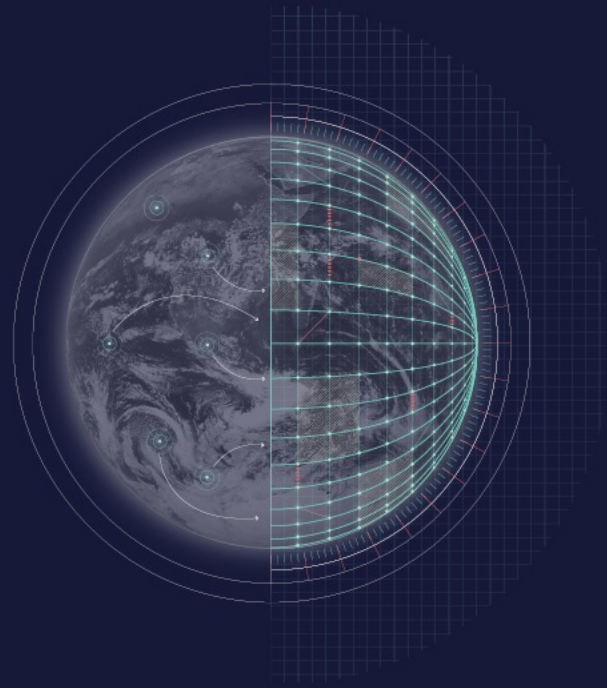
Destination Earth and Digital Twins

A European opportunity for HPC

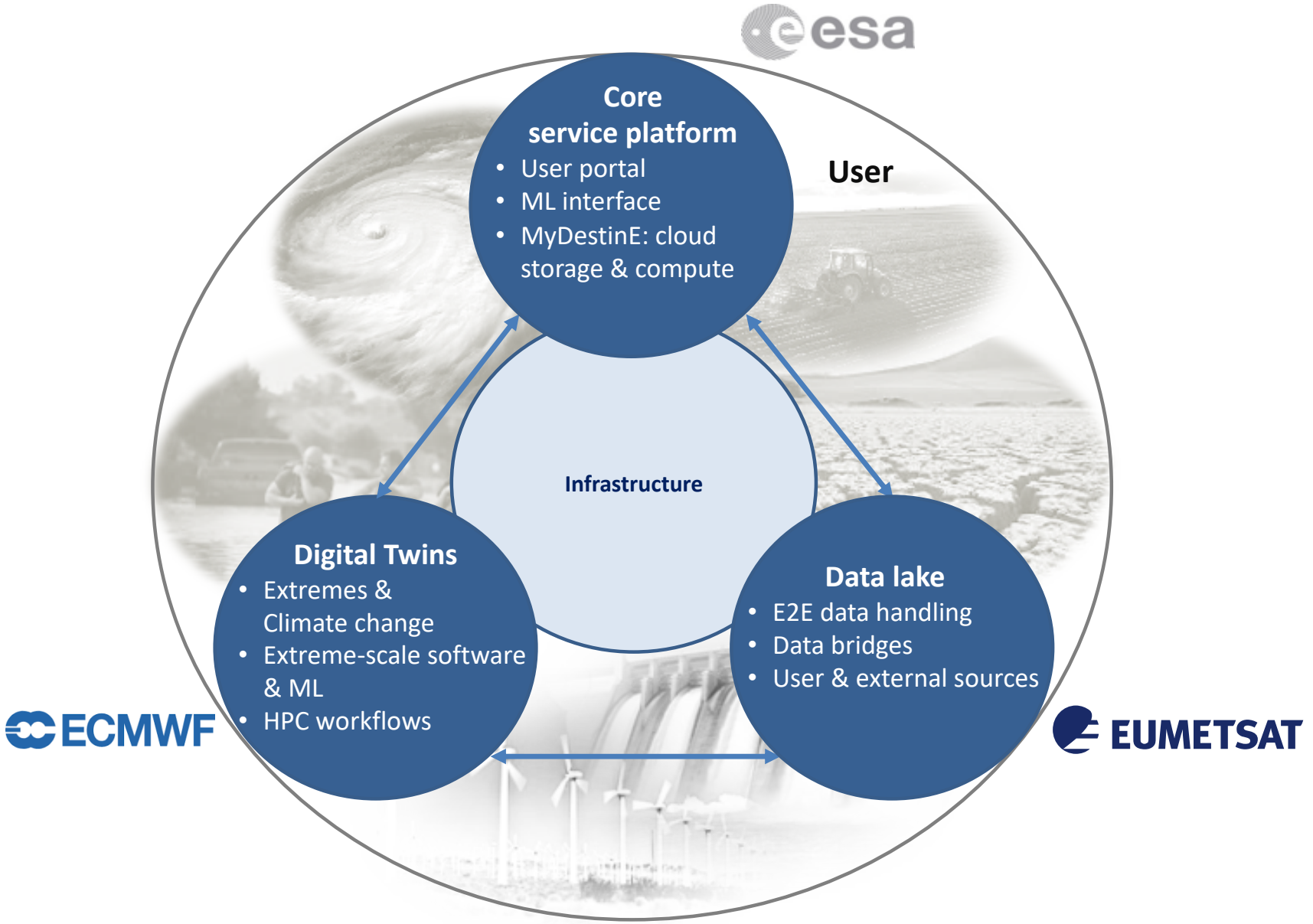


Peter Bauer

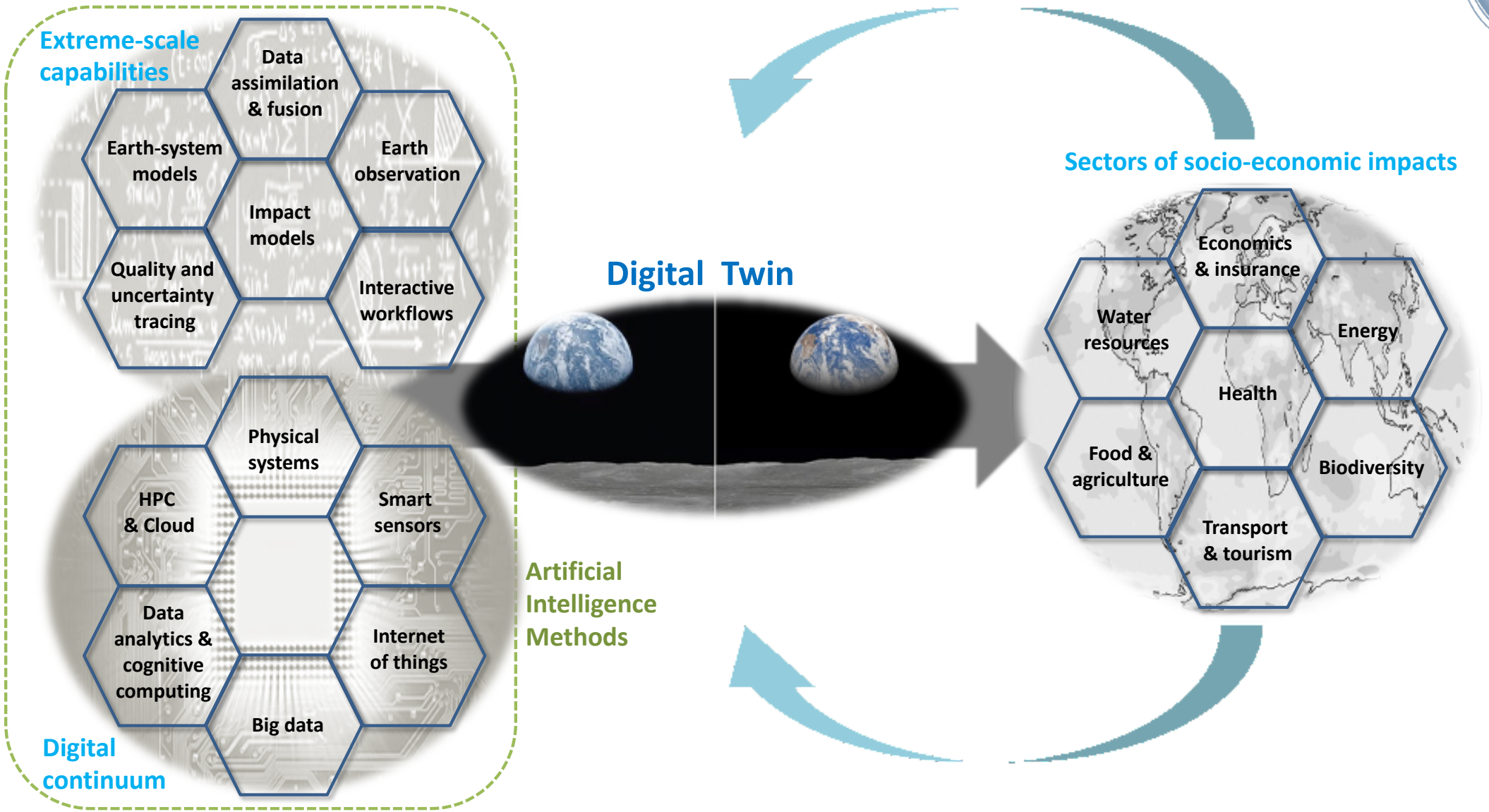
ECMWF

Home:	€7.5B Digital Europe Programme 2021-2027; R&D support from Horizon Europe Programme
