Geosciences, 35(6), 1334-1342, 2009, doi:10.1016/j.cageo.2008.08.008
- Folch, A.; Costa, A., **Macedonio**, G., FPLUME-1.0: An integral volcanic plume model accounting for ash aggregation, Geoscientific Model Development, 2016, doi:10.5194/gmd-9-431-2016
- **Macedonio**, G.; Giudicepietro, F.; D'Auria, L.; Martini, M., Sill intrusion as a source mechanism of unrest at volcanic calderas, Journal of Geophysical Research-Solid Earth, 119(5), 3986-4000m 2014, doi:10.1002/2013JB010868
- Costa, A.; Folch, A.; **Macedonio**, G., Density-driven transport in the umbrella region of volcanic clouds: Implications for tephra dispersion models, Geophysical Research Letters, 40(18), 4823-4827, 2013, doi:10.1002/grl.50942

Dr. Andrea Morelli (M) holds a PhD in Physics, he is Chief Scientist at INGV and Adjunct Professor at Bologna University. His interests concentrate on seismic tomography and imaging earth structure at different scales; numerical simulation of seismic ground motion in realistic media; seismological studies of glacial and urbal environments. He is currently director of the INGV Center for monitoring underground energy technologies. He coordinated and participated to many EU and national research projects. He served in several panels for the evaluation of research.

Selected publications:

- Baron, J., and A. **Morelli**, 2017, Full-waveform seismic tomography of the Vrancea, Romania, subduction region, Phys. Earth Planet. Int., 273, 36-49, doi: 10.1016/j.pepi.2017.10.009

- Berbellini, A., A. **Morelli**, and A.M.G. Ferreira, 2016, Ellipticity of Rayleigh waves in basin and hard-rock sites in Northern Italy, Geophys. J. Int., 206, 395-407, doi: 10.1093/gji/ggw159
- Gualtieri, L. and Stutzmann, E. and Capdeville, Y. and Farra, V. and Mangeney, A. and **Morelli**, A., 2015, On the shaping factors of the secondary microseismic wavefield, Journal of Geophysical Research: Solid Earth, 120, 9, 624-6262, doi:10.1002/2015JB012157
- Molinari, I., Argnani, A., **Morelli**, A., Basini, P. Development and testing of a 3D seismic velocity model of the Po Plain sedimentary basin, Italy, Bulletin of the Seismological Society of Am., April 2015 105:753-764
- Gualtieri L., P. Serretti, and A. **Morelli**, 2014, Finite-difference P-wave travel time seismic tomography of the crust and uppermost mantle in the Italian region, Geochemistry, Geophysics, Geosystems, 15, 69-88, DOI: 10.1002/2013GC004988

4.1.18 University of Helsinki

4.1.18.1 Brief description of organisation

Institute for Atmospheric and Earth System Research (INAR) at the University of Helsinki has over 30 years of experience in atmospheric research. 150 scientists and doctoral students are currently engaged in this area. The main research subjects are aerosol dynamics, atmospheric chemistry, climate change, dynamic and radar meteorology, forest-atmosphere interactions, aerosol-cloud-climate interactions, and urban air quality. With the multidisciplinary team structure and comprehensive measurement and modeling tools, INAR is one of the few groups in the World capable of efficiently combining the climate change, greenhouse gases, trace gases, aerosol processes and vegetation processes. The INARs significant infrastructure, and/or major items of technical equipment are: (i) field station network (ii) laboratories, (iii) modeling & super-computer capacity, including remote sensing data and airborne measurements. We operate four field stations in Finland called the SMEAR (Station for Measuring Forest Ecosystem Atmosphere Relations) stations. The *SMEAR II* is the world leading station due to its comprehensive research program and due to its unique time series of aerosol formation and biogeochemical fluxes. For the Global coverage, we analyse data from several field sites in "climate space" to identify and prioritize key gaps in understanding of global features in the climate change. We are intensively involved with a super-site concept development in Europe and outside Europe incl. in China (Nanjing, Beijing), Estonia (Järvselja), South Africa (Welgegund), Italy (San Pietro Capofiume), India (Gual Pahari) and Saudi Arabia (Jeddah). Via Pan Eurasian Experiment (PEEX) program UHEL provide a unique set of data to be utilized for the atmosphere -ecosystem research in the circumpolar Arctic-boreal context. INAR has three laboratories: (i) Aerosol Particle Laboratory: mass spectrometers, particle generators, aerosol, cluster and ion spectrometers, and equipment for analysing the hygroscopic properties and volatility of aerosol particles, characterization of novel instrumentation, calibration, optimization, (ii) Ecophysiological laboratory: growth chambers, mini-rhizotrons, physiological measurement systems with stable isotope equipment, (iii) and Laboratory of Analytical Chemistry: a suite of commercial and self-modified/self-constructed instruments, incl. aerosol mass spectrometry, portable gas chromatography-mass spectrometry, multidimensional chromatographic techniques, size-selective sampling, combination of mass spectrometry and chromatography. The available models establish a hierarchy reaching across the scales of UHEL research, e.g. ECHAM-HAM, SALSA, MALTE, JSBACH, GLOMAP, MPI-ESM. The model framework gives us an opportunity to develop and combine models operating at different spatial and temporal scales. IT Center for Science Ltd (CSC) as a workflow and computing infrastructure topics partner, has an active role in the ESM and Large Eddy Simulations.

4.1.18.2 Excellence

INAR has expertise in the several areas of the Earth system; atmosphere, climate feedbacks, and air quality-climate interactions It is involved in several Euroepan and international research projects such as GlobalSMEAR and European ESFRIs (ACTRIS; ICOS; ANAEE, ELTER). It also has extensive expertise in instrument technology.

Expertise in land-atmosphere interaction and feedbacks initiates from the feedback hypothesis relevant to boreal and Mediterranean and Arctic marine environments. The COBACC (COntinental Biosphere-Aerosol-Cloud-Climate) feedback hypothesis is relevant in the Northern Eurasian regions. The COBACC is related to climate change, and a comprehensive multi-pollutant approach to air quality and has two major overlapping loops. First, increased CO_2 levels increase plant gross primary production (GPP) and therefore carbon sink, that enhances, via emitted biogenic volatile organic compounds (BVOC), secondary organic aerosol (SOA) formation, the condensation sink, total aerosol volume and surface area in the atmosphere. These atmospheric aerosols increase the share of diffuse solar radiation, which further increases plant GPP. In the second loop, increased CO_2 levels increase, via BVOC and SOA, cloud condensation nuclei in the atmosphere and further cloud droplet number concentration. This will regionally, at least partly, offset global warming. Thus, the COBACC feedback is a broad framework that connects human activities, the continental biosphere, and changing climate conditions.

The Global SMEAR (Stations Measuring Earth Surfaces - Atmosphere Relations) initiative is an approach towards integrated Global Earth observatory coordinated by INAR, University of Helsinki. The SMEAR concept is supporting the implementation of the Global SMEAR initiative. The SMEAR (Stations for Measuring Earth surface - Atmosphere Relations) Concept offers an integrated observation platform that provides continuous,

comprehensive environmental information from local level up-to the global Grand Challenges. Combining data from these comprehensive stations with the data from satellite-based remote sensing, laboratory experiments and computer models would enable to us to track and quantify land – atmosphere – ocean feedbacks and solve the air quality chemistry and physics at regional and global scales. The prototype of the most well-equipped station implementing the SMEAR Concept is the SMEAR II station. SMEAR II station has been a major contributor to several Pan-European research infrastructure design, integrated activity and preparation projects that are currently on the ESFRI Roadmap, such as ICOS, AnaEE and eLTER.

The core of the INAR innovation activity is focused in the development, refinement and utilization of innovative, world-leading measurement techniques and networks, including: multiscale measurements from nano- to global scales; revolutionizing detection of rare trace gases, clusters and aerosol particles; portable and low-power instrument design for remote environments; drones in aerosol and ecosystem measurements; low-cost sensors for in situ active fluorescence measurements; and, establishing polar marine and mountain-top observation station networks. These core technologies of the atmosphere – Earth surface monitoring can be applied in several other domains. We have established spin-off companies, for example, Airmodus provides aerosol particle counters and mass spectrometer products; Karsa produces detectors of trace amounts of explosives for air cargo and other safety purposes; and SMEAR Ltd. provides infrastructures and services needed for spreading the Global SMEAR. The Future and Emerging Technologies (FET) are expected especially in mass spectrometers, aerosol instrumentation and multi-source data integration.

4.1.18.3 Personnel

Markku Kulmala (M) directs the Institute for Atmospheric and Earth System Research (INAR) at the University of Helsinki and has served as a professor at the University of Helsinki since 1996. Kulmala also acts as coordinator for the Centre of Excellence, appointed by the Academy of Finland first time in 2002 and for Nordic Center of Excellence, appointed by Nordforsk (CRAICC), which is the largest joint Nordic research and innovation initiative to date, aiming to strengthen research and innovation regarding climate change issues in the Nordic and high-latitude Regions. Prof. Kulmala together with Prof. Hari is the primary inventor of the SMEAR concept. According to the ISI Web of Knowledge, M. Kulmala is in the first place in the Citation Rankings in Geosciences (since 1.5.2011). His H-factor is 100. Prof. Kulmala has received several international awards such as the Smoluchovski Award (1997), the International Aerosol Fellow Award (2004), the Wilhelm Bjerkenes medals (2007), Fuchs Memorial Award (2010), Litke Medal (2015) and The Wihuri International Prize (2017). In 2015 he was acknowledged by a membership of the CASAD, Chinese Academy of Sciences, (CAS). Kulmala together with the Prof. Sergej Zilitinkevich is the initiator of the large scale multi - disciplinary Pan-Eurasian Experiment (PEEX) Program (https://www.atm.helsinki.fi/peex/).

Selected publications:

- **Kulmala**, M., Kontkanen, J., Junninen, H., Lehtipalo, K., Manninen, H.E., Nieminen, T., Petäjä, T., Sipilä, M., Schobesberger, S., Rantala, P., Franchin, A., Jokinen, T., Järvinen, E., Äijälä, M., Kangasluoma, J., Hakala, J., Aalto, P.P., Paasonen, P., Mikkilä, J., Vanhanen, J., Aalto, J., Hakola, H., Makkonen, U., Ruuskanen, T., Mauldin III, R.L., Duplissy, J., Vehkamäki, H., Bäck, J., Kortelainen, A., Riipinen, I., Kurtén, T., Johnston, M.V., Smith, J.N., Ehn, M., Mentel, T.F., Lehtinen, K.E.J., Laaksonen, A., Kerminen, V.-M., Worsnop., D.R.: Direct observations of atmospheric aerosol nucleation. *Science*, 339, 943, DOI: 10.1126/science.1227385, 2013.
- **Kulmala**, M., Petäjä, T., Nieminen, T., Sipilä, M., Manninen, H.E., Lehtipalo, K., Dal Maso, M., Aalto, P.P., Junninen, H., Paasonen, P., Riipinen, I., Lehtinen, K.E.J., Laaksonen, A., Kerminen, V.-M.: Measurement of the nucleation of atmospheric aerosol particles, *NATURE PROTOCOLS*, 7, 1651–1667, 2012.
- **Kulmala** M: China's choking cocktail, NATURE, Volume: 526, Pages: 497-499, 2015
- **Kulmala** M: Build a global Earth observatory, NATURE, Volume: 553, Issue: 7686, Pages: 21-23, Published: JAN 4 2018
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- Smolander S, He Q, Mogensen D, Zhou L, B\"ack J, Ruuskanen T, Noe S, Guenther A, Aaltonen H, **Kulmala** M, Boy M: Comparing three vegetation monoterpene emission models to measured gas concentrations with a model of meteorology, air chemistry and chemical transport, BIOGEOSCIENCES, Volume: 11, Issue: 19, Pages: 5425-5443, DOI: 10.5194/bg-11-5425-2014, 2014

Tuukka Petäjä (M) Professor and Head of Aerosol laboratory since 2013, Head of Värriö sub-arctic research station and SMEAR I-II stations since 2013 and Pan Eurasian Experiment science director since 2014. He was a Post-doctoral researcher at National Center for Atmospheric Research (NCAR) 2007-2008. Thompson Reuters Highly Cited Scientist, 2014-; Academician, International Academy of Eurasian Studies, 2014-; Science and Technology in Society Future Leader, New York Academy of Sciences, 2015; Väisälä award, for innovations in aerosol science and technology, 2013; PI for Biogenic Aerosols – Effects on Clouds and Climate (BAECC) for US Department of Energy. Currently 321 peer reviewed journal articles out of which 8 in Science, 8 in Nature and 1 in Physical Review Letters. Total citations: 12 503, h-index: 55 (ISI Web of Knowledge, 1.5. 2018); ISI ranking in

Geosciences: 52; 29 Highly cited papers (8th place in Geosciences in number of highly cited papers); Thompson-Reuters Highly Cited Scientist.

Selected publications:

- **Petäjä**, T., Järvi, L., Kerminen, V.-M., Ding, A., Sun, J., Nie, W., Kujansuu, J., Virkkula, A., Yang, X., Fu, C., Zilitinkevich, S. and Kulmala, M. (2016) Enhanced air pollution via aerosol-boundary layer feedback in China, Sci. Rep. 6, 18998, doi: 10.1038/srep18998.
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- Rose, C., Zha, Q., Dada, L., Yan, C., Lehtipalo, K., Junninen, H., Mazon, S.B., Jokinen, T., Sarnela, N., Sipilä, M., **Petäjä**, T., Kerminen, V.-M., Bianchi, F. and Kulmala, M. (2018) Observations of biogenic ion-induced cluster formation in the atmosphere, Sci. Adv. 4: eaar5218.

Lappalainen (F), Pan-Eurasian Experiment (PEEX) Program and Global SMEAR Secretary General, works currently at PEEX Headquarters, at the University of Helsinki, Institute for Atmospheric and Earth System Research (INAR). She the lead editor of the PEEX Science Plan together with Academician Markku Kulmala and Prof. Sergej Zilitinkevich. Hanna Lappalainen has a long-term experience of coordinating large-scale research projects and funding applications and has been working as a research coordinator and a science coordinator of large scale projects EU-FP7-IP EUCAARI (2007-2011) and the Finnish Centre of Excellence in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change (2012-2013). She has received NASA Goddar Team Award EOS-AURA satellite OMI-Team in 2005 and an International Eurasian Academy of Sciences (IEAS) Silver medal in 2015. Since 2014 Lappalainen has been a representative of Finland in the Sustainable Arctic Observing Network (SAON) Data working group, a Future Earth - iLEAPS Steering Group Member and starting from 2017 as a national delegate of the International Arctic Science Committee (ISAC) - The International Science Initiative in the Russian Arctic (ISIRA), a member of the Arctic Futures (AFI) IIASA Steering Committee and a member of the SIOS Data Board. She obtained her PhD. from the Department of Biological and Environmental Sciences, University of Helsinki, Finland and has been engaged in analysis of the atmospheric concentration of the Biogenic Volatile Organic Compounds (BVOCs) and plant phenological time series and modelling.

Selected publications:

- **Lappalainen**, H. K., Kerminen, V.-M., Petäjä, T., Kurten, T., Baklanov, A., Shvidenko, A., Bäck, J., Vihma, T., Alekseychik, P., Andreae, M. O., Arnold, S. R., Arshinov, M., Asmi, E., Belan, B., Bobylev, L., Chalov, S., Cheng, Y., Chubarova, N., de Leeuw, G., Ding, A., Dobrolyubov, S., Dubtsov, S., Dyukarev, E., Elansky, N., Eleftheriadis, K., Esau, I., Filatov, N., Flint, M., Fu, C., Glezer, O., Gliko, A., Heimann, M., Holtslag, A. A. M., Hõrrak, U., Janhunen, J., Juhola, S., Järvi, L., Järvinen, H., Kanukhina, A., Konstantinov, P., Kotlyakov, V., Kieloaho, A.-J., Komarov, A. S., Kujansuu, J., Kukkonen, I., Duplissy, E.-M., Laaksonen, A., Laurila, T., Lihavainen, H., Lisitzin, A., Mahura, A., Makshtas, A., Mareev, E., Mazon, S., Matishov, D., Melnikov, V., Mikhailov, E., Moisseev, D., Nigmatulin, R., Noe, S. M., Ojala, A., Pihlatie, M., Popovicheva, O., Pumpanen, J., Regerand, T., Repina, I., Shcherbinin, A., Shevchenko, V., Sipilä, M., Skorokhod, A., Spracklen, D. V., Su, H., Subetto, D. A., Sun, J., Terzhevik, A. Y., Timofeyev, Y., Troitskaya, Y., Tynkkynen, V.-P., Kharuk, V. I., Zaytseva, N., Zhang, J., Viisanen, Y., Vesala, T., Hari, P., Hansson, H. C., Matvienko, G. G., Kasimov, N. S., Guo, H., Bondur, V., Zilitinkevich, S., and Kulmala, M.: Pan-Eurasian Experiment (PEEX): towards a holistic understanding of the feedbacks and interactions in the land–atmosphere–ocean–society continuum in the northern Eurasian region, Atmos. Chem. Phys., 16, 14421-14461, https://doi.org/10.5194/acp-16-14421-2016, 2016.
- Hanna K. **Lappalainen**, Markku Kulmala, Joni Kujansuu, Tuukka Petäjä, Alexander Mahura, Gerrit de Leeuw, Sergej Zilitinkevich, Merli Juustila, Veli-Matti Kerminen, Bob Bornstein, Zhang Jiahua, Xue Yong, Qiu Yubao, Liang Dong, Liu Jie & Guo Huadong (2018) The Silk Road agenda of the Pan-Eurasian Experiment (PEEX) program, Big Earth Data, 2:1, 8-35, DOI: 10.1080/20964471.2018.1437704
- P. Alekseychik, H. K. **Lappalainen**, T. Petäjä, N. Zaitseva, M. Heimann, T. Laurila, H. Lihavainen, E. Asmi, M. Arshinov, V. Shevchenko, A. Makshtas, S. Dubtsov, E. Mikhailov, E. Lapshina, S. Kirpotin, Yu. Kurbatova, A. Ding, H. Guo, S. Park, J. V. Lavric, F. Reum, A. Panov, A. Prokushkin and M. Kulmala: Ground-based station network in Arctic and Subarctic Eurasia: an overview, J. Geography Environment Sustainability, 02(09), 75-88, 2016.

Risto Makkonen (M), PhD, Guidance group leader at INAR, also Research Professor (tenure track) at Finnish Meteorological Institute. He has 21 peer-reviewed publications, and has received the Finnish Aerosol Association Award in 2015. Two of his first-author papers were cited in IPCC AR5, one of which was included in radiative forcing assessment. He is a PI in projects focusing on e.g. biosphere-aerosol-climate feedbacks in Sahara and citizen-science climate experiments. Dr. Makkonen is a work package leader in EU FP7 project BACCHUS and

Nordforsk Center of Excellence eSTICC.

Selected publications:

- **Makkonen**, R., Asmi, A., Korhonen, H., Kokkola, H., Järvenoja, S., Räisänen, P., Lehtinen, K. E. J., Laaksonen, A., Kerminen, V.-M., Järvinen, H., Lohmann, U., Bennartz, R., Feichter, J., and Kulmala, M.: Sensitivity of aerosol concentrations and cloud properties to nucleation and secondary organic distribution in ECHAM5-HAM global circulation model, Atmos. Chem. Phys., 9, 1747-1766, doi:10.5194/acp-9-1747-2009, 2009.
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- **Makkonen**, R., Seland, Ø., Kirkevåg, A., Iversen, T., and Kristjánsson, J. E.: Evaluation of aerosol number concentrations in NorESM with improved nucleation parameterization, Atmos. Chem. Phys., 14, 5127-5152, doi:10.5194/acp-14-5127-2014, 2014.

Jaana Bäck (F), Professor 2013-, Head of Ecophysiology laboratory and Ecosystem Processes team Institute for Atmospheric and Earth System Research (INAR). Currently >130 peer reviewed research articles and chapters in books (1 in Science and 2 in Scientific Reports), H index 22 with total 2217 citations. She is at the INAR Board, SMEAR Board of Directors, vice member at the Faculty Board of Faculty of Agriculture and Forestry and vice chair of the Doctoral Programme ATM-DP and MSc Programme ATM-MP (both in UH). Research topics: forest ecology and ecophysiology, especially the ecosystem-climate interactions. She is the national contact point and participant in the ecosystem infrastructures AnaEE (FP7 ESFRI roadmap infra) and eLTER (H2020, ESFRI roadmap emerging infra). Recently she led the EASAC assessment on 'Multi-functionality and Sustainability in the European Union's Forests' (www.easac.eu/home.html). She was awarded the first Pro Scientia –award, given by the Finnish Academy of Sciences and Letters in 2017.

Selected publications:

- EASAC (2017) Multi-functionality and sustainability in the European Union's forests. EASAC policy report 32, April 2017. ISBN: 978-3-8047-3728-0 https://easac.eu/publications/details/multi-functionality-and-sustainability-in-the-european-unions-forests/
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- Kulmala, M., Nieminen T., Nikandrova A., Lehtipalo K., Manninen H., Kajos M., Kolari P., Lauri A., Petäjä T., Krejci R., Hansson H.-C., Swietlicki E., Lindroth A., Christensen T.R., Arneth A., Hari P., **Bäck** J., Vesala T., & Kerminen V.-M. (2014) CO2 induced terrestrial climate feedback mechanism: From carbon sink to aerosol source and back. - Boreal Env. Res. 19 (suppl. B): 122–131.
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Timo Vesala (M), Professor of Meteorology, University of Helsinki. Awards and Memberships: The Finnish Aerosol Award for theoretical work in aerosol science, 1991 Väisälä Award for meteorological research, The Finnish Society of Sciences and Letters, 2003 The 2004 Norbert Gerbier-MUMM International Award for the paper: B.E. Law et al., Agric. Forest Meteorol. 113; 97, 2002; Member in The Finnish Association for Aerosol Research; Finnish Physical Society; The Finnish Society of Forest Science; The Finnish Society of Sciences and Letters; Geodetic-Geophysical National Committee of Finland; International Eurasian Academy of Sciences; University of Helsinki Collegium, 2018-2021. Most important research funding: 47 projects (29 national and 18 international; coordinating 4 international projects) Total sum 21 117 000€. Scientific and societal impact: 318 peer-reviewed articles, 19 book sections, 1 book (Editor), 38 popular articles, h-index 61, over 19000 citations without self-citations: Merits in producing and distributing research results and data: Vesala has established long-term CO_2, CH_4 and water vapour flux measurement sites (forests, wetlands, urban environment) and they are among the longest and most utilized in the research community of biogeochemistry. Vesala has established the longest flux measurement site over a lake and published the only paper on micrometeorological flux measurements over a river. Vesala has been Interim Director General of building ICOS ESFRI Infrastructure (Integrated Carbon Observation System) in 2013-14 and ICOS started its operation phase in 2015 (ICOS ERIC).

Selected publications:

- Nordbo, A., L. Järvi, S. Haapanala, C.R. Wood and T. **Vesala**: Fraction of natural area as main predictor of net CO_2 emissions from cities. Geophys. Res. Letters, 39, L20802, doi:10.1029/2012GL053087, 2012
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- Dengel, S., D. Zona , T. Sachs, M. Aurela, M. Jammet, F.J.W. Parmentier, W. Oechel and T. **Vesala**: Testing the applicability of neural networks as a gap-filling method using CH_4 flux data from high latitude wetlands. Biogeosciences 10, 8185 – 8200, 2013.

- **Vesala**, T., S. Sevanto, T. Grönholm, Y. Salmon, E. Nikinmaa, P. Hari and T. Hölttä: Effect of leaf water potential on internal humidity and CO_2 dissolution: Reverse transpiration and improved water use efficiency under negative pressure. Frontiers in Plant Science, doi: 10.3389/fpls.2017.00054, 2017.
- Dewar, R., A. Mauranen, A. Mäkelä, T. Hölttä, B. Medlyn and T. **Vesala**: New insights into the covariation of stomatal, mesophyll and hydraulic conductances from optimization models incorporating nonstomatal limitations to photosynthesis. New Phytologist, doi:10.1111/nph.14848, 2017.

Veli-Matti Kerminen (M), University of Helsinki, has been working in the field of atmospheric sciences since 1990, with the main areas of expertise being the formation and transformation of atmospheric aerosol particles, aerosol-cloud interactions, and air quality-climate interactions. He has has published 263 peer-reviewed research articles with >13 000 citations and H-factor of 60. He has participated in 6 EU projects and lead 8 nationally-funded research projects. He received the "Marian Smoluchowski Award for Aerosol Research" in 2007 and acted as a "Lead Author" in the Working Group I of the IPCC Assessment Report 5 (2013). Here is currently editor in "Atmospheric Chemistry and Physics" and "Boreal Environment Research".

Selected publications:

- **Kerminen** V.-M., Paramonov M., Anttila T., Riipinen I., Fountoukis C., Korhonen H., Asmi, E., Laakso L., Lihavainen H., Swietlicki E., Svenningsson B., Asmi A., Pandis S. N., Kulmala M. and Petäjä T. (2012) Cloud condensation nuclei production associated with atmospheric nucleation: a synthesis based on existing literature and new results. *Atmos. Chem. Phys.* 12, 12037-12059.
- Vakkari V., **Kerminen** V.-M., Beukes J. P., Tiitta P., van Zyl P. G., Josipovic M., Venter A. D., Jaars K., Worsnop D. R., Kulmala M. and Laakso L. (2014) Rapid changes in biomass burning aerosols by atmospheric oxidation. *Geophys. Res. Lett.* 41, 2644-2651.
- Paramonov M., **Kerminen** V.-M., Gysel M., Aalto P. P., Andreae M. O., Asmi E., Baltensperger U., Bougiatioti A., Brus D., Frank G. P., Good N., Gunthe S. S., Hao L., Irwin M., Jaatinen A., Juranyi Z., King S. M., Kortelainen A., Kristensson A., Lihavainen H., Kulmala M., Lohmann U., Martin S. T., McFiggans G., Mihalopoulos N., Nenes A., O'Dowd C. D., Ovadnevaite J., Petäjä T., Pöschl U., Roberts G. C., Rose D., Svenningsson G., Swietlicki E., Weingartner E., Whitehead J., Wiedensohler A., Wittbom C. and Sierau B. (2015) A synthesis of cloud condensation nuclei counter (CCNC) measurements within the EUCAARI network. *Atmos. Chem. Phys.* 15, 12211-12229.
- Ding A. J., Huang X., Nie W., Sun J. N., **Kerminen** V.-M., Petäjä T., Su H., Chen Y. F., Yang X.-Q., Wang M. H., Chi X. G., Wang J. P., Virkkula A., Guo W. D., Yuan J., Wang S. Y., Zhang R. J., Wu Y. F., Song Y. Zhu T., Zilitinkevich S., Kulmala M. and Fu C. B. (2016) Enhanced haze pollution by black carbon in megacities in China. *Geophys. Res. Lett.* 43, 2873-2879, doi:10.1002/2016GL067745.
- Lihavainen H., Asmi E., Aaltonen V., Makkonen U. and **Kerminen** V.-M. (2015) Direct radiative feedback due to biogenic secondary organic aerosol estimated from boreal forest site observations. *Environ. Res. Lett.* 10, 104005, doi:10.1088/1748-9326/10/10/104005.

