

DESTINATION EARTH

DIGITAL TWINS OF THE EARTH SYSTEM

Irina Sandu

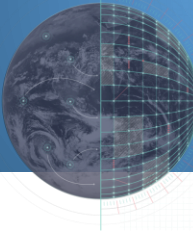


Funded by
the European Union

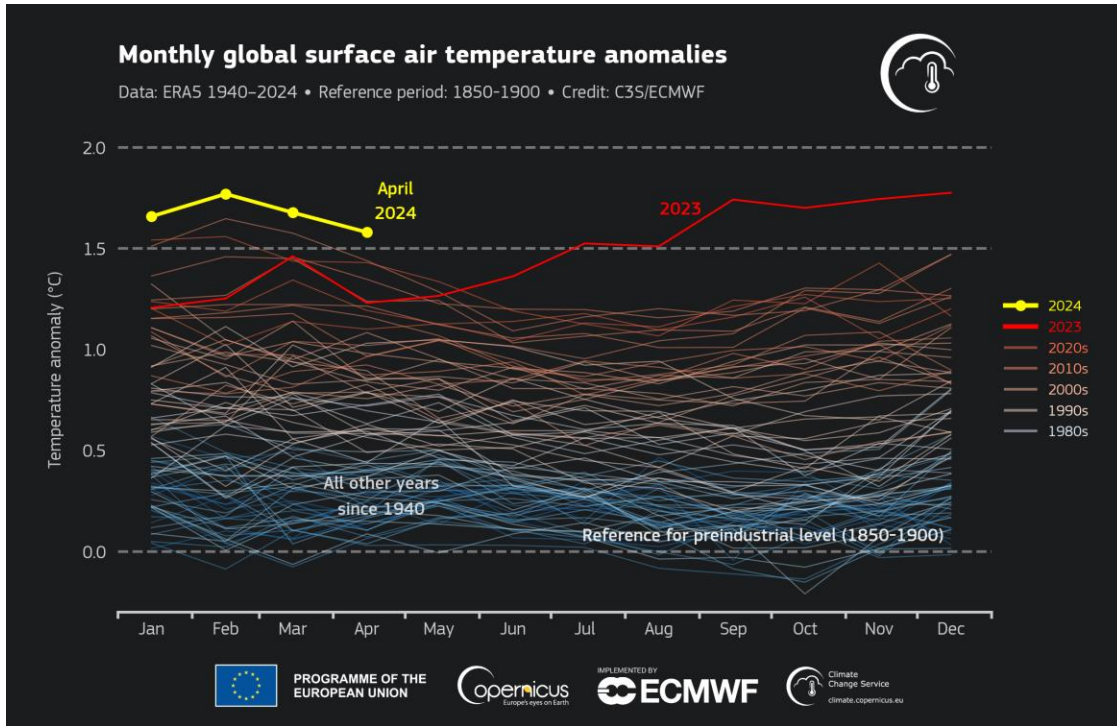
Destination Earth

implemented by

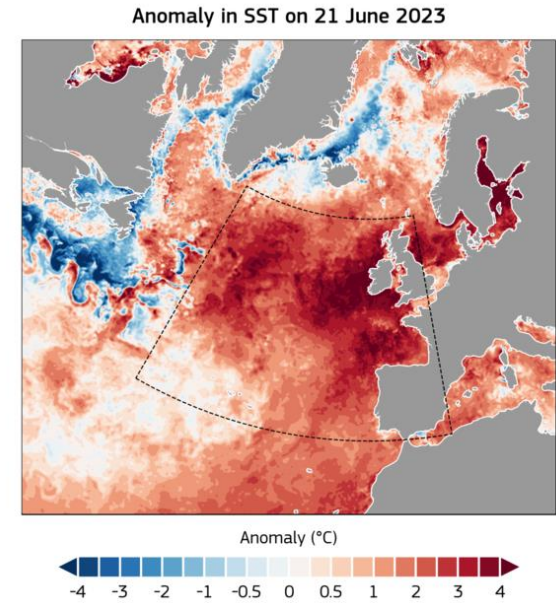




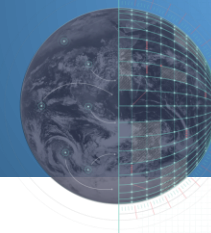
CLIMATE CHANGE AND INCREASE OF EXTREME EVENTS



Flash floods in Slovenia, August 2023



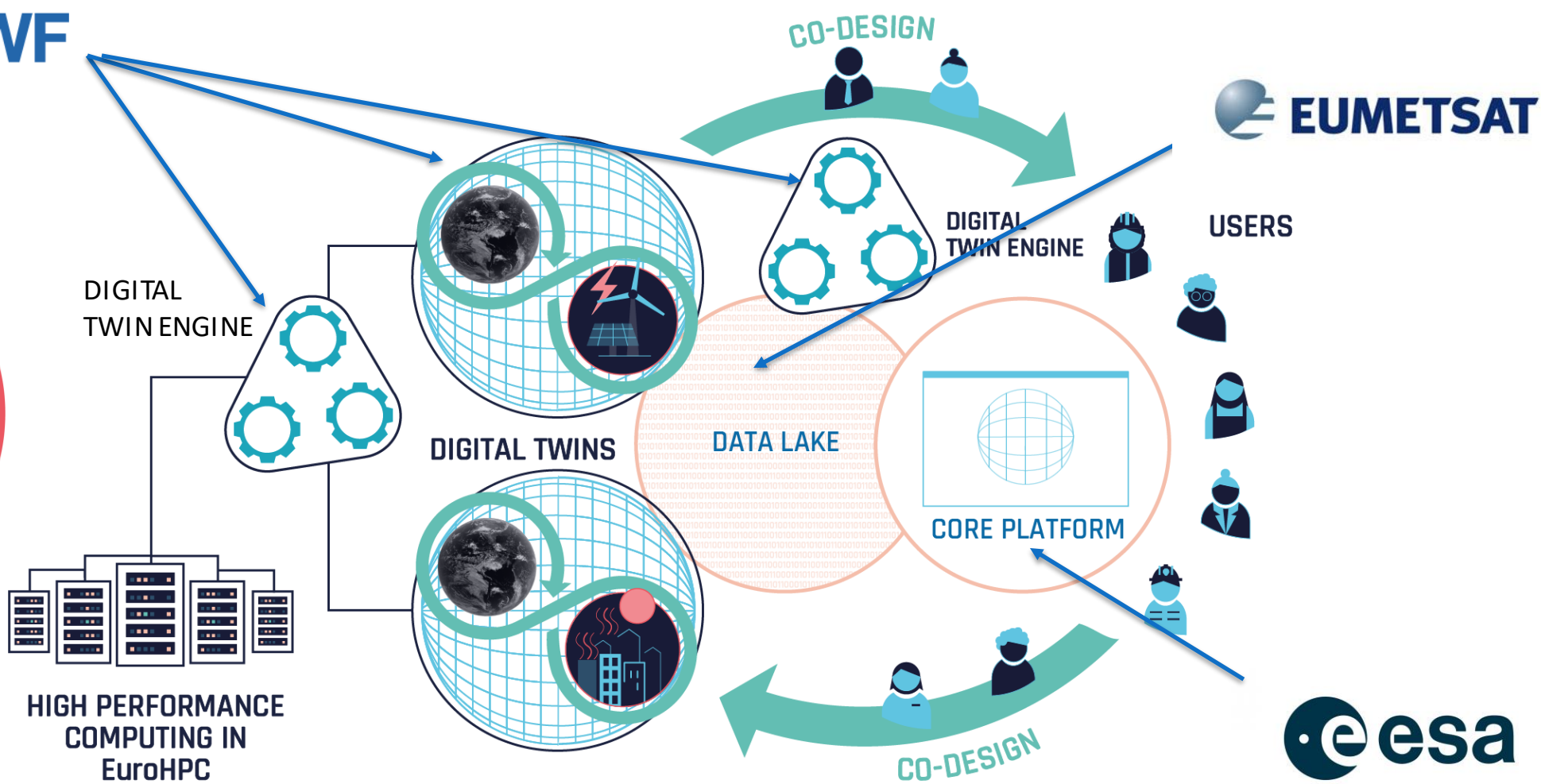
Marine heatwave in the Atlantic, Summer 2023

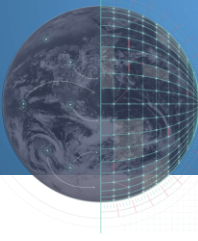


DESTINE: A NOVEL INFORMATION SYSTEM

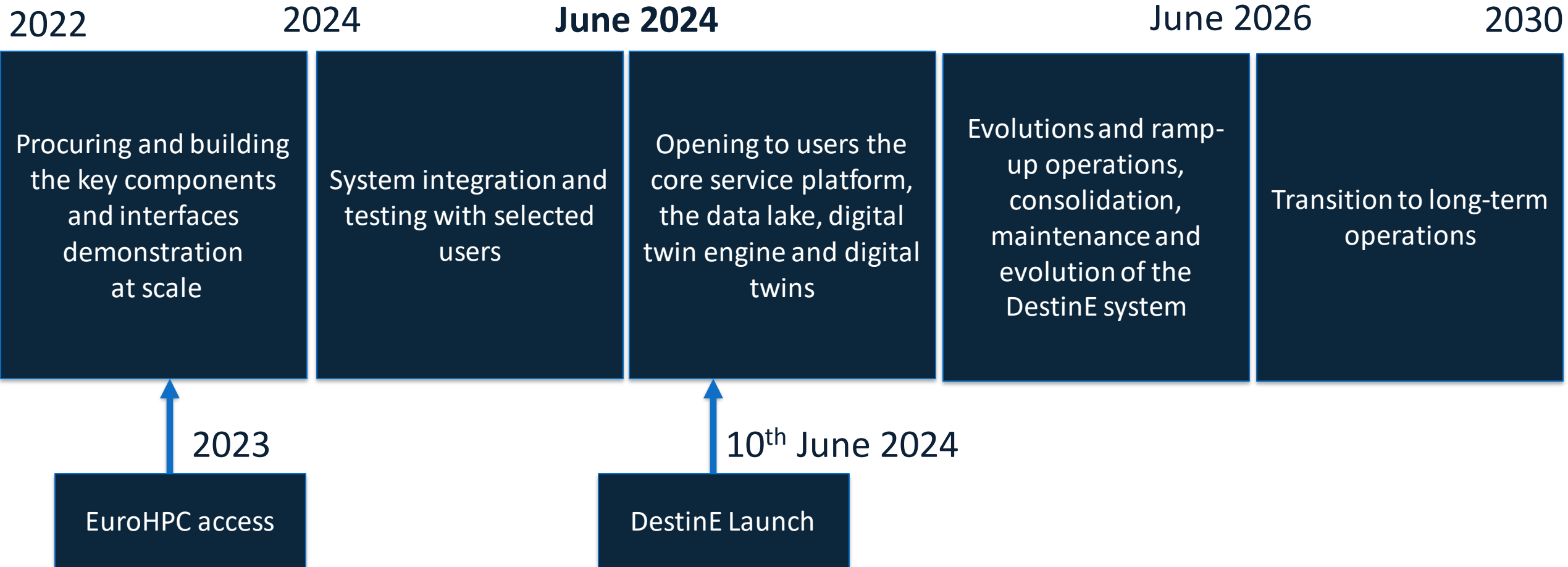


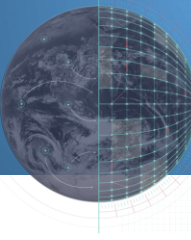
27 Countries
116 Organizations
60 Private/Industry
24 SMEs





