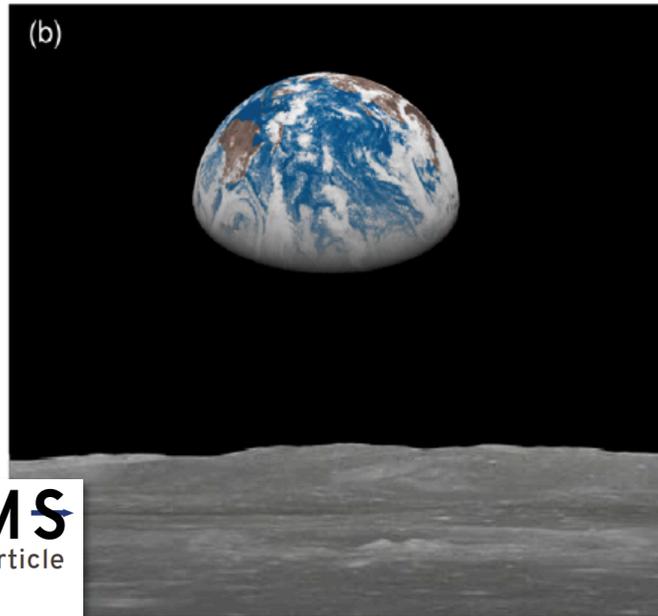


Digital twins in Destination Earth as a step-change for Earth-system modelling and observational data assimilation

Photo taken by Apollo 11 crew from
the moon on 20 July 1969

ECMWF simulation (29-hour forecast
initialized with ERA-40 reanalysis*)



BAMS
Article

Forecasting the Past

Views of Earth from the Moon and Beyond

Philippe Lopez

(*no satellite data in 1969)

Peter Bauer
ECMWF

(with the help of many)

Destination Earth (DestinE) formal announcement

Aim and goals

Key initiative, announced in:

A European Green Deal (2019)

A European strategy for data (2020)

Shaping Europe's digital future (2020)



Develop a **very high precision digital model of the Earth (Digital Twin)** of the Earth to monitor and simulate natural and human activity and to develop and test scenarios for

- more sustainable development and achievement of the EU green deal objectives
- saving lives
- avoiding large economic downturns
- **support EU policy-making and implementation**
- reinforce Europe's industrial and technological capabilities in advanced computing, simulation, modelling, predictive data analytics and Artificial intelligence (AI)

DestinE candidate implementation



- **Lead and business owner: European Commission (DG CONNECT)**
- **Strategic partnership** with ESA-ECMWF-EUMETSAT
- Responsibilities:
 - **ESA : key role of system integrator and implementer of the core platform**
 - ECMWF: Digital Twin implementer
 - EUMETSAT: responsible for the big data lakes and data integration
- Formal organization: **“contribution agreements”** by summer 2021

2021-2023

- Operational cloud-based platform
- First two digital twins

2023-2025

Platform integrates the next operational digital twins and offers services to public sector users

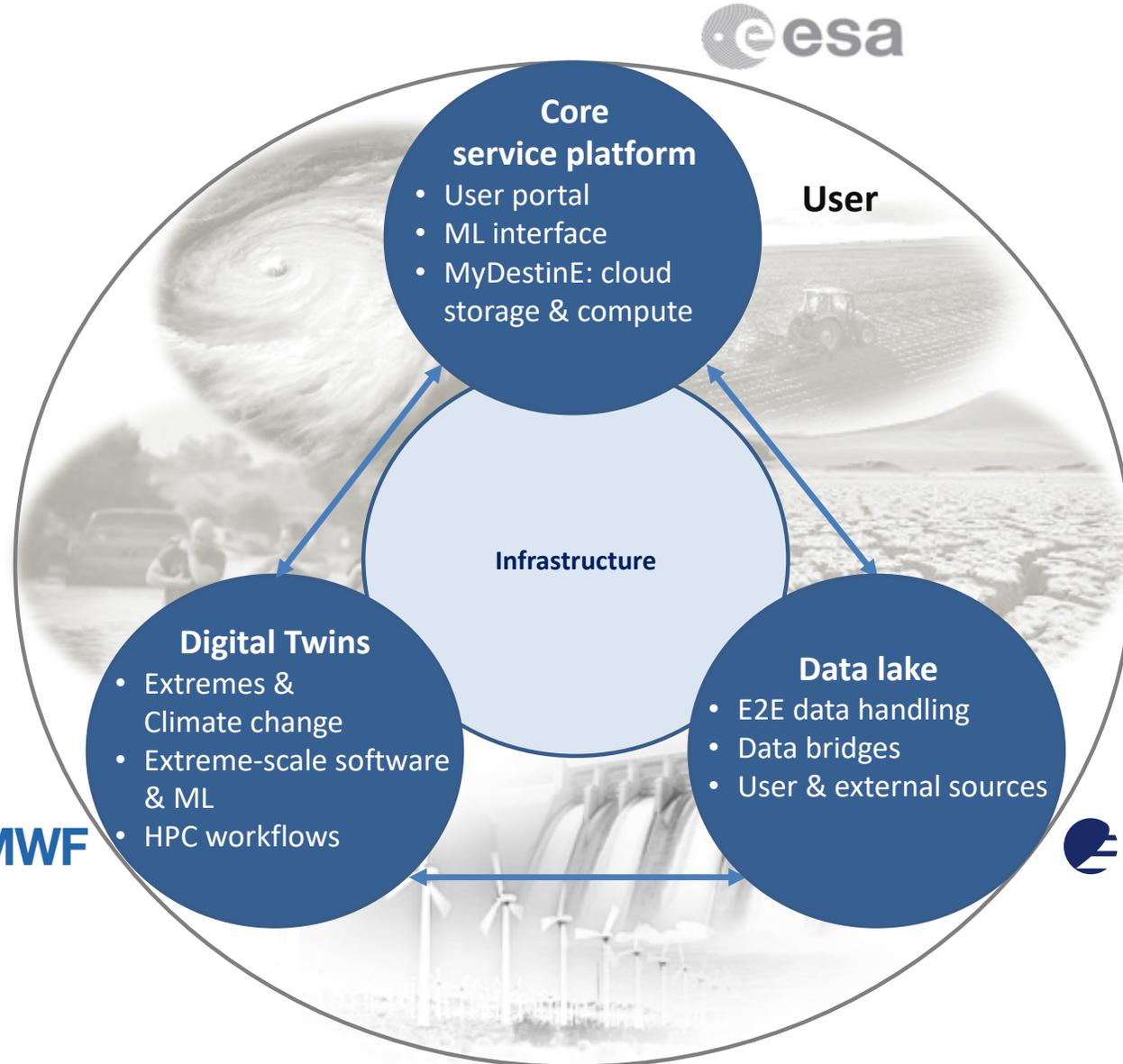
2025-2027+

Towards a full “digital twin of the Earth” through a convergence of multiple digital twins on the platform

