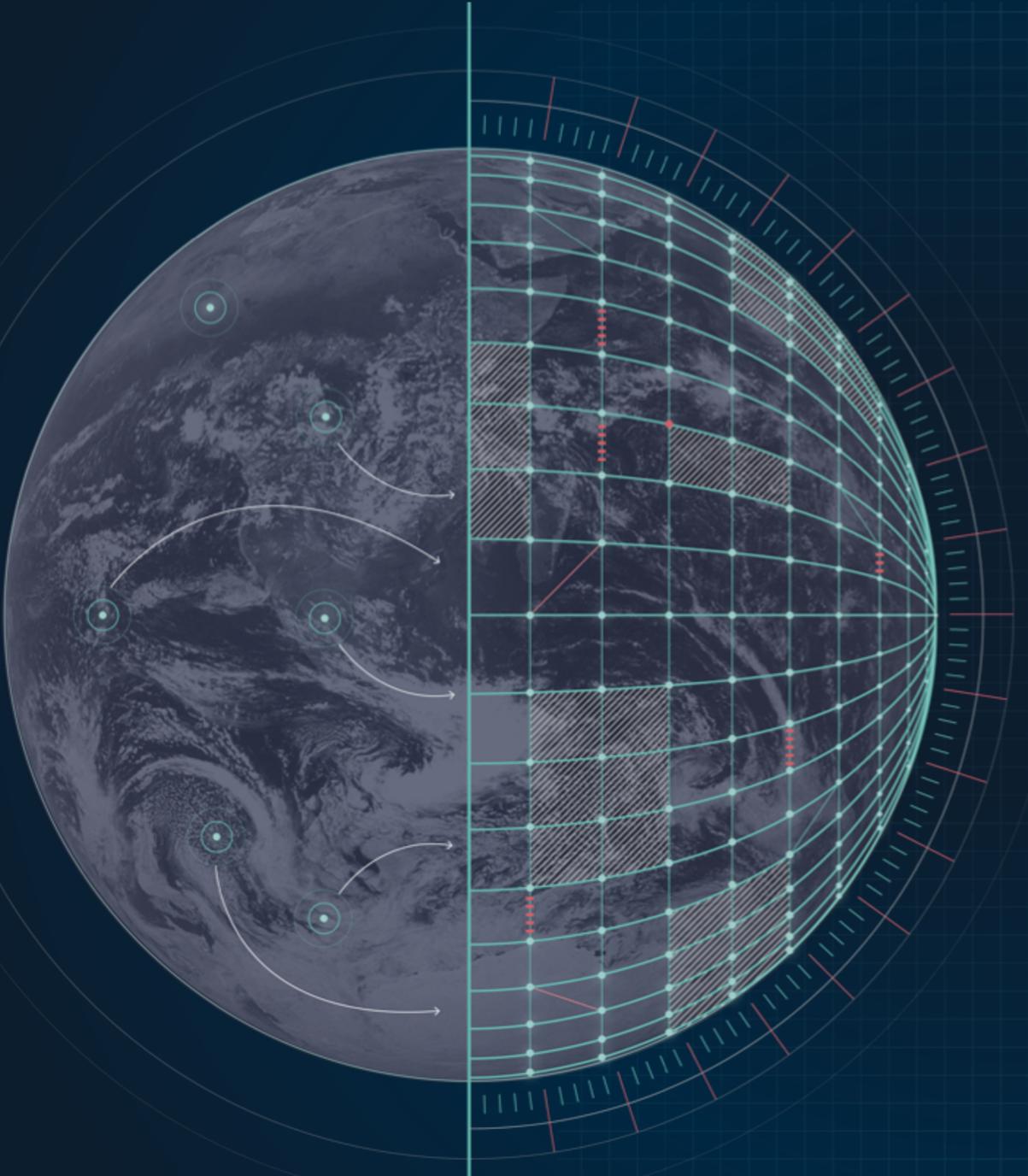


# DESTINATION EARTH

## OPPORTUNITIES & CHALLENGES FOR DIGITAL TWINS OF THE EARTH SYSTEM

Nils Wedi



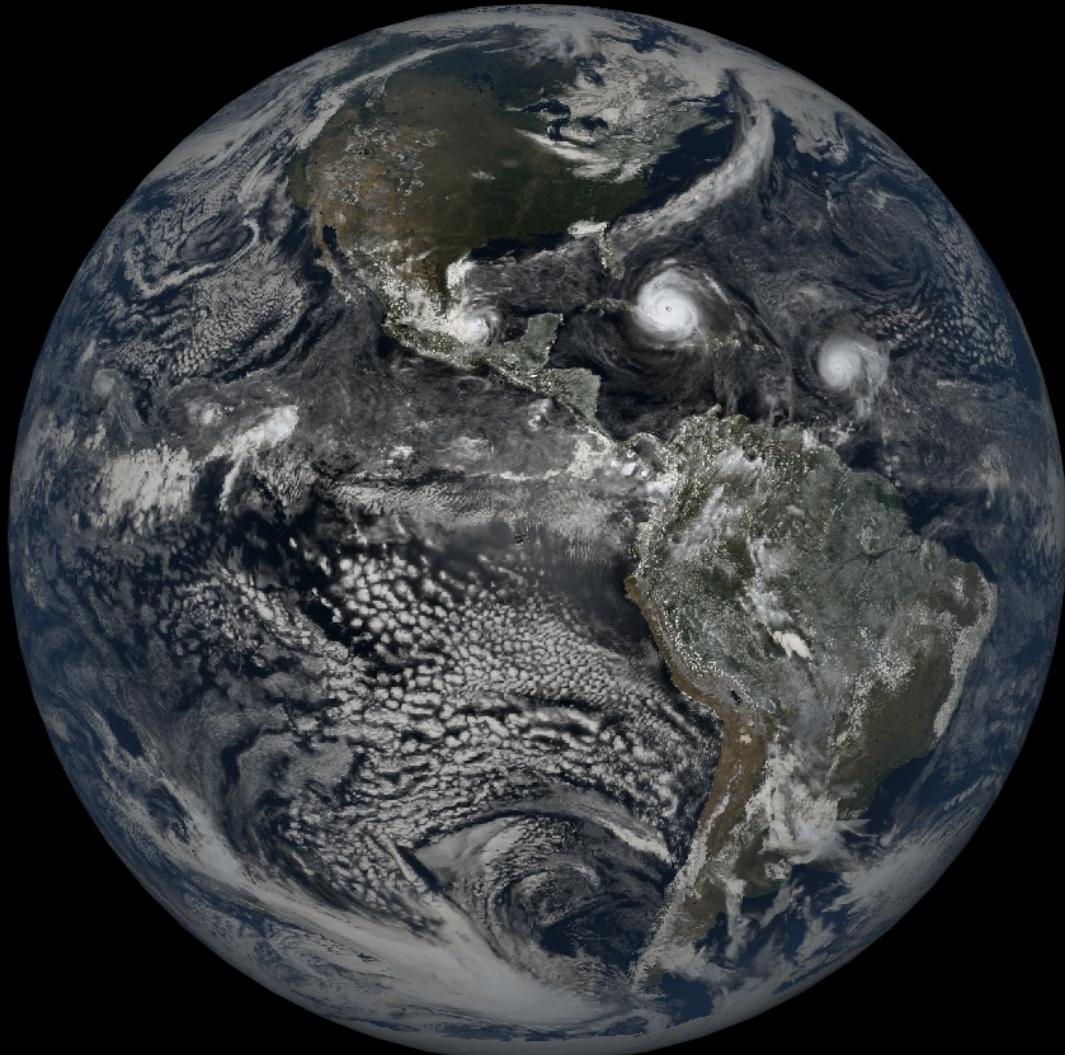
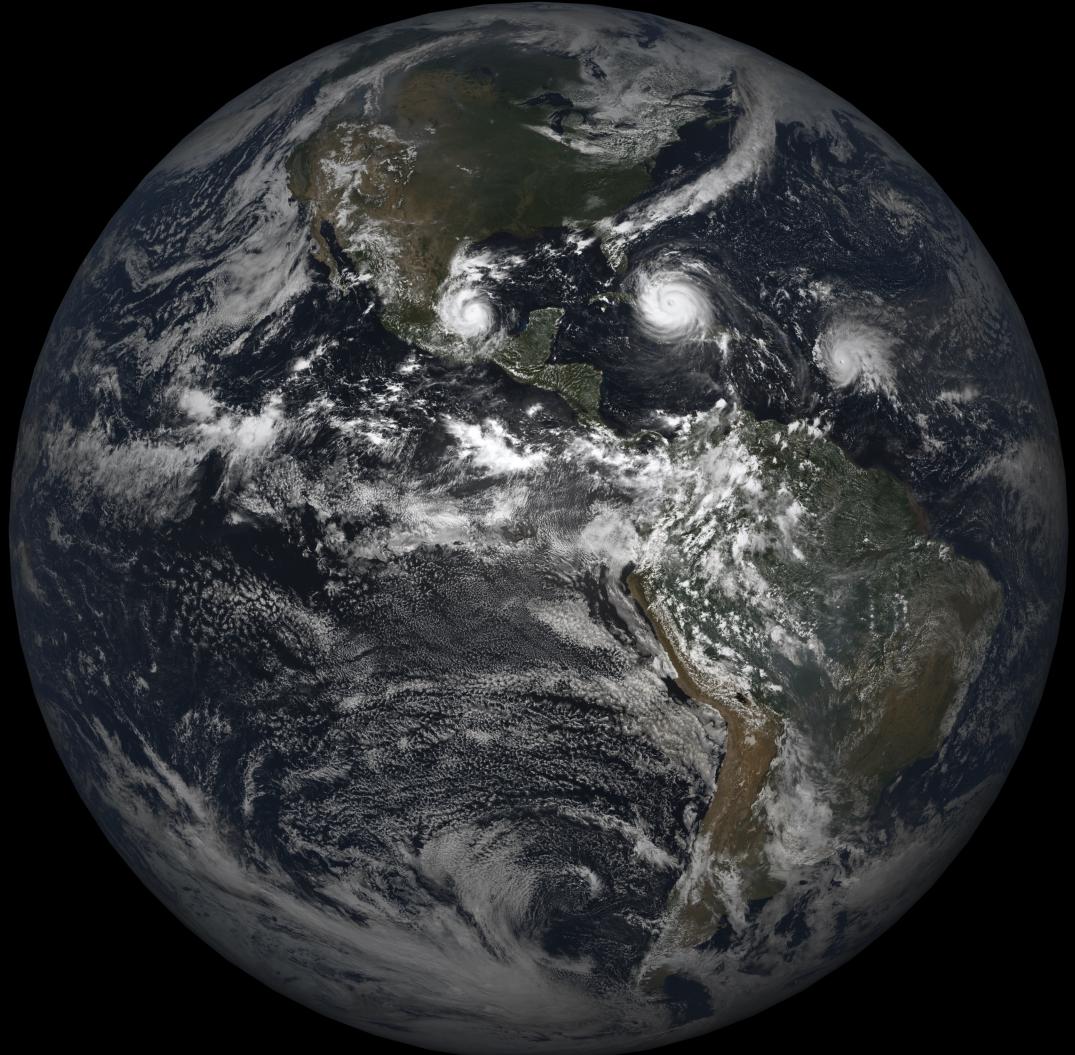
Funded by the  
European Union