DESTINE: A PILLAR OF THE GREEN AND DIGITAL TRANSITION

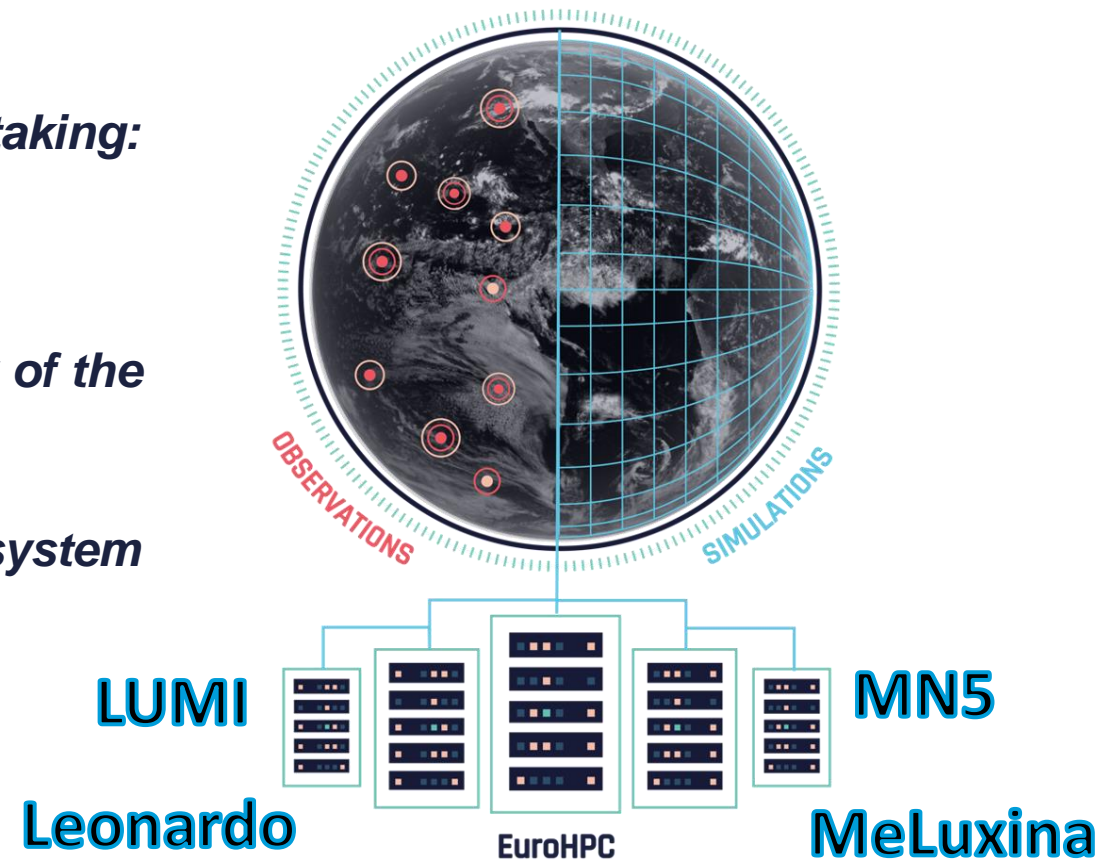


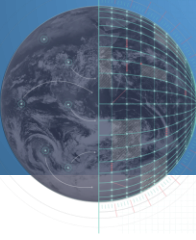


DESTINE: DIGITAL REPLICAS OF OUR PLANET TO RESPOND AND ADAPT TO CLIMATE CHANGE AND EXTREME EVENTS

DestinE, in strategic partnership with EuroHPC Joint Undertaking:

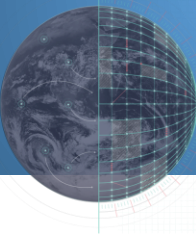
- *Establishes bespoke cutting-edge simulation capabilities*
- *Provides Earth-system information at scales where many of the impacts of extreme events and climate change are felt*
- *Fosters an innovative and thriving AI-enabled digital ecosystem*





DestinE builds on European investments in Earth-system modelling & observations, AI and EuroHPC

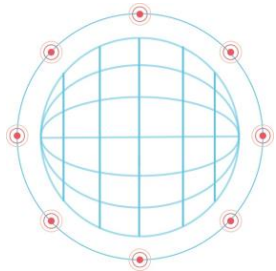
to take Europe's decision-making capabilities to the next level



LIMITATIONS OF CURRENT SYSTEMS



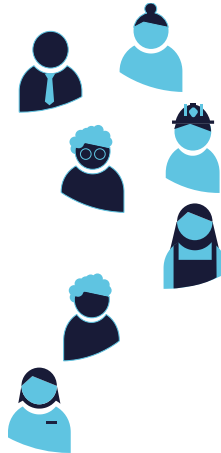
ESM and
observations



Impact
sectors



Users



Separation of ESM and sector models

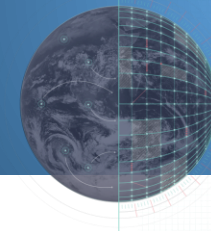
Limited versatility to access and interact
with data

Limited resolutions

Small scales processes not represented

Experimental design and outputs not
flexible

Update frequency doesn't meet user
needs (CMIP every 7 years)

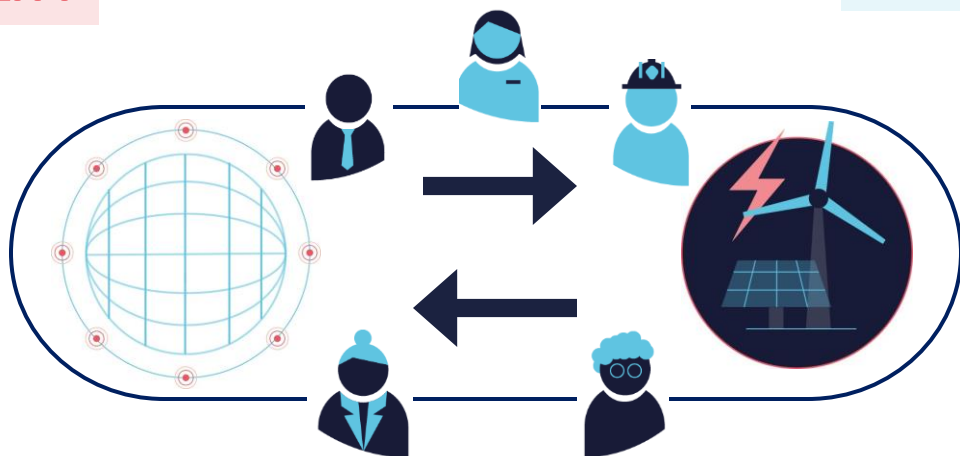


DESTINE'S DIGITAL TWINS OF THE EARTH

OPERATION

QUALITY

IMPACTS



UNCERTAINTY
QUANTIFICATION

INTERACTIVITY



1. Integration of sectoral models in the DTs workflow
2. Co-design



1. High-frequency data streaming
2. Bespoke cutting-edge simulations



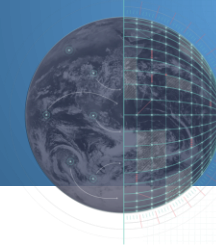
1. Increasing ESM resolution to km-scale
2. Improving the physics of km-scale



1. Physics-driven ensemble, scenarios
2. AI/ML ensemble



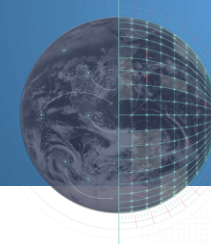
1. Weather-impact sector predictions
2. Operational multi-decadal projections



DestinE's DTs: Weather-induced Extremes and Climate Change Adaptation

Establish bespoke cutting-edge simulation capabilities of the Earth system

Provide Earth-system information at scales where many of the impacts of extreme events and climate change are felt



TWO DIGITAL TWINS FOR WEATHER AND CLIMATE IMPACTS

WEATHER-INDUCED EXTREMES DIGITAL TWIN

A few days ahead



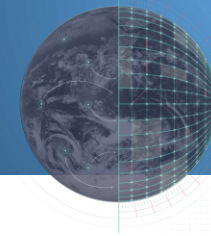
*When will the wind farm shutdown
and what will happen to energy production?*

CLIMATE CHANGE ADAPTATION DIGITAL TWIN

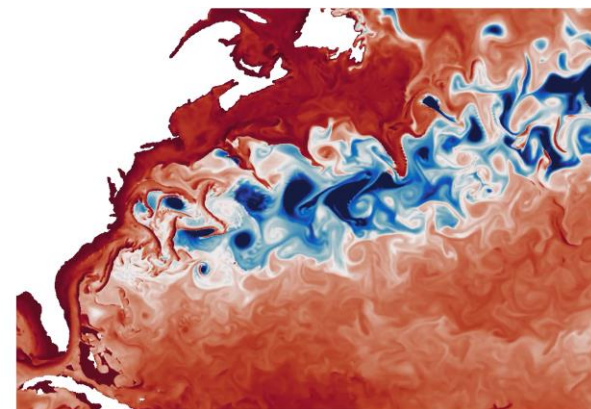
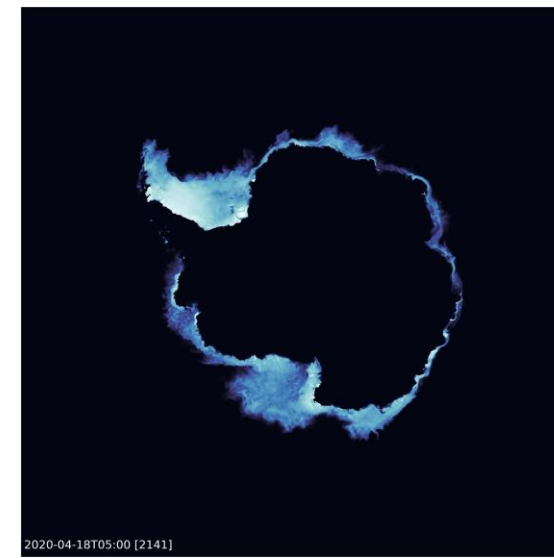
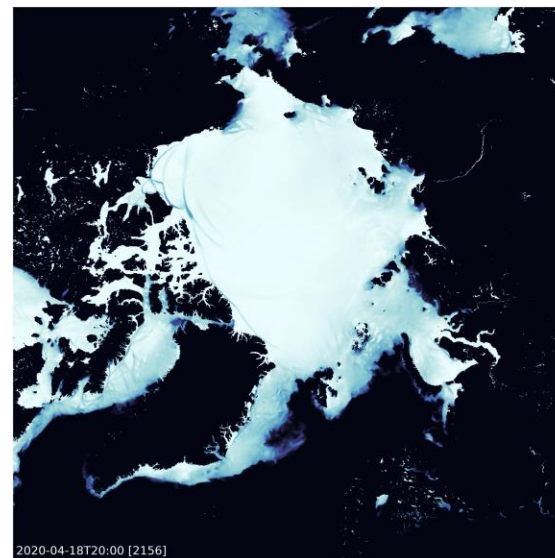
Multi-decadal timescales



*Where should we build the next wind farms knowing storm
occurrences could shift depending on different scenarios?*