4.2 Third Parties involved in the project

No third parties involved.

5 Ethics and Security

5.1 Ethics

No ethics issues have been identified for the *ExtremeEarth-PP* project.

5.2 Security

Please indicate if your project will involve:

- activities or results raising security issues: NO
- 'EU-classified information' as background or results: NO

6 Letters of Support and Endorsements

ExtremeEarth-PP has gathered over 100 letters of support and endorsements, from the following organisations:

Aarhus University	Netherlands Water Services
Actris	Institut Cartografic I Gelologic de Catalunya
Agencia Estatal de Meteorologia	Institute of Geophysics, Polish Academy of Sciences
Agricultural Model Intercomparison and Improvement Project (AgMIP)	Instituto Geográfico Nacional
Alfred Wegener Institute	Instytut Meteorologii i Gospodarki Wodnej, Poland
Arcadis	International Institute for Applied Systems Analysis
Asian Disaster Preparedness Center	International Soil Modeling Consortium
Atos Bull	Italian Met Service
Austrian Institute of Technology	Joint Programming Initiative "Connecting Climate Knowledge for Europe" (JPI Climate)
Austrian National Weather Service ZAMG	Joint Programming Initiative "Water challenges for a changing world"
AXA	Karlsruhe Institute of Technology
Bayer CropScience	Katholieke Universiteit Leuven
British Antarctic Survey	Koninklijk Nederlands Meteorologisch Instituut
Bulgarian National Institute of Meteorology and Hydrology	Leibniz Centre for Agricultural Landscape Research
Capgemini	Lund University
Center of Ecology and Hydrology	MagmaEnergy Italia
Center of Excellence for Exascale in Solid Earth	Max-Planck Institute for Chemistry
Centre of Excellence in Simulation of Weather and Climate in Europe	Mercator Ocean International
Centro de Investigaciones Energéticas Medioambientales y Tecnológicas	Met Eireann
CERFACS - European Centre for Research and Advanced Training in Scientific Computation	Meteologica
CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH	Meteorological and Hydrological Service of Croatia
City of Barcelona	MeteoSwiss
City of Rotterdam	MetOffice United Kingdom
City of Wien	Munich Re

Consiglio Nazionale delle Ricerche	IRSTEA - French Instutite of Science and Technology for Environment and Agriculture
Consiglio Nazionale delle Ricerche - Istituto di Meteorologie per l'Analisi Ambientale	Nationaal Kennis- en innovatieprogramma Water en Klimaat
Copernicus Climate Change Service C3S	National Meteorological Administration Romania
Copernicus Atmosphere Monitoring Service - CAMS	National Meteorological Service of Slovenia
CRAY	National Oceanography Centre
CSC - IT Center for Science Ltd	NGI
Czech Hydrometeorological Institute	Norwegian Meteorological Institute
Danish Meteorolgical Institute	NVIDIA
Deutscher Wetterdienst	Paul Scherrer Institute
EDF	Potsdam Institute for Climate Impact Research (PIK)
European Environment Agency	PRACE (Partnership for Advanced Computing in Europe)
Energy oriented Centre of Excellence for computing applications	Practical Action
ENVRIPlus	Research Program on Climate Change, Agriculture and Food Security
Equinor	Royal Meteorological Institute Belgium
Estonian University of Life Sciences	RWTH Aachen
EUDAT	Siemens Gamesa
EuroGeoSurveys	Stockholm University
European Aerosol Research Lidar Network	SURF
European Association of Remote Sensing Companies	Swedish Meteorological and Hydrological Institute
European Organisation for the Exploitation of Meteorological Satellites	Swiss Re
European Technology Platform for High Performance Computing	The Alan Turing Institute
Finnish Meteorological Institute	The Cyprus Institute
Food and Agriculture Organization of the United Nations	UBIMET - Institute for Ubiquitous Meteorology
FORECA Ltd	United Nations Office for Disaster Risk Reduction
Geo.8 - European Network for Earth Sciences	University of Bonn
Geoverbund	University of Cologne
GFZ German Research Centre for Geosciences	University of Eastern Finland
Global Energy and Water Exchanges (GEWEX) project	University of Leeds
Global Facility for Disaster Reduction and Recovery	University of Maryland
Global Volcanic Model	University of Oslo
Hellenic National Meteorological Service	University of Reading
Helmholtz Centre for Environmental Research - UFZ	Uppsala University
Helmholtz Gesellschaft	Vestas
Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research	Vortex
Hungarian Meteorological Service	WienEnergy
Icelandic Met Service	Willis Towers Watson
ICLEI - Local Governments for Sustainability	World Energy & Meteorology Council (WEMC)
Institute for Atmospheric and Earth System Research (INAR)	World Meteorological Organization
Institute for Water Education	World Water Assessment Programme of the United Nations

The received letters have been copied below, and can also be found at http://www.extremeearth.eu/endorsements.

AARHUS
UNIVERSITY

To:
Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

cc.
Prof. Torben Røjle Christensen
Prof. Merete Bilde
Prof. Henrik Skov

Deans Office

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Dean

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Mobile Tel.: +452 2899 2541
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Sender's CVR no.: 31119103

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

This letter from Aarhus University (AU) is to endorse the Flagship candidate project ExtremeEarth. We at AU represent a wide range of relevant existing research on the physical, chemical and biological processes important for climate change in the Arctic. We hold long time series of measurements of key parameters from the Arctic and especially the possibility of carrying out new experiments e.g. at our large infrastructure platforms that include the Zackenberg in North-East Greenland, laboratory facilities at Aarhus University and Villum Research Station in North Greenland.

We are using field measurements, laboratory experiments, monitoring data, climate models and atmospheric chemistry transport modelling of short-lived climate forcers (e.g. black carbon, ozone, and methane) and CO2. Our focus is on the natural environments including the North Atlantic and Arctic Ocean, the circum-Greenland coastal waters and sediments, freshwater environments, terrestrial ecosystems and the surface of the Greenlandic ice sheet. We are strongly connected with several both national and international networks such as the Greenland Ecosystem Monitoring (GEM) program, Arctic Monitoring And Assessment program (AMAP), the EU Integrated Carbon Observing System (ICOS), the EU programmes; INTERACT, EUROCHAMP 2020, ACTRIS and the ERAPLANET projects iCUPE and iGOSP.

AU find the Flagship candidate project a very important initiative and potentially lead to new paradigm for Artic research. Therefore, AU is happy to endorse ExtremeEarth. The

AARHUS
UNIVERSITY
SCIENCE AND TECHNOLOGY

AU endorsement of the Flagship candidate project ExtremeEarth implies that AU supports the scientific, technological and programmatic objectives of ExtremeEarth. This endorsement does not at this point include any legal or financial commitments towards the ExtremeEarth project.

Yours sincerely,

Niels Christian Nielsen
Dean of Faculty of Science & Technology
Aarhus University
Denmark

adpc

Asian Disaster Preparedness Center

979/69, 24th Floor, SM Tower, Paholyothin Road, Samsen Nai, Phayathai, Bangkok, 10400, Thailand
Tel: (02) 2980681-92, Fax: (02)2980012-13, E-mail: adpc@adpc.net, Website: www.adpc.net

No. 663 / 2018

27 August, 2018

Dr. Peter Bauer
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading RG2 9AX
United Kingdom

Dear Dr. Bauer,

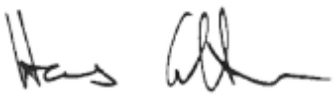
Asian Disaster Preparedness Center (ADPC) is an independent intergovernmental organization that works to build the resilience of people and institutions to disasters and climate change impacts in Asia and the Pacific. Established in 1986 ADPC has thematic focal areas; Risk Governance, Climate Resilience, Urban Resilience, Health Risk Management, Preparedness for Response and Resilient Recovery. In addition, addresses three cross-cutting themes: Gender and Diversity, Poverty and Livelihoods, and Regional and Transboundary Cooperation.

We are looking forward to supporting the Extreme Earth flagship proposal for the call "Tackling Grand Interdisciplinary Science and Technology Challenges", specifically to support risk management in Asia and the Pacific. In Asia, disasters claim thousands of lives every year, and we hope that an investment in Extreme Earth could prevent this loss of life, safeguard livelihood and reduce the economic impact of disasters. We would be interested to support the work linking earth system data with data about society and vulnerable systems, to understand potential impacts and how to build resilience.

ADPC has been working in the region in building climate resilience with the support from Norway, Sweden, UK and other donors. ADPC has also been a key actor in providing training and capacity building programs for national hydro-meteorological services (NHMSs) in South and Southeast Asia in the use of numerical weather prediction models. We welcome the open data promise of Extreme Earth, and we look forward to developing the link with these country-level agencies to interact with the data from Extreme Earth.

We hope the proposal is funded, and we look forward to working with you.

Sincerely,



Hans Guttman
Executive Director

GOBIERNO DE ESPAÑA MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA

AEMet Agencia Estatal de Meteorología

Ref.: RRII / 763 / 18 / PR

Madrid, 7 August 2018

Dr. Florence Rabier
Director General
European Centre for Medium Range Weather Forecast
Shinfield Park, Reading RG2 9AX
REINO UNIDO

SUBJECT: Endorsement letter of support for ExtremeEarth

Dear Mrs. Florence,

Being aware of the importance of the future ExtermeEarth (www.extremeearth.eu) project to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data, hereby with this endorsement letter, I would like to express AEMET's strong support for it following the ECMWF Council's decision to lead it as a preparatory project for an EU Flagship.

Nowadays there are limitations in the physics of existing meteorological models and computational restrictions (for instance in ensemble data assimilation methods, or methods of empirical inference) that restrict the ability to ingest and make use of data collected continually by a vast array of sensors: satellites, ground stations, organized surface networks, commodity device sensing, etc. The data scale and computing needs are orders of magnitudes larger than current capabilities and these facts imply a strong necessity of a radical re-design of current software frameworks and hardware systems. In this context, ExtremeEarth will build upon and strengthen European excellence in Earth sciences, support European institutions, and launch a new wave of innovation at the intersection of Earth-system and information science and will bring an entirely new quality to the European HPC programme.

AEMET would employ the novel capabilities that ExtremeEarth will develop, and would contribute to future requirements and the ability to adapt to fundamentally new systems need to be accounted for very early on in the ExtremeEarth. The involvement of National Meteorological Services such as AEMET will be crucial for defining the ExtremeEarth full-scale end-to-end demonstrators as these are key project deliverables that will revolutionize their capabilities.

I fully trust on the success of this project and the opportunities ahead of it.

Yours sincerely,

LOPEZ GONZALEZ MIGUEL ANGEL - 00275663P

Firmado digitalmente por LOPEZ GONZALEZ MIGUEL ANGEL - 00275663P
Fecha: 2018.08.08 19:07:06 +02'00'

Miguel Ángel López
President of AEMET

E - mail
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September 05, 2018

Dr. Peter Bauer, ECMWF Consortium Leader for ExtremeEarth

Dear Dr. Bauer,

On behalf of the international community and leaders of AgMIP – the Agricultural Model Intercomparison and Improvement Project – I write to enthusiastically support the Flagship candidate project ExtremeEarth and its intent to enormously advance capabilities in model parameterization, data assimilation, and empirical inference for a greatly improved Earth system and climate simulations of the past, present, and future.

These capabilities are greatly needed to improve agricultural models and scientific and technological capabilities for assessing impacts of climate variability and change and other driving forces on agriculture, food security, and poverty at local to global scales – the mission of AgMIP. The anticipated computational, science, and technology advancements will greatly improve information on key drivers affecting food security, enabling improved coordinated global and regional assessments of impact. The advancements in data and model interoperability will accelerate innovation in agricultural models of the future – including improved simulation of agricultural systems and adaptations important to sustainable food security in both developed and developing regions. The higher resolution of data and models will improve our understanding of extreme events and their unique characteristics across space and time, leading to better approaches for climate adaptation, disaster resilience, and anticipation of market and social vulnerability.

We anticipate that many in the AgMIP community are well placed to directly contribute to the planning and execution of ExtremeEarth, and we stand ready to help advance it. Our endorsement of the Flagship candidate project ExtremeEarth means AgMIP supports the scientific, technological and planned objectives of ExtremeEarth, and we share this statement and our logo for this purpose. Our support does not, however, constitute any legal or financial commitment towards the ExtremeEarth project.

We wish you every success in advancing the vision of ExtremeEarth.

Sincerely, and on behalf of the AgMIP Leaders and Members,

Cynthia Rosenzweig
Executive Committee, AgMIP
Senior Research Scientist, NASA GISS
Adjunct Senior Research Scientist, Columbia University

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Alfred Wegener Institute, PO Box 12 01 61, 27515 Bremerhaven, Germany

Dr. Peter Bauer
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
UK

Prof. Dr. Antje Boetius
Director

phone: +49/471-48 31-11 00
fax: +49/471-48 31-11 02

E-Mail: director@awi.de

17.01.2018
AB/AD

Endorsement of the FET Flagship ExtremeEarth

Dear Dr. Bauer,

it is my pleasure to let you know that the Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research, endorses the proposal for a FET Flagship project entitled ExtremeEarth. For our institute, the scientific and technological developments proposed in ExtremeEarth would be of extremely high relevance for many of our research activities, especially those related to Earth System Modelling.

With best regards

Antje Boetius

Prof. Dr. Antje Boetius
(Director)

Alfred Wegener Institute
Helmholtz Centre for
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BREMERHAVEN

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ARCADIS Design & Consultancy for natural and built assets

European Centre for Medium-Range Weather Forecasts
Research Department
Dr. Peter Bauer
Shinfield Park,
Reading RG2 9AX
United Kingdom

Arcadis Nederland B.V.
Piet Mondriaanlaan 26
3812 GV Amersfoort
P.O. Box 220
3800 AE Amersfoort
The Netherlands
Tel +31 (0)88 4261261
www.arcadis.com

Subject: Request to endorse a EU-Flagship proposal
Date: 25 July 2018

Dear sir Bauer,

On behalf of Arcadis, I am expressing my strongest support for the CSA proposal to develop a FET Flagship Project ExtremeEarth. This activity of the climate and earth system science communities to develop a joint FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

The Arcadis mission is to improve quality of life. ExtremeEarth will provide insights that will support us in fulfilling that mission.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership.

ExtremeEarth also brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

The Arcadis role in this project could be early adaptor and partner in testing and implementation of ExtremeEarth. Arcadis has a rather extended client base that we could use. With our WBCSD membership we have a good connection to other frontrunners in the private sectors. With our strong presence in many European countries (outside Europe as well) we can also access potential public partners.

Arcadis Nederland B.V. - Registered office: Arnhem - Registered number: 09036504

ARCADIS Design & Consultancy for natural and built assets

The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth. This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

With kind regards,
Arcadis

Frank Goossensen
Director Business Development
UK, Europe, Middle East

Contact: Frank Goossensen
E-mail: frank.goossensen@arcadis.com
Direct line: +31 (0)627060154

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martin.jung@ait.ac.at | www.ait.ac.at

To whom it may concern,

15.02.2018

Endorsement of the European Flagship candidate project ExtremeEarth (CSA proposal)

On behalf of the Austrian Institute of Technology (AIT) I express our support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.

We are following the activities of the climate and geoscience communities to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

We understand that the capacities and capabilities will provide the basis for knowledge on future development of climate change of a scale relevant to action by regions and cities. AIT could act as an institution using these capacities, translating them into relevant services for regions, cities and communities. An example could be to provide relevant data sets for climate change processes of the City of Vienna which might see significant increase in draughts and heat waves with the resulting needs for adaptation of municipal infrastructures and services.

With our applied research background in relevant fields, we see strong links to the aims of the proposed project ExtremeEarth. Therefore, AIT very much welcomes and strongly supports this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship

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project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

AIT Austrian Institute of Technology GmbH

Nikolas Neubert
HBV
Sustainable Buildings and Cities

Nikolas Neubert

Martin Jung

redefining / standards

Alban de Mailly Nesle
AXA Group Chief Risk Officer & Group
Head of Insurance Office

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX,
UK

Paris, 16th February 2018

Dear Dr. Bauer,

AXA support to ExtremeEarth

ExtremeEarth has a very ambitious goal to build the modeling, supercomputing and data handling technologies needed to simulate the Earth's system with unprecedented accuracy in order to enhance our ability to predict geo-hazards and prevent loss of life and infrastructure. This poses significant scientific, technological and societal challenges, which require a step change in our computing capabilities (in particular through exascale computing systems) and our abilities to source and exploit new sources of data. ExtremeEarth's development of ultra-high-resolution modelling capabilities of the entire Earth-system is expected to accelerate the development of applications through a value-chain that integrates our scientific and impact prediction capability.

AXA, as an insurance company operating worldwide, seek to offer protection and compensation against geo-hazards. It is critical for AXA to assess any changes in the frequency and intensity of hazards, especially those related to extreme weather in a warming climate. AXA performs some research in house and increasingly seeks collaboration with environmental scientists in areas keys to its business in particular through the AXA Research Fund.

For these reasons AXA fully supports the preparatory action of the *ExtremeEarth* initiative, which, if eventually selected as a European flagship project, will deliver critical advice to enable Europe to better plan for, adapt to and mitigate the effects of geo-hazards in general and high-impact weather events in particular.

Yours sincerely,

Alban de Mailly Nesle
alban.demaillynesle@axa.com

25, avenue Matignon 75008 Paris, France
www.axa.com

Barcelona City Council
Plaça Sant Jaume 1,
08002 Barcelona

Letter of support for the ExtremeEarth project

The **ExtremeEarth** project is a project coordinated by the European Centre for Medium-Range Weather Forecasts (ECMWF) aiming to revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on society, enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

I the undersigned, confirm on behalf of the **Barcelona City Council** that the institution has been informed about the ExtremeEarth project and express our interest in the proposal and its potential impact in monitoring and reducing air pollution, a domain that is of high interest for the city.

The **ExtremeEarth** project will allow to bring together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today, enhancing our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact, thus improving climate change policies.

The **Barcelona City Council** would like to be kept informed about the progress of this proposal and supports the project for its interest, wishing every success to the applicants for the accomplishment of the proposed work.

This document has not any legally binding character and any costs will be covered by the project funding.

Yours sincerely,

13th February 2018

Gerardo Pisarello Prados

First Deputy Mayor

Manager's Office of the Area of Economy and Work, Digital City and International Relations.

Barcelona City Council

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Professor Dame Jane Francis
Director, British Antarctic Survey
High Cross, Madingley Road,
Cambridge CB3 0ET

Phone: +44(0)1223 221449
Email: j.francis@bas.ac.uk

Professor John Ludden
British Geological Survey,
Keyworth, Nottingham NG12 5GG

16th August 2018

Dear John,

I am writing to provide strong support from the British Antarctic Survey for Extreme Earth.

At a time when our environment is changing so rapidly due to anthropogenic impacts, we need multidisciplinary projects such as this to understand the complexity of Earth systems, their drivers and their impacts, in order to be able to predict future changes to our environment and find solutions where we can.

In BAS we undertake multidisciplinary science to understand the polar regions and how changes in these remote and extreme environments are driving global effects, such as the rise in global sea levels as a result of melting ice sheets. We have a wealth of data from the polar regions about climate, cryosphere, geology, terrestrial and marine ecosystems and oceanography that is extremely relevant to the aims of Extreme Earth.

We look forward to contributing to Extreme Earth in future.

Sincerely,

Jane Francis

Professor Dame Jane Francis
Director

Bayer CropScience

Prof. Jan Vanderborght
Forschungszentrum Jülich IBG-3
Wilhelm-Johnen-Straße
52428 Jülich
Germany

February 15th, 2018

Dr.-Ing. Ole Peters
Head BAG-CS-DI-TECH
Digital Farming

Bayer AG
Crop Science Division
40789 Monheim
Germany

Mobile: +491734025232
ole.peters@bayer.com
www.bayercropscience.com

Letter of endorsement for the Extreme Earth Flagship project proposal

Bayer Digital Farming's major objective is to make agriculture more sustainable and efficient.

Digital Farming Solutions are a key element to improve conventional agriculture while shaping the future of crop protection by avoiding yield losses and saving chemicals. xarvio™ Field-Manager empowers farmers to take smarter decisions through a sophisticated automated disease management as well as treatment planning. Data aggregation, data modeling and data analytics result in management recommendation considering crop protection, field specific timing and variable rate application maps.

High spatio temporal resolution weather data will have substantial added value for our customers and the environment. Leveraging Digital Farming crop growth models and disease risk estimations will result in even more optimized timing and planning, leading to a higher return-on-investment and less environmental pollution.

Weather and climate data in high resolution is a key driver for plant growth and health. Weather analytics are the back bone of Digital Farming's well validated and proven disease risk models. Field specific agronomic practice heavily depends on this critical data source. In cooperation with university research Bayer Digital Farming is tackling climate modeling aiming to generate weather data at high spatial resolution down to field level. Research aspects include scientific computing for environmental modeling and climate modeling in HPC environments. In addition to its value for agricultural issues, weather data also enables important services providing information for allergy sufferers.

Against this background, Bayer Digital Farming endorses the

--- ExtremeEarth Flagship project (FETFLAG-01-2018) ---

Great value is seen in the scaling up of supercomputing capacity for climate and weather modeling with beneficial value for applications in agriculture.

This endorsement does not imply any legal or financial commitments of the Bayer Group in view of the ExtremeEarth project.

With best regards,

Dr.-Ing. Ole Peters

Bayer CropScience AG
Digital Farming
Elisabeth-Selbert-Str. 4a
D-40764 Langenfeld

BULGARIAN ACADEMY OF SCIENCES
NATIONAL INSTITUTE OF METEOROLOGY AND HYDROLOGY

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БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ
НАЦИОНАЛЕН ИНСТИТУТ ПО МЕТЕОРОЛОГИЯ И ХИДРОЛОГИЯ

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http://www.meteo.bg

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Our Ref. : НС-02-48-1 ***Date :*** 28.08.2018г.

Subject : Commitment to the ExtremeEarth flagship proposal

Dear Dr. Bauer,

this letter expresses the commitment of the National Instite of Meteorology and Hydrology (NIMH) in Bulgaria to the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

NIMH fully supports the technological and scientific ambitions of ExtremeEarth. This project has the potential to enable large capability breakthroughs in our areas of weather, marine and other environment media prediction and future climate projections.

If the next stage of the evaluation of the proposal is as successful as the first one, NIMH will take the opportunity of the Coordination and Support Action to highlight what it ambitions to bring into the Flagship. Our envisioned cooperation would envolve research on climate, weather and marine extremes through development of physical models used in our institute.

NIMH looks forward to be part of the ExtremeEarth Flagship, once successful in getting EU support.

Yours sincerely,

Prof. Dr. Hristomir Branzov,
Director

Bull
atos technologies

Object: Endorsement letter
Date: January 25th, 2018

To whom it may concern,

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth. This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

By this letter, Bull endorses this project and proves its interest in the deliverables.

Arnaud Bertrand
Atos Fellow
SVP Strategy and Innovation
Big Data and Security

Bull SAS Société par actions simplifiée au capital social de 185 533 673.50 euros R.C.S. Versailles B 642 058 739
Tél. 01 30 80 70 00 - Télécopie 01 30 80 72 40 - Adresse postale : BP 68 Rue Jean Jaures 78340 Les Clayes sous Bois Cedex - www.bull.fr

Mr Arnaud Demesse
Aero Space & Defense Market Unit Director
Capgemni
109 Einsenhower avenue
31039 Toulouse France

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

February, 14th 2018

Dear Peter

ExtremeEvents

The vision of *ExtremeEarth* is to develop a wholly new class of models for more accurate prediction of extremes in our weather and climate systems, and to couple these to impacts in the food, water, health, energy and insurance sectors. *ExtremeEarth* will give unprecedented new insights into the processes and mechanisms responsible for weather extremes, and allow us to understand how the frequency and intensity of such events will alter in response to climate change, thereby leading to increased predictive skill. This will require the development of new models of the climate system at unprecedented resolution, and with the inclusion of new physics and numerical algorithms, which will be run on the next generation of High Performance Computing platforms.

ExtremeEarth will revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

ExtremeEarth will develop the software needed for these systems and work with commercial partners towards their exploitation in the broader market. In that framework of an ambitious goal to create a unique production capability and to co-design the technological components required for its cost-effective operation, Capgemini therefore fully support the *ExtremeEarth* initiative, which will deliver critical advice to enable Europe to better plan for, and mitigate, the effects of high-impact weather events.

Yours sincerely

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Centre for Ecology & Hydrology
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www.ceh.ac.uk

Professor Prudhomme

24 January 2018

Dear Professor Prudhomme

Extreme Earth

I am pleased to provide you with CEH endorsement for this exciting initiative. CEH is the UK's lead for research on terrestrial and freshwater systems and their interaction with the atmosphere. CEH has a long history of flood and drought research, both in the UK and internationally, and is at the forefront of new WMO initiatives in this area. We are also moving forward to translate hydrometeorological services into impacts for other stakeholders, including agriculture and industrial interests. CEH is a NERC-aligned centre and, as such, receives National Capability funding to advance terrestrial and freshwater science and to derive appropriate impact (from that science) in support of policy and environmental management. We see that Extreme Earth will offer a great opportunity to enhance our science and impact activities through collaboration with the consortium. In this respect, we not only endorse ExtremeEarth but we would also seek to assist the initiative in taking flagship projects forward and, if appropriate, in helping to coordinate some aspect of its activity.