Schedule:	Kick-off November 2021; phase 1 2021-2024; phase 2+ 2024-2027
Budget:	Phase 1: €150M (€60M ECMWF, €50M ESA, €40M Eumetsat); mostly procured
WWW:	https://digital-strategy.ec.europa.eu/en/library/destination-earth

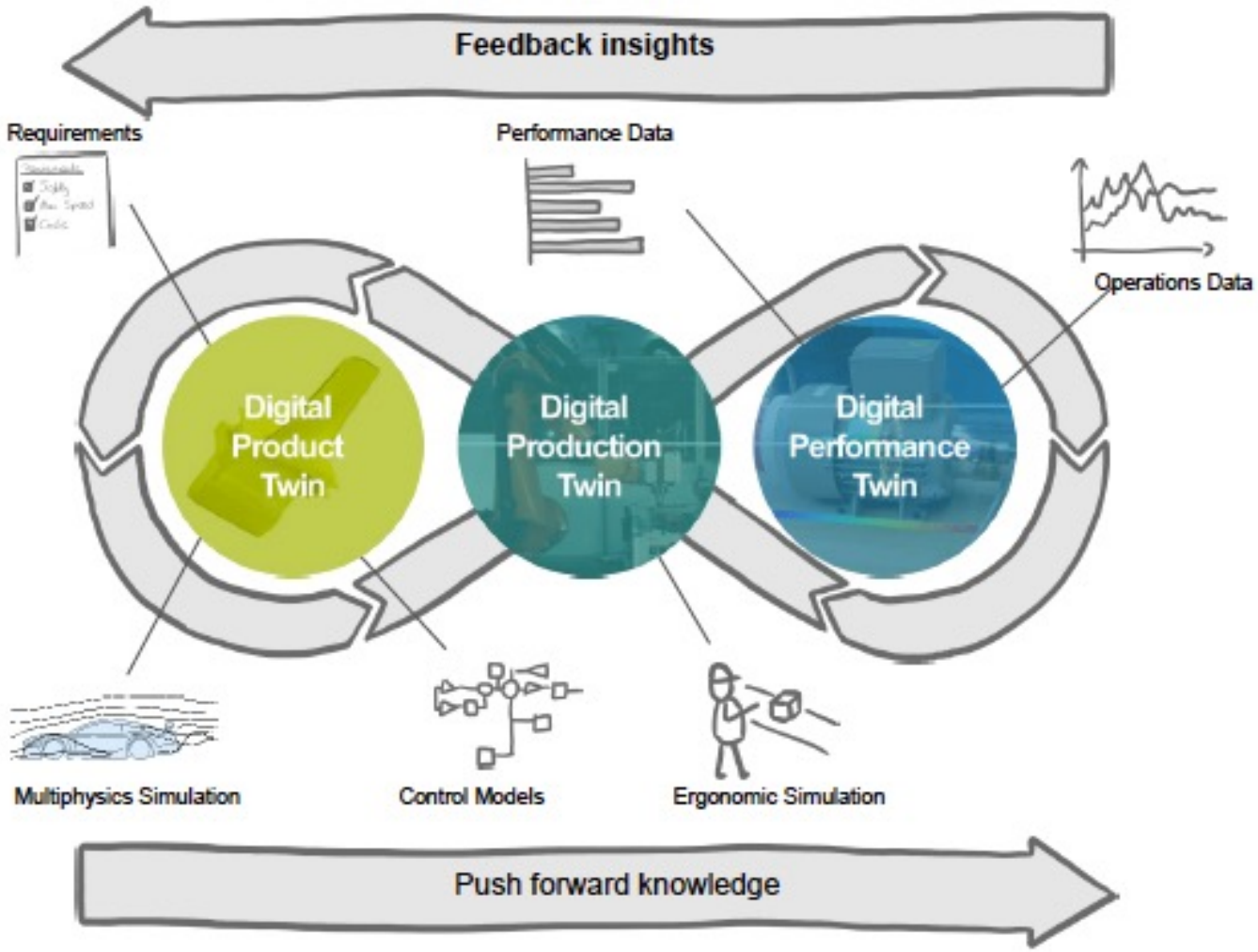
Triangle of Destination Earth (DestinE)