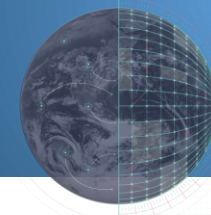


A HD+ VIEW OF THE EARTH SYSTEM FROM DAYS TO DECADES AHEAD



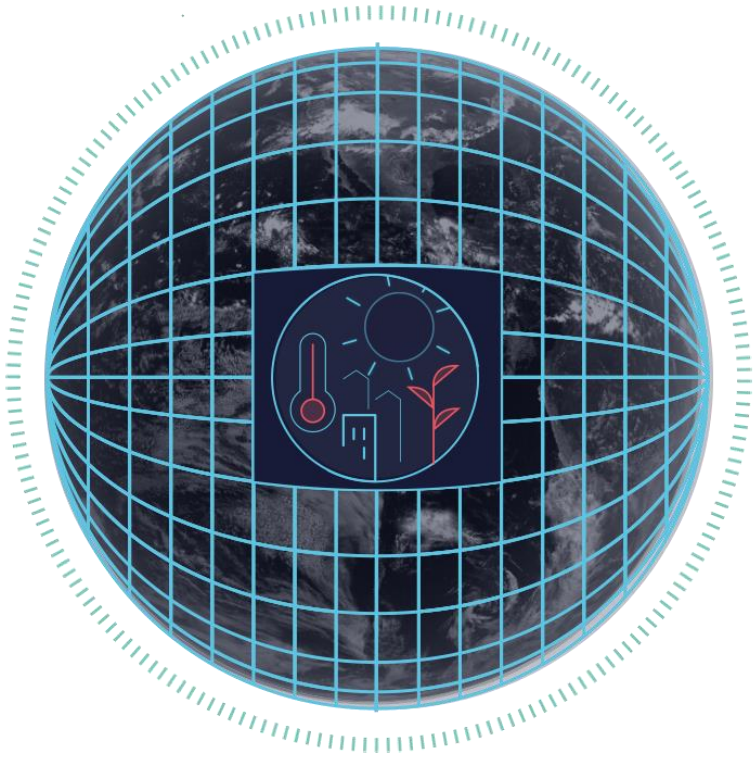
Building on





GLOBALY CONSISTENT INFORMATION WITH LOCAL GRANULARITY

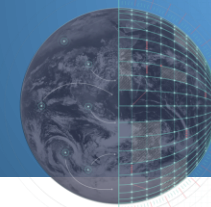




CLIMATE CHANGE ADAPTATION DIGITAL TWIN

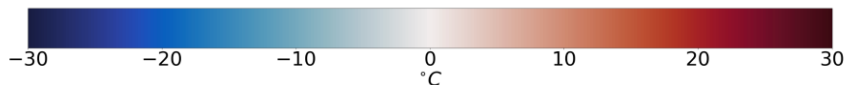
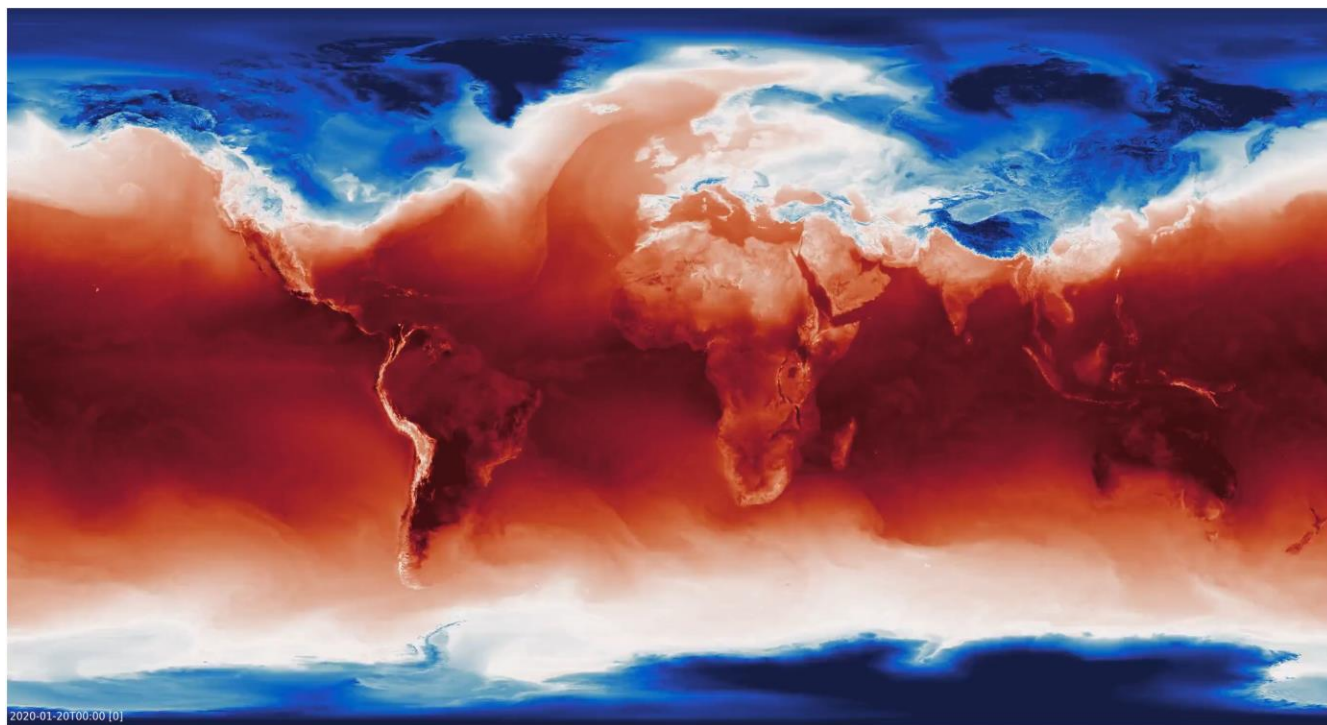


CSC	CSC – IT Center for Science	FI
BSC	Barcelona Supercomputing Center/Centro Nacional de Supercomputación	ES
MPI - M	Max Planck Institute for Meteorology	DE
UH	University of Helsinki	FI
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research	DE
CNR-ISAC	Consiglio Nazionale delle Ricerche, Istituto di Scienze dell'Atmosfera e del Clima	IT
POLITO	Politecnico di Torino	IT
FMI	Finnish Meteorological Institute	FI
DWD	National Meteorological Service of Germany	DE
UFZ	Helmholtz Centre for Environmental Research	DE
UCLouvain	Université catholique de Louvain	BE
DKRZ	German Climate Computing Centre	DE
HPE	Hewlett Packard Enterprise	FR



CLIMATE DT: 1ST OPERATIONAL CAPABILITY FOR CLIMATE PROJECTIONS

To test the impact of certain events, scenarios or policy decisions on multi-decadal timescales



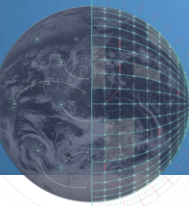
Regularly updated (yearly) and on-demand

1 x scenario 30 years

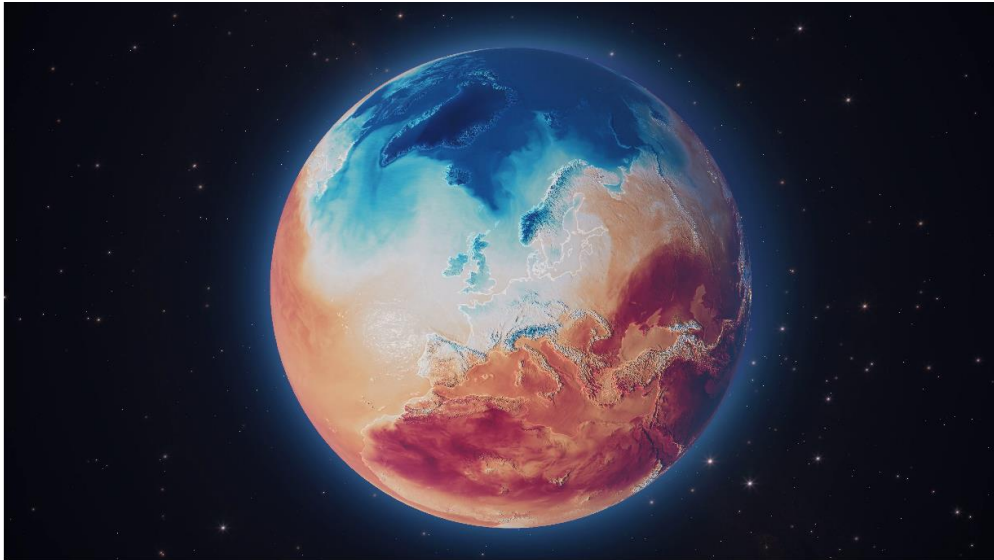
≡ 1-1.5 Million GPU h or 34 Million CPU-core h

How will the climate evolve over the next decades following scenario A or B or if a particular event happens?



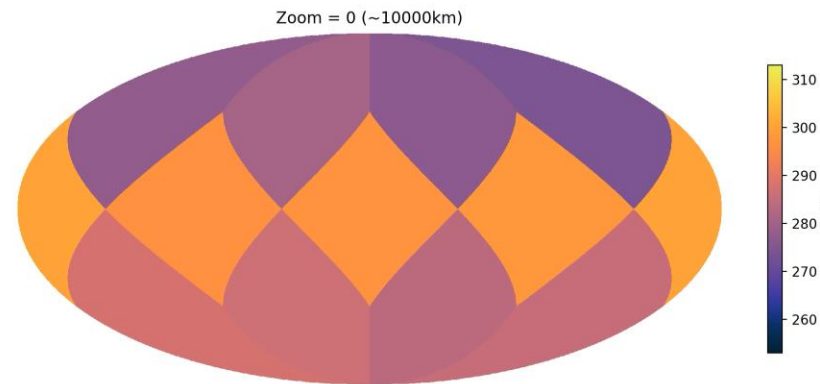
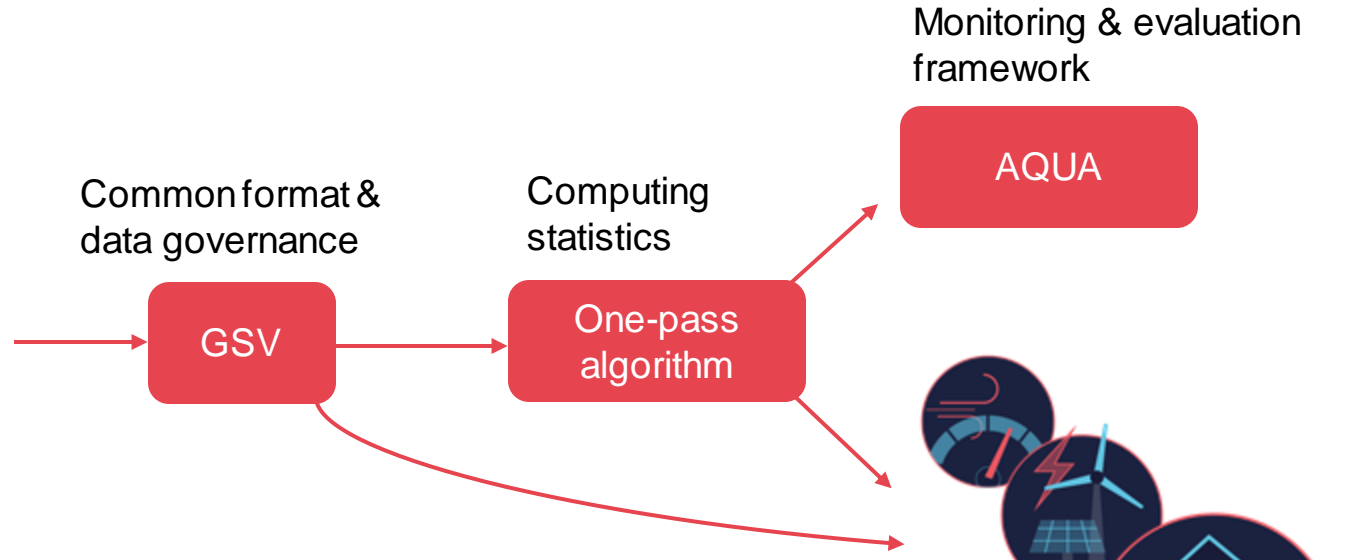