I look forward to seeing CEH engage fully in ExtremeEarth and to seeing it maximise the potential offered by such a powerful consortium. Please do not hesitate to let me know how we can help in moving it forward.

Yours sincerely

Professor Alan Jenkins
Deputy Director & Director, Water and Pollution Science

Tel. 01491 692440
Email: jinx@ceh.ac.uk
www.ceh.ac.uk

CERFACS

CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE

Dr. Peter Bauer, Deputy Director of Research
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading RG2 9AX
United Kingdom

17th September 2018

O/Ref : CL-18/09/210

Subject: Endorsement of the *ExtremeEarth* preparatory project.

Dear Dr. Bauer,

With this letter, the European Centre for Research and Advanced Training in Scientific Computation (CERFACS) wishes to express its strong support for *ExtremeEarth*, a proposed project for an FET Flagship. There is no doubt that *ExtremeEarth* provides a unique opportunity to revolutionize Europe's capability to predict and monitor environmental extremes and their impact on society, and that the steps required to achieve this objective will result in far-reaching scientific and technological breakthroughs.

CERFACS is a leading institute in the development of software, algorithms and modelling techniques for solving large-scale simulation and optimization problems on high-performance computers. CERFACS research activities are organized into five strategic axes: data-driven modelling (data assimilation, uncertainty quantification, data science), linear algebra, numerical methods, coupling, and exascale computing. These core research activities are driven by the needs of applications of both industrial and societal interest, including Earth system modelling and prediction (ocean, atmosphere, and coupled ocean-atmosphere), and environmental monitoring and security (hydrology and hydraulics, wildfire propagation, atmospheric composition). For these reasons, CERFACS is especially interested in the core developments proposed by *ExtremeEarth* and would look forward to contributing to the success of the project should it be funded.

Yours sincerely,

Catherine LAMBERT
Director

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ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range
Weather Forecasts
Shinfield Park, Reading RG2 9AX
United Kingdom

Geneva, 12 February 2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Bauer,

On behalf of the CLOUD experiment at CERN, I am very happy to endorse the ExtremeEarth Flagship proposal.

As you know, the Intergovernmental Panel on Climate Change (IPCC, 2013) considers that our ability to make accurate projections of long-term climate change is limited by the uncertainty in how aerosols and clouds have changed since pre-industrial times due to increases of sulphur dioxide and other pollutants in the atmosphere, and how they may continue to change in the future. The resultant uncertainty in Earth's climate sensitivity (between 1.5 and 4.5°C for a doubling of CO_2) has persisted through all IPCC assessments since 1996 and, indeed, since the seminal 1979 Charney report of the US National Academy of Sciences.

The CLOUD experiment is helping to reduce the uncertainties of atmospheric aerosols and clouds by performing laboratory measurements at CERN under precisely-controlled atmospheric conditions. In a series of experiments, CLOUD has identified the main vapours responsible for atmospheric aerosol particle formation and is measuring the particle nucleation and growth rates. CLOUD has become established as the world's leading facility for atmospheric aerosol nucleation research through a series of ground-breaking results in high-impact journals over the last six years. Following CLOUD's success, the Chinese Academy of Sciences is currently considering a similar but much larger project near Beijing with several CLOUD-like chambers and a construction budget of more than 100M Euro.

CLOUD is operated by a consortium of 21 mainly-European institutes that includes both experimental physicists and chemists and also global aerosol modelers. The integration within a single consortium and project of laboratory measurements at CERN, field and aircraft observations, and global modelling has proved highly successful. While the global models are solely capable of simulating and eventually predicting global climate, their reliability depends on a sound foundation of the fundamental physico-chemical processes and on verification against field and aircraft observations.

In summary, on behalf of the CLOUD experiment at CERN, I am very happy to endorse the ExtremeEarth Flagship proposal, and CLOUD looks forward to contributing towards a robust, experimentally-based foundation for its Earth-system models.

Sincerely,
Jasper Kirkby

Prof. Jasper Kirkby
Spokesperson PS215/CLOUD
CERN and Goethe University Frankfurt

* Adresse postale pour le courrier posté en France: CERN: Site de Prévessin, F-01631 CERN CEDEX

Dr. Peter Bauer, ECMWF, consortium leader ExtremeEarth

With this letter I'd like to provide official endorsement for the ExtremeEarth Flagship project (FETFLAG-01-2018). The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) addresses the increasing challenge of global warming and declining food security on agricultural practices, policies and measures through a strategic collaboration between CGIAR and Future Earth. With a budget of US$60m per year, it is a major global program involving dozens of institutions, from university partners in the north and south, through to CGIAR centers and national government stakeholders in developing countries.

In our work, accurate climate information from seasonal through to decadal and multi-decadal scales is essential to support adaptation and mitigation processes to secure future food security. Ourselves and our partners are large consumers of climate information, yet are often faced with serious barriers to use as the uncertainties are high, spatial scale often unfit for use, and limitations in timeliness of information for dynamic decision making. The better physical representation of key processes, at a resolution of 1 km, and more accurate global Earth System and Climate modeling proposed by the ExtremeEarth Flagship will be a leap forward for our work. The improved prediction and detailed accounting of uncertainties will be instrumental in allowing better-informed decision from local to national and regional scales.

We hope to both collaborate with the ExtremeEarth Flagship project by linking to the demands from our stakeholders for improved climate information, and also be a user of the results that come out of the project. This endorsement of the Flagship candidate project ExtremeEarth implies that we support the scientific, technological and planned objectives of ExtremeEarth. This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of CCAFS may be shown on the ExtremeEarth website.

Andy Jarvis

Flagship Leader for Climate Smart Agriculture, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)
Research Area Director, Decision and Policy Analysis, International Center for Tropical Agriculture (CIAT)

ChEESE

Dr. Arnau Folch
Dpt. Computer Applications in Science and Engineering (CASE)
Barcelona Supercomputing Center (BSC)
Phone: +34 93 413 7925; e-mail: arnau.folch@bsc.es

TO: Dr. Peter Bauer
Extreme Earth proposal Coordinator

Barcelona, 10th August 2018

SUBJECT: Letter of Support to the Extreme Earth proposal

Dear Sir,

The Center of Excellence for Exascale in Solid Earth (ChEESE) has recently been funded under the H2020 topic INFRAEDI-02-2018 (grant number 823844). The ChEESE project will prepare flagship codes and enable services for Exascale supercomputing in the area of Solid Earth (SE) as well as harness European institutions in charge of operational monitoring networks, tier-0 supercomputing centers, academia, hardware developers and third-parties from SMEs, Industry and public-governance. The scientific ambition of ChEESE is to prepare 10 flagship codes to address Exascale Computing Challenging (ECC) problems on computational seismology, magnetohydrodynamics, physical volcanology, tsunamis, and data analysis and predictive techniques for earthquake and volcano monitoring, all in collaboration with the European Plate Observing System (EPOS) in order to facilitate the integration of HPC services to widen the access to codes to the SE users community.

All the objectives above are fully aligned with the Extreme Earth proposal for an EU flagship, particularly on the development of ultra-high-resolution modeling capabilities, development of Exascale computing systems and data platforms, capacity to observe and monitor the state of the Earth, and characterize their societal impact.

As Coordinator of ChEESE, I will be delighted to collaborate with Extreme Earth and to promote synergies and alignment of objectives and efforts between both projects.

Yours faithfully,

Dr. Arnau Folch
ChEESE project coordinator

CZECH
HYDROMETEOROLOGICAL
INSTITUTE

Mark Rieder
Director

Prague, 20th August 2018
Ref.:

Subject: Letter of support for ExtremeEarth

Dear Dr. Rabier,

Czech Hydrometeorological Institute (CHMI) wishes to express its strong support for your initiative to promote the ExtremeEarth project to the level of an EU Flagship. As other European countries, Czech Republic is not spared from environmental extremes, varying from short to seasonal scales. We may take current drought as a fresh example of a high economic impact. Therefore, strengthening the European cooperation in monitoring and forecasting, together with addressing the technological evolution of high performance computing, is a right ambitious step forward.

As it regards our possible involvement in the ExtremeEarth project, for which we hope for a successful selection, we see it in research and development of high resolution numerical weather prediction models but not only. As you surely know it, CHMI is a very active member in the ALADIN and RC-LACE consortia, already contributing to the world-leading developments in that field. In addition, CHMI encompasses meteorology and climatology, hydrology, and air quality branches, and so our environmental interdisciplinary orientation and know-how might also be a positive contribution to the project.

Yours Sincerely,

Dr. Florence Rabier
Director-General
ECMWF
Shinfield Park, Shinfield Road, Reading
RG2 9AX, United Kingdom

Na Šabatce 2050/17, 143 06 Praha 4, Czech Republic, Tel.: +420 241 765 614, www.chmi.cz

MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES

Ciemat

To:
Dr. Peter Bauer
ExtremeEarth CSA proposal Coordinator

Madrid, September, 1st 2018

Dear Sir,

We are very much interested in your Coordinated Support Action (CSA) initiative to propose a FET Flagship project, in which energy and meteorology/climate will play a strong part in the Flagship proposal. This project aims to improve the prediction and monitoring of environmental extremes natural hazards – such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis – and their impacts on society by the imaginative integration of computing and the real-time exploitation of pervasive environmental data.

The Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), which is the Spanish representative in International fora such as the European Energy Reseach Alliance (EERA) or the European Climate Reseach Alliance (ECRA) among many others, is fully interested in the results to be provided by the ExtremeEarth CSA proposal initiative, as well as in participating in future consortia related to the ExtremeEasth initiative.

Kind Regards,

José M. Pérez.
CIEMAT. Dept. of Technology, director.

José M. Pérez
Department of Technology.
Director

Avenida Complutense, 40
28040 - Madrid. Spain
Tel.: +34 91 346 6399
email: jm.perez@ciemat.es

Consiglio Nazionale delle Ricerche
Istituto di Metodologie per l'Analisi Ambientale

From:
Prof. Gelsomina Pappalardo
Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale
C.da S. Loja
85050 Tito Scalo (Potenza), Italy
+39 0971427263
e-mail: gelsomina.pappalardo@imaa.cnr.it

To :
Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 12/02/2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

As coordinator of the European Aerosol Research Lidar Network (EARLINET), co-coordinator of the GAW Aerosol Observation Lidar Network (GALION) and the ACTRIS-2 EU Project (Aerosols, Clouds and Trace gases Research Infrastructure), it is a pleasure to write you regarding ExtremeEarth Flagship proposal, 1st stage of a two-stage submission procedure for FETFLAG-01-2018.

EARLINET is the European coordinated lidar network, established in 2000, measuring aerosol vertical profiles with the goal of creating a quantitative, comprehensive, and statistically significant database for the horizontal, vertical, and temporal distribution of aerosols on a continental scale (www.earlinet.org).

GALION is the lidar observation network of the WMO (World Meteorological Organization) designed with the aim to provide the vertical component of the aerosol distribution through advanced laser remote sensing in a network of ground-based stations globally distributed.

ACTRIS is the European Research Infrastructure integrating state-of –the –art European ground-based stations for long term observations of aerosols, clouds and short lived gases. ACTRIS has the essential role to support building of new knowledge as well as policy issues on climate change, air quality, and long-range transports of pollutants. ACTRIS is funded by the European project ACTRIS-2 (Aerosols, Clouds, and trace gases Research Infrastructure), supported by the European Commission Horizon 2020 Research and Innovation Framework Programme (H2020-INFRAIA-2014-2015, GA No 654109) (www.actris.eu). In 2016 the ACTRIS research infrastructure has been included in the ESFRI roadmap.

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Consiglio Nazionale delle Ricerche
Istituto di Metodologie per l'Analisi Ambientale

I want to provide also my endorsement with respect to a number of international initiatives and networks, I'm involved in, which can strongly benefit from the funding of this proposal. These include global networks like: GRUAN, The Global Climate Observing System (GCOS) Reference Upper-Air Network measuring essential climate variables above Earth's surface, the H2020 projects like EUNADICS-AV (European Natural Airborne Disaster Information and Coordination System for Aviation) where several European organizations work together to close the significant gap in European-wide data and information availability during airborne hazards; a number of activities supported by the European Space Agency (ESA) for the design and validation of EarthCARE and Sentinel-5P upcoming satellite missions; the large involvement within the Copernicus Climate Changes Service (C3S) with the aim to facilitate the access to in-situ harmonized reference and baseline observations for several climate variables.

Therefore, I am fully supportive of the ExtremeEarth project and I delegate endorsements to individuals who will reflect the views and requirements of scientific, technological and service oriented communities that are included in the project.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Yours sincerely,

Gelsomina Pappalardo

CNR Research Director

LAPENNA VINCENZO
12.02.2018 15:41:17 UTC

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Copernicus Climate Change Service

17/9/2018

To: Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Dear Dr. Bauer,

ECMWF has been entrusted by the European Commission to implement the Copernicus Climate Change Service (C3S).

In its role of Entrusted Entity of C3S, we would like to highlight that many of the C3S datasets and products rely on outputs and information derived from earth system modelling: Climate reanalysis, Essential Climate Variables (ECVs), Seasonal Forecasts, long term Climate Projections. In the future, C3S ambitions to add two important components to its current portfolio: Attribution (of extreme events), and decadal predictions, both also fully dependant on earth system models. The quality and credibility of the C3S service, and most importantly, its value to the users, critically depends therefore on the reliability of the underpinning models.

Reducing systematic biases in current weather and climate simulations, improving the representation of physical processes of operational models of the global atmosphere, land and oceans, are paramount to improve the fidelity of the information provided by the current and new elements of the C3S Service. Moreover, a much higher horizontal resolution of the models, down to 1 km, would allow the development of a whole new range of highly demanded climate services. All our current and future users, from policy makers to business, as well as the society in general, would greatly benefit from those improved products in an area as important for the future of our planet as climate change.

Yours sincerely

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climate.copernicus.eu | copernicus.eu | ecmwf.int

Copernicus Climate Change Service

Juan Garces de Marcilla
Director of Copernicus Services
European Centre for Medium-Range Weather Forecasts (ECMWF)

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climate.copernicus.eu | copernicus.eu | ecmwf.int

17/9/2018

To: Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Dear Dr. Bauer,

ECMWF has been entrusted by the European Commission to implement the Copernicus Atmosphere Monitoring Service (CAMS)

The Copernicus Atmosphere Monitoring Service provides daily air quality forecasts at the global scale and, with higher resolution, over Europe. These forecasts account for routine pollutants emissions but include also information on exceptional events such as large wildfires or volcanic eruptions. These forecasts are used daily by a wide range of public and commercial users who use information for decision-making, smartphone applications and websites or for downscaling to local areas in order to inform the public or assess health impacts. CAMS services are currently reaching millions of citizens in Europe and worldwide.

CAMS strongly rely on weather forecast models to deliver its products and services to its users, such as global and regional air quality and pollen forecasts and reanalysis, UV and radiation forecasts, aerosols, and greenhouse gases. Reducing systematic biases in current weather models and improving its physics of current models will bring very important improvements to the quality of our products and its value to our users. Improving the spatial resolution of the models down to the km-scale will bring a whole new dimension to the CAMS services as the current downscaling statistical techniques are often inadequate, and constrain the uptake of the CAMS products at local or individual citizen level

Yours sincerely

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atmosphere.copernicus.eu | copernicus.eu | ecmwf.int


Juan Garces de Marcilla
Director of Copernicus Services
European Centre for Medium-Range Weather Forecasts (ECMWF)

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From: "Dominik Ulmer"
To: "Peter Bauer"
Cc: "Pascal Barbolosi", "Fiona Burgess" , "Adrian Tate" , "Mario Mattia"
Sent: Wednesday, 10 January, 2018 16:20:05
Subject: Endorsement

Dear Dr. Bauer,

With this letter, I would like to express Cray's fullest support of the project ExtremeEarth submitted as flagship project proposal to the EC under the call FETFLAG-01-2018, should the project be selected for funding.

Cray builds innovative systems and solutions enabling researchers to meet existing and future simulation and analytics challenges. Leveraging years of experience developing the world's most advanced supercomputers, Cray brings a comprehensive portfolio of supercomputing, storage, and data analytics solutions delivering unrivalled performance, efficiency, and scalability. Cray continues to invest in and leverage key technologies in order to provide the best possible solutions to the numerical weather prediction and earth system modelling communities. In addition, Cray has more than 25 software application personnel dedicated to weather, climate, and ocean modelling - many in Europe. Cray also has a long and strong collaborative relationship with the weather and climate community around the world. Furthermore, Cray has extensive experience in co-designing purpose-built and leading-edge supercomputer solutions with scientific communities.

Cray supports the aims of the ExtremeEarth project for realising a step-change enhancement of the earth-system modelling capabilities in the future. The objectives of the project represent some of the most challenging and most urgent scientific, technical, and societal challenges in scientific supercomputing. As Cray's mission is building computational tools that help changing the world, we fully endorse the project and are interested in contributing to its success.

Sincerely yours,

Dominik Ulmer
--
Dominik Ulmer
VP EMEA Business Operations
Cray Computer GmbH
Technologiepark Basel
Hochbergerstrasse 60C
4057 Basel
Switzerland

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

CSC

Date: 12th February 2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

CSC – IT Center for Science Ltd. (CSC) recognizes the importance of strengthening Europe's global lead in Earth-system prediction and producing a step-change in advancing societal resilience through the development of physical models, as well as the need to drive novel large-scale computing and data intensive methodologies across all related disciplines.

Thus CSC endorses the ExtremeEarth Flagship proposal and gives its support to the scientific, technological and programmatic objectives of the proposal.

CSC – IT Center for Science Ltd is Finnish national IT competence center for science, administered by the Ministry of Education, Science and Culture. CSC is a non-profit company developing and providing advanced e-infrastructure services for academia, research institutes and companies. CSC is strongly involved in key European e-infrastructures, such as EUDAT (Coordinator), PRACE, and EOSC-hub. CSC has a long-standing partnership with environmental and earth science research communities, including partnerships in thematic national and Nordic Centers of Excellence and partnership in the FP7 ENVRI and H2020 ENVRIPlus ESFRI cluster projects.

CSC supports this initiative and is looking forward to its successful implementation.

Kimmo Koski, Managing Director

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Danish Meteorological Institute

Dr. Florence Rabier
Director-General
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading
RG2 9AX
United Kingdom

Office/Department
The director

Date
10 September 2018

J. no. 2018-679

Endorsement letter for ExtremeEarth

The purpose of this letter from the Danish Meteorological Institute (DMI) is to endorse the EU Flagship candidate ExtremeEarth led by the European Centre for Medium-Range Weather Forecasts.

Extreme natural phenomena and the mounting impact of climate change radically affect all sectors of society. ExtremeEarth is exceptionally ambitious as regards both weather and climate predictions, fields that are essential to DMI.

DMI's strategic focus areas include high resolution weather modelling, including extreme convective precipitation events, energy forecasting, regional climate prediction and monitoring, ice sheet and sea ice modelling, and monitoring and earth system science. In all of these areas a united European effort, as promised by the ExtremeEarth project, will lead to faster progress, which we would certainly welcome at DMI and like to be a part of.

DMI hopes that the ExtremeEarth project will become reality and wish to become part of the project in the future and help bring value to ExtremeEarth on areas that matches DMI's field of expertise.

Best regards

Marianne Thyring
Director
Danish Meteorological Institute

The Danish
Meteorological
Institute

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www.dmi.dk

→ Peter

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Deutscher Wetterdienst - Postfach 10 04 65 - 63004 Offenbach

Dr. Florence Rabier
Director-General
European Centre for Medium-Range
Weather Forecasts
Shinfield Park,
Reading RG2 9AX, UK

Der Präsident

Ansprechpartner:
Prof. S. Jones
Telefon:
+49 69/8062-2720
E-Mail:
Sarah.Jones@dwd.de

Geschäftszeichen:
FE/Extr. Earth
Fax:

UST-ID: DE221793973

Offenbach, 06 August 2018

Reference:
ExtremeEarth EU Flagship proposal; 2nd stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Letter of support

With this letter of support, Deutscher Wetterdienst (DWD) wishes to express its strong support for the project ExtremeEarth, a candidate European Commission Future and Emerging Technology Flagship. Given the evidence for rapid climate change the proposed project is very timely and has immense scientific and societal significance as it seeks to revolutionize Europe's capability of predicting and monitoring environmental extremes and their impacts. ExtremeEarth will enable European governments and society to plan more effectively and become more resilient to the environmental impacts, especially extreme natural phenomena.

DWD looks forward to collaborating with the ExtremeEarth project consortium should it be positively evaluated and receive funding. The envisioned co-operation would involve research on weather and climate extremes through

- further developing our seamless high-resolution ICON modelling framework for weather, climate and environmental forecasts,
- performing research on ultra-high-resolution weather, climate and environmental predictions,
- developing downstream applications based on ExtremeEarth simulations for key customers of DWD, especially in the field of emergency response agencies and renewable energy, and
- utilizing our comprehensive monitoring networks of the atmospheric state.

ExtremeEarth with its focus on physical models of the Earth system with unprecedented resolution and accuracy will strengthen Europe's global lead in Earth-system prediction and support DWD's future mission.

Yours sincerely,

Dr. P. Becker
for Prof. Dr. G. Adrian

REPUBLIC OF CROATIA
METEOROLOGICAL AND HYDROLOGICAL SERVICE

Zagreb, 27 August 2018

Dr Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range
Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Letter of Support for ExtremeEarth

Dear Dr. Bauer,

This letter expresses the commitment of Meteorological and Hydrological Service of Croatia (Državni hidrometeorološki zavod, DHMZ) to the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

DHMZ fully supports the technological and scientific ambitions of ExtremeEarth. It has the potential to enable large capability breakthroughs in our areas of weather and other environment media prediction and become central initiative at the EU and global level in the science of climate and climate change, supported by the new advances in the IT and computing technologies. These advances are requirement for the reliable estimates of the climate change impacts at the regional, national and local levels.

If the next stage of the evaluation of the proposal is as successful as the first one, DHMZ will take the opportunity of the Coordination and Support Action to highlight what it ambitions to bring into the Flagship. DHMZ looks forward to collaborating with the ExtremeEarth project consortium should it be positively evaluated and receive funding. Specifically, our envisioned cooperation would involve research on climate and weather extremes, both through development of world leading physical models and utilizing our wide monitoring networks of the atmospheric state.

DHMZ looks forward to be part of the ExtremeEarth Flagship, once successful in getting EU support.

Yours sincerely,

Dr Branka Ivančan-Picek
Director

Dr Peter Bauer
Deputy Director Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park,
Reading RG2 9AX,
UK.
5th September 2018

Subject: Letter of Support for the Extreme Earth Initiative

Dear Dr Peter Bauer,

On behalf of EARSC, I am pleased to support the Extreme Earth Initiative, a proposed FET Flagship Programme FETFLAG-01-2018 of the European Commission (EC) that starts with a CSA proposal ExtremeEarth-PP as its preparatory project.

EARSC is the European organization which – on a non-profit basis – promotes the use of Earth Observation (EO) technology and especially the companies in Europe which offer EO-related products and services. We are a membership-based organisation with the mission to foster the development of the European EO geo-information services industry. Today, EARSC has over 100 members comprising companies of all sizes from 22 European countries. The sector is dominated by small and micro companies which make up over 95% of the population.

The ExtremeEarth project's scientific, technological and programmatic objectives are of interest for the industry. We are generally interested in supporting innovative and promising approaches that demonstrate the value of EO technologies and especially to extend the user base. The industry is also interested to work with partners to extend the range of commercial products to be offered. Finally, EARSC supports the mission of ExtremeEarth that will revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on the society.

We shall be interested to be kept informed on the progress and to support the activities through the industry network. We can envisage industrial interest to engage with the project as it progresses and can offer to facilitate networking between the project and the EO service community.

European Association of Remote Sensing Companies, 26, Rue Beranger, Forest, 1190, BELGIUM
Phone: 0032476737564; E-mail: secretariat@earsc.org ; web-site : www.earsc.org
VAT Number: BE0447243442
Bank Account: BNP Paribas Fortis Bank, Brussels, Belgium. IBAN Code :BE08210005496013 BIC, GEBABEBB36A

EARSC
European Association of Remote Sensing Companies

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

We are looking forward to future interactions.

Yours sincerely,

F.G.Sawyer

EARSC Secretary General

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Phone: 0032476737564; E-mail: secretariat@earsc.org ; web-site : www.earsc.org
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Isabelle FLOUR
Head of Department
Fluid Mechanics, Energies and Environment
EDF Lab Chatou
6 Quai Watier
78400 CHATOU – FRANCE

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

08 February 2018

Ref.: ExtremeEarth
Our Ref.: I8G/18/001 - LD

Dear Dr Bauer

The vision of ExtremeEarth is to develop a wholly new class of models for more accurate prediction of extremes in our weather and climate systems, and to couple these to impacts in the food, water, health, energy and insurance sectors. ExtremeEarth will then give unprecedented new insights into the processes and mechanisms responsible for weather extremes, and allow us to understand how the frequency and intensity of such events will alter in response to climate change, thereby leading to increased predictive skill.

The energy sector is looking forward to such developments, which will have direct applications, in particular regarding the fast and massive development or Renewable Energies, which requires increased accuracy in short term forecasts at local scale, as well as increased understanding about future resource under climate change. Increased forecast quality and resource estimation will be a key driver in the development of more resilient energy systems.

This will require the development of new models of the climate system at unprecedented resolution, and with the inclusion of new physics and numerical algorithms, which will be run on the next generation of High Performance Computing platforms.

ExtremeEarth is essential if we are to fully understand the drivers of weather extremes and climate variability, and the impacts of these on the energy sector. We believe this issue cannot be solved by a single centre and a pan-European approach is then needed to construct the next generation models that include suitable physics, and will perform effectively on the High Performance Computing platforms of the near future.

