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
Triangle of Destination Earth (DestinE)

Core service platform
• User portal
• ML interface
• MyDestinE: cloud storage & compute

User

Infrastructure

Digital Twins
• Extremes & Climate change
• Extreme-scale software & ML
• HPC workflows

Data lake
• E2E data handling
• Data bridges
• User & external sources
Digital Twin of the Earth system

Sectors of socio-economic impacts
- Energy
- Biodiversity
- Health
- Food & agriculture
- Transport & tourism
- Water resources
- Economics & insurance

Artificial Intelligence Methods
- Physical systems
- Data analytics & cognitive computing
- Big data
- Smart sensors
- Internet of things
- HPC & Cloud

Quality and uncertainty tracing
- Impact models
- Interactive workflows
- Earth observation
- Data assimilation & fusion
- Earth-system models

Digital continuum
- Extreme-scale capabilities

Digital Twin

Internet of things
- Physical systems
- Smart sensors
- Big data
- HPC & Cloud
- Data analytics & cognitive computing

Data assimilation & fusion
- Impact models
- Interactive workflows
- Earth observation
- Earth-system models
- Quality and uncertainty tracing

Extreme-scale capabilities
- Earth-system models
- Quality and uncertainty tracing
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
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... 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
Ideally, continuous innovation and co-design cycle for services
Federated resource management philosophy
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?

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 supercomputing 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.

- 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?

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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

novel algorithms and benchmarks
feature applications
new HW&SW technologies
extreme-scale infrastructures
New approaches to model software design

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

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

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
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>16:20-16:40</td>
<td>Destination Earth and Digital Twins - A European opportunity for HPC</td>
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<tr>
<td>Speaker: Peter Bauer (ECMWF)</td>
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<tr>
<td>16:40-17:00</td>
<td>How could/should digital twin thinking change how we use HPC in weather and climate?</td>
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<td>Speaker: Bryan Lawrence (NCAS, University of Reading)</td>
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<tr>
<td>17:00-17:20</td>
<td>Building Global Kilometer-Scale Prediction Models</td>
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<td>Speaker: Mark Govett (NOAA Earth System Research Laboratory)</td>
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<td>13:20-13:40</td>
<td>Machine learning, high performance computing and numerical weather prediction</td>
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<td>Speaker: Peter Dubeen (ECMWF)</td>
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<tr>
<td>13:40-14:00</td>
<td>Machine learning models to emulate gravity wave drag by Atos Center of Excellence</td>
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<td>Speakers: Alexis Giorka, Christophe Bovalo (Atos)</td>
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<td>14:00-14:20</td>
<td>AI vs. mathematical models: climate and weather a</td>
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<td>Speaker: Thomas Chen (Mathematics, Science, a</td>
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<td>09:50-10:10</td>
<td>Bridging gaps: The Maestro Data-Aware Middleware</td>
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<td>Speaker: Utz-Uwe Haus (HPE HPC EMEA Research Lab)</td>
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<td>10:10-10:30</td>
<td>On the Convergence of HPC, Cloud and Data Analytics for Exascale Weather Forecasting - ECMWF Present and Future</td>
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<td>Speaker: Tiago Quintino (ECMWF)</td>
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<td>10:30-10:50</td>
<td>Autosubmit: An end-to-end workflow manager</td>
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<td>Speaker: Wilmer Uruchi (Barcelona Supercomputing Center)</td>
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<td>08:40 → 09:00</td>
<td>ESCAPE 2: Energy-efficient Scalable Algorithms for weather and climate Prediction at Exascale</td>
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<td>Speaker: Andreas Mueller (ECMWF)</td>
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<td>09:00 → 09:20</td>
<td>NEC SX-Aurora TSUBASA for your better application performance</td>
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<td>Speaker: Yasuhisa Masaoka (NEC Corporation)</td>
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<td>10:10 → 10:30</td>
<td>Overview of the Heterogeneous Computing Project in the Weather &amp; Climate Center of Excellence</td>
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<td>Speaker: Erwan Raffin (Atos)</td>
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<td>10:30 → 10:50</td>
<td>Next generation ICON NWP forecasting system on NVIDIA GPUs at MeteoSwiss</td>
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<td>Speaker: Carlos Osuna (MeteoSwiss)</td>
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<td>10:30 → 10:50</td>
<td>Towards fault tolerance in high-performance computing for numerical weather and climate prediction</td>
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<td>Speaker: Tommaso Benacchio (Politecnico di Milano)</td>
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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
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DestinE needs to be the catalyst for reaching sufficient critical mass to deliver enough & on time

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