CLIMATE DT: 1ST OPERATIONAL CAPABILITY FOR CLIMATE PROJECTIONS

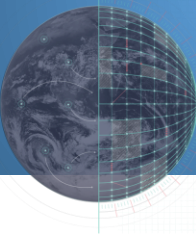


3 global climate models at ~5km

IFS-NEMO
IFS-FESOM
ICON

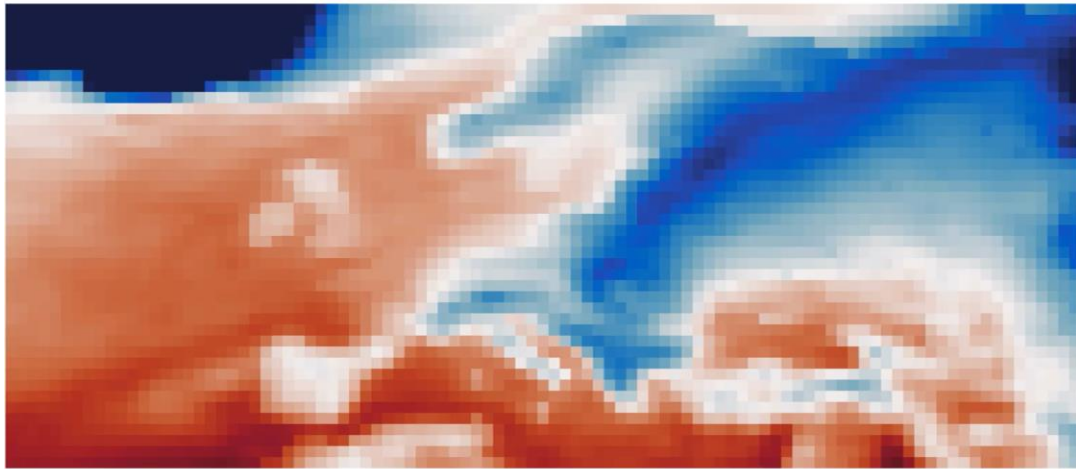


Healpix a common grid for climate DT outputs

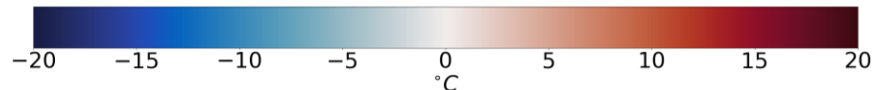
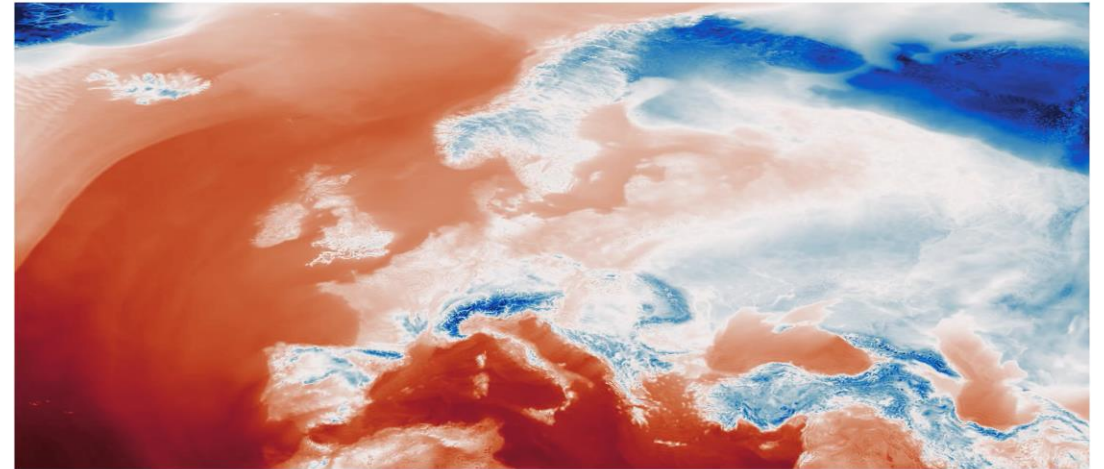


CLIMATE DT: PRODUCTION OF GLOBALLY CONSISTENT CLIMATE INFORMATION AT KM-SCALE, REGULARLY OR ON DEMAND

IPCC AR6 (2021), 100km



Digital Twin, 5km

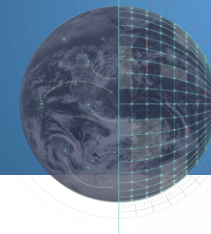


Current climate projections:

run through research efforts, in 7 to 10 years cycles,
100km spatial resolution, 6 hourly temporal resolution

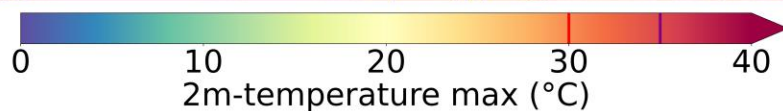
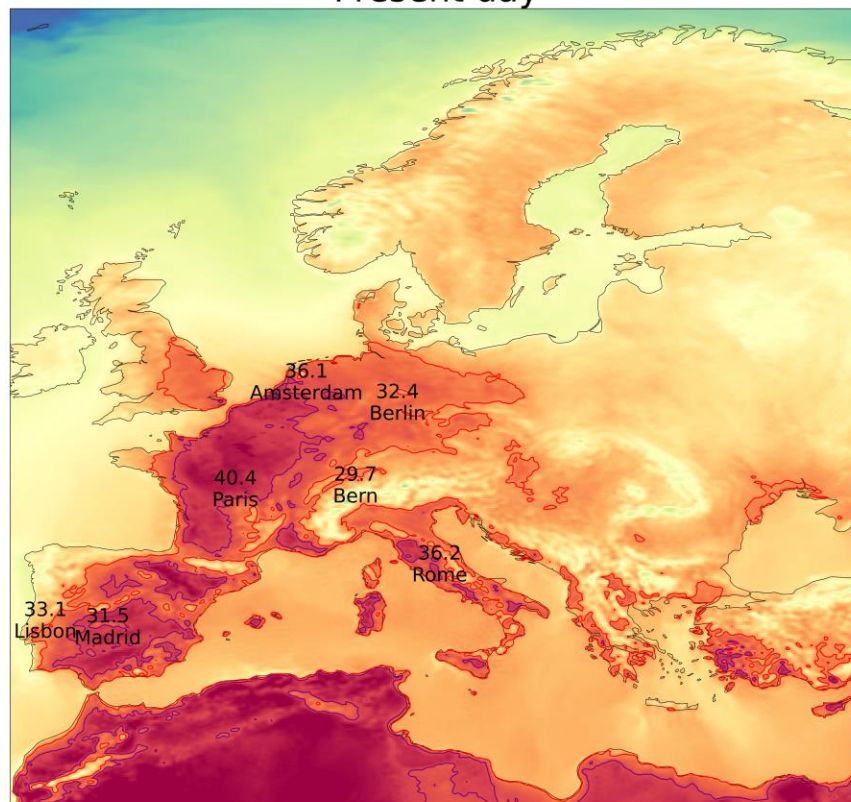
Climate DT

multi-decadal projections (yearly or on demand), higher
temporal resolution (hourly), 5 -10 km spatial resolution,
flexible workflows that can be tailored to user requirements

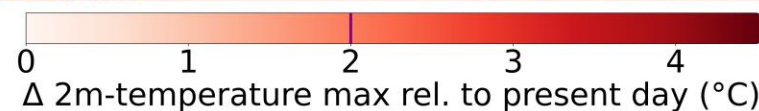
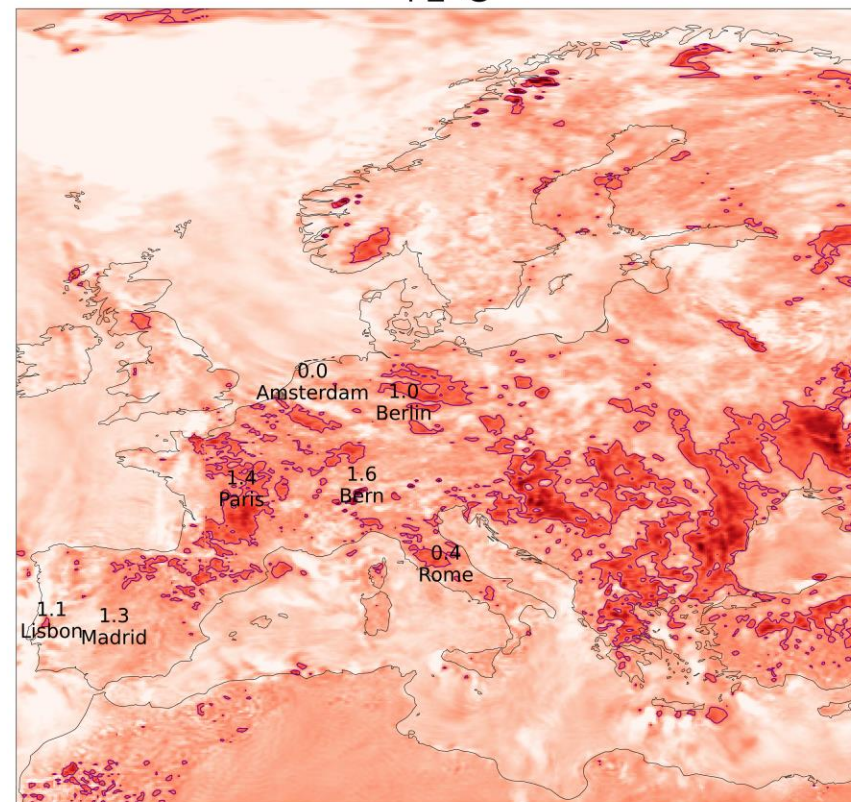


CLIMATE DT: STORYLINES OF EXTREME EVENTS

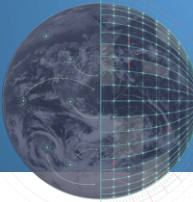
Present day



+2°C



IFS-FESOM
with large-scale
nudged towards
ERA5 (2018-2023)



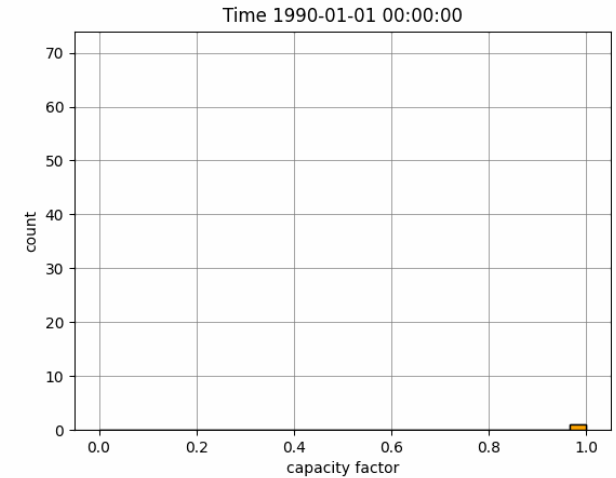
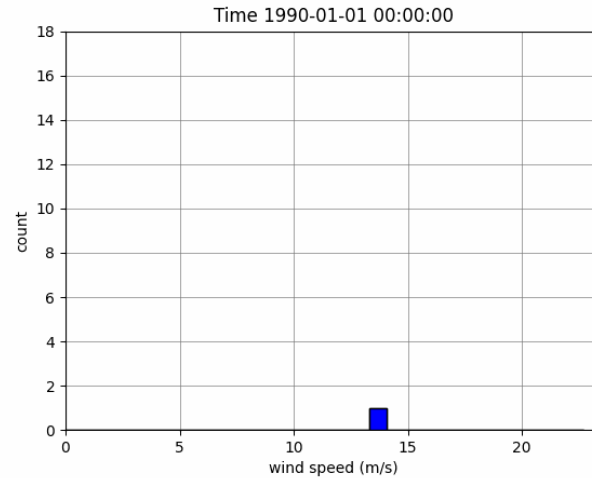
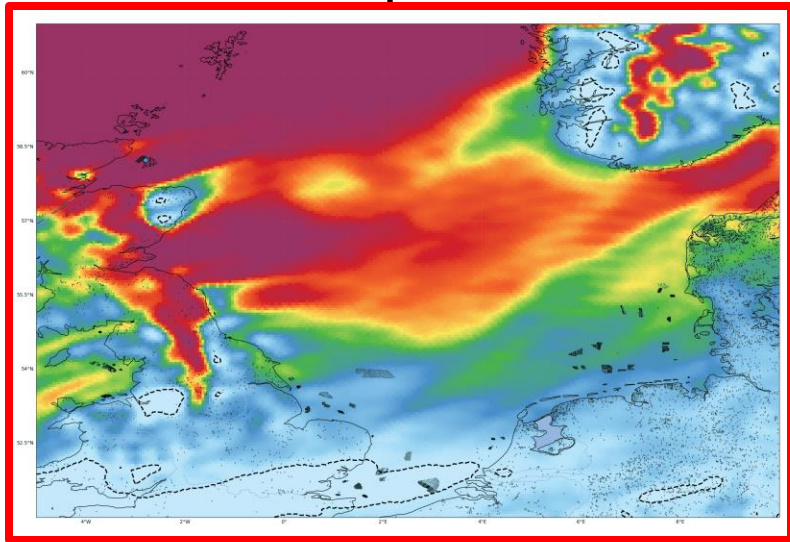
STREAMING DATA TO APPLICATIONS & TAILORING IT TO USERS NEEDS

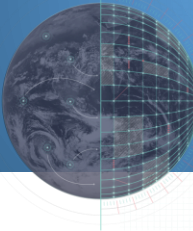
Streams raw climate variables through the one-pass layer (data-reduction tasks that compute indicators) to the data consumer computing user-relevant indicators on-the-fly.