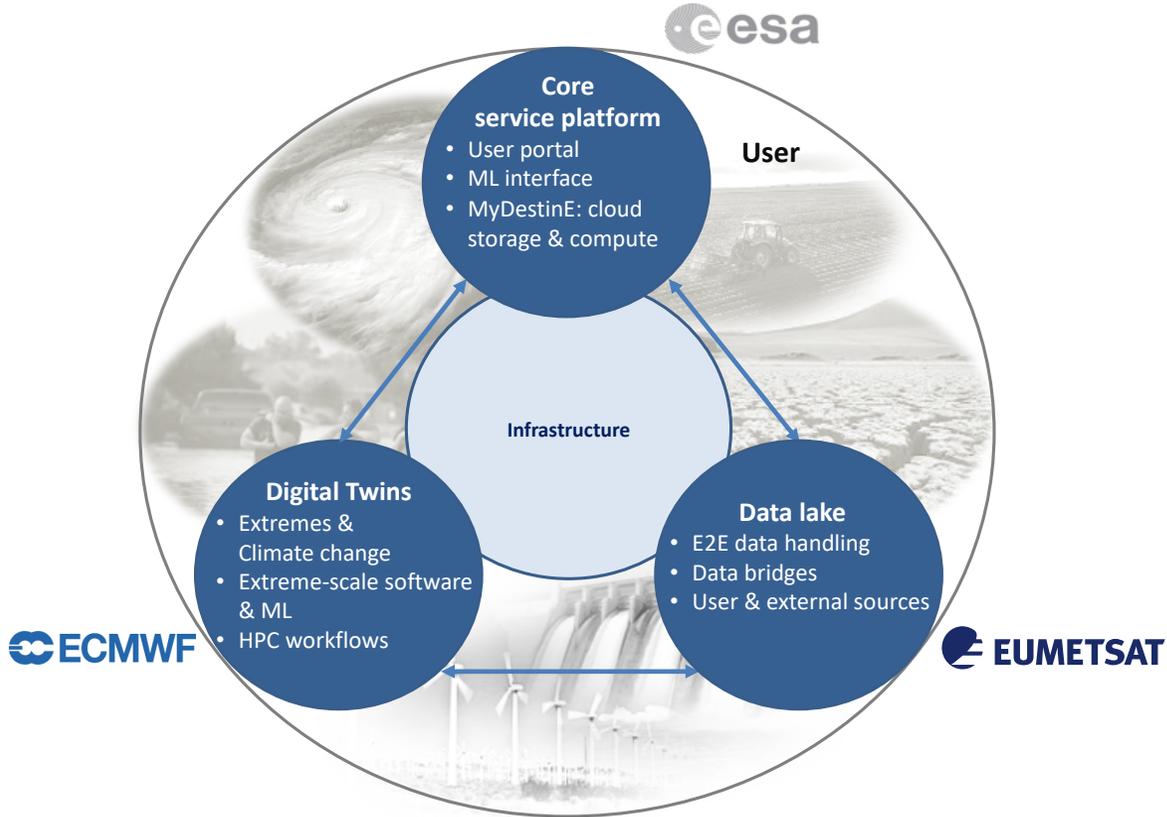
DestinE partnership



Governance incl. external advice



High-priority Digital Twins in DestinE



Weather-induced and Geophysical Extremes:

“Environmental extremes at very high spatial resolution and close to real-time decision-making support at continental, country, coastline, catchment and city scales in response to meteorological, hydrological and air quality extremes”

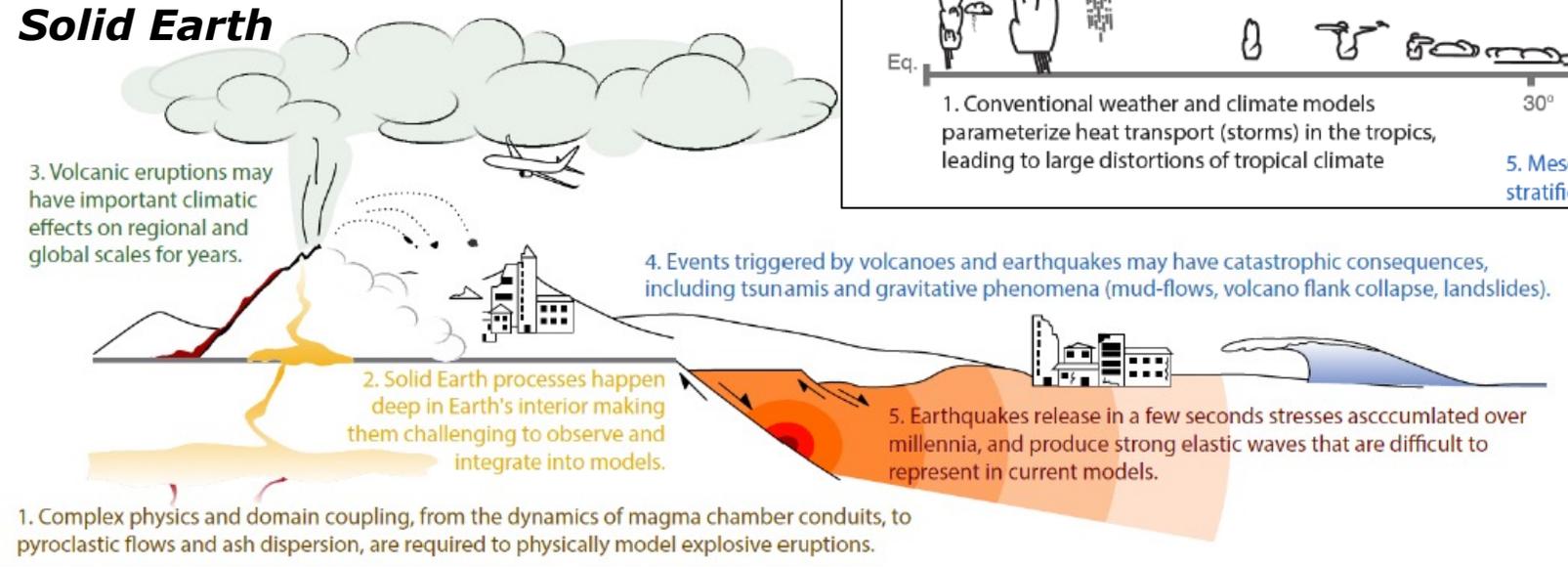
Climate Change Adaptation:

“Climate change adaptation policies and mitigation scenario testing at decadal timescales aiming at a real breakthrough at the level of reliability at regional and national levels, for understanding the causes and explaining the feedback mechanisms of change, and predicting possible evolution trajectories”

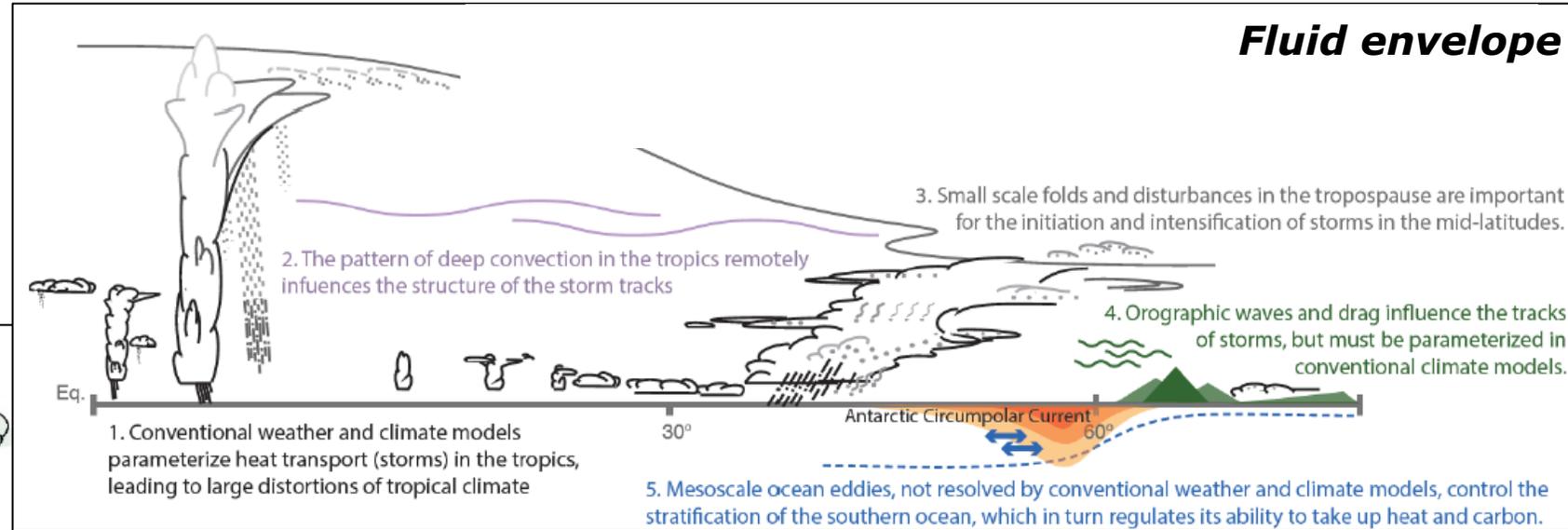
How is it different?