Digital Twin of the Earth system



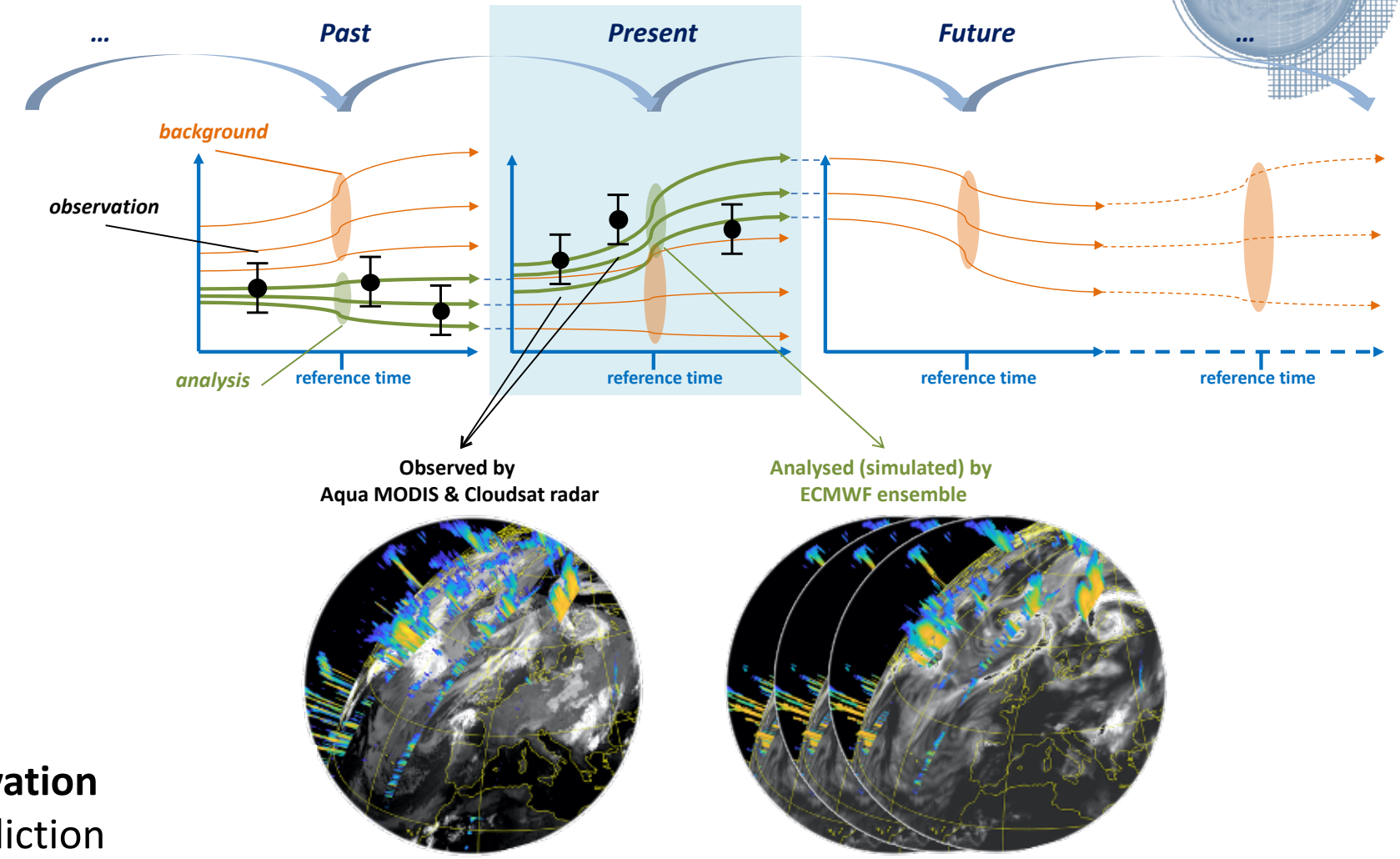
Digital Twins in industry



- continuous **simulation & observation**
- **performance** monitoring & prediction
- **technical user interaction**
- scientific theory and adaptation **scenario testing**

Courtesy Dirk Hartmann, Siemens

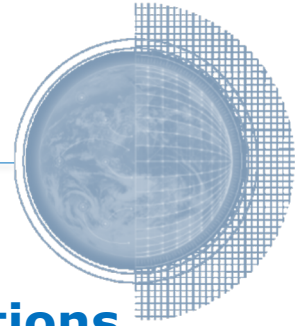
Earth-system digital twin



- continuous **simulation & observation**
- **performance** monitoring & prediction
- **technical user interaction**
- scientific theory and adaptation **scenario testing**

Bauer et al. Nature Comp. Sci., 2021

How is this different from an Earth-system model?



1. **Much more realistic models, better combination of simulations + observations**

2. **Full integration of policy sectors (energy, food, water, …) in workflow**

3. **Domain expert – non-expert configuration and information extraction**

How is this different from an Earth-system model?

1. Much more realistic models, better combination of simulations + observations

2. Full integration of policy sectors (energy, food, water, …) in workflow

3. Domain expert – non-expert configuration and information extraction

… which are enabled by digital technologies …

1. Extreme-scale computing and data handling

2. Multi-scale/disciplinary models, algorithms, machine learning

3. Open and interactive platform with access to data, software and workflows

Necessary digital technology is more than HPC

The TransContinuum Initiative: eliminating the silos in order to achieve a better orchestration of complex applications