Model outputs **raw climate variables**
(e.g., 100u, 100v)

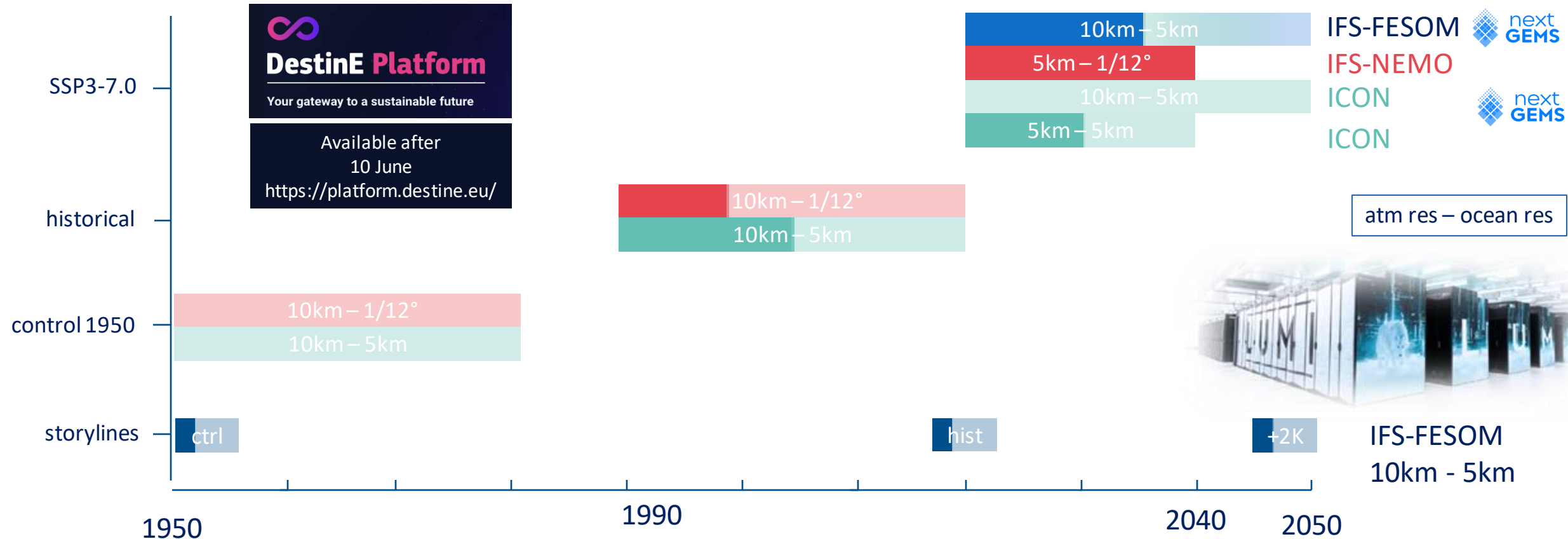
One-pass algorithms compute on-the-fly distribution of **wind speed**

Data consumers can use it to compute climate indicators anywhere in the world (e.g., weekly capacity factor of any turbine)



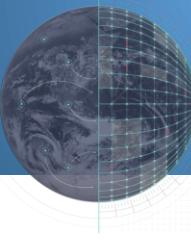


CLIMATE DT : SIMULATIONS



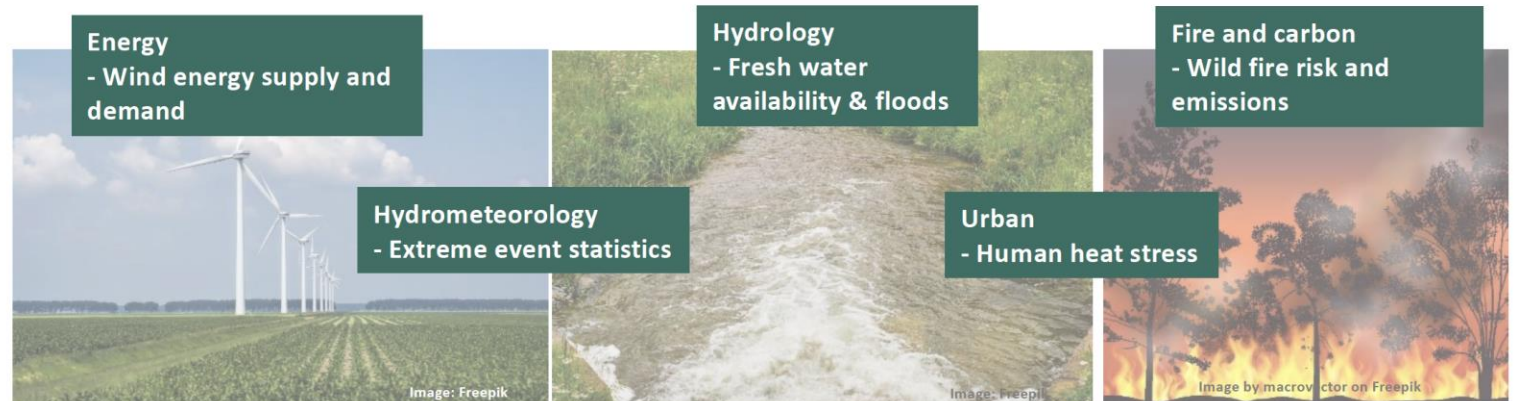
End-to-end climate DT workflow, including selected applications, deployed on LUMI, in less than one year!

First ever prototype projections at ~ 5km across earth-system components running now on LUMI with 2 models (IFS-NEMO, ICON), streaming information to selected applications ; and historical runs at 10km since 1990

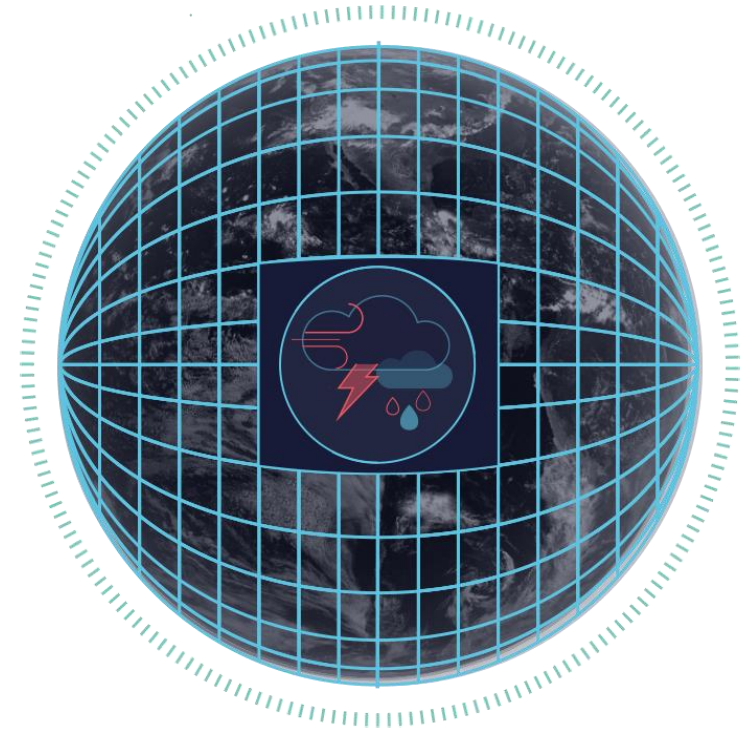


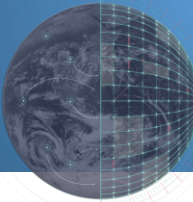
CLIMATE DT: PHASE 1 DELIVERY

- Set-up end-to-end workflows on LUMI to operationalize multi-decadal projections using advanced high-resolution (5km and 10km) global Earth-system simulation and including selected applications
- First ever prototype projections (2020-2040) at ~ 5km across earth-system components running now on LUMI with 2 models (IFS-NEMO, ICON), streaming information to selected applications ; historical runs from 1990 at 10km; storylines for extremes
- Capability to monitor and assess the quality of the DT simulations
- Capability to stream Earth-system information to selected impact models /use cases included in the DT workflow



WEATHER-INDUCED EXTREMES DIGITAL TWIN





EXTREMES DT : A MAGNIFYING GLASS ON EXTREME WEATHER EVENTS



GLOBAL

DETECTION/
TRIGGERING



REGIONAL



Global and **daily** simulations of extreme weather
4 days ahead at **4.4km**

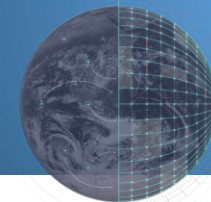
On-Demand regional simulations
2 days ahead at **750m** to **500m**