Earth-system monitoring & prediction boost

Solid Earth



Fluid envelope

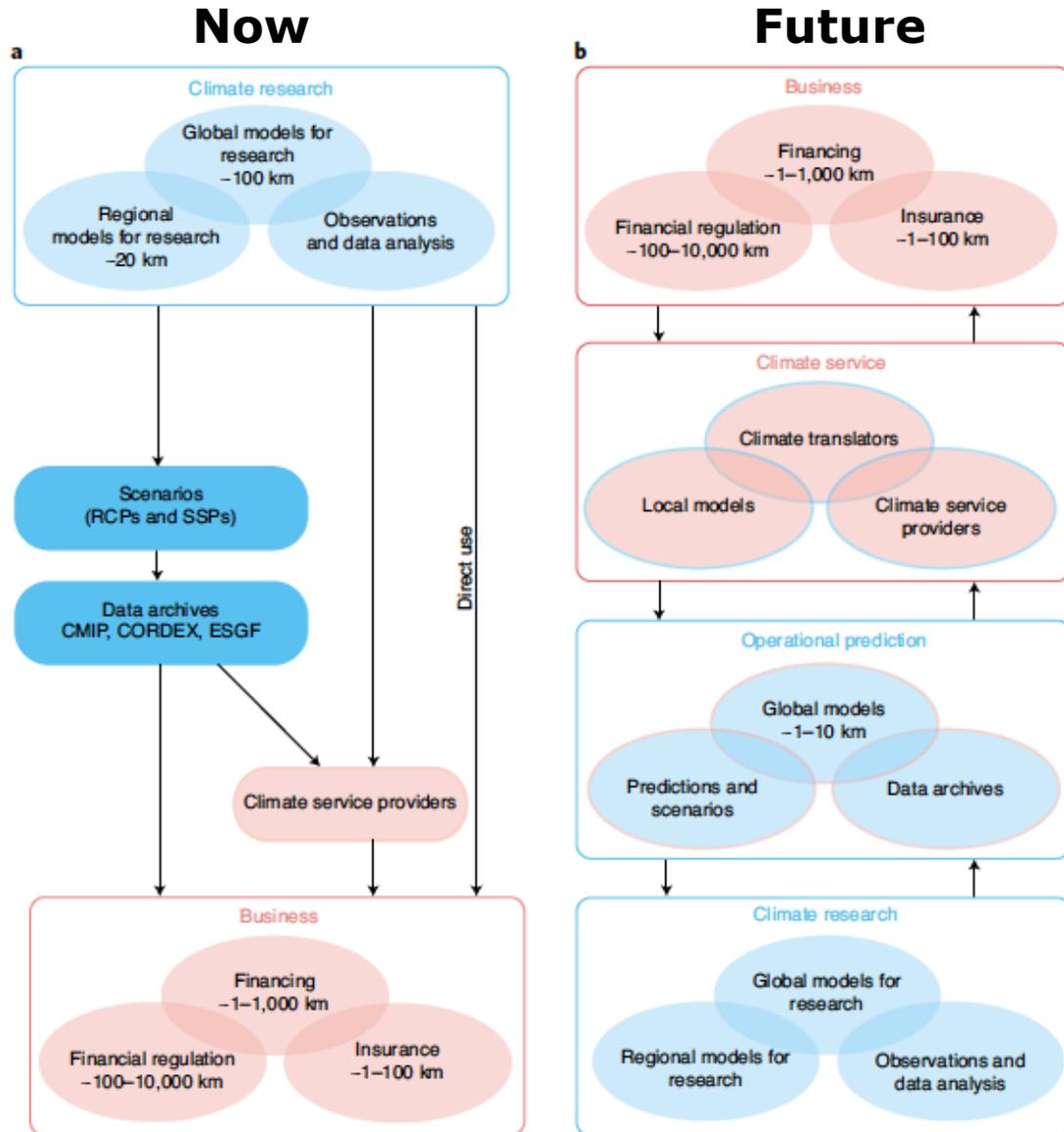


+ **water**
+ **vegetation**
+

“Conventional models are unable to resolve important processes that drive the Earth system and that influence extremes. Many of these processes are now becoming computable, but require new types of models, observations and new computational approaches”

How is it different?

Changing direction of design



“... Redefining the connection between business and climate research, highlighting the **need for climate projection to be professionalized as an operational service**, informed by business needs and the results communicated via a climate service (with strong science engagement). Note, demands by business are communicated to the climate research community via the climate service to ensure two-way communication. **Climate services and operational prediction thereby perform an intermediary function between business and science ...**”

nature
climate change

PERSPECTIVE

<https://doi.org/10.1038/s41558-020-00984-6>

Check for updates

Business risk and the emergence of climate analytics

Tanya Fiedler¹, Andy J. Pitman², Kate Mackenzie³, Nick Wood⁴, Christian Jakob⁵ and Sarah E. Perkins-Kirkpatrick²

DestinE break-throughs

- 1. Extreme-scale computing and data handling**
= *much more realistic models + better combination of simulations + observations*
- 2. Full integration of policy sectors in workflow**
= *Earth-system + energy + food + water + finance*
- 3. Open and interactive access to data, software and workflows**
= *non-expert access and intervention*



Science Contents News Careers Journals

f t in 2



At 1-kilometer resolution, a European climate model (left) is nearly indistinguishable from reality (right). (LEFT RIGHT) ECMWF; © EUMETSAT

Europe is building a 'digital twin' of Earth to revolutionize climate forecasts

By Paul Voosen | Oct. 1, 2020, 10:40 AM



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Building digital twins of Earth could help Europe cut carbon emissions

f t w in o e

ENVIRONMENT 12 October 2020

By Adam Vaughan



HPC wire

Since 1987 - Covering the Fastest Computers in the World and the People Who Run Them