It is time for the European community to come together, using the fully-integrated approach proposed within ExtremeEarth, to address problems that are critically important for society. I therefore fully support the ExtremeEarth initiative, which will deliver critical advice to enable Europe to better plan for, and mitigate, the effects of high-impact weather events on the energy sector, as well as generating new scientific understanding and advancing modelling technology, which will greatly benefit research and application development at EDF, and in the energy sector in general.

Yours sincerely

Isabelle FLOUR.

European Environment Agency

17.09.2018

ECMWF
att. Dr. Juan Garces de Marcilla
Director, Copernicus services
ShinfieldPark
Reading RG2 9AX
UK

Dear Dr. Juan Garces de Marcilla,

Subject: Letter of support for the ExtremeEarth proposal

We are pleased to endorse the Extreme Earth flagship programme proposal on behalf of the Copernicus team at EEA, and by extension on behalf of the colleagues of our agency dealing with Climate Change information and mitigation.

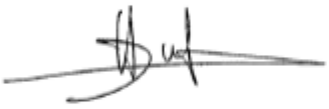
By providing information on climate change in Europe, the EEA supports the implementation of legislation on climate mitigation in Europe, the evaluation of EU policies and the development of long-term strategies to mitigate climate change. EEA information — data, indicators, assessments and projections — focuses on greenhouse gas emissions trends, projections, and policies and measures in Europe.

Hence a better understanding, including the ability to predict frequency of extreme events and intensity thereof is of paramount importance to the EEA as part of our tasks in support to the Climate change related policies the European Commission is putting into place. In that context, the EEA works closely together with DG Climate Action, DG Joint Research Centre, and Eurostat, as well as with experts from its European Topic Centres on Air and Climate Change Mitigation (ETC/ACM) and with its country network (Eionet).

European Environment Agency

Moreover, it is our understanding that beyond climate change sensu stricto, the outcome of Extreme Earth will improve our knowledge in domains as broad as water management, health or sustainable resource management, domains for which the provision of scientifically sound information and knowledge in support of Community policies is also part of EEA's core tasks. Therefore we are happy to endorse the Extreme Earthe Flagship initiative.

Yours sincerely,



Hans Dufourmont
Project manager Copernicus land services

Chris Steenmans
Head of Programme

cc:.
Enclosure(s): Click to enter enclosure(s)

Dear Dr. Bauer,

I would like, on the behalf of the EoCoE project, express my support to your ExtremeEarth flagship proposal.
EoCoE is the Energy Oriented Center of Excellence, one of the 9 center of excellence for computing application set-up by the EC in framework of the H2020 work-program.
EoCoE is using the prodigious potential offered by the ever-growing computing infrastructure to foster and accelerate the European transition to a reliable and low carbon energy supply.
It is contributing to the energy transition via targeted support to four renewable energy pillars. Out of these four pillars, two are directly connected to the activities proposed in the ExtremeEarth : Our « Meteorology for Energy » workpackage cope with the variability of weather on renewable energies such as solar and wind sources to gain in supply predictability, it is particularly concerned with the prediction of rare events that could results in a global Network failure. In the « Water for Energy » work package, we analyze the possible production and storage hydropower scenarios under climate change constraints and geothermal heat and electricity production possibilities under heavy populated areas.

All the work done is EoCoE could certainly be leverage in a futur flagship and the EoCoE project, which should hopefully continue, would greatly benefit form the creation of the ExtremEarth flagship.

Best regards,

Edouard Audit, EoCoE coordinator.

Dr. Peter Bauer

Deputy Director, Research Department

European Centre for Medium-Range Weather Forecasts

Shinfield Park, Reading RG2 9AX, UK

Ref: ExtremeEarth Our Ref: 23082018WH Date: 23rd August, 2018

Dear Dr Bauer

This letter shows Equinor's support to the ExtremeEarth proposal which has an ambitious vision to develop an accurate prediction of extremes of both weather and climate systems and to ascertain the impacts in the food, water, health, energy and insurance sectors. Equinor believes that ExtremeEarth will demonstrate extreme-scale computer and data capabilities in a co-design and co-production framework that will drive digital technology and European roadmaps on both technology and research and development.

Equinor is an international energy company with operations in 40 countries and is committed to accommodating the world's energy needs in a responsible manner. By utilizing world leading offshore oil/gas platform experiences which have been developed for 45 years, Equinor is one of the most influential offshore wind farm developers in the world. More specifically, Equinor is the major developer for more than eight offshore wind farms. For those, increasing accuracy of short-term predictions and better knowledge of the climate change impact on long-term production is very much in our interest. ExtremeEarth is true for both Equinor in particular and the wider energy sector in general.

The Renewable Technology Department at Equinor has participated in more than 10 EU FP7 and H2020 collaborative Research and Innovation projects. Equinor has benefited from many innovative results from European funded large offshore wind programs. I therefore fully support ExtremeEarth initiative and am looking forwards to ground-breaking results.

Your sincerely,

Wei He

Wei He, Dr. Principal Researcher (Co-ordinator of EU H2020 wind projects at Equinor)

Renewable Technology, Equinor

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Dr. Joachim Biercamp
Head of Applications Department
ESiWACE Project Coordinator

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Dr. Peter Bauer

Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Letter of Commitment for the ExtremeEarth initiative

Dear Dr. Bauer,

in my role as coordinator of the H2020 project ESiWACE and also its second phase which is in the grant preparation phase, I herewith express my strong support for the ExtremeEarth proposal, and the commitment of the ESiWACE Center of Excellence to contribute to the goals of ExtremeEarth.

A central objective of ESiWACE is to enable leading European weather and climate models to leverage the available performance of future high performance computing systems and to support the climate and weather research community in using these models. This clearly concurs with the goal of ExtremeEarth *to develop domain-specific processing capabilities at the interface between edge, cloud and centralized high-performance computing exploiting existing and emerging new data sources.*

The challenges our community is facing with respect to both a) the complexity of the Earth System and consequently the software and data infrastructure needed to predict its evolution and b) the complexity of upcoming HPC hardware and software systems, cannot be met by individual institutes or projects but needs a mission-oriented inter-disciplinary approach.

I am convinced that ExtremeEarth if successful as a European Flagship or Mission will have invaluable positive impact on science, society and economy.

Sincerely,

Dr. Joachim Biercamp

ESiWACE project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 675191
www.esiwace.eu

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Eesti Maaülikool
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www.emu.ee

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 09.02.2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

On behalf of the Estonian University of Life Sciences, I would like to express our strong support for the ExtremeEarth initiative. The rapid changes impacting on the environment induced by humankind do not let much of a time window open to develop scientific driven mitigation strategies and to ensure societal resilience under the premises of growing urbanization, growing population, and shrinking natural resources. Answers to these global challenges are further impacted by prediction uncertainty and the challenge to implement and apply monitoring data on appropriate large scale. One critical step is to build the inter- and multidisciplinary competence to tackle these challenges. ExtremeEarth is, to our opinion, a necessary step to build this competence on a European level.

The Estonian University of Life Sciences represents the Estonian large scale climate research station SMEAR Estonia, uniting scientists from the fields of atmospheric physics, agriculture, biosphere-atmosphere exchange, ecology, earth-sciences, geology, forestry, mathematical modeling and theory building spread over different Universities and research institutions in Estonia. We are glad to contribute with our competence, data and monitoring capacities to the ExtremeEarth initiative.

We express our strong support for the ExtremeEarth proposal towards a European Commission Future and Emerging Technology Flagship, to help to predict, to monitor, and to create deep understanding of environmental extremes and their impacts on society.

Steffen M. Noe

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Collaborative
EUDAT Data Infrastructure
Data shared and preserved across borders and disciplines

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 12 February 2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

On behalf of EUDAT, I would like to express my support regarding the ExtremeEarth Flaghip proposal.

As clearly explained by your consortium, "the diversity and volume of Earth observation data requires the adoption of novel and efficient pre-processing and information extraction supported by edge-based computing infrastructures at the front-end, and user-friendly information analytics combining components of the Earth system at the back-end. *ExtremeEarth* will reform the handling and analytics of big data volumes along the science-to-impact modeling chain, and by including the vast resources of Earth observation data through complex data assimilation methods."

EUDAT brings together several major European data & compute centers and supports the scientific, technological and programmatic objectives of ExtremeEarth. Several members of EUDAT are directly involved in the initiative or are tightly connected to organisations involved which offers a natural link between EUDAT and ExtremeEarth which we will be able to leverage in our future collaboration.

Yours faithfully,

Dr. Damien Lecarpentier
Programme Director, Research Infrastructures
EUDAT CDI Head of Secretariat
CSC – IT Center for Science, LTD, Finland
Tel: +358503819515

www.eudat.eu/cdi

EuroGeoSurveys
The Geological Surveys of Europe

Brussels, 24 August 2018

Our reference: 2018/1756

Dr Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Subject: Endorsement letter

Dear Dr Peter Bauer,

I am pleased to provide you with EuroGeoSurveys endorsement for the Extreme Earth Initiative, a proposed FET Flagship Programme FETFLAG-01-2018 of the European Commission (EC) that starts with a CSA proposal ExtremeEarth-PP as its preparatory project.

EuroGeoSurveys (EGS), The Geological Surveys of Europe, is a not-for-profit organisation representing 37 National Geological Surveys and some regional Surveys in Europe. EGS members, the National Geological Surveys, are public sector institutions carrying out operations and research in the field of geosciences by conducting research focused on their national subsurface.

EuroGeoSurveys and its members provides expert, neutral, balanced and practical pan-European advice and information as an aid to problem-solving, policy, regulatory and programme formulation in areas of (a) the use and the management of on- and off-shore natural resources related to the subsurface of the Earth, (b) the identification of natural hazards of geological origin, their monitoring and the mitigation of their impacts, (c) the environmental management, sustainable urban development and safe construction, and (d) e- government and the access to geoscientific metadata / data and the development of interoperable and harmonised geoscientific data at the European scale.

Two areas of EGS research background are perfectly aligned with ExtremeEarth Initiative, firstly in the identification and understanding of natural hazards of geological origin (deficit or excess of trace elements in soils and waters, earthquakes, natural emissions of hazardous gases, landslides and rockfalls, land heave and subsidence, shrinking and swelling clays), and secondly facilitating the access to geoscientific metadata and data and developing interoperable and harmonised geoscientific data at the European scale. Understanding the past extreme natural phenomena (earthquakes, volcanoes, floods ....) and the impact of climate change (desertification, glacier melting or growing ...) assists in better understating, predicting and mitigating environmental pressures on the human population in the modern world.

The ExtremeEarth project's scientific, technological and programmatic objectives are aligned with the future directions of EGS. Therefore, EGS supports the mission of ExtremeEarth that will revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on the society.

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www.eurogeosurveys.org

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

We are looking forward to future interactions.

Yours sincerely,

Prof Teresa Ponce de Leão
EuroGeoSurveys - President

EUROPEAN TECHNOLOGY PLATFORM FOR HIGH PERFORMANCE COMPUTING

European Technology Platform for High Performance Computing (ETP4HPC)
Science Park 140
1098 XG Amsterdam
The Netherlands

To whom it may concern

Endorsement of the Flagship candidate project ExtremeEarth

ETP4HPC understands ExtremeEarth wants to increase the capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

Therefore, *ExtremeEarth* will need to drive HPC and data intensive methodologies to a new level: the diversity and volume of Earth observation data requires the adoption of novel and efficient pre-processing and information extraction, supported by edge-based computing infrastructures at the front-end, and user-friendly information analytics combining components of the Earth system at the back-end.

Those technological challenges faced by *ExtremeEarth* are at the heart of the ETP4HPC activities: ETP4HPC advocates that the development of future architectures must rely on strong co-design between the applications owner and the technology providers. The latest version of ETP4HPC's Strategic Research Agenda (SRA) reflects this in a key section dedicated to applications requirements. The "Extreme Scale Demonstrators" concept developed within ETP4HPC is also fully in line with these considerations.

ETP4HPC fully supports *ExtremeEarth* approach and is looking forward to contributing to tackling the technological challenges faced by the *ExtremeEarth* community.

Jean-Pierre Panziera
Chairman of ETP4HPC

منظمة الأغذية والزراعة للأمم المتحدة
联合国粮食及农业组织
Food and Agriculture Organization of the United Nations
Organisation des Nations Unies pour l'alimentation et l'agriculture
Продовольственная и сельскохозяйственная организация Объединенных Наций
Organización de las Naciones Unidas para la Alimentación y la Agricultura

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3 SEP 2018

Endorsement of the ExtremeEarth Flagship proposal

Dear Mr Bauer,

It is our pleasure to endorse the European Commission's ExtremeEarth Flagship proposal "Tackling Grand Interdisciplinary Science and Technology Challenges".

The proposed Flagship aligns closely with key areas prioritised by the Food and Agriculture Organization of the United Nations (FAO). To meet the demands posed by major global trends in agricultural development and challenges faced by member nations, FAO has identified five key priorities on which it is best placed to intervene. One of these areas is to increase the resilience of livelihoods to threats and crises, including by using early warnings to protect people from disaster impact ahead of time. If implemented, the Flagship programme will be a critical step towards improving the quality and accessibility of scientific and technological forecasting mechanisms to support quality early warnings for agriculture and food security.

FAO can contribute to the Flagship through its Early Warning Early Action (EWEA) initiative, which translates early warnings into anticipatory actions to reduce the impact of disaster events on vulnerable agriculture-based communities. FAO will be able to provide highly relevant EWEA expertise to the project design, in addition to the agency's broader technical expertise in agriculture and food security.

FAO fully endorses the ExtremeEarth initiative, with its scientific, technological and programmatic objectives. While this endorsement does not imply any legal or financial commitments towards the ExtremeEarth project, we endorse our statement and logo to be shown on the website.

We look forward to close interactions in the future.

Yours sincerely,

Daniel Gustafson
Deputy Director-General (Programmes)
and Officer-in-Charge, Technical Cooperation Department

Mr Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Reading

FINNISH METEOROLOGICAL INSTITUTE

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 10.2.2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

With this endorsement letter, the Finnish Meteorological Institute (FMI) wishes to express its strong support for the project *ExtremeEarth*, a candidate European Commission Future and Emerging Technology Flagship. The proposed project is very timely and has immense scientific and societal significance as it seeks to revolutionize Europe's capability of predicting and monitoring environmental extremes and their impacts.

FMI looks forward to collaborating with the *ExtremeEarth* project consortium should it be positively evaluated and receive funding. Specifically, our envisioned cooperation would involve research on climate and weather extremes, both through development of world-leading physical models and utilizing our wide monitoring networks of the atmospheric state.

Sincerely,

Hannele Korhonen

Prof. Hannele Korhonen
Director of Climate Research Programme

Finnish Meteorological Institute
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FORECA

Fabio Venuti
ECMWF Data Services Team Leader
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading
RG2 9AX
UNITED KINGDOM

29.08.2018

Subject: Endorsement of the Preparatory EU FET Flagship Project ExtremeEarth

Dear Fabio Venuti,

On behalf of the Foreca Ltd I express our strong support for the proposal to develop the FET Flagship Project ExtremeEarth. The project is extremely ambitious, but given our decade long experience in dealing with ECMWF, we feel that there is no-one more capable of tackling a challenge of this magnitude.

The cutting-edge Earth-system modelling capabilities that ExtremeEarth proposes to build will enable substantial progress in overall safety. As a leading road weather provider, we see all weather forecast quality improvements as crucial. Foreca's mission as a private weather company is to help our professional customers to improve road safety by delivering road weather information for professional winter road/runway maintenance and future autonomous driving systems. In these use cases, all gains in weather forecasting accuracy lead to better decisions and increased safety on the roads.

Yours Sincerely,

Samu Karanko
Chief Analyst
Foreca Ltd

Geoverbund ABC/J | Coordination Office | Jülich

Geoverbund ABC/J | Scientific Director
Prof. Dr. Harry Vereecken

Coordination Office Geoverbund ABC/J | Head
Dr. Daniel Felten

Forschungszentrum Jülich GmbH
in the Helmholtz Association
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www.geoverbund.de

Jülich, 15 December 2017

Letter of Support for the FET Flagship Candidate Project Extreme Earth (CSA proposal)

To whom it may concern,

Geoverbund ABC/J – as the geoscientific network within the research region of **A**achen-**B**onn-**C**ologne/**J**ülich – has a very strong interest in developing a FET Flagship Extreme Earth and thus offers best support to the proposal.

Since 2009, the geoscientific institutes of RWTH Aachen University, the University of Bonn, the University of Cologne, and Forschungszentrum Jülich collaborate under the umbrella of Geoverbund ABC/J. The cooperation efficiently pools and interconnects the expertise in geoscientific research and education gained at these institutions over several decades. Geoverbund ABC/J initiates and promotes research projects spanning different locations, supports early-career scientists, and encourages easy access to scientific infrastructures.

The Flagship's research focus is covered by Geoverbund ABC/J's guiding research themes, which are *evolution of Earth and life*, *environmental dynamics and atmosphere in global change*, *terrestrial systems and georesource management*, and *risks and risk regulation*. Our members have strong and proven expertise in monitoring, analyzing and managing extreme natural phenomena, e.g. floods, droughts, earthquakes, volcanoes, tsunamis, desertification, glacier melting, and sea-level rise. Our network will thus be able to provide a significant contribution on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the integration of edge and exascale computing, and the real-time exploitation of environmental data.

In this context, Geoverbund ABC/J also has direct access to the high-performance supercomputers of Forschungszentrum Jülich through the centre of excellence *High-Performance Scientific Computing in Terrestrial Systems* (HPSC TerrSys). This centre was founded by Geoverbund ABC/J in 2011. Together with the associated Simulation Laboratory (SimLab TerrSys) and in close cooperation with the *Jülich Supercomputing Centre* (JSC), HPSC TerrSys provides the geoscientists of the ABC/J region with scientific and technical support for their research activities by means of its supercomputers.

Yours sincerely,

Prof. Dr. Harry Vereecken
Scientific Director
Geoverbund ABC/J

A Core Project of the World Climate Research Programme on
Global Energy and Water Exchanges

January 24, 2018

RE: Extreme Earth Flagship Project

TO WHOM IT MAY CONCERN:

Based on the information we received about the Extreme Earth Flagship Project (FETFLAG-01-2018) to be funded under the European Union H2020, I am pleased to confirm that the expected results of the project are of direct interest to GEWEX. The Global Energy and Water Cycle Exchanges (GEWEX) Project under the auspices of the World Research Climate Programme (WRCP) has as one of its objectives, the improvement in the observations and prediction of hydrologic fluxes, and, in particular those of precipitation. The Extreme Earth Flagship Project is expected to improve the way climate and weather predictions are generated in high-resolution impact modeling (e.g., agriculture, droughts, floods) and to lead to much more robust and accurate information addressing weather extremes, predicting future dominant climate patterns, and providing consistent, robust and seamless climate information from the farm scale, to the advisory services, national and international scales – relevant for management decision within the season, to annual, decadal and multi decadal scale adaptation goals.

In closing, we are very pleased to be cooperating on this important project as it has many aspects that overlap with GEWEX and we support in any other way feasible that would make this a successful endeavor.

Sincerely,

Dr. ir. Petrus (Peter) J. van Oevelen
Director,
International GEWEX Project Office
Sr. Scientist,
Universities Space Research Association

International GEWEX Project Office
425 3rd Street, Ste 605 | Washington, DC 20024 USA
Tel: 1-202-527-1827 E-mail: gewex@gewex.org URL: http://www.gewex.org

GFDRR
Global Facility for Disaster Reduction and Recovery

August 31, 2018

To Whom It May Concern

Re: Support for The Extreme Earth proposal

Dear Sir/Madam,

We recently had an opportunity to learn about the ExtremeEarth proposal submitted to the European Commission (EC) Future and Emerging Technology Flagship, prepared in response to the EC's call for Coordination and Support Actions.

Having careful review of the proposal, we would like to express our strong support to its objectives and vision, namely, to revolutionize a capability to predict and monitor environmental extremes and their impacts on society by working closely with NMHSs, disaster prevention and mitigation agencies, as well as academia, commercial entities and other stakeholders. These objectives are in line with and complementary to the objectives set under the World Bank/GFDRR hydromet program that is implemented in more than 40 developing countries around the world.

GFDRR hydromet program helps governments strengthen hydromet monitoring, forecasting and early warning systems, and supports robust weather, climate and hydrological services to save lives, reduce impacts from disasters, and promotes sustainable economic growth in the developing countries that are particularly vulnerable to climate change and disaster risks.

We believe that the activities presented in the ExtremeEarth proposal are likely to contribute to capacity building of the national agencies which is the biggest challenge and an important factor in sustainable development and provision of trustworthy and reliable weather and climate services. The development and testing of the new prediction capabilities and scenarios to regions and countries where environmental extremes are particularly harmful are critical to help the developing countries better plan and prepare for extreme weather.

To conclude, we believe that the successful launch and implementation of this proposal will contribute to a more sustainable growth of the Global Weather Enterprise, and therefore to the ability of countries to provide accurate and reliable weather information and services that save lives, protect infrastructure and enhance economic output.

Sincerely,

Vladimir Tsirkunov
Hydromet Lead

Global Facility for Disaster Reduction and Recovery

Global Facility for Disaster Reduction and Recovery, The World Bank, 1818 H Street, NW, Washington DC 20433, MSN# U3-307,
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Telephone +44(0)131 6671000
Direct Line +44(0)131 6500417
E-mail sclou@bgs.ac.uk

17 September 2018

Dear Professor Papale,

I am writing to you on behalf of the 'Global Volcano Model network', to express our strong and enthusiastic support for your proposal 'Extreme Earth'.

Extreme Earth represents an urgent and transformative step forward in bringing together the Earth Science, Atmospheric science and Informatics/Technology communities in Europe to provide scientific evidence upon which risk reduction and resilience can be built. The plans for Earth-system prediction models and assimilation of observational data real-time and across scales demonstrate world leading vision, coordination and capabilities. Such scientific evidence and technological capability is essential to underpin effective decision-making, to build resilience and to enable timely mitigation, risk reduction and sustainable development in anticipation of environmental change and natural extremes.

The international GVM network began in 2012 to create a sustainable, accessible information platform on volcanic hazard and risk with systemic evidence, data and analysis of volcanic hazard and risk at regional and global scales. It supports volcano observatories at a local scale. The GVM network is developing capabilities to anticipate future volcanism and its consequences. Importantly, this is a *network*, so capabilities and resources are being developed at multiple sites but with common standards, designs and approaches. Despite increasingly effective community networking (e.g. GVM network) and research infrastructures (e.g. EPOS and EUROVOLC), volcano science communities working at local to global scales are currently held back by limited access to appropriate technical and computing resources. This was a key finding of a consultation process held within the GVM network in 2016 and now Extreme Earth directly addresses this barrier to progress.

The GVM network will contribute to planning and implementation of Extreme Earth. Our network includes research institutions, practitioners (e.g. volcano observatories), public sector (e.g. civil protection), private sector (e.g. reinsurance) and NGOs who will work together to ensure that our combined knowledge and experience contributes to development of technical plans combined with an understanding of diverse needs. We can offer support in many ways but some examples are as follows:

- The GVM network coordinated 130 scientists from 86 institutions in nearly 50 countries to produce evidence on global volcanic hazard and risk and the first global model of ash fall hazard for the UN 'Global Assessment Report' 2015. We will contribute a similar level of coordination for the UN Global Assessment Report in 2021 and commit to doing so in collaboration with Extreme Earth which could take a key and leading role.

- The GVM network is developing a series of global relational databases with common data collection standards, volcano ids and opportunities for use in modelling hazard and risk. We will continue to ensure that data, databases and resources are being developed that contain appropriate standards (of data collection), metadata, uncertainties and content so they can be effectively used for modelling purposes. The GVM network works closely with the Global Earthquake Model (GEM), developing data schema for multi-hazards and collaborating on the use of GEM exposure databases and other resources.

- The GVM network will come together to ensure that existing modelling capabilities and hazards tools in Europe are fully utilised for the benefit of Extreme Earth. In addition, the volcano community is increasingly generating evidence relating to impact and dynamic risk so we will ensure this learning and knowledge is accessible to Extreme Earth.

- We strongly advocate for co-design and co-development of research, resources, products and services with users and will support such approaches. We will engage with our networks of scientists and our networks of users on behalf of Extreme Earth.

- We also commit to align projects, resources and future endeavours to ensure the success of Extreme Earth.

On behalf of the GVM network I wish you the very best of luck with this proposal.

Yours sincerely

SC Loughlin

Sue Loughlin
Global Volcano Model (Chair of the Management Board)

Dr Florence Rabier
Director – General
European Centre for Medium – Range Weather Forecasts
Shinfield Park
Reading
RG2 9AX
UNITED KINGDOM

Date : September 13, 2018

Subject: *Letter of support for ExtremeEarth*

Dear Dr. Rabier,

This letter expresses the commitment of Hellenic National Meteorological Service (HNMS) to the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

HNMS fully supports the technological and scientific ambitions of ExtremeEarth, which has the potential to enable large capability breakthroughs in the area of weather, climate and a variety of environmental issues.

HNMS is looking forward to collaborate with the ExtremeEarth project consortium, should it be positively evaluated and receive funding. Specifically, our cooperation could involve research on climate, weather and marine extremes, through the further development of physical models which are already being used in our service.

Yours sincerely,

Brigadier General (HAF) Nikolaos Vogiatzis
Director of HNMS

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HELMHOLTZ
CENTRE FOR
ENVIRONMENTAL
RESEARCH – UFZ

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
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United Kingdom

Executive Management
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fax: +49 235 1388
gf@ufz.de

Leipzig, 9th February 2018

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To the Coordinator of the ExtremeEarth CSA project proposal

On behalf of the Helmholtz Centre for Environmental Research – UFZ, we are expressing our strongest support for the CSA proposal to develop a FET Flagship Project Extreme Earth.

The UFZ develops strategies and instruments that ensure the persistence of various ecosystem services and the resilience of ecosystems in times of global change and increasing pressure. We develop and apply smart models and monitoring systems in order to analyze complex environmental systems and to make reliable predictions about how environmental systems will react to anthropogenic disturbance. To achieve a sustainable use of natural resources for the well-being of humans and the environment, we aim at understanding how stakeholders from the political arena, the economy and society will react to certain environmental issues and which basic conditions and interests propel them to act in the way that they do. Against this background, the UFZ develops and provides science-based options for political and societal decision-making processes.

