DESTINATION EARTH

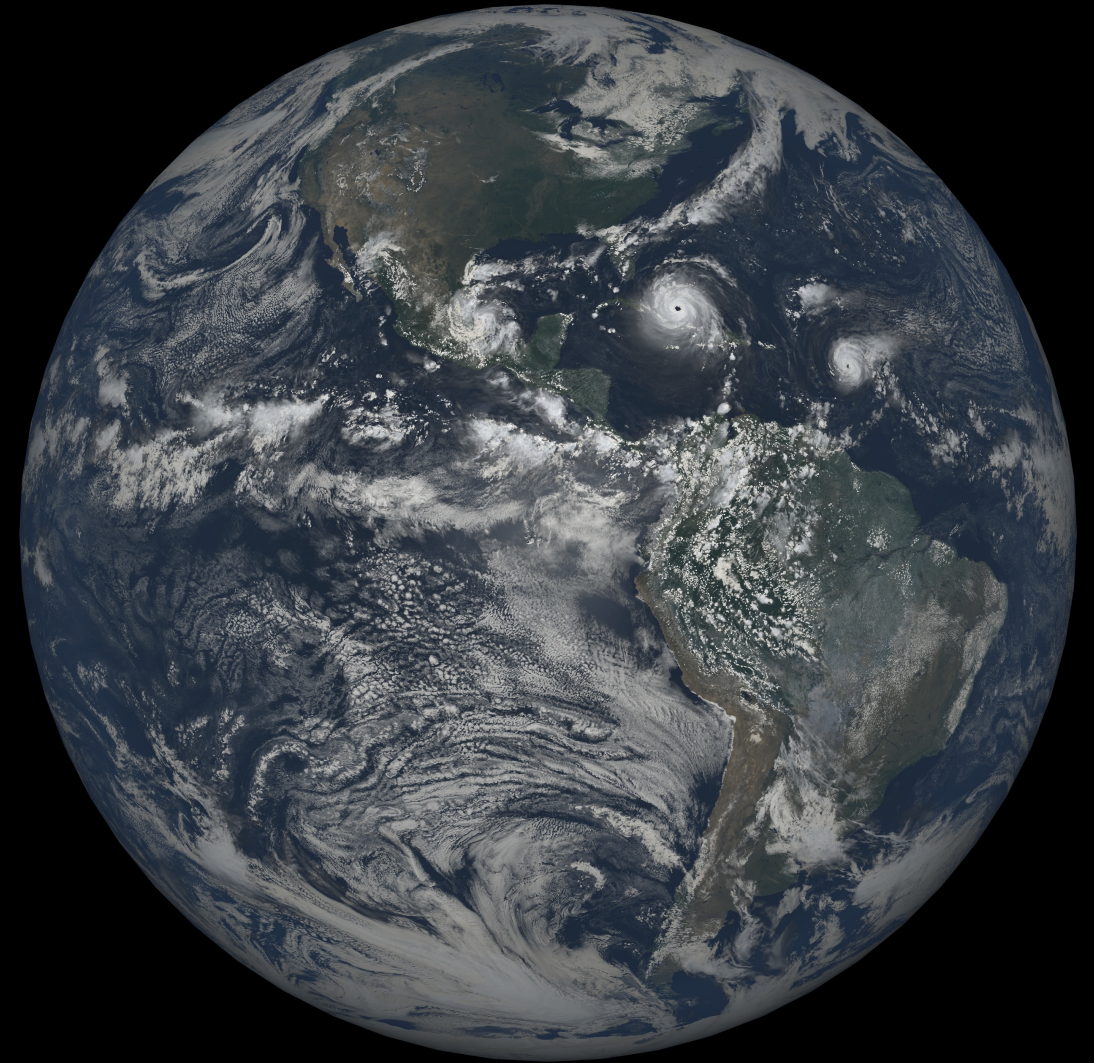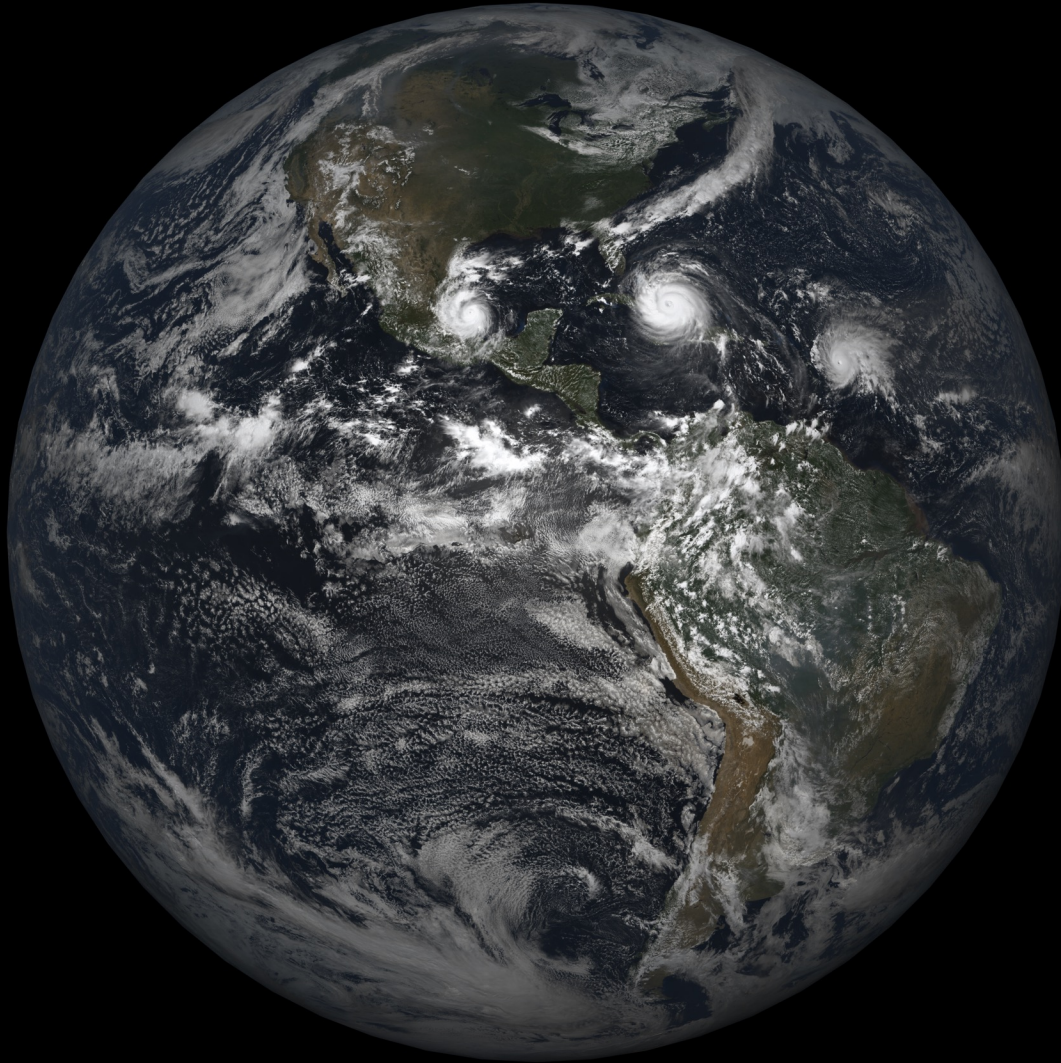## OPPORTUNITIES & CHALLENGES