# RTTOV-MFASIS: simulated imagery in the visible..

GOES16\_ABI CH2\_3\_1 composite 20170908 1800 UTC

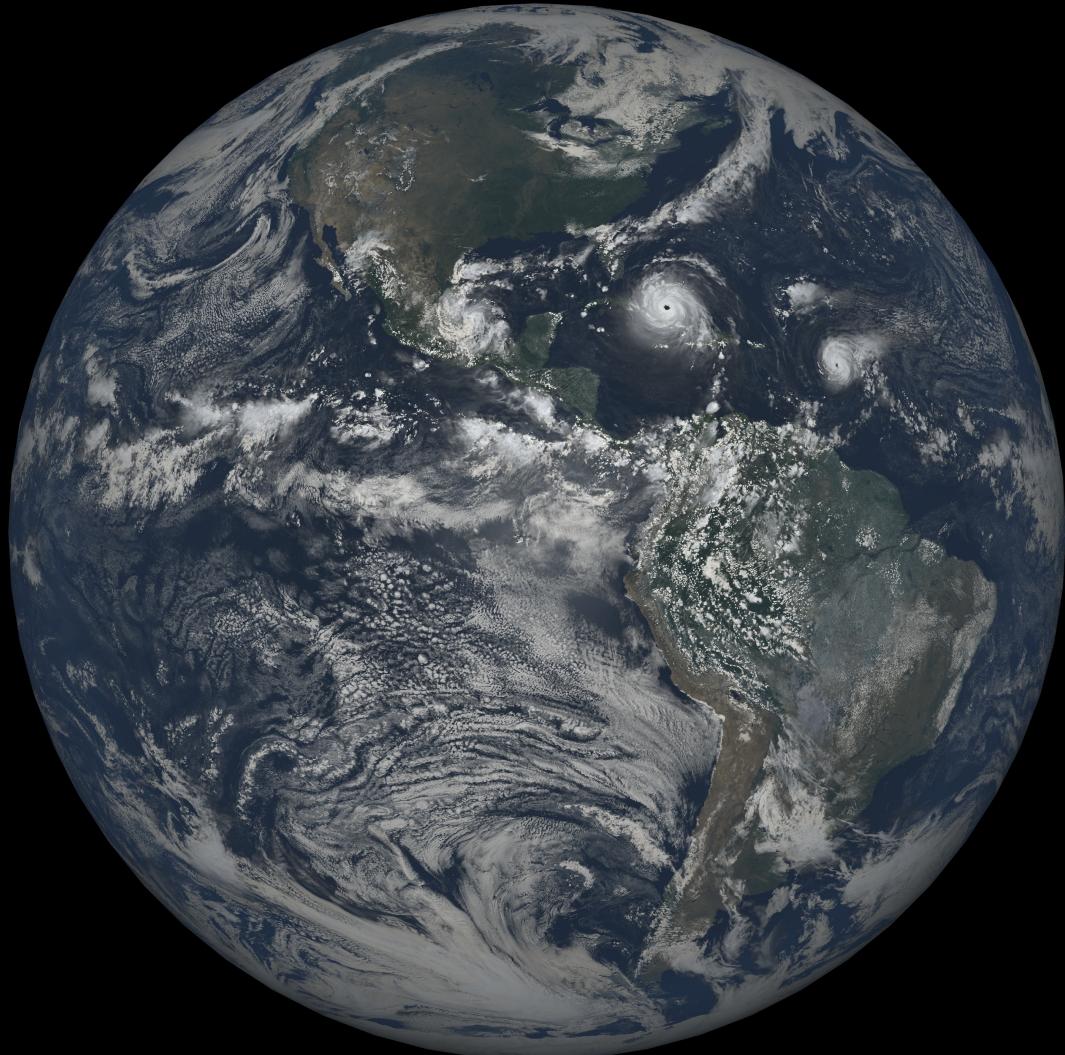
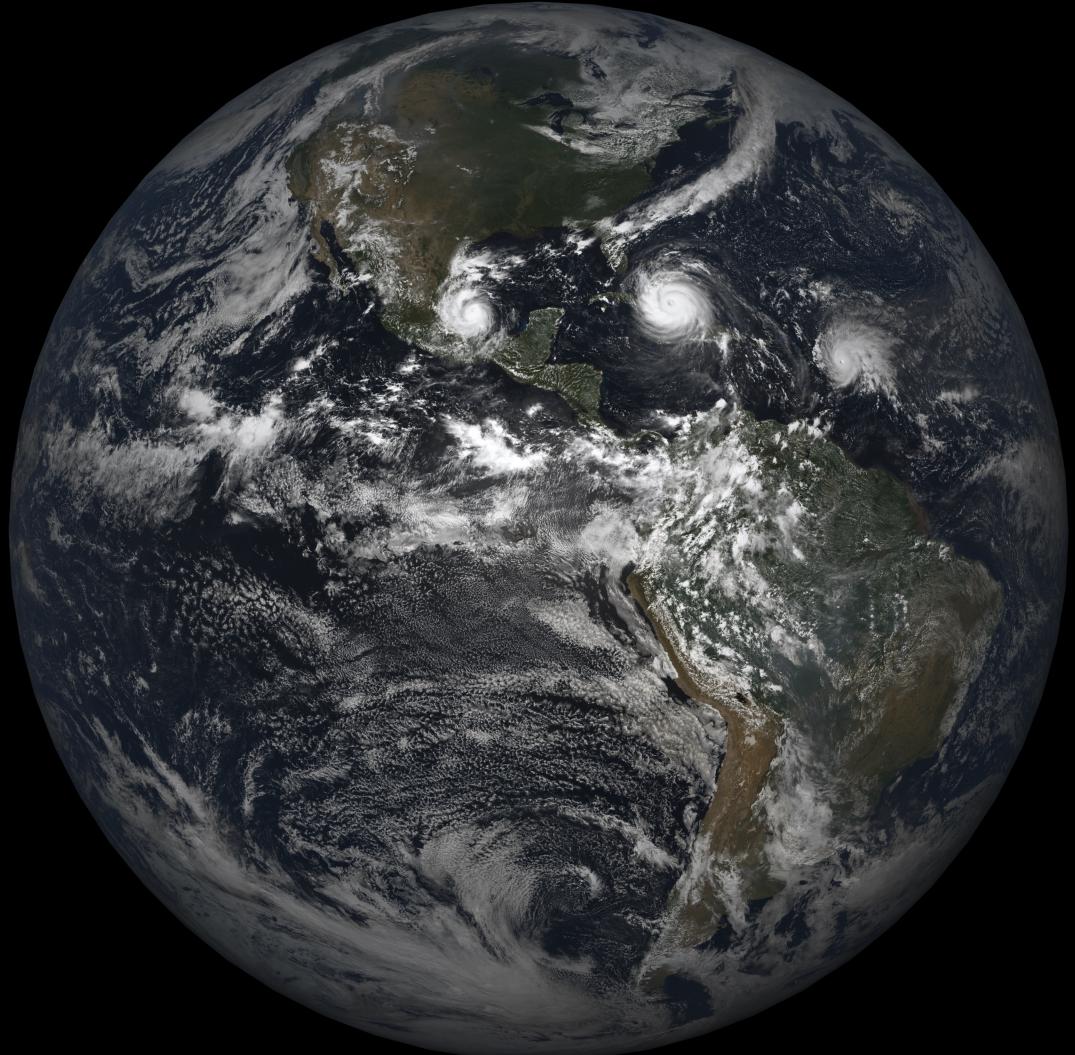
IFS FC+18h at 9 km (oper)



# RTTOV-MFASIS: simulated imagery in the visible..

GOES16\_ABI CH2\_3\_1 composite 20170908 1800 UTC

IFS FC+18h at 2.5 km

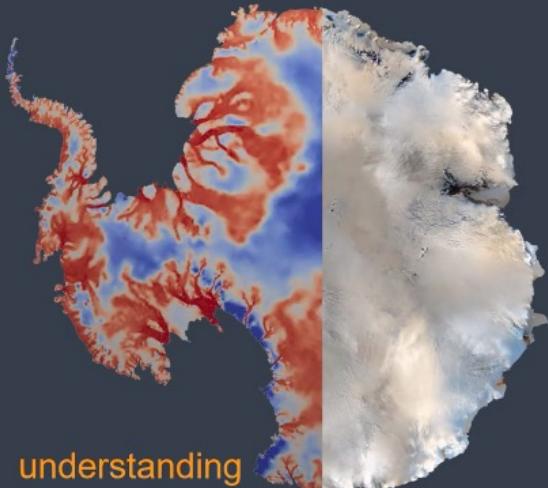


# Digital Twins

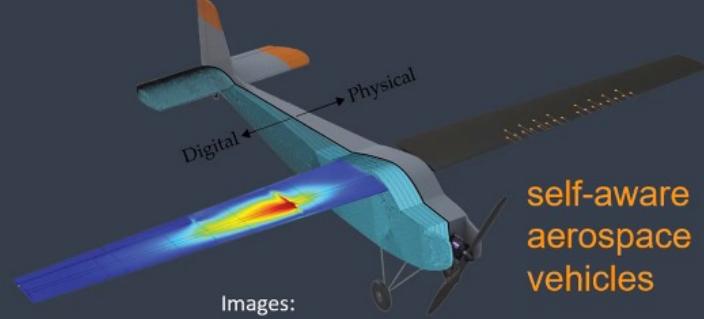
Digital twins have the potential to revolutionize decision-making across science, technology & society



Digital ← → Physical

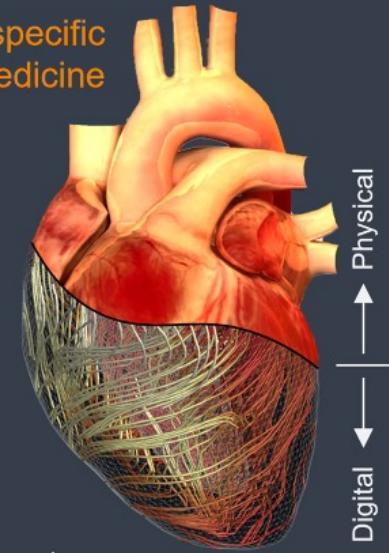


Images:  
O. Ghattas



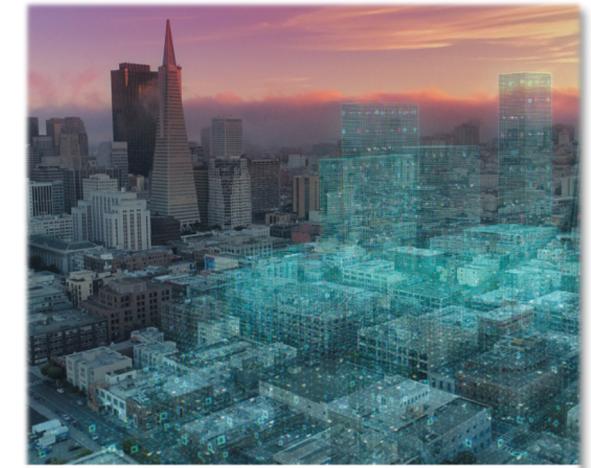
Images:  
M. Kapteyn,  
K. Willcox

patient-specific  
medicine



Images:  
G. Foss, H. Liu,  
M. Sacks

Courtesy Karen Willcox, U TX



Make more  
digital twins

Virtual models boost smart manufacturing by simulating decisions and optimization, from design to operations, explain Fei Tao and Qinglin Qi.