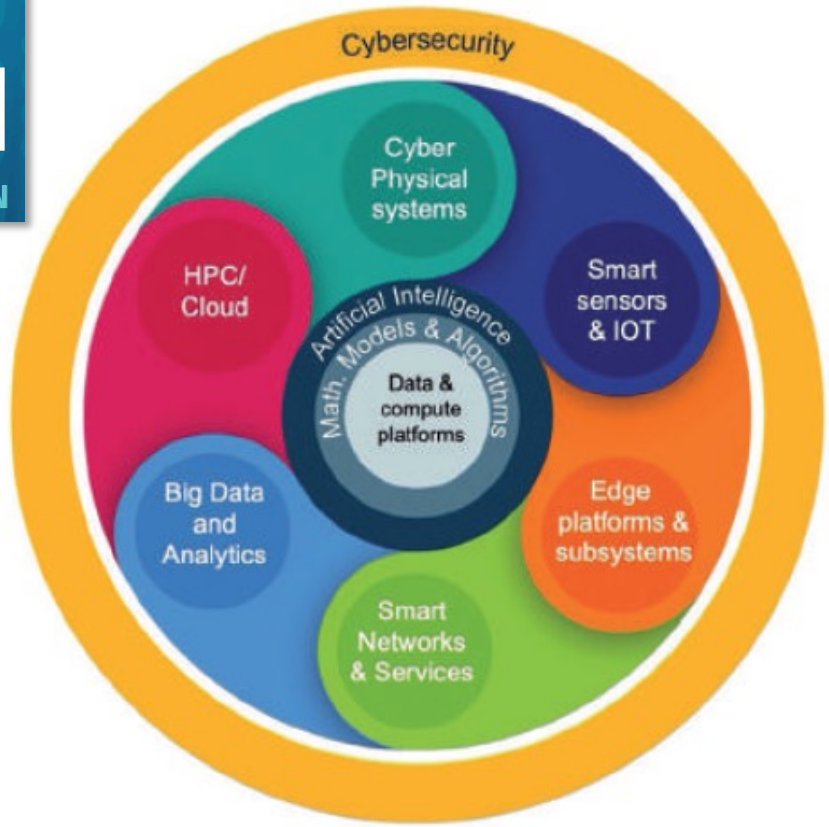
The continuum of computing

By MARC DURANTON, MICHAEL MALMS and MARCIN OSTASZ

The TransContinuum Initiative: exploiting the full range of digital technologies for the prediction of weather and climate extremes

The extremes prediction use case

By PETER BAUER, MARC DURANTON and MICHAEL MALMS

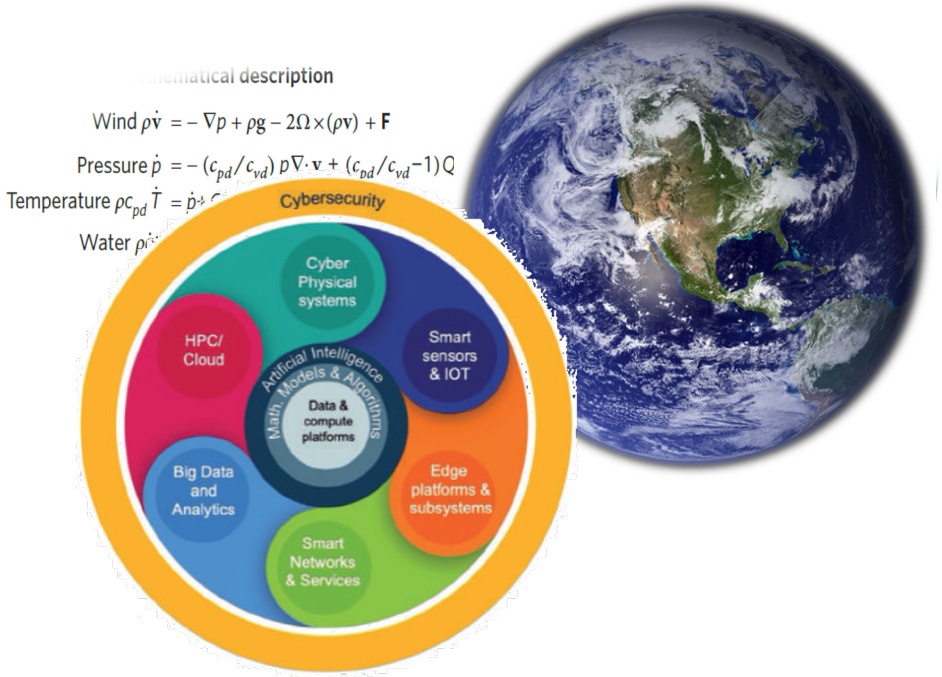


A continuous dynamic workflow

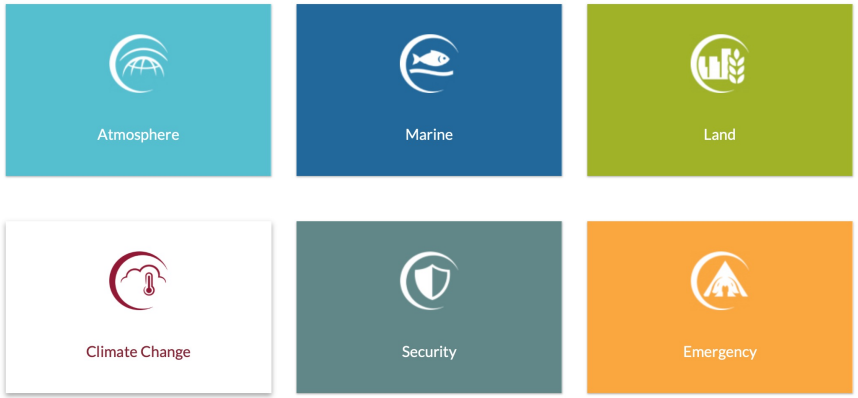
Between
Smart Sensors and IOT devices
and
HPC / cloud centers
passing through
Edge platforms & subsystems
as well as
Smart Networks and Services
executing
Simulation & Modelling, Big Data Analytics and ML*
based on
Math. Methods & Algorithms incl. MSODE**
pervasively augmented by
Artificial Intelligence
protected and secured by
Cybersecurity
back to
Cyber-Physical Systems,
all based on
Data and compute platforms (hw and sw)

