Please check our wiki for help on navigating the form.

# Horizon 2020

## Call: H2020-FETFLAG-2018-2020

(FET FLAGSHIPS – Tackling grand interdisciplinary science and technology challenges)

## Topic: FETFLAG-01-2018

## Type of action: CSA

## Proposal number: SEP-210501240

## Proposal acronym: ExtremeEarth-PP

Deadline Id: H2020-FETFLAG-2018-01

## Table of contents



### *How to fill in the forms*

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the steps in the submission wizard.



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

# 1 - General information

| | | | |
|---|---|---|---|
| Topic | FETFLAG-01-2018 | Type of Action | CSA |
| Call Identifier | H2020-FETFLAG-2018-2020 | Deadline Id | H2020-FETFLAG-2018-01 |

| | |
|---|---|
| Acronym | ExtremeEarth-PP |
| Proposal title | ExtremeEarth Preparatory Project |

*Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &*

| | |
|---|---|
| Duration in months | *12* |
| Fixed keyword 1 | Earth and related environmental sciences |
| Fixed keyword 2 | Physical sciences |
| Fixed keyword 3 | Computer and information sciences |
| Free keywords | *Earth System, Climate Change, Natural Resources, high-precision modelling, extreme-scale computing, extreme-scale data handling, model-data integration* |

*Abstract*

ExtremeEarth-PP is a preparatory project for ExtremeEarth, a proposed FET Flagship Programme FETFLAG-01-2018 of the European Commission. It addresses the specific need, articulated in the Call for Preparatory Actions, for “New technologies and approaches for high-precision modelling and simulation, including the necessary data integration, that enable an in-depth understanding of the earth, natural hazards and climate change.”

Environmental extremes are responsible for thousands of casualties and billions of € in damages in Europe annually. Societal risks associated with many of these extremes are poorly understood in today’s climate – even more so as climate changes. Knowledge gaps arise from the inadequacy of existing models, which are unable to capture key physical processes and hence cannot fully incorporate an expanding palette of observations. 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.

ExtremeEarth will develop the technologies for a required thousand-fold increase in computation, and fundamentally redesign workflows to dynamically expose the full information content of a new generation of models and data to users. These developments will exploit the complementarity of ExtremeEarth’s domain sciences, be realised through co-design by scientists, application communities and technologists, and become an engine for European innovation across a broad range of sectors.

The ExtremeEarth-PP will prepare the ExtremeEarth project proposal, by identifying partners and stakeholders, specifying an operating and governance model, developing a project roadmap and work plan. In addition it will build support from EU member states and other agencies, contribute to EC policies and support efforts for the Flagship Programme also through an appropriate dissemination and communication strategy.

Remaining characters 2

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under Horizon 2020 or any other EU programme(s)? ◯ Yes ◉ No

| Please give the proposal reference or contract number. | |
|---|---|
| *xxxxxx-x* | |

## *Declarations*

| | |
|---|---|
| 1) The coordinator declares to have the explicit consent of all applicants on their participation and on the content of this proposal. | ☒ |
| 2) The information contained in this proposal is correct and complete. | ☒ |
| 3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct). | ☒ |

4) The coordinator confirms:

| | |
|---|---|
| - to have carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year. Where the result was "weak" or "insufficient", the coordinator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check); or | ○ |
| - is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check); or | ◉ |
| - as sole participant in the proposal is exempt from the financial capacity check. | ○ |

5) The coordinator hereby declares that each applicant has confirmed:

| | |
|---|---|
| - they are fully eligible in accordance with the criteria set out in the specific call for proposals; and | ☒ |
| - they have the financial and operational capacity to carry out the proposed action. | ☒ |

The coordinator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

**Personal data protection**

The assessment of your grant application will involve the collection and processing of personal data (such as your name, address and CV), which will be performed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the purposes and means of the processing of your personal data as well as information on how to exercise your rights are available in the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Detection and Exclusion system of the European Commission (EDES), the new system established by the Commission to reinforce the protection of the Union's financial interests and to ensure sound financial management, in accordance with the provisions of articles 105a and 108 of the revised EU Financial Regulation (FR) (Regulation (EU, EURATOM) 2015/1929 of the European Parliament and of the Council of 28 October 2015 amending Regulation (EU, EURATOM) No 966/2012) and articles 143 - 144 of the corresponding Rules of Application (RAP) (COMMISSION DELEGATED REGULATION (EU) 2015/2462 of 30 October 2015 amending Delegated Regulation (EU) No 1268/2012) for more information see the Privacy statement for the EDES Database.

# 2 - Participants & contacts

| # | Participant Legal Name | Country | Action |
|---|---|---|---|
| 1 | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS | UK | |
| 2 | THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD | UK | |
| 3 | MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV | DE | |
| 4 | FORSCHUNGSZENTRUM JULICH GMBH | DE | |
| 5 | EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH | CH | |
| 6 | CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS | France | |
| 7 | FONDAZIONE CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI | IT | |
| 8 | STICHTING NETHERLANDS ESCIENCE CENTER | NL | |
| 9 | STICHTING DELTARES | NL | |
| 10 | DANMARKS TEKNISKE UNIVERSITET | DK | |
| 11 | JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION | BE | |
| 12 | BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION | ES | |
| 13 | STICHTING INTERNATIONAL RED CROSS RED CRESCENT CENTRE ON CLIMATE CHANGE AND DISASTER PREPAREDNESS | NL | |
| 14 | NATURAL ENVIRONMENT RESEARCH COUNCIL | UK | |
| 15 | UNIVERSITEIT UTRECHT | NL | |
| 16 | METEO-FRANCE | FR | |
| 17 | ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA | IT | |
| 18 | HELSINGIN YLIOPISTO | FI | |

# 2 - Administrative data of participating organisations

| ***PIC*** | ***Legal name*** |
|---|---|
| *999916741* | *EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS* |

## *Short name: ECMWF*

*Address of the organisation*

| | |
|---|---|
| Street | SHINFIELD PARK |
| Town | READING |
| Postcode | RG2 9AX |
| Country | United Kingdom |
| Webpage | www.ecmwf.int |

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ............................................................yes

Non-profit ...............................................................yes

International organisation .......................................yes

International organisation of European interest ........yes

Secondary or Higher education establishment .........no

Research organisation ............................................yes

Legal person ...................................yes

Industry (private for profit).................no

### Enterprise Data

SME self-declared status......................................... unknown

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## Department(s) carrying out the proposed work

**Department 1**

Department name: Research Department

☐ not applicable

☒ Same as proposing organisation's address

Street: SHINFIELD PARK

Town: READING

Postcode: RG2 9AX

Country: United Kingdom

## Dependencies with other proposal participants

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Peter** Last name: **Bauer**

E-Mail: **peter.bauer@ecmwf.int**

Position in org.: Deputy Director of Research

Department: Research Department ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: SHINFIELD PARK

Town: READING Post code: RG2 9AX

Country: United Kingdom

Website: www.ecmwf.int

Phone: +44 118 949 9080 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Daniel | THIEMERT | daniel.thiemert@ecmwf.int | +44 118 949 9024 |

| ***PIC*** | ***Legal name*** |
| --- | --- |
| *999984350* | *THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD* |

## *Short name: UOXF*

*Address of the organisation*

Street WELLINGTON SQUARE UNIVERSITY OFFICE

Town OXFORD

Postcode OX1 2JD

Country United Kingdom

Webpage www.ox.ac.uk

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........yes

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................22/12/1570 - no

SME self-assessment ............................................. unknown

SME validation sme................................................. unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



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## Department(s) carrying out the proposed work

**Department 1**

Department name: Department of Physics ☐ not applicable

☐ Same as proposing organisation's address

Street: Clarendon Laboratory, Parks Road

Town: Oxford

Postcode: OX1 3PU

Country: United Kingdom

## Dependencies with other proposal participants

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.
Sex: (●) Male ( ) Female

First name: **Tim** Last name: **Palmer**

E-Mail: **tim.palmer@physics.ox.ac.uk**

Position in org.: Royal Society Research Professor

Department: Department of Physics ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Clarendon Laboratory, Parks Road

Town: Oxford Post code: OX1 3PU

Country: United Kingdom

Website: http://www2.physics.ox.ac.uk/contacts/people/palmer

Phone: +441865272897 Phone 2: +441865272200 Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Michele | Warren | grants@physics.ox.ac.uk | *+441865272406* |
| Gill | Wells | ecresearch@admin.ox.ac.uk | *+441865289842* |
| Joanna | Frost | joanna.frost@physics.ox.ac.uk | *+xxx xxxxxxxxx* |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999990267* | *MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV* |

## *Short name: MPG*

*Address of the organisation*

Street HOFGARTENSTRASSE 8

Town MUENCHEN

Postcode 80539

Country Germany

Webpage www.mpg.de

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ................................................................no

Non-profit ..................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................05/04/2016 - no

SME self-assessment .............................................05/04/2016 - no

SME validation sme.................................................31/10/2008 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Max Planck Institute for Meteorology ☐ not applicable

☐ Same as proposing organisation's address

Street: Bundesstr. 53

Town: Hamburg

Postcode: 20146

Country: Germany

**Department 2**

Department name: Max-Planck-Institut für Chemie ☐ not applicable

☐ Same as proposing organisation's address

Street: Hahn-Meitner-Weg 1

Town: Mainz

Postcode: 55128

Country: Germany

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

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Title: Prof.

Sex: (•) Male ( ) Female

First name: **Bjorn** Last name: **Stevens**

E-Mail: **bjorn.stevens@ecmwf.int**

Position in org.: Director

Department: Max Planck Institute for Meteorology ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Bundesstr. 53

Town: Hamburg Post code: 20146

Country: Germany

Website: https://mpimet.mpg.de/en

Phone: +49 40 41173 421 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Chenbo | Guo | chenbo.guo@mpimet.mpg.de | +xxx xxxxxxxxx |
| Reinhard | Budich | reinhard.budich@mpimet.mpg.de | +xxx xxxxxxxxx |
| Jos | Lelieveld | jos.lelieveld@mpic.de | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999980470* | *FORSCHUNGSZENTRUM JULICH GMBH* |

## *Short name: FZJ*

*Address of the organisation*

Street WILHELM JOHNEN STRASSE

Town JULICH

Postcode 52428

Country Germany

Webpage www.fz-juelich.de

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body .............................................................no

Non-profit ..............................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................05/12/1967 - no

SME self-assessment ............................................. unknown

SME validation sme.................................................05/12/1967 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**No department involved**

Department name *Name of the department/institute carrying out the work.* ☒ not applicable

☐ Same as proposing organisation's address

Street *Please enter street name and number.*

Town *Please enter the name of the town.*

Postcode *Area code.*

Country *Please select a country*

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

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Title: Dr.

Sex: ◯ Male ◉ Female

First name **Maria** Last name **Wolff**

E-Mail **m.wolff@fz-juelich.de**

Position in org.: Business Development

Department: FORSCHUNGSZENTRUM JULICH GMBH ☒ Same as organisation name

☒ Same as proposing organisation's address

Street: WILHELM JOHNEN STRASSE

Town: JULICH Post code: 52428

Country: Germany

Website: www.fz-juelich.de

Phone: +492461611795 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

## *Other contact persons*

| *First Name* | *Last Name* | *E-mail* | *Phone* |
|---|---|---|---|
| Harald | Bolt | h.bolt@fz-juelich.de | +xxx xxxxxxxxx |
| Martin | Schultz | m.schultz@fz-juelich.de | +xxx xxxxxxxxx |
| Norbert | Attig | n.attig@fz-juelich.de | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999979015* | *EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH* |

*Short name: ETHZ*

*Address of the organisation*

| | |
|---|---|
| Street | Raemistrasse 101 |
| Town | ZUERICH |
| Postcode | 8092 |
| Country | Switzerland |
| Webpage | www.ethz.ch |

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ...............................................................yes

Non-profit .................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........yes

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................06/01/2009 - no

SME self-assessment ............................................. unknown

SME validation sme.................................................06/01/2009 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## Department(s) carrying out the proposed work

**Department 1**

| | | |
|---|---|---|
| Department name | Department of Physics - Institute for Theoretical Physics | ☐ not applicable |
| | ☐ Same as proposing organisation's address | |
| Street | Via Trevano 131 | |
| Town | Lugano | |
| Postcode | 6900 | |
| Country | Switzerland | |

**Department 2**

| | | |
|---|---|---|
| Department name | Department of Earth Sciences | ☐ not applicable |
| | ☐ Same as proposing organisation's address | |
| Street | Sonneggstrasse 5 | |
| Town | Zürich | |
| Postcode | 8092 | |
| Country | Switzerland | |