The joint activity of the climate and earth system science communities to develop an FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

Helmholtz Centre for Environmental Research – UFZ

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MinDirig Wilfried Kraus

Management Board:
Prof. Dr. Georg Teutsch and
Prof. Dr. Heike Graßmann

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EMAS

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

With our research background in the fields of monitoring and prediction of trends and extremes, modeling of landscapes and hydrosystems, as well as the interactions of society and environment, we see strong links to the aims of the proposed project ExtremeEarth. Therefore, we strongly support this proposal and we are looking forward to further intense involvement in this joint European activity.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website

With kind regards,

Prof. Dr. Georg Teutsch
Scientific Managing Director

Prof. Dr. Heike Graßman
Administrative Managing Director

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Geschäftsführung

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Internet www.hzg.de

Datum
16.02.2018

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To the Coordinator of the ExtremeEarth CSA project proposal

On behalf of *Helmholtz Zentrum Geesthacht, Centre for Materials and Coastal Research* I am expressing my strongest support for the CSA proposal to develop a FET Flagship Project Extreme Earth.

This activitiy of the climate and earth system science communities to develop a joint FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

The Helmholtz Zentrum Geesthacht, is strongly involved in research activities with focus on coastal systems and, through its entity the Climate Service Centre Germany-GERICS, in climate services. Coastal regions are among the most rapidly changing environments. More than 40% of the human population live at the coast, exposed to extremes such as storms, floods and sea level rise. At the same time, human activity in the coastal zone increases continuously and exposure and vulnerability to climate risks increase.

Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

Coastal communities are highly vulnerable to extreme weather conditions, advancing predictive capabilities as proposed by ExtremeEarth is therefore of high relevance for our coastal research and climate service activities. Extreme Earth has a remarkable potential to support society in their efforts to adapt to changing extreme conditions. With our research background in the fields of coastal research and climate services, we see strong links to the aims of the proposed project ExtremeEarth.
Therefore, we strongly support this proposal and we are looking forward to further intense involvement in this joint European activity.
The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.
This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

With kind regards

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Prof. Dr. Wolfgang Kaysser

Michael Ganß

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Helmholtz Association • Anna-Louisa-Karsch-Straße 2 • 10178 Berlin • Germany

Coordinator of the ExtremeEarth CSA project proposal
European Centre for Medium –Range Weather Forecasts –ECMWF
Dr. Peter Bauer
Shinfield Park
Reading, Berkshire, RG2 9AX
UNITED KINGDOM

07.02.2018/AT

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

Dear Dr. Bauer,

On behalf of the Helmholtz Association of German Research Centres I am expressing my strongest support for the CSA proposal to develop a FET Flagship Project ExtremeEarth.

This activity of the climate and earth system science communities to develop a joint FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

The Helmholtz Association of German Research Centres is strongly involved in Earth and environmental research activities which are pursued at eight Helmholtz Centres.

Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

Within the Helmholtz research field Earth and Environment we will continue to pool the capacities and expertise in interdisciplinary activities to tackle the future Earth system challenges. This strategy will facilitate the expansion of Earth observation and knowledge systems as well as integrated Earth system modelling approaches. Here we see strong links to the aims of the proposed project ExtremeEarth.

The President
Prof. Dr. med. Dr. h.c. mult. Otmar D. Wiestler

Hermann von Helmholtz Association
of German Research Centres

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

This project is therefore one of the future Flagship Initiatives the Helmholtz Association considers to be of the highest strategic relevance.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Sincerely yours,

Otmar D. Wiestler

www.helmholtz.de

Hungarian Meteorological Service

The President

Our reference:	*ELN-560-2/2018*
Person of contact:	*Eszter Lábó*
Phone:	*+36 1 346 4664*
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E-mail:	*labo.e@met.hu*
Date:	*11/09/2018*

ECMWF

Dr. Florence Rabier
Director-General

Shienfield Park
Reading, RG2 9AX
ENGLAND

Subject: Support to ExtremeEarth initiative

Dear Dr. Rabier,

Thank you very much for your letter on the ExtremeEarth Flagship project, informing on the preparatory phase and submission of full project proposal in response to the call FETFLAG-01-2018 in the area Energy, Environment and Climate change. I would like to highlight the importance of this project in delivering weather and environmental forecasts in a scientifically and technically improved manner. I am convinced that ExtremeEarth has strong capabilities to reinvent how forecasting is done.

Let me express the commitment of the Hungarian Meteorological Service to fully support the project, and if granted, please be informed that OMSZ is ready to contribute to it scientifically as well in different areas, notably in limited area numerical weather prediction modelling, climate modelling, and with our homogenization and interpolation system (MISH and MASH) skills.

Yours sincerely,

Dr. Kornélia Radics
PR of Hungary with WMO

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Icelandic
Meteorological Office

Veðurstofa
Íslands

Dr. Peter Bauer,
ECMWF
Shinfield Park, Shinfield Road,
Reading, RG2 9AX, UK

Date: August 24, 2018
Ref.: 5801
Ref. no.: 2018-229

Subject: Endorsement Letter – **ExtremeEarth** preparatory project for an EU Flagship

The Icelandic Meteorological Office (IMO) fully endorses the FET Flagship project *ExtremeEarth*. The preparatory phase of *ExtremeEarth* covers all the unifying goals set by the EU. The novel use of real-time, sensor-based data for exascale computing will produce new technological approaches and scientific results with widespread benefit to Europe and beyond. With the increasing societal impact of extreme weather and Earth-based natural hazards, the vision offered by *ExtremeEarth* will enable accurate assessments and predictions of the timing and impact of extreme Earth System events; an output that will have far-reaching societal implications for decades to come.

In Iceland, IMO has a government mandate to monitor and warn against a spectrum of natural hazards, including severe weather, flooding, damaging earthquakes, volcanic eruptions, and various types of mass movements. Furthermore, IMO is a designated State Volcano Observatory. To accomplish its tasks, IMO operates modern national monitoring networks for weather, water and the Earth, including radars specifically employed to monitor volcanic ash. The office also conducts multidisciplinary research in meteorology, climatology, hydrology, glaciology, seismology, and volcanology. This track-record is exemplified by several decades of international research funding and scientific collaboration. Furthermore, IMO is designated by the government to conduct hazard and risk assessments in all of its research fields.

IMO is responsible for handling large volumes of digital data, including satellites products and measurements from various national-scale monitoring networks. This diverse range of assimilated data, in a location prone to frequent and occasionally far-reaching natural hazards, could be put to excellent use in *ExtremeEarth*. Moreover, the project fits exceptionally well with IMO's ongoing development of forecasting strategies for hazards, in particular for volcanic eruptions, volcanic ash clouds and earthquakes but also extreme weather and severe flooding from land and sea. Hence, we are certain that the IMO could have very unique contribution to *ExtremeEarth*.

Bústaðavegur 7–9 IS-108 Reykjavík + 354 522 60 00 office@vedur.is www.vedur.is

In addition to being a member of the ongoing Horizon 2020 project *EPOS*, IMO is also a partner of the *Center of Excellence for Exascale in Solid Earth (ChEESE)*, which begins this year with funding from the Horizon 2020 Programme. The solid-earth, exascale computing goals of the *ChEESE* project will complement the groundbreaking physical models that will be developed by *ExtremeEarth*.

We would be delighted to collaborate with the *ExtremeEarth* consortium and we wish you every success with this flagship venture. You are welcome to add this letter to the *ExtremeEarth* web-site as IMO's endorsement.

Sincerely yours,

Dr. Jórunn Harðardóttir
Director of Research / Managing Director of Processing & Research
jorunn@vedur.is / +354 8628323

Dr Peter Bauer
European Centre for Medium-Range
Weather Forecasts
Shinfield Park
Reading RG2 9AX
United Kingdom

Cape Town, South Africa
28/08/2018

RE: ENDORSEMENT OF THE *EXTREMEEARTH FLAGSHIP* PROPOSAL

Dear Dr. Bauer

ICLEI is driving sustainable urban development worldwide by:

- working with over 1500 cities, towns and regions,
- across 22 offices,
- in 124 countries, and
- impacting 37% of the global urban population.

ICLEI Africa, the African Secretariat of ICLEI, is happy to support the *ExtremeEarth Flagship* proposal for the call "Tackling Grand Interdisciplinary Science and Technology Challenges".

City-regions are key contributors to greenhouse gas emissions, and are where the rubber hits the road in terms of experiencing the impacts of climate change; thus improving city stakeholder's understanding and use of climate change information is an essential part of the climate change solution. The proposed *ExtremeEarth Flagship* project is therefore extremely relevant and timely as it aims to improve the climate and weather information used by cities around the world.

ICLEI Africa works with sub-national actors in Sub-Saharan Africa to enable development that is resilient, low emission, circular, nature-based, equitable and people-centred. To build resilience in rapidly urbanising areas around the world, our city officials require climate and weather information at relevant spatial and temporal scales. The *ExtremeEarth Flagship* project, proposes taking an important step in improving the information available for city-scale decision making, including short-term forecasts to allow city officials to anticipate extreme events that will impact their population.

ICLEI Africa is extremely interested in playing an active role in the *ExtremeEarth Flagship* project. We have over 20 years' experience in implementing sustainability projects in cities, and creating platforms for successful engagement between sub-national government stakeholders, such as politicians, city administrators, researchers, the private sector and civil society. We could play a strong role in:

- enabling improved collaboration between the producers and users of weather and climate data and information;
- improving the buy-in and up-take of the improved weather and climate data produced via the *ExtremeEarth Flagship* project, by harnessing our existing relationships within cities to better understand what the user's requirements are in terms of the data and information they need to make better decisions; and

ICLEI - Local Governments for Sustainability is the leading global network of over 1,500 cities, towns and regions committed to building a sustainable urban future.

By helping the ICLEI Network to become sustainable, low-carbon, ecomobile, resilient, biodiverse, resource-efficient, healthy and happy, with a green economy and smart infrastructure, we impact over 25% of the global urban population.

ICLEI- Local Governments for Sustainability

Africa Secretariat

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PBO No. 930 032 155

- harness our vast experience in running training, capacity building and advocacy engagement activities and events to run laboratories that enable co-production and use of data and information.

The above will be useful in refining the project ideas as well as during project implementation.

We would like to congratulate the consortium on focusing on such a pertinent issue, and look forward to collaborating with you in the near future.

Yours sincerely,

Kobie Brand

Regional Director
ICLEI Africa

Dr. habil. Werner Leo Kutsch
Director General
Integrated Carbon Observation System (ICOS ERIC)
Email: werner.kutsch@icos-ri.eu

Helsinki, 19. February 2018

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for
Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Letter of endorsement for the *ExtremeEarth* Flagship proposal

Dear Dr. Bauer,

in my role as Coordinator of the Environmental Research Infrastructure Cluster Project ENVRIplus I herewith express my strong support for the ExtremeEarth Flagship proposal.

ICOS and many other Research Infrastructures in the ENVRIplus project support the scientific, technological and programmatic objectives of ExtremeEarth. We see the strong necessity to improve Europe's capability to model, to predict and to monitor environmental extremes and their impacts. As main data providers we endorse ExtremeEarth as an important initiative of world leading Earth-system science centres in Europe that will built on our observations.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Good luck with your proposal. We are looking forward to discuss further cooperation with you soon.

Sincerely,

Dr. habil. Werner Leo Kutsch

ICOS ERIC Head Office | Erik Palménin aukio 1, FI-00560 Helsinki | info@icos-ri.eu | **www.icos-ri.eu**

MINISTERIO DE FOMENTO

OBSEVATORIO GEOFÍSICO CENTRAL

DIRECCIÓN GENERAL DEL INSTITUTO GEOGRÁFICO NACIONAL

Dr. Carmen López
Instituto Geográfico Nacional
C/Alfonso XII, n14, 28014, Madrid, Spain

To: Dr. Arnau Folch
ExtremeEarth CSA proposal Coordinator

Madrid, 16th August 2018

Dear Sir,

We are very much interested in your Coordinated Support Action (CSA) initiative to propose a FET Flagship project, in which geophysics and meteorology/climate will play a strong part in the Flagship proposal. This project aims to improve the prediction and monitoring of environmental extremes natural hazards – such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis – and their impacts on society by the imaginative integration of computing and the real-time exploitation of pervasive environmental data.

The *Instituto Geográfico Nacional* (IGN), which is responsible for the Seismic, Tsunami and Volcano Monitoring Early Warning System and associated risks assessments in Spain, and responsible for the surveillance of active volcanoes in the Canary Islands, and archipelago with several volcanic eruptions in historical time (last one in 2011, on El Hierro Island).

Therefore, we are fully interested in promoting ExtremeEarth CSA proposal initiative.

We are very pleased to support this project.

Kind Regards,

Carmen López Moreno
Director of Central Geophysical Observatory
Instituto Geográfico Nacional

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TEL.: +34 627625937

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Markus Amann
Program Director
Air Quality and Greenhouse Gases

February 12, 2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

I am happy to inform you that the International Institute for Applied Systems Analysis (IIASA) endorses the ExtremeEarth proposal for a candidate European Commission Future and Emerging Technology Flagship, targeting a visionary unifying goal for new technologies and approaches for high-precision modelling and simulation.

The International Institute for Applied Systems Analysis (IIASA) is an international scientific institute that conducts research into the critical issues of global environmental, economic, technological, and social change that we face in the twenty-first century. IIASA's work reveals options to policymakers to shape the future of our changing world.

For this mission, it will be critical to enhance the understanding and our ability to predict and monitor environmental extremes and their impacts on society reliably, as envisaged by the proposed ExtremeEarth project. The ExtremeEarth activities will provide important input to a wide range of IIASA's activities, which integrate natural, social, and economic systems to produce independent, interdisciplinary research into real-world problems.

Dr. Markus Amann
Program Director
Air Quality and Greenhouse Gases
International Institute for Applied Systems Analysis

Consiglio Nazionale delle Ricerche
Istituto di Metodologie per l'Analisi Ambientale

From:
Prof. Vincenzo Lapenna
Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale
C.da S. Loja
85050 Tito Scalo (Potenza), Italy
+39 0971427252

To:
Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 12/02/2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

In ExtremeEarth, we delegate endorsements to individuals because everybody has his/her own networks and we will be more efficient and successful if requests are issued by those indviduals. We (ExtremeEarth) are now looking for potential future partners and stakeholders to endorse our project. These can be national and international institutes and organisations, networks, companies, etc. These endorsements will be collected on our website so that we can simply link to this information from the proposal. The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the ***endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.*** *This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.*

<Signature>

Consiglio Nazionale delle Ricerche - IMAA -

LAPENNA VINCENZO
12.02.2018 15:41:21 UTC

Prof. Vincenzo Lapenna
Director of CNR-IMAA

[1] One copy of this Annex shall be included for each beneficiary except for the coordinator.

[2] If the signatory is not the Rector/President of the Higher Education Institution (or Vice-Rector, Vice-President Chancellor, Vice- Chancellor), a specific project-related statement signed by the Rector/President must be provided authorizing the signatory person to commit the whole institution.

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ICGC
Institut
Cartogràfic i Geològic
de Catalunya

Dr. Peter Bauer
"ExtremeEarth" proposal coordinator
ECMWF
Reading Enterprise Centre, Shenfield Rd, Reading RG2 9AX
RG6 6BU, Reading; UK

Subject: Support letter for the ExtremeEarth Coordination and Support Action (CSA) proposal initiative.

Dear Sir,

We are pleased to support your project proposal to submit into a preparatory action in the FET Flagships topic call of the Coordination and Support Action (CSA) initiative under the European Commission H2020 program.

From the information you have provided we know that the ExtremeEarth project propose the integration of competitive digital technologies and the real-time exploitation of pervasive environmental data to increase the societal resilience to environmental extremes by greatly enhancing the capability to observe and monitor the state of the Earth and predict extreme environmental risks -such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis- and characterize their impact.

The *Institut Cartogràfic i Geològic* de Catalunya (ICGC) is the official institution on geodesy and, cartography, on the infrastructure of spatial data of Catalonia, on the actions related to the knowledge, the prospection and the information on the soil and subsoil, on the development and maintenance of the seismic network, the study and evaluation of geological hazards (earthquakes, avalanches, subsidence, landslides etc ...), and on the support to protection civil authorities regarding these phenomena among other competences. Therefore, we are fully interested in the developments and results issued of this project.

Should the proposal be selected for funding, the ICGC will contribute by providing data and advice and collaborate in the dissemination of the results, impacts and benefits of the ExtremeEarth CSA proposal initiative.

Yours sincerely,

Jaume Massó i Cartagena
Director

Barcelona, 7th September 2018

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Generalitat de Catalunya

acting DIRECTOR GENERAL
Joanna Szczepańska

Warsaw, 30 August 2018
OGŁ/NZ-062-64/18/DN-1609

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Dear Dr Peter Bauer,

With honour and pleasure I would like to inform you that all R&D units of the Institute of Meteorology and Water Management – National Research Institute MGW-PIB), Poland (including remote sensing, nowcasting and NWP departments, as well as many dependent sections) are really interested and looking forward to establishing and maintaining a truly European cooperation within the field of Extreme Earth Flagship programme in the forthcoming call for proposals EU Horizon 2020.

IMGW-PIB together with Meteo-France and other 26 Aladin-HIRLAM national Met Services for over 20 years have been cooperating fluently on a wide range of international technical, interpersonal and research issues achieving remarkably high level of expertise. We have developed AROME and ALARO models from their very beginning, and hope that substantial increase of computer power will enable to raise the precision and predictability scores of all our models, as well as to integrate them with Meteo-France's global model ARPEGE.

New data assimilation algorithms are expected to add coherence to the model results more efficiently, providing a stronger and more rapid common alerting system against severe weather events. This seems to be the most challenging task to do during ever increasing climate change and massive rise of frequency and destructive power of extreme weather events. The potential consequence of this kind of development within Extreme Earth Flagship programme is saving something incomparable with any property: human lives.

Let me express my very real hope that the Extreme Earth Flagship Programme will be the dawn of a new era of multilateral, pan-European cooperation, in one of the most important, universal fields in the 3rd decade of 21st century.

With best regards,

p.o. DYREKTORA
Joanna Szczepańska

Institute of Meteorology and Water Management - National Research Institute
61 Podleśna Street, 01-673 Warsaw, POLAND
tel: (+48) 22-56-94-301, fax: (+48) 22-834-18-01, e-mail: joanna.szczepanska@imgw.pl

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

12.February.2018, Helsinki, Finland

Reference: ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement for ExtremeEarth

To: Dr. Peter Bauer, ExtremeEarth-PP
From: Dr. Hanna Lappalainen, GlobalSMEAR Initiative

We are pleased to endorse on the ExtremeEarth Flagship proposal (Coordination and support actions, the 1st stage of a two-stage submission procedure for FETFLAG-01-2018) coordinated by European Centre for Medium-Range Weather Forecasts.

ExtemeEarth proposal has synergy with the GlobalSMEAR concept. GlobalSMEAR is an initiative towards integrated Earth observatory coordinated by Institute for Atmospheric and Earth System Research (INAR), Helsinki, Finland. GlobalSMEAR measurement concept has been developed at the flagship observatory "SMEAR II" in Finland (61°51' N, 24°17' E) starting from 1995. It introduces comprehensive Earth surface – atmosphere measurement system, which consists of two main blocks: climate feedbacks and air quality. GlobalSMEAR intiative is collaborating with the European research infrastructures such as ICOS, ACTRIS, ANAEE and eLTER. A long-term vision is to have, within 10-15 years, a network of 600-1000 highly instrumented environmental observatories carrying out observations on Earth surface - atmosphere relations: concentrations, profiles, fluxes, processes and feedbacks across disciplines.

Accordingly, we are pleased to endorse the above ExtremeEarth proposal with support from the GlobalSMEAR program. If approved, the GlobalSMEAR will be implemented and coordinated by the GlobalSMEAR coordination team in Helsinki.

Signed: _____
Secretary General Dr. Hanna Lappalainen
GlobalSMEAR coordination

Address: PEEX HQ at the Institute for Atmospheric and Earth System Research (INAR)
University of Helsinki
Gustaf Hällströmin katu 2a FI-00560 Helsinki
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E-mail: peex-hq@helsinki.fi

United Nations Educational, Scientific and Cultural Organization

IHE DELFT
Institute for Water Education
In partnership with UNESCO

Rectorate

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IHE Delft
PO Box 3015
2601 DA Delft
The Netherlands

Peter Bauer
ECMWF
Shinfield Park
Reading
RG2 9AX
United Kingdom

Reference
OR/007/EMO

Date
25 January 2018

Subject: Support to the ExtremeEarth proposal

Dear Mr Bauer,

I have learned about the development of a multidisciplinary proposal to revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on society (ExtremeEarth) to be potentially funded under the Future and Emerging Technology programme.

With this letter, IHE Delft Institute for Water Education (IHE Delft) would like to show its endorsement for the ExtremeEarth proposal. As an Institute contributing to the education and training of professionals with a view towards creating sustainable management of water and environmental resources, IHE Delft is fully supportive of initiatives, such as ExtremeEarth, which can provide important capabilities for evaluating proposed measures within the context of achieving the targets set out in the sustainable development goals as well as the Paris Agreement.

I am also convinced of the strength and commitment of the consortium led by ECMWF including the highly qualified pan-European partners. IHE Delft is in full agreement to have its name and logo appear in any supportive channels regarding the ExtremeEarth proposal.

Sincerely Yours,

Eddy Moors
Rector IHE Delft

irstea
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DE L'ENVIRONNEMENT

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Président

Dr Peter Bauer
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
United Kingdom

Antony, 17 September 2018

Dear Dr. Bauer,

On behalf of IRSTEA, I am very pleased to provide my endorsement to the ExtremeEarth FET Flagship Project. Being aware of current forecasting, modelling and computational limitations, ExtremeEarth aims at the integration of edge and exascale computing as well as the real-time exploitation of pervasive environmental data. The project is a most timely initiative that will contribute amongst others to improving extreme events preparedness and response.

IRSTEA, the French Research Institute of Science and Technology for Environment and Agriculture, has a long history on extreme events research, both in France and internationally. Our research interests include, among many others, the development of multi-model approaches in hydrological forecasting (flooding and drought), the communication of uncertainties in the hydrologic forecasting chain, and the evaluation of the impacts of global changes in hydrological processes. Results from our research seek a better management of water resources in the light of current and emerging extreme events. Hydrological operational services and engineering consultancy firms are the main users of our research products.

As referred to above, the project will offer a great opportunity to enhance our knowledge and research capabilities. In this respect, IRSTEA wishes to reiterate its endorsement to the initiative as well as its interest to support future endeavours in the form of upcoming endorsements, consultations or project partnerships. As Executive Chairman, I will facilitate the engagement of our scientists in this initiative.

I wish you success in the final preparation of the proposal and in any future activities.

Yours sincerely,

Marc MICHEL
Executive Chairman of IRSTEA

Institut national de recherche en sciences et technologies
pour l'environnement et l'agriculture
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Institute of Geophysics
Polish Academy of Sciences

Dr. Peter Bauer

Deputy Director

Research Department

European Centre for Medium - Range Weather Forecasts

Shinfield Park, Reading RG2 9AX, UK

Letter of endorsement for the ExtremeEarth Flagship proposal

Dear Dr Bauer,

as a Director of the Institute of Geophysics Polish Academy of Sciences I herewith express my strong support for the ExtremeEarth Flagship proposal, a European Commission candidate for a Future and Emerging Technology Flagship.

The proposed project has immense scientific and societal significance as it helps to predict, monitor and create deep understanding of environmental extremes in rapidly changing climate.

We are glad to contribute with our competence, data and monitoring capacities to the ExtremeEarth Initiative. I look forward to seeing IG PAS engage fully in ExtremeEarth project consortium.

Yours sincerely

Beata Orlecka-Sikora

Director of the Institute of Geophysics PAS
Chairwomen of the GeoPlanet Centre
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ISMC
International Soil Modeling Consortium

January 26, 2018

Letter of Support Extreme Earth Flagship Project

ISMC intends to collaborate and/or commit resources/expertise to the Extreme Earth Flagship Project (FETFLAG-01- 2018) to be funded under the European Union H2020. This proposal for a European Flagship project that will valorize the foreseen scaling up of supercomputing capacity for Earth system modeling corresponds strongly to the ambitions of ISMC.

The International Soil Modeling Consortium (ISMC) has as one of its objectives, the improvement in the prediction capacities of soil processes, hydrologic and gaseous fluxes and exchanges with the atmosphere, and this at the global scale, in high-resolution modeling leading to much more accurate global Earth System and Climate modeling. Along with the unprecedented capacity for prediction, the foreseen collaboration will also reflect on the views and requirements of scientific, technological and service/business oriented communities.

The International Soil Modeling Consortium fully supports and will strongly be cooperating on this important project in any way feasible that would make this a successful endeavor.

Chairs of the International Soil Modeling Consortium

Harry Vereecken and Michael Young

Coordination Office International Soil Modelling Consortium (ISMC)
Institute of Bio and Geosciences IBG-3 Agrosphere, Forschungszentrum Jülich, Germany
https://soil-modeling.org

Italian Air Force
Operational Forces Command
Permanent Representative of Italy with WMO

To: **Dr. Florence Rabier**
ECMWF Director-General

Subject: Letter of support for *ExtremeEarth*.

Dear Dr Rabier,

in line with ECMWF Council's decision and because of the importance that *ExtremeEarth* project could have for the sake of people all over the planet, ITAF-ReMet strongly supports ECMWF, with the present letter of endorsement, in its activity of preparation of the full proposal for an EU Flagship and its leadership.

Italy has a geomorphologic structure and a peculiar geographic position and shape that have great impact on social and everyday life; the Alpine and Apennines chains as well as the Mediterranean Sea around and the closeness to African continent, strongly influence meteorological perturbations and climate regimes to an extent that makes forecasts and climatological outlook a constant daily challenge. Moreover, being our Country prone to extreme natural phenomena, such as flash floods, droughts, wind storms, earthquakes and volcano eruptions, it becomes paramount the chance to employ in the future the capabilities developed by such Project to strengthen the resilience of human infrastructures and to improve more and more the capability of governmental organizations to safeguard the whole society, coping as fast as possible with natural disasters.

