

DESTINATION EARTH

EARTH SYSTEM DIGITAL TWINS & AI MODELS

Irina Sandu

On behalf of ECWMF and over 100 partner organisations in
Member and Co-operating States

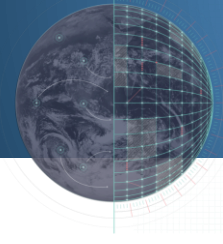


Funded by
the European Union

Destination Earth

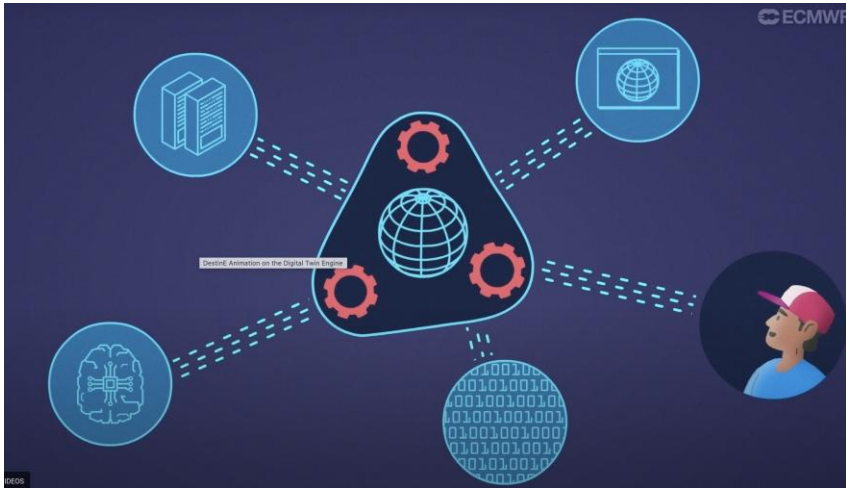
implemented by





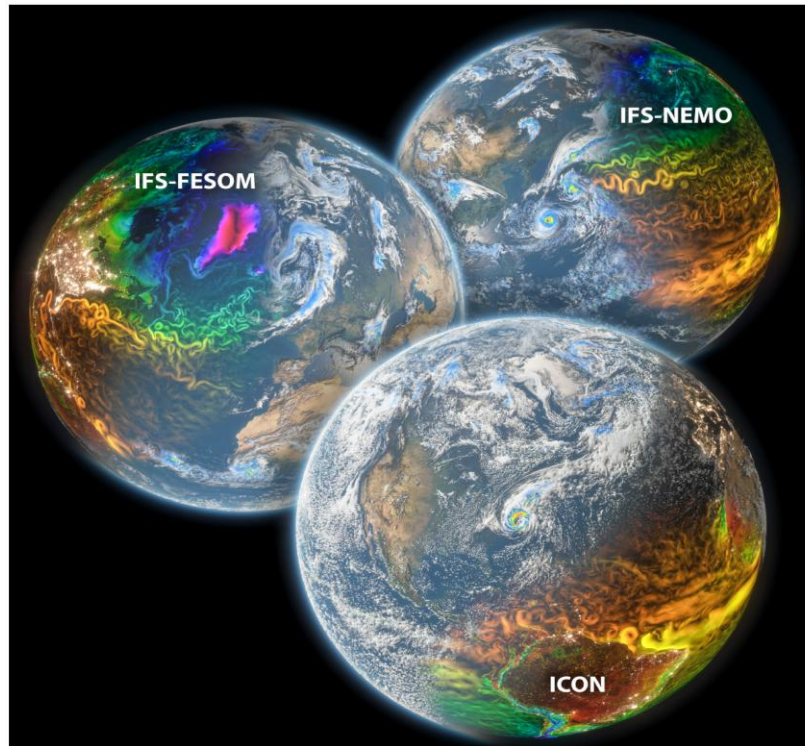
IMPLEMENTING DIGITAL TWIN TECHNOLOGY

Software engines, tooling & services

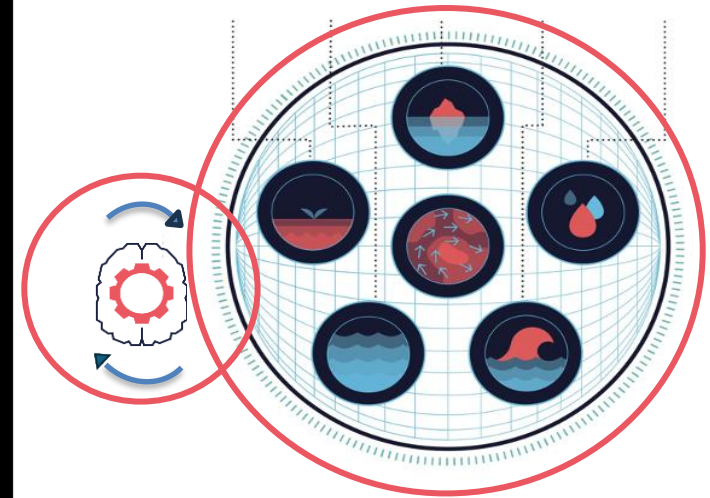


Digital twin engine

Next generation modelling systems – physics & AI-based



Digital twins



AI models & solutions

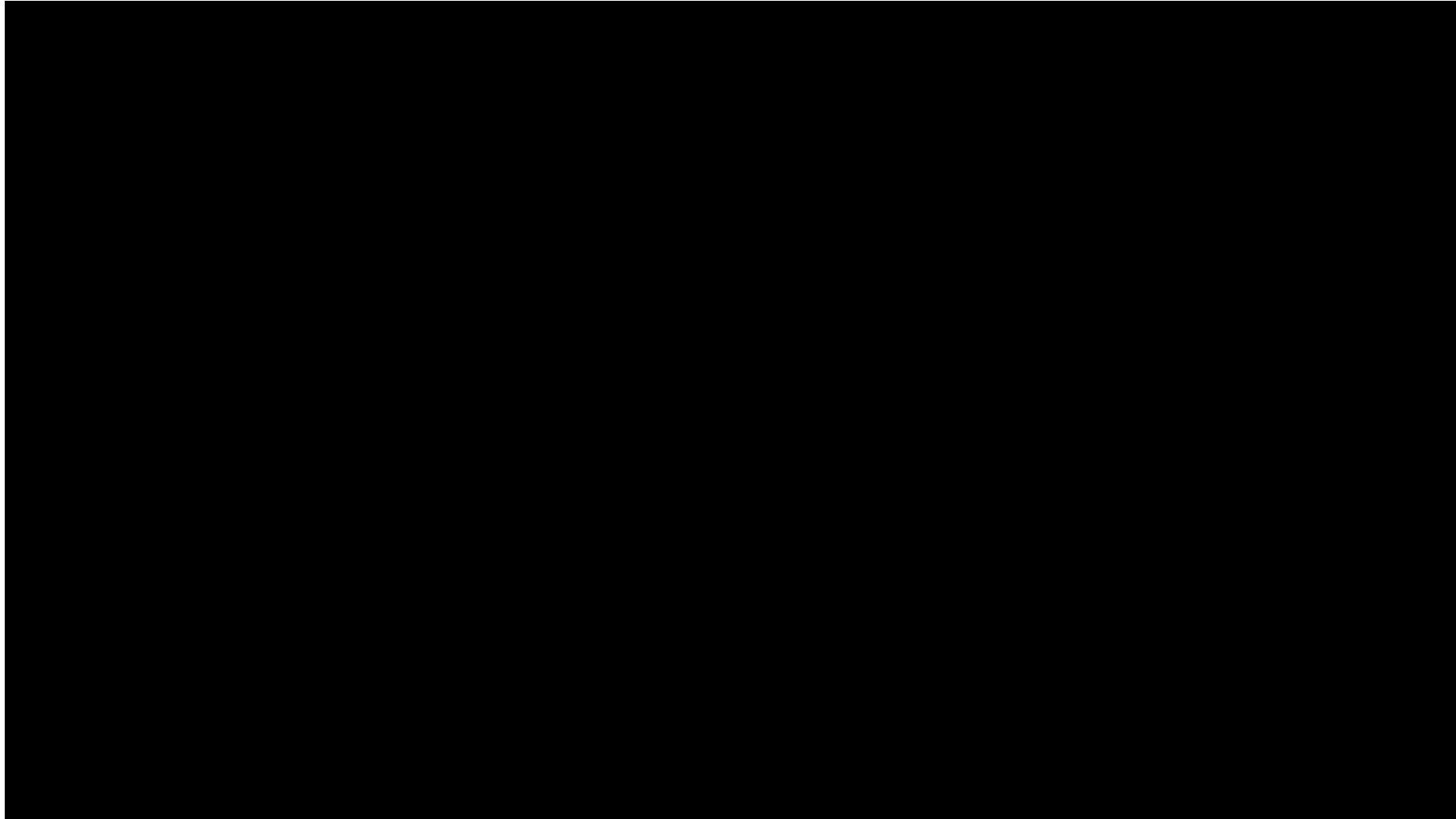


FLEXIBLE SIMULATION FRAMEWORKS: REGULAR PRODUCTION & WHAT-IF SIMULATIONS





HIGH-RESOLUTION EARTH-SYSTEM & IMPACT-SECTOR INFORMATION

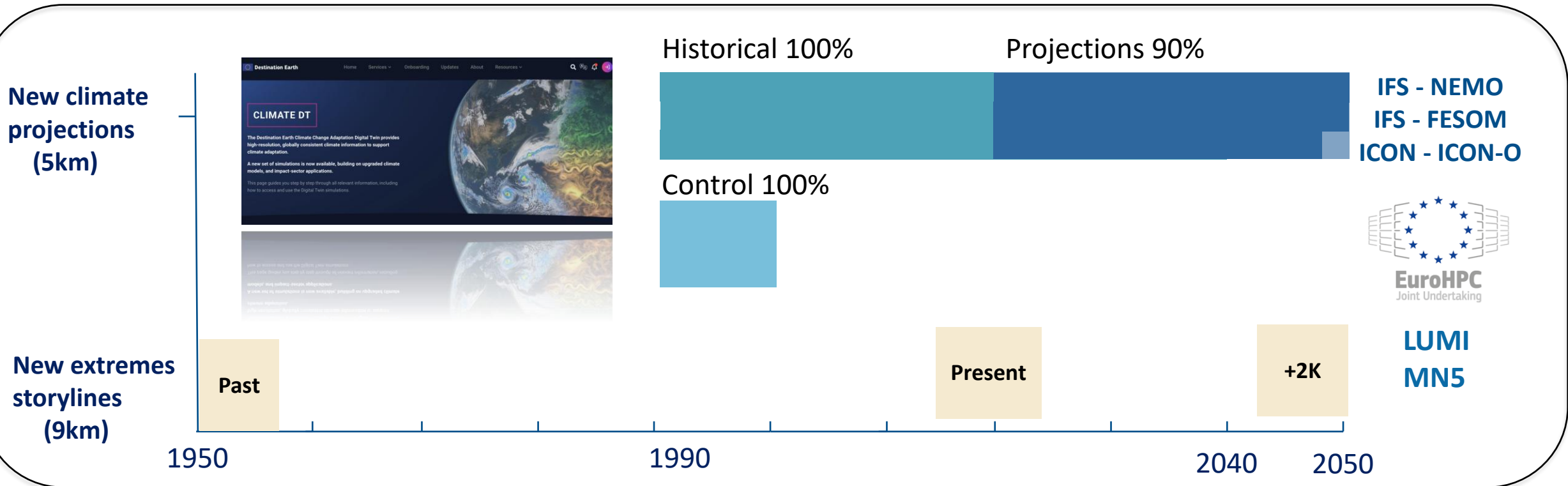


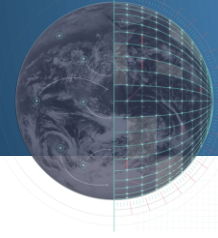
[illegible]