Impact-sector models:
user-relevant information for societal impacts

IFS-NEMO

Arome
Harmonie-Arome
Alaro





EXTREMES DT : A MAGNIFYING GLASS ON EXTREME WEATHER EVENTS

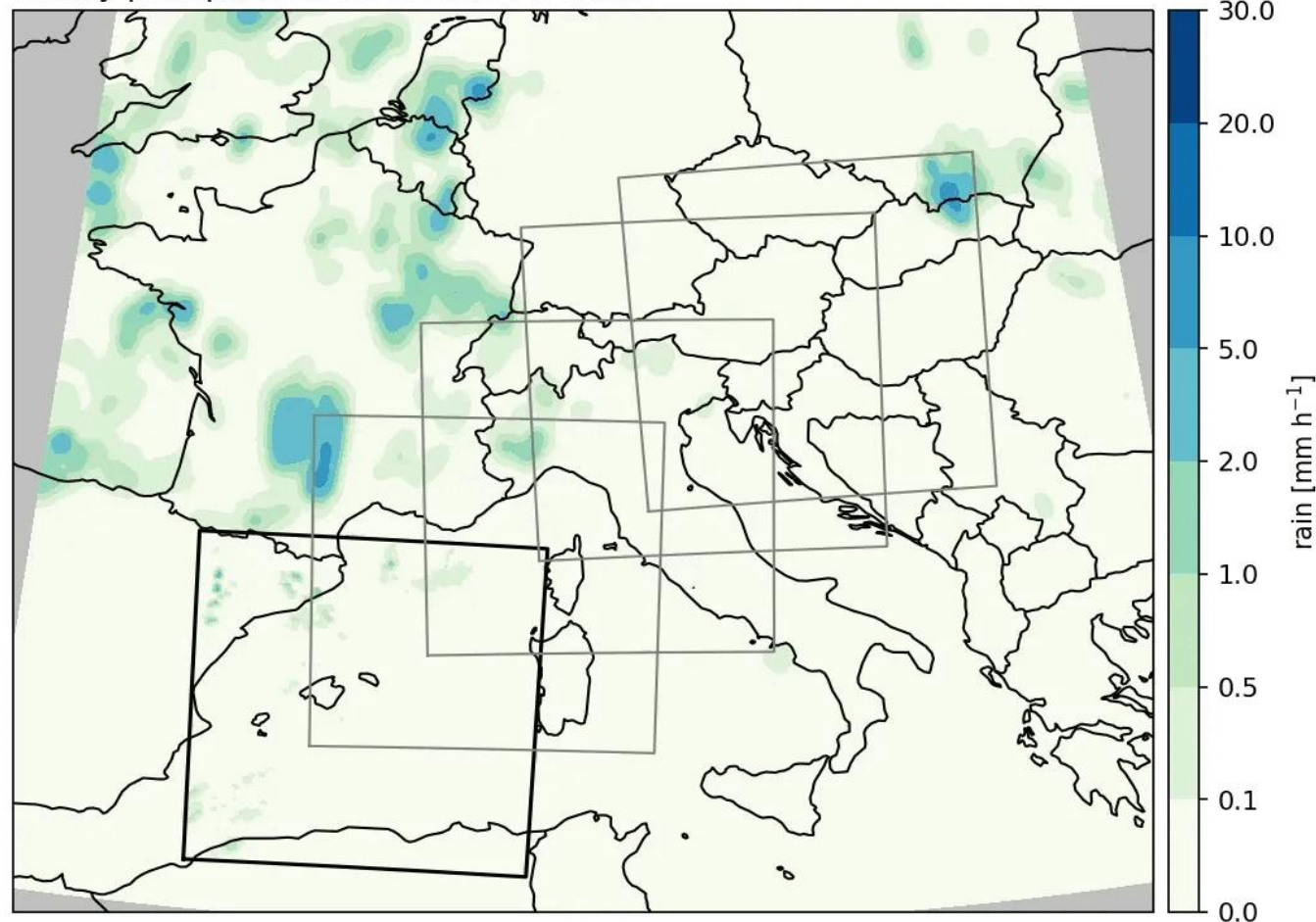


Global and **daily** simulations of extreme weather
4 days ahead at 4.4km

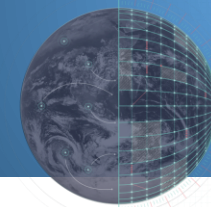
IFS-NEMO



Hourly precipitation for for init +1 hours



On-Demand regional simulations
2 days ahead at 750m to 500m



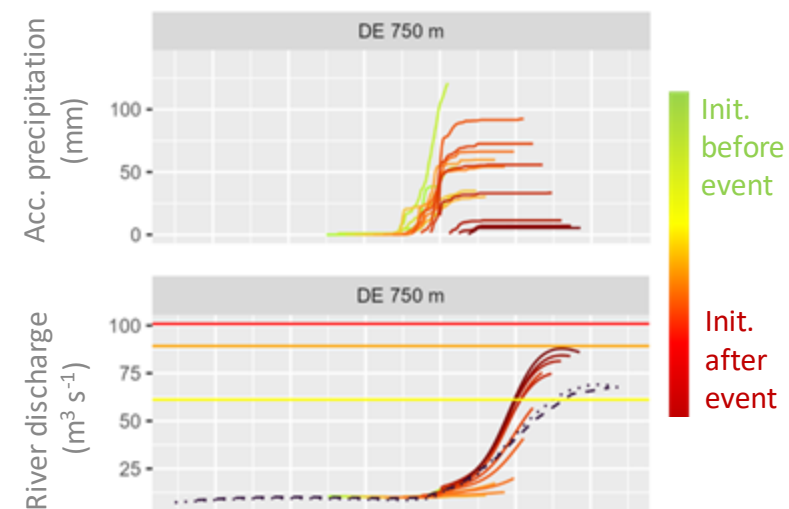
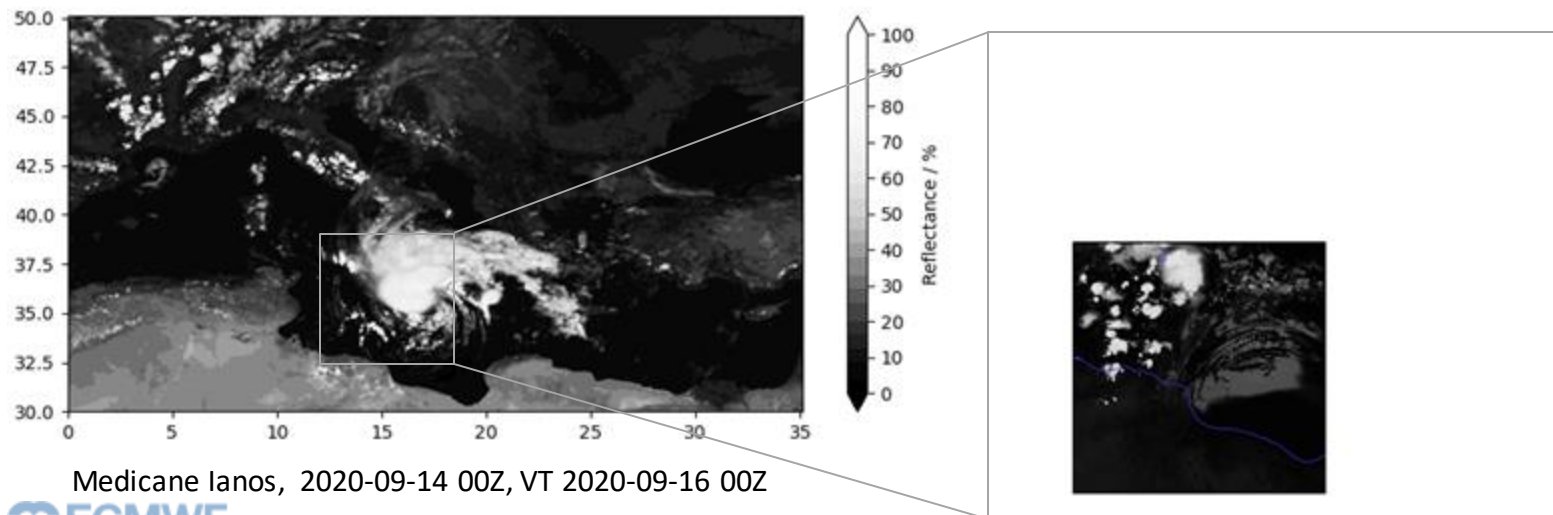
EXTREMES DT : A MAGNIFYING GLASS ON EXTREME WEATHER EVENTS

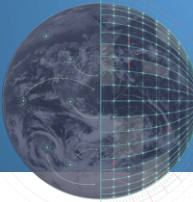


Global and **daily** simulations of extreme weather
4 days ahead at ~5km

On-Demand regional simulations
2 days ahead at 750m to 500m

Impact-sector models:
user-relevant information for societal impacts



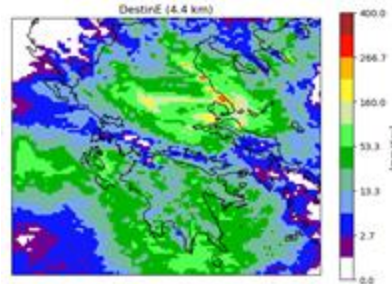


NOTABLE EVENTS ANALYZED IN THE EXTREMES DT SINCE AUGUST 2023

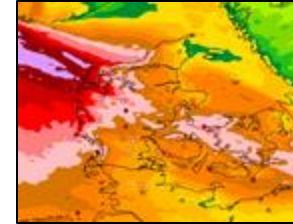
Extreme precipitation (03/08) Austria

TC Lee (08/09) Atlantic

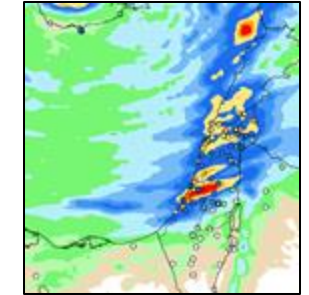
Storm Daniel
Precipitation in Greece (06/09)
Flooding in Libya (10/09)



Storm Pia (20/12)
Wind gust in Denmark



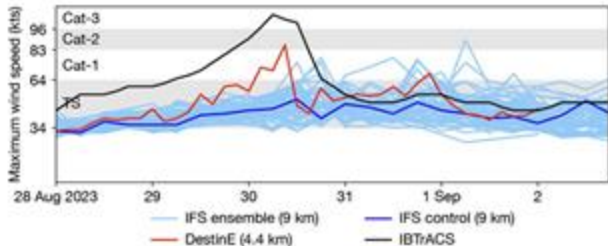
Heavy rain in (27/01) Israel



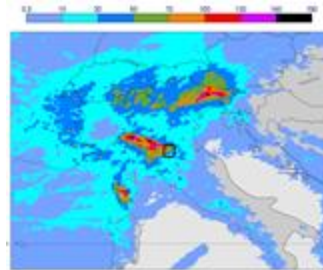
2023

2024

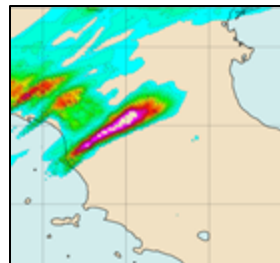
TC Idalia (30/08) Florida



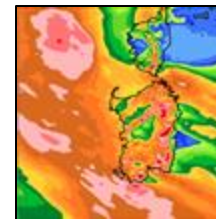
TC Otis (24/10) Mexico



Storm Ciaran
Wind gust in Brittany (01/11)
Floods in Tuscany (02/11)

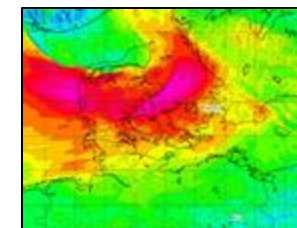


Wind gust (23/12) Corsica

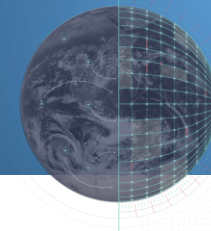


TC Belal (14/01) La Réunion

Storm Rolf (23/02) Denmark



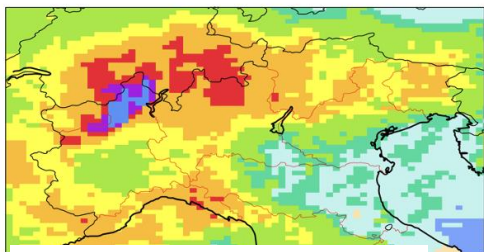
Floods (10/03) South of France



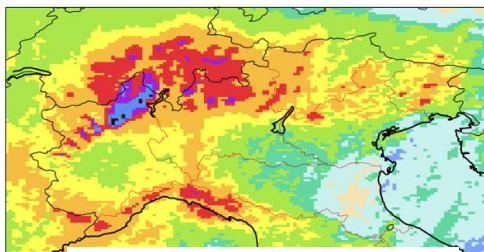
GLOBAL EXTREMES DT

Storm Alex 2020/10/01 24h TP

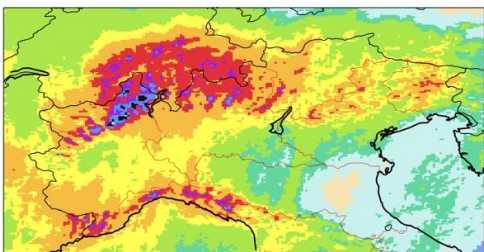
ECMWF OPER (9km)



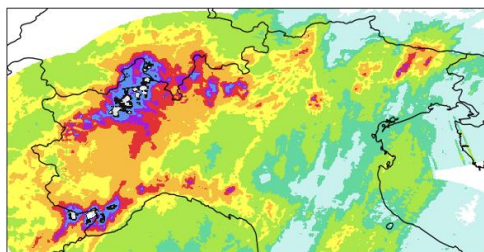
b DestinE (4.4km)



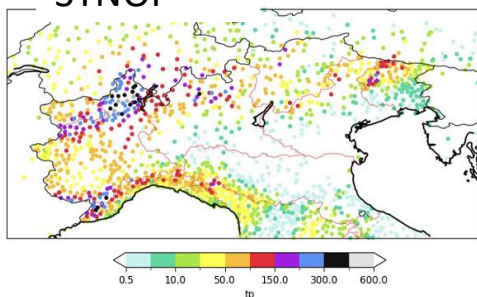
DestinE (2.8km)



d Radar + gauges

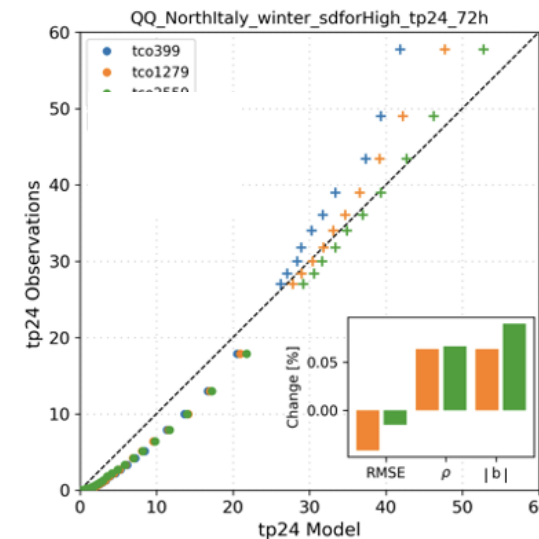
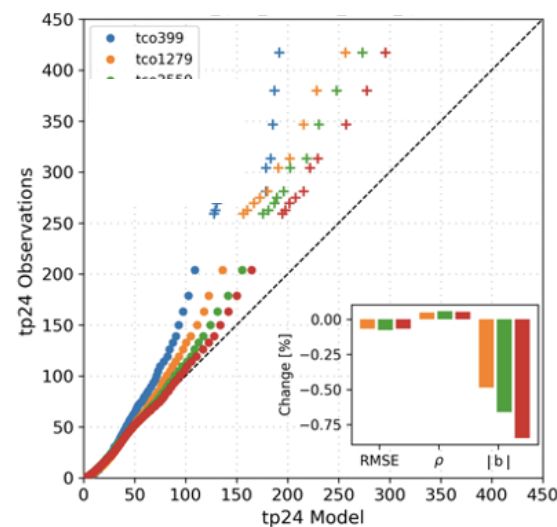