# New horizons of machine learning, autonomous driving & gaming engines blurring the real and the physical world



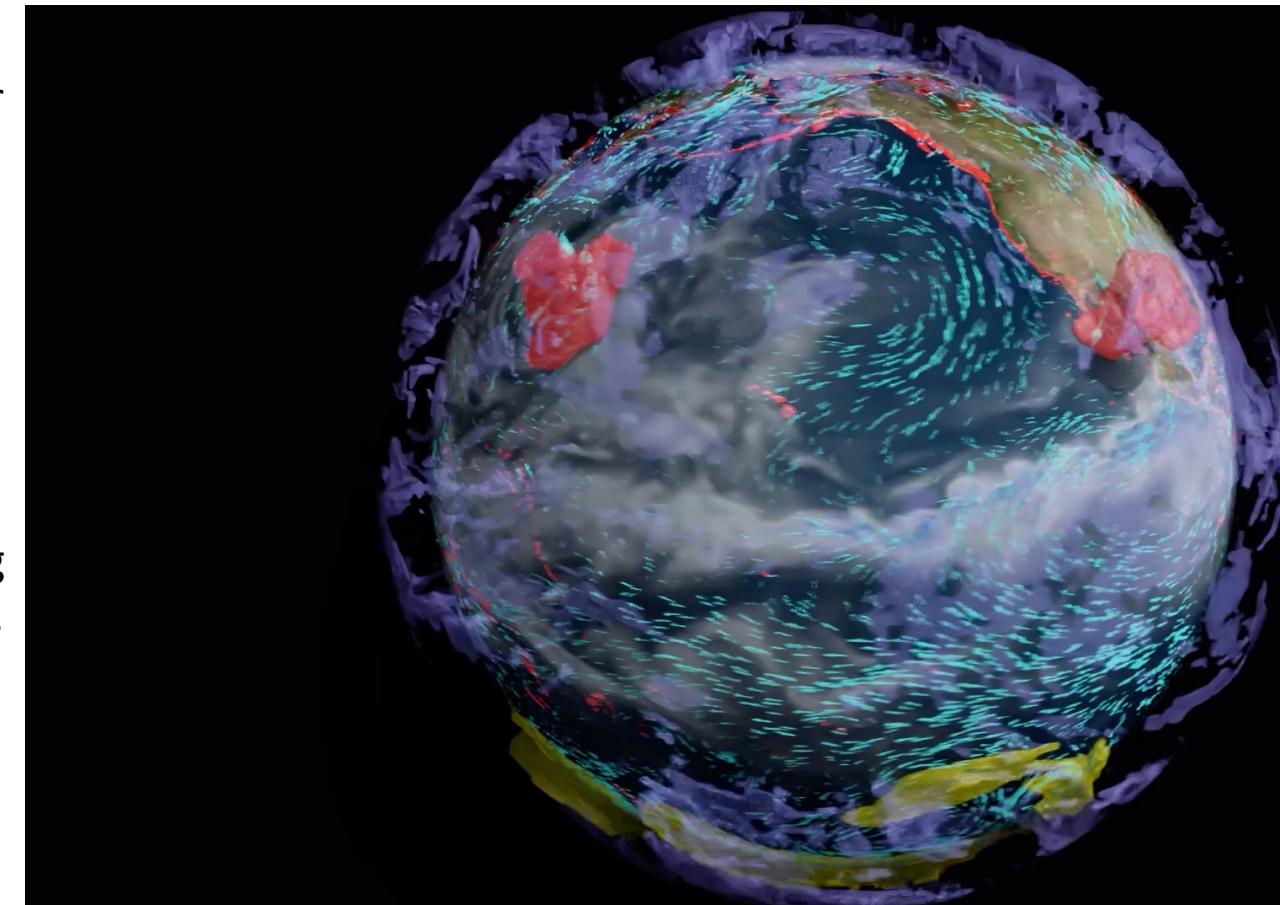
HOME    AI    DATA CENTER    DRIVING    GAMING    PRO GRAPHICS    AUTONOMOUS MACHINES    HEALTHCARE    STARTUPS    AI PODCAST

## NVIDIA to Build Earth-2 Supercomputer to See Our Future

November 12, 2021 by JENSEN HUANG

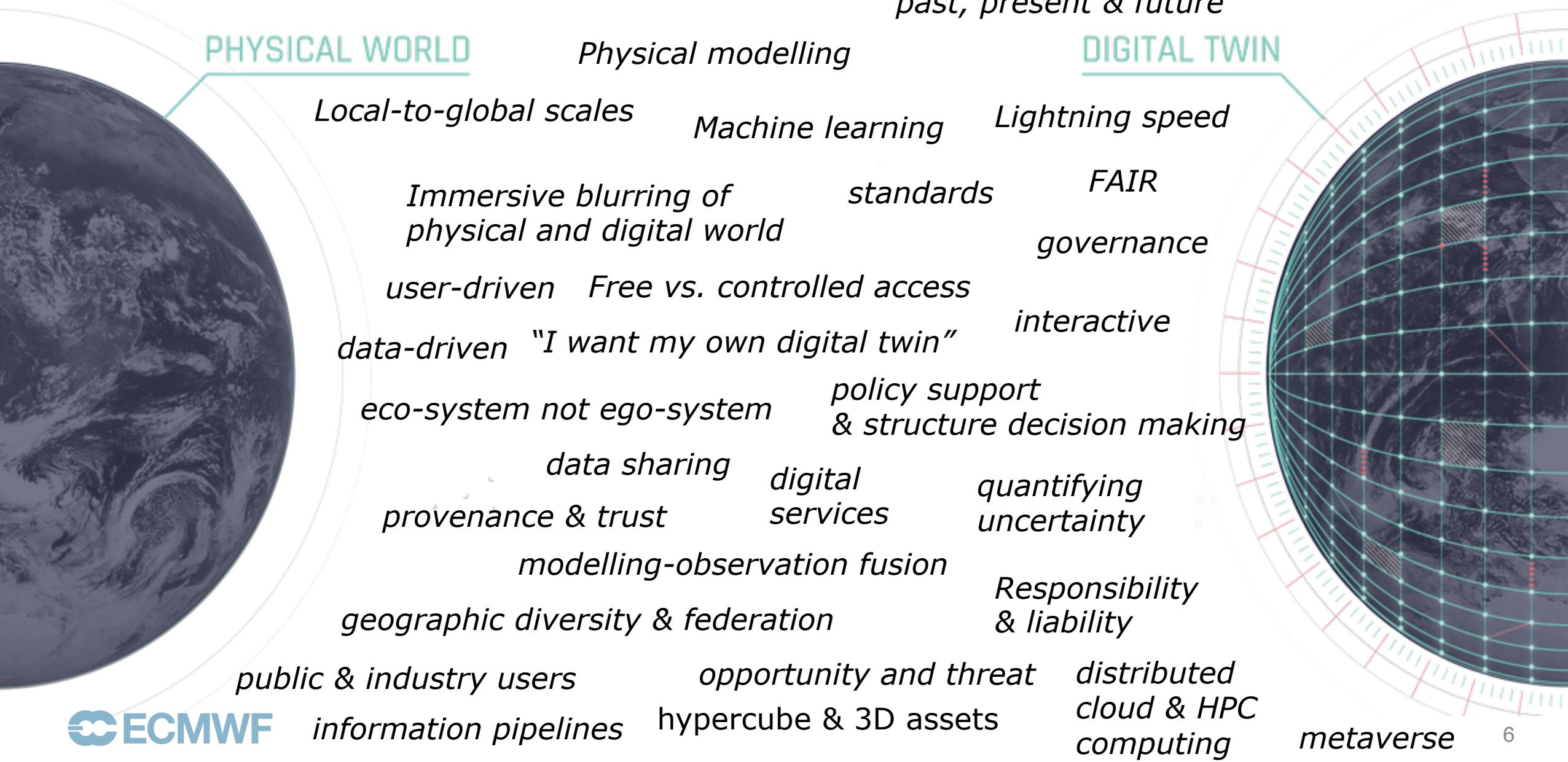
“So, we will dedicate ourselves and our significant resources to direct NVIDIA’s scale and expertise in computational sciences, to join with the world’s climate science community.