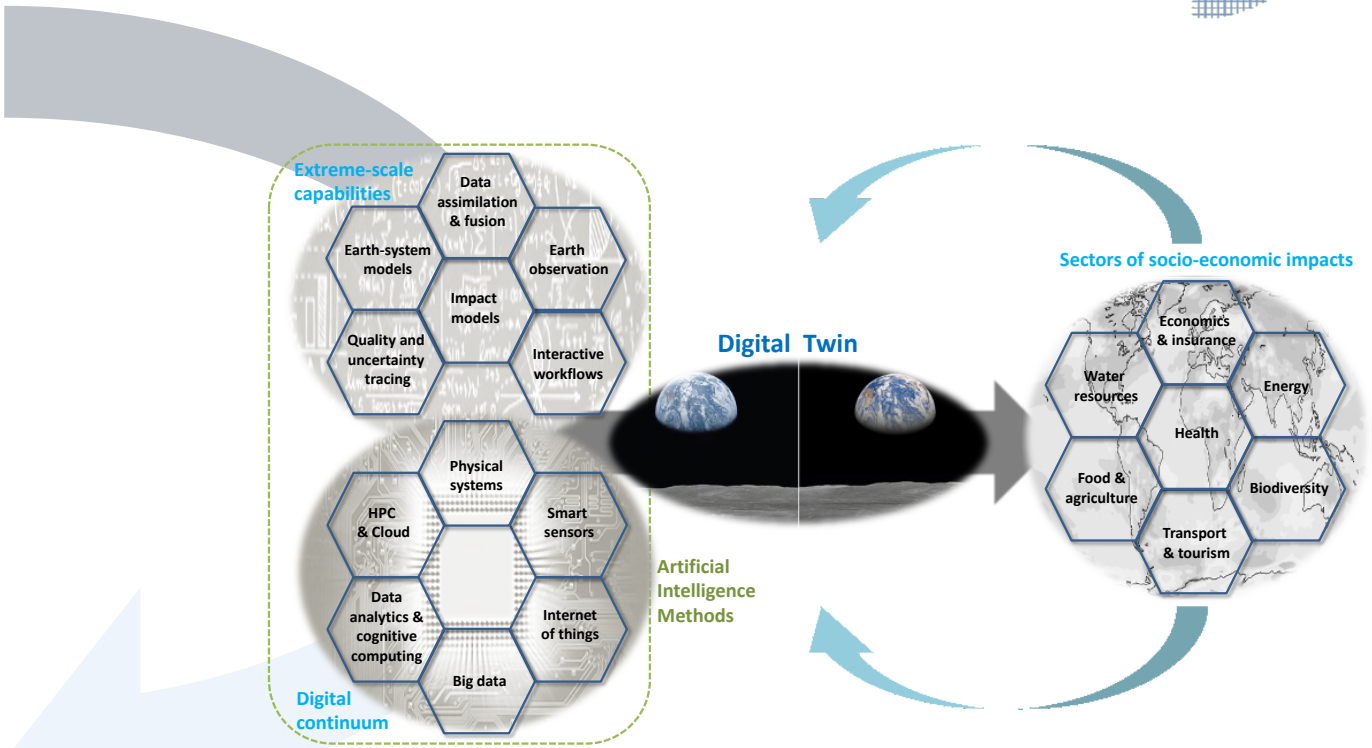
* ML: Machine Learning
** MSODE: Modelling, Simulation and Optimization in Data-rich Environment