Nils Wedi

Funded by the European Union
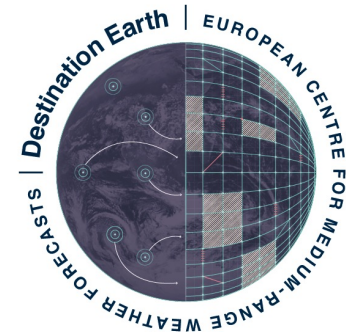
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RTTOV-MFASIS: simulated imagery in the visible.

GOES16_ABI CH2_3_1 composite 20170908 1800 UTC

IFS FC+18h at 2.5 km

Philippe Lopez

ECMWF's role in EU's Destination Earth (DestinE) initiative

Towards a Digital Twin Earth

DestinE entrusted entities

ECMWF is responsible for the delivery of:

The DestinE **Digital Twin Engine** (DTE):
- common approach for a unified orchestration of Earth-system simulations and their fusion with observations, requiring **large-scale HPC** and data handling resources

Weather-induced and Geophysical **Extremes Digital Twin**:
- capabilities and services for the assessment and prediction of **environmental extremes**

Climate Change Adaptation **Digital Twin**:
- capabilities and services in support of climate change **adaptation policies and mitigation scenario** testing

DIGITAL TWIN ENGINE

The Engine will provide the software infrastructure needed for

high-performance computing · data handling · simulation-observation fusion · machine learning · complex process optimisation · standardised Digital Twin interfaces

- Framework for Digital twins Workflows
  - HPC adaptation /DT optimisation
  - IO and data workflows
  - Software management, controlling workflows, cloud environments, visualization

- *Think of a Game Engine type framework but for Earth Systems…*
  - Collection of API's and Services
  - Opt-in initial components portfolio in DestinE:

Workflow manager (e.g. ecFlow)
Data structures and Parallelization library (Atlas)
Model Plugin architecture for interactive capabilities including ML/AI
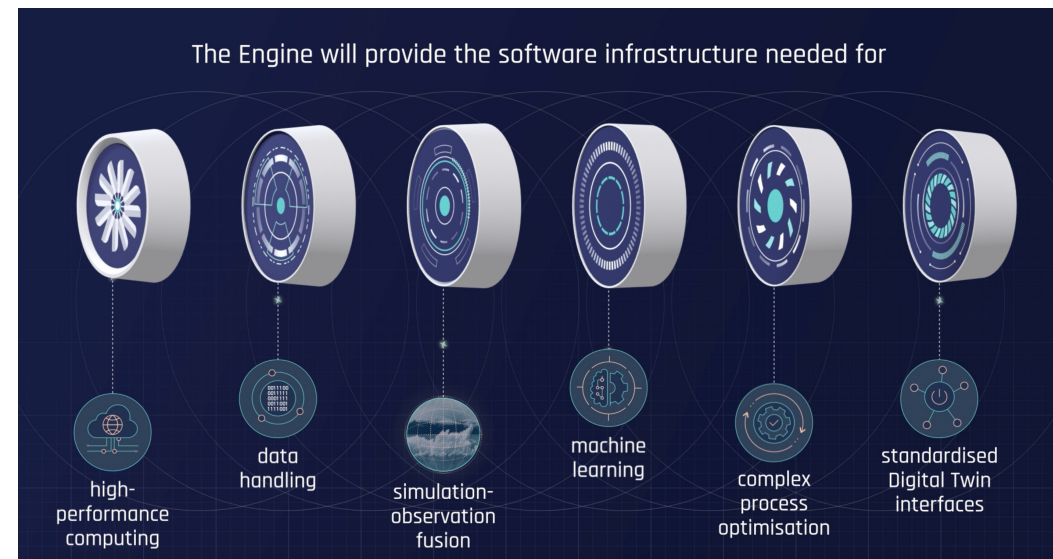**Key-Value Object Storage with Semantic Data access API (FDB)**
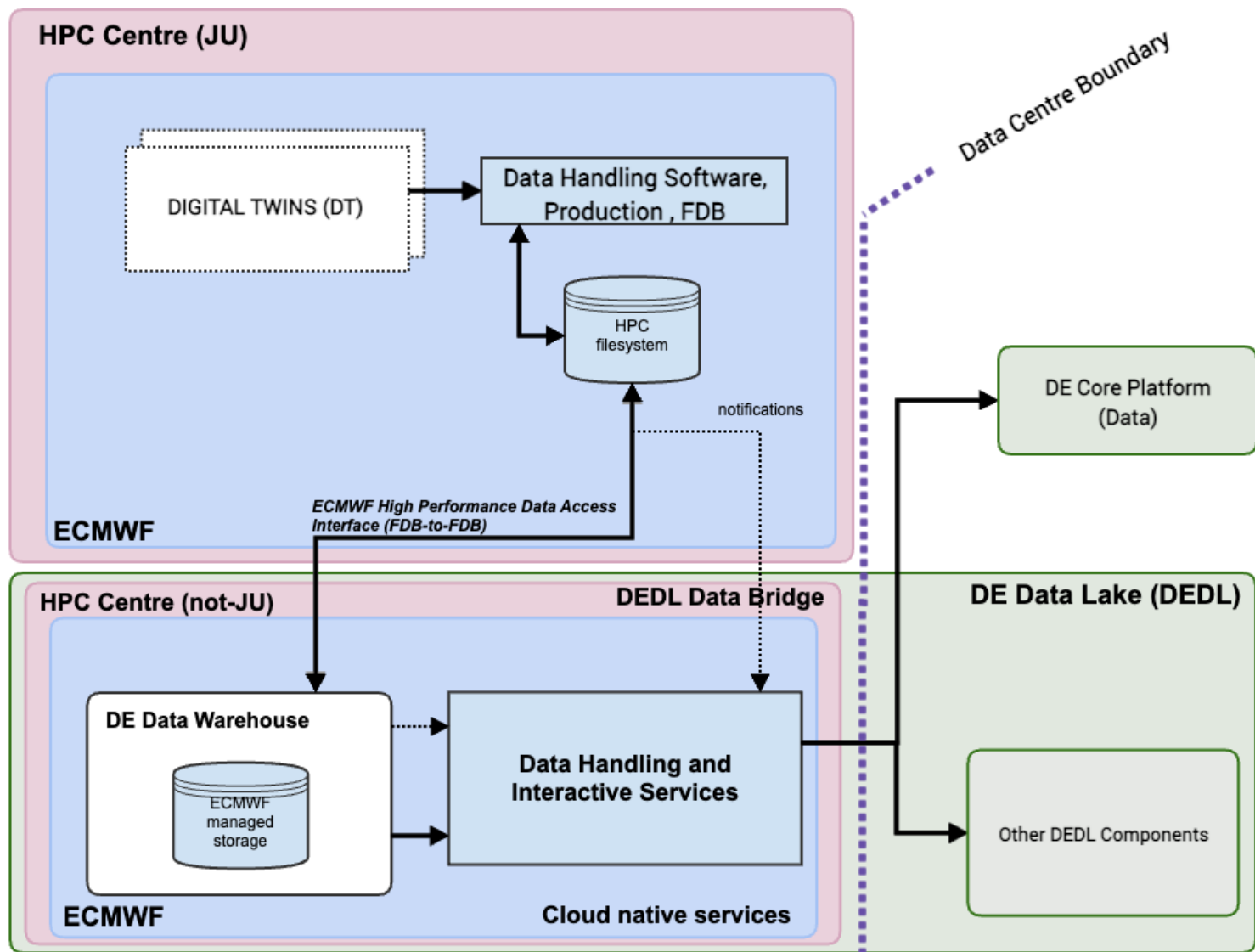**Multiplexing IO-Server API (MultIO)**
On-The-Fly Post-Processing API
Data Notification system (Aviso)
Data Cube API (Polytope)
Visualisation & Rendering services