CLIMATE DT: MULTI-DECADAL PROJECTIONS & STORYLINES

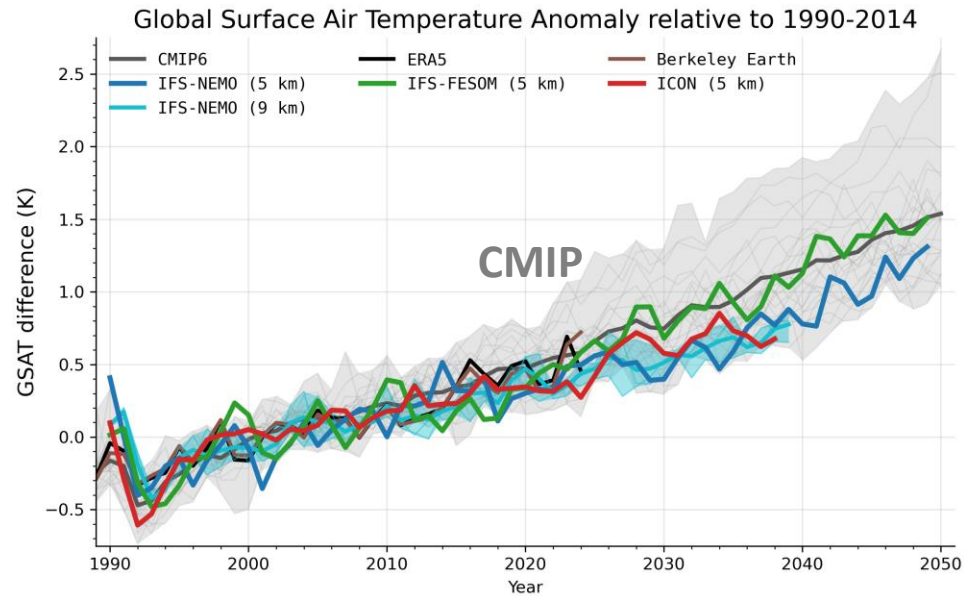
First set of simulations with operational suites released in May; impact sector data coming soon



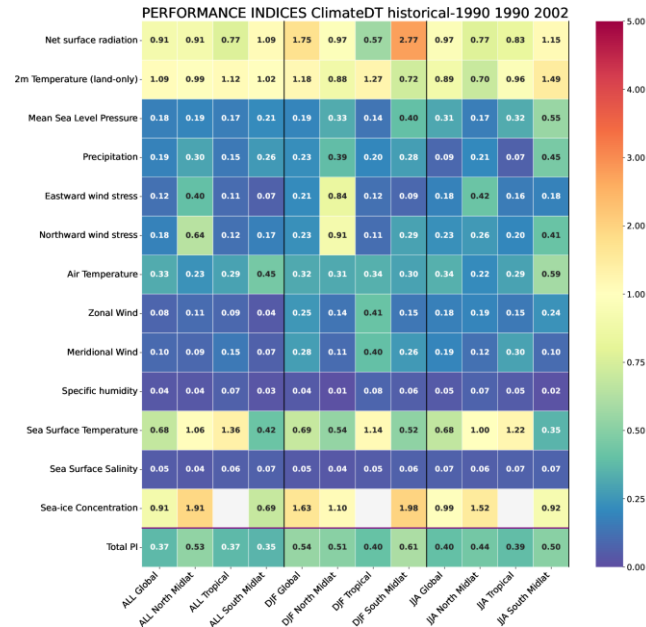


CLIMATE DT: QUALITY CONTROL & EVALUATION

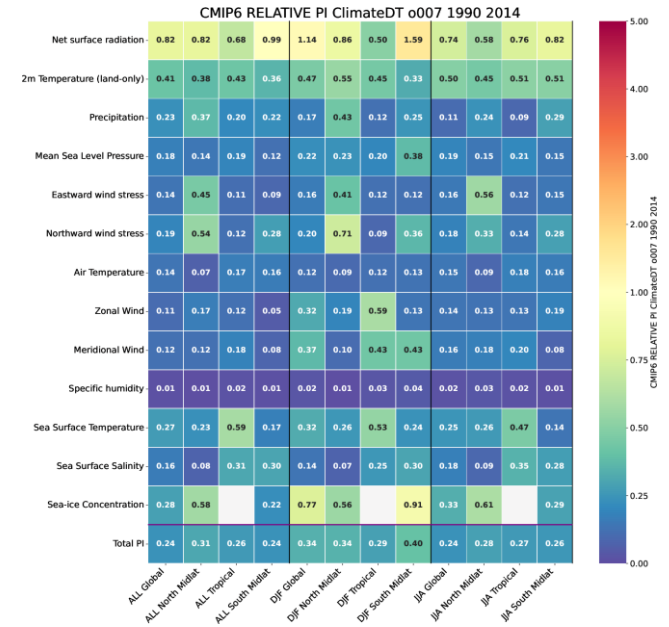
New set of simulations quality-controlled on-the-fly & contextualized with CMIP6



Phase 1, IFS-NEMO



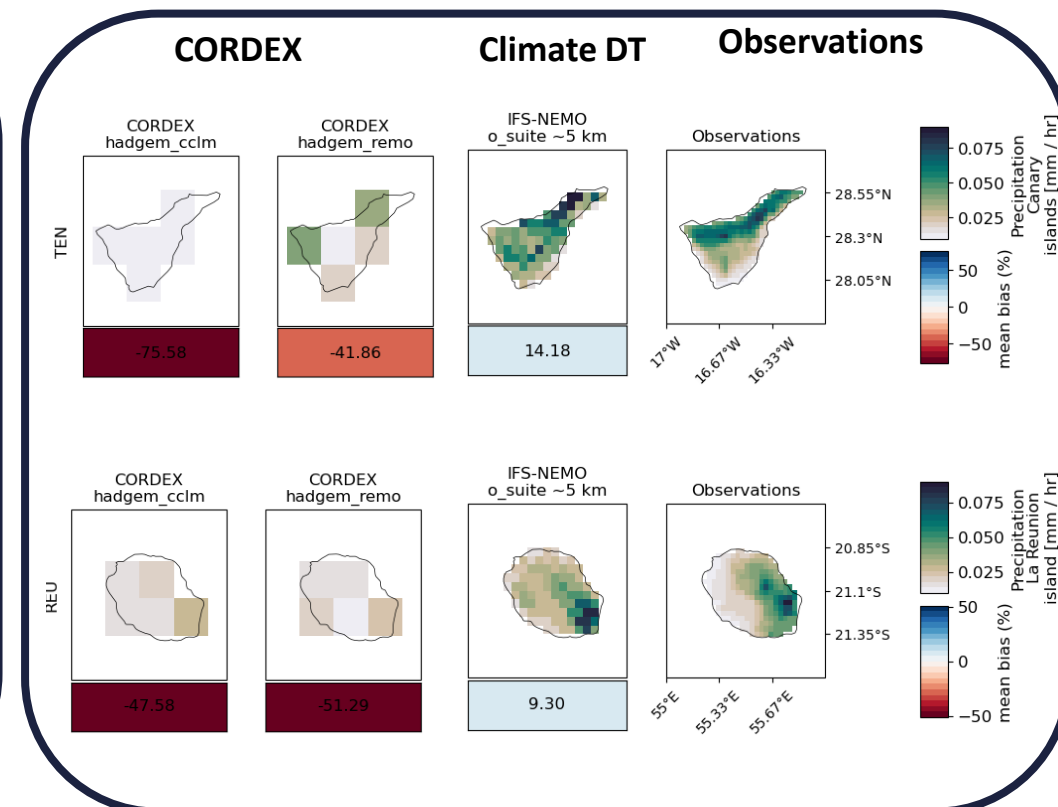
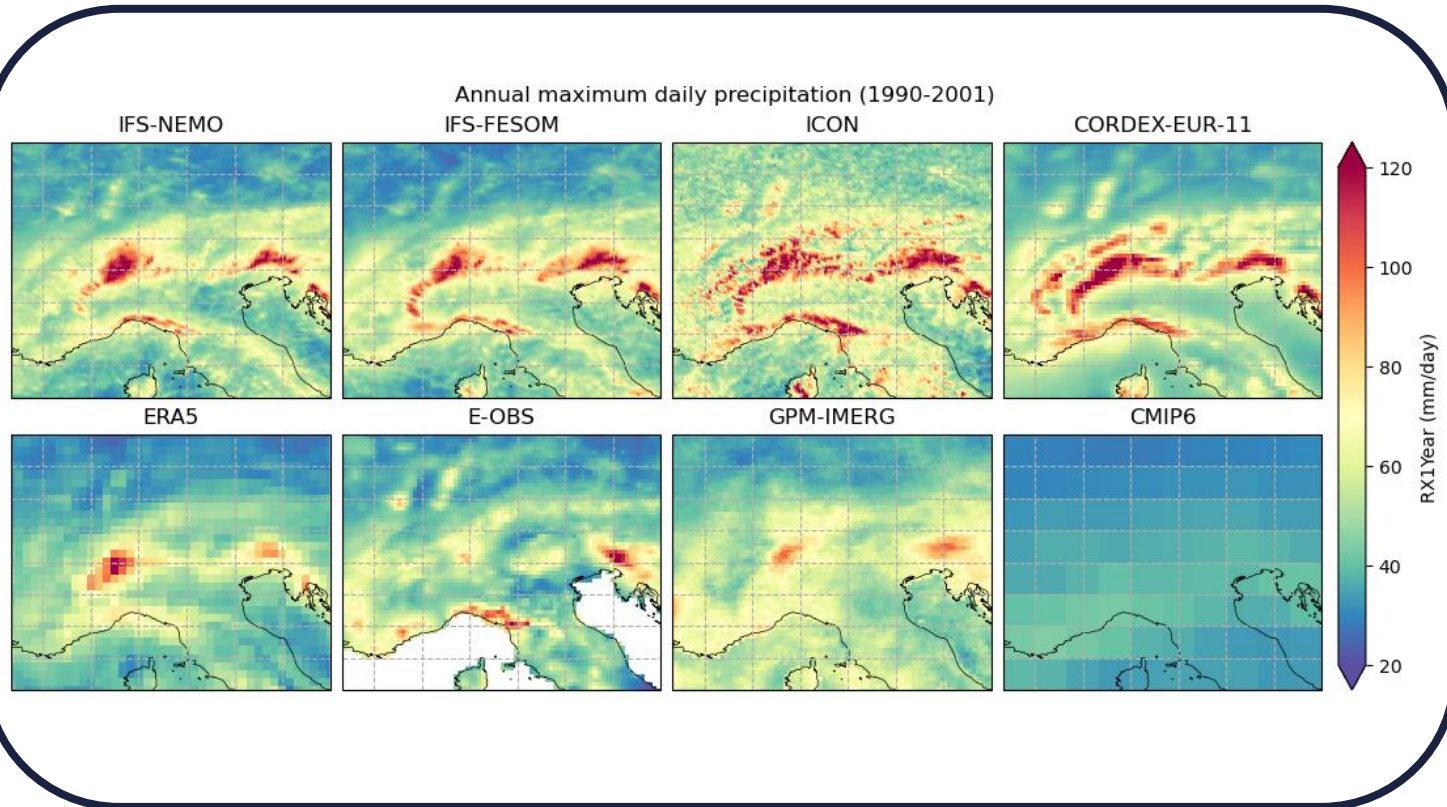
Phase 2, IFS-NEMO