Furthermore, in these last 10 years, international organizations like WMO itself and EUMETNET have underpinned and fostered programmes related to disaster risk reduction through the improvement of extreme weather events forecasting systems and a real-time dissemination and sharing of such information by web-media. Italy is actively part of such programmes and aware that these activities represent one of the main pillars of future developments in our capability to forecast the occurrence of natural hazards and mitigate their impact on the environment and human life.

Finally, it is worthwhile to mention that our involvement will be supportive, if not crucial, to define the directions of the developments and the expected outcomes of the project. For this reason Italy looks forward for any further collaboration in the fields of extreme weather predictions and monitoring of Earth system.

Yours sincerely,

Brig. Gen. Silvio CAU
(Permanent Representative of Italy with WMO)

JPI - Connecting Climate Knowledge for Europe
Dr. Frank McGovern
Chair,
Avenue Louise 231
B – 1050 Brussels/Belgium

ECMWF
Dr. Peter Bauer
Shinfield Park
Reading RG2 9AX
United Kingdom

Reference: "ExtremeEarth" FET proposal

Date: 7/2/2017

Dear Dr. Bauer,

At its meeting on 29th November the Governing Board (GB) of JPI Climate heard a presentation on the "ExtremeEarth" proposal for a Future and Emerging Technology (FET) Flagship. The Governing Board recognised the potential for ExtremeEarth to revolutionize Europe's capacity in advanced climate modelling and forecasting; in particular to better address future extremes, and therefore their impacts on key sectors, including food production, energy systems and water.

The GB welcomed the presentation, recognised the need to advance such modelling capacity and considered that, if successful, the proposal had significant relevance for the future work of JPI Climate. The GB therefore expressed its support for ExtremeEarth and the endorsed it as a FET Flagship proposal. The GB requested that it be kept informed about the progress of ExtremeEarth in the FET process.

Yours sincerely

F McGovern

Frank McGovern

Central Secretariat
Joint Programming Initiative JPI - Connecting Climate Knowledge for Europe
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About JPI Climate

JPI Climate was launched in 2011 and involves 17 European countries which are committed to coordinating their activities in climate related research. JPI Climate provides a platform for climate knowledge and decision support services for societal innovation.

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Karlsruhe Institute of Technology

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Executive Committee
Vice President for Research
Prof. Dr. Oliver Kraft

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Web: www.kit.edu

Official in charge:
Our reference:
Date: 2018-02-08

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To the Coordinator of the ExtremeEarth CSA project proposal

On behalf of Karlsruhe Institute of Technology (KIT) we are expressing our strongest support for the CSA proposal to develop a FET Flagship Project Extreme Earth.
This activitiy of the climate and earth system science communities to develop a joint FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.
Karlsruhe Institute of Technology (KIT) is strongly involved in research activities with focus on climate change and extreme weather.
Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.
With our research background in the fields of climate change and extreme weather, we see strong links to the aims of the proposed project ExtremeEarth.

Karlsruhe Institute of Technology

Therefore, we strongly support this proposal and we are looking forward to further intense involvement in this joint European activity.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Prof. Dr. Oliver Kraft
Vice President for Research

Dr. Karl-Friedrich Ziegahn
Head of Division Natural and Built Environment

Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and Water Management

> Return address PO Box 201 3730 AE De Bilt

Dr. F. Rabier
Director General
ECMWF
Shinfield Park
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KNMI

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Contact
Hans Roozekrans
(Hans.Roozekrans@knmi.nl)

Date: August 7th, 2018
Subject: Letter of support for ExtremeEarth

Our reference
KNMI-2018/2039

Your reference
DG/18-198

Enclosure(s)

Dear Dr Rabier,

I am writing this letter to express my support for ExtremeEarth as a preparatory project for an EU Flagship. As Director General of the Netherlands' public weather service, I attach great value to the realization of this project. Let me explain why. As national weather service, KNMI makes use of the best weather and climate models to inform Dutch society about the changes in the weather, climate and related subjects. In my view the success of ExtremeEarth as an EU Flagship project will contribute substantially to the continuous improvement of our services, here in Europe and elsewhere.

KNMI has a particular interest in early warning concepts, as climate change leads to extreme weather events that occur more frequently than in the past. Good forecasts of hazardous weather and solid scenarios of the climate targeted to societal and regional impact assessment are essential to save life and property. Predictions of extreme weather events rely on very advanced numerical models. The skill of these models to predict extremes is limited by computing capabilities. The development of applications for novel digital infrastructures as proposed by ExtremeEarth is therefore essential for the future development of the services to be delivered to society by KNMI.

As described in the high-level introduction (see www.extremeearth.eu/introduction) the ExtremeEarth proposal addresses these issues with an excellent group of research partners. Many of these groups are closely related to KNMI. We have active engagement not only with ECMWF and other meteorological organisations, but also with the group focusing on the benefits of an ExtremeEarth activity for hydrological applications and the Dutch E-Science Centre. The consortium will pave the way towards new exascale computing platforms. Projects like ExtremeEarth will make a crucial link between the scientific and computing needs of KNMI and the European Commissions' ambitions towards exascale computing and the real-time exploitation of environmental data. This will be essential to further develop reliable and trustworthy meteorological and climate services by KNMI.

It is for these reasons that I would like to express my strong support for the approval of the ExtremeEarth project. The realization of this project will not only be beneficial for a national weather service like KNMI in the Netherlands, but for a

large group of European environmental services. It will lead to a safer and more resilient Europe in times of climate change.

KNMI is happy to contribute actively to the preparatory project. We can help formulating the requirements and organizational structure that will optimize the added value to water authorities, traffic control centers, health organizations, climate impact communities and our stakeholders in our national and international collaboration networks. We are also willing to host meetings, contribute to outreach activities or participate in feasibility studies.

It is in our joint interest that ExtremeEarth will be as successful as it deserves to be.

With kind regards,

Prof. Gerard van der Steenhoven
Director-General of KNMI

KU LEUVEN

THE RECTOR

To whom it may concern

OUR REFERENCE .../2017/LS
YOUR REFERENCE
LEUVEN 12 December 2017

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To whom it may concern,

I am writing in my capacity as Rector of University of Leuven to express my strongest support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.

With great interests we are following the activities of the geoscience community to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

KU Leuven has a collaboration agreement with Forschungszentrum Juelich that has already led to strong collaboration in the Earth Sciences through joint projects and publications, such as the SOGLO project, which focuses on the impact of Global Change on soil systems. The complementary expertise of KU Leuven and FZ Juelich in the Earth Science domain provides a strong building ground for further collaboration in the framework of new innovative projects such as FET Flagship Project Extreme Earth.

Extreme natural phenomena – such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis – and the escalating impact of climate change – such as desertification, ice-sheet and glacier melting, sea-level rise – dramatically affect all sectors of society. Historically, environmental pressure on the human population has reshaped entire civilizations, and there is a need for effective mechanisms dealing with future change and extremes now. Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

With our research background in the fields of evolution of life and earth, environmental dynamics, georesource management and georisk assessment, we see strong links to the aims of the proposed project ExtremeEarth. One of the missions and fields of expertise of the KU Leuven is to conduct research that has an impact on the development of countries in the South. Especially in developing

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MEMBER OF ASSOCIATIE KU LEUVEN

NO. OF PAGES 2

OUR REFERENCE .../2017/LS

YOUR REFERENCE

LEUVEN 12 December 2017

countries, the impact of extreme weather conditions on local agricultural production is very large and need to be assessed properly for deriving resilient agricultural production systems that are a corner stone of the development of these countries. As such this project could also address societal issues related with immigration and provide input to European policies supporting the development of African nations. Therefore, I very much welcome and strongly support this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Yours sincerely,

Luc Sels
Rector

LUND UNIVERSITY

Dept of Physical Geography and
Ecosystem Science
Professor Ben Smith, Head of Department

12 Feb 2018

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Endorsement letter

ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Dear Dr Peter Bauer

Lund University notes with interest the development of the proposal *ExtremeEarth* to establish a Future and Emerging Technology Flagship focused unifying technologies and approaches to advance understanding of the Earth System, natural hazards and climate change with a focus on extremes.

We are a leading institute for research, education and outreach in the Environmental Sciences, and a key node for European research infrastructure for greenhouse gas measurements (ICOS) and aerosols, clouds and trace gases (ACTRIS). The Carbon Portal, a central facility of ICOS-ERIC, is hosted by the Dept of Physical Geography and Ecosystem Science, benefitting for mutual interactions with strong in-house research on ecosystem biogeochemistry, greenhouse gas exchange and interactions with the climate system. Our profile makes us a natural partner for ExtremeEarth with its aim to bring together major European centres for Earth system modelling, monitoring, analysis to improve the scientific evidence base for societal aspirations to respond to climate changes and extremes.

We fully endorse the ExtremeEarth initiative, with its scientific, technological and programmatic objectives, and look forward to close interactions in the future.

Benjamin Smith
Head of Department

Sven Lidin
Dean of the Faculty of Science

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magma ENERGY ITALIA

Dr. Paolo Papale
Research Director
Istituto Nazionale di Geofisica e Vulcanologia
Sezione di Pisa, Via Della Faggiola, 32, 56126
Pisa, Italy

Arezzo- Italy, 13.09.2018

LETTER OF INTEREST

Project Proposal: H2020 FET Flagship /ExtremeEarth- PP

On the behalf of MAGMA ENERGY ITALIA S.R.L., I highly appreciate the initiative of the **H2020 FET Flagship /ExtremeEarth- PP** consortium

As a Company engaded in the geothermal energy development , we are very interested to new technologies and approaches for high-precision modelling and simulation that can enable an in-depth understanding of geothermal systems and increase the contribution of geothermal energy to a low-carbon economy

The expected work and outcomes of the project are indeed relevant to the current work and planned future activities of Magma Energy Italia S.r.l., notably:
- Participating to the 'map & match' processes, in particular mapping interests and capacities of stakeholders and matching them with actual and suitable funding opportunities and mechanisms (EU, National, Regional)
- Sharing information on our research priorities and ongoing RD&I activities.
- Liaising with other stakeholders to execute some of the geothermal R&I activities

We are keen on reviewing the outcomes of the project and on making use of its results in our current and future program of work.

We trust the consortium to establish a strong and efficient support unit and we are looking forward to cooperate under this initiative with the ambition to accelerate the development of geothermal energy in Europe.

Yours sincerely,

Fausto Batini
Chief Technolgy Officer

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Max-Planck-Institut für Chemie
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Prof. Dr. Dr. h.c. J. Lelieveld
Director
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jos.lelieveld@mpic.de

Re: Endorsement ExtremeEarth
8 February 2018

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Dear Dr. Bauer,

On behalf of the Max Planck Institute for Chemistry, I would like to express strong support for the ExtremeEarth initiative. Humankind has induced a new geological epoch, the Anthropocene, with significant impacts on the Earth's geology and environment, including climate change. The human-induced environmental changes are unprecedented in the history of our planet, and it is yet difficult to foresee to what extent the frequency and occurrence of extremes may develop, and how this may affect society. It is critical that Earth scientists in Europe team up under ExtremeEarth to monitor the state of the environment and develop predictive capability to advance societal resilience.

Given the opportunity, our institute will be glad to contribute relevant environmental datasets and provide expertise on Earth system modelling. The latter focuses on atmospheric composition and chemistry, exchange processes between the atmosphere and marine and terrestrial ecosystems, and environmental impacts of global change, including public health. The latter activity can provide support for the management of health risks from atmospheric pollution, the spreading of vector borne diseases, and of heat extremes due to climate change, being areas where we have developed new modelling approaches. An integrative strategy of assessing global environmental risks to humanity will be critical.

We strongly support the ExtremeEarth proposal towards a European Commission Future and Emerging Technology Flagship, to help predict and monitor environmental extremes and their impacts on society.

With best regards,

Jos Lelieveld

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MAX-PLANCK-GESELLSCHAFT

Ramonville St Agne, 31st August 2018

Dr. Peter BAUER, Deputy Director
Research Department
ECMWF
Shinfield Park
Reading RG2 9AX
United Kingdom

Re: PB-LM 18/116

Subject: Support letter for the Extreme Earth PP

Dear Dr. Bauer,

Mercator Ocean International (MOI) a leading global ocean forecasting center, was tasked by the EU in 2014 to implement the operational phase of the Copernicus Marine Service. MOI is an important actor of the Nucleus for European Modelling of the Ocean (NEMO) consortium in charge of the joint development of ocean and ice modelling tools in Europe.

As part of our activities, we are running global high resolution ocean (physics, ice and biogeochemistry) reanalysis, analysis and forecasting systems. Our plan for the next decade is to move towards resolutions of a few kilometers globally together with advanced data assimilation methods (ensemble methods) and increased complexity in the way our systems are coupled to wave/atmosphere/coastal/land components to better describe and forecast the oceans at fine scale. We are heavily dependent on high performance computing technology, software and data infrastructure.

We thus strongly welcome and support the ExtremeEarth-PP project for ExtremeEarth, a proposed FET Flagship Programme of the European Commission (EC). Our marine modeling community is facing important challenges with respect to the complexity of upcoming HPC hardware and software systems that require new and inter-disciplinary approaches. ExtremeEarth, if successful as a European Flagship, will have a major impact to solve them.

If the preparatory project is accepted, we are ready to work actively with the project team to help designing and be part of a future FET flagship initiative that takes into account long term needs of European operational oceanography community and, in particular, of the Copernicus Marine Service and its users/applications .

Yours sincerely,

The Director General
Pierre BAHUREL

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Subject: commitment to the ExtremeEarth flagship proposal

Date: 7th September 2018

Dear Dr. Bauer,

This letter expresses the commitment of Met Éireann to the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

Met Éireann fully supports the technological and scientific ambitions of ExtremeEarth. It has the potential to enable large capability breakthroughs in our areas of weather and other environment media prediction and future climate projections.

If the next stage of the evaluation of the proposal is as successful as the first one, Met Éireann will take the opportunity of the Coordination and Support Action to highlight what it ambitions to bring into the Flagship. It is envisaged that Met Éireann's involvement would include research on extreme weather and climate risks.

Met Éireann looks forward to be part of the ExtremeEarth Flagship, once successful in getting EU support.

Yours sincerely,

Eoin Moran

Director

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The Irish Meteorological Service

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Reference: ExtremeEarth Flagship proposal / Coordination and support actions /
1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Date: 7th September 2018

Dear Dr. Peter Bauer,

With this endorsement letter, Met Éireann the Irish National Meteorological Service wishes to express its strong support for the project ExtremeEarth, a candidate European Commission Future and Emerging Technology Flagship. The proposed project is very timely and has immense scientific and societal significance as it seeks to revolutionize Europe's capability of predicting and monitoring environmental extremes and their impacts.

Met Éireann looks forward to collaborating with the ExtremeEarth project consortium should it be positively evaluated and receive funding. Specifically, our envisioned cooperation would involve research on extreme weather and climate, both through development of world-leading physical models and utilizing our wide monitoring networks of the atmospheric state.

Eoin Moran

Director

Meteorologisk institutt

To:
Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Our date:
31 Aug 2018

Letter of support, ExtremeEarth

Dear Dr. Bauer,

The Norwegian Meteorological Institute (MET Norway) supports and is enthusiastic to engage in the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

The national meteorological services must, in order to stay relevant and be authoritative on weather forecasts, warnings and on disaster risk reduction, constantly identify new areas of investigation and directions for interdisciplinary research. This implies to provide guidance beyond traditional numerical weather prediction and climate monitoring applications. A Flagship like ExtremeEarth will enable the emerging involvement of individual non-expert contributions, broader and deeper collaboration on mathematical tools, computer science and new technologies.

MET Norway associates itself with and will benefit from the technological and scientific goals of ExtremeEarth. Guided by the science for service approach, our operational value chain structure can enable an efficient transformation of research results into better informed decision making for users. Replacing parameterisations with explicit process representations in Earth System, Climate and NWP and ocean forecast models, will provide crucial leaps in process-understanding and prediction, and advance the exploitation of all kinds of observational data. Thus, the flagship has a strong potential to enable unprecedented breakthroughs in our own areas of responsibility, such as environment, weather and climate monitoring and prediction, including the hydrological cycle, ocean, sea-ice and pollution. This will in turn be of great importance for enhancing the quality of the services we provides to the society, like our world-leading weather app Yr.

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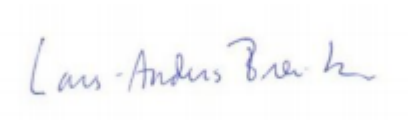
MET Norway can contribute to the future work of preparing ExtremeEarth. ExtremeEarth might enable us to perform environmental ensemble forecasts on a scale of a few hundreds of meters with a coupled earth system model system. MET Norway has experience in both operational and research collaborations on numerical modelling and forecasting, including the Arctic and might contribute dependent on directions and needs in the project e.g. with:

- knowledge about atmospheric and oceanographic processes specific to Northern-Europe and the Arctic
- collaboration on very high resolution regional numerical prediction models of the earth system, including assimilation of emerging and existing observations
- user-centric post-processing of NWP data using a massive amount of observations
- aerosols, aerosol-cloud-climate interactions and fresh water cycling
- regional climate modeling, downscaling and post-processing
- monitor and forecast extreme events in a changing climate
- efficient and timely development of user-specific data and products under an open data policy

We look forward to hear the result of next stage and to get a chance to discuss possibilities for involvement in the ExtremeEarth Flagship.

Yours sincerely



Lars-Anders Breivik
Director of Research

METEOLOGICA

Fabio Venuti
ECMWF Data Services Team Leader
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading
RG29AX
United Kingdom

Madrid 06-09-2018

Subject: Endorsement of the Preparatory EU FET Flagship Project ExtremeEarth

Dear Fabio Venuti,

On behalf of Meteologica SA I would like to express our clear support for the proposal of the FET Flagship Project ExtremeEarth.

The ambition and scope of ExtremeEarth will allow Europe to lead Earth monitoring and forecasting technologies for the first half of XXI century.

Meteologica provides forecasts of weather related variables for the energy sector to hundreds of clients in more than 60 countries. We provide an information flow that helps integrate renewable energy and to optimise energy management worldwide. The societal value of our forecasts relies on the quality (temporal and spatial resolution, accuracy...) of the state of the art Numerical Weather Prediction Systems (NWPS). ExtremeEarth will provide the basis for a giant forward leap of NWPS performance and therefore of the quality and usefulness of the forecasting services for the Energy sector.

We also have a deep trust in the capability and commitment of the ExtremeEarth consortia, specially of its leading partner, ECMWF.

Yours sincerely,

Rafael Borén
President
Meteologica SA

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Schweizerische Eidgenossenschaft
Confédération suisse
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Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss
International Affairs Division

CH-8058 Zurich Airport
MeteoSwiss

ECMWF
Dr. Florence Rabier, Dr. Dieter Bauer
Shinfield Park
Shinfield Road
Reading, RG2 9AX
United Kingdom

Your reference:
Our reference no./file no.:
Our reference: kea
Contact person: Manuel Keller
Zurich Airport, 10 September 2018

Subject: ExtremeEarth (preparatory action for new flagship - FETFLAG-01-2018); letter of support by MeteoSwiss

Dear Dr. Rabier, dear Dr. Bauer

With this letter, the Federal Office of Meteorology and Climatology MeteoSwiss is pleased to express its strong support for the project ExtremeEarth, a candidate European Commission Future and Emerging Technology Flagship.

In general, the outcomes of the suggested project ExtremeEarth are of high relevance, not only from a societal perspective but also from a scientific and technological one. A quantum jump in innovation of weather and climate forecasting can be expected. The impacts of extreme meteo-hydrological events on our society have increased in recent years. Given the ongoing climate change, it is likely that we will need to tackle even more such extremes in the future. A next generation of advanced capabilities to predict the frequency and intensity of such extremes as well as the related impacts more reliably is, therefore, of high relevance.

From a MeteoSwiss perspective, ExtremeEarth is bringing the climate and weather modeling community a substantial step ahead in terms of both the way we formulate key physical processes in our numerical models and the way we use our modeling capability. In particular, it will enable to replace parameterizations of unresolved physical processes with first principle description closer to the underlying physical laws. The project will yield important benefits with respect to our capacity to model and predict weather and extreme events and thus improve our capability to fulfill our core duties, namely to properly inform the population and authorities in case of extreme weather.

MeteoSwiss is keen to become involved in the ExtremeEarth project and its preparatory action. Such involvement could consist of sharing technological and scientific knowledge as well as experience in

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weather, climate and impact based modeling, dialogue with users and stakeholders as well as in reviewing project related documentation. In recent years, MeteoSwiss has been engaged in the co-design of numerical tools and software frameworks tackling earth system modelling and the dedicated supercomputing system where the models can be run. Thanks to this, MeteoSwiss has been the first national weather service adopting Graphical Processing Units (GPU) technology for its operational numerical weather prediction, which considerably increased the computational efficiency of the workflow and reduced the energy consumption. Our development together with the Swiss Super Computing Centre CSCS has been awarded the Swiss ICT award in 2016.

The Swiss National Center for Climate Services (NCCS) has been established at MeteoSwiss, coordinating the elaboration and dissemination of climate scenarios and services in the spirit of the Global Framework for Climate Services (GFCS) of the World Meteorological Organization (WMO). In this context, substantially improved modelling capacities would allow to explore future extreme climate events in complex terrains such as the Alps.

MeteoSwiss and the Swiss Federal Institute of Technology ETH Zurich have established a joint Centre for Climate System Modelling (C2SM) to be prepared for future modelling challenges as addressed with ExtremeEarth. In addition, a chair for Weather and Climate Risks (WCR) as a joint professorship has been established. Combining numerical modelling of weather and climate risks with the engagement of decision makers and end-users, his research aims to explore ways to strengthen resilience based on a shared understanding of their weather and climate susceptibility.

MeteoSwiss is therefore interested to engage in the project and contribute in particular to the following two areas:

Key Technology 1 : Distributed extreme-scale computing. The ability to run extreme-scale computing for weather and climate systems is a great challenge for our community that will completely change the capabilities to do weather and climate forecasts at very high resolutions. We would like to engage to the software framework developments required within the co-design of the entire workflow. Our contribution would be based on our knowledge in porting workflows on various hardware architectures, including GPU based systems over the past years.

Demonstrators: MeteoSwiss delivers weather information through many channels to a diverse set of users and stakeholders both in the public and private domain. We will support co-development, testing and implementation of ExtremeEarth demonstrators, not least in the context of the recently established NCCS and WCR Group. This will allow us to pro-actively engage with stakeholders to help transform our ability to interact with models and a vast array of environmental data, using user friendly platforms to underpin an intense dialogue.

Please note that the present letter of support does not imply any legal or financial commitments by MeteoSwiss towards the ExtremeEarth project.

Yours sincerely,

Federal Office of Meteorology and Climatology MeteoSwiss

P. Binder

Dr. Peter Binder
Director General

Manuel Keller
Head of International Affairs Division

MINISTRY OF ENVIRONMENT
NATIONAL METEOROLOGICAL ADMINISTRATION
METEO ROMANIA

Date: 10 September 2018

Dr. Florence RABIER, Director-General
European Centre for Medium-Range Weather Forecast (ECMWF)
Shinfield Park, Reading RG2 9AX, UK

Subject: Endorsement letter for ExtremeEarth Preparatory Project proposal

Dear Dr. Florence RABIER,

It is well known Europe has experienced a significant number of severe meteorological and hydrological events in recent years. These natural hazards have had significant impacts: human lives have been lost, properties and infrastructure damaged, well-functioning of key economic sectors affected. In this context, the ExtremeEarth project, aiming at revolutionizing Europe's capability of predicting and monitoring environmental extremes and identifying knowledge gaps arisen from the inadequacy of existing forecasting and warning models, becomes of paramount importance.

It is obvious that the objectives of the ExtremeEarth project are impressive and has immense scientific and societal significance, contributing to the understanding of the earth, natural hazards and climate change. ExtremeEarth will deliver the methods needed to achieve a step change in simulation accuracy and data integration, to allow scientists to understand the drivers of extremes and application communities to anticipate their impact. An accurate monitoring and predicting of environmental extremes and their impacts on society needs a European wide approach. In this context, we strongly believe that the outcome of this project will represent steps forward in the direction of minimizing the impacts of hazardous weather events on people, infrastructure and industry, thus protecting lives and livelihoods of the people.

As a General Director of the National Meteorological Administration, I would like to express our full support for an EU Flagship and ECMWF's involvement as a leader of the ExtremeEarth preparatory project. This project naturally falls in the direction ECMWF has been approached for many years, that of building high-quality research capacities and

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contributing not only to the progress of environmental science in general but also to the high-precision modelling development and global numerical weather predictions.
Population safety and security, water and food security, economic growth and sustainable development, increasing prosperity, enhancing resilience to disasters and climate change, and
improving public health, are issues of fundamental importance for the Romanian government. In this context, the National Meteorological Administration's main duty is to predict extreme weather phenomena, warn the authorities and the population, thus minimizing casualties and damage, protecting lives and properties. With its proven expertize in high quality weather observation and monitoring, the National Meteorological Administration could become a reliable project parter and bring a significant contribution to the success of the project.

We wish you every success with the project proposal!

Yours sincerly,

Dr. Elena MATEESCU

Director General

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Rijkswaterstaat
Ministry of Infrastructure and Water Management

RWS INFORMATION - PERSONALLY CONFIDENTIAL

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Our reference
-

Date 15 augustus 2018
Subject Support letter CSA proposal / Project Extreme Earth

Dear dr. Kwadijk,

On behalf of Rijkswaterstaat I am expressing my strongest support for the CSA proposal to develop a FET Flagship Project Extreme Earth. This activity of the climate and earth system science communities to develop a joint FET Flagship candidate project is a most timely and appropriate measure for the future of Europe. It will drastically enhance Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

Rijkswaterstaat is the executive organisation of the ministry of Infrastructure and Water Management. We maintain and develop national roads, waterways and open waters, and will be supporting a sustainable environment. With others we commit ourselves to a country that is protected against floods. With sufficient nature and sufficient and clean water. Where you can travel fluently and safely from A to B. To be engaged with others to make the Netherlands safe, livable and accessible.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership.
ExtremeEarth also brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

RWS INFORMATION - PERSONALLY CONFIDENTIAL

Rijkswaterstaat Water, Verkeer en Leefomgeving

Date
15 augustus 2018

Our reference
-

The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth. This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website. Rijkswaterstaat reserves the right to withdraw this support in case of conflicting interests.