NVIDIA revealed plans to build the world’s most powerful AI supercomputer dedicated to predicting climate change. Named Earth-2, or E-2, the system would create a digital twin of Earth in [Omniverse](#).“



# MANAGING PERCEPTIONS – WHAT IS A DIGITAL TWIN (DT) ?

*digital factory      change of perspective  
past, present & future*



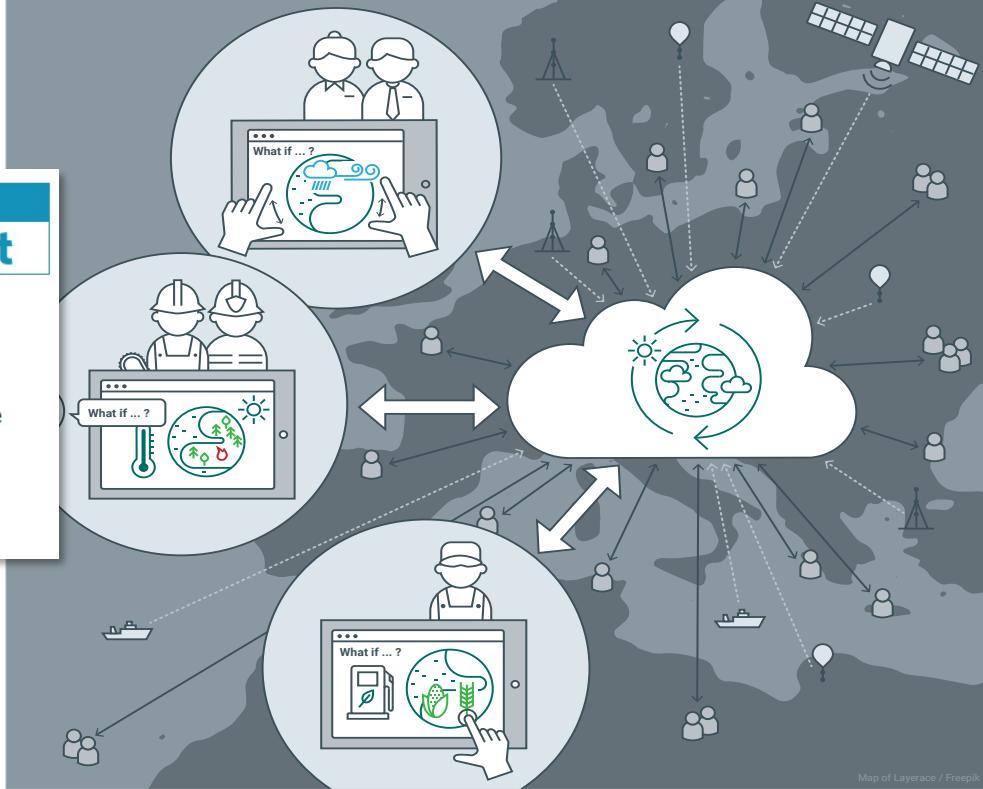
Check for updates

comment

## A digital twin of Earth for the green transition

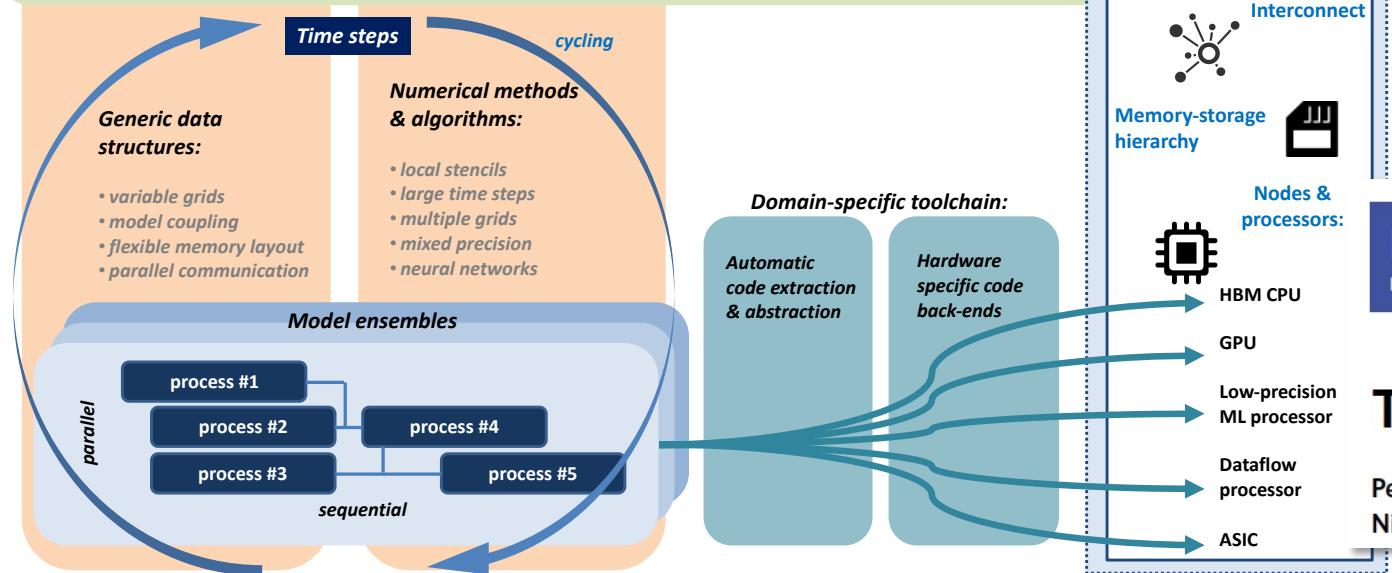
For its green transition, the EU plans to fund the development of digital twins of Earth. For these twins to be more than big data atlases, they must create a qualitatively new Earth system simulation and observation capability using a methodological framework responsible for exceptional advances in numerical weather prediction.

Peter Bauer, Bjorn Stevens and Wilco Hazeleger



### 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



## PERSPECTIVE

<https://doi.org/10.1038/s43588-021-00023-0>

nature  
computational  
science

Check for updates

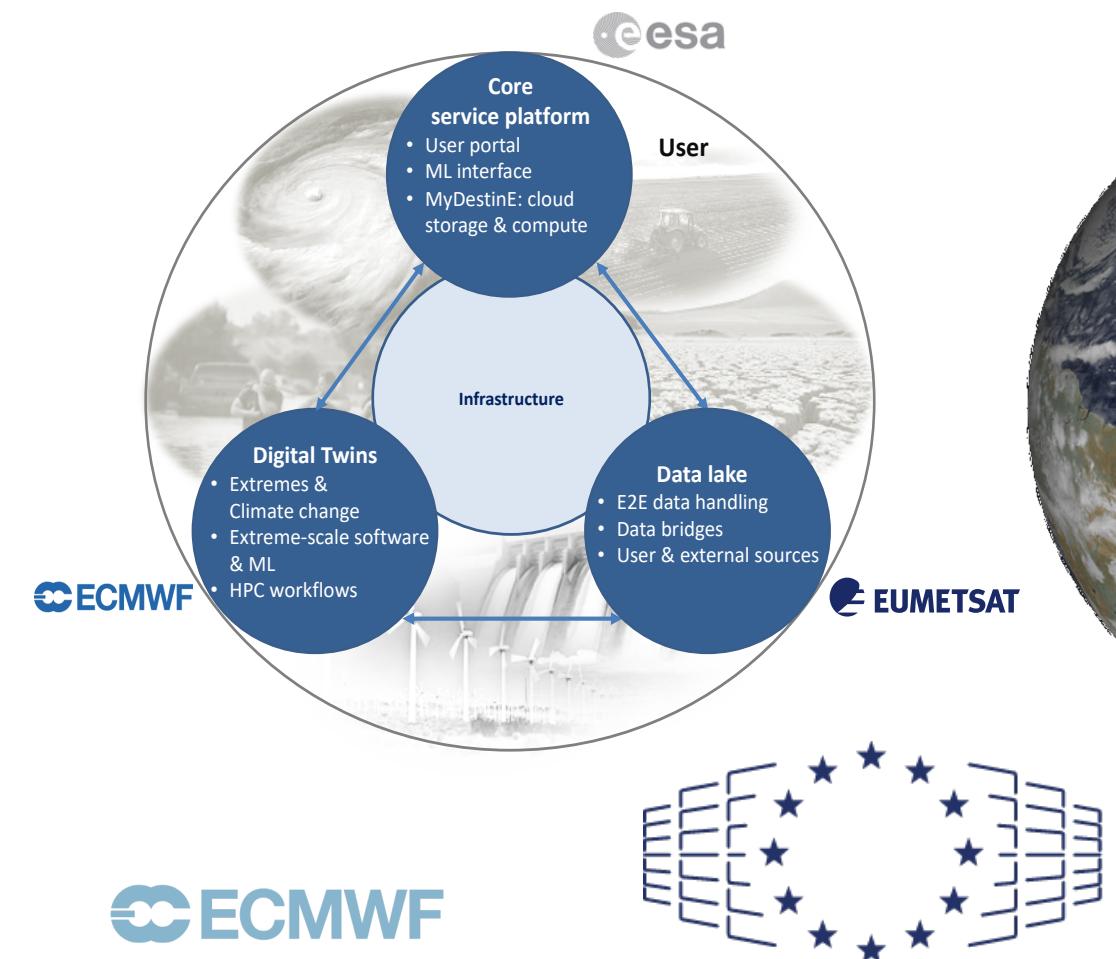
## The digital revolution of Earth-system science

Peter Bauer <sup>1</sup>✉, Peter D. Dueben<sup>1</sup>, Torsten Hoefer<sup>2</sup>, Tiago Quintino <sup>3</sup>, Thomas C. Schultheiss<sup>4</sup> and Nils P. Wedi<sup>1</sup>

# DESTINATION EARTH<sup>1</sup> – DIGITAL TWINS - EUROHPC

<sup>1</sup><https://ec.europa.eu/digital-single-market/en/destination-earth-destine>