e SYNOP



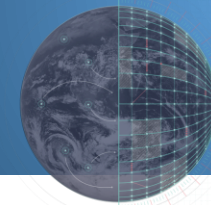
Winter 2022 daily forecasts

4 case studies



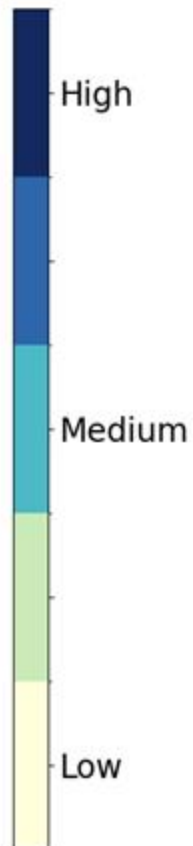
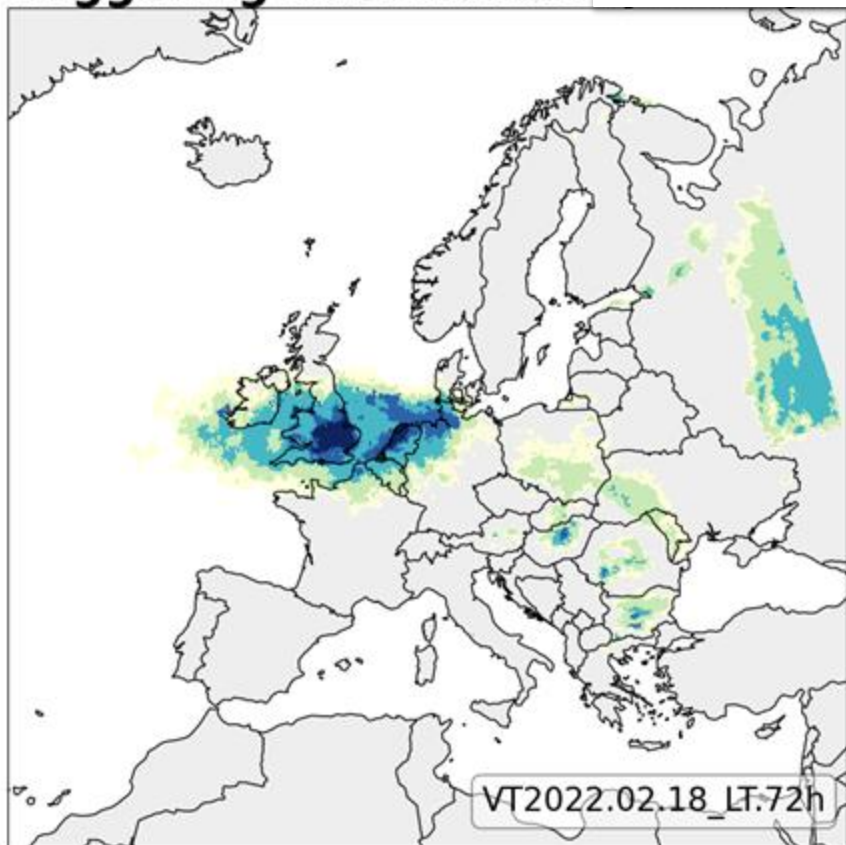
Global Extremes DT workflow deployed on LUMI, in less than a year

4-day simulations at 4.4km run a few times per week



GLOBAL – REGIONAL EXTREMES DT END TO END DEMONSTRATION

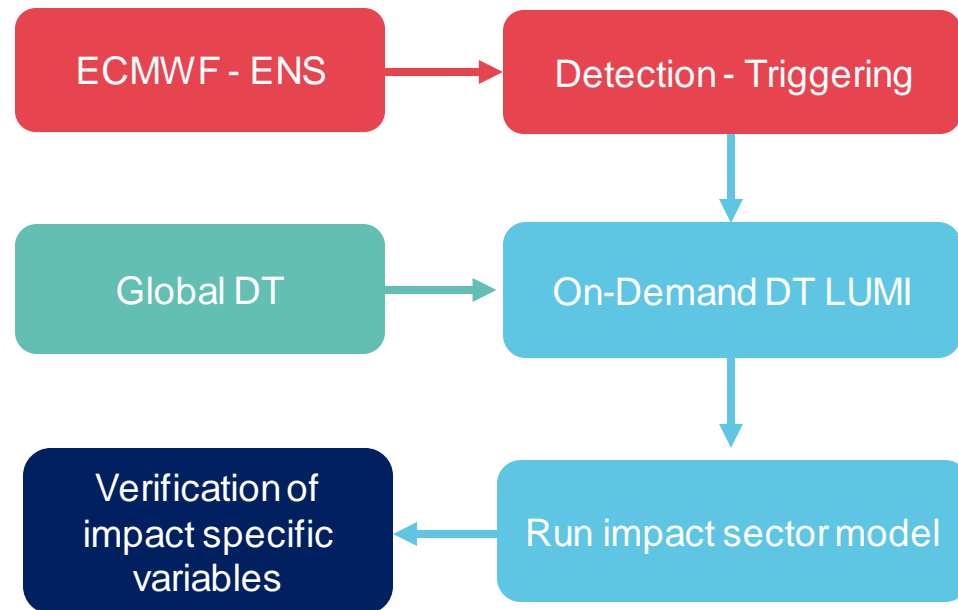
Triggering information

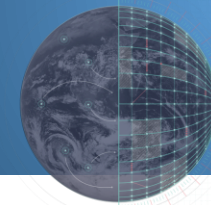


10m day max wind gust, base time 2022-02-16 00Z, VT 2022-02-18 (Step 48-72)