EU to Create 'Digital Twins' of Earth, Run on EuroHPC Supercomputers

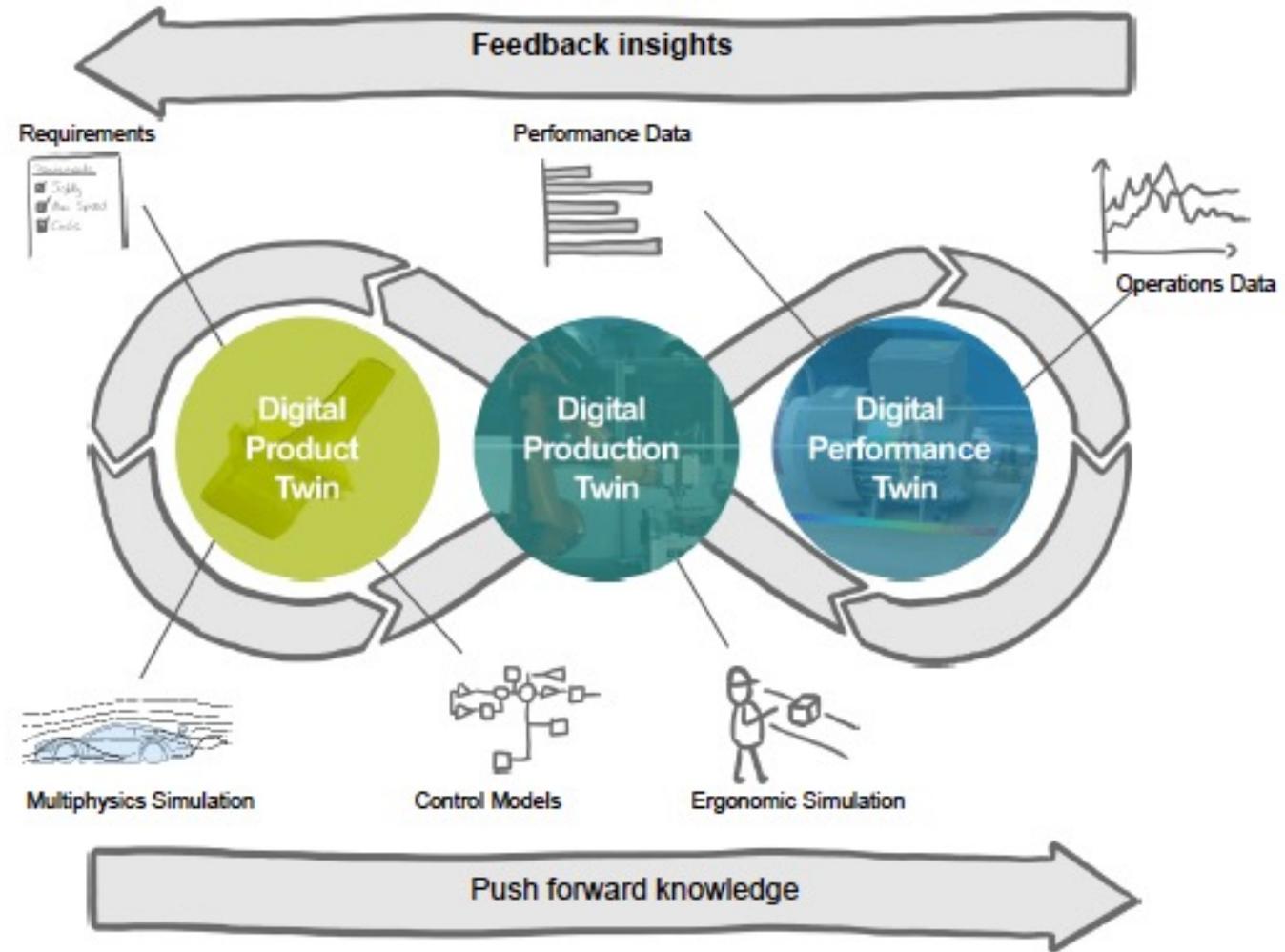
By Oliver Peckham

October 10, 2020

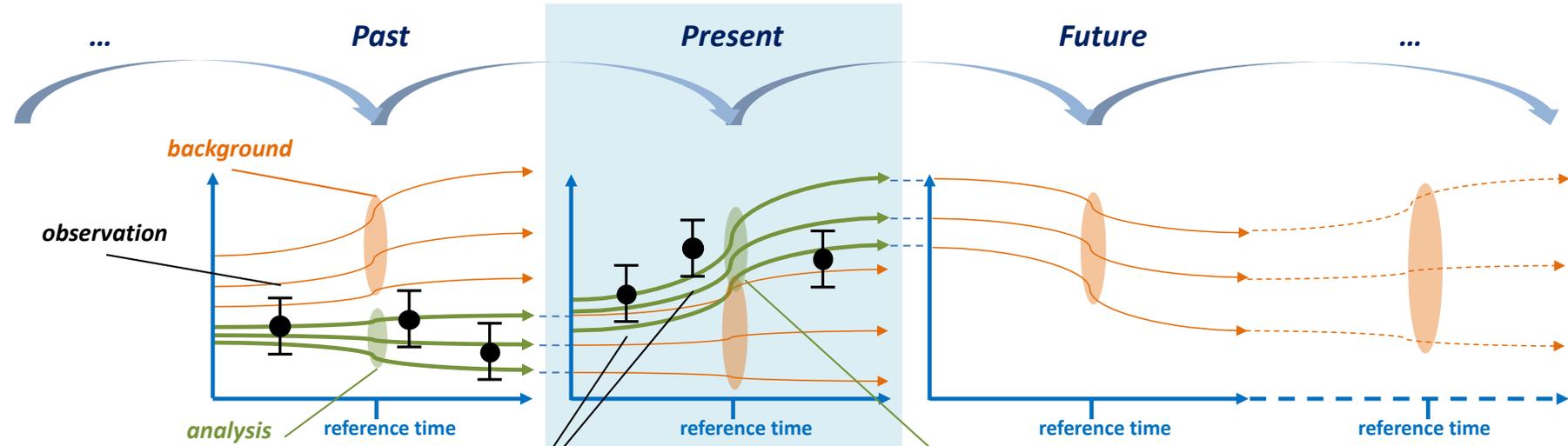
Industrial Digital Twins



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

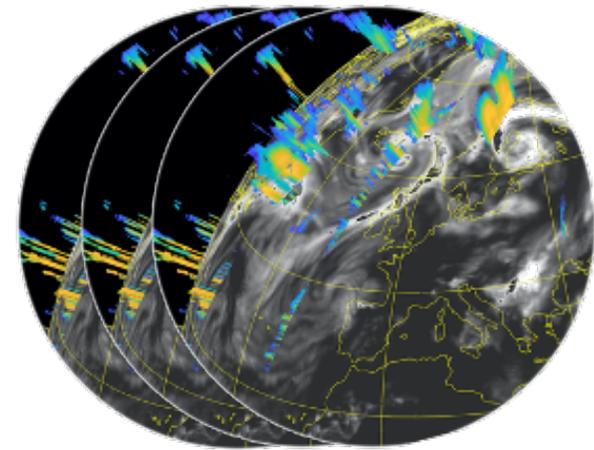
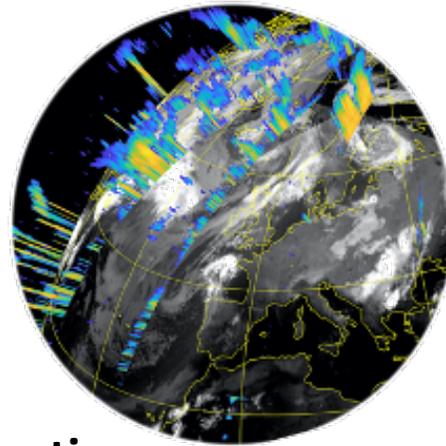


Digital Twin Engine = rather close to data assimilation



Observed by
Aqua MODIS & Cloudsat radar

Analysed (simulated) by
ECMWF ensemble



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

Digital Twin production modes

simulations *observations*



continuous real-time prediction cycle

continuous real-time monitoring cycle

time

on-demand, USER driven:

- regional, hyper-resolution
- more frequent updates
- added data
- impact sector specific extensions
- adaptation/mitigation scenarios

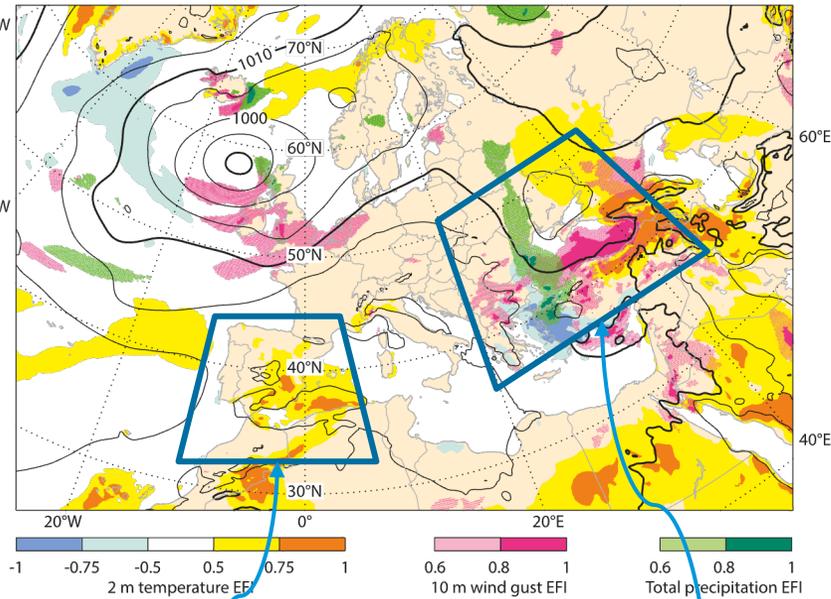
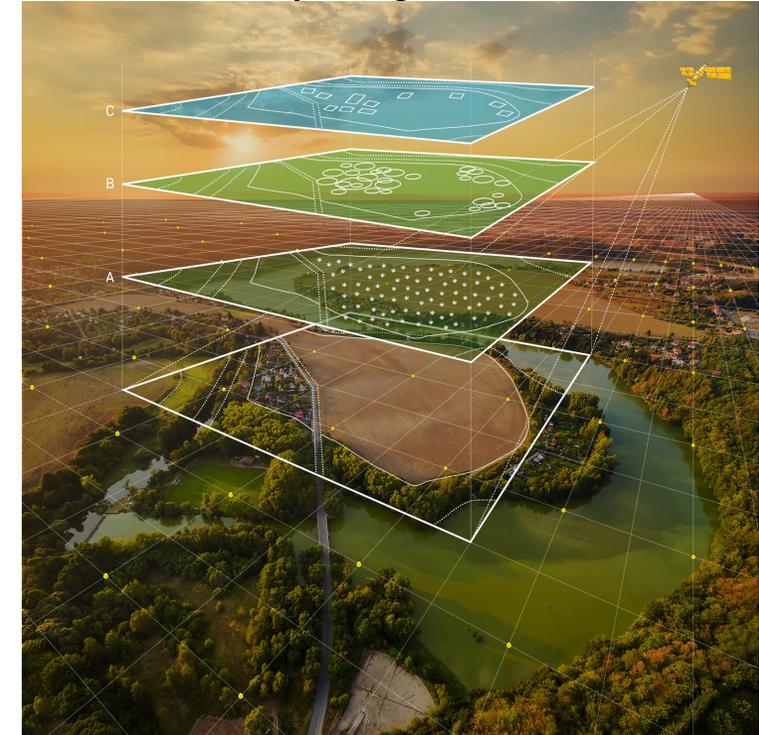
on-demand, EVENT driven:

- regional, hyper-resolution
- more frequent updates
- added data
- impact sector specific extensions
- adaptation/mitigation scenarios

extreme event
X

New levels of flexibility: on-demand downscaling & configuration

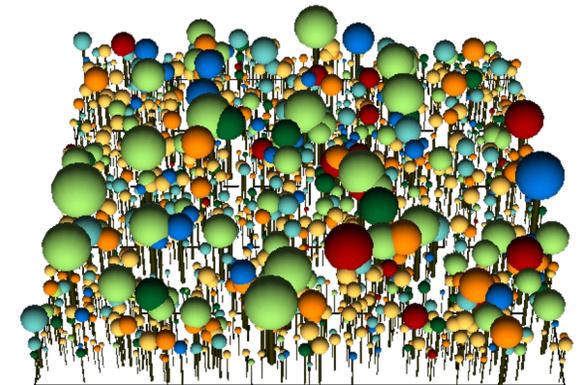
Courtesy Georg Teutsch, UFZ



- simulation – observation fusion
- hyper-resolution limited-area nesting
- extreme-type added components
- more value-chain components
- adaptation & mitigation planning

heat/drought case

wind-storm/flooding case

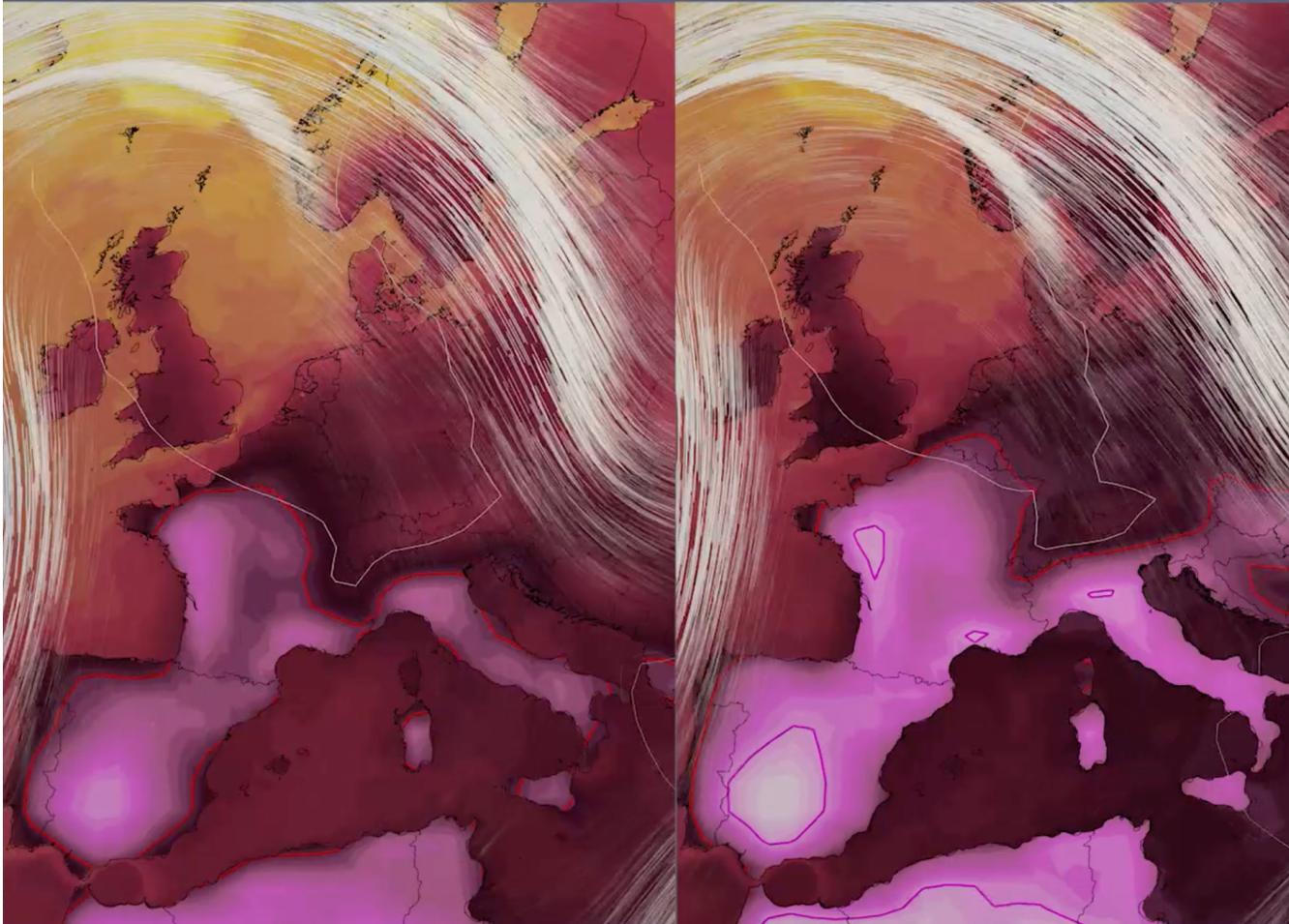


Future weather under climate change



28.06.2019 11:00

2095



What would the June 2019 heatwave look like in a +4° climate?

HELMHOLTZ
CLIMATE INITIATIVE
Courtesy Thomas Jung, AWI

'Hanging' glacier broke off to trigger India flood



Soutik Biswas
India correspondent

22 hours ago | Comments



Climate change



The benefits of having invested in the Scalability Programme

Input data = $\sim 10^8$ observations/day + IoT; Output data = PBs/day; Compute = ~ 100 PFLOP/s:

FEATURE 10 October 2018

Could the world's mightiest computers be too complicated to use?

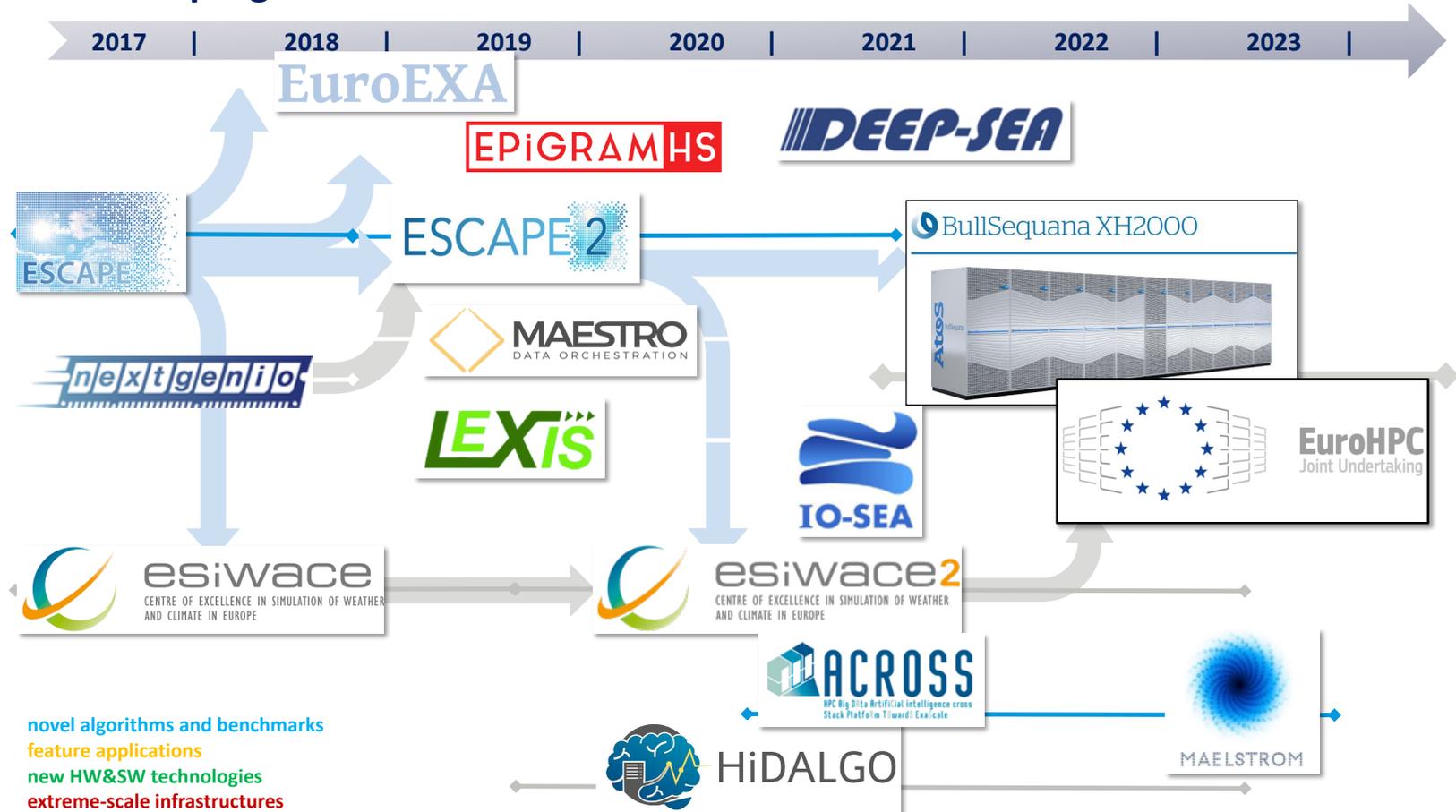
China, Japan and the US are racing to build the first exascale computer – but devising programmes clever enough to run on them is a different story