ECMWF

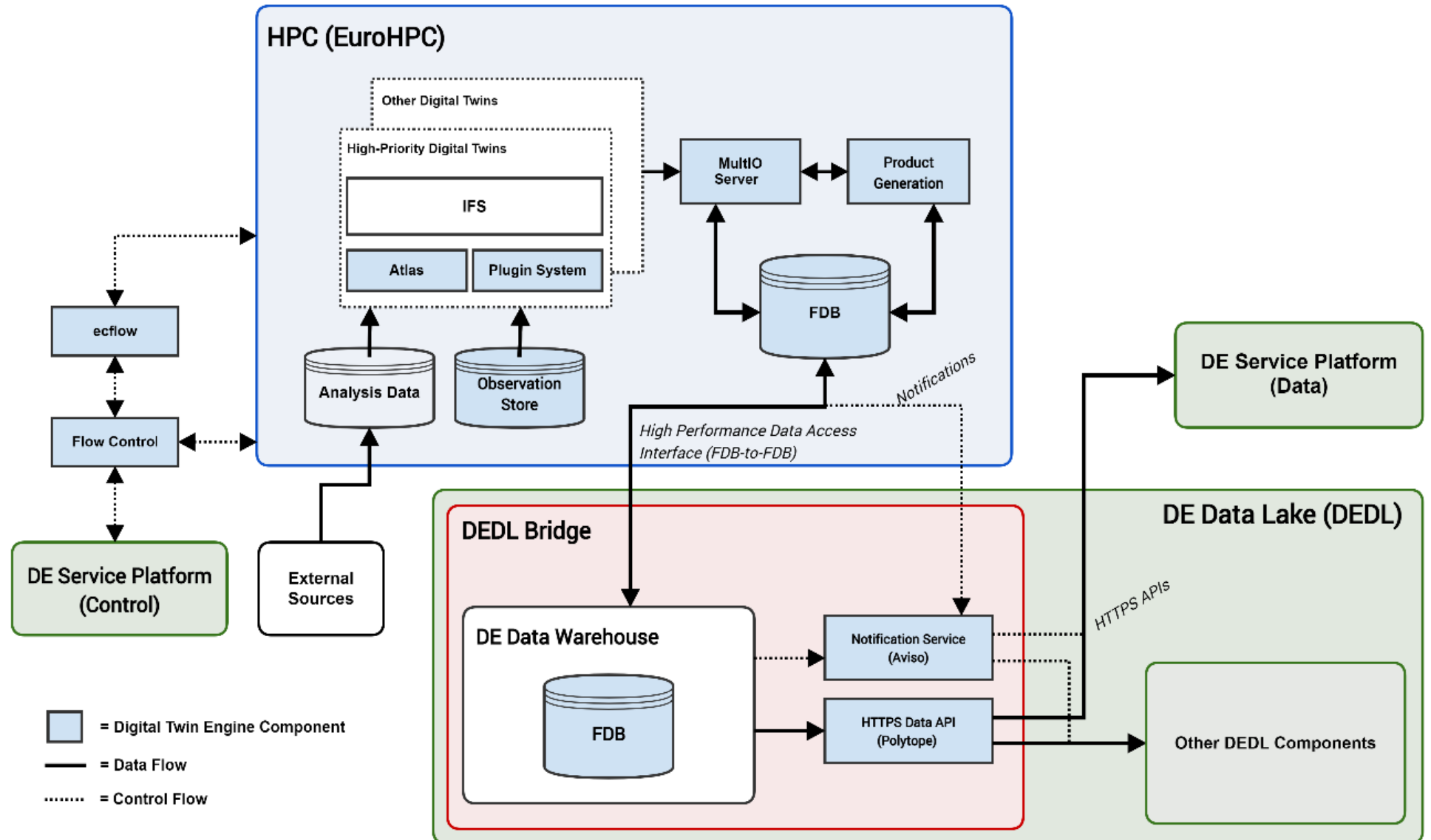# DIGITAL TWINS – HIGH LEVEL DESCRIPTION AND ARCHITECTURE AND LINK TO EUROHPC

Components of the Digital Twin Engine (DTE), spanning multiple infrastructure components of Destination Earth

DIGITAL TWINS – INTERFACES

- Generation & Streaming of DT data on the HPC
- Processing on the fly and product generation
- Seamless transfer to the DEDL data bridge
- Subsequent hyper-cube extraction of selected Earth-system information to serve user requests or internal DEDL components that further harmonise user-triggered data requests

Components of the Digital Twin Engine (DTE), spanning multiple infrastructure components of Destination Earth

6

EUROHPC: €8 BILLION PROGRAMME TOWARDS EXASCALE

#EuroHPC (high performance computing)
Joint Undertaking

The European High Performance Computing Joint Undertaking (EuroHPC JU) will pool European resources to develop top-of-the range exascale supercomputers for processing big data, based on competitive European technology.

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and Turkey.

EuroHPC Joint Undertaking

Supercomputers

Currently six EuroHPC supercomputers are under construction across Europe:

LUMI

LUMI Finland, 552/375 Pflops
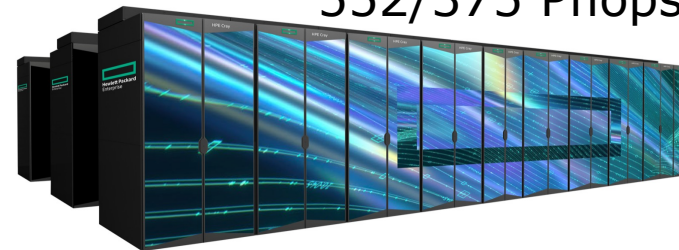
*from Sept 2022

© HPE

The LUMI system will be a Cray EX supercomputer supplied by Hewlett Packard Enterprise (HPE) and located in Finland.

Sustained performance:	375 petaflops
Peak performance:	552 petaflops
Compute partitions:	GPU partition (LUMI-G), x86 CPU-partition (LUMI-C), data analytics partition (LUMI-D), container cloud partition (LUMI-K)
Central Processing Unit (CPU):	The LUMI-C partition will feature 64-core next-generation AMD EPYC™ CPUs
Graphics Processing Unit (GPU):	LUMI-G based on the future generation AMD Instinct™ GPU
Storage capacity:	LUMI's storage system will consist of three components. First, there will be a 7-petabyte partition of ultra-fast flash storage, combined with a more traditional 80-petabyte capacity storage, based on the Lustre parallel filesystem, as well as a data management service, based on Ceph and being 30 petabytes in volume. In total, LUMI will have a storage of 117 petabytes and a maximum I/O bandwidth of 2 terabytes per second
Applications:	AI, especially deep learning, and traditional large scale simulations combined with massive scale data analytics in solving one research problem
Other details:	LUMI takes over 150m2 of space, which is about the size of a tennis court. The weight of the system is nearly 150 000 kilograms (150 metric tons)