Addresses the European Green Deal + Europe's Digital strategy



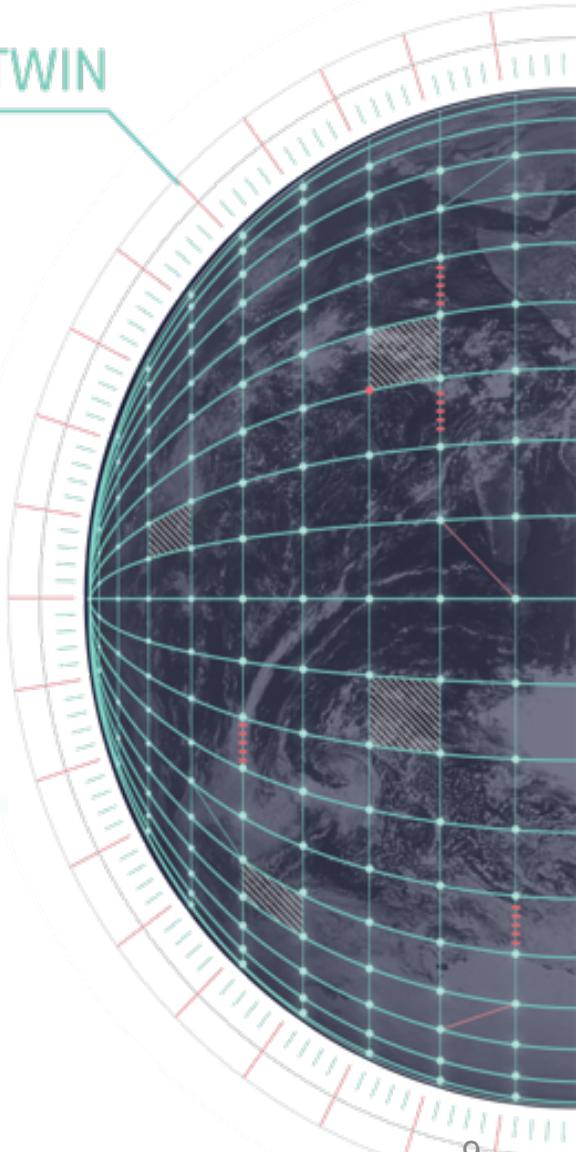
simulated      observed



PHYSICAL WORLD



DIGITAL TWIN



**Delivers a digital-twin system framework through a Digital Twin Engine (DTE)**

**Delivers two high-priority Digital Twins on Extremes and Climate Change Adaptation**

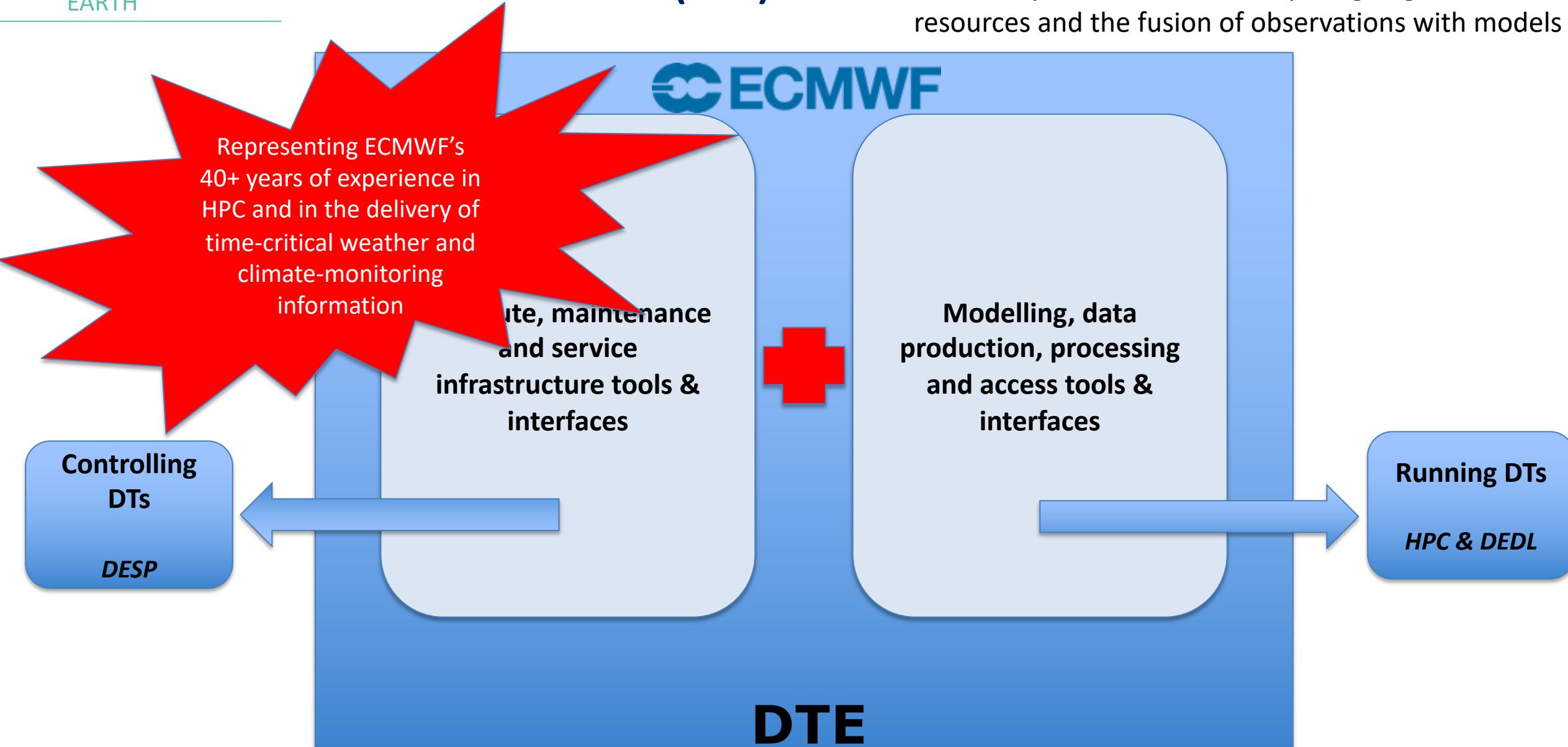
**Procures key components for Extremes and Climate Digital Twins, use cases and visualization/immersive technologies**

**Phase 1 (2021-2024):** Delivery of 1<sup>st</sup> digital twin generation; demonstration of new capabilities at scale

**Phase 2+ (2024-):** Extend to new applications; fully integrate components; widen DTE scope

# DIGITAL TWIN ENGINE (DTE)

common system approach to a unified orchestration of Earth-system simulations requiring large-scale HPC resources and the fusion of observations with models



#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.



- 3 large ( $O(100\text{PFlops})$ ) 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 ( $\sim 1000 \text{ Pflops}$ ) by 2023-2024 tbd



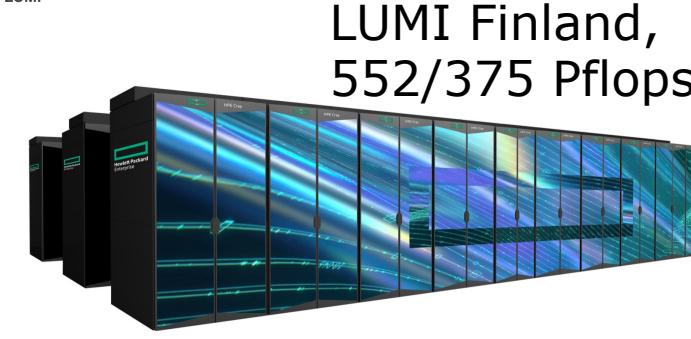
**MareNostrum 5**  
~200 Pflops

The current proposal is to set aside a maximum of **10%** of the Union's access time for strategic initiatives.

## Supercomputers

Currently six EuroHPC supercomputers are under construction across Europe:

LUMI



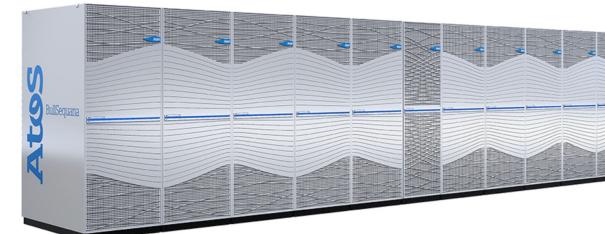
**LUMI Finland,  
552/375 Pflops**

© HPE	
The <a href="#">LUMI</a> 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 150m <sup>2</sup> of space, which is about the size of a tennis court. The weight of the system is nearly 150 000 kilograms (150 metric tons)

The LUMI consortium includes the Swiss CSCS, building software-defined Alps ~300-500 Pflops by 2023