New Scientists

Totto Renna

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

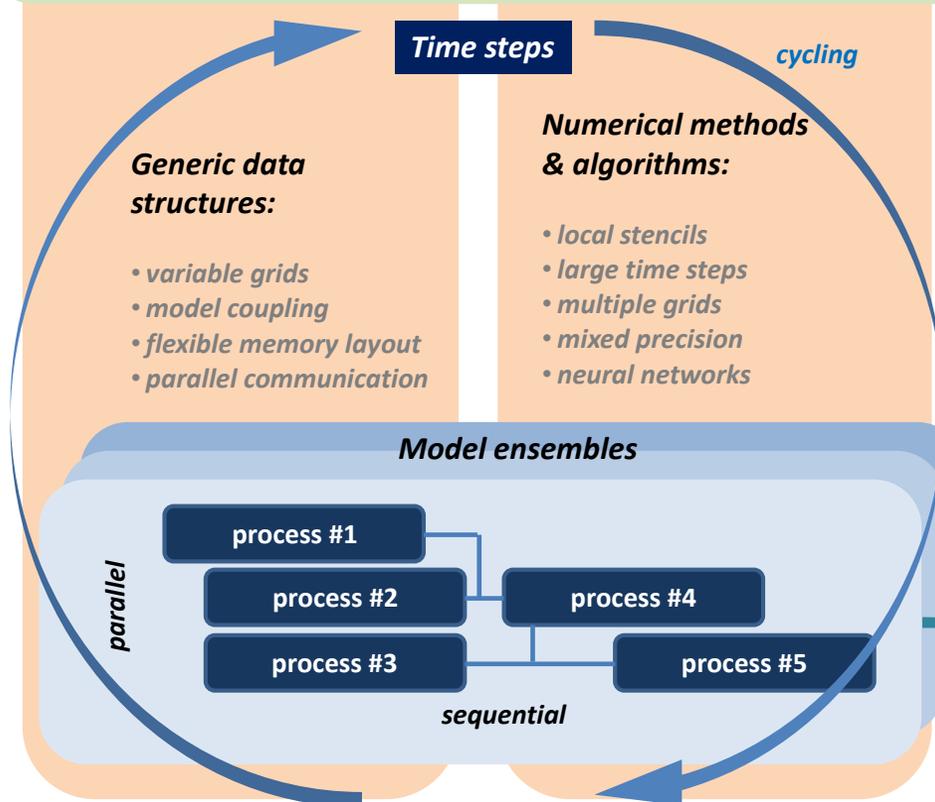


- novel algorithms and benchmarks
- feature applications
- new HW&SW technologies
- extreme-scale infrastructures

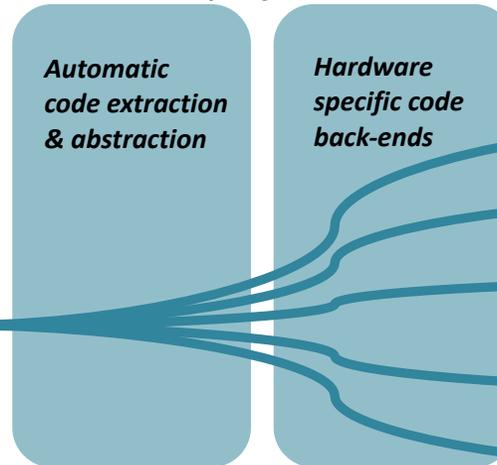
A template for a digital infrastructure

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



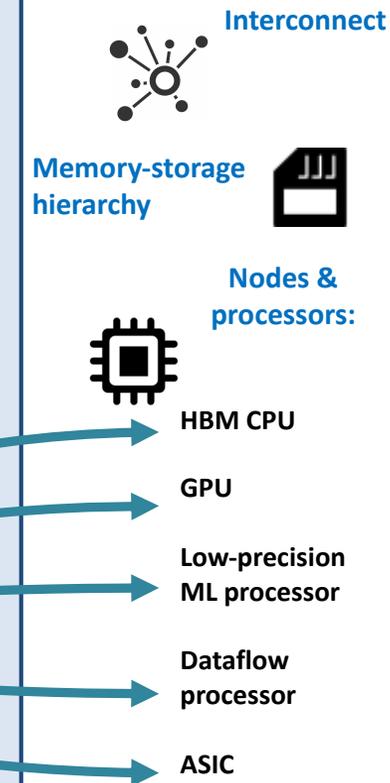
Domain-specific toolchain:



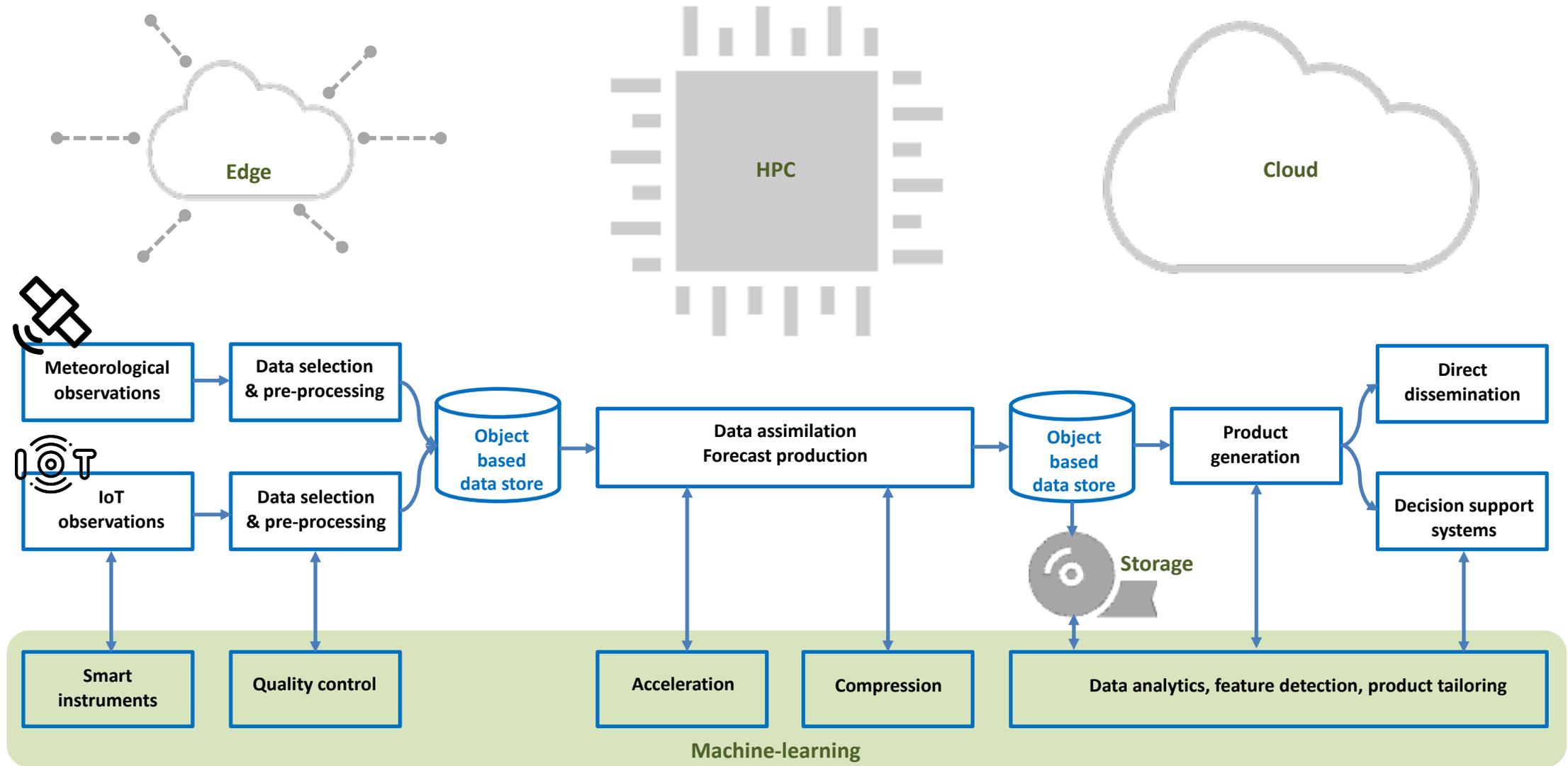
Cloud federation Architecture

- Orchestration across centers
- Access management for users

System architecture



Machine learning is everywhere



Partnership is essential

DestinE will engage in continuous partnerships to co-evolve its components and deliverables:

- Science
- Technology
- Services
- Infrastructures

User Requirements Database



List of Requirements

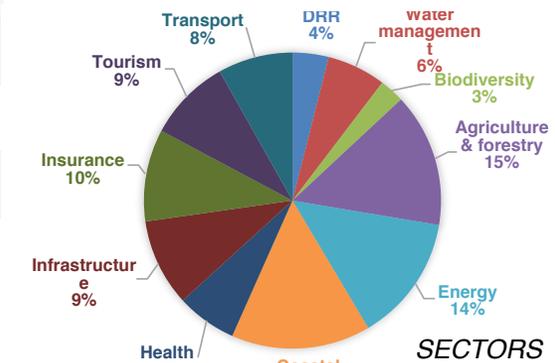
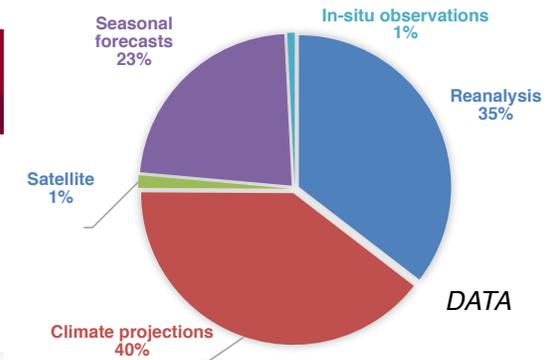
Showing 3480 requirements