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**Department 3**

Department name: Department of Environmental Systems Science ☐ not applicable

☐ Same as proposing organisation's address

Street: Universitätstrasse 16

Town: Zürich

Postcode: 8092

Country: Switzerland

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Thomas** Last name: **Schulthess**

E-Mail: **schulthess@cscs.ch**

Position in org.: Professor

Department: Department of Physics - Institute for Theoretical Physics ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Via Trevano 131

Town: Lugano Post code: 6900

Country: Switzerland

Website: http://www.itp.phys.ethz.ch

Phone: +41 91 610 82 01 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Agatha | Keller | grants@sl.ethz.ch | +416345350 |
| Domenico | Giardini | domenico.giardini@erdw.ethz.ch | +xxx xxxxxxxxx |
| David | Bresch | dbresch@ethz.ch | +41797701592 |
| Kasia | Pawlikowska | kasia@cscs.ch | +xxx xxxxxxxxx |
| Ulrike | Lohmann | ulrike.lohmann@env.ethz.ch | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999997930* | *CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS* |

*Short name: CNRS*

*Address of the organisation*

Street RUE MICHEL ANGE 3

Town PARIS

Postcode 75794

Country France

Webpage www.cnrs.fr

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..........................................................yes

Non-profit ...........................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ...........................................yes

Legal person ...................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................18/11/2008 - no

SME self-assessment ............................................ unknown

SME validation sme.................................................18/11/2008 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Laboratoire des Sciences du Climat et de l'Environnement (LSCE) ☐ not applicable

☐ Same as proposing organisation's address

Street: Av de la terrasse

Town: GIF SUR YVETTE

Postcode: 91198

Country: France

**Department 2**

Department name: LABORATOIRE DE MÉTÉOROLOGIE DYNAMIQUE ☐ not applicable

☐ Same as proposing organisation's address

Street: Tour 45-55, CP99, 4 place Jussieu

Town: Paris

Postcode: 75252

Country: France



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

**Department 3**

Department name: Institute Pierre Simon Laplace

☐ not applicable

☐ Same as proposing organisation's address

Street: Tour 45-55, CP99, 4 place Jussieu

Town: Paris

Postcode: 75252

Country: France

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Mrs

Sex: ◯ Male ◉ Female

First name: **Sylvie**  Last name: **Joussaume**

E-Mail: **sylvie.joussaume@lsce.ipsl.fr**

Position in org.: Researcher

Department: Laboratoire des Sciences du Climat et de l'Environnement (LSCE)  ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Av de la terrasse

Town: GIF SUR YVETTE  Post code: 91198

Country: France

Website: http://www.lsce.ipsl.fr/

Phone: +331 69 08 56 74  Phone 2: +xxx xxxxxxxxx  Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Olivier | Boucher | olivier.boucher@ipsl.fr | +xxx xxxxxxxxx |
| Marie-Hélène | PAPILLON | delegue@dr4.cnrs.fr | +xxx xxxxxxxxx |
| Philippe | Ciais | philippe.ciais@lsce.ipsl.fr | +xxx xxxxxxxxx |



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| **PIC** | **Legal name** |
|---|---|
| *999419422* | *FONDAZIONE CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI* |

## Short name: CMCC

*Address of the organisation*

Street VIA A IMPERATORE 16

Town LECCE

Postcode 73100

Country Italy

Webpage www.cmcc.it

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................no

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ............................................yes

Legal person ...................................yes

Industry (private for profit).................no

### Enterprise Data

SME self-declared status.........................................11/05/2005 - no

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## Department(s) carrying out the proposed work

**Department 1**

Department name: CSP - Climate Simulation and Prediction Division

☐ not applicable

☐ Same as proposing organisation's address

Street: Viale Berti Pichat 6/2

Town: Bologna

Postcode: 40127

Country: Italy

## Dependencies with other proposal participants

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Antonio**

Last name: **Navarra**

E-Mail: **antonio.navarra@cmcc.it**

Position in org.: President

Department: CSP - Climate Simulation and Prediction Division

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Viale Berti Pichat 6/2

Town: Bologna

Post code: 40127

Country: Italy

Website: www.cmcc.it

Phone: +390283623433

Phone 2: +390832288650

Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Giulia | Galluccio | giulia.galluccio@cmcc.it | +390283623433 |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *946813800* | *STICHTING NETHERLANDS ESCIENCE CENTER* |

*Short name: NLeSC*

*Address of the organisation*

Street SCIENCE PARK 140

Town AMSTERDAM

Postcode 1098 XG

Country Netherlands

Webpage www.esciencecenter.nl

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................no

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................14/06/2016 - no

SME self-assessment .............................................14/06/2016 - no

SME validation sme................................................. unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Netherlands eScience Center ☐ not applicable

☐ Same as proposing organisation's address

Street: SCIENCE PARK 140

Town: AMSTERDAM

Postcode: 1098 XG

Country: Netherlands

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.


Title: Prof.

Sex: (●) Male ( ) Female

First name: **Wilco** Last name: **Hazeleger**

E-Mail: **w.hazeleger@esciencecenter.nl**

Position in org.: Director

Department: STICHTING NETHERLANDS ESCIENCE CENTER ☒ Same as organisation name

☒ Same as proposing organisation's address

Street: SCIENCE PARK 140

Town: AMSTERDAM Post code: 1098 XG

Country: Netherlands

Website: www.esciencecenter.nl

Phone: +31 20 4604770 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*


## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Otto | van Rhee | o.vanrhee@esciencecenter.nl | *+31 652561938* |
| Aletta | Debernardi | a.debernardi@esciencecenter.nl | *+31 649944007* |

| ***PIC*** | ***Legal name*** |
|---|---|
| *999520302* | *STICHTING DELTARES* |

## *Short name: Deltares*

*Address of the organisation*

Street BOUSSINESQWEG 1

Town DELFT

Postcode 2629 HV

Country Netherlands

Webpage www.deltares.com

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................no

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................30/11/1990 - no

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Inland Water Systems ☐ not applicable

☐ Same as proposing organisation's address

Street: BOUSSINESQWEG 1

Town: DELFT

Postcode: 2629 HV

Country: Netherlands

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Jaap**

Last name: **Kwadijk**

E-Mail: **jaap.kwadijk@deltares.nl**

Position in org.: Senior Specialist

Department: Inland Water Systems

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: BOUSSINESQWEG 1

Town: DELFT

Post code: 2629 HV

Country: Netherlands

Website: www.deltares.nl

Phone: +31613601220

Phone 2: +31883358273

Fax: +31883358582

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Ap | van Dongeren | ap.vandongeren@deltares.nl | *+31646911195* |
| Herman | Scholten | herman.scholten@deltares.nl | *+31655413028* |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999990655* | *DANMARKS TEKNISKE UNIVERSITET* |

## *Short name: DTU*

*Address of the organisation*

Street ANKER ENGELUNDSVEJ 1 BYGNING 101 A

Town KGS LYNGBY

Postcode 2800

Country Denmark

Webpage www.dtu.dk

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........yes

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................01/01/2001 - no

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Department of Electrical Engineering ☐ not applicable

☐ Same as proposing organisation's address

Street: Elektrovej, Building 325, room 123

Town: Kgs. Lyngby

Postcode: 2800

Country: Denmark

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Pierre** Last name: **Pinson**

E-Mail: **ppin@elektro.dtu.dk**

Position in org.: Professor

Department: Department of Electrical Engineering ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Elektrovej, Building 325, room 123

Town: Kgs. Lyngby Post code: 2800

Country: Denmark

Website: http://pierrepinson.com/

Phone: +45 45 25 35 41 Phone 2: +45 23 98 32 21 Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Frants | Lüttichau | fpsl@adm.dtu.dk | +45 93 51 18 32 |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999992304* | *JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION* |

*Short name: JRC*

*Address of the organisation*

Street Rue de la Loi 200

Town BRUSSELS

Postcode 1049

Country Belgium

Webpage https://ec.europa.eu/jrc

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................21/08/2008 - no

SME self-assessment ............................................. unknown

SME validation sme.................................................21/08/2008 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



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## *Department(s) carrying out the proposed work*

**Department 1**

| | | |
|---|---|---|
| Department name | Directorate D: Sustainable Resources, Food Security Unit | ☐ not applicable |
| | ☐ Same as proposing organisation's address | |
| Street | Via E. Fermi | |
| Town | 21027 | |
| Postcode | Ispra | |
| Country | Italy | |

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Frank**

Last name: **Dentener**

E-Mail: **frank.dentener@ec.europa.eu**

Position in org.: Senior Expert/Group leader

Department: Directorate D: Sustainable Resources, Food Security Unit

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Via E. Fermi

Town: Ispra

Post code: 21027

Country: Italy

Website: https://ec.europa.eu/jrc/en

Phone: +390332786392

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Stefano | GALMARINI | stefano.galmarini@ec.europa.eu | +xxx xxxxxxxxx |
| Marijn | VAN DER VELDE | marijn.van-der-velde@ec.europa.eu | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
| --- | --- |
| *999655520* | *BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION* |

## *Short name: BSC*

*Address of the organisation*

Street Calle Jordi Girona 31

Town BARCELONA

Postcode 08034

Country Spain

Webpage www.bsc.es

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................01/03/2005 - no

SME self-assessment ............................................. unknown

SME validation sme................................................. unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Earth Sience Department ☐ not applicable

☐ Same as proposing organisation's address

Street: NEXUS II building, Jordi Girona 29

Town: Barcelona

Postcode: 08034

Country: Spain

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Francisco J.** Last name: **Doblas-Reyes**

E-Mail: **francisco.doblas-reyes@bsc.es**

Position in org.: Directof of the Earth Science department

Department: Earth Science department ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: NEXUS II building, Jordi Girona 29

Town: Barcelona Post code: 08034

Country: Spain

Website: www.bsc.es

Phone: +34 934137719 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Mar | Rodriguez | mar.rodriguez@bsc.es | +34 934137566 |
| Kim | Serradell | kim.serradell@bsc.es | +34 934134051 |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *974802471* | *STICHTING INTERNATIONAL RED CROSS RED CRESCENT CENTRE ON CLIMATE CHANGE AND* |

*Short name: RedC*

*Address of the organisation*

Street LEEGHWATERPLEIN 27

Town DEN HAAG

Postcode 2502 KC

Country Netherlands

Webpage http://www.climatecentre.org

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................no

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ............................................no

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status.........................................29/04/2004 - no

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Climate Science Team ☐ not applicable

☒ Same as proposing organisation's address

Street: LEEGHWATERPLEIN 27

Town: DEN HAAG

Postcode: 2502 KC

Country: Netherlands

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.


Title: Dr.

Sex: ○ Male ◉ Female

First name: **Erin**

Last name: **Coughlan de Perez**

E-Mail: **coughlan@climatecentre.org**

Position in org.: Manager

Department: Climate Science Tea

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: LEEGHWATERPLEIN 27

Town: DEN HAAG

Post code: 2502 KC

Country: Netherlands

Website: www.climatecentre.org

Phone: +16467706788

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx


## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Christiana | Vogel | vogel@climatecentre.org | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999989200* | *NATURAL ENVIRONMENT RESEARCH COUNCIL* |

*Short name: NERC*

*Address of the organisation*

Street Polaris House, North Star Avenue

Town SWINDON WILTSHIRE

Postcode SN2 1EU

Country United Kingdom

Webpage http://www.nerc.ac.uk

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................25/02/2016 - no

SME self-assessment .............................................25/02/2016 - no

SME validation sme................................................. unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## Department(s) carrying out the proposed work

**Department 1**

Department name: British Geological Survey ☐ not applicable

☐ Same as proposing organisation's address

Street: Nicker Hill, Keyworth

Town: Nottingham

Postcode: NG12 5GG

Country: United Kingdom

**Department 2**

Department name: National Centre for Atmospheric Science ☐ not applicable

☐ Same as proposing organisation's address

Street: University of Leeds

Town: Leeds

Postcode: LS2 9JT

Country: United Kingdom

## Dependencies with other proposal participants

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **John** Last name: **Ludden**

E-Mail: **jludden@bgs.ac.uk**

Position in org.: Executive Director

Department: British Geological Survey ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Nicker Hill, Keyworth

Town: Nottingham Post code: NG12 5GG

Country: United Kingdom

Website: www.bgs.ac.uk

Phone: +441159363226 Phone 2: +441159363100 Fax: +441159363200

## Other contact persons

| First Name | Last Name | E-mail | Phone |
|---|---|---|---|
| Stephen | Mobbs | stephen.mobbs@ncas.ac.uk | +41133435158 |
| Laura | Platt | laupla@bgs.ac.uk | +441159363336 |
| Bryan | Lawrence | bryan.lawrence@ncas.ac.uk | +xxx xxxxxxxxx |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999985805* | *UNIVERSITEIT UTRECHT* |