LEONARDO

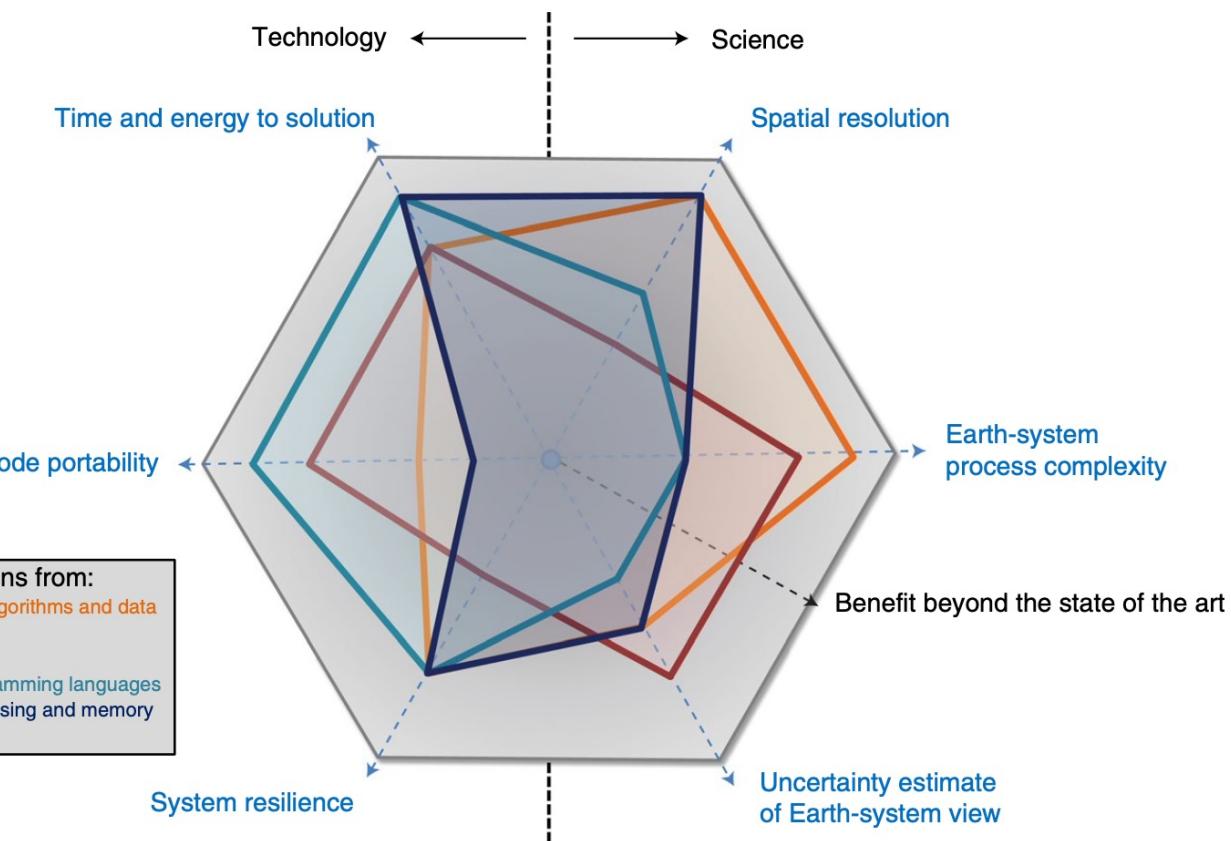
**Leonardo Italy:  
322/249 PFlops**



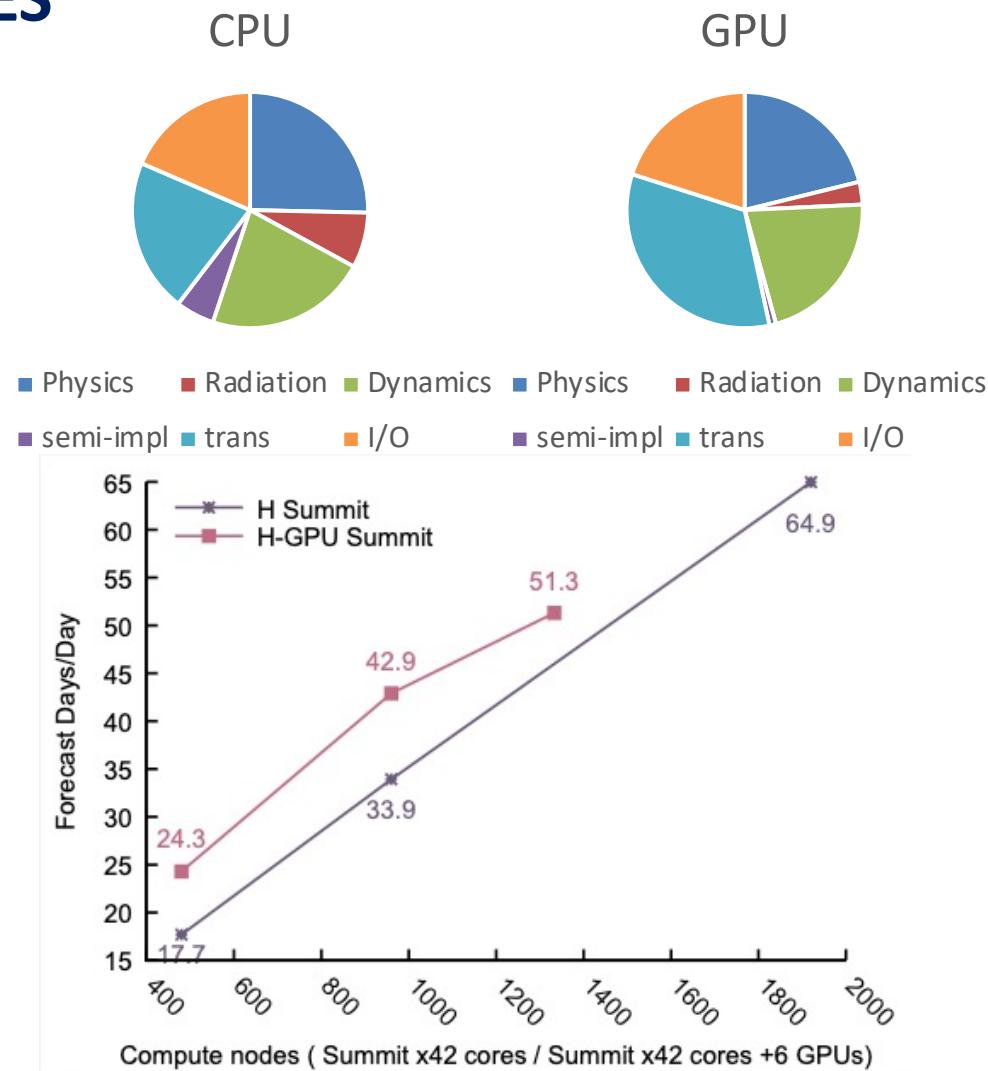
© Atos	
The <a href="#">LEONARDO</a> will be supplied by ATOS, based on a BullSequana XH2000 supercomputer and located in Italy.	
Sustained performance:	249.4 petaflops
Peak performance:	322.6 petaflops
Compute partitions:	Booster, hybrid CPU-GPU module delivering 240 PFlops, Data-Centric, delivering 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

Courtesy P.L. Vidale

# EFFICIENCY AND ACCURACY ADVANCES



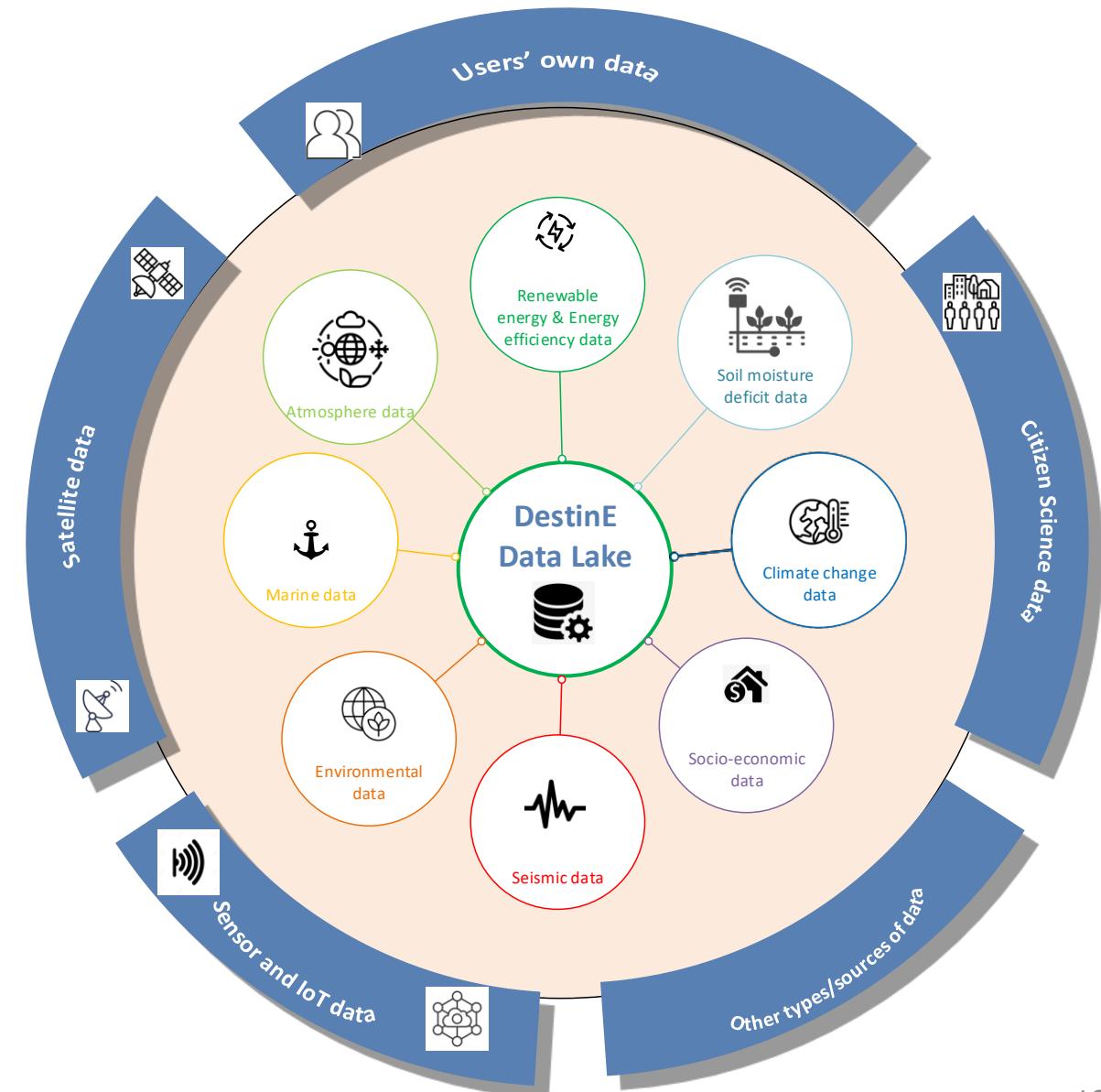
Bauer et al. Nature Comp 2021

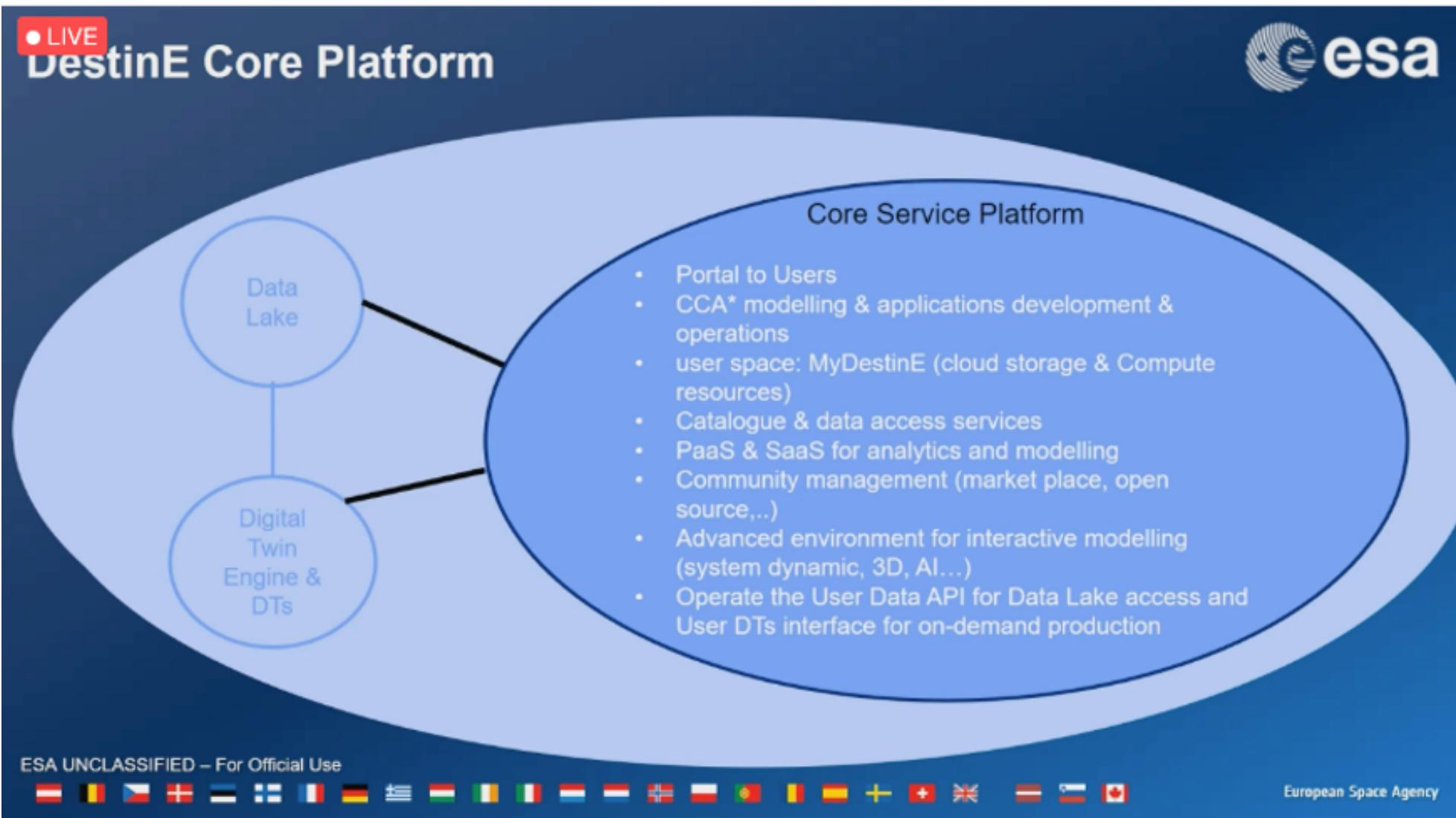


This research used resources of the Oak Ridge Leadership Computing Facility, which is a DOE office of Science User Facility supported under contract DE-AC05-00OR22725