Filter results Export results

Visible columns

ID	SUMMARY	TOPIC	SUBJECT
C3S-000001	Provide a comprehensive database for climate data where we can choose the variables according to our needs	SIS General	Website
C3S-000002	Provide indicators tailored to the tourism sector: TCI/CIT/HCI	SIS Data	New data request
C3S-000003	Provide indicators tailored to the tourism sector: sea level rise data	SIS Data	New data request
C3S-000004	Provide indicators tailored to the tourism sector: Fire Weather Index	SIS Data	New data request

<http://urdb.copernicus-climate.eu>

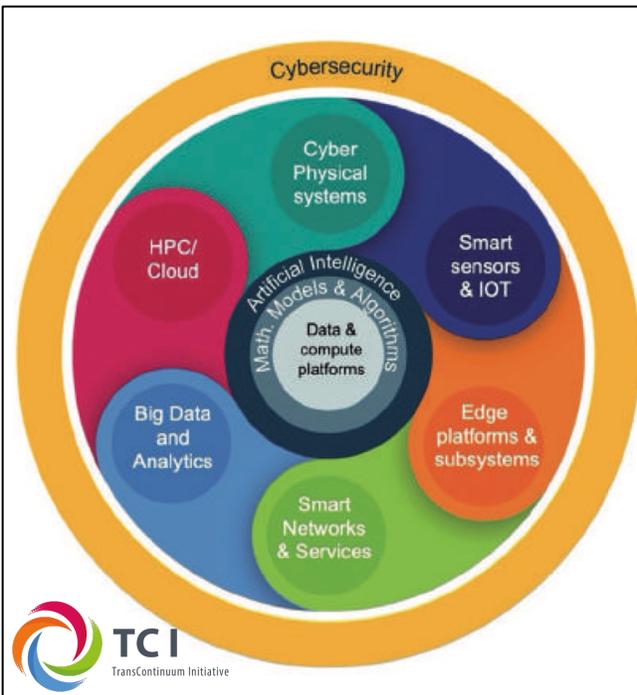


Courtesy Carlo Buontempo

A continuous dynamic workflow

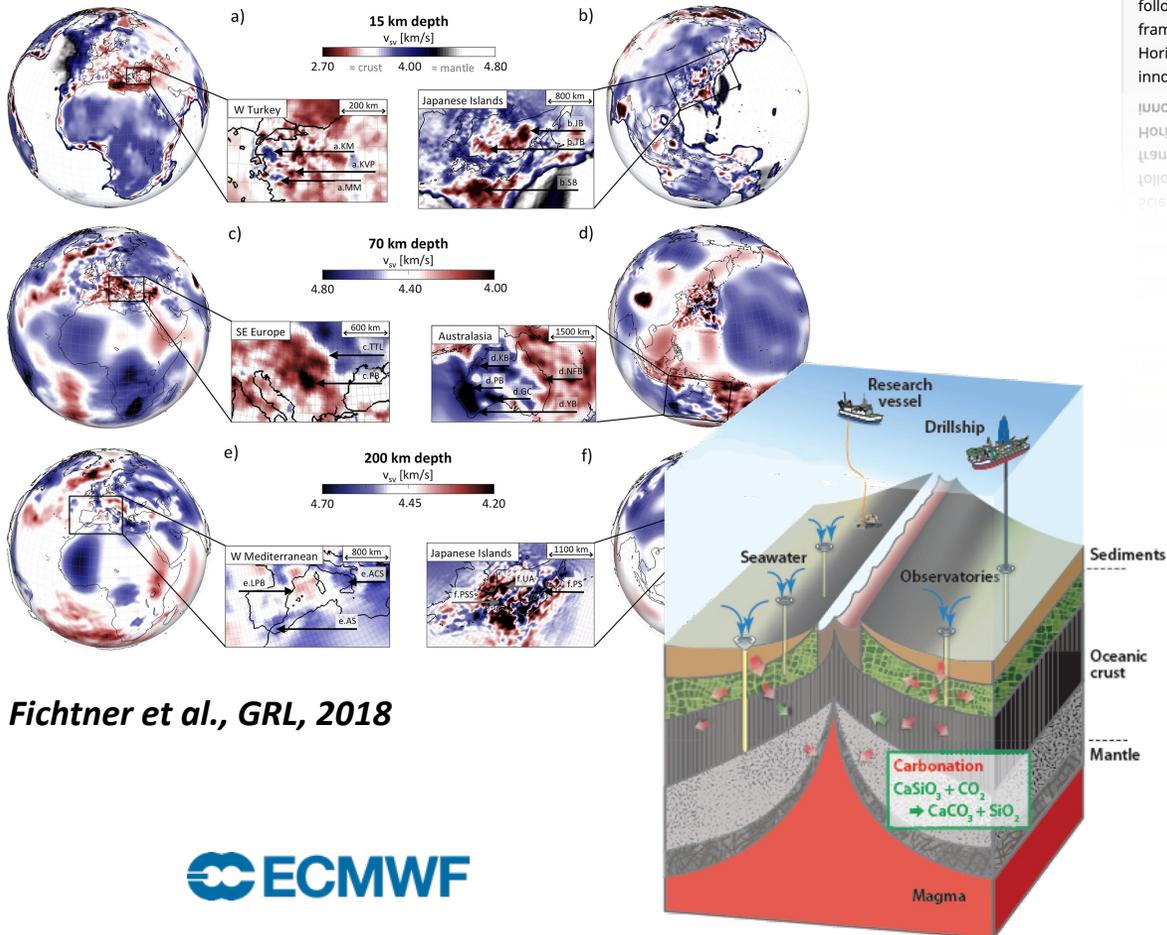
Between **Smart Sensors and IOT devices** and **HPC / cloud centers** passing through **Edge platforms & subsystems** as well as **Smart Networks and Services** executing **Simulation & Modelling, Big Data Analytics and ML*** based on **Math. Methods & Algorithms incl. MCODE**** pervasively augmented 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
** MCODE: Modelling, Simulation and Optimization in Data-rich Environment



DestinE Phase 2: Digital Twins of the Solid Earth

What is the likely seismic response to geothermal energy harvesting and carbon storage?



Fichtner et al., GRL, 2018

Framework Programmes

Science | Business journalists and experts in Brussels, together with our partners in the Science | Business Network, are closely following developments of the EU's research framework programmes, Horizon 2020 and Horizon Europe, which aim to boost innovation in Europe until 2020 and beyond.

πιστοποίηση η επιλογή των 5050 αυτών που έχουν
 η οριζόντια επιλογή η οποία είναι το ποσό
 η επένδυση βιοεπιστήμης η οριζόντια αυτών
 η οριζόντια επένδυση της ΕΠΙΣ 2020-2024
 η οριζόντια επένδυση της ΕΠΙΣ 2020-2024

09 Feb 2021 | News

Viewpoint: how Horizon Europe could change the face of earthquake prediction

Accepted wisdom holds earthquakes can't be predicted. But a large-scale AI supported sensor system could change that, at the same time building Europe's skills in real time environmental monitoring and becoming a standard bearer for citizen science

By Ramon Alexander Wyss

By Ramon Alexander Wyss

στατιστικά στοιχεία για την πρόβλεψη

αυτοί που είναι οι πιο σημαντικοί στην πρόβλεψη
 η πρόβλεψη των σεισμών είναι η πρόβλεψη
 η πρόβλεψη των σεισμών είναι η πρόβλεψη

What is the occurrence and likely evolution and impact of catastrophic volcanic eruptions?



The 1991 eruption of Mount Pinatubo in the Philippines, classified as VEI 6, cooled global climate by up to 0.7 °C for several years.

Papale and Marzocchi, Science, 2019

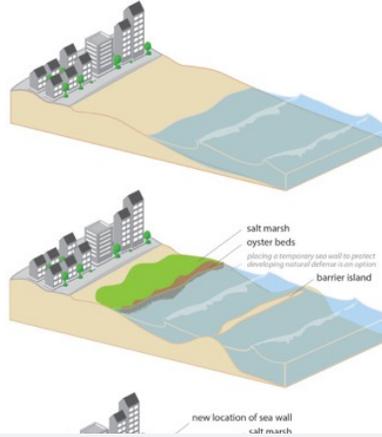
DestinE Phase 2: Digital Twins of the Ocean

Courtesy Martin Visbeck, GEOMAR

Minimal Defense
Many communities have developed right along the ocean with only minimal natural defenses from a small strip of beach between them and the ocean.