## *Short name: UUT*

### *Address of the organisation*

Street HEIDELBERGLAAN 8

Town UTRECHT

Postcode 3584 CS

Country Netherlands

Webpage www.uu.nl

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ...............................................................yes

Non-profit .................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........yes

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................01/01/2008 - no

SME self-assessment ............................................. unknown

SME validation sme.................................................26/05/2008 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Earth Sciences

☐ not applicable

☐ Same as proposing organisation's address

Street: Heidelberglaan 2

Town: Utrecht

Postcode: 3584

Country: Netherlands

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Jeannot**

Last name: **Trampert**

E-Mail: **j.a.trampert@uu.nl**

Position in org.: Head of Department

Department: Earth Sciences

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Heidelberglaan 2

Town: Utrecht

Post code: 3584

Country: Netherlands

Website: https://www.uu.nl/

Phone: +31 30 253 5088

Phone 2: *+xxx xxxxxxxxx*

Fax: *+xxx xxxxxxxxx*

## *Other contact persons*

| ***First Name*** | ***Last Name*** | ***E-mail*** | ***Phone*** |
|---|---|---|---|
| Mirjam | van Kan-Parker | m.vankan@uu.nl | *+xxx xxxxxxxxx* |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999578890* | *METEO-FRANCE* |

*Short name: MF*

*Address of the organisation*

Street AVENUE DE PARIS 73

Town SAINT MANDE CEDEX

Postcode 94165

Country France

Webpage www.meteo.fr

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation ............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................18/06/1993 - no

SME self-assessment ............................................ unknown

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Centre National de la Recherche Météorologique (CNRM)

☐ not applicable

☐ Same as proposing organisation's address

Street: 42, avenue Coriolis

Town: Toulouse cedex 1

Postcode: F-31057

Country: France

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



This proposal version was submitted by **Daniel THIEMERT** on **20/02/2018 15:18:28** Brussels Local Time. Issued by the Participant Portal Submission Service.

## Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name **Alain** Last name **Joly**

E-Mail **alain.joly@meteo.fr**

Position in org.: Head, Numerical weather prediction and data assimilation research group

Department: Centre National de la Recherche Météorologique (CNRM) ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: 42, avenue Coriolis

Town: Toulouse cedex 1 Post code: F-31057

Country: France

Website: http://www.umr-cnrm.fr/

Phone: +33 5 61 07 93 56 Phone 2: +33 5 61 07 93 70 Fax: +xxx xxxxxxxxx

## Other contact persons

| *First Name* | *Last Name* | *E-mail* | *Phone* |
|---|---|---|---|
| David | Salas y Melia | david.salas@meteo.fr | +33 5 61 07 96 65 |



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| ***PIC*** | ***Legal name*** |
|---|---|
| *999472675* | *ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA* |

*Short name: INGV*

*Address of the organisation*

Street Via di Vigna Murata 605

Town ROMA

Postcode 00143

Country Italy

Webpage www.ingv.it

*Legal Status of your organisation*

**Research and Innovation legal statuses**

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation ........................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........no

Research organisation .............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

**Enterprise Data**

SME self-declared status..........................................05/05/2016 - no

SME self-assessment .............................................05/05/2016 - no

SME validation sme................................................ unknown

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## Department(s) carrying out the proposed work

**Department 1**

Department name: Department of Volcanoes ☐ not applicable

☐ Same as proposing organisation's address

Street: Via di Vigna Murata 605

Town: ROMA

Postcode: 00143

Country: Italy

**Department 2**

Department name: Department of Earthquakes ☐ not applicable

☐ Same as proposing organisation's address

Street: Via di Vigna Murata 605

Town: ROMA

Postcode: 00143

Country: Italy

## Dependencies with other proposal participants

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

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|---|---|
| *999994535* | *HELSINGIN YLIOPISTO* |

## *Short name: UHELS*

*Address of the organisation*

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Country Finland

Webpage www.helsinki.fi

## *Legal Status of your organisation*

### Research and Innovation legal statuses

Public body ..............................................................yes

Non-profit ................................................................yes

International organisation .......................................no

International organisation of European interest ........no

Secondary or Higher education establishment .........yes

Research organisation ............................................yes

Legal person ....................................yes

Industry (private for profit)..................no

### Enterprise Data

SME self-declared status..........................................09/02/2009 - yes

SME self-assessment ............................................. unknown

SME validation sme.................................................09/02/2009 - no

**Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.**

## *Department(s) carrying out the proposed work*

**Department 1**

Department name: Faculty of Science, Inst. for Atmosph. and Earth System Research

☐ not applicable

☐ Same as proposing organisation's address

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Town: University of Helsinki

Postcode: 00014

Country: Finland

## *Dependencies with other proposal participants*

| ***Character of dependence*** | ***Participant*** | |
|---|---|---|
| | | |



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## *Person in charge of the proposal*

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## *Other contact persons*

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# 3 - Budget

| | |
|---|---|
| Total requested EU contribution for the proposal/ € | 1 000 000 |



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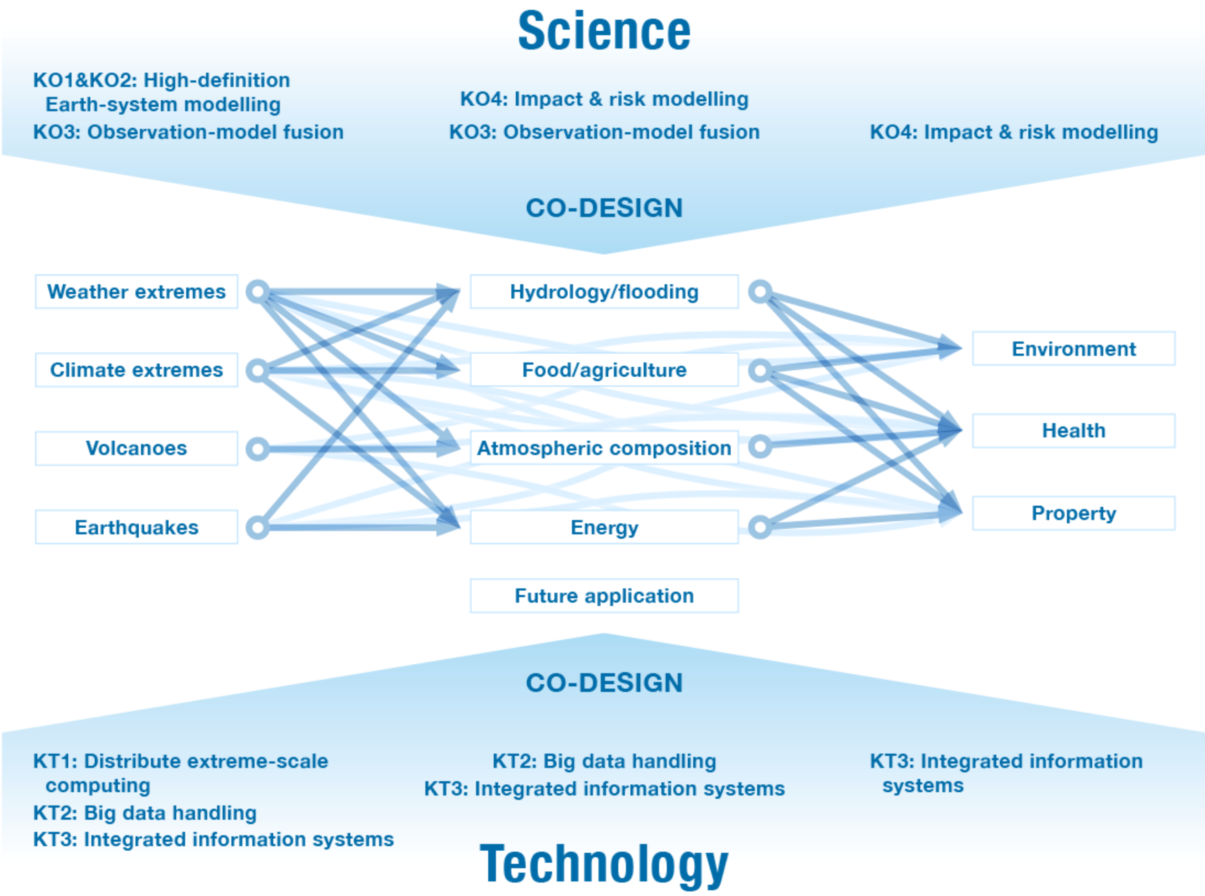
## Contents



# 1. Excellence

## 1.1. Vision and unifying goal




*ExtremeEarth* is a futuristic vision, grounded in on-going technological developments and expertise in its domain sciences, to deliver the information technological underpinnings for a new quality of European Earth-system services. By emphasizing capacity building it brings together the whole of the European Earth science community, from national weather and hydrological centres, to leading climate science and seismology labs.

*ExtremeEarth* is a technology project designed to deliver new software and hardware frameworks for predicting and studying geo-hazards and extremes. It is built around two core ideas: (i) developing the technological basis to enable the harnessing of new computing and data technologies necessary for a step change in the precision and fidelity with which we can simulate and observe the transient dynamics of Earth's fluid envelope (its atmosphere, ocean) and processes in the solid Earth that bounds it; (ii) developing a software infrastructure that blurs the line between data and computation, past and future, and opens the full richness of our ability to simulate the solid and fluid Earth to new application communities.

*ExtremeEarth* includes two large-scale multi-disciplinary dimensions: (i) flexible value chains from predicting hazards in the Earth system to predicting impacts on socio-economic sectors and performing risk-assessments; (ii) science-technology co-design of algorithms, computing hardware and software as well as data handling and data analytics at extreme scales, and interactive user interfaces.



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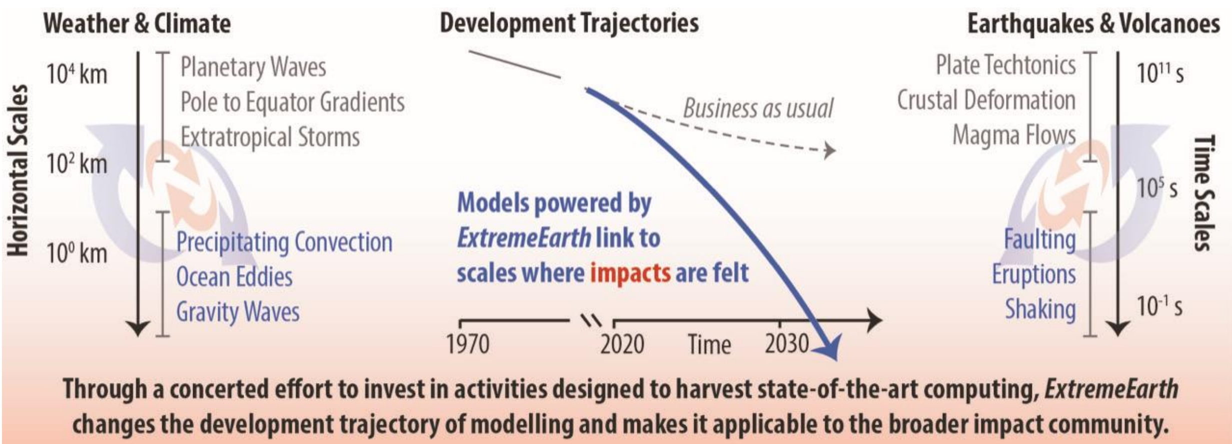
### *1.1.1. The need for ExtremeEarth*

Europe’s and the world's civil society and economy are highly vulnerable to natural hazards, and the impacts of extreme weather conditions, volcanoes and earthquakes are increasing, with ensuing loss of life, and, damage to property and cultural heritage. Between 1970 and 2012 severe weather events claimed 150,000 lives and caused a total damage of € 270 billion[1]. 2017 ranks as the year with the second highest recorded global reinsurance payouts of € 108 billion caused by extreme weather events, earthquakes and volcanoes.