- 3 large (O(100PFlops)) supercomputers in Finland, Italy, Spain
- 5 smaller ones (size of Archer in UK) in Luxembourg, Slovenia, Portugal, Czech Republic, Bulgaria
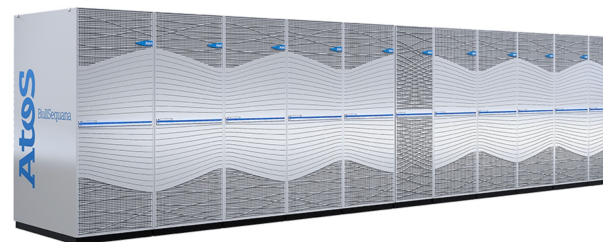- 1-2 high-end supercomputer (~1000 Pflops) by 2024

MareNostrum 5
~314 Pflops
*from July 2023

*from March 2023
Leonardo Italy: 322/249 PFlops

LEONARDO

© Atos

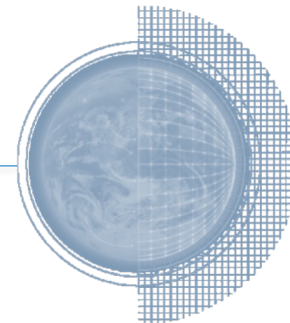LEONARDO will be supplied by ATOS, based on a BullSequana XH2000 supercomputer and located in Italy.
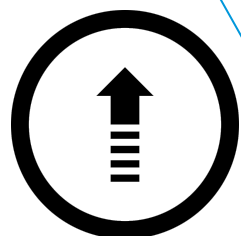
Sustained performance:	249.4 petaflops
Peak performance:	322.6 petaflops
Compute partitions:	Booster, hybrid CPU-GPU module delivering 240 PFlops, Data-Centric, delivering 9 Pflops and featuring DDR5 Memory and local NVM for data analysis
Central Processing Unit (CPU):	Intel Ice-Lake (Booster), Intel Sapphire Rapids (data-centric)
Graphics Processing Unit (GPU):	NVIDIA Ampere architecture-based GPUs, delivering 10 exaflops of FP16 Tensor Flow AI performance
Storage capacity:	Leonardo is equipped with over 100 petabytes of state-of-the-art storage capacity and 5PB of High Performance storage
Applications:	The system targets: modular computing, scalable computing applications, data-analysis computing applications, visualization applications and interactive computing applications, urgent and cloud computing
Other details:	Leonardo will be hosted in the premises of the Tecnopolo di Bologna. The area devoted to the EuroHPC Leonardo system includes 890 sqm of data hall, 350 sqm of data storage, electrical and cooling and ventilation systems, offices and ancillary spaces

a maximum of **10% of the Union's access time for strategic initiatives**.

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Workflows

(1) Investment in adaptation to emerging & diverse HPC

fast & flexible user interface

extremes & hazard management

climate change adaptation

Cloud Computing

analytics

interactive workflow management

extreme-scale compute and data handling

big data handling

Simulated Observed Observed Simulated

data lakes

(2) Prototyping cloud-technology based IT infrastructures suitable for data & compute intensive HPC tasks

Cloud Computing

production

High-performance & Cloud computing

Digital twin engine

Internet of things **Earth observation** **Earth system models**

methodologies
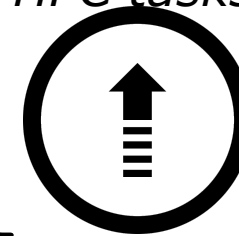
full integration of impact sectors

(3) Edge-computing On-the-fly processing ML/AI data pipelines Hypercube data access

A science-to-services paradigm
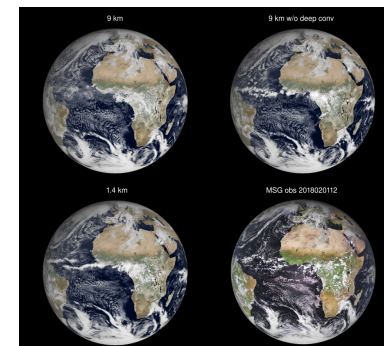
Digital twins

DestinE's first two high priority Digital Twins: Content
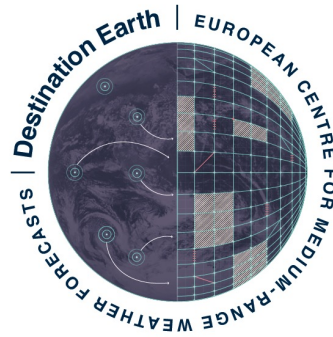
Extremes and Climate DT:

- Earth-system observation fusion/assimilation and initialization
- Earth-system modelling and simulations **at storm-resolving scale, a few days ahead/multi-decadal**
- On-demand/configurability
- Use cases for selected impact-sectors
- Evaluation and uncertainty quantification
- Workflow set-up and monitoring on pre-exascale EuroHPC systems
- End-to-end demonstration at scale with timely delivery

ECMWF

On-demand Extremes DT

Flexible and scalable workflows for the monitoring and short-range prediction of extremes at sub-km scales, that are configurable and operable on demand; builds on the ACCORD prediction system and selected impact models