CLIMATE DT: QUALITY CONTROL & EVALUATION

New set of simulations quality-controlled on-the-fly & contextualized with CMIP6 & CORDEX



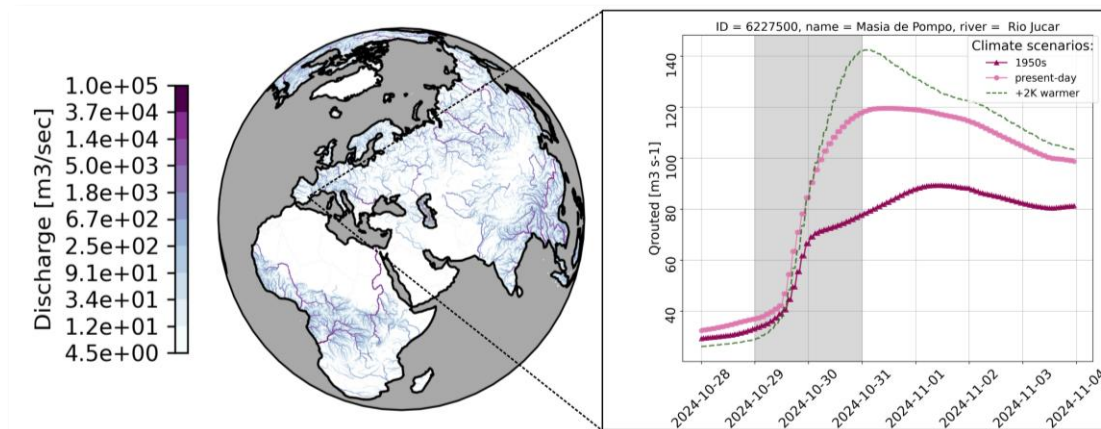
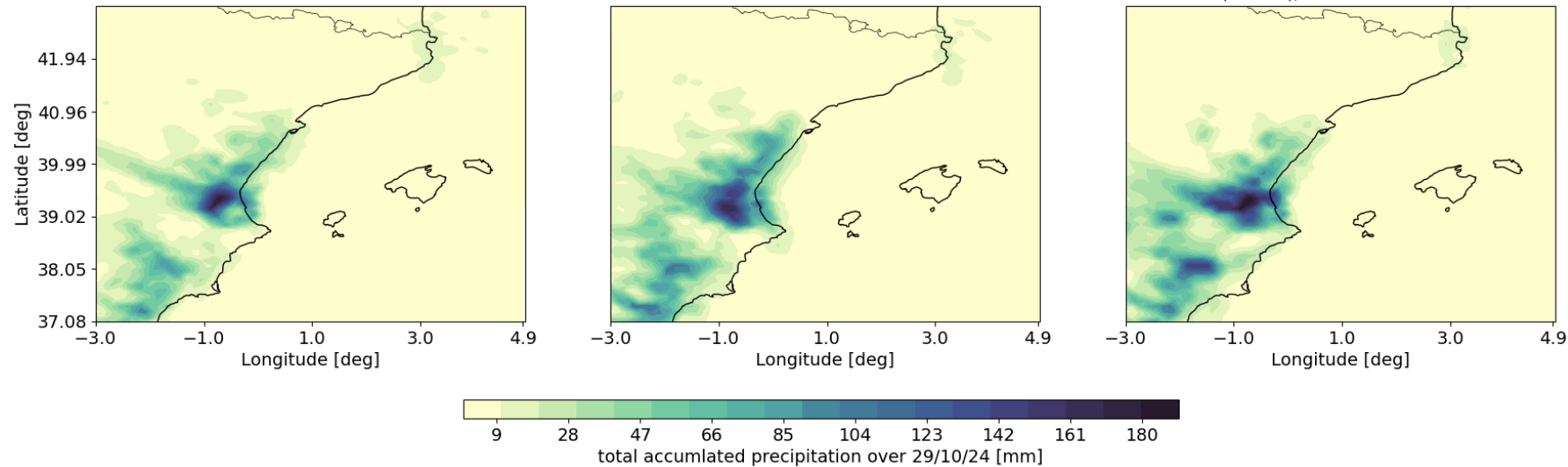


CLIMATE DT: REPLAYING THE VALENCIA FLOODS, OCT 24

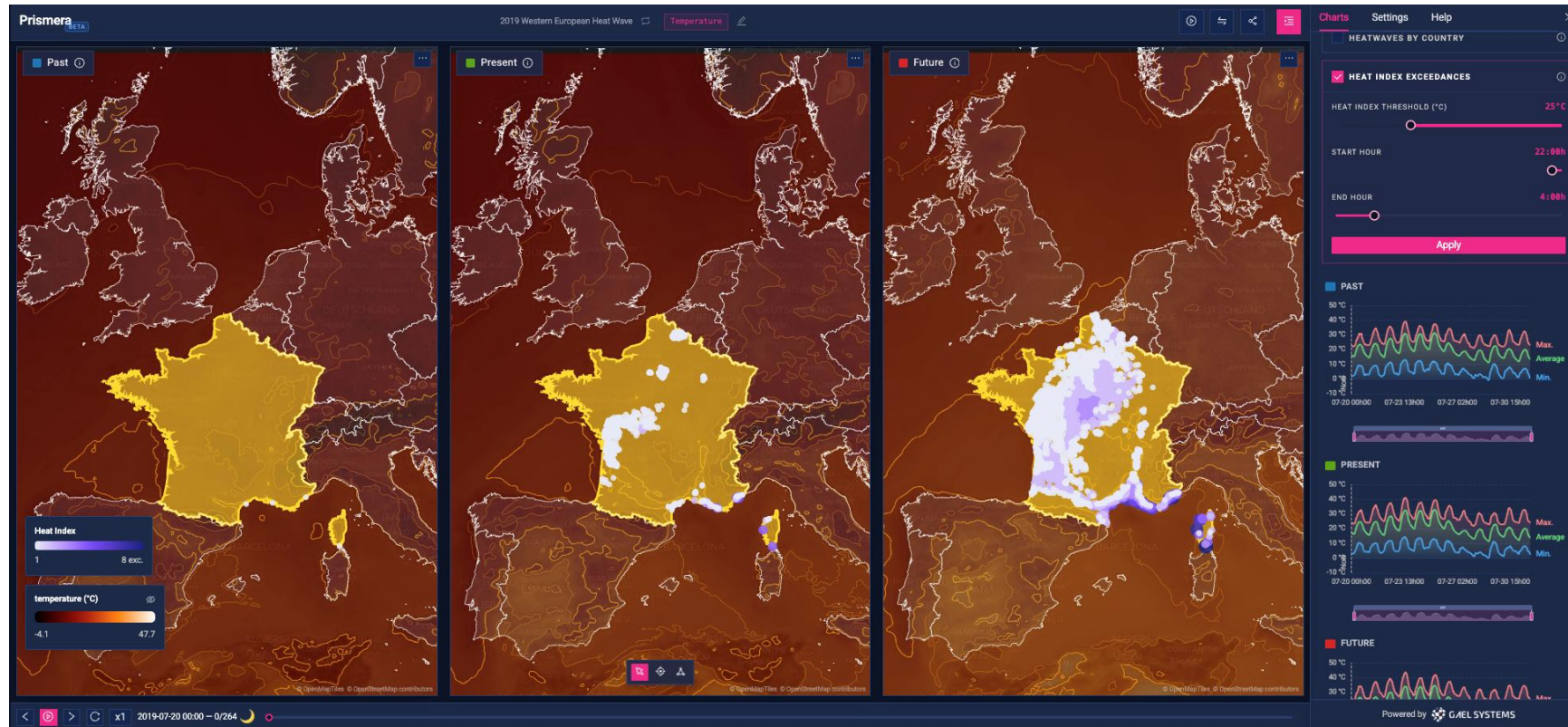
1950: 180 km² over 100 mm

2024: 340 km² over 100 mm

2050 (+2C): 510 km² over 100 mm



STORYLINE VIEWER ON DESTINE PLATFORM



Interactive simulation tool to compare how extreme weather events unfold under past, present, and future climate conditions.

Two case studies

- Western European Heat Wave July 2019
- Central European Floods, Storm Boris, September 2024

Past Climate

Representing the climate state of approximately 1950

Present climate

Representing the climate state at the time the event actually occurred (2017-2025).