Natural
Natural habitats that can provide storm protection include salt marsh, oyster and coral reefs, mangroves, seagrasses, dunes, and barrier islands. A combination of natural habitats can be used to provide more protection, as seen in this figure. Communities could restore or create a barrier island, followed by oyster reefs and salt marsh. Temporary infrastructure (such as a removable sea wall) can protect natural infrastructure as it gets established.

Managed Realignment
Natural infrastructure can be used to protect built infrastructure in order to help the built infrastructure have a longer lifetime and to provide more storm protection benefits. In managed

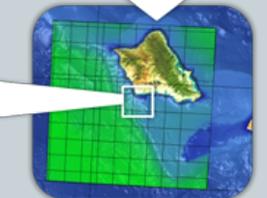
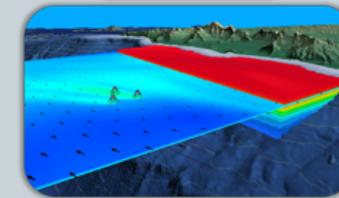
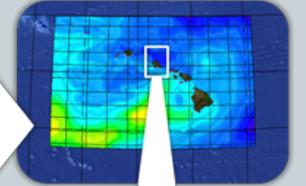
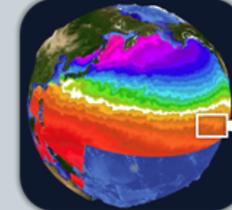


What is the most cost effective option to mitigate the coastal impact of sea level rise?



Global Models

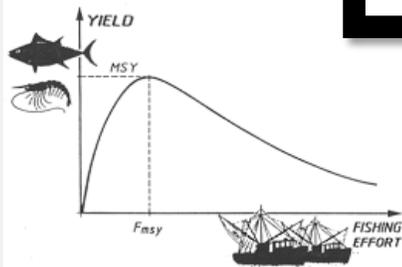
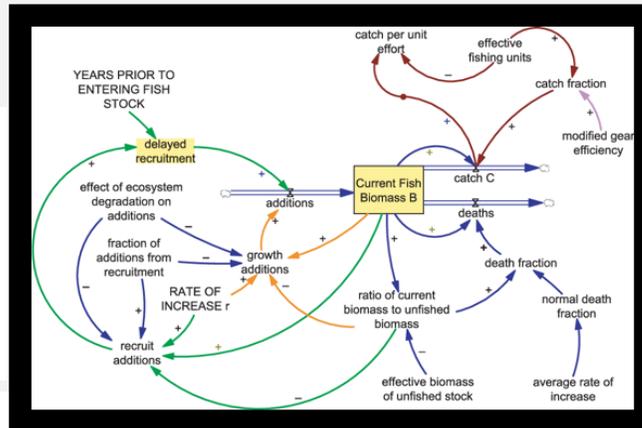
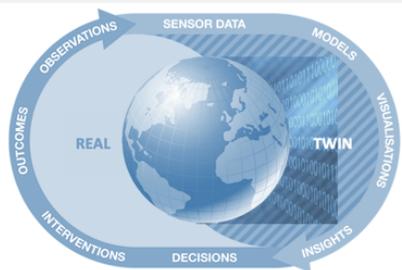
Regional Models



Coastal Models

Local Models

What is the most sustainable way to capture wild fish?



Digital Twins of the Ocean

Digital Twins in a nutshell

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.

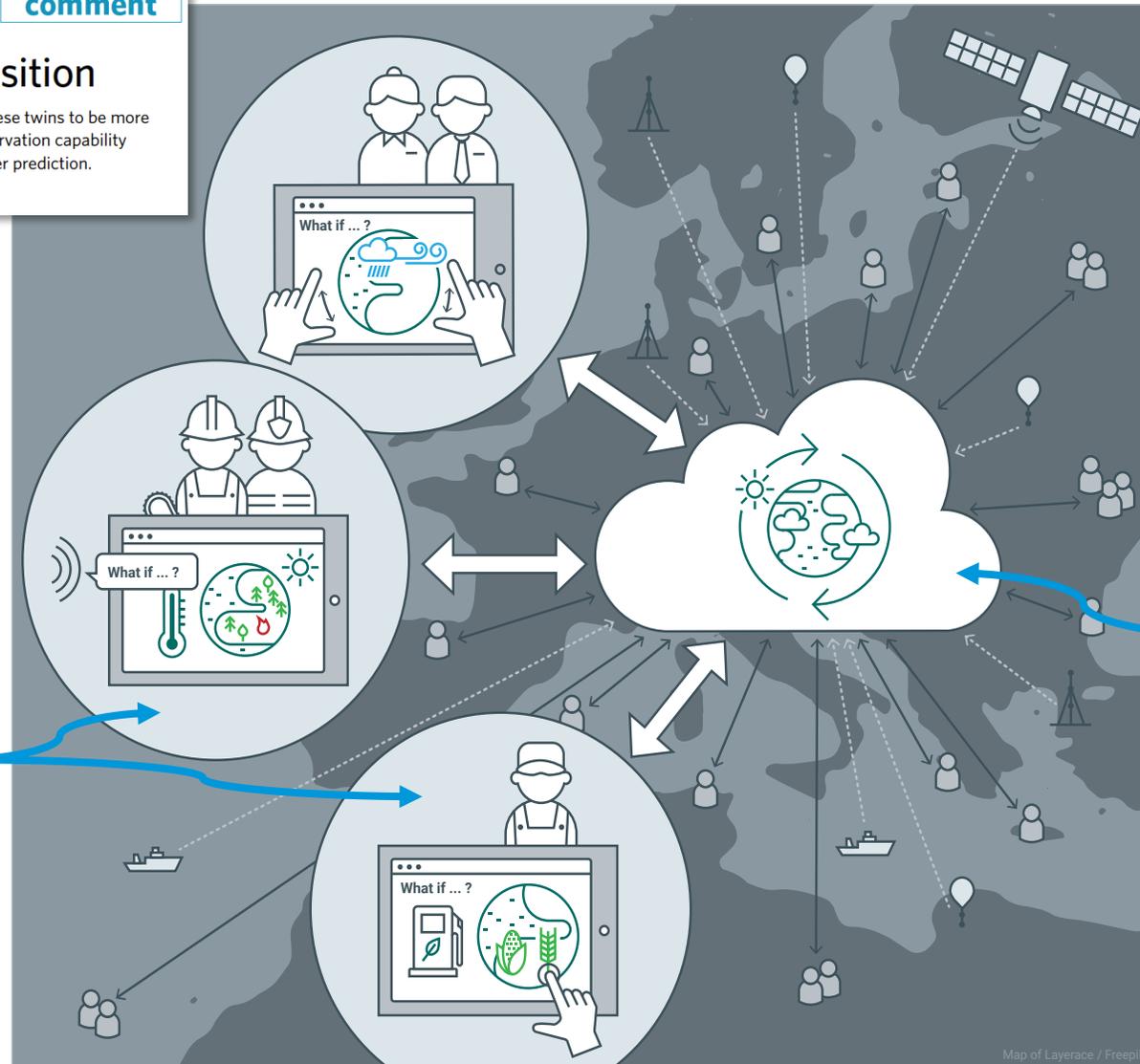
Peter Bauer, Bjorn Stevens and Wilco Hazeleger

“A leap in ...
information quality & intervention
... and a role as a substrate”

Offered by Core Service Platform

Offered by
Digital Twin Engine

... with Data Lake as the
global repository



DestinE in the media

European Commission

- <https://ec.europa.eu/digital-single-market/en/destination-earth-destine>
- https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en
- https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Science and Nature

- <https://www.sciencemag.org/news/2020/10/europe-building-digital-twin-earth-revolutionize-climate-forecasts>
- https://www.nature.com/articles/s41558-021-00986-y?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+nclimate%2Frss%2Fcurrent+%28Nature+Climate+Change+-+Issue%29
- <https://www.nature.com/articles/s43588-021-00023-0>

Other

- <https://www.newscientist.com/article/2256715-building-digital-twins-of-earth-could-help-europe-cut-carbon-emissions/>
- <https://www.hpcwire.com/2020/10/10/eu-to-create-digital-twins-of-earth-run-on-eurohpc-supercomputers/>
- <https://geographical.co.uk/nature/climate/item/3940-the-eu-announces-plans-to-build-destination-earth-a-digital-twin-of-our-planet>

... thanks to many people having worked on this for months in addition to their regular duties