Yours sincerely,

de directeur-generaal Rijkswaterstaat,
namens deze,
directeur Veiligheid en Water
Rijkswaterstaat Water, Verkeer en Leefomgeving

R. Allewijn

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Professor Angela Hatton
Director of Science and Technology
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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

3 October 2017

Dear Peter

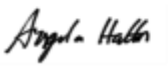
European Programme on Extremes of Weather, Climate and Computing (EPECC)

The vision of EPECC is to develop a wholly new class of models for more accurate prediction of extremes in our weather and climate systems, and to couple these to impacts in the food, water, health, energy and insurance sectors. EPECC will give unprecedented new insights into the processes and mechanisms responsible for weather extremes, and allow us to understand how the frequency and intensity of such events will alter in response to climate change, thereby leading to increased predictive skill. This will require the development of new models of the climate system at unprecedented resolution, and with the inclusion of new physics and numerical algorithms, which will be run on the next generation of High Performance Computing platforms.

The ocean plays a critical role in the climate system and in air-sea interactions, which are important in driving weather extremes. The National Oceanography Centre (NOC) already undertakes research into the mechanisms for decadal-timescale changes in the climate system, their links to weather extremes, and the development and application of high-resolution state-of-the-art ocean models. EPECC will not only complement and enhance the current NOC modelling capability, but is essential if we are to fully understand the drivers of weather extremes and climate variability. This issue cannot be solved by a single centre and a pan-European approach is also needed to construct the next generation of ocean models that include suitable physics, and will perform effectively on the High Performance Computing platforms of the near future.

It is time for the European community to come together, using the fully-integrated approach proposed within EPECC, to address problems that are critically important for society. I therefore fully support the EPECC initiative, which will deliver critical advice to enable Europe to better plan for, and mitigate, the effects of high-impact weather events, as well as generating new scientific understanding and advancing ocean modelling technology, which will greatly benefit research and model development at the NOC.

Yours sincerely



Angela Hatton

NGI

Dr Peter Bauer
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
UK

31st July 2018

Letter of Endorsement for the ExtremeEarth Flagship Project

Dear Dr Bauer,

This letter confirms that the Norwegian Geotechnical Institute (NGI) officially endorses for the FET Flagship project ExtremeEarth.

One of the major challenges facing the modern societies today is dealing with the risk posed by extreme natural hazard events to critical infrastructures. Improving our ability to predict the characteristics of extreme events at a given location would significantly improve our ability to manage the risk and make the society more resilient. The improved physical representation of key processes and more accurate global Earth System and Climate modelling proposed by the ExtremeEarth Flagship will be an immensely valuable step forward in this respect.

The letter implies that the endorsement and logo of NGI may be shown on the ExtremeEarth website.

Sincerely yours
for NORWEGIAN GEOTECHNICAL INSTITUTE

Farrokh Nadim, ScD
Technical Director

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ISO 9001/14001
CERTIFIED BY BSI
FS 32989/EMS 612006

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Letter of Endorsement

09 Jan 2018

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
United Kingdom

Dear Dr. Bauer,

Thank you for information regarding the research initiative ExtremeEarth, and the opportunity for NVIDIA to potentially participate in the high performance computing (HPC) aspects of its development. Following previous collaborations with ECMWF, and with acknowledgement of your important ongoing technical achievements, NVIDIA express our sincere endorsement and support for the EtremeEarth Proposal.

With the introduction of the general purpose Graphics Processing Unit (GPU) in 2004, NVIDIA set a milestone in HPC. Since then, NVIDIA expertise developed in programmable GPUs has led to breakthroughs in parallel computing, while also providing cost-effective solutions in HPC and artificial intelligence. NVIDIA would like to offer this expertise and other resources you may require to ensure success in ExtremeEarth.

NVIDIA offers our commitment and support that can include the following resources:

- Provide nominal seed hardware of latest generation Tesla GPUs for local development
- Provide remote access to a GPU cluster at NVIDIA HQ for performance testing
- Technical guidance on applications engineering from the NVIDIA Devtech group
- Access to latest PGI compilers including OpenACC collaborations with ExtremeEarth
- Frequent roadmap updates on hardware and system software relevant to ExtremeEarth
- Technical support on local installations; cluster access and use; bug fix support
- Participation and contributions to workshops on HPC for weather/climate modeling
- Marketing support and if desired, worldwide distribution of content on project success

NVIDIA are interested in this initiative in two respects. We are generally interested in supporting innovative and promising approaches that demonstrate the capabilities of GPU-based system architectures with relevant real-life applications. Further, NVIDIA have interest in the experiences to be gained with implementing optimized GPU-routines that can apply to increased accuracy and ultimately societal impact in the science of weather forecasting and climate modeling.

Thank you for the opportunity to review and potentially participate in ExtremeEarth research.

Sincerely yours,

Mr. Stan Posey
HPC Program Manager
Earth System Modeling Domain
NVIDIA Corporation
sposey@nvidia.com

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Villigen PSI, 12 February 2018

ExtremeEarth Flagship proposal, Endorsement Letter

Dear Dr. Bauer,

It is our pleasure to send you herewith our endorsement letter for your ExtremeEarth Flagship proposal on behalf of Paul Scherrer Institut, Villigen, Switzerland (PSI). Specifically, we fully support the scientific, technological and programmatic objectives of ExtremeEarth. While this endorsement does not imply any legal or financial commitments towards the ExtremeEarth project, we endorse our statement and logo to be shown on the ExtremeEarth website.

We believe that with our long-term engagement in European infrastructures for ground based observations (EUSAAR, ACTRIS, ACTRIS-2) and atmospheric simulation chambers (EUROCHAMP), the CLOUD project at CERN (always as part of the steering group), our numerous participation in EU projects, our long-term aerosol measurements at the high altitude station Jungfraujoch (since 1988) as well as our leading expertise on aerosol source apportionment and black carbon characterization we will be able to provide highly useful expertise to the consortium.

Yours sincerely
Paul Scherrer Institut

Prof. Dr. Urs Baltensperger
Head, Laboratory of Atmospheric Chemistry

Dr. André Prévôt
Head, Gasphase and Aerosol Chemistry Group, Laboratory of Atmospheric Chemistry

Dr. Martin Gysel
Head, Aerosol Physics Group, Laboratory of Atmospheric Chemistry

P I K

Potsdam Institute for Climate Impact Research P.O. Box 60 12 03 D-14412 Potsdam

Dr. Peter Bauer
Deputy Director
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European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
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Member of the Leibniz Association

Director:
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ExtremeEarth - Letter of Support

13. September 2018

Prof. Dr. Dr. h.c. H. J. Schellnhuber
Director
phone: +49-331 288 2502
director@pik-potsdam.de

The Potsdam Institute for Climate Impact Research (PIK) has an outstanding scientific record on climate and earth system analysis, climate impact assessments, scenario analysis for climate change mitigation and sustainable development, and advanced scientific method development in complex dynamic systems and networks (www.pik-potsdam.de). PIK also has its own high-performance computer for complex model simulations in different scientific disciplines as well as highly demanding integrated assessment studies. In 2012, PIK has initiated the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, www.isimip.org).

ISIMIP offers a framework for consistently projecting the impacts of climate change across a wide range of affected sectors at global and regional scales. An international network of climate-impact modelers, covering more than 100 different impact models, contributes to a comprehensive and consistent picture of the world under different future climate-change scenarios. In October 2017, this emerging community met for the second Impacts World Conference in Potsdam, with more than 400 participants. PIK is hosting the ISIMIP scientific coordination group.

PIK, together with the emerging ISIMIP network of climate impact modelers, is committed to making an essential contribution to the ExtremeEarth Flagship project for improving Europe's capability to predict and monitor environmental extremes and their impacts on society. As part of the future PIK research strategy, multi-disciplinary modelling of planetary boundaries in connection with management of global commons, like the atmosphere, will require advanced capabilities for high-performance computing and big-data handling. PIK fully supports the scientific, technological and programmatic objectives of Extreme-Earth, especially Key Objectives 1 and 4.

Key Objective 1: Enable a step-change in our ability to simulate and predict extreme events with weather and climate models: PIK will contribute strong modelling capabilities in regional and global climate models of intermediate complexity to improve the understanding of a range of extreme events. Moreover, PIK has an excellent record of linking climate models to specific impact models in various sectors, which will be a valuable contribution for developing the ExtremeEarth Flagship.

Key Objective 4: Enable a step-change in our ability to link fundamentally new capabilities for simulating and predicting extremes along with their impacts across value chains and render such services accessible to all communities: PIK will contribute its excellent capabilities in modelling and assessment of climate risks for various economic sectors (hydrology and water, food and agriculture, energy, health) and related value chains and services. Moreover, PIK has a unique scientific capacity in integrating climate risks across sectors and assessing climate damages related to overall economic output, macroeconomic growth, and income distribution.

I understand that this Letter of Support does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of PIK and the ISIMIP network may be shown on the ExtremeEarth website.

I am looking forward to the joint development of the ExtremeEarth Flagship project in an excellent research consortium.

Sincerely,

Hans Joachim Schellnhuber
Director

Dr Peter Bauer
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, United Kingdom

21 August 2018

Subject: **Endorsement of the ExtremeEarth Flagship proposal**

Dear Dr. Bauer,

It is my pleasure to write a letter of support on behalf of Practical Action for the ExtremeEarth flagship proposal for the call "Tackling Grand Interdisciplinary Science and Technology Challenges". Practical Action is a Non-Governmental Organization working across the developing world to build resilience to disasters and adaptation to climate change.

This Flagship project has great potential to support our work in building resilience to disasters in the world's most vulnerable areas. While current support for international emergency response operations could grow dramatically with increased extreme events due to climate change, our work aims to create resilient communities that are equipped to withstand extreme events when they happen. We have supported national governments to build Early Warning Systems across Africa, Asia, and Latin America, and a key challenge in this work is the quality and availability of Earth System information. Working on landslide early warning systems, for example, requires detailed and high-resolution weather information to be integrated with vulnerability and exposure information for local populations. ExtremeEarth would provide the technology and science capacity to make this possible.

Practical Action would be happy to provide links between ExtremeEarth and the disaster risk reduction and food and agriculture communities around the world. Our expertise can inform the design and development of the externally-facing user interfaces for the ExtremeEarth information, to allow our networks to interact with this plethora of data and extract critical information about disaster risks in their area.

We look forward to working with you and the entire consortium on this Flagship.

Yours sincerely,

Greg Beeton, Group Director, Practical Action

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Institut Royal Météorologique de Belgique

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Subject : commitment to the ExtremeEarth flagship proposal

Dear Dr. Bauer,

As the National Meteorological Service of Belgium, the Royal Meteorological Institute (RMI) critically depends on numerical models to ensure the security of the Belgian population and its socio-economic entities through timely weather and climate predictions. Society is becoming increasingly vulnerable to extreme weather and climate events. We believe that a major cross-disciplinary European project such as ExtremeEarth is the only way forward to create the necessary scientific breakthroughs needed to prepare the Earth systems to address the future challenges.

So the RMI fully supports the technological and scientific ambitions of the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

If the next stage of the evaluation of the proposal will be successful, the RMI, possibly in concertation with its university partners, is willing to take the opportunity of the Coordination and Support Action to express its own ambitions and vision. The RMI has been very active in the context of the ALADIN NWP consortium and the ECMWF-led ESCAPE H2020 project and would be happy to see how it can contribute to this project with its own expertise.

Yours sincerely,

The General Director a.i. of RMI,

Dr Daniel Gellens

Politique Scientifique Fédérale

.be

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To whom it may concern,

I am writing in my capacity as Rector of RWTH Aachen to express my strongest support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.

With great interest we are following the activities of the geoscience community to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

As a member of Geoverbund ABC/J we are strongly involved in geoscientific research activities with focus on the investigation of the dynamic earth-human system.

Extreme natural phenomena – such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis – and the escalating impact of climate change – such as desertification, ice-sheet and glacier melting, sea-level rise – dramatically affect all sectors of society. Historically, environmental pressure on the human population has reshaped entire civilizations, and there is a need for effective mechanisms dealing with future change and extremes now. Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing climate risks. ExtremeEarth brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. ExtremeEarth will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

With our research background in the fields of evolution of life and earth, environmental dynamics, georesource management and georisk assessment, we see strong links to the aims of the proposed project ExtremeEarth. Therefore, I very much welcome and strongly support this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

his endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Univ.-Prof. Dr.-Ing. Ernst Schmachtenberg
Rector RWTH Aachen

RWTH AACHEN UNIVERSITY
Der Rektor
der Rheinisch-Westfälischen
Technischen Hochschule Aachen
18. Jan. 2018

Univ.-Prof. Dr.-Ing. E. Schmachtenberg

Lehr- und Forschungsgebiet
Neotektonik und Georisiken
der RWTH Aachen
Prof. Dr. K. Reicherter
Lochnerstr. 4-20, 52056 Aachen
Germany

SIEMENS Gamesa
RENEWABLE ENERGY

Date 23-8-2018

Dr. Peter Bauer

Deputy Director

Research Department

European Centre for Medium-Range Weather Forecasts

Shinfield Park, Reading RG2 9AX, UK

Ref: ExtremeEarth

Dear Dr Bauer

Siemens Games Renewable Energy is the market leader for offshore wind power plants, and among the top two wind power company overall. In our data centre, we monitor live data from all our turbines in service around the world in more than 30 countries. For us and our customers there is large value in an increased accuracy of the short-term predictions, especially the extreme wind and wave impacts, and in better knowledge of the climate change impact on the long-term production.

The step change in forecasting accuracy proposed by ExtremeEarth distributed through the co-creation platform will be important for the future of renewable energy.

Therefore, SGRE supports the ExtremeEarth proposal, and will collaborate with the project on workshops and possibly as a data provider from their offshore and onshore wind farms.

Best regards,

Per Hesselund Lauritsen

Offshore Research Manager, Siemens Gamesa Renewable Energy

[Siemens Gamesa Legal Entity]
Management: [Names]

[Sample Street]
[Sample City, Sample ZIP Code]
[Country]

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Dr Florence RABIER,
Director General, ECMWF
Shinfield Park, Shinfield Road
Reading, RG2 9AX
UNITED KINGDOM

Number: 5110-13/2018-2
Your reference: DG/18-198
Date: 31 July 2018

Subject: **Letter of support for Extreme Earth**

Dear Dr Rabier,

Slovenian Environment Agency strongly supports the ExtremeEarth preparatory project for an EU Flagship and ECMWF's involvement as a leader of the project.

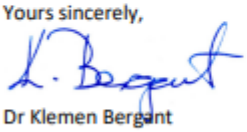
Slovenia is frequently facing environmental extremes, such as droughts, heat waves, floods and flash floods, freezing rain, storms with hail and strong winds, high PM10 and ozone concentrations, ect.

In the role of the National Meteorological, Hydrological, Oceanographic and Seismological Service, we continuously monitor, analyse and forecast phenomena and processes in the environment, with a special focus on extremes, to reduce risks of loss of human lives, damages on property, environment and cultural heritage, economic loss, and increase resilience of our society. Being able to efficiently monitor, predict and early warn on these environmental extremes and their impacts on one hand, and being well prepared with realistic scenarios for their frequency and intensity in the future on the other hand, is therefore one of our main goals.

As a small country and a small service we strongly rely on regional and European cooperation, such as EUMETSAT, ECMWF, EUMETNET, RC-LACE etc. It is clear from our perspective that efficient development to increase our capability for monitoring and predicting environmental extremes and their impacts on society also needs a European wide approach. All available data, computing resources, tools and knowledge shall be gathered to reach this goal, and ExtremeEarth preparatory project is an important step into the right direction.

Primarily, we see our agency as a user of the ExtremeEarth project results. But by providing a wide range of environmental data and through our regional involvement in assuring high quality of observations, as well as monitoring and predicting different extremes (our agency hosts the WMO Regional Instrument Centre, Drought Management Centre for South-eastern Europe and Sava Flood Forecasting and Warning System, and is an active member of the RC-LACE consortium), we might also contribute to the success of this project.

Yours sincerely,



Dr Klemen Bergant
Director of Meteorology and Hydrology Office

SMHI

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range
Weather Forecasts (ECMWF)
Shinfield Park, Reading RG2 9AX
UK

Date: August 23, 2018
Our ref: 2018/1575/11.2

Subject: Commitment to the ExtremeEarth flagship proposal

Dear Dr. Bauer,

This letter expresses the commitment of Swedish Meteorological and Hydrological Institute (SMHI) to the ExtremeEarth Flagship proposal to be submitted to the second stage of the call FETFLAG-01-2018 in the area Energy, Environment and Climate change.

SMHI fully supports the technological and scientific ambitions of ExtremeEarth, which has the potential to enable large capability breakthroughs in our areas of weather, climate and other environmental issues.

SMHI looks forward to collaborating with the ExtremeEarth project consortium should it be positively evaluated and receive funding. Specifically, our envisioned cooperation would involve research on the fully coupled Earth modelling system, including impact modelling as well as the initialization and data assimilation problem for convective- and higher scale forecasting systems.

Yours sincerely,

Rolf Bremmerfelt
Director General, SMHI

SMHI – Swedish Meteorological and Hydrological Institute
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SMHI
Hans Michelsensgatan 9
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SMHI
Universitetsallén 32
SE-851 71 Sundsvall

Prof. Dr.-Ing. Harald Bolt

Mitglied des Vorstands
Forschungszentrum Jülich GmbH
52425 Jülich

Magistrat der Stadt Wien
MD – Klimaschutzkoordination
Rathaus, Stiege 5, DG, Zi. 505
A-1082 Wien
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Fax: (+43 1) 4000 - 75 089
E-Mail: post@md-kli.wien.gv.at
www.wien.at/umwelt/klimaschutz

Endorsement of the European Flagship
candidate project ExtremeEarth
(CSA proposal)

Vienna, 14 Feb 2018

On behalf of the City of Vienna I express our support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.
We are following the activities of the climate and geoscience communities to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

We understand that the capacities and capabilities will provide the basis for knowledge on future development of climate change of a scale relevant to action by regions and cities like Vienna. The City of Vienna could benefit from these capacities, if properly translated them into relevant services for our city. The Austrian Institute of Technology (AIT) would be an institution to provide this service. An example could be to provide relevant data sets for climate change processes in the City of Vienna which might see significant increase in draughts and heat waves with the resulting needs for adaptation of municipal infrastructures and services.

Therefore, we very much welcome and strongly support this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Head of Department
The Climate Protection Coordinator

Mag. DDr. Christine Fohler-Norek

Verkehrsverbindungen: Linie U2 Station Rathaus. DVR: 0000191

Stockholm University

February 21, 2018

To
Dr Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Endorsement letter

concerning the ExtremeEarth Flagship proposal / coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Dear Dr Peter Bauer

Stockholm University notes with interest the development of the proposal Extreme Earth to establish a Future and Emerging Technology Flagship focused unifying technologies and approaches to advance understanding of the Earth System, natural hazards and climate change with a focus on extremes.

Stockholm university having the largest science faculty and environmental science department in Sweden including the Bolin Centre for Climate Research based on 6 departments and the Stockholm Resilient Centre that within the Bolin Centre focus on extending and disseminating knowledge about the Earth's natural climate system, climate variations, climate impacting processes, climate modelling, human impact on the climate and climate impacts on ecosystems, biodiversity and human conditions as well as how society can minimize negative impacts through responsible management.

Our profile makes us a natural partner for ExtremeEarth with its aim to bring together major European centres for Earth system modelling, monitoring and analysis to improve the scientific evidence base for societal aspirations to respond to climate changes and extremes.

We fully endorse the ExtremeEarth initiative, with its scientific, technological and programatic objectives, and look forward to close interactions in the future.

Magnus Breitholtz
Head of Department

Radovan Krejci
Deputy Head of Atmospheric Science Unit

Department of Environmental Science and Analytical Chemistry | ACES

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EEWRC/OUT/022018/3968

Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date: 9th February 2018

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

On behalf of The Cyprus Institute, and in particular the Energy, Environment and Water Research Centre, we would like to respond to your "*ExtremeEarth*" call for potential future partners and stakeholders to endorse your project.

As a Cyprus based Institute with national, regional and international outreach and impact, we candidate to represent the Eastern Mediterranean and Middle Eastern community related to science, research, technology and innovation, through endorsement, consultation and potential formal partnership to your "*ExtremeEarth*" project.

We hereby understand that our endorsement will be step-wise developed throughout the evolution of "*ExtremeEarth*", from preparatory action to Flagship project. Our endorsement of the Flagship candidate project "*ExtremeEarth*" **supports the scientific, technological and programmatic objectives of "ExtremeEarth"**. While our support implies that our statements and logos may be shown on the "*ExtremeEarth*" website, this endorsement does not imply any legal or financial commitments towards the "*ExtremeEarth*" project, except if there will be potential formal partnership in the future.

Signature: C. N. Papanicolas

Prof. Costas N. Papanicolas, President, The Cyprus Institute

UBIMET
WEATHER MATTERS

Fabio Venuti
ECMWF Data Service Team Leader
European Centre for Medium Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Vienna, 20.08.2018

Letter of Support for ExtremeEarth

Dear Fabio Venuti,

As frontrunner in the field of severe weather warnings in Austria and one of the market leaders in Europe UBIMET is highly interested in the impacts of global climate change potentially leading to a significant increase in extreme weather events.

The inherent physical complexity of the Earth system, the chaotic nature of the underlying processes, today's lack of sufficient and accurate observational data, the lack of accurate models to simulate the system's complexity and uncertainty, and the missing link between physical science and impact models still leads to insufficient forecast acurracy and thus reduce the potential of limiting the damages caused by severe weather.

Since our own models use ECMWF model data among others as input, **we highly support the project ExtremeEarth**, that aims at improving the model capabilities regarding unprecedented resolution and accuracy and enhancing the capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and predict their societal impact. ExtremeEarth's development of ultra-high-resolution modelling capabilites of the entire Earth-system is expected to enhance our capability in forecasting and analysis of hyper local severe weather events.

Yours sincerely,

Manfred Spatzierer
CEO
UBIMET GmbH

UBIMET GmbH · A-1220 Wien · Donau-City-Straße 11 · T +43 1 263 11 22 · F +43 1 263 11 22 219 · E office@ubimet.com · www.ubimet.com
ATU57988547 · FN 248415 t · Firmenbuchgericht HG Wien · Firmensitz Wien

United Nations Nations Unies

OFFICE FOR DISASTER RISK REDUCTION • BUREAU POUR LA REDUCTION DES RISQUES DE CATASTROPHES

9-11 RUE DE VAREMBE, CH-1202 GENÈVE, FAX: +41-22-733-9531, TEL: +41-22-917-8907/8908

Ref. ISDR/OUT/2018/00422

10 September 2018

Dear Dr. Bauer,

It is with pleasure that I endorse the ExtremeEarth Flagship proposal (FETFLAG-01-2018). The UN Office for Disaster Risk Reduction (UNISDR) supports this project which, if implemented, would make a significant contribution to the realization of the outcome, goals and targets of the Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework), which was adopted by the Third UN World Conference on Disaster Risk Reduction on 18 March 2015 in Sendai, Japan. The Sendai Framework is a 15-year voluntary, non-binding agreement that maps out a broad, people-centred approach to understanding and managing risk in the context of sustainable development.

High-precision modelling and simulation, including the necessary data integration that enable an in-depth understanding of hazards, the effects of climate change and their dynamic interactions with systemic risk, are essential to understanding and identifying sustainable pathways in the 21st century. Simulation accuracy and the transmission of relevant and accessible risk information is the basis for governments and communities to better understand and anticipate the potential impact of hazards and allow informed decision-making that facilitates risk reduction and avoids risk creation and propagation thereby increasing resilience.

UNISDR, in collaboration with partners, has recently embarked on the development of the Global Risk Assessment Framework (GRAF), which brings together probabilistic risk modeling, risk assessment, early warning and other risk information outputs, to provide tools and products that support risk analysis and risk-informed decision-making at all scales. The GRAF will be launched at the Global Platform for Disaster Risk Reduction in May 2019 and will be further developed in the years ahead, to support the realization of the goals and targets of the Sendai Framework and the 2030 Agenda for Sustainable Development. The better physical representation of key earth systems processes, at higher resolution, and more accurate global Earth System and Climate modelling proposed by the ExtremeEarth Flagship, is in alignment with the fundamental principles of, and will make a powerful contribution to, the Global Risk Assessment Framework; the products of which could in turn benefit the ExtremeEarth Flagship project.

Dr Peter Bauer
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
United Kingdom

We look forward to collaborating with the ExtremeEarth Flagship project, assisting the positioning of its outcomes with the demands of decision-makers for improved risk information and analysis, and strengthening the outputs of the Global Risk Assessment Framework. This endorsement of the Flagship candidate project ExtremeEarth implies that we support the scientific, technological and planned objectives proposed therein but does not imply any legal or financial commitments towards it.

Yours sincerely,

Mami Mizutori

Mami Mizutori
Special Representative of the Secretary-General
for Disaster Risk Reduction

UNIVERSITÄT BONN

RHEINISCHE
FRIEDRICH-WILHELMS-
UNIVERSITÄT BONN

UNIVERSITÄT BONN · Der Rektor · 53012 Bonn

Der Rektor Prof. Dr. Dr. h.c. Michael Hoch

Regina-Pacis-Weg 3
53012 Bonn
Tel. 0228/73-7297
Fax 0228/73-7262
rektor@uni-bonn.de
www.uni-bonn.de

Bonn, 20.12.2017

To whom it may concern

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

Dear Sir/Madam,

I am writing in my capacity as Rector of University of Bonn to express my strongest support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.

With great interest we are following the activities of the geoscience community to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

As a member of Geoverbund ABC/J we are strongly involved in geoscientific research activities with focus on the investigation of the dynamic earth-human system.