Future +2°C warming

illustrating how the severity of such events may intensify under continued climate change

Meteorological variables

- Temperature
- Humidity
- Accumulated precipitation



Funded by
the European Union

Destination Earth

implemented by



ECMWF



esa



EUMETSAT



EXTREME DT

Operationalizing an end-to-end framework for producing bespoke extremes information & exploring “what-if” scenarios

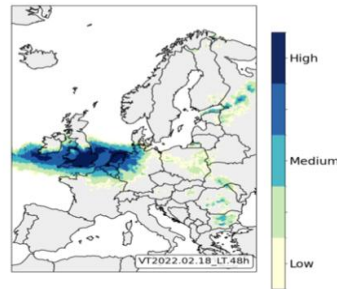
Global simulations



IFS-NEMO (4.4 km)

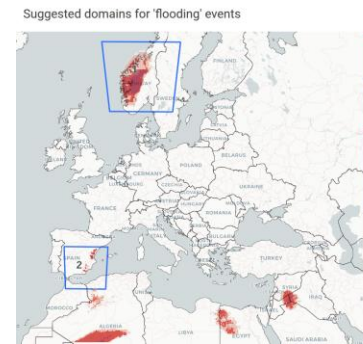
- Run daily
- 4 days
- 4.4 km

Detection/Configuration



- Detection of extremes
- Wind, precipitation, CAPE, surge...

Regional simulations



ALARO, AROME, HARMONIE-AROME

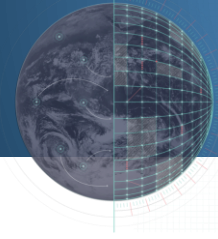
- Run in near-real-time for hundreds of cases
- Flexible domain
- 2 days
- 750-500m

Impact sector models



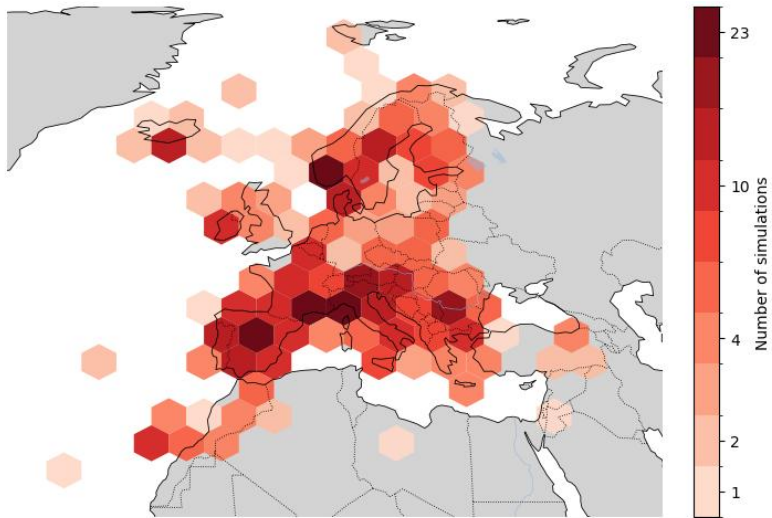
- Floods, renewable energy, air quality, storm surge, thermal comfort, fire
- User-relevant information



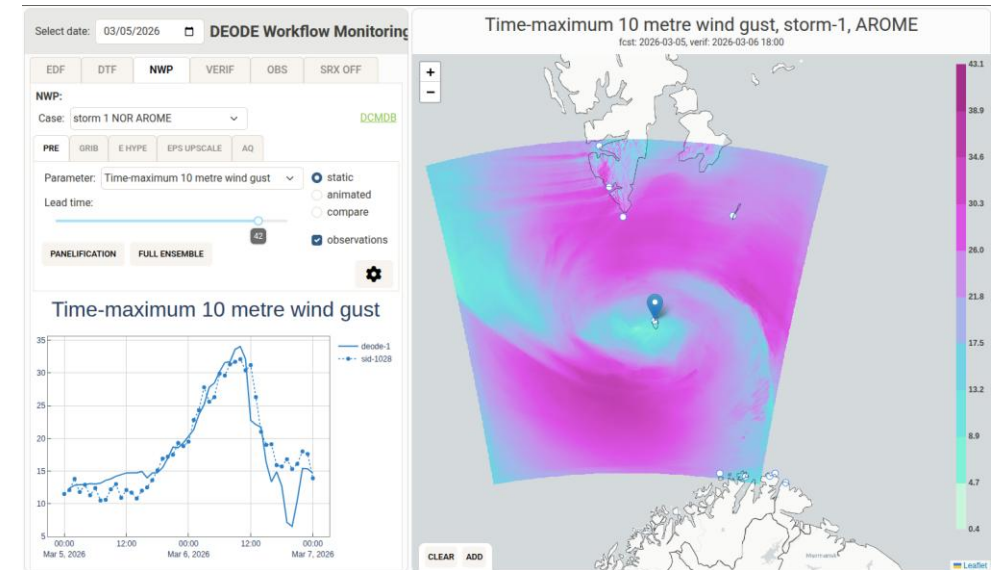


TAILORED EXTREME EVENTS INFORMATION

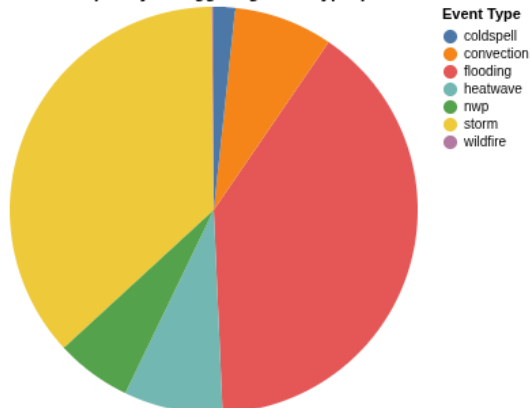
Regional Extremes DT runs



Bear Island, Norway, 5-6 March



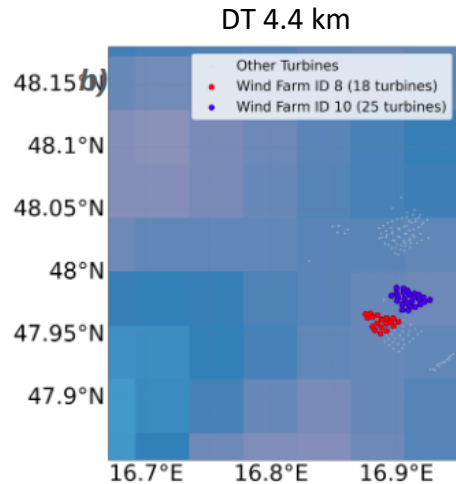
Frequency of triggering event types)