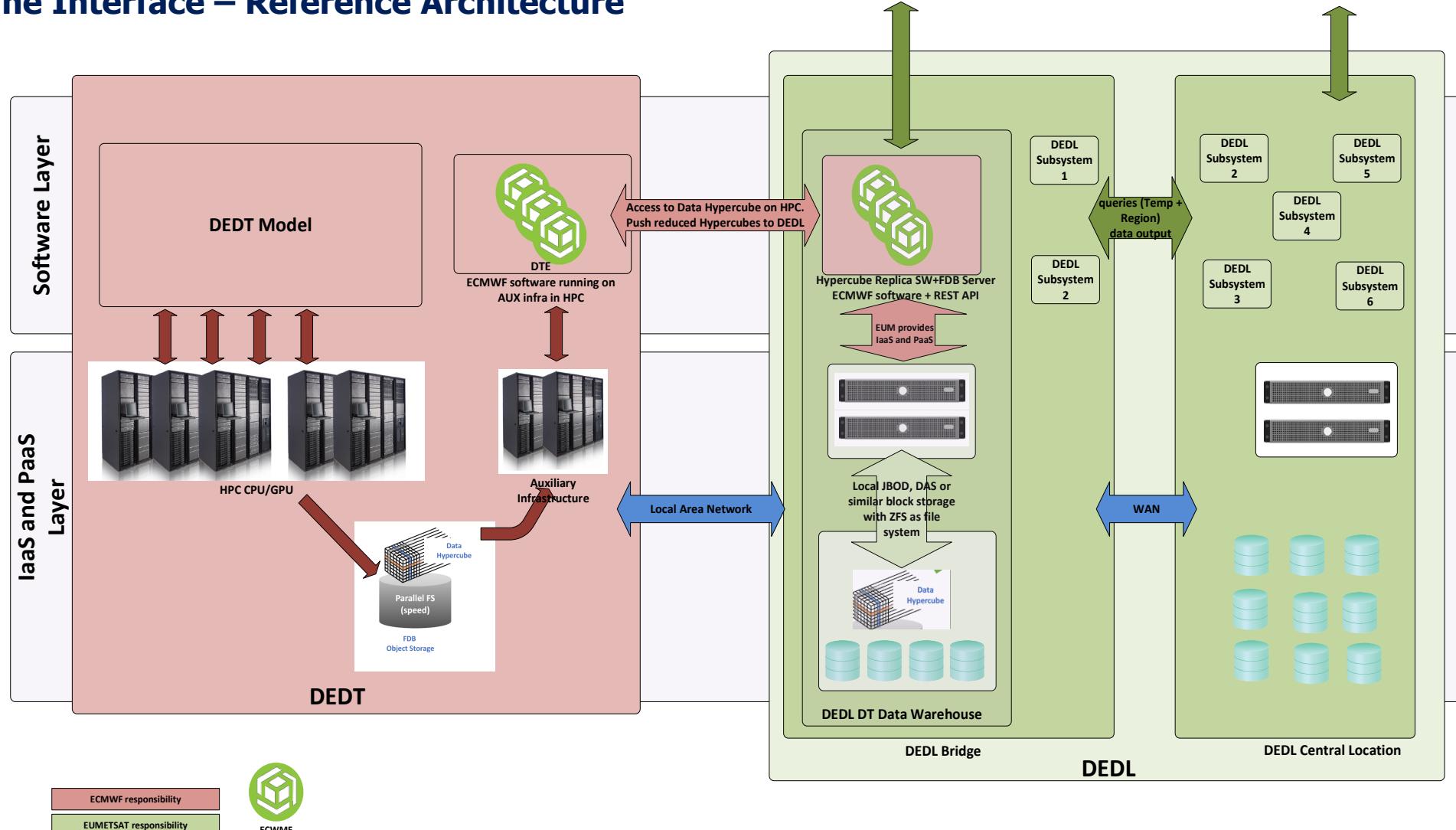
- **Self-standing component, built from geographically distributed physical elements that references and provides seamless access to all DestinE user required data. Available from external data spaces or generated by the DestinE Digital Twins, regardless of data type and location.**
- **Near-data processing to maximize throughput and service scalability**
- **Harmonisation of data access, beyond anything that exists today**



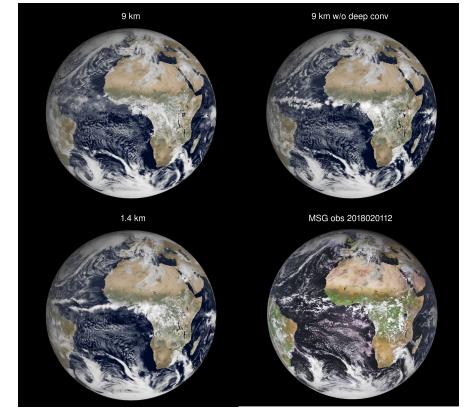
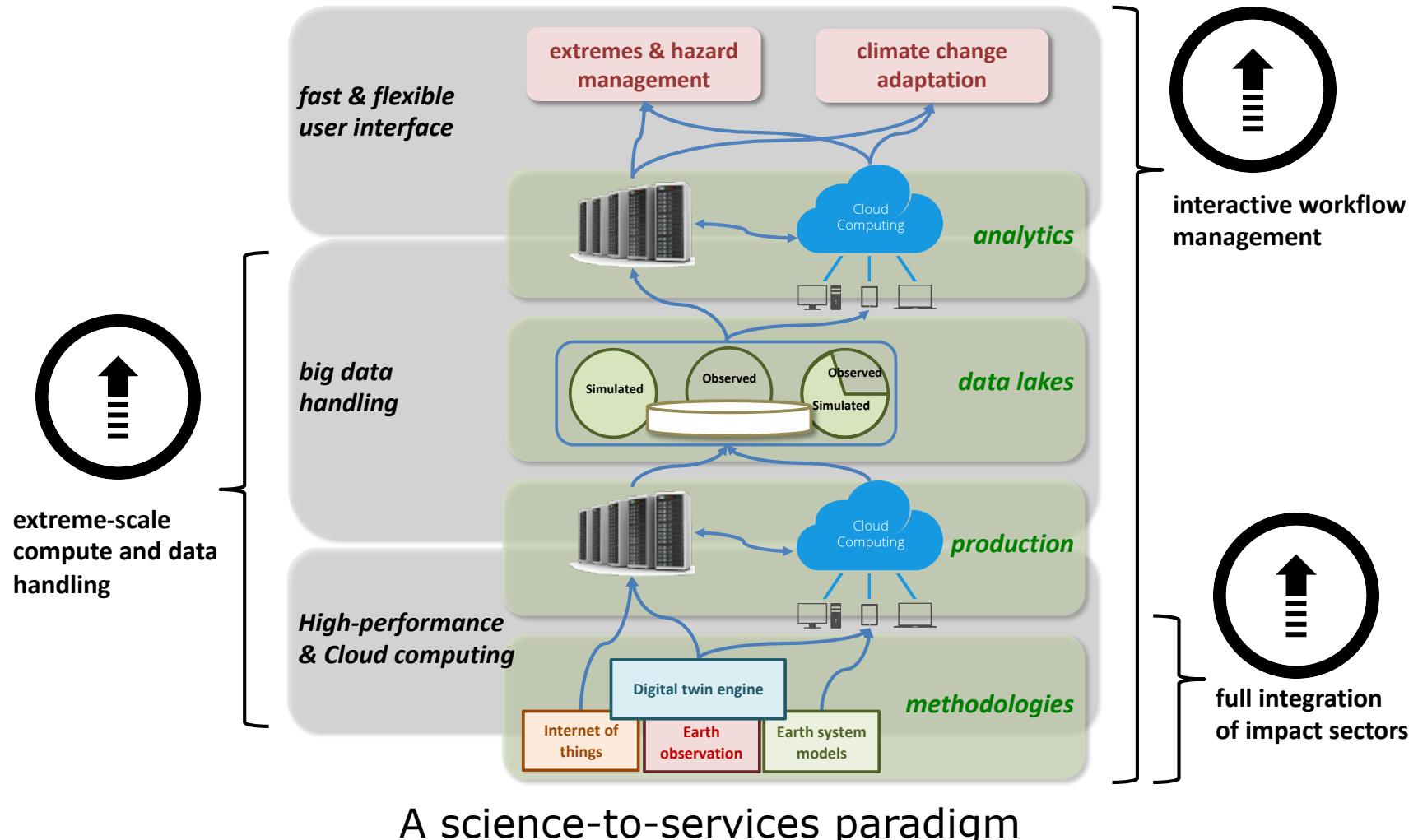


# WORKING TOGETHER

## Digital Twin Engine Interface – Reference Architecture



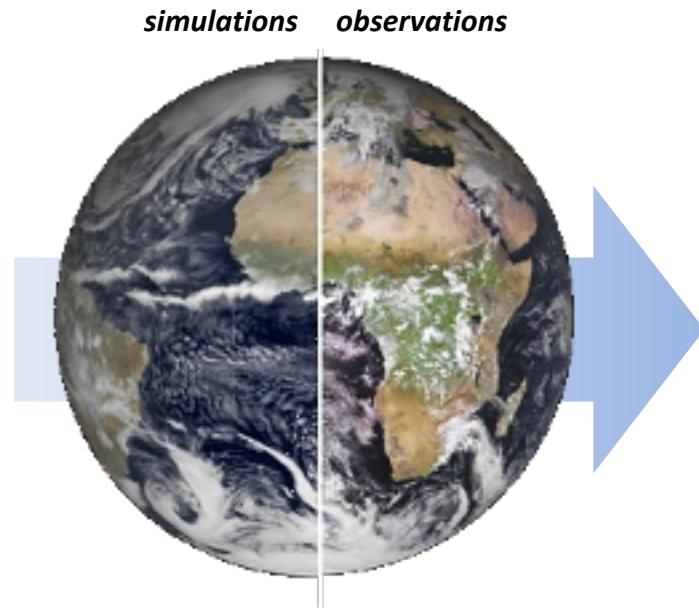
# WORKFLOWS



Digital  
Twins

Edge-computing  
On-the-fly processing  
Big ML/AI data pipelines  
Hypercube data access  
...