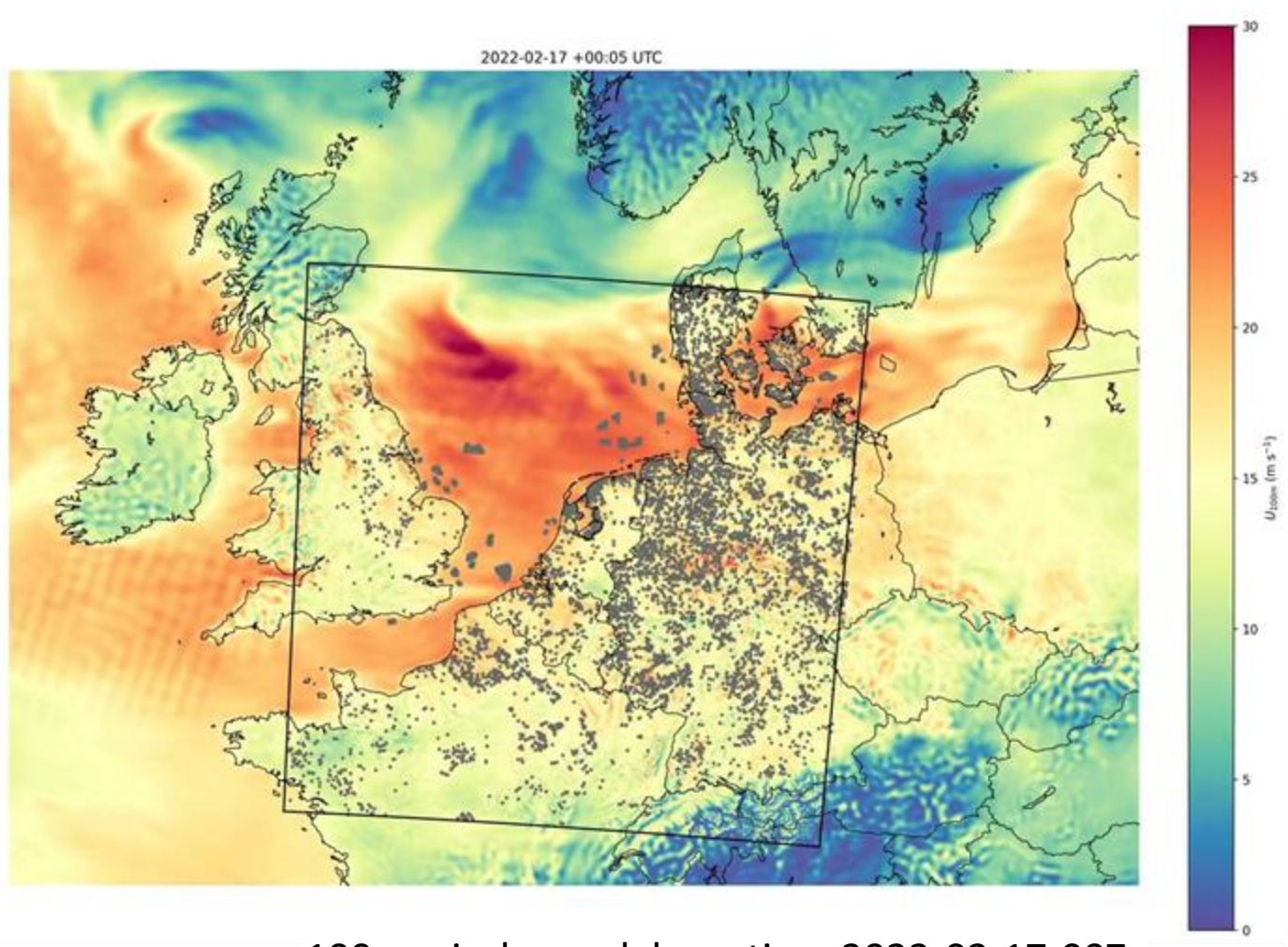
Every day extreme detection diagnostics

- total precipitation
- CAPE shear
- 10m-wind gust

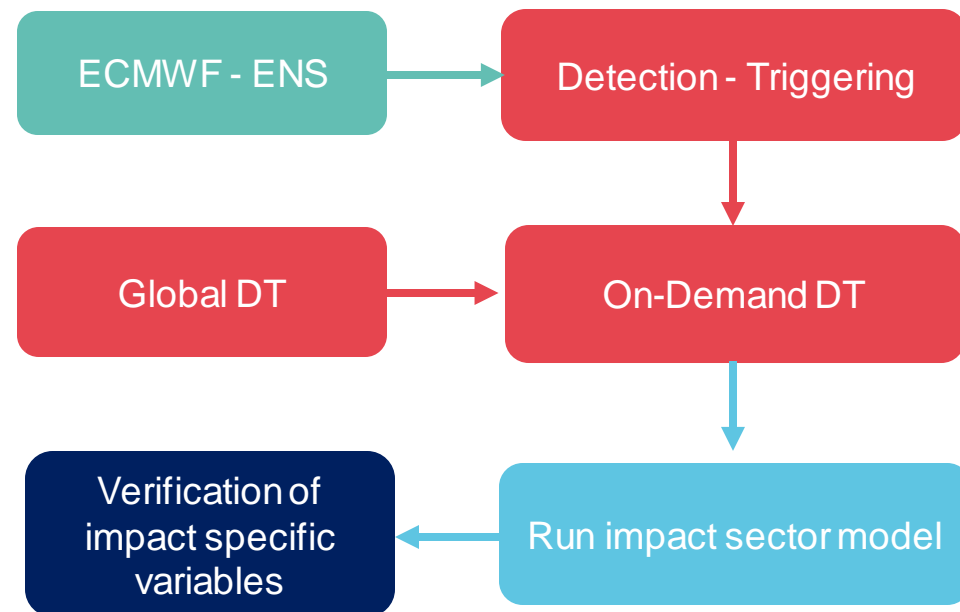


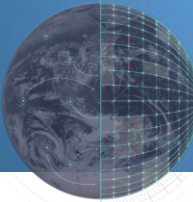


GLOBAL – REGIONAL EXTREMES DT END TO END DEMONSTRATION

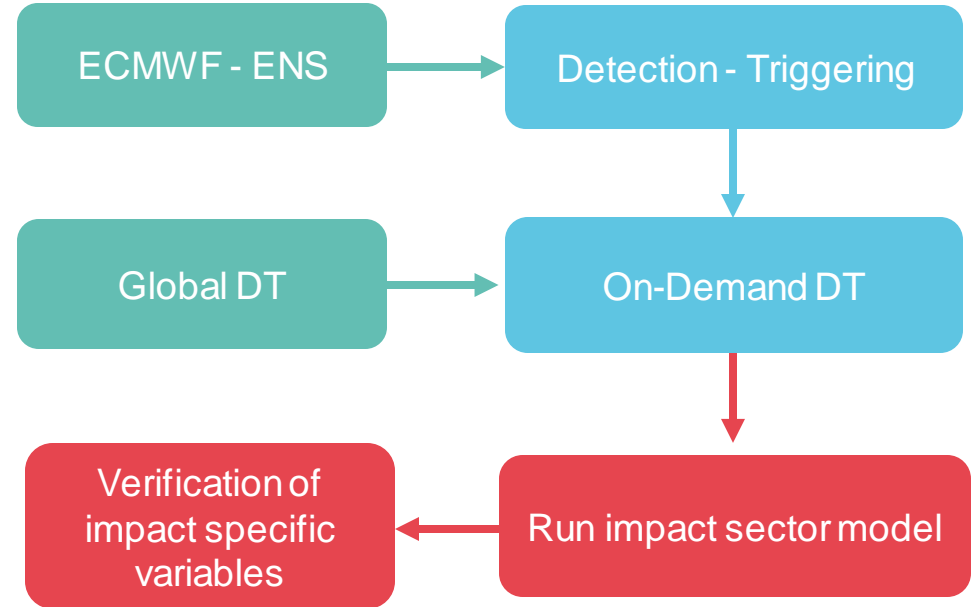
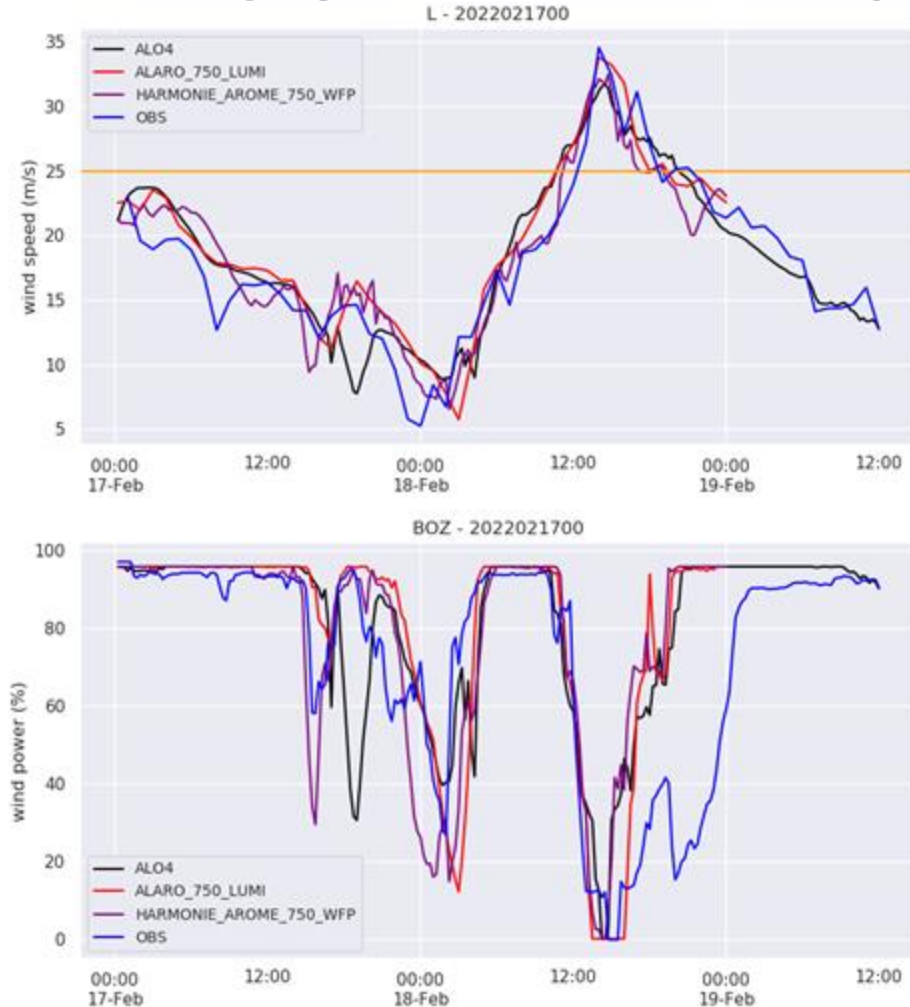


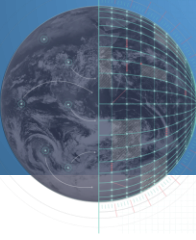
100m wind speed, base time 2022-02-17 00Z, lead time T+0 to T+48





GLOBAL – REGIONAL EXTREMES DT END TO END DEMONSTRATION





EXTREMES DT: PHASE 1 DELIVERY

- Demonstrated regular and on-demand production at enhanced simulation scales (2.8 to 4.4 km globally, 500-700 m regionally) on timescales of 2 to 4 days ahead for selected extreme cases
- Performed the first comprehensive and in near-real time evaluation of global medium-range forecasts at 4.4 km - demonstrating clear benefits at local scale (TC, orographic precipitation) - based on daily runs performed on ECMWF Atos since August 2023
- Set-up end-to-end workflows on LUMI to provide extremes information globally, in a continuous mode, and ran regularly global simulations at 4.4km and for 4 days ahead since December 2023
- Setting up end-to-end workflows for the regional, on-demand, component for selected configurations, and including impact sector models for selected use cases, first configurations expected to become available end of 2024

Renewable
energy

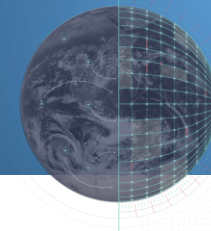


Floods

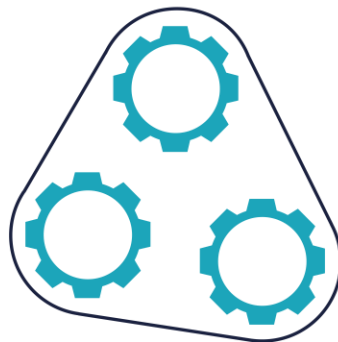


Air quality





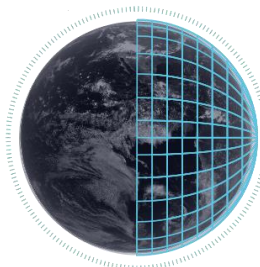
THE DIGITAL TWIN ENGINE



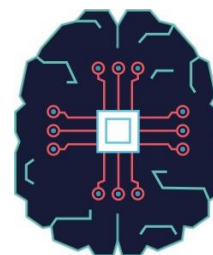
Software environment



Ensuring complex simulations are run efficiently on EuroHPC



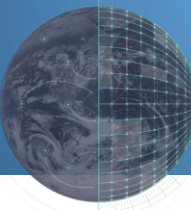
Powering the digital twins and managing big data



Using ML/AI to increase the efficiency of the digital twins and estimate uncertainty

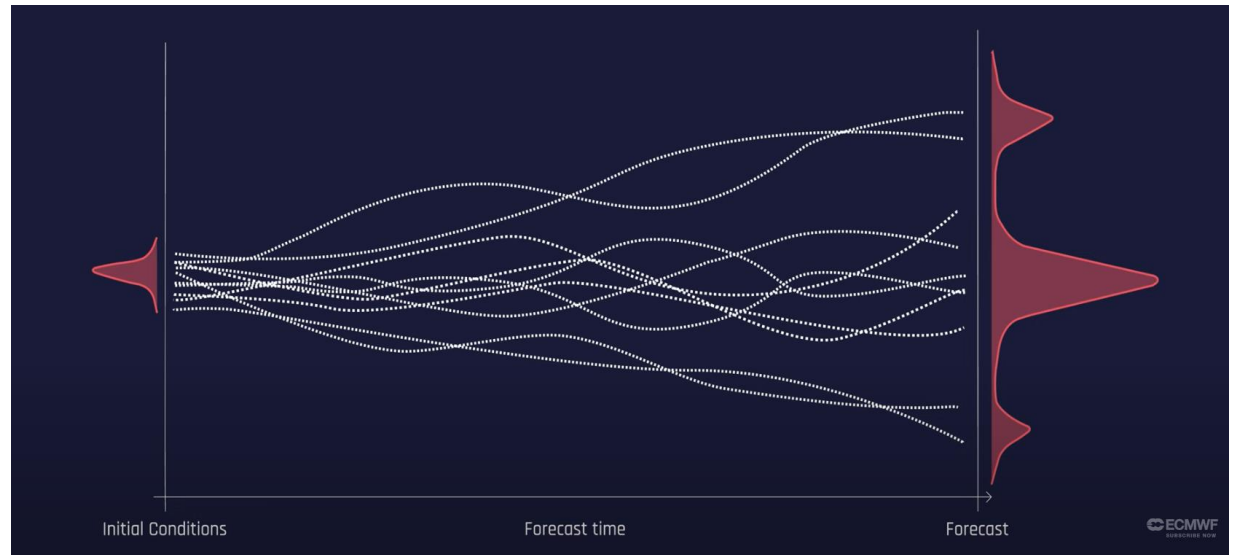
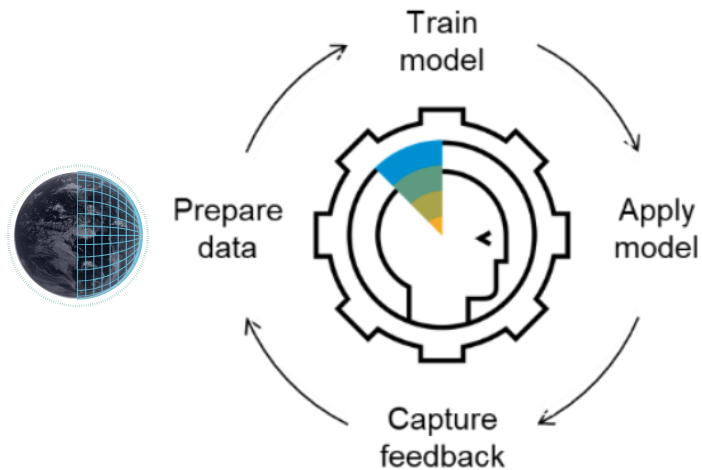


Tailoring information to user's needs and interactivity



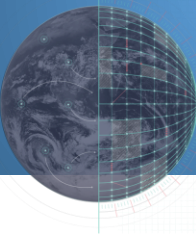
DATA-DRIVEN SIMULATIONS FOR UNCERTAINTY QUANTIFICATION

Training



*AI/ML training: 9 Million GPU h ; min. 1 Million GPU h
Cost is based on 1 full training per year*

AI/ML Inference: 0.1 GPU h cost per use



AI ACTIVITIES IN PHASE 2

Towards a earth-system machine learning model leveraging DestinE data

Developing end-to-end workflows for ML model components like land, ocean, sea-ice, hydrology

Using data-driven methods for uncertainty quantification of Extremes and Climate DT

Climate emulator to rapidly explore 'what-if' scenarios **ITT NOW OPEN**

Enhanced interactivity

Developing a forecast-in-a-box concept.

ITT OPEN SOON

Building ML demonstrators for impact-sectors (e.g., health, agriculture, urban)

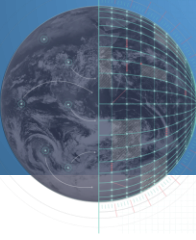
Develop of a weather and climate chatbot **ITT `NOW OPEN**

Partnership and training

MOOCAI through the lens of the earth system

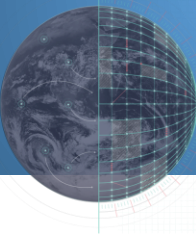
AI4Good

Ethical AI **ITT CLOSED**



IN CONCLUSION

- Successfully set-up complex Digital Twin workflows and adapted to completely new EuroHPC platforms within less than one year, reaching the maturity levels needed for production at scale
- Demonstrated DTs initial capabilities and piloted km-scale simulations at scale, data production, access and delivery, feeding into selected impact-sector application
- Readiness for DestinE launch event in June **2024**
- DestinE complements existing national and EU capabilities and services, and boosts Europe's ability to respond and adapt to extreme events and climate change. *Following the principle of subsidiarity (Article 5 of the Treaty on European Union), while DestinE will provide data and tools to predict extreme events at the global and regional scales, it falls within the exclusive competence of Member States' responsibility to provide warnings in their territory in their essential role of protecting life and property.*



FOR MORE INFO ON DESTINE'S DTS SEE

<https://destination-earth.eu/destination-earth/destines-components/digital-twins-digital-twin-engine/>

<https://destine.ecmwf.int/digital-twins/>

<https://stories.ecmwf.int/explainer-digitaltwins/index.html>

<https://destine.ecmwf.int/news/climate-change-adaptation-digital-twin-a-window-to-the-future-of-our-planet/>

<https://destine.ecmwf.int/news/the-fast-development-of-destines-climate-change-adaptation-digital-twin/>

<https://destine.ecmwf.int/news/a-digital-twin-to-sharpen-our-vision-of-extreme-weather/>

<https://www.bsc.es/news/bsc-news/bsc-key-player-the-development-digital-twin-simulate-future-impacts-climate-change-earth> - WATCH THE MOVIES