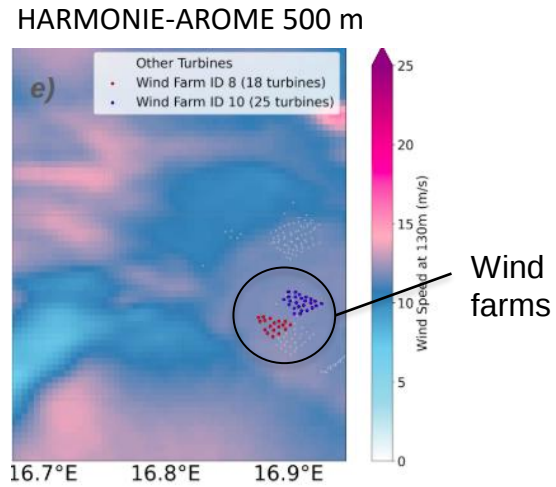


REGIONAL EXTREMES DT COMPLEMENTS EXISTING PREDICTION SYSTEMS

Wind energy

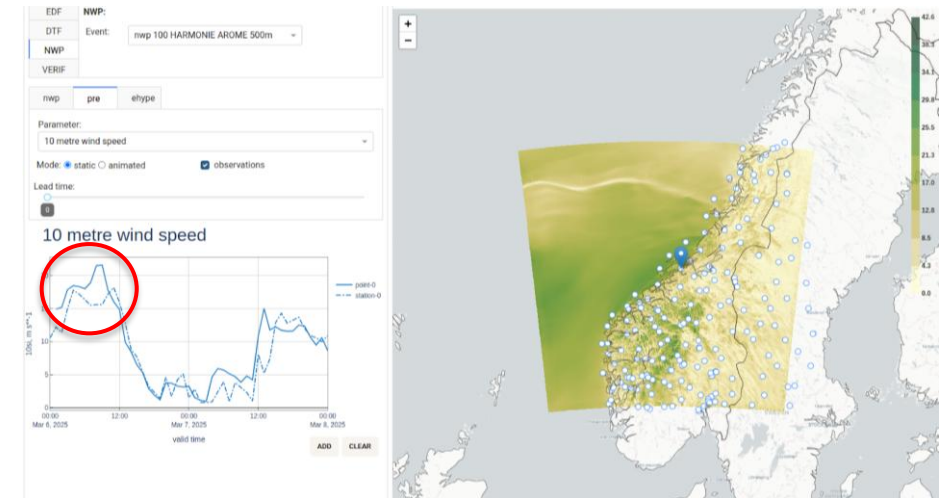


Wind energy production in Austria



Supporting events

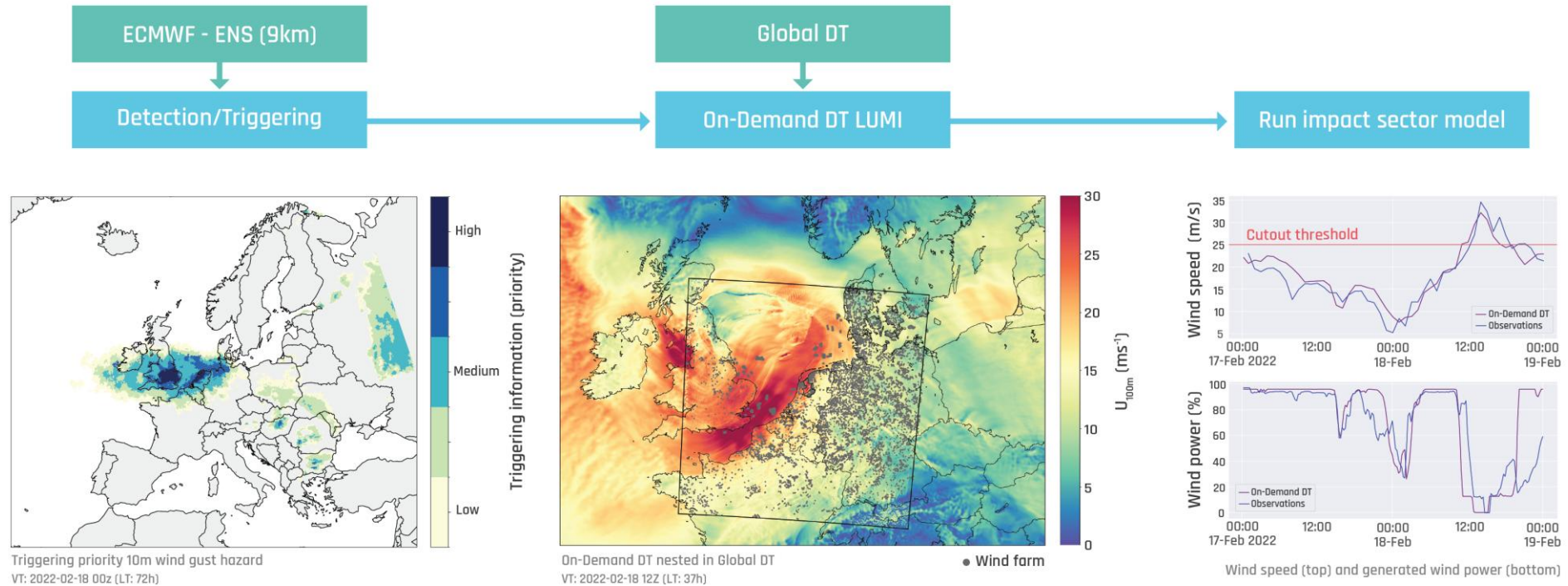
FIS Nordic World Ski Championships 2025





EXTREMES DT: LEARNING FROM PAST CASES

Simulation of the drop in off-shore wind energy production during Storm Eunice (2022)



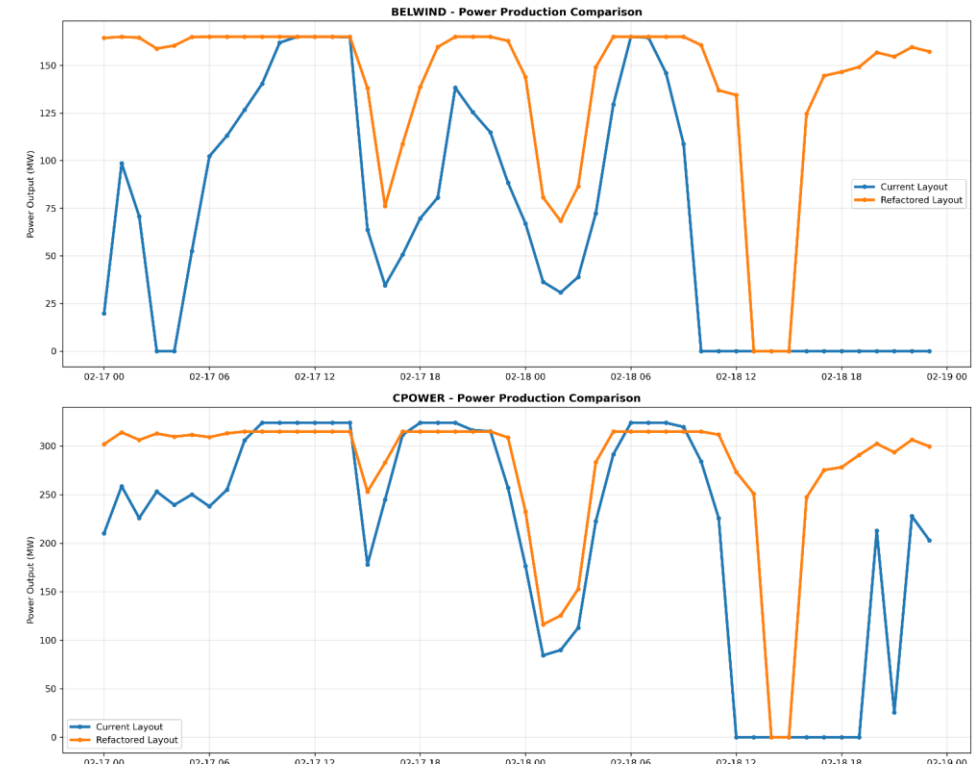
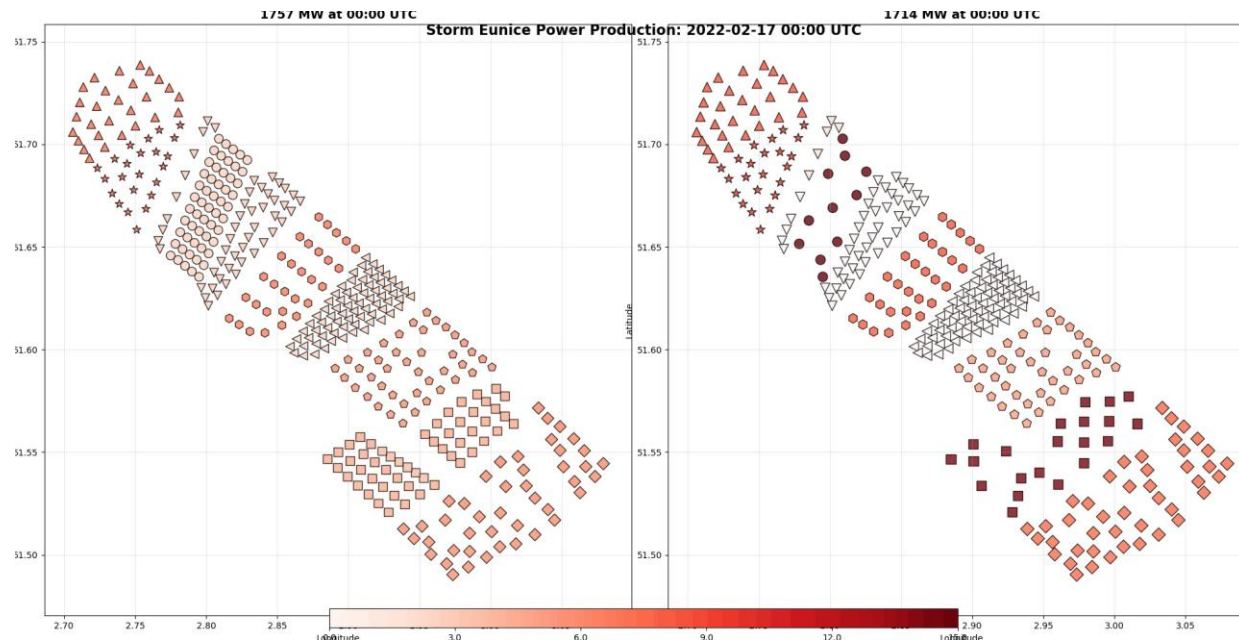


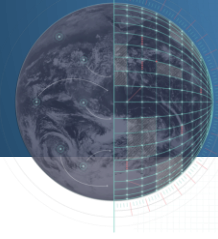
... NOW LET'S REPLAY THE STORY

What if an offshore wind farm had been refactored with modern turbines before Storm Eunice?

Current farm (398 turbines)

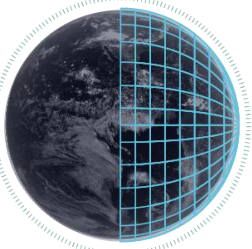
Refactored farm (321 turbines)





DIGITAL TWINS: PHASE 3

**Operate & upgrade
digital twins & engine**



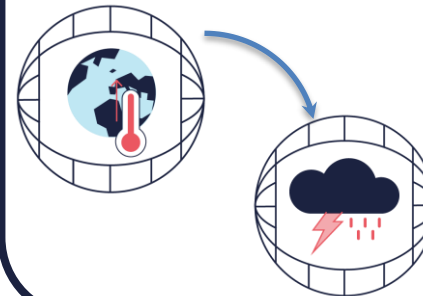
**Run regular & bespoke
'what-if' simulations**



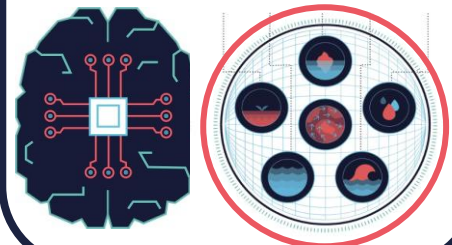
**Deliver tailorclimate,
extremes & impact-sector
information**



**Link Climate & Extremes
DT for joint storyline
simulations**

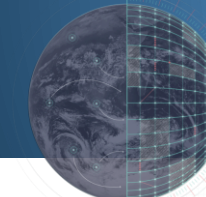


**Tailored AI-ready
datasets**



Areas of focus:

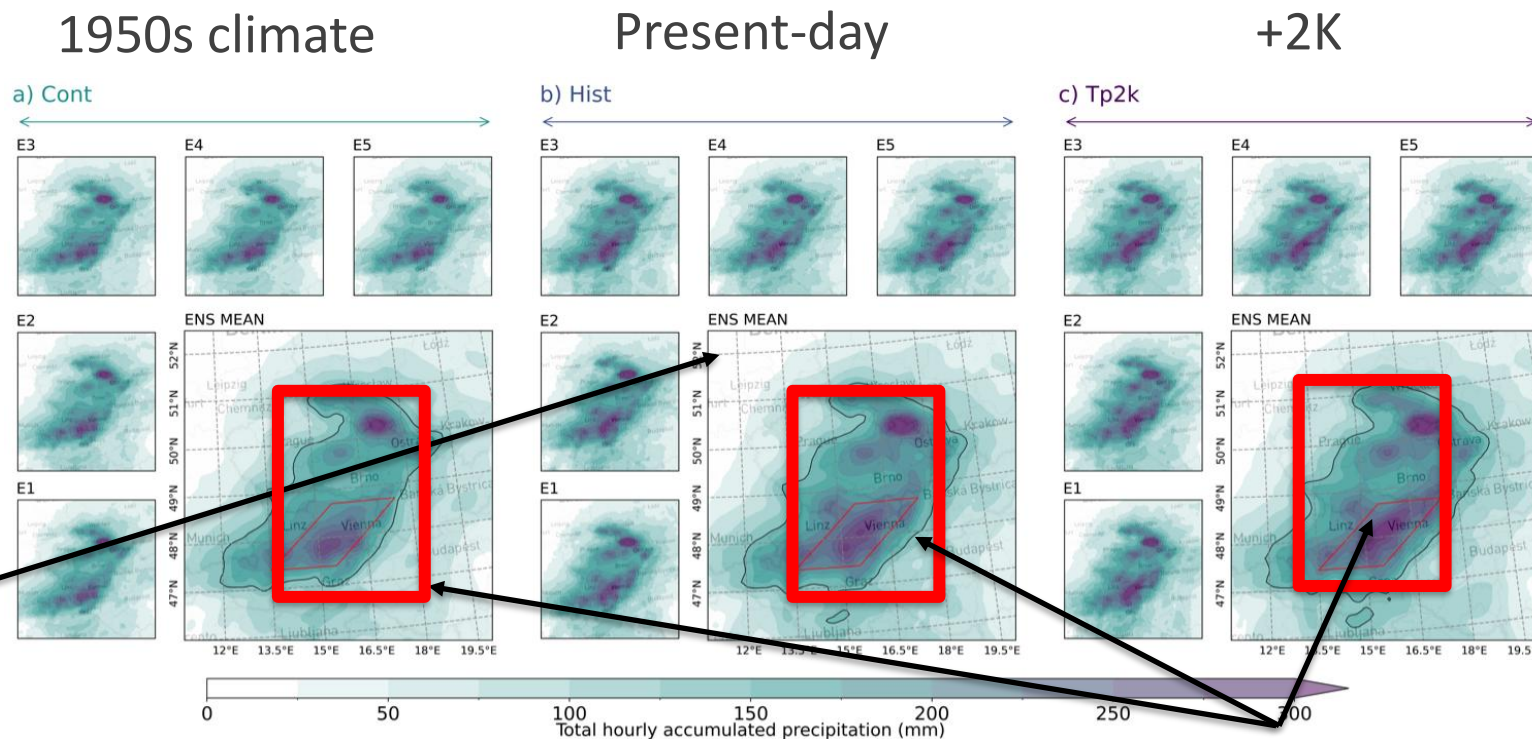
- Defining and executing 'what-if' scenarios
- Coupling regional extremes and climate DTs to explore future extremes
- Translating climate/extremes data to impact-sector information
- Uncertainty quantification & combination with existing datasets
- Documentation and support of uptake by national / EU institutions



JOINT STORYLINE ANALYSIS:

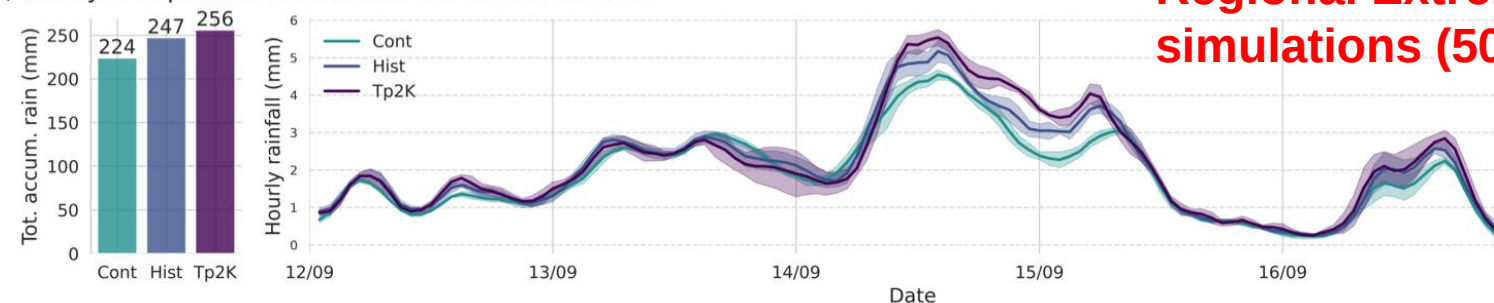
Central European floods September 2024

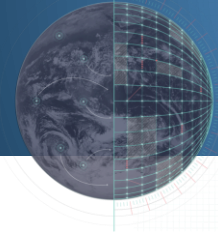
Global Climate DT simulations (9km)



Regional Extremes DT simulations (500m)

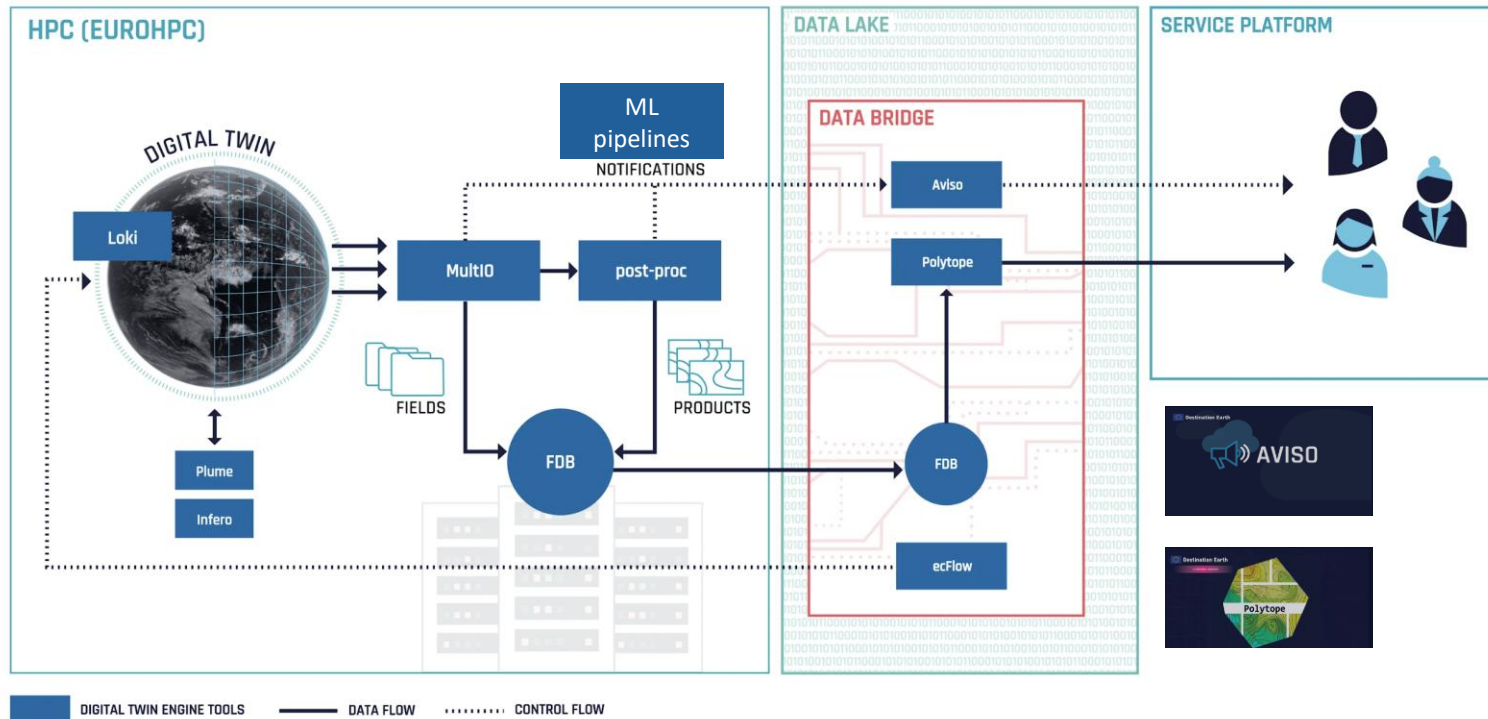
d) Hourly Precipitation recieved for the area of interest



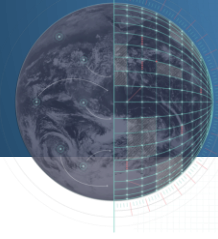


DIGITAL TWIN ENGINE : PHASE2

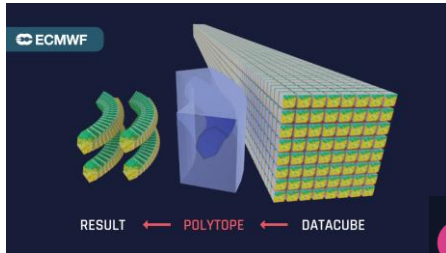
Operates digital twin workflows on EuroHPC & provides services for accessing and interacting with digital twin data



- Operations, data flows and handling on distributed HPC & cloud infrastructure
- Adaptation / optimisations on GPU & CPU
- Semantic data access & notification
- ML pipelines (building on Anemoi)



INTEROPERABLE SEMANTIC DT DATA ACCESS



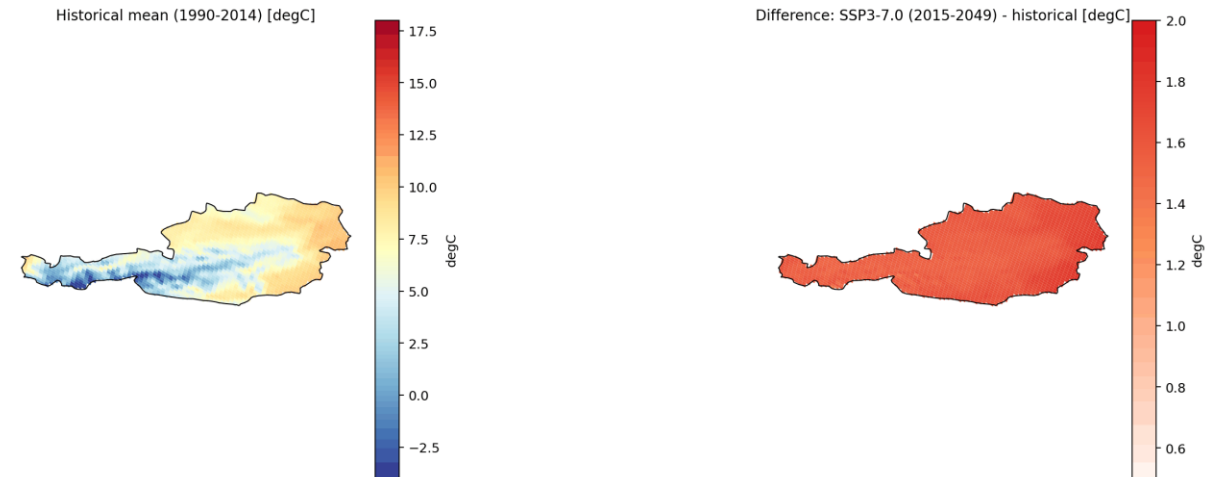
Polytope - service

Examples:

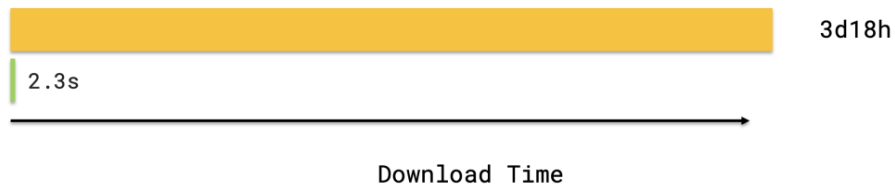
<https://github.com/destination-earth-digital-twins/polytope-examples>



IFS-FESOM mean near-surface temperature - Austria



Time series in a single point from a 20 years climate projection



Research | [Open access](#) | Published: 01 November 2025

Polytope: an algorithm for efficient feature extraction on hypercubes

[Mathilde Leuridan](#) ✉, [James Hawkes](#), [Simon Smart](#), [Emanuele Danovaro](#), [Martin Schultz](#) & [Tiago Quintino](#)

Journal of Big Data **12**, Article number: 243 (2025) | [Cite this article](#)

553 Accesses | 1 Altmetric | [Metrics](#)

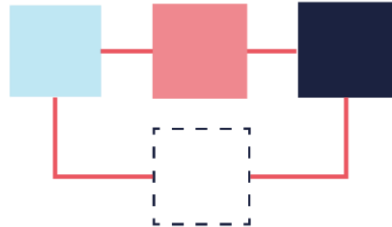


DIGITAL TWIN ENGINE: PHASE 3

Operate & upgrade digital twin engine



Interoperable & configurable data production pipelines



Observability, data governance & provenance



Interactivity: user-defined simulation & data delivery

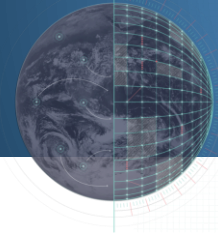


Integrated ML, AI-ready datasets, training & inference



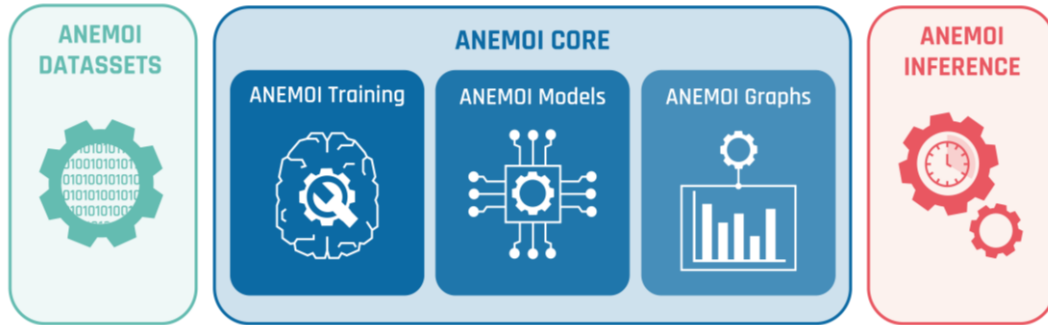
Areas of focus:

- Integration and tailoring of ML/AI pipelines in digital twin workflows
- Production & integration of AI-ready datasets with AI factories
- Tailored access or on-the-fly generation of data
- Documentation and support of uptake by national / EU institutions