Everyone can recall recent examples of extreme events. Earthquakes continue to cause destruction in the European-Mediterranean region and the world: the 1999 earthquake in Izmit, 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 both European large cities (e.g., Naples with 3 million people at risk from Vesuvius and Campi Flegrei) and Europe as a whole. The small 2010 Icelandic Ejafjallajökull eruption caused the shut-down of air traffic operations over central-northern Europe for several days (estimated economic loss of € 1 billion per day). Droughts and heat waves in Europe have caused an increase in the number of affected areas and people of almost 20% between 1976 and 2006. The 2003 heat wave and drought affected over 100 million people over a third of the EU territory with a cost of at least € 8.7 billion and a death toll exceeding 70,000[2]. The total cost of droughts over the past 30 years is estimated at € 100 billion[3]. Fires in Spain and Portugal in 2017 claimed over 100 casualties and led to an estimated damage of € 600 million. Winter storms in Europe caused significant economic damage, for example the most recent storm Burglind (€ 1.1-1.6 billion[4]) but also Kyrill in 2007 (€ 5.7 billion), Lothar and Martin in 1999 (€ 10 billion), Daria (€ 6.9 billion) and Vivian (€4.5 billion) in 1990, and 87J in 1987 (€ 5.2 billion)[5]. Floods in the European region affected 3.4 million people, and killed more than 1,000 people in the period from 2000 to 2011. The widespread floods of 2002 and 2013 caused economic damage of € 13.2 billion and € 12.8 billion[6], respectively, most of which were uninsured. The Global gross domestic product (GDP) exposed to river floods is on average € 77 billion each year[7]. These impacts occur despite the current prediction capabilities – so these are clearly insufficient.

Improving the resilience of our societies in the face of extreme events in the Earth system is an urgent priority today and in decades to come. Decision makers at all levels – from multinational organizations, the European Union, sovereign states, sub-sovereigns, cities and companies down to the local community – need to know the potential hazards and the vulnerability of society that they expose. Protection standards will be raised worldwide with the ongoing urbanization and economic developments in areas prone to natural hazards[8]. This will inevitably lead to a call for more accurate assessments and predictions of both occurrence and magnitude of extreme events.

### *1.1.2. The science case*




The science case for *ExtremeEarth* expresses the conviction that concerted development of advancing information technologies can be used to: (i) provide a new foundation for predictions of Earth-system hazards and vulnerability; (ii) integrate diverse, unconventional, and previously un-usable data streams to document Earth’s present and past state; (iii) enable the fusion of models and data – of past, present and future – in ways that expose them to the full ingenuity of diverse application communities. In so doing *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. These advances will also change our capacity to model and even predict

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[1] https://public.wmo.int/en/media/press-release/joint-press-release-wmocreducl-atlas-of-mortality-and-economic-losses-from
[2] Robine et al., 2008: Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies,* 331 (2), 171–178.
[3] EC Communication, 2007: Addressing the challenge of water scarcity and droughts in the European Union. COM(2007)414 final.
[4] http://www.air-worldwide.com/Press-Releases/AIR-Worldwide-Estimates-Insured-Losses-from-Winter-Storm-Eleanor/Burglind-Will-Be-Between-EUR-1-1-Billion-and-EUR-1-6-Billion.https://www.perils.org/losses regularly
[5] http://media.swissre.com/documents/sigma2_2017_en.pdf
[6] https://www.munichre.com/en/media-relations/publications/press-releases/2013/2013-07-09-press-release/index.html
[7] http://www.wri.org/blog/2015/03/world%E2%80%99s-15-countries-most-people-exposed-river-floods
[8] http://documents.worldbank.org/curated/en/387821467309551281/pdf/WPS7663.pdf



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more disparate events within the Earth system, e.g., air pollution impacts on health, floods, storm surges, droughts, fires, and disease vectors. This also brings other science domains into *ExtremeEarth's* technology scope.

#### 1.1.2.1. Increasing the Physics in Predictions — Weather and Climate Extremes

Advances in high-performance computing (HPC) have brought us to the point where it is now possible to contemplate substituting crude statistical models of crucial climate processes (called 'parameterisations') by more fundamental principles[9]. Extreme computing is making it possible to replace rules of thumb by laws of nature; to replace parameterisations of ocean eddies, of precipitating deep convection, of gravity waves, by explicit representations of the transient dynamics of these processes. Harnessing the power of extreme computing towards this end will allow us to develop qualitatively different models[10], ones much better grounded in the laws of physics, providing less biased and more reliable insights into how extremes respond to warming, and what large surprises a warmer world may entail[11]. This need is identical for weather and climate prediction.

Changes in large-scale patterns of atmospheric and oceanic circulations are a wild card of climate change, and expose vulnerability of societies to environmental change. Will the basic structure of the tropical circulation qualitatively change as the Earth warms? Will the West Antarctic ice sheet collapse and if so, how soon? How will patterns of winter storms change and what do these changes imply for weather extremes and sea-level? What will be the societal impacts of these extreme events? Even in the absence of climate change we have frightfully little insight into these types of questions, as our imagination is held hostage to models that were never developed for such tasks, and whose inadequacies in confronting such challenges has slowly become apparent[12].

Key parameterisations in existing global weather and climate models condition the behaviour of these large-scale aspects of the climate system to a disproportionate extent: momentum transport by parameterised gravity waves, or Rossby waves emanating from large-scale patterns of parameterised convection in the tropics, determine the position of the storm tracks; tropical convection interacts intimately with patterns of sea-surface temperatures and fine-scale currents and the processes in the upper ocean to determine the structure of the tropical climate, and parameterisations of ocean eddies condition the stability of the southern ocean and its ability to transport heat through the climate system (and to the ice-sheets) as well as carbon. Advances in HPC, if they can be harvested, make it possible to directly simulate crucial processes – ocean eddies, ice fracture, atmospheric gravity waves, and precipitating deep convection – and offer an opportunity to develop entirely new insights into the large-scale dynamics of our changing climate, and the risk they pose for present and future society[13]. Similarly, much higher-resolution regional models (e.g. turbulence resolving) will lead to better local predictions of high-impact weather.

#### 1.1.2.2. Increasing the Physics in Predictions — Earthquakes and Volcanic Eruptions

The inherent physical complexity of the solid Earth – the chaotic nature of the interaction of its crustal fault systems, or of its underground magma flows and their interaction with confining rock systems, combined with the lack of sufficient and accurate observations to study phenomena occurring below Earth's surface – introduces enormous computing challenges similar to those faced by weather and climate. Until now these challenges have forced models in the solid Earth domains to disproportionately rely on statistical and piecemeal modelling approaches. *ExtremeEarth* will build the technology platform of the scale and power required to tackle, for the first time, the ambitious goals of (i) predicting three fundamental aspects of earthquakes: their spatial and temporal distribution, their initiation and rupture, and their resultant seismic shaking at frequencies most relevant for our built environment, and (ii) creating the first global volcanic simulator capable of predicting the initiation of a volcanic eruption, the space-time evolution of the eruption dynamics, its impacts on the territory, and the space-time aerial distribution of volcanic ash.

It is often said that earthquakes will never be predicted, but we are in a period where the observation of earthquakes and our physical understanding of rupture phenomena, magma flow, and wave propagation in heterogeneous media are all advancing rapidly. At the same time, extreme-scale computing is reaching a scale where it offers the promise to attain the spatial and temporal resolution and complexity necessary to model and integrate all these elements together. This situation motivates *ExtremeEarth's* ambition to develop the tools required to predict important aspects of earthquakes and possibly even volcanic eruptions.

To this end, *ExtremeEarth* will enable the community to transcend traditional approaches – based on scarce historical information and crude statistics – to build multi-scale physics-based predictive models ultimately capable of protecting society. These new models will make it possible to integrate information about active faults, geodetic strain rates, remote sensing imaging, seismicity distribution and geodynamic constraints, and thus enable the simulation of the physical processes leading to earthquakes and volcanoes. For instance physical models integrating the newest earthquake dynamics on complex fault geometries with real-time data assimilation from near-fault observatories will be constructed, to identify possible precursors and map the initiation and evolution of rupture.

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[9] Stevens and Bony, 2013: What Are Climate Models Missing? *Science*, 340(6136), 1053–1054.
[10] Bony et al. 2015: Clouds, circulation and climate sensitivity. *Nature Geoscience*, 8, 261–268.
[11] IPCC, WG II, https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-FrontMatterA_FINAL.pdf
[12] Marotzke et al., 2017: Climate research must sharpen its view. *Nature Climate Change*, 7, 89-91.
[13] Palmer, 2014: Build high-resolution global climate models. *Nature*, 515, 338-339.



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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 the occurrence of an eruption. Additionally, methodologies for full-waveform simulations in complex heterogeneous media – accounting for the geological and sedimentary structures observed at the Earth's surface and in the upper crust – that have been developed in recent years, can be developed into a fully integrated European broad-band platform through extreme scale computing. The target capability is to generate synthetic seismograms across Europe up to 10 Hz in frequency corresponding to a wavelength of 60-100 m for the typical sedimentary basins on which most of our cities are built.

#### 1.1.2.3. Fusing models and data

Limitations in the physics of existing models, as well as computational restrictions (for instance in ensemble data assimilation methods, or methods of empirical inference) also restrict our ability to sensibly ingest and make use of data collected continually by a vast array of sensors: satellites, ground stations, organised surface networks, commodity device sensing, etc. Data assimilation, the process whereby diverse and heterogeneous measurements of different quality are cast into a structure that makes them usable is limited by the quality and resolution of our physical models. New methods of empirical inference (deep learning) are only beginning to tap into the potential of the vast amounts of fused model-observation data. By simulating the Earth system on the scales at which it is observed, and by explicitly representing the transient dynamics of the processes that are observed, rather than a crude estimate of their statistics, it will become possible to integrate increasingly diverse data streams and exploit their full information, in ways that blur the distinction in how users interact with models and data, or look at the past versus the future.

### *1.1.3. The technology case*

The technology case of *ExtremeEarth* expresses the conviction that the entire European Earth-system modelling and prediction community, targeting both fluid and solid Earth, can achieve unprecedented skill levels through a unified and concerted development of advanced information technology. These advances will transform existing, and create wholly new user communities in areas that have not yet realized the potential of such information.

#### 1.1.3.1. High-performance technology

The scale of data and computing needs required to realise this vision is orders of magnitudes larger than current capabilities and this requires a radical re-design of current software frameworks and hardware systems. A full integration of computing, data and connectivity is envisaged where HPC and cloud technology will converge, becoming a unique challenge and opportunity building upon current institutional, industrial as well as transnational initiatives as the EOSC and EuroHPC[14]. To meet that challenge we will adopt a contemporary approach to software with components that are widely supported in the ICT industry and that are part of the main roadmaps of digital technology development. This way, *ExtremeEarth* will bring an entirely new quality to the European HPC programme, one that is fundamentally different from current exascale computing developments in East Asia and the USA. The latter are driven by a race for leadership in the Top500[15] list, which results in powerful supercomputers that perform extremely well on computing benchmarks, but can be very inefficient for real Earth-system applications. *ExtremeEarth* on the other hand, will motivate technology development that is focused on the science case and on achieving its grand challenges, thus producing tangible and significant socio-economic benefit.
*ExtremeEarth* will deliver a new system design of extreme-scale HPC, data and connectivity. Taking the European exascale and institutional digital infrastructures as a baseline, *ExtremeEarth* will co-design HPC-based platforms that are driven by our applications. It will capitalise on the convergence of HPC and cloud technologies and it will develop optimised hardware-software linkages[16] that make a new way of working possible for all users.
Preparing for the future requires a very different approach – one that can only be realised by a concerted effort that a technology Flagship makes possible – as it requires a focused technical development over a very long timescale exploiting application-driven co-design of both software and hardware. 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* envisions 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 at an unprecedented rate by both high-definition models and observational sensor networks.

#### 1.1.3.2. Empowering new and existing user communities

To fully exploit this model-data fusion *ExtremeEarth* introduces the idea of the ExtremeEarthScienceCloud (EEsC). The EEsC will take full advantage of modern software technologies and exploit extreme-scale computing

[14] https://ec.europa.eu/digital-single-market/en/eurohpc-joint-undertaking
[15] www.top500.org
[16] Schulthess, 2015: Programming revisited. *Nature Physics*, 11, 369–373.



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and big data capabilities to unburden users and communities from excessive technological challenges. The EEsC will 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 realize value chains as a collaborative space, one which allows for interactions between domain scientists and application communities at all levels. This will be the ultimate technological and scientific game changer as it requires ground-breaking developments in extreme computing and data technology and a radically different way of interacting with simulations and data for scientists and users of scientific information.

To meet this objective, *ExtremeEarth* will perform a true end-to-end, application-driven co-design of rapidly developing digital technology with applied and computational scientists, software engineers and hardware architects based on the Earth-system application-specific requirements. Through its EEsC, *ExtremeEarth* will be a major driver of extreme-scale computing beyond the current European exascale programmes, and it will provide the digital innovations for future European infrastructure projects in the Earth-science domain.