Ideally, continuous innovation and co-design cycle for services



Copernicus Services





Federated resource management philosophy

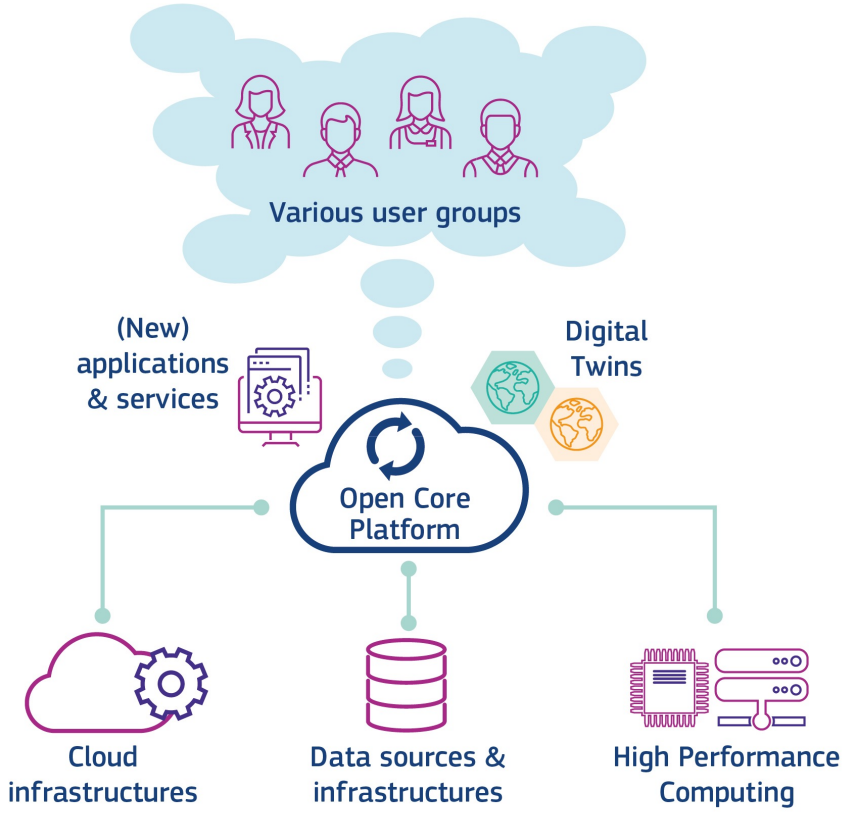
FENIX RESEARCH INFRASTRUCTURE

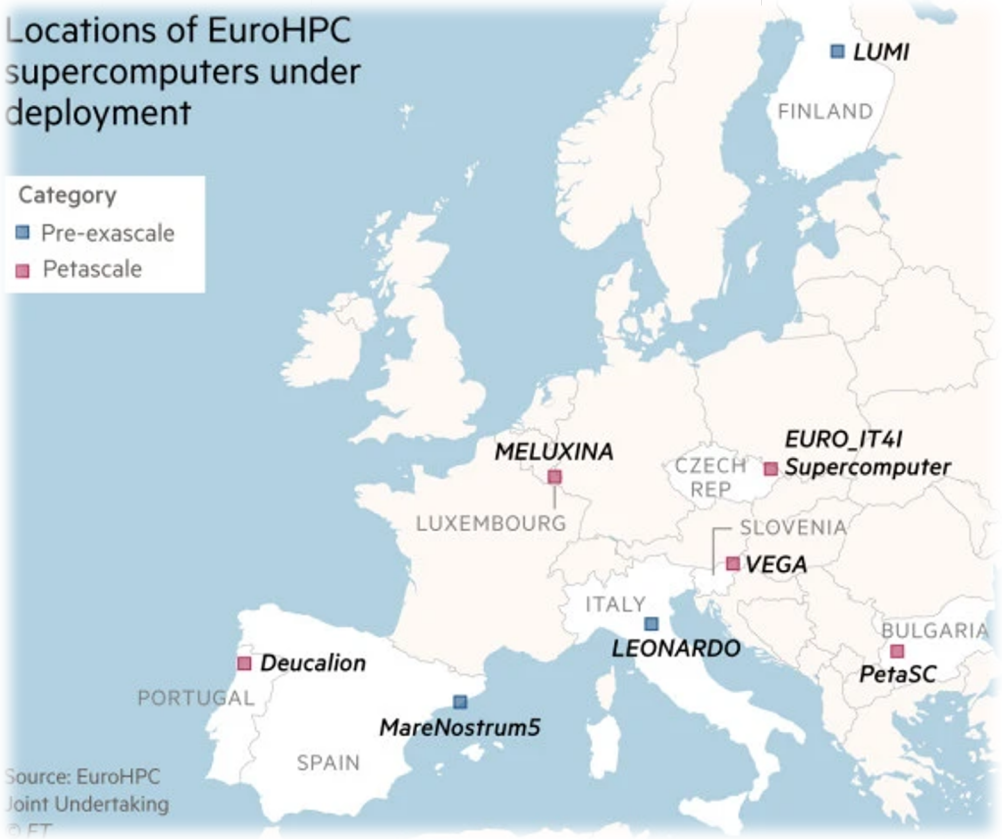
EUROPEAN OPEN SCIENCE CLOUD

opernicus Europe's eyes on Earth

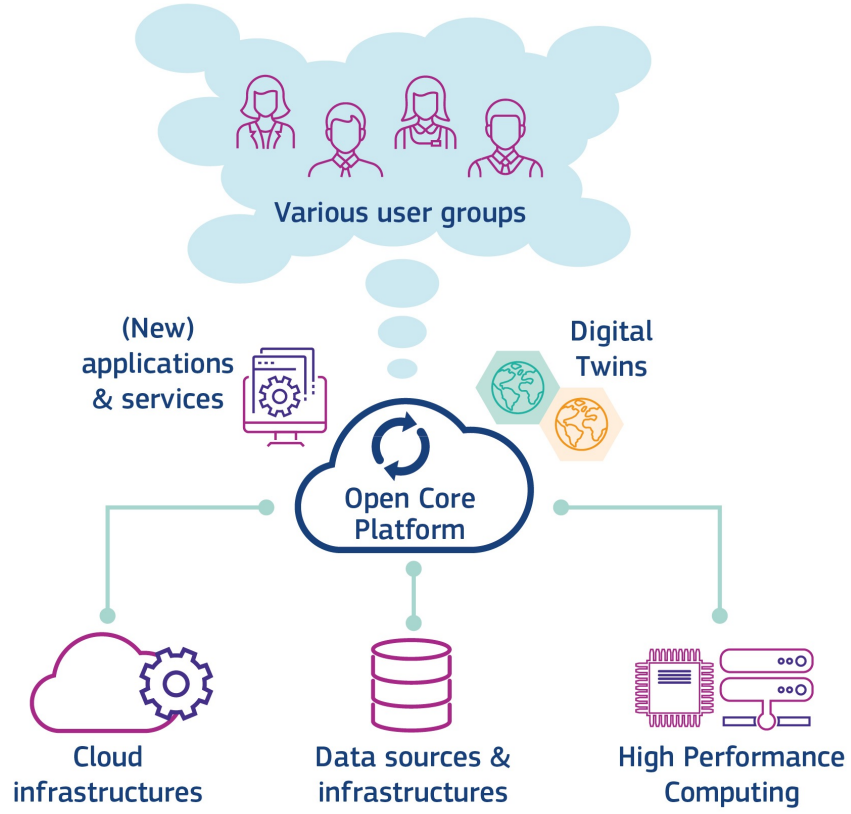
GAIA-X

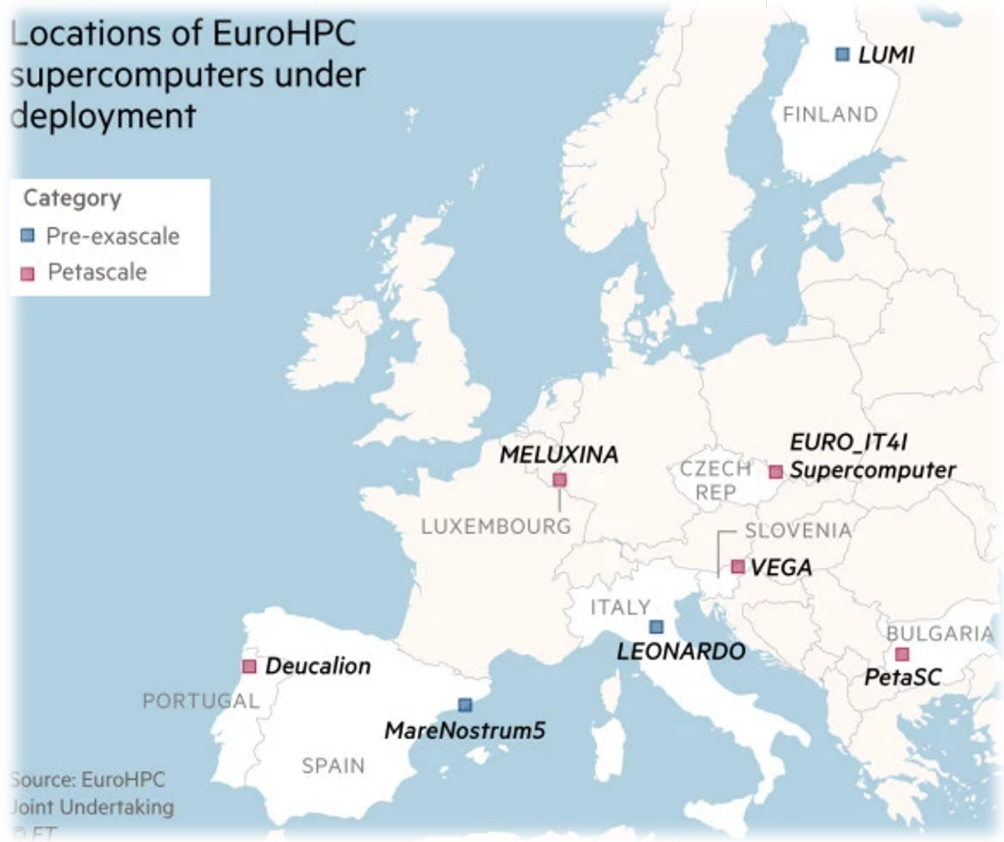
EuroHPC Joint Undertaking





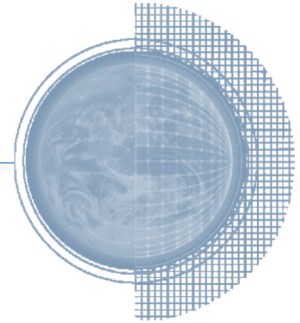
Federated resource management philosophy





Burning question: How do we achieve this through a patchwork of European (Digital, Horizon, Space), national, int'l funding programmes & partners?

… or do we need a new centre – like ITER or CERN?