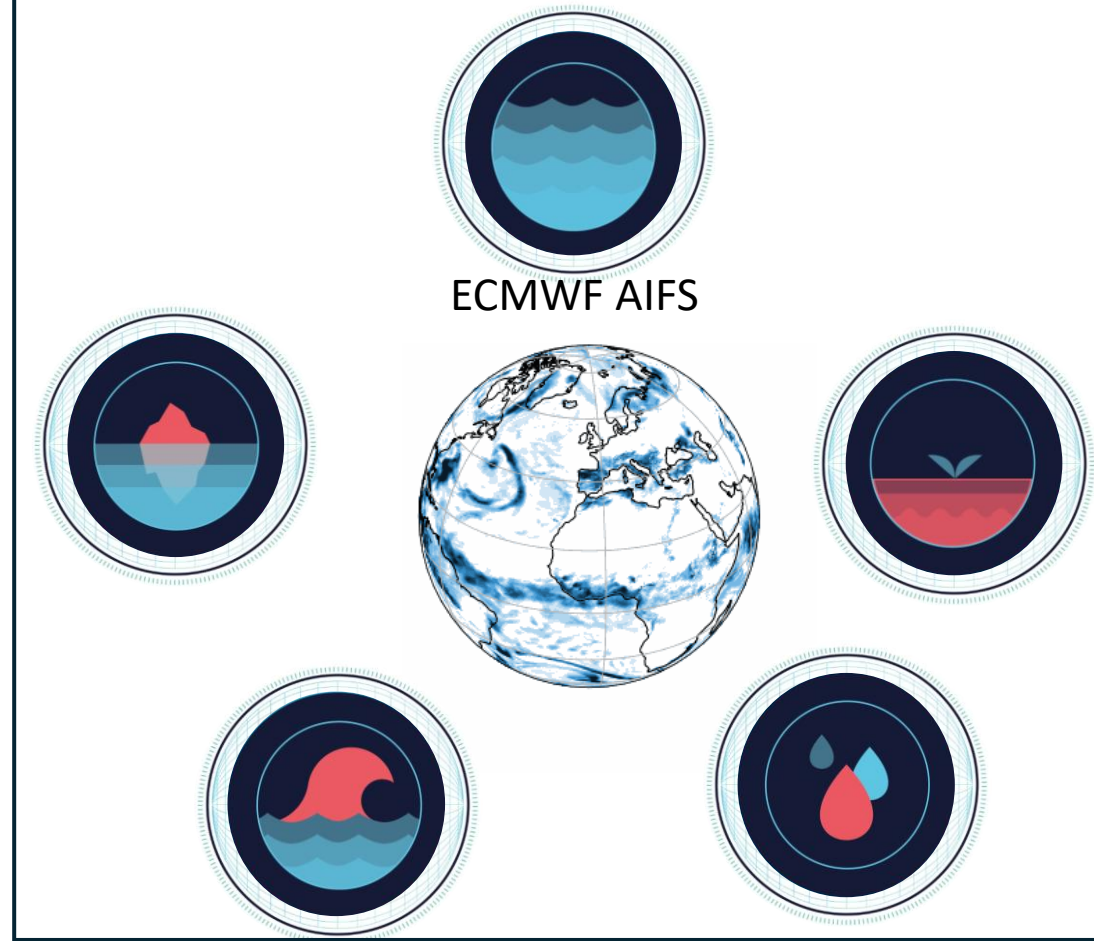


AI EARTH SYSTEM MODEL

Building on Anemoi & AIFS



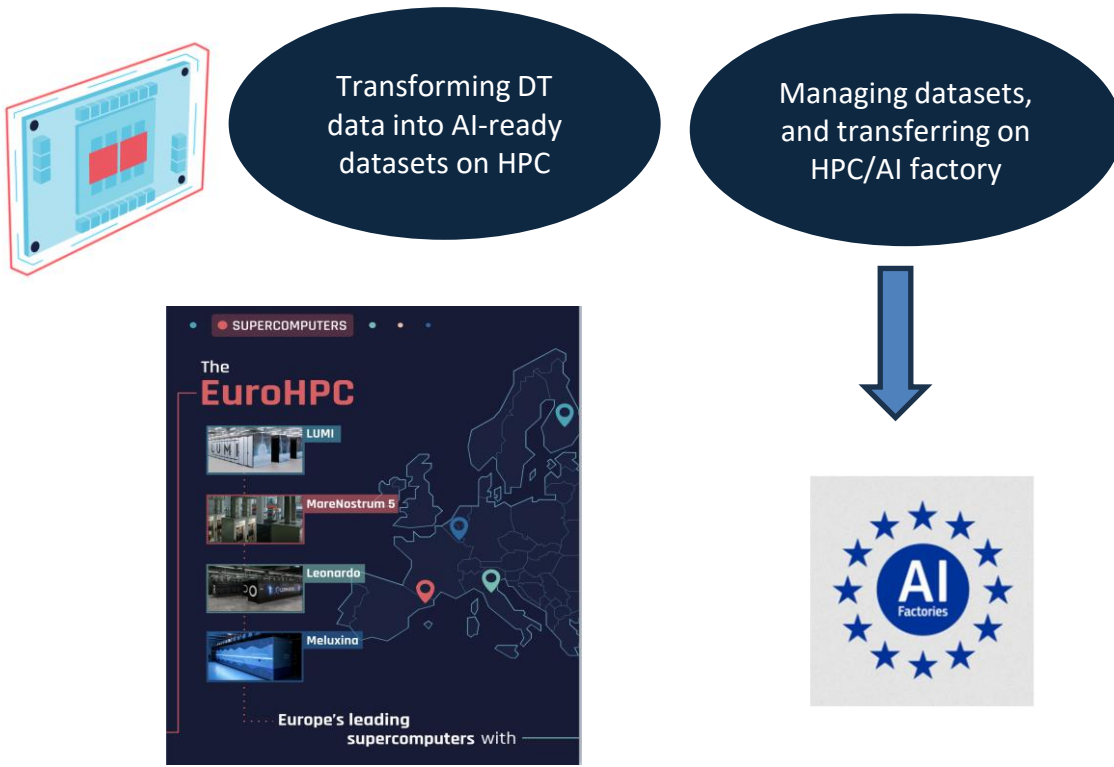
ML Earth system components



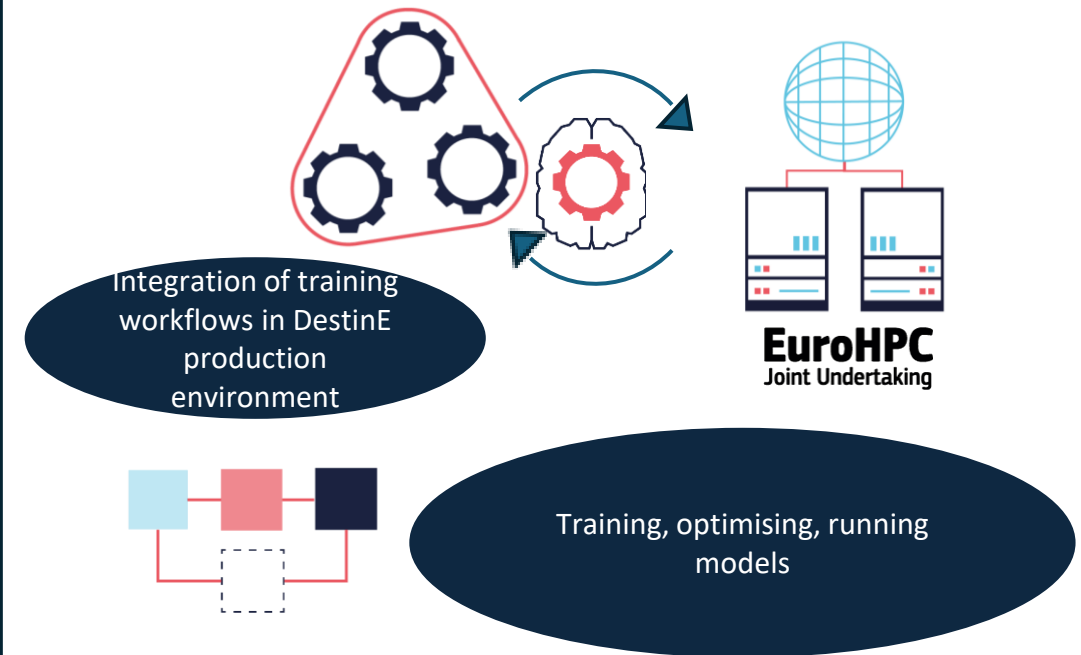


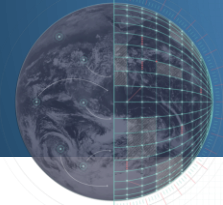
BUILDING ON ANEMOI TO INTEGRATE ML PIPELINES IN THE DIGITAL TWIN ENGINE

Producing, managing, transferring datasets



Training & optimizing models

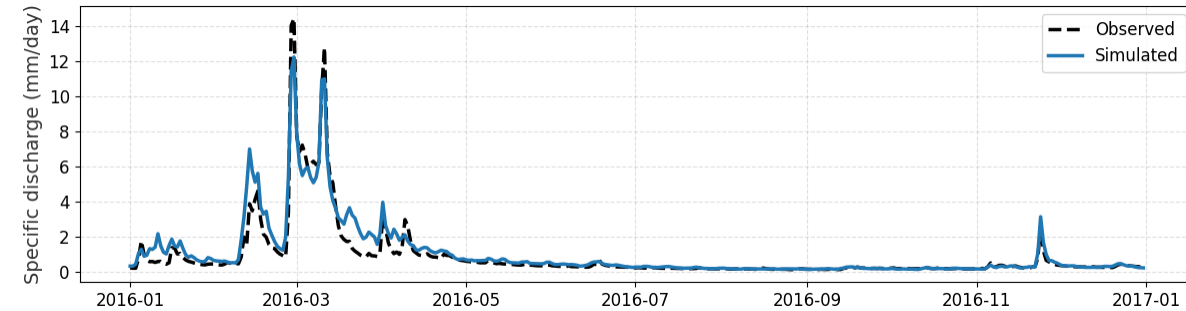
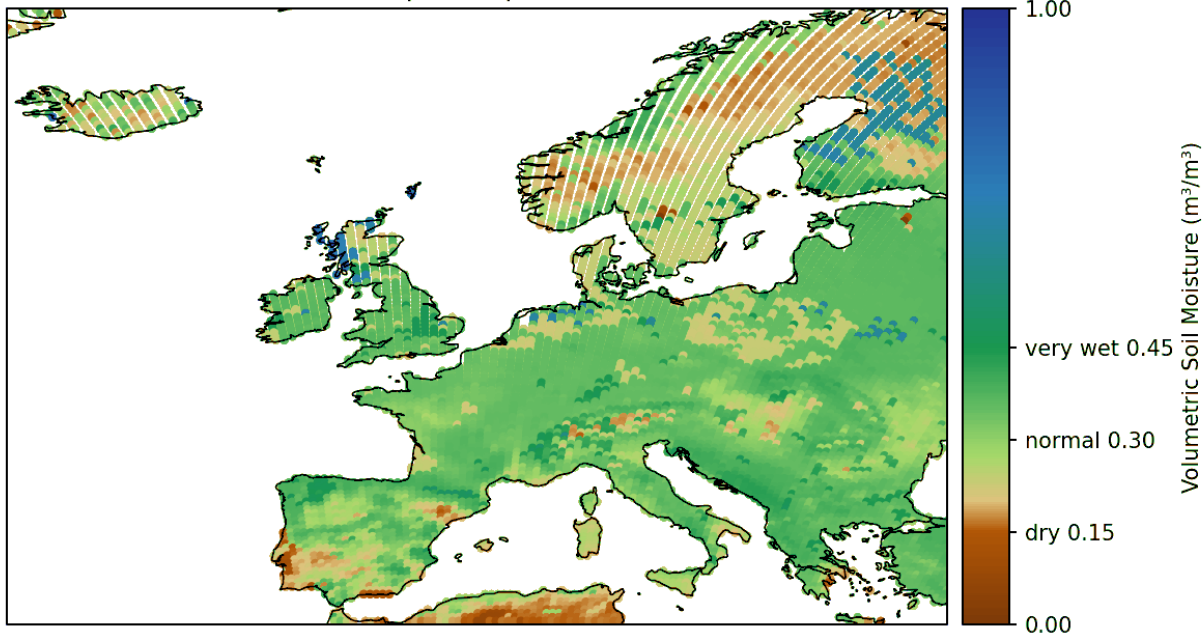




SOIL MOISTURE AND RIVER DISCHARGE



Volumetric Soil Moisture — 7-day mean
01 Apr-07 Apr 2022



Discharge simulations for a basin in Spain.

An AI forecast-in-box

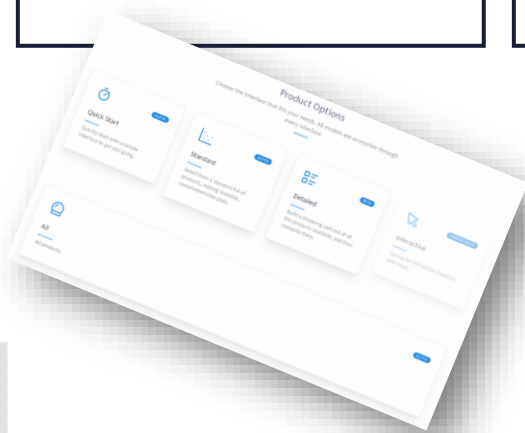


Deploy
Anywhere

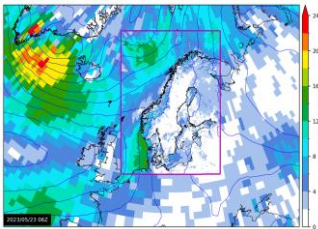
*Configure,
initialise & run*

*Choose the
AI model*

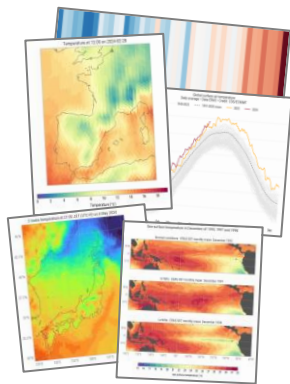
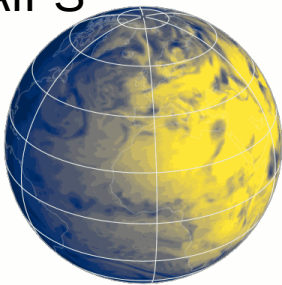
*Select Products /
Visualise*

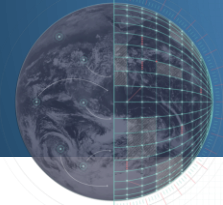


BRIS



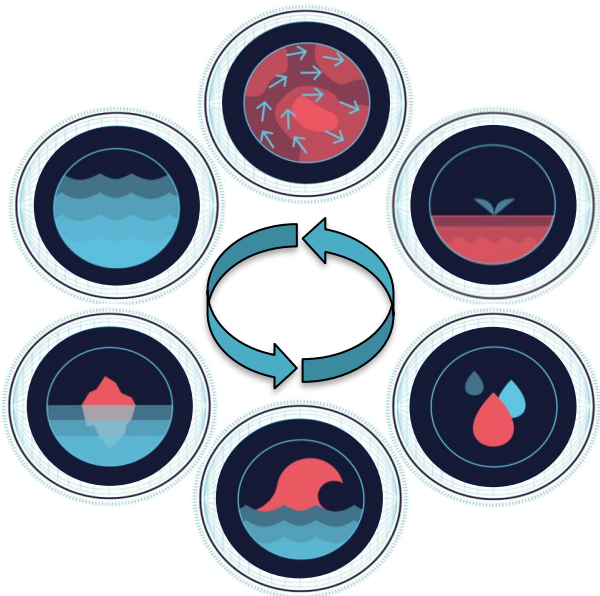
AIFS



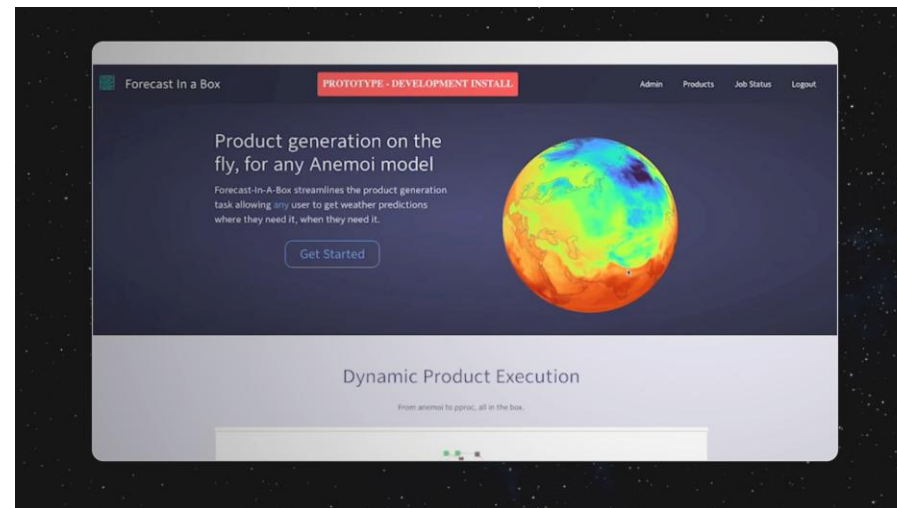


AI PHASE 3: PRODUCTION-READY EARTH SYSTEM MODELS & SOLUTIONS

Towards an AI - ESM



Forecast-in-a-box



Chatbot: Digital Twin assistant