### *1.1.4.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-PP*. Due to the complexity of the project, the engagement with existing communities and programmes to define both domain specific and cross-domain developments from day one of the project 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 the wider science and technology community, stakeholders and service infrastructures, the European Commission, and the public.
2. The definition of the *ExtremeEarth* strategic science and technology agenda (SSTA), which breaks 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 need ingestion into *ExtremeEarth*.
3. The definition of success metrics (KPI) for the SSTA across the range of components and full systems (demonstrators), and an initial identification of alternative development scenarios for high-risk elements. An important part of this step is the drafting of a risk management plan.
4. The definition of a collaboration strategy (CS) between the *ExtremeEarth-PP* and potential *ExtremeEarth* partners and collaborators based on excellence and sectors crucial for verifying the *ExtremeEarth* areas of impact (Section 2.1). An important component in this step is the coordination with existing advanced technology developments that *ExtremeEarth* will depend on.
5. The definition of a co-funding strategy through consultation with national and international, public and private entities following the establishment of the SSTA and the CS. Co-funding risks will be covered in the risk management plan.
6. 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.

The *ExtremeEarth-PP* consortium has the scientific, technological and management competence to realize this approach and prepare an ambitious yet feasible Flagship project. The *ExtremeEarth-PP* partners represent gateways to the respective communities and are co-designers across communities thus multiplying the project's effectiveness. All possible collaboration channels – electronic means, dedicated workshops, sessions embedded in community workshops and conferences, townhall meetings and public events – will be used in this process.

#### 1.1.4.1. Science and technology

The collaboration with the scientific community within *ExtremeEarth-PP* will be organized along and across science areas hosted by selected *ExtremeEarth-PP* partners, who will initiate and oversee the collaboration during the preparatory project. Following the definition of the *ExtremeEarth-PP* SSTA, the CS and the associated collaboration roadmap will be implemented.

A survey of existing science and technology research infrastructures, programmes and projects across the *ExtremeEarth* international community 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 *ExtremeEarth* community leadership in research and innovation as well as coordination and support actions governed by the EC's Research, Climate Action, Connect, Enviroment directorates, but also consult non-European, international expertise that the *ExtremeEarth* community is already well connected with.

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 European research community working in a field of Earth system sciences that is already utilizing the European infrastructures ICOS (Integrated observation system), ACTRIS (Aerosol, Clouds, and Trace gases) and LTER



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(Long-term ecological research network) and ANAEE (Analysis and Experimentation on Ecosystem). The involvement of EPOS and ICOS will provide operational services to access observational data and to develop new data products for risk mitigation and geo-hazard assessment. The 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 two novelties that *ExtremeEarth* introduces are science-technology co-design and the full science-impact integration. These require entirely new infrastructures in the form of virtual research centres defined around selected *ExtremeEarth* partners. The matrix management between vertical science centres and horizontal co-design and application centres requires special attention in the *ExtremeEarth-PP* governance approach.

#### 1.1.4.2. Stakeholder involvement

*ExtremeEarth* distinguishes between partners and stakeholders by defining partners as entities that actively participate in co-development while stakeholders actively participate in defining the framework and focus of the project. The status of partners and stakeholders can obviously change in the course of the project, and *ExtremeEarth-PP* will lay out the approach for partnership and collaboration. The present *ExtremeEarth-PP* consortium has already started to engage potential partners and stakeholders through an endorsement process[17], 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.

The largest 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 their future requirements and ability to adapt to fundamentally new systems need to be accounted for very early on in the *ExtremeEarth-PP*. Examples are Copernicus services, 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. ESA and EUMETSAT), ground-based network providers, 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 WMO, FAO, World Bank, GEOSS, GDACS/JRC, 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, investment and consultancy firms. For this sector *ExtremeEarth* offers substantial growth potential that is complementary to the institutionally funded services.

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 revolutionize 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.

*ExtremeEarth* will lay the foundation for future European research infrastructures in digital technologies and their applications, and a core novelty is the EEsC pioneering an interactive configuration of science and technology components given specific user needs, existing and new user groups will be strongly involved in *ExtremeEarth-PP*. The success metric will be the value generated for the European citizens benefiting from decision support systems for coping with extremes in the Earth system that are more accurate and reliable than available today, thus reducing loss of human lives and reducing costs of adapting to changing extremes.

Throughout *ExtremeEarth-PP*, stakeholders will be involved in the design of the Flagship project through open workshops, the roadmap developments and consultations, and in the co-design elements of its vision.

#### 1.1.4.3. Industry involvement

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 EuroHPC) 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 involves large computing and data handling problems, such as material sciences and fluid dynamics which also have many industrial applications.

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

[17] www.extremeearth.eu



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offers significant momentum to engage with the HPC industry, also because *ExtremeEarth* moves well beyond centralized and into distributed (and 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 ETP4HPC[18].
*ExtremeEarth* will provide major industrial sectors dealing with infrastructures, 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 distribution chains. *ExtremeEarth* will engage with these and other industrial sectors to provide novel on-demand services to optimize the production line as well as increase resilience against extreme events.

#### 1.1.4.4. 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, which will be critical for securing co-funding for the Flagship project. Another important element for securing co-funding will be to align future national and international funding programmes with the goals of *ExtremeEarth*. For this purpose, the *ExtremeEarth-PP* will develop a professional communication and public support strategy. The most important principle 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 to ensure that EU Member States can support 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' with a particular focus on sub-area 'Earth, Climate Change and Natural Resources'. Its vision is to revolutionize Europe's capability to predict and monitor environmental extremes and their impacts on society enabled by 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* 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* for realizing step-change advances in predictive skill, and with a focus on *'natural hazards'*. The *'new technologies and approaches'* in *ExtremeEarth* include *'data integration'* and focus on the development of domain specific extreme-scale computing, data handling and integrated information systems. *ExtremeEarth* further aims to realize the full value chain from science to impact prediction, thus *'helping to manage/mitigate … impacts on human activity and natural resources'*. *ExtremeEarth* fully integrates impact sectors referred to in the call text such as *'agriculture'*, *'energy'* but also water (highly relevant for *'protecting natural ecosystems'*) and disaster management including the effects of volcanoes and earthquakes. 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* addresses the Work Programme's general goals. The core partners are representing the world leading scientific expertise in their fields and their scientific approach has a strong multi-disciplinary basis.

## 1.3. Objectives

*ExtremeEarth* will be delivering a step-change in our capabilities to predict environmental extremes and their impacts on society along four *ExtremeEarth* Key Objectives (Section 1.3.1). These objectives can only be realized by developing novel Key Technologies (Section 1.3.2) through a multidisciplinary co-design approach. *ExtremeEarth* will demonstrate the success of this approach by implementing complete versions of these capabilities with domain specific technology at full scale – ready for transition to operational European service infrastructures. The impact of meeting these objectives on society, economy, research infrastructures, technology development and education with a special emphasis on Europe will be addressed in Section 2.1.

### *1.3.1. New science capabilities*

**Key Objective 1: Enable a step-change in our ability to simulate and predict extreme events with weather and climate models**. The KPI for this objective is to develop weather and climate models that are "indistinguishable" from observations (at near-grid and larger scales) and that can simulate 5 years per wall-clock day at 1 km horizontal resolution for global models, and at 10 m resolution for regional models.

[18] http://www.etp4hpc.eu, ECMWF is a full member.
[19] www.extremeearth.eu



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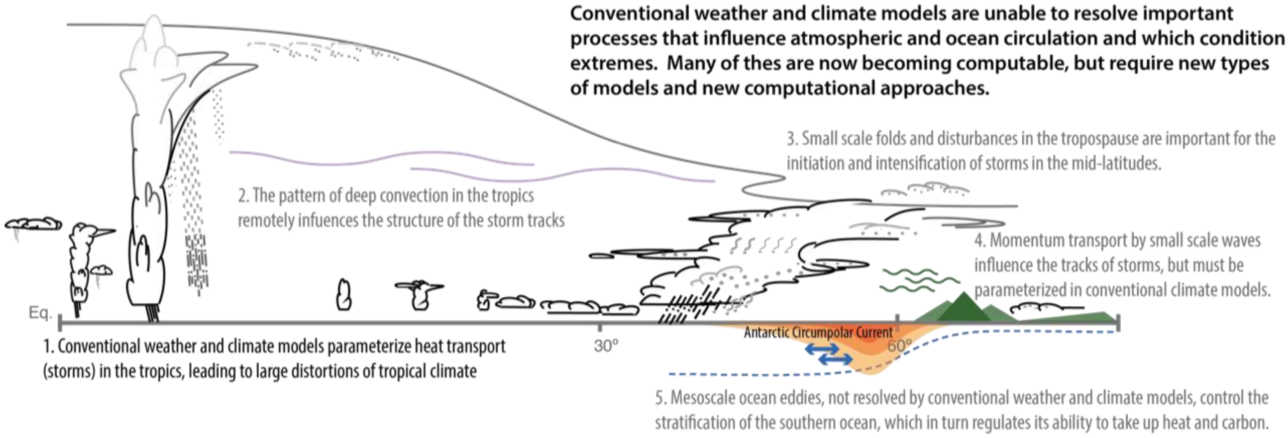
*Aims*: *ExtremeEarth* promises a step-change in our ability to represent extreme events in weather and climate models. For climate prediction these phenomena include atmospheric convection, gravity waves, extratropical storms and ocean eddies at the kilometre-scale globally; for weather prediction these are tropical storms, local circulations, individual clouds, fog, and urban air quality at the decametre-scale. Progress will be measured by the ability of models to pass the "climate Turing test"[20], i.e. one cannot tell whether looking at model output rather than observational data. This includes alleviating long standing systematic errors of climate models, also implying that more realistic emission scenario assessments can be performed for centennial time scales.
Furthermore, probabilistic predictions at daily-to-seasonal time scales and of climate projections at multi-decadal time scales of unprecedented quality for extreme events with a computing throughput of 5 years per day become a reality. Only this new level of skill will be sufficient to drive impact models to the level that is required for mitigating and adaptation to climate change and its effect on extreme weather and climate events. *ExtremeEarth* will, for the first time, provide the scientific basis for actual political and emergency response decision making at regional, country and community scales. The project will also lay the foundation for understanding and projecting environmental changes on much longer timescales, namely from centuries to millennia.




*Progress beyond the state of the art*: Current generation climate models that will contribute to the next Coupled Model Intercomparison Project Phase 6 (CMIP6) employ horizontal resolutions of around 100 km, the best having resolutions of around 25 km. Global weather prediction models operate at 10-15 km resolution while limited-area models reach 1 km. Considering the anticipated development in HPC hardware and codes, it will be at least 30 years before global weather and climate model ensembles can be run at resolutions at which many parametrizations become obsolete, because the underlying processes will be fully resolved and described by accurate laws of physics. The same rate of progress applies to limited-area prediction models, which need to be dynamically coupled with continental-scale coastal, surface, and groundwater models at a resolution of 10 m. High-resolution modelling also needs to reach break-throughs for globally consistent datasets of surface elevation, land cover (incl. urban), water infrastructure (incl. man-made), natural vegetation and crop types, bathymetry of rivers, lakes and reservoirs, wetlands, snow and glaciers, soil properties and hydrogeology.
*Approach to fulfil objective*: This scientific ambition will require substantial investments in new technologies including both software and hardware[21] (***Key Technologies 1-3***), and it will approach both with a true co-design to reach the objective. It is anticipated that a radical reformulation of all layers between mathematical kernels, numerical and multi-scale physics methods, observational and model data handling, and workflows will be required. We also argue that these developments need to be domain specific to obtain the necessary computational speed-up factors. These developments will be complemented by hyper-resolution datasets for building continental to global scale whole-system models of the terrestrial water, ice sheets, nutrient and carbon cycles at unprecedented spatial and temporal resolution.

**Key Objective 2: Enable a step-change in our ability to simulate and predict geo-extremes: Earthquakes and volcanic eruptions**. The KPI for this objective is to develop a unified geo-extreme prediction system to: (i) forecast the spatial and temporal distribution of earthquakes at regional scale by incorporating models of crustal deformation and faults activity, (ii) predict seismic shaking at 10 Hz with a fully integrated broad-band simulation platform generating synthetic seismograms across Europe; (iii) predict volcanic eruption scenarios using a simulator that globally integrates the main physical systems contributing to the volcano structure.