CERNCOURIER | Reporting on international high-energy physics

Physics ▾ | Technology ▾ | Community ▾ | In focus | Magazine

THE ROYAL SOCIETY

CLIMATE CHANGE : SCIENCE AND SOLUTIONS | BRIEFING 1

Next generation climate models:
a step change for net zero and climate adaptation

In brief

Climate models are fundamental to understanding climate change and anticipating its risks. They provide the basis for predicting impacts, guiding adaptation decisions and setting mitigation targets. Society now needs more detailed and precise information to enable robust decision-making in the face of rapidly amplifying climate change and for achieving its goal of net zero by 2050.

Existing technological potential and scientific capability can be harnessed through a new level of international cooperation and investment in next-generation super-computing and Earth system science. This step-change transformation could deliver the robust science required to support greater ambition in mitigation and adaptation in the coming decades.

POLICY | OPINION

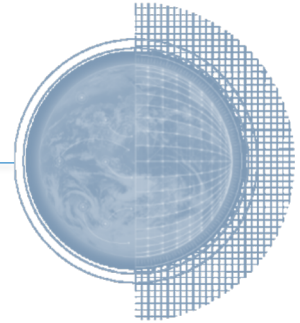
'A CERN for climate change'

2 July 2021

An exascale computing facility modelled on the organisation of CERN would enable a step-change in quantifying climate change, argue Tim Palmer and Bjorn Stevens.

- A dedicated facility, of unprecedented scale, with a role similar to that of CERN in particle physics, would overcome the scientific and technical barriers of delivering timely, detailed, consistent and actionable climate predictions for the coming century, building on the construction of Earth system models that has been one of the great scientific achievements of the last 50 years.

… or do we need a new centre – like ITER or CERN?



CERNCOURIER | Reporting on international high-energy physics

Physics ▾ | Technology ▾ | Community ▾ | In focus | Magazine

THE ROYAL SOCIETY

CLIMATE CHANGE : SCIENCE AND SOLUTIONS | BRIEFING 1

Next generation climate models:
a step change for net zero and climate adaptation

In brief

Climate models are fundamental to understanding climate change and anticipating its risks. They provide the basis for predicting impacts, guiding adaptation decisions and setting mitigation targets. Society now needs more detailed and precise information to enable robust decision-making in the face of rapidly amplifying climate change and for achieving its goal of net zero by 2050.

Existing technological potential and scientific capability can be harnessed through a new level of international cooperation and investment in next-generation super-computing and Earth system science. This step-change transformation could deliver the robust science required to support greater ambition in mitigation and adaptation in the coming decades.

POLICY | OPINION

'A CERN for climate change'

2 July 2021

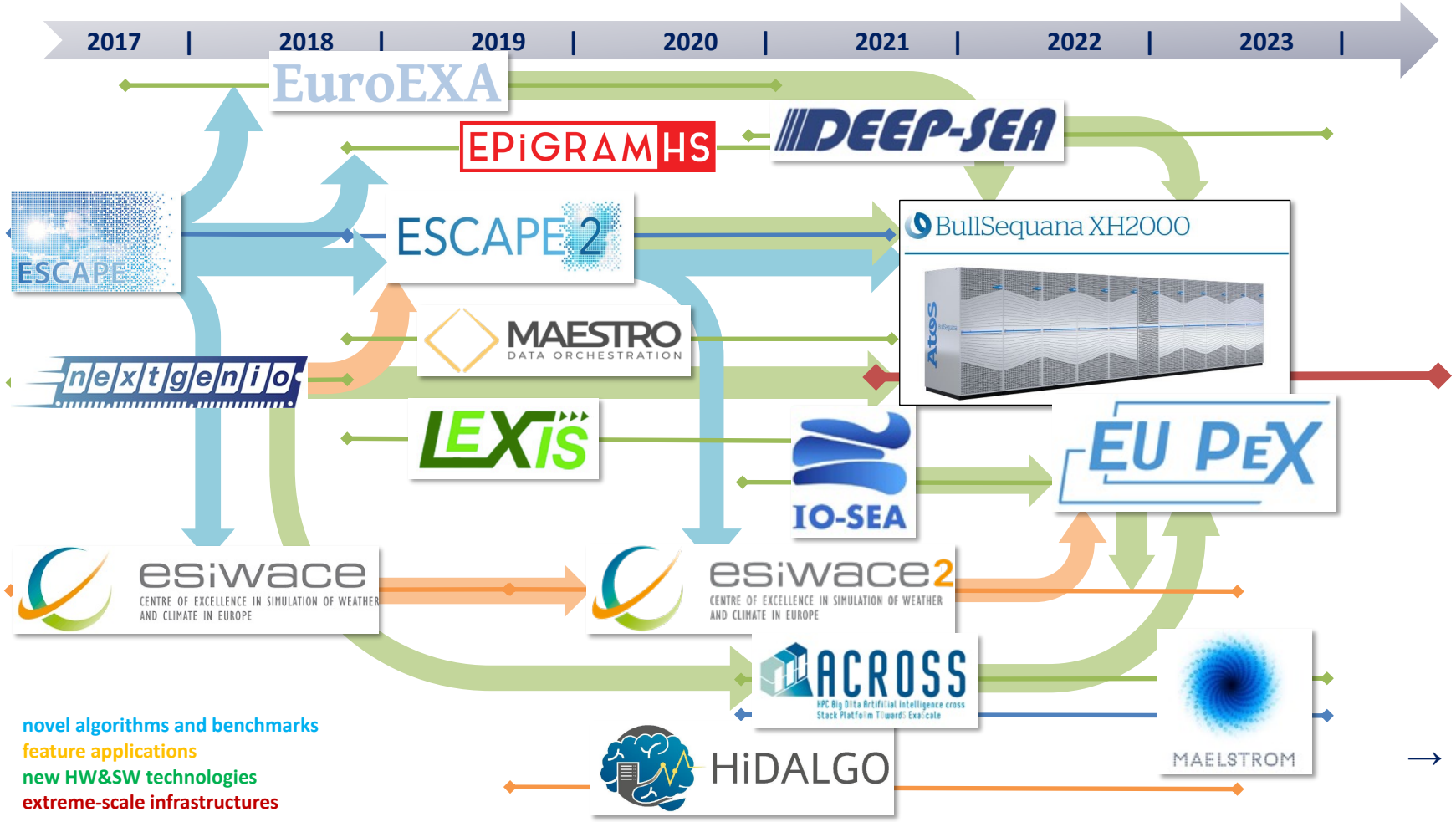
An exascale computing facility modelled on the organisation of CERN would enable a step-change in quantifying climate change, argue Tim Palmer and Bjorn Stevens.

- A dedicated facility, of unprecedented scale, with a role similar to that of CERN in particle physics, would overcome the scientific and technical barriers of delivering timely, detailed, consistent and actionable climate predictions for the coming century, building on the construction of Earth system models that has been one of the great scientific achievements of the last 50 years.