Meteo-France led consortium

Today's prediction systems

Examples of configurability

Participant Countries and agencies

Sweden Spain Slovenia Slovakia Portugal Poland Netherlands Lithuania Latvia
Ireland Iceland Hungary Finland Estonia Denmark Czech Republic Croatia Bulgaria
Belgium Austria France Norway
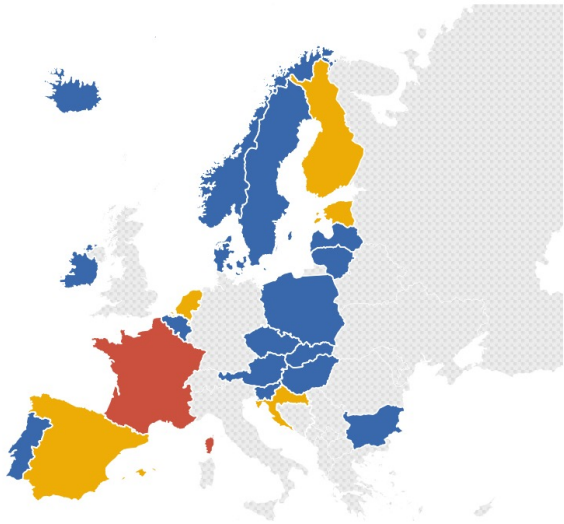
Source: MeteoFrance • Hover in the countries to read the entities involved.
Yellow: Countries with another agency involved in addition to the National Meteorological service.

A Flourish map

ECMWF

Continuous Extremes DT – initial extreme events cases (2016-2022)

5 days forecasts at 4.5 km with ECMWF IFS (and 9 and 29km equivalents)
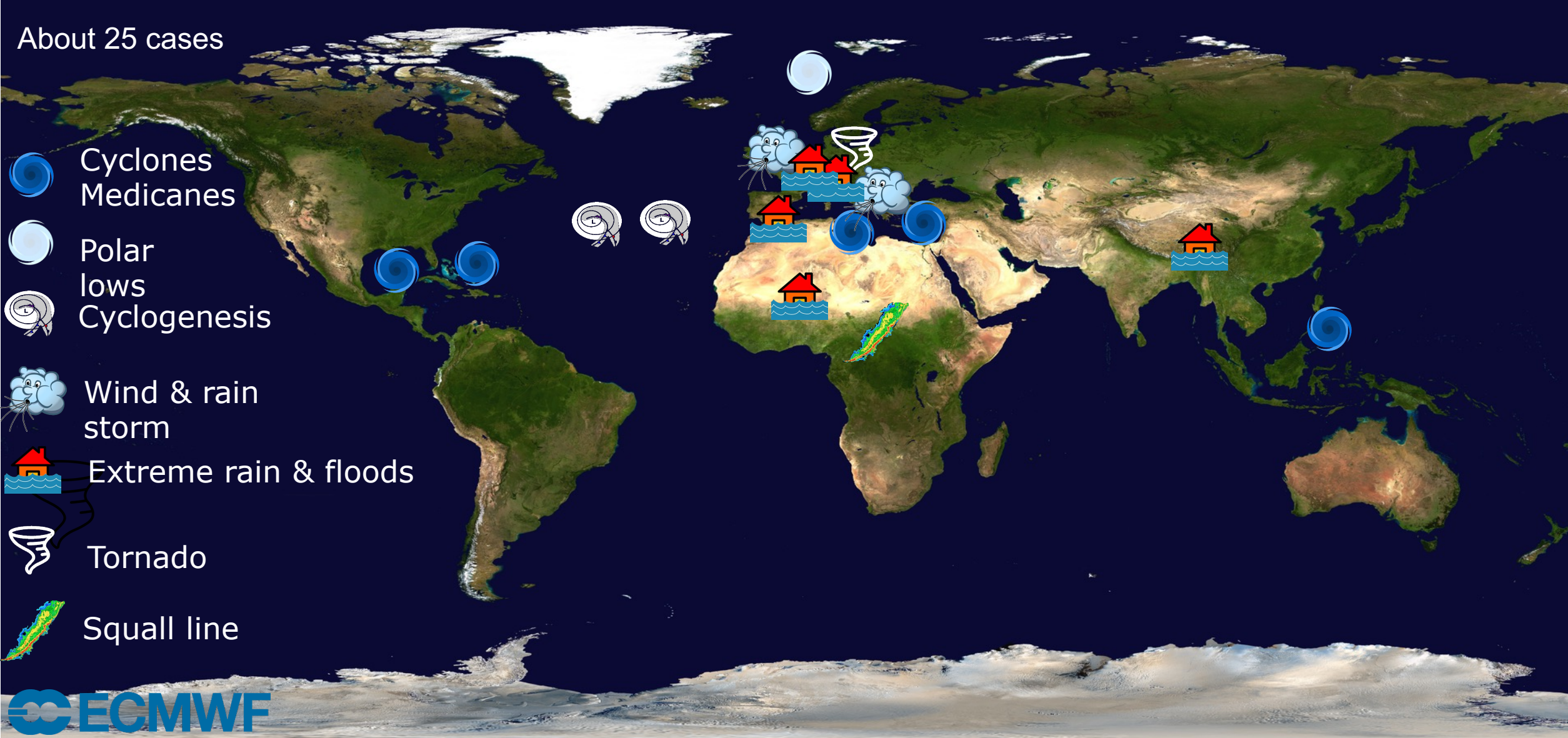
DestinE's Digital Twins: Quality + Impacts + Interaction
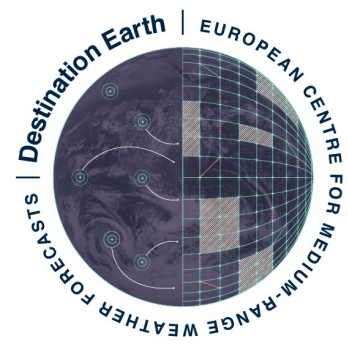
1. **Better simulations** based on **more realistic models**

2. **Better ways of combining all observed and simulated information** from entire Earth system = physical + food/water/energy/health **supporting action scenarios**