*Aims:* The combination of new physics-based modelling approaches, the assimilation of data from multi-parameter networks in densely monitored pilot areas and the new computational capabilities will bring to light extreme phenomena which take place below the Earth's surface. *ExtremeEarth* will overcome present critical

[20] Palmer, 2016: A personal perspective on modelling the climate system. *Proc. Roy. Meteor. Soc. A*, doi: 10.1098/rspa.2015.0772.
[21] Mitchell et al, 2012: Infrastructure strategy for the European Earth System Modelling community 2012-2022. ENES Report Series 1, 33 pp. doi.org/10.5285ca90b281d6ff4cffb9a9bbdeb5fa63f3



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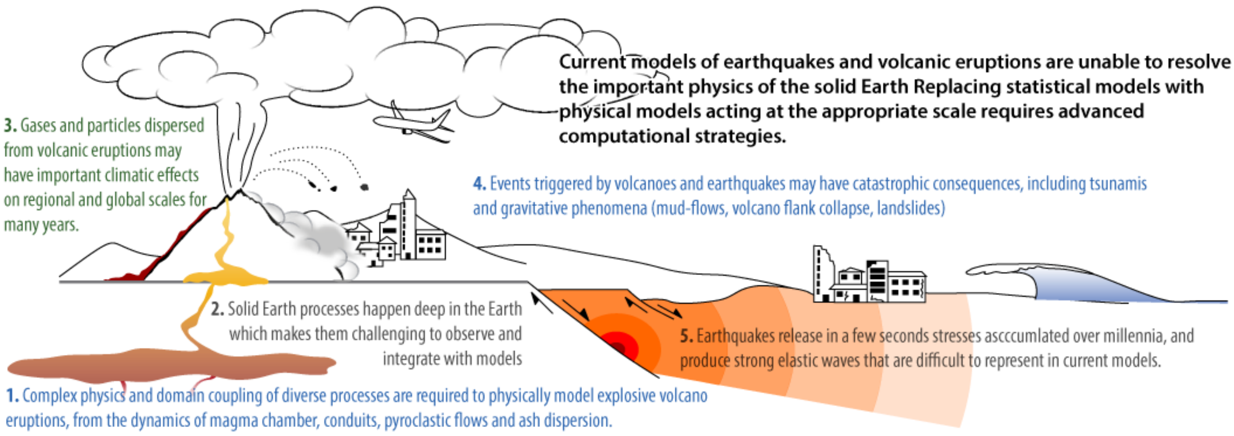
oversimplifications (e.g. poor time-space resolution, over-simplified physics, restriction to single dynamical domains) to generate platforms that realistically model the coupled processes and force controlling the evolution (and impacts) of volcanic and earthquake processes – the key to establishing physically sound links between surface observables, underground dynamics, and the development of prediction capabilities.

For the forecasting of the spatial and temporal distribution of earthquakes, *ExtremeEarth* will generate physics-based models of fault interactions, crustal deformation and earthquake occurrence, on variable mesh scales, integrating active faults (over 100,000 km mapped in the Euro-Mediterranean region), geodetic strain rates from GPS and InSAR satellite imagery, seismicity and geodynamic constraints. These models will characterize and forecast future earthquake occurrence at all scales – from single fault activation to regional Euro-Mediterranean scale activity, and from hours to millennia. A special focus will be on the earthquake generation at the detailed scale of a single fault, integrating the newest earthquake dynamics knowledge with real-time assimilation of multi-scale and multi-parameter data from near-fault observatories, deep underground laboratories and GEO supersites, to identify possible precursors and develop a new operational capacity to map the initiation and evolution of earthquake rupture[22]. Data from satellite based monitoring of ionospheric anomalies will also be incorporated.

For the prediction of earthquake shaking, methodologies for full-waveform simulations in complex heterogeneous media – accounting for the geological and sedimentary structures observed at the Earth's surface and in the upper crust – will be extended to reach the 10 Hz frequency goal relevant for the resonance of shallow sediment basins and buildings. Extreme computing will enable developing a fully integrated platform capable of generating synthetic seismograms across Europe on a variable mesh and accounting for the surface geology at local, city and regional scale[23]. This platform will be linked with real-time assimilation of data from monitoring networks to condition the generation of shake-maps during earthquake emergencies.

For the prediction of large volcanic eruptions, *ExtremeEarth* will foster the creation of a Global Volcano Simulator (GVS) representing a break-through in our capability to model the complexities of volcanic processes from the deep regions of magma storage into the atmosphere, with 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 surface. The GVS will consist of a suite of models that can be run separately or combined, each provided with full verification capability. This will represent the new international reference volcano model[24]. The GVS will also 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.




*Progress beyond the state of the art*: The modelling platforms will enable unprecedented advances in the capacity to predict earthquake occurrence and shaking and volcanic eruptions, and it will promote the prediction of extreme seismic and volcanic phenomena. The platforms and their new capabilities they will also enable transformational, lasting impact in areas of key importance for safe and secure society.

*Approach to fulfil objective*: The development of radically new technology platforms will include software, hardware and the integration of real-time feeds from monitoring networks at all geographical scales, including near-fault observatories and supersites (***Key Objective 3***). A true co-design approach will be implemented with the organizations in charge of ensuring data access (primarily through EPOS) and the agencies working in the areas of societal relevance impacted by the expected advances in earthquake prediction. As for ***Key Objective 1***, a radical reformulation of all layers between mathematical kernels, multi-scale physics methods, observational and model data handling, and workflows will be developed. The multi-disciplinary effort will integrate competences from volcano and earthquake disciplines with backgrounds in physics, geology, engineering, numerical modelling and mathematical methods, code architecture and optimization, massive data analysis and automatic signal detection.

[22] Di Toro et al., 2011: Fault lubrication during earthquakes. *Nature*, 471, 494–498, doi:10.1038/nature09838.
[23] Zhu et al., 2012: Structure of the European upper mantle revealed by adjoint tomography. *Nature Geoscience*, 5: 493-498. doi: 10.1038/ngeo1501.
[24] http://www.globalvolcanomodel.org/



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**Key Objective 3: Enable 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 to exploit the full range of hundreds of billions of observations per day describing the Earth system obtained from present and future satellites, ground based networks and commodity devices (i) in real time, (ii) at full model resolution and (iii) within the time critical production path of the entire multi-disciplinary prediction system.

*Aims: ExtremeEarth* will produce a break-through in our ability to exploit information from the wide range of existing and future Earth-system observations both for monitoring the state of the Earth system as well as - in combination with models - for producing Earth system evolution trajectories consistent with the physics modelled in *ExtremeEarth* simulators of the fluid and solid Earth. *ExtremeEarth* will provide the model-data integration framework to realize the observational part of the "Turing test" (see ***Key Objective 1***) and to produce a step change in forecast reliability for weather, climate, volcanoes and earthquakes, and impact prediction models by achieving unprecedented accuracy in the initial conditions and observational constraints, and a better handle on uncertainties. This step-change requires very tight collaboration with the vast network of data providers.

*Progress beyond the state of the art*: 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, only 5% of the available data is used. In collaboration with observational data providers, *ExtremeEarth* will fundamentally revise the information extraction from the growing fleet of satellites, reference stations, 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 the investment in high-resolution Earth-system modelling, *ExtremeEarth* will advance data fusion and artificial intelligence methodologies for creating a complete four-dimensional view of the Earth. A positive feedback with ***Key Objective 1-2*** is that much enhanced models will produce a better match with observations so that also more observational information can be used.

*Approach to fulfil objective*: Reaching this stage requires very high-resolution, fully coupled, non-linear algorithms and artificial intelligence technologies that can be flexibly tied together with Earth-system prediction models, and that can be run on computers as efficiently as the forecasts themselves. This system needs 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 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**. The KPI for this objective is to implement full-scale demonstrators that stream Earth-system prediction and observational information (***Key Objective 1-3***) into impact and risk models as part of the critical production path. Impact information will be tailored for representative end-users and reliable probabilistic forecasts of impacts and risks will be provided. This KPI also includes the novel possibility of interactively managing upstream Earth-system predictions according to end-user needs (see ***Key Technology 3***) and to make fine-scale information available to end-users in an open and flexible way.

*Aims*: The implementation of an interactive value-chain approach for the prediction of geo, weather and climate induced extremes and their impacts is key for realizing the full socio-economic value of *ExtremeEarth*. *ExtremeEarth* will provide a comprehensive application programming interface to extreme-scale computing (through the EEsC in ***Key Technology 3***), which will allow existing impact modelling communities to make much better and easier use of extreme-scale computing, as well as render Earth-system modelling and observation accessible to new communities. Full-scale demonstrators will be built for key impact sectors to demonstrate the added value of high spatio-temporal resolution modelling and observation of Earth-system extremes. These demonstrators will be co-developed with the respective science and impact communities. The step from a wide variety of natural hazards to impacts will be explicitly built into the modelling 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 strawmen for their own future impact model development.

Demonstrators will vary in complexity and combine knowledge across sectors, more specifically:

- Risk modelling will include natural phenomena triggered by the primary weather and geo-extremes covered in ***Key Objectives 1-2***, which can have catastrophic consequences in urbanized areas located in particular in coastal and mountainous regions. These will include tsunamis, storm surges, lahars, other gravitational phenomena (e.g. land- and rock-slides, debris-flows, volcano flank collapse) and ash-clouds.
- For impacts on critical infrastructures, probabilistic impact modelling resolving building blocks will be enabled. Damage can be quantified and cost/benefit assessments of risk management options be provided. Further, the role of green versus gray infrastructures can be explored at unprecedented resolution.



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- For the energy sector, *ExtremeEarth* will provide true seamless prediction capability of all energy-relevant variables at the site of all energy assets as well as along the grid. This will enable planning and real-time operation of a highly interconnected renewable energy system and render it more resilient.
- For hydrology and water, *ExtremeEarth* will provide high-resolution probabilistic hydrological modelling at unprecedented resolution, and the explicit treatment of water scarcity and drought at sub-farm level.
- For food and agriculture, the provision of accurate information on weather and climate extremes at sub-plot scale will be provided. Mutual benefits will be achieved by feeding big data sets collected at farm level back into the prediction models to improve skill.
- For the health sector, the link between environmental predictions and real-time information on the state of society will be implemented, for example, disease incidence data that will be continuously combined with air quality, temperature and rainfall forecasts to identify areas at high risk of disease outbreaks[25], triggering targeted health protection investments in specific neighbourhoods and villages.
- For the emergency management sector, the improved capacity to predict the impending occurrence of catastrophic events as well as to map their evolution and consequences in real time with increased spatial and temporal precision will bring a paradigm shift in how national services and civil protection agencies manage the intervention phase during and after the occurrence of catastrophic events.

*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 transfer of ensemble modelling based uncertainty estimation into user-specific value chains is crucial for much improved decision making.

*Progress beyond the state of the art*: 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 such as the Climate Change, Atmospheric Monitoring and Emergency Response services already include global-to-regional downscaling and interfaces of weather and climate information to atmospheric composition/air quality/flood prediction/renewable energy segments. However, none of these has a specific focus on extremes and the related impact modelling for example on critical infrastructures, and the links to informed decision-making by commercial, civil protection and disaster relief sectors are grossly underdeveloped. Similarly, the correct assessment of seismic risk forms the basis for planning the whole range of mitigation measures. And yet, no reference earthquake risk model has been established so far for Europe. In addition, seismicity induced by underground technologies has also grown in importance. Similarly for volcanoes, where for example no unified approach to simulate and propagate ash clouds exist, thus limiting society's ability to better prepare and manage the resulting risks. The transition into a renewables-based energy system is underway but today's energy systems are not taking full advantage of weather and climate information and the seamless integration of pertinent information is still at an infant stage. At present, there are only site-specific models of the water cycle at the local and regional scale, but the outputs from global models are far too coarse and unreliable to provide inputs commensurate with the high resolution and accuracy required to provide sufficiently detailed insight into environmental and socio-economic impacts, and to build the business case that can underpin future investments. Moreover, large-scale coastal and riverine flooding models do not include information on flood protection infrastructure and hence do not allow a comprehensive appraisal of management options[26]. In the food and agriculture sectors[27], generic short-term weather information is increasingly integrated into in-season management decisions. European farms are currently up to ca. 150 ha in size but reliable information on weather and climate extremes is not available on these scales[28]. Similar in the health sector, where apart from the fact that many of the most life-threatening events cannot yet be well-predicted because current models do not resolve natural hazard extremes, their translation into useful early action for health protection is missing due to the lack of information on infrastructure and population vulnerability[29]. Air quality forecasts highly depend on the accuracy and reliability of the hosting climate/weather prediction model, but air quality impact is often needed at even finer scale than weather extremes prediction. This imposes significant constraints on the host models and their computational speed and data handling requirements.

*Approach to fulfil objective*: *ExtremeEarth* will implement interactive value chains along several directions that need to be developed in a concerted way to achieve the best possible outcome for end-users given the quantum leap in upstream modelling and observational capabilities produced by ***Key Objective 1-3***. Firstly, the level of accuracy for the impact models of the individual sectors needs to match the level of spatial and temporal detail and process complexity required to provide actionable information on risk. For hydrology, agriculture, and energy, for example, this calls for resolutions of 10-metre, and street level for air quality information. Even new processes need to be

[25] Proestos et al., 2015: Present and future projections of habitat suitability of the Asian tiger mosquito, a vector of viral pathogens, from global climate simulation. *Phil. Trans. R. Soc. B* 370: 20130554.
[26] Monier et al., 2018: Toward a consistent modeling framework to assess multi-sectoral climate impacts. *Nature Comm.*, 9:660. doi: 10.1038/s41467-018-02984-9
[27] Tripathi et al., 2016: Paradigms of climate change impacts on some major food sources of the world: A review on current knowledge and future prospects. *Agri., Ecosys. and Environ.*, 216, 356-373.
[28] Ramirez-Villegas et al., 2013: Implications of regional improvement in global climate models for agricultural impact research. *Environ. Res.*, 8, 1-12.
[29] Forzieri et al., 2017: Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study. *Lancet*, 1, e200-e208.