# PRODUCTION MODES



*Lists not exhaustive;  
not all capabilities fully  
developed in phase 1*

## **Reference workflows; continuous production mode:**

- global storm resolving scale simulations
- leading models, extended and scaled up
- observational data streams (initialization; evaluation)
- built-in applications where beneficial
- uncertainty estimation
- frequent innovation uptake
- driving digital twin engine software developments
- benefiting from EuroHPC technology

## **Configurable workflows; on-demand production mode:**

- (above)
- options for global/regional focus, hyper-resolution
- options for added data
- options for added impact sector models
- options for adaptation/mitigation scenario testing

# MACHINE LEARNING

## Speed the twins up

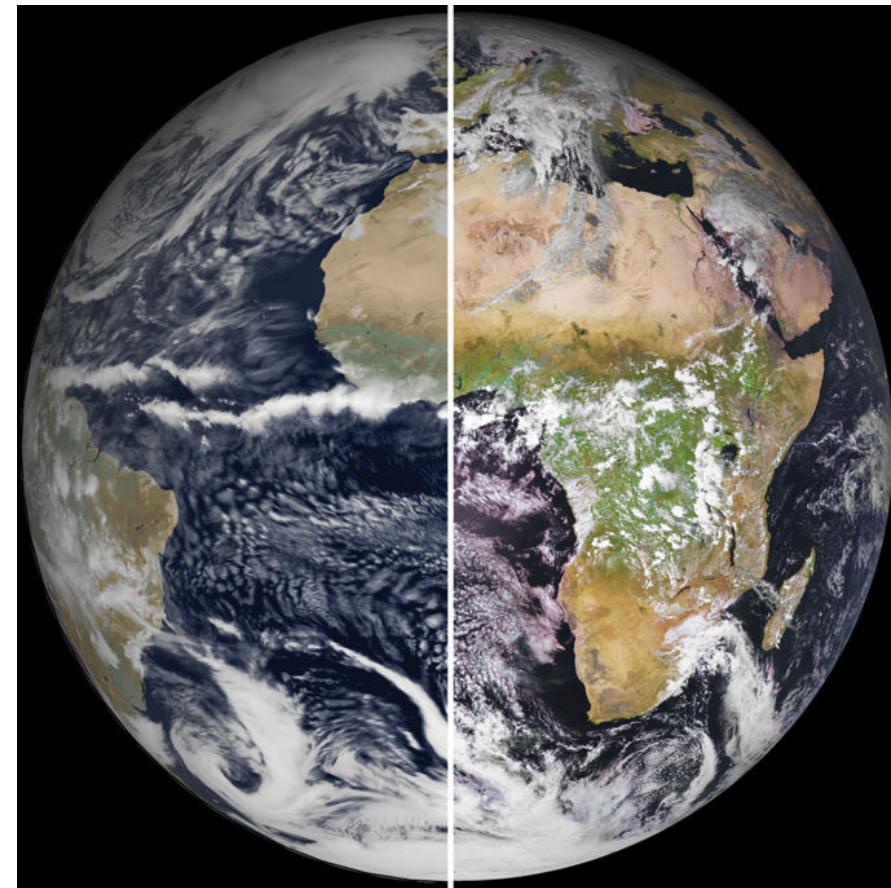
- Emulate model components
- Port emulators to heterogeneous hardware
- Use reduced numerical precision
- Preconditioning of linear solvers
- Optimise HPC and data workflow
- Data compression
- ...

## Improve the twins

- Represent 3D cloud effects in radiation schemes
- Correct biases
- Quality control of observations and observation operators
- Quantify uncertainties
- Feature detection
- ...

## Build new tools and enable new science

- Impact models within simulations
- Fuse information content from different data sources
- Quantify uncertainties
- AI powered visualisation
- Unsupervised learning and causal inference



## Uptake of the data by the community

- Health – e.g. for to predict risks
- Energy – e.g. for local downscaling
- Transport – e.g. to combine weather and IoT data
- Pollution – e.g. to estimate sources
- Extremes – e.g. to predict wild fires
- ...

# DIGITAL TWIN(S) OF THE OCEAN



<https://digitaltwinocean.mercator-ocean.eu/>

DITTO a Global Program of the UN Decade of Ocean Science for Sustainable Development (2021-2030) <https://ditto-oceandecade.org/>

Horizon Europe R&I:  
<https://www.ocean-twin.eu/>



DITTO - Digital Twins of the Ocean

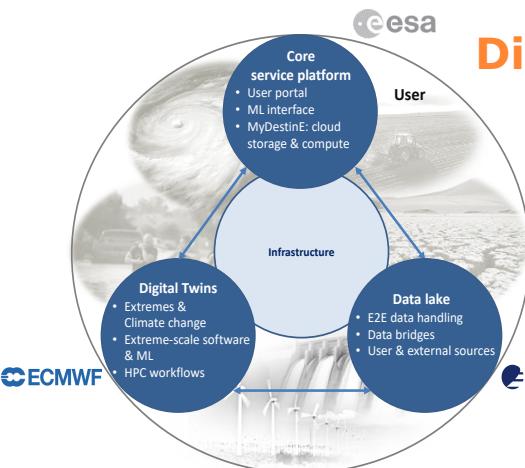


# DIGITAL TWIN PARTNERSHIPS

- **interoperability** protocols for data, metadata and workflow semantics across disciplines and research infrastructures
- workflow management, high-performance computing and data handling **software infrastructures compatible with the Digital Twin Engine**
- **Digital Twin ecosystem options:**
  - directly integrated in the existing DestinE simulation and data fusion system (i.e. **full integration mode**)
  - integrated in a sequential workflow where new Digital Twins operate their own simulation and data fusion tasks interfacing with the existing DestinE Digital Twins (i.e. **coupling mode**)
  - integrated as data post-processing applications without own Earth-system component simulation tasks (i.e. **post-processing mode**).



# PARTNERSHIP FOR CREATING SYNERGY ACROSS PROGRAMMES



**Digital twins/Platform/Lake**

European Environment Agency



**Services**



**Technology  
& infrastructures**

**EuroHPC**  
Joint Undertaking



**ECMWF**

**Earth-system  
& impact science**

Grand  
Challenge

Mission

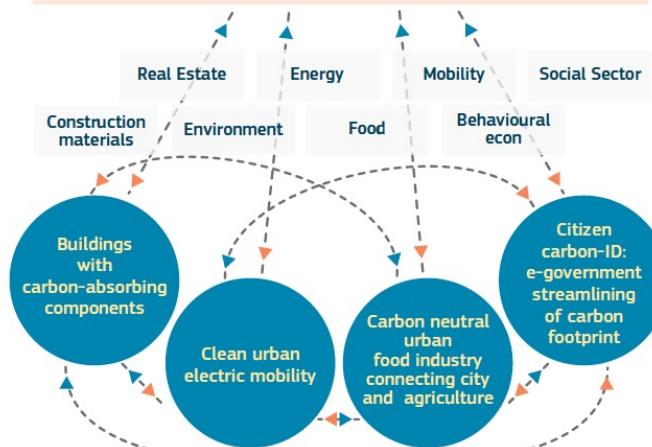
Areas of interest  
& cross-sector

R&I Projects

**CLIMATE CHANGE**

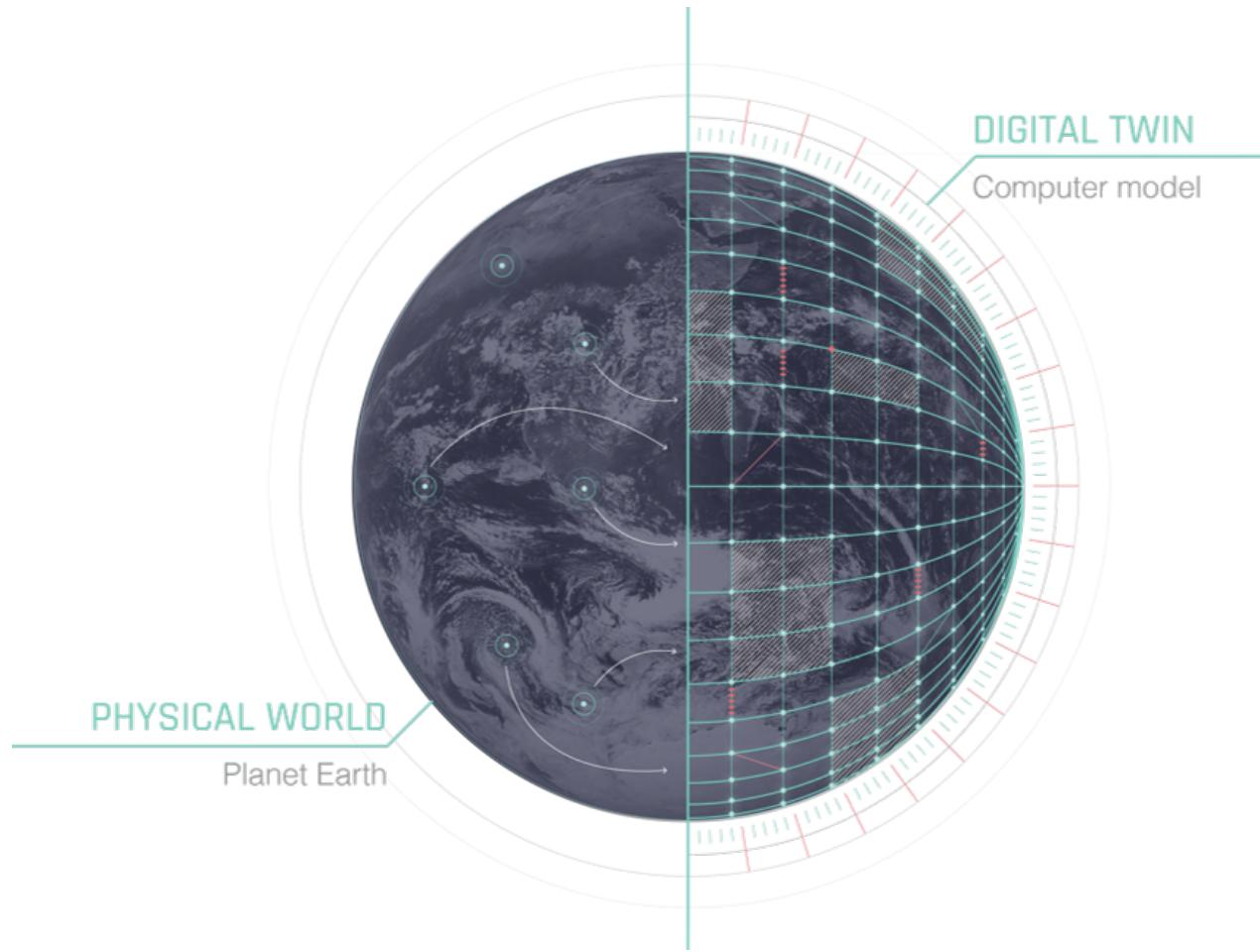
**100 CARBON NEUTRAL CITIES BY 2030**

Reach net zero greenhouse gas emissions balance of 100 European cities by 2030



## CONTACT AND FURTHER INFORMATION

[www.ecmwf.int/destine](http://www.ecmwf.int/destine)



Funded by the  
European Union