3. **Interactive and configurable access to all data, models and workflows**

c. N Koldunov

c. T. Rackow

c. G. Balsamo

More realistic at *global* scale

More realistic at *local* scale

Include impacts where they matter

Trial different adaptation and mitigation scenarios
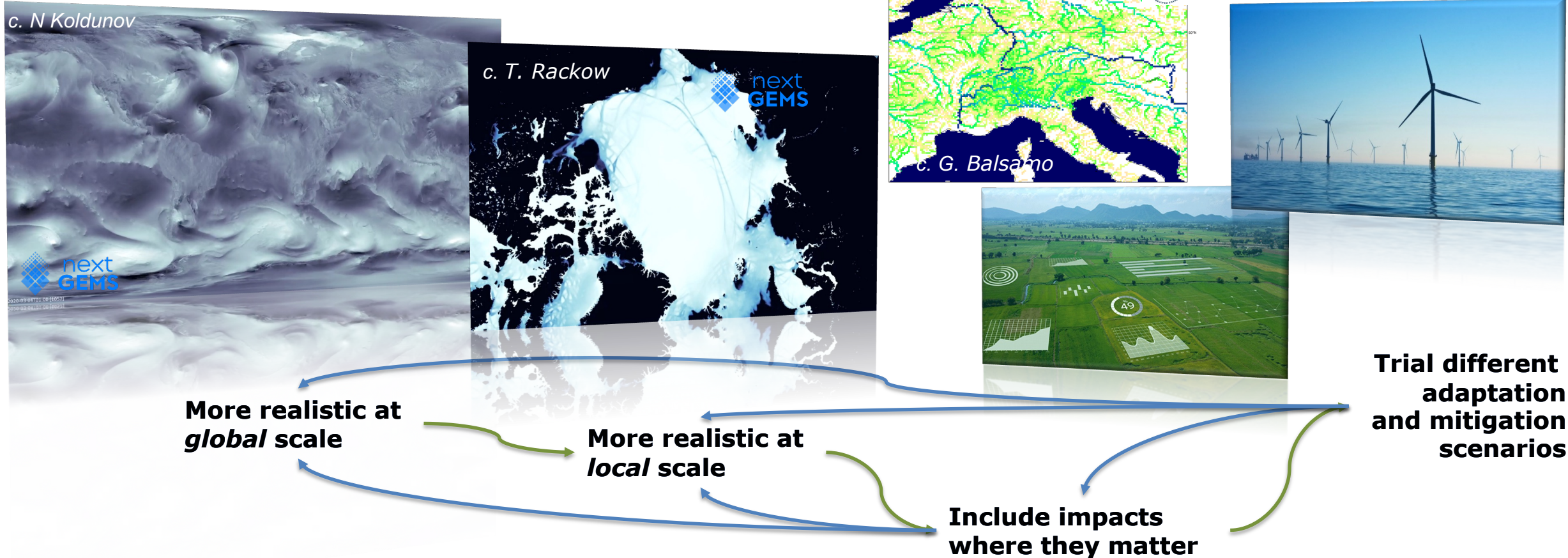
Working together – regular workstream development sprints

e-suite for DestinE Q2 2023

Deploy on demand

workstream 1
Adaptation & Simulations
Balthasar Reuter

- **Feature**
- **Enabler**
- **Enabler**
- **Feature**

adaptation of physics (LOKI), wave model, spectral transforms to GPU (AMD+Nvidia),

incorporate and test/link I/O prototypes

integrate into IFS branch, demonstrate and run within RAPS on LUMI/Meluxina

allow scientists to run on EuroHPC (LUMI/Meluxina) research experiments on 48r1; improve scalability

demonstrate plugins for AI and auxiliary workflows (e.g. flexible processing alongside running DT);
AI/ML analytics tools

workstream 2
CI/CD, workflow control, cloud, visualization
Andrew Bennett / Vasilis Baousis