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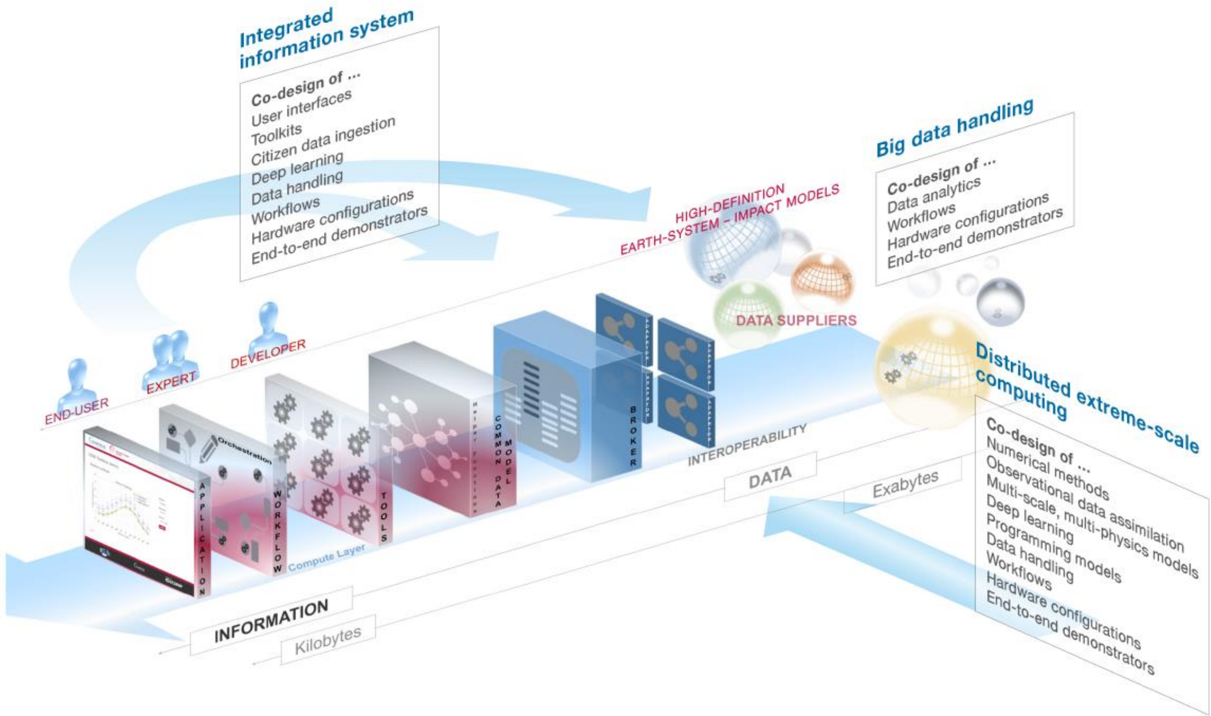
added, including anthropogenic contributions. Secondly, the prediction chain will be based on probabilistic ensemble techniques allowing an end-to-end simulation of uncertainty. Lastly, *ExtremeEarth* will provide the technologies that allow tailoring the value chain approach according to specific end-user needs and to the most cost effective way. Realizing this concept with full-scale demonstrators will be the ultimate measure of success for *ExtremeEarth* as it integrates all scientific capabilities. This entirely relies on the combination of all *ExtremeEarth* technological capabilities. The integrated information will enable society at large as well as specific actors to make crucial decisions about how to deal with the whole range of natural hazards in the coming decades.

### *1.3.2. New technology*

The main technological aim is to develop extreme-scale computing and data handling capabilities to monitor, understand and predict environmental extremes fulfilling the grand science objectives outlined in Section 1.3.1. The project will lead to a new paradigm where users interact with the computations and with data from observational networks or simulations at any place in the value chain. 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. This will drive digital technology and European roadmaps on scientific and technological research and development (Section 2.1) for decades to come.




*ExtremeEarth* will demonstrate extreme-scale compute and data capabilities in a co-design and co-production framework that will drive digital technology and European roadmaps on technology and research and development. It will lead to a new paradigm where users interact with the computations and with data from observational networks or simulations at any place in the value chain. 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.

**Key Technology 1: Domain-specific distributed high-performance computing**. The KPI for this technology is to run service-like end-to-end demonstrators at the required computational speed (***Key Objective 1-4***). Numerical code acceleration will be compared to the status quo at the beginning of the Flagship project, with the aim to scale quasi-linearly and with a throughput of multiple years of climate simulations at 1 km horizontal resolution within one wall-clock day, and suite of elastic wave field simulations to 10 Hz in high-resolution global Earth models, all within one wall-clock day, both with energy footprints that remain similar as today. Progress will be demonstrated on pre-exascale hardware initially and fully demonstrated on domain-specific extreme-scale computing systems at the end of the project.

*Aims*: *ExtremeEarth* will implement and demonstrate a new hardware and software system design that is optimized for the full range from physical models to application sectors. The codes will not be single climate or seismological models anymore, but rather a full framework of scientific-technological solutions in which European Earth-science prediction systems will be developed and implemented, and impact models will be integrated.

*Progress beyond the state of the art*: The state of the art builds upon numerical codes that have developed over the past decades and have adjusted to available hardware technologies with incremental steps. Recent developments have ported compute kernels to accelerator hardware producing enhanced performance and lower energy footprints[30]. However, this approach proved insufficient for reaching the scientific goals of *ExtremeEarth* because

[30] 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.



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it does not provide the expected algorithmic flexibility, performance and portability. Only a full co-design of numerical Earth-system science codes and data handling, considering the entire workflow, will achieve the necessary performance, and make code portable to present and future hardware systems[31].

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

The initial stage will focus on 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 (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*.

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 backends that map specific functions onto the particular processor and memory architecture. The approach will be similar to that used by popular machine learning frameworks (e.g. Keras) that enable data scientists to productively implement deep neural network models using say Python and benefit from highly optimized back-ends (e.g. Tensorflow, CNTK) that themselves map onto specialized architectures. The Earth-system scientists would work in a software environment, in which, by combining both machine learning and update modelling framework, 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 and iteratively in the current model frameworks. This new approach will allow scalable mapping onto general-purpose supercomputing architectures of the time, allowing European Earth-system modellers to use pre-exascale and exascale (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. The software framework will now be mature enough to allow optimizing performance on entirely new hardware technologies and demonstrate the ambitious high-definition simulations.

**Key Technology 2: Domain-specific big data handling**. The KPI for this technology is the demonstration of two capabilities: (i) the ability to run high-resolution weather, climate, and solid Earth models at the required speed (***Key Objective 1-2***) including all necessary data handling, and (ii) the ability for users to access and manipulate the resulting data within petabyte-scale workflows which can compare and contrast value-chain simulations with all available observations (***Key Objective 3-4***).

*Aims*: *ExtremeEarth* will co-design scalable and interoperable data workflows and the tools to manage them. It will make Earth-system data and workflows FAIR (Findable, Accessible, Interoperable and Re-usable). 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. *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 IoT networks in cities). Data will be made available in integrated storage solutions providing seamless access to central, cloud or edge based archives. Delivering data to end users will be realized in real time, employing in-transit analysis by developing and implementing cloud technologies of today and tomorrow (e.g. blob-file systems, object stores or data lakes). These technologies will be integrated with extreme-scale computing. towards the vision of the 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.

*Progress beyond the state of the art*: Current European initiatives around Earth-system data primarily focus on harmonization and improved handling of data from government sources (e.g. INSPIRE) and research infrastructures (e.g. ESFRIs and also developing EOSC). Much of the ongoing 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, licencing, GPDR, business models, etc.) will be dealt with in collaboration with existing and emerging infrastructures (EOSC, ESFRIs, INSPIRE, GEOSS, Copernicus Services etc.).

[31] Lawrence et al., 2017: Crossing the Chasm: How to develop weather and climate models for next generation computers? *Geosci. Model Dev. Discuss*, https://doi.org/10.5194/gmd-2017-186, in review, 2017.



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*Approach to fulfil objective*: The vast amount of information that will be generated in *ExtremeEarth* requires a fundamental re-thinking of current data handling strategies and connectivity[32]. Future HPC hardware will very likely consist of multi-layered storage architectures, and the classical "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 the 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 an earthquake is imminent.

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, or Apple, 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 (Section 2.1), which will radically improve discovery, access, and use of Earth-system data for everyone.

**Key Technology 3: Domain-specific integrated information system**. The KPI for this technology is a set of full-scale end-to-end demonstrations in a cloud-like software environment where users can find, access, and process a major fraction of all available observational data for given extreme events, and use these data in combination with a sequence of custom-triggered model simulations to obtain progressively better assessments of the environmental situation and its impacts on a timescale of a few hours (***Key Objective 1-4***).

*Aims*: *ExtremeEarth* will develop the capability to run simulations on dedicated platforms designed to maximize throughput and make simulation data as well as observational data real time available in the EEsC framework, which integrates ***Key Technology 1*** and ***Key Technology 2***. Checkpoints from these runs will be distributed, allowing the numerical models to be rerun in parallel on cloud-like architectures. This will allow the broader user community to apply data analytics techniques to rerun the model, accessing its entire state and integrate it with data streams in ways that are tailored to their specific needs, for instance, in developing impact assessment, or to advance methods of empirical inference using machine learning, or to explore new ways of ingesting data to advance simulation and confront the model simulation with observations. In addition to exposing the user community to a much richer source of information these methods will actually maximize data compression.

*Progress beyond the state of the art*: Presently models and application communities work within well defined boundaries. Modellers develop and run models, using existing and separately developed computational infrastructure, and the output is used by application communities whose influence on the simulations is likewise limited. The EEsC will allow users (modellers, impact communities, data providers) to explore the entire state of the models of the solid or fluid Earth and impact models, as well as observational streams. It makes the solid and fluid envelopes of Earth system data and models both accessible and programmable by a broad user community. *ExtremeEarth* will enable to link models and data, users and applications, at the point of computation. It will develop a software framework to enable this workflow. That is, the EEsC will enable users to deploy and steer Earth system simulations on extreme scale compute facilities, deploy impact models and assess in real time the results and interact with observational data.

*Approach to fulfil objective*: A key technological concern of *ExtremeEarth* has to be the development of a modular workflow concept, which allows the replacement and "repositioning" of analysis methods, application models and high-end numerical models. A user should be able to interact with the data and models in any part of the workflow chain. It requires well defined and open interfaces and flexibility of the choices to be made by a user, whether from Earth science or any other application. The 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 only through application-driven co-design, which involves the commitment and "buy-in" of a large part of the community working on weather and climate extremes and geo-hazards, the transformation required to achieve its Key Objectives can be realized. Moreover, because the Key Objectives are not independent, and the communities required to achieve them have diverse disciplinary backgrounds and

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



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organizational cultures, they must be addressed in an integrated fashion, which 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. Typically, this is also the time needed to develop new prediction models from pure scientific principles. However, given the demanding performance requirements (factor of 1000 for computing speed[33], 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 forecast models themselves are only one element in the production chain, radically new ways of dealing with critical aspects such as observational data handling, data assimilation, and model-application workflows also need to be implemented. Further, the introduction of deep learning and artificial intelligence methods to better link users to models and data imply also a long-term development effort.

There is no question that a radical reformulation of Earth system prediction science 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 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 climate, weather, geo, 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 dedicated HPC infrastructure to serve society through its member institutions.

The *ExtremeEarth-PP* consortium is very well connected both across and outside of Europe, through very strong researcher networks built from a history of coordinated modelling 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 EC's Copernicus programme.

*ExtremeEarth* has strong links to leading hardware providers (Atos/Bull, NVIDIA, Cray, IBM, Intel etc.), 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 exascale 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 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.

### *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 propel these partners to a wholly new way of working, 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, something that cannot be achieved on the scale of national programmes.

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[33] Bauer et al., 2015: The quiet revolution of numerical weather prediction. *Nature*, doi:10.1038/nature14956.
[34] Kulmalla, 2018: Build a global Earth observatory. *Nature*, doi:10.1038/d41586-017-08967-y.