Million(s)-dollar question: Who would contribute the central, extreme-scale digital platform?

ECMWF builds on Scalability Programme heritage for DestinE

Projects with ECMWF lead/partner roles supported by DG CNECT's FET-HPC & EuroHPC R&I actions:



→ **Programming**

→ **Algorithms**

→ **Architecture**

→ **Data handling**

→ **Centres of Excellence**

New approaches to model software design

PERSPECTIVE
https://doi.org/10.1038/s43588-021-00023-0
nature computational science
Check for updates

The digital revolution of Earth-system science

Peter Bauer[1✉], Peter D. Dueben[1], Torsten Hoefler[2], Tiago Quintino[3], Thomas C. Schulthess[4] and Nils P. Wedi[1]

Digital-twin engine control layer:

- *Resilient workflow management (centralized & federated)*
- *Ensemble assimilation algorithms (variational, Kalman/digital filters, ML)*
- *Building blocks (observations, observation simulators, pre-conditioners, minimizers)*
- *Interfaces with Earth-system & impact models*

Time steps — *cycling*

Generic data structures:

- *variable grids*
- *model coupling*
- *flexible memory layout*
- *parallel communication*

Numerical methods & algorithms:

- *local stencils*
- *large time steps*
- *multiple grids*
- *mixed precision*
- *neural networks*

Model ensembles

parallel

process #1
process #2
process #3
process #4
process #5

sequential

Domain-specific toolchain:

Automatic code extraction & abstraction

Hardware specific code back-ends

Cloud federation Architecture

- *Orchestration across centers*
- *Access management for users*

System architecture

Interconnect

Memory-storage hierarchy

Nodes & processors:

- HBM CPU
- GPU
- Low-precision ML processor
- Dataflow processor
- ASIC

=

EuroHPC Joint Undertaking

19th Workshop evidence of community success

16:20 → 16:40 **Destination Earth and Digital Twins - A European opportunity for HPC**
Speaker: Peter Bauer (ECMWF)

16:40 → 17:00 **How could/should digital twin thinking change how we use HPC in weather and climate?**
Speaker: Bryan Lawrence (NCAS, University of Reading)

17:00 → 17:20 **Building Global Kilometer-Scale Prediction Models**
Speaker: Mark Govett (NOAA Earth System Research Laboratory)

09:50 → 10:10 **Bridging gaps: The Maestro Data-Aware Middleware**
Speaker: Utz-Uwe Haus (HPE HPC EMEA Research Lab)

10:10 → 10:30 **On the Convergence of HPC, Cloud and Data Analytics for Exascale Weather Forecasting - ECMWF Present and Future**
Speaker: Tiago Quintino (ECMWF)

10:30 → 10:50 **Autosubmit: An end-to-end workflow manager**
Speaker: Wilmer Uruchi (Barcelona Supercomputing Center)

13:20 → 13:40 **Machine learning, high performance computing and numerical weather prediction**
Speaker: Peter Dueben (ECMWF)

13:40 → 14:00 **Machine learning models to emulate gravity wave drag by Atos Center of Excellence**
Speakers: Alexis Giorka
Christophe Bovalo (Atos

14:00 → 14:20 **AI vs. mathematical m**
climate and weather a
Speaker: Thomas Chen
Mathematics, Science, a

09:50 → 10:10 **Driving Numerical Weather Prediction with NVIDIA technology**
Speaker: Peter Messmer (NVIDIA)

10:10 → 10:30 **Overview of the Heterogeneous Computing Project in the Weather & Climate Center of Excellence**
Speaker: Erwan Raffin (Atos)

10:30 → 10:50 **Next generation ICON NWP forecasting system on NVIDIA GPUs at MeteoSwiss**
Speaker: Carlos Osuna (MeteoSwiss)

08:20 → 08:40 **Single-Precision in Earth-System Models**
Speaker: Sam Hatfield (ECMWF)

08:40 → 09:00 **A mixed precision implementation in Numerical Weather Prediction models**
Speaker: Stella Valentina Paronuzzi Ticco (Barcelona Supercomputing Center)

09:00 → 09:20 **Supercomputer Fugaku and new achievement using Fugaku and AI technologies for high-resolution, real-time tsunami inundation prediction**
Speakers: Toshiyuki Shimizu (Fujitsu Limited), Yusuke Oishi (Fujitsu Limited)

Guzman Ruiz
omputing Center)

08:40 → 09:00 **ESCAPE 2: Energy-efficient SCalable Algorithms for weather and climate Prediction at Exascale**
Speaker: Andreas Mueller (ECMWF)

09:00 → 09:20 **NEC SX-Aurora TSUBASA for your better application performance**
Speaker: Yasuhisa Masaoka (NEC Corporation)

refinement and a
system modelling
Speaker: Johannes Holke (German Aerospace Center (DLR))

10:30 → 10:50 **Towards fault tolerance in high-performance computing for numerical weather and climate prediction**
Speaker: Tommaso Benacchio (Politecnico di Milano)

14:50 → 15:10 **European Weather Cloud: A community cloud service tailored for Meteorology**
Speaker: Vasileios Baousis (ECMWF)

15:10 → 15:30 **IFS on AWS - Running RAPS in the cloud**
therton (MAXAR)

uting accelerate
earch to operations for
cycling data
awrence
)

ncil-oriented framework
e-portable weather and
tions in Python
Speaker: Stefano Ubbiali (ETH Zurich)

16:40 → 17:00 **Implementation of a performance-portable global atmospheric model using a domain-specific language in Python**
Speaker: Oliver Fuhrer (Allen Institute for Artificial Intelligence)

17:00 → 17:20 **Exascale Computing for NWP and Climate Science**
Speaker: Ilene Carpenter (Hewlett Packard Enterprise)

DestinE & digital twins

- Digital twins are much more than better models
- Weather & climate community mostly agrees on software concepts
  – but we need to accelerate!
- Substantial investments in general purpose infrastructures & research exist
  – urgency of extremes/climate can demonstrate societal value of HPC* investment

***EuroHPC in Europe; without sufficient EuroHPC resources DestinE will fail**

DestinE & digital twins

- Digital twins are much more than better models
- Weather & climate community mostly agrees on software concepts
  – but we need to accelerate!
- Substantial investments in general purpose infrastructures & research exist
  – urgency of extremes/climate can demonstrate societal value of HPC* investment

DestinE needs to be the catalyst for reaching sufficient critical mass to deliver enough & on time

***EuroHPC in Europe; without sufficient EuroHPC resources DestinE will fail**