- **Enabler**
- **Feature**
- **Feature**
- **Enabler**

explore containerization as alternative workflows

prepare for remote data processing

prepare for simplified remote workflow control for forecast only

on-demand deployment and provision of control for plugins

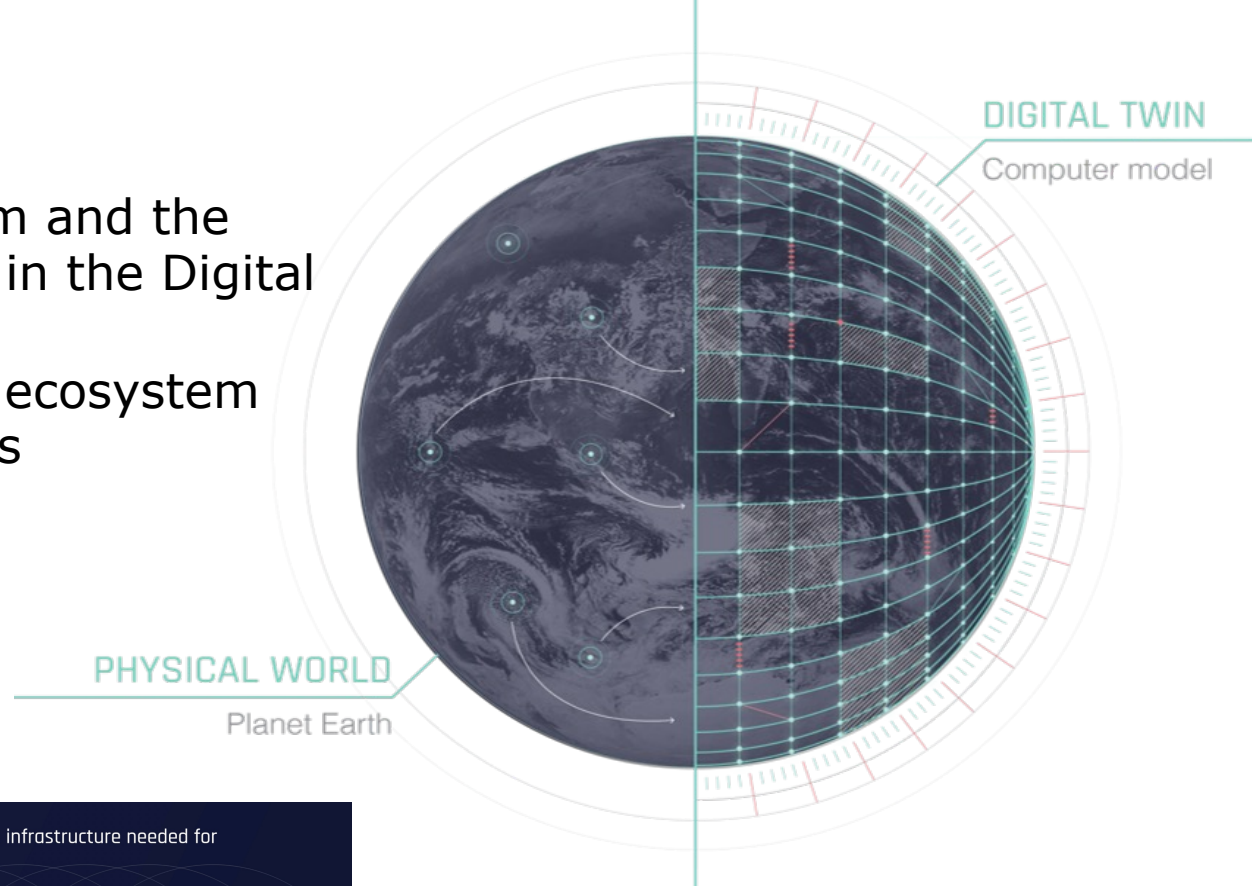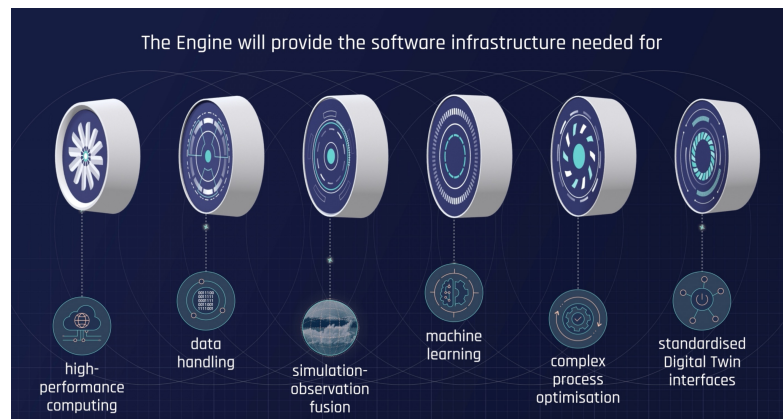prepare esuite in coordination with science

Deploy performance monitoring tools

analysis at ECMWF, forecast, verification & archive at EuroHPC

enable cloud-native verification/visualization /modelling
on DT data supporting use cases/impacts

workstream 3
I/O, data workflows
Simon Smart

- **Feature**
- **Enabler**
- **Enabler**
- **Feature**

prototype FDB/mult-IO, incl compression on grib2 data, data transfer

prototype for ecflow with remote/web interface

optimization of data workflows; data bridge / data lake connection ; AI/ML access of data

routine data production, governance and availability in data lake portfolio for human and machine readable access

DIGITAL TWIN ENGINE

DIGITAL TWIN
Computer model

- Developments of digital twins of the Earth System and the supporting software and standards encapsulated in the Digital Twin Engine (DTE) components
- Earth-system data accessible in the wider digital ecosystem including associated compute & storage resources
- Working together to address complexity!

PHYSICAL WORLD
Planet Earth

The Engine will provide the software infrastructure needed for

high-performance computing · data handling · simulation-observation fusion · machine learning · complex process optimisation · standardised Digital Twin interfaces
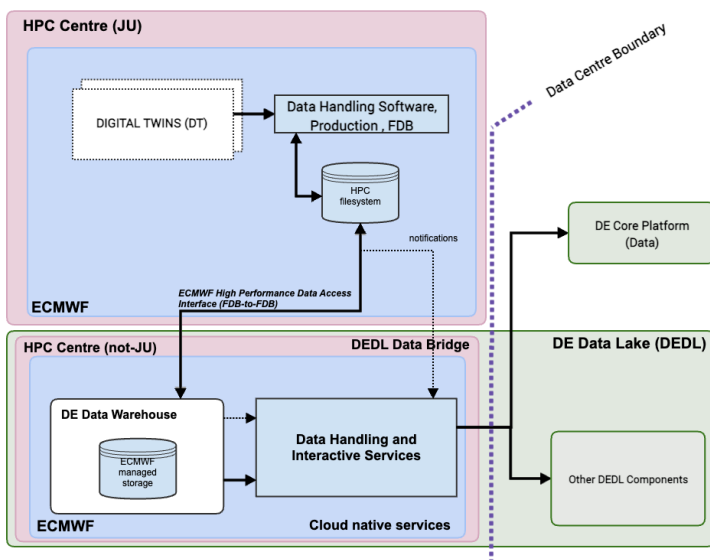
www.ecmwf.int/destine

Funded by the European Union

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EUMETSAT