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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 centre of excellence) as well as FET-HPC projects (ESCAPE, ESCAPE-2, NextGenIO, EuroEXA, MAESTRO, EPiGRAM-HS). These provide a foundation of research into numerical methods, programming models, workflow and application design for Euro-HPC 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, ACTRIS, ICOS, EURO-ARGO, as well as efforts such as EUDAT and EOSC. Also at European scale are links to ESA and EUMETSAT, and the Copernicus services for climate change, atmospheric monitoring (both hosted by ECMWF), marine environment monitoring, land monitoring and emergency management services represent large-scale efforts to centralize European capabilities, mostly with input from the Copernicus satellite programme. The data focus is further strengthened through partnerships with national and international organisations, in particular to the WMO, Global Atmospheric Watch, and core projects of the World Climate and World Weather Research Programmes.
The *ExtremeEarth* science-to-impact focus is also built on a very well developed European service provision infrastructure that comprises national hydro-meteorological, earthquake prediction and civil protection services. *ExtremeEarth* is thus ideally placed to provide the prediction and technology capabilities that these service infrastructures require in the next decades to come. Europe is therefore in a unique position to exploit the collaboration between these infrastructures and novel technologies allowing to full exploitation of the information content the new generation of environmental data from models and observations that *ExtremeEarth* will enable.
In terms of computing infrastructure the 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 projects such as BDVA, and the key concerted European efforts on super-computing, data networks and data infrastructures, namely PRACE, GEANT and EUDAT. These entities are already involved in *ExtremeEarth* planning efforts, and these links will be integrated and extended during the *ExtremeEarth-PP*.

# 2. Impact

## 2.1. Expected Impacts

### *2.1.1. Science and technology break-through*

Not only will *ExtremeEarth* offer a break-through in our ability to simulate and predict extreme events, it will radically change the way in which this information is made available to society. This break-through will be achieved by developing science-technology solutions delivering unprecedented levels of predictive skill for extremes as well as their potential consequences for society. For the first time, we will have reliable, impact-oriented forecasts at scales that are relevant for decision-making in countries, regions, coastlines, cities. *ExtremeEarth* radically deviates from the traditional impact assessment approach, in which individual, disconnected communities operate downstream of Earth–system modellers and use selected outputs as inputs to their own risk models. *ExtremeEarth* will implement a fully integrated science-impact value chain allowing users to optimally 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 four *ExtremeEarth* ***Key Objectives***.
These key objectives can only be realized by a substantial investment in technology. Again, *ExtremeEarth* deviates from traditional thinking by focusing on domain-specific and away from general-purpose technologies. This is necessitated by the fact that the computational requirements for realizing the scientific advances are way beyond what will be achievable from incremental progress through broad-market solutions. Here, software development is a crucial component of *ExtremeEarth* technologies. *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 needed away 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 forecasts of weather and climate have improved significantly over recent decades, Europe continues to suffer billions of Euros of damage from extreme events every year. First, many damages occur because current forecasting systems do not predict the (i) precise location and (ii) 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. Further, *ExtremeEarth* is expected to narrow down uncertainty in how circulation patterns will change because of human



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greenhouse gas emissions. The value of early and better information about the transient climate response will allow to optimize the long-term socio-economic trajectories, and avoid the additional cost of delayed actions[35].
*ExtremeEarth* will contribute to both short-term preparedness as well as long-term resilience building. For short-term warnings, *ExtremeEarth* will allow producing forecasts of the socio-economic impact of extremes 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. 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 billions[36] – with a huge potential for improvement.
With sufficient lead-time, vulnerable people can be evacuated and assets 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 Sendai Framework for Disaster Reduction[37] and the EC action plan[38] 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[39].
When planning for the coming decades, governments and private sector companies need detailed projections on (i) the expected impacts of extremes on our economies and societies over the coming decades; (ii) the measures to reduce damage, and (iii) their cost. The ground-breaking Earth-system modelling capabilities developed in *ExtremeEarth* will provide this information at the required resolution and accuracy, enabling substantial progress in overall safety levels as urban and industrial infrastructures and networks are gradually upgraded or replaced.
In addition, the Earth-system technology concepts of *ExtremeEarth* will allow for comprehensive assessment of the benefits of proposed climate change adaptations, such as large-scale land use changes, re-forestation, re-greening degraded lands and restauration of wetlands and sustainable urban drainage systems, potentially attractive options to sequestrate carbon, mitigate the effects of droughts, and protect areas against flooding. With such information, *ExtremeEarth* will strengthen EU leadership in the highly connected global community to grow to a low carbon global economy by providing the capabilities for more evidence-based policymaking. *ExtremeEarth* will thus contribute to the 5-year global stocktaking assessment of the Paris climate agreement and provide major contributions to IPCC's good practice on greenhouse gas and climate impact reporting under the UNFCCC. *ExtremeEarth-PP* will allow assessing the quantitative socio-economic impact potential together with relevant stakeholders in a dedicated work package to provide estimates of the return on investments.

#### *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 in products and services. The industrial landscape continues to undergo dramatic changes following the digital revolution including the adaptation to robotics, artificial intelligence, and big data analytics techniques. *ExtremeEarth* will be both a beneficiary of the changing digital environment and a contributor to ongoing change. *ExtremeEarth's* initial industrial impact provides a boost to a relatively small, but quintessential European HPC industry (e.g. ATOS/Bull). 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 the scale foreseen in *ExtremeEarth* is unprecedented and 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)[40]. The EEsC will give the technologically advanced industries unprecedented access to accurate forecasted products of Earth-science related hazards and their impacts. *ExtremeEarth* will also change the services delivered by the research institutes involved. Researchers currently target their scientific expertise to inform the society on (changes in) weather, climate, associated extremes and geo hazards. The capabilities *ExtremeEarth* will develop will move away from more assessment-focused research outputs towards research that develops actual services. The co-design process ensures that these will be developed in collaboration with environmental researchers, applied research institutes, SME's and engineering companies alike, who can each can test their innovations on the platforms that *ExtremeEarth* will develop.

[35] https://www.ncbi.nlm.nih.gov/pubmed/26438286
[36] http://www.unisdr.org/files/3612_GlobalSurveyofEarlyWarningSystems.pdf
[37] http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf
[38] https://ec.europa.eu/echo/news/european-commission-launches-sendai-action-plan-disaster-risk-reduction_en
[39] https://ec.europa.eu/echo/news/resceu_en
[40] www.extremeearth.eu



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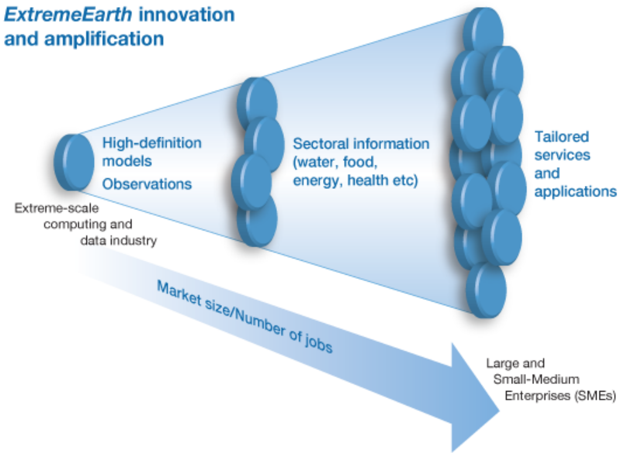


The largest impact in terms of jobs is anticipated in the environmental consultancy industry that consists to a large extent of large and small-medium enterprises (SME). These will be able to develop, through the EEsC, new tailored data products in the entire chain from environmental conditions to societal impact. They will be able to evaluate the impacts of options for adaptation and mitigation across the entire water-energy-food nexus far beyond their direct surroundings and including possible feedback loops to the weather and climate system. Today these industries will have to obtain their information through a cumbersome and expensive chain of data deliveries. The *ExtremeEarth* innovations give rise to entirely new business models for developing tailored information to customers in an already multi-billion Euro consulting industry with a huge competitive advantage. *ExtremeEarth* will be instrumental in the development of the Single Digital Market in Europe.

*ExtremeEarth* is a game-changer that will establish the competitiveness of the European climate services sector, which will become unique in its ability 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 future extremes at high resolution worldwide. This will provide governments and businesses with information on the potential impacts (***Key Objective 4***) on their investments, infrastructure, production and distribution facilities, now and for the coming decades.

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 provided by *ExtremeEarth* through ***Key Objectives 1-4*** will lead to more comprehensive probabilistic modelling of risk and hence allow for risk reduction, which will lead to more affordable pricing of insurances, loans and guarantees, as well as reduced costs for governmental support. Early warning services can be built based on better *predictions* of extreme events once provided by *ExtremeEarth*.

Today, annualized damages of 1-12% of 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. 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, in particular the impact of extremes associated with long-term climate change projections, 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 4***, namely the capabilities for simulating and predicting extremes and their impacts, enables us to include the consequences of economic development and to estimate the aggravating effect of climate change. To this end, *ExtremeEarth* will reduce the uncertainty bands around such estimates. 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 SMEs the capabilities to map the information needed to actively manage and mitigate catastrophes, 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 to 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 the health sector, *ExtremeEarth* will allow to trigger targeted health protection investments in specific neighbourhoods and villages at unprecedented 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].

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[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.



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Finally, impact modelling services may be developed to estimate the potential effects of natural disasters on national security concerns including migration (***Key Objective 4***). This is critical for the European economy, which needs to account for risk in economic strategies and investment decisions at full 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. Reliable weather predictions will support operations by enabling to seamlessly monitor and predict all energy variables at various temporal and spatial scales for demand and production forecasting. This will help optimizing the mix of renewable resources and reducing the need for hydrocarbon combustion.

Detailed weather and climate information 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 on energy saving 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 2*** 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 ultimately enable the energy transition to renewable geo-energy technologies.

With the current and projected fraction of fossil fuels in the steadily growing global primary energy demand, humankind is on a path to exceed the COP21 global warming targets of 1.5-2°C. In addition to exploiting conventional mitigation and adaptation options our society will soon be forced to deploy technologies to counteract climate change, such as direct $CO_2$ capture from the atmosphere (Negative Emissions Technologies) and reducing the effect of solar radiation onto the Earth (Radiation Management methods). *ExtremeEarth* will create the knowledge to implement $CO_2$ geological sequestration while controlling induced seismicity (***Key Objective 2***) as well as to predict and monitor 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 of unprecedented precision and skill (***Key Objectives 1, 4)***. For example, the tourism sector will be able to improve operational planning and adaptive measures to minimize damages from extreme events.

*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 Objectives 3-4***, ***Key Technologies 1-3***). *ExtremeEarth* will 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, 3-4***, ***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 infrastructure*

By revolutionizing the modelling, data handling, and computing capabilities in Earth system science, *ExtremeEarth* will provide two critical missing elements for research today: (i) the integration of the full value chain into a

[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.
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seamless prediction system, and (ii) solving thousand-fold larger computing tasks at operational production speed expected to be achievable in 2020. The impact on science and service would be immediate: *ExtremeEarth* will be an excellent demonstrator for the European Data Infrastructure with PRACE, GEANT and EUDAT.

*ExtremeEarth* will design extreme-scale computing and data systems to solve extremely ambitious problems in Earth system sciences, but the algorithmic motifs and data flow problems are typical for many other domains. 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. 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 find application in other domains as well and *ExtremeEarth* will motivate and lead their development.

*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 deep learning, 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 for the oceans, as well as for modelling research infrastructures such as IS-ENES for climate and ECMWF for weather predictions. 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 (NOAA, NASA, JMA, CMA, KMA) 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, TERENO, eLTER, *ExtremeEarth* will trigger the development and use of low-cost innovative sensors integrated into personal wear products, drones and other monitoring devices. These will be provided by specialised manufacturers to respond to the requirements of the new generation of simulators.

The ambition of the *ExtremeEarth* endeavour is unprecedented in the field of Earth and environmental sciences and ensuring institutional commitments and a coordinated development path over a period of 10+ years is a complex challenge comparable to the large international high-energy physics endeavours. Consequently, *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. JPI Urban Europe. JPI-Climate and JPI-Water) and the 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 science communities, impact science together with the HPC community and with service providers operating with different constraint and incentives than scientists. In this way, *ExtremeEarth* breaks down disciplinary borders, namely those between weather, climate, solid Earth modelling and downstream application sciences related to the water, energy, agriculture and food sciences as well as the financial and health sectors, and those between applied science and computing science. *ExtremeEarth* will invest substantially in creating an education and training programme at the interface between these disciplines.

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, 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 energy innovation community, and the reinsurance sector, customized education portals for partner institutes; Simulation Laboratories at partner institutions. The details of this programme will be defined in the course of *ExtremeEarth-PP*.



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