With our research background in the fields of evolution of life and earth, environmental dynamics, georesource management and georisk assessment, we see strong links to the aims of the proposed project ExtremeEarth. Therefore, I very much welcome and strongly support this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project. Support will imply that statements and logos of supporters may be shown on the ExtremeEarth website.

Yours faithfully

Prof. Dr. Dr. h.c. Michael Hoch

Wir
SEIT 200 JAHREN

www.200jahre.uni-bonn.de

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Sparkasse KölnBonn
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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

Date: 28. 08. 2018.

Subject: Endorsement letter for the ExtremeEarth project

Dear Dr Bauer,

On behalf of the Faculty of Physics, University of Belgrade, I am writing you to express my strong support for the Coordinated Support Action proposal to develop a Future and Emerging Technology Flagship Project *ExtremeEarth*.

The Faculty of Physics (FP) is the national oldest and leading educational and research institution in the field of physical science in Serbia. FP is composed of two institutes, Institute of Physics and Institute of Meteorology. Main research objectives of the Institute of Meteorology is in the fields of meteorology and climatology, and majority of research is related to the numerical modelling of the geophysical processes, from weather to climate scales. Research in area of numerical modelling started in the beginning of 1970's. In that period Institute of Meteorology together with Federal hydrometeorological institute (of ex Yugoslavia) starts to develop numerical weather prediction model, which become known as *Eta model*, and which in 1990's became operational model for NWP in NOAA/NCEP in the USA. Today, research related to climate modelling, within Institute, relies on the development of the coupled regional climate model EBU-POM (combination of Eta and Princeton Ocean Model), which participates to the Med-CORDEX initiative. In the past, researchers from Institute of Meteorology, participated in many projects related to climate and climate change.

The FP and Institute of Meteorology are strongly interested in to the outcomes of the project and potentially can contribute in project preparation, modelling efforts, research on climate and weather extremes and their impacts on nature and society. It will be our honour to participate and contribute in such a strong consortium.

We wish you success in your efforts to secure this project approval.

Kind regards,

prof. dr Jablan Dojčilović
Faculty dean
Faculty of Physics, University of Belgrade

The Rector of the University of Cologne

Herrn
Dr. Daniel Felten
Leiter Koordinationsbüro Geoverbund ABC/J
Forschungszentrum Jülich GmbH
in der Helmholtz-Gemeinschaft
IBG-3 Agrosphäre
52425 Jülich

Cologne, 18/12/2017

Endorsement of the Flagship candidate project ExtremeEarth (CSA proposal)

To whom it may concern

I am writing in my capacity as Rector of the University of Cologne to express my strongest support for the proposed CSA proposal to develop a FET Flagship Project *ExtremeEarth*.

With great interest we are following the activities of the geoscience community to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the imaginative integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

As a member of Geoverbund ABC/J we are strongly involved in geoscientific research activities with focus on the investigation of the dynamic earth-human system.

Extreme natural phenomena – such as floods, droughts, wind storms, earthquakes, volcanoes, tsunamis – and the escalating impact of climate change – such as desertification, ice-sheet and glacier melting, sea-level rise – dramatically affect all sectors of society. Historically, environmental pressure on the human population has reshaped entire civilizations, and there is a need for effective mechanisms dealing with future change and extremes now. Understanding and advancing our ability to predict the frequency of occurrence and intensity of extremes reliably is of paramount importance for efforts to make society more resilient to the environmental impacts of the present and changing climate, and it will allow European governments and businesses to plan more effectively than they are able for current and changing

Albertus-Magnus-Platz · D-50923 Cologne GERMANY Phone: +49 221 470 2201
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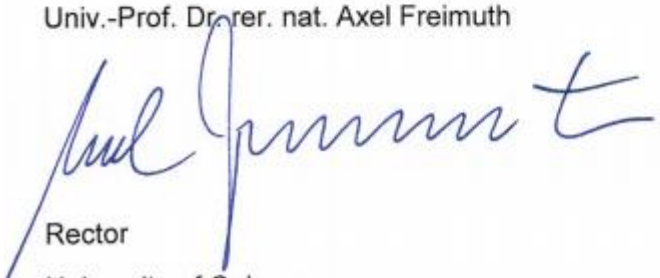
climate risks. *ExtremeEarth* brings together Earth-system scientists and associated down-stream science and application communities, joining forces with those pushing the envelope in digital technology, to realize in the next five to ten years what seems unfeasible today. *ExtremeEarth* will greatly enhance our capacity to observe and monitor the state of the Earth, predict extremes, understand their underlying drivers, and characterize their societal impact.

With our research background in the fields of evolution of life and earth, environmental dynamics, georesource management and georisk assessment, we see strong links to the aims of the proposed project *ExtremeEarth*. Therefore, I very much welcome and strongly support this proposal.

The *ExtremeEarth* project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of *ExtremeEarth*, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project *ExtremeEarth* implies that the endorsing entity supports the scientific, technological and programmatic objectives of *ExtremeEarth*.

This endorsement does not imply any legal or financial commitments of the University of Cologne towards the *ExtremeEarth* project. Support will only imply that statements and logos of supporters may be shown on the *ExtremeEarth* website, with the option that this permission can be revoked for important reasons.

Univ.-Prof. Dr. rer. nat. Axel Freimuth



Rector

University of Cologne

Faculty of Science and Forestry / Department of Environmental and Biological Sciences

16. February 2018

UNIVERSITY OF EASTERN FINLAND

University of Eastern Finland

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Dr. Peter Bauer
Deputy Director
Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
+44 118 949 9080

Date:

Reference: ExtremeEarth Flagship proposal / Coordination and support actions / 1st stage of a two-stage submission procedure for FETFLAG-01-2018

Subject: Endorsement Letter

Dear Dr. Peter Bauer,

We are happy to be involved in the ExtremeEarth, and support its scientific, technological and programmatic objectives. We have ongoing projects on disturbance effects in boreal and sub-arctic ecosystems including the effect of forest fires on soil carbon and nitrogen cycles, permafrost thawing and their consequent effects on the emission greenhouse gases. These processes are being studied in projects "Long term effects of fire on carbon and nitrogen pools and fluxes in the arctic permafrost and subarctic forests (ARCTICFIRE)" funded by the Academy of Finland 2015-2018 and "Yedoma: an overlooked source of nitrous oxide (N2O) from the Arctic?" (Yedoma-N) 2015-2019 in our team. We are also studying the effects of forest management and animal grazing on ecosystem carbon and nitrogen balance. All these processes play an important role in regulating the greenhouse gas fluxes between ecosystems and atmosphere.

The ExtremEarth supports the work conducted in our research unit and the top-level international research areas "Aerosols, Climate Change and Human Health" and "Forests, Global Change and Bioeconomy" in the University of Eastern Finland.

Sincerely yours

Jukka Pumpanen
Professor in Microbial Biogeochemistry
Department of Environmental and Biological Sciences
University of Eastern Finland
P.O. Box 1627
FI- 70211 Kuopio, FINLAND
Phone:+358 50 4486127

UNIVERSITY OF MARYLAND
DEPARTMENT OF GEOGRAPHICAL SCIENCES

2181 LeFrak Hall
College Park, Maryland 20742
301.405.4050 TEL 301.314.9299 FAX

February 28th 2018

Dear Dr. Bauer,

On behalf of UMD and as Co-Chair of the GEOGLAM Executive Committee, I am writing to express my strong support for the ExtremeEarth flagship proposal to the European Union's Horizon2020 Programme. Extreme climate events are presenting a number of challenges to governments, businesses and farmers. This flagship proposal to dramatically improve climate modeling would require novel computational infrastructures, strategies, and algorithms and a scaling up of today's capabilities. To provide modeling and forecasting of extreme climate events will require much better physical representation of key processes, at finer spatial resolutions than are currently available.

From the GEOGLAM perspective, current climate models are insufficient to reliably predict or forecast extreme events beyond 10 - 15 days. Improved forecasting on a 2- 6 months basis would be extremely useful in the context of Food Security and Early Warning. Process-based crop models driven by input from climate models would also benefit from improved forecasts at finer spatial scales. A detailed accounting of uncertainties, would allow better-informed decision-making from farm-level to business and governmental organizations.

The GEOGLAM initiative represents the interests of the Agricultural Monitoring Community of Practice and as Co-Chair I would be very much interested in interacting with your proposed flagship, providing input from the community on requirements for agriculture and testing of some the products and model outputs that you would be developing.

I am familiar with the work of a number of the Coordination Team identified in your proposal, they represent the leaders in the field and I find it to be a very strong and competitive team. In my role as GEOGLAM Co-Chair, I would like to express strong support for your ExtremeEarth proposal, which will be an extremely relevant to the GEOGLAM initiative.

Yours Sincerely,

Chris Justice, GEOGLAM Co-Chair

Chair of the Department of Geographical Sciences

UiO : University of Oslo
Faculty of mathematics and natural sciences

Extreme Earth consortium
Professor **Harald Bolt**
Forschungszentrum Jülich
Wilhelm-Johnen-Straße
52428 Jülich
Germany

Date: 19 December 2017
Officer: Geir Horn
Tel: +47 93 05 93 35
Email: Geir.Horn@mn.uio.no

Extreme Earth endorsement

Dear Professor Bolt,

I am pleased to learn that Professor Dag Olav Hessen and Professor Frode Stordal have been accepted as collaborators of your Extreme Earth FET Flagship initiative. We do hope that the proposal for the structuring Coordination and Support Action (CSA) will be successful and leading to the establishment of a decade of excellent research in the Extreme Earth flagship.

The University of Oslo and the Faculty of Mathematics and Natural Sciences are fully committed to this initiative, and will support our involved colleagues to ensure timely deliveries from our side in all phases of the proposal and the flagship execution.

With our very best wishes and hopes for a successful submission,

Professor **Morten Dæhlen**
Dean
Faculty of Mathematics and Natural Sciences

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10 September 2018

Dear Dr Bauer

***ExtremeEarth*: Letter of Support**

The University of Reading is extremely supportive of the vision of *ExtremeEarth*, and shares its ambition to combine the best science with new and untested next-generation technologies to transform forecast skill for weather, climate and weather-driven natural hazards, and so radically improve disaster risk-reduction strategies. We share the view that delivering this vision demands the highly co-ordinated efforts of multiple scientific and technological communities on a pan-European and wider international scale; to construct the next-generation of Earth system models which will perform effectively on the next-generation computing platforms. The international technical and scientific leadership of *ExtremeEarth* clearly has the potential to develop such a system.

The University of Reading is very well placed to contribute to *ExtremeEarth* from a number of perspectives, given our world-leading expertise and strategic focus on: understanding and modelling the dynamics of interactions between weather and climate; developing of Earth system models; developing synergies between mathematics, computer science and the environment; and identifying improved risk-reduction strategies. This capability exists as a connected research community across the University, largely in the Department of Meteorology, Department of Geography & Environmental Science, Department of Computer Science, National Centre for Atmospheric Science (NCAS) and the National Centre for Earth Observation (NCEO).

By way of outlining more explicitly the relevance of our expertise and potential contribution to *ExtremeEarth*:

(i) The Department of Meteorology at Reading is widely regarded as one of the top university departments worldwide spanning the range of weather and climate research, and is the largest such department in Europe. Exploiting the synergy between weather and climate, for example for the understanding of climate risk associated with extreme weather events, is a strategic priority for the Department and the University, and is also a focus of the NCAS and NCEO research groups that are embedded within the Department. Experience in weather science has shown that explicit simulation of the atmosphere at the km scale leads to a step-change in the accuracy of the modelled phenomena, because many of the key processes such as convection no longer need to be parameterized. However this is currently only feasible for limited domains and time horizons, as in weather prediction.

The Queen's Anniversary Prizes 2011

Climate models still require parameterizations, and this places a fundamental limitation on their accuracy. By allowing climate simulations to be performed at weather-resolving spatial scales, *ExtremeEarth* would finally bridge the gap that has long existed between weather and climate; a game-changing capability.

(ii) The Department of Geography & Environmental Science has world-leading expertise and experience in the development of Earth System models for disaster risk-reduction, and in the co-production of land-surface forecasting systems for natural hazards (including floods, droughts and heatwave health hazards, with national and international partners). There is a strong focus on bridging research-community boundaries to provide demonstrable Earth System capabilities, for example as demonstrated in the work on flood forecasting with numerical weather prediction models for humanitarian support. The research approach challenges practice in the weather and climate modelling community, for example blending hyper-resolution modelling concepts with uncertainty representation to advance impacts research.

(iii) *ExtremeEarth*'s ambitious technology goals require advances in fundamental computational (and computer) science and the development and exploitation of a range of computational technologies. The University of Reading is well placed to contribute to this spectrum of activities, having recently made structural changes in its organisation to better enable the synergies between mathematics, computer science, and the environment. As well as bringing together the relevant Departments together into the school of Mathematical, Physical and Computational Sciences, we have established a research group in "Advanced Computing for Environmental Sciences" (https://aces.cs.reading.ac.uk), to complement expansions in existing strengths in data science. Academic competencies of direct relevance to *ExtremeEarth* include the necessary data systems, high performance computing, cloud computing, and exascale computational techniques.

As well as having potential for contributing to the science and development of *ExtremeEarth*, the University also sees itself as one of the stakeholders in the success of the project. The proposed technology advances are likely to revolutionise the ability to conduct environmental science, and so the University would expect to benefit directly. We would also plan to use *ExtremeEarth* developments in our teaching and training programmes, enabling the further dissemination of the benefits downstream to graduates in mathematics, computer science, geography and meteorology. Given the immense potential value of a successful *ExtremeEarth* programme, the University of Reading is keen to provide in-kind support to this preparatory project. As Dean for Environmental Research, I will support and facilitate the engagement of our connected research community outlined above, to harness a focused contribution that helps to develop the *ExtremeEarth* proposal and approach.

Yours sincerely

Phil Newton
Research Dean (Environment)

UPPSALA UNIVERSITET

Department of Earth Sciences
Geocentrum, Villavägen 16,
752 36 Uppsala
Sweden

10th September 2018

Letter of Support for **ExtremeEarth**

Dear Dr Bauer,

We are writing on behalf of the Centre of Natural Hazards and Disaster Science, CNDS, directed by Uppsala University, in strong support of your proposal to develop a Flagship project ExtremeEarth. We believe that the proposed project will revolutionise Europe's ability to conduct natural hazards and disaster science and to predict and monitor environmental extremes and their impacts upon society.

CNDS is a Swedish national platform for research on the nexus between socio-technical vulnerability and extreme events, bringing together world leading researchers in engineering, social and earth sciences. The overall aim of CNDS's research is to contribute to enhancing society's ability to prevent and cope with natural hazard risks in the national and international context. We have world leading expertise in the development of earth system models for disaster risk reduction and in the coproduction of land surface forecasting systems for natural hazards. We have a strong interdisciplinary focus to our practice demonstrated in our research on disaster preparedness and communication, the design and effective use of early warning systems, decision support for disaster prevention and mitigation and disaster response.

ExtremeEarth is aligned very closely with our aims and activities, and we are well situated to contribute strongly to the project and are thus keen to offer in kind support for the preparatory project. We also see the important direct benefits for CNDS from the technological advances proposed in this project, which would revolutionise the ways in which we could undertake natural hazards and disaster science.

We fully endorse the ExtremeEarth initiative and look forward to closely interacting with the project as it goes forward.

Prof Giuliano Di Baldassarre

Prof of Hydrology and CNDS Director

Prof Hannah Cloke

Guest Professor and CNDS Fellow

Vestas

Classification: Public

Dr. Peter Bauer
Deputy Director, Research Department
European Center for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK

København S, 3 September 2018/LIBAC

Endorsement of the Flagship candidate proposal ExtremeEarth

Vestas Wind Systems A/S is a leading global partner on sustainable energy solutions and has installed more wind power than anyone else. To sustain our leading role within sustainable energy, we have built a strong tradition of partnering with the research community and have been participating in a range of public funded R&D projects in the field of atmospheric science and data integration.

Advances in weather forecasting of the extreme events in the present and in the future climate are fundamental for the optimal design and operation of wind plants. The wind industry depends on knowing the risks wind turbines will be subject to. The accuracy of weather and climate information in general, and extreme events in particular, enables safe operation of wind turbines, optimal management of our customer's assets, lowers the cost of renewable energy and increases its penetration in the electricity grids. The required technological advances in creating and analysing a large amount of data are aligned with our vision for data-driven performance analysis and predictions. Vestas uses large volumes of data to interpret, forecast, and exploit wind resources and deliver best-in-class wind power solutions.

We are therefore happy to endorse the project and are looking forward to benefit from the project results.

Yours sincerely
Vestas Wind Systems A/S

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SVP, Innovation & Concepts
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Pep Moreno

CEO, Vortex

Parc Tecnologic Barcelona
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08042 Barcelona
Spain

Dr. Peter Bauer

Deputy Director

Research Department

European Centre for Medium-Range Weather Forecasts

Shinfield Park, Reading RG2 9AX, UK

Ref: ExtremeEarth

Dear Dr Bauer

Vortex is a leading company in the resource analysis and in operational predictions of wind power. For us and our customers, which include project developers, OEM, agencies and consultancies, an increased accuracy of the short-term predictions would mean more efficient operations and ultimately cheaper wind power for everyone. More accurate knowledge of the climate change impact on the long-term production would decrease financing cost for wind power and make educated guesses possible on where to site and not to site wind power plants.

The step change in forecasting accuracy proposed by ExtremeEarth distributed through the co-creation platform will be important for the future of renewable energy.

Therefore, Vortex supports the ExtremeEarth proposal, and will collaborate with the project on intelligence sharing, workshops and in the scoping and development of the co-creation platform.

We really believe this project will have a critical impact in making this step change in the prediction technology and will have a direct impact in increasing the fidelity of the wind resource tools and applications for the Wind Industry.

We look forward to contributing to Extreme Earth in future.

Best regards,

Pep Moreno
CEO, Vortex

WEMC
World Energy &
Meteorology Council

9th September 2018

Dr. Peter Bauer
Deputy Director, Research Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, UK
Email: peter.bauer@ecmwf.int

Letter of support for the ExtremeEarth Flagship Programme initiative

Dear Peter,

It is a pleasure to present this letter of support on behalf of the World Energy & Meteorology Council (WEMC) to endorse the ExtremeEarth proposal for a candidate European Commission Future and Emerging Technology Flagship, targeting a visionary unifying goal for new technologies and approaches for high-precision modelling and simulation of the Earth system.

WEMC is a non-profit organisation devoted to promoting and enhancing the interaction between the energy industry and the weather, climate and broader environmental sciences community. Established in 2015, it builds on the growing body of work, knowledge and experience in weather and climate risk management in the energy industry. Its primary goal is to enable improved sustainability, resilience and efficiency of energy systems under ever changing weather and climate (for more information please see: http://www.wemcouncil.org).

Enhancing our understanding and ability to predict and monitor environmental extremes and their impacts on society reliably, as envisaged by the proposed ExtremeEarth project, would greatly assist with WEMC's goals. Specifically, the technologies that ExtremeEarth will develop such as very high-resolution weather and climate forecasts, integrated with application models, will assist with the deployment, operations, and management of energy systems, particularly in the fast-growing area of renewable energy.

WEMC would be happy to collaborate with the ExtremeEarth on a number of areas by for instance:

i) Promoting the interaction between energy and meteorological experts to improve energy sector operations, planning and management, such as through our newsletters, workshops and our flagship event, the International Conference Energy & Meteorology;

ii) Developing best practise in energy management of weather risk in the face of climate variability and change and maximising the exchange of information between energy & meteorology globally, in both developed and developing countries;

iii) Fostering a stronger energy & meteorology community so as to significantly contribute to the resilience of energy systems and the development of clean energies as well as to activities such as the Global Framework for Climate Services and the UN decade of Sustainable Energy for All.

We strongly support the ExtremeEarth Flagship Programme initiative and we wish you best of luck with your preparatory phase, and we look forward to collaborating with you.

Yours Sincerely,

Prof. Alberto Troccoli
Managing Director, World Energy & Meteorology Council
c/o School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK
T: +44 (0)1603 59 1413 – E-mail: alberto.troccoli@wemcouncil.org

www.wemcouncil.org info@wemcouncil.org +44 (0)20 3286 3250
The Enterprise Centre, University of East Anglia, Norwich, NR4 7TJ, UK.

Endorsement of the European Flagship candidate project ExtremeEarth (CSA proposal)

To whom it may concern,

On behalf of WIEN ENERGIE I express our support for the proposed CSA proposal to develop a FET Flagship Project Extreme Earth.

We are interested to possibly become involved as stakeholder in the activities of the climate and geoscience communities to develop a joint FET Flagship candidate project on enhancing Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by the integration of edge and exascale computing and beyond, and the real-time exploitation of pervasive environmental data.

We understand that the capacities and capabilities of the ExtremeEarth community will provide the basis for knowledge on future development of climate change of a scale relevant to action by regions and cities like Vienna. This does strongly include issues and matters related to energy supply, distribution and use. WienEnergie could benefit from these capacities, if properly translated into relevant services for our company. One subject of interest for us could be to receive relevant data sets for climate change processes in the City of Vienna which might see significant increase in draughts and heat waves with the resulting needs for adaptation of municipal infrastructures and services, especially in the energy field.

Therefore, we very much welcome and strongly support this proposal.

The ExtremeEarth project aims to reflect the views and requirements of scientific, technological and service oriented communities that are included in the project for realizing a step-change enhancement of their capabilities in the future. The representation of these communities will be developed throughout the evolution of ExtremeEarth, from preparatory action to Flagship project, through endorsements, consultations and formal project partnership. The endorsement of the Flagship candidate project ExtremeEarth implies that the endorsing entity supports the scientific, technological and programmatic objectives of ExtremeEarth.

This endorsement does not imply any legal or financial commitments towards the ExtremeEarth project.

Signature

Wien Energie GmbH
Thomas-Klestil-Platz 14
1030 Wien

Brigitte Bach

Wien Energie GmbH

TN – Telekommunikation u. neue Geschäftsfelder / Leitung

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WMO OMM

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Our ref.: 24846/2018-RES/ARE

Dr Florence Rabier
Director-General
European Centre for Medium-Range
Shinfield Park,
READING RG2 9AX
United Kingdom

11 September 2018

Subject: **Endorsements of the ExtremeEarth Flagship proposal**

Dear Dr Rabier, FLORENCE.

It is my pleasure to endorse the ExtremeEarth Flagship proposal to be submitted to the second stage of a two-stage submission procedure for the call "Tackling Grand Interdisciplinary Science and Technology Challenges". If implemented, this Flagship will create an unprecedented scientific and technological framework for weather, climate and environmental science communities, and in turn, it will bring multiple science-for-science benefits to the Members of the World Meteorological Organization (WMO).

The proposed Flagship addresses key areas covered by the World Climate Research Programme (WCRP), the World Weather Research Programme (WWRP), and the Global Atmosphere Watch Programme (GAW). WMO Commission for Atmospheric Sciences (CAS) included these research activities in its five key research priorities on Seamless Research for Weather, Climate, Water and Environment, based on the outcome of the Science Summit held in Geneva during October 2017.

The evolution of a seamless Earth System approach and the development of adequate future infrastructures are key ingredients of this Flagship proposal, and well aligned with WMO Strategic Plan for 2019-2023 and the new WCRP strategic plan currently being developed. If fully implemented, this proposal will be a potential game changer that could revolutionize the entire Earth System science. WMO, through its research programmes (GAW and WWRP), and the co-sponsored WCRP, working in partnership with other international initiatives, have a keen interest in playing an active role in the development and eventual implementation of ExtremeEarth.

Considering the above mentioned close alignment in priorities between the ExtremeEarth Flagship with those in the WMO Strategic Objectives, I look forward to continue to work closely with you and Dr P Bauer on this initiative. For any further information on WMO engagement, Dr Bauer is kindly requested to contact P. Ruti (pruti@wmo.int).

Yours sincerely,

(P. Taalas)
Secretary-General

cc: Dr Peter Bauer, Deputy Director of Research, ECMWF

Leibniz Centre for
Agricultural Landscape Research
(ZALF)

Leibniz Centre for Agricultural Landscape Research (ZALF)
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Date:
24.07.2018

Endorsement of the Flagship ExtremeEarth

Dear Dr. Bauer,

On behalf of the consortium Digital Bioeconomy - Transforming agriculture and food systems for environment and society (https://www.digital-bioeconomy.eu/) I am expressing our strong support for the proposal of the future ExtremeEarth Flagship. The scientific and technological developments proposed in ExtremeEarth would be of very high relevance for many of our research activities, a great value is seen in the scaling up of supercomputing capacity for climate and weather modelling with beneficial value for applications in agriculture and the larger bioeconomy.

Kind Regards,

Prof. Dr. Frank Ewert
Leader of the Consortium Digital Bioeconomy

Certification according to ISO 9001

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Dr Florence Rabier
Director-General
European Centre for Medium-Range Weather Forecasts
Shinfield Park
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Your reference / Your message from	Our reference	Person of contact / Phone extension / e-mail	Date
DG/18-198	04/18-EC	Dr. Michael Staudinger / 2001 / m.staudinger@zamg.ac.at	16.08.2018

Subject: *Letter of support for ExtremeEarth*

Dear Dr. Rabier,

I am writing this letter as Executive Director of the Austrian National Weather Service ZAMG to express our strong support for ExtremeEarth as a preparatory project for an EU flagship. ZAMG is particularly interested in the impacts of global climate change potentially leading to a significant increase in extreme weather events, and in all aspects of bringing together model and monitoring data e.g. through data assimilation technologies. As chair of the Austrian National ISDR platform, I am particularly interested in enhancing the predictability of and increasing our resilience towards natural disasters. We also think that increasing our physical insights into such phenomena will have considerable impact on the application side.
ZAMG is looking forward to collaborate in the framework of the preparatory project, for example by contributing to the requirements of the ExtremeEarthScienceCloud (EEsC) and by contributing its knowledge with regard to national and international coordination and service provision activities (ISDR Plattform, ARISTOTLE project with EU ERCC). In a potential future project, ZAMG could additionally contribute its experience in modelling and data assimilation.

Yours sincerely

Dr. Michael Staudinger
Director

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