

DESTINATION EARTH

OVERVIEW: DIGITAL TWINS & DIGITAL TWIN ENGINE

Jörn Hoffmann, ECMWF

AI for Preparedness: Building capacity for AI-powered Disaster Risk Management

June 17, 2025

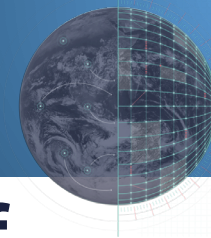


Funded by
the European Union

Destination Earth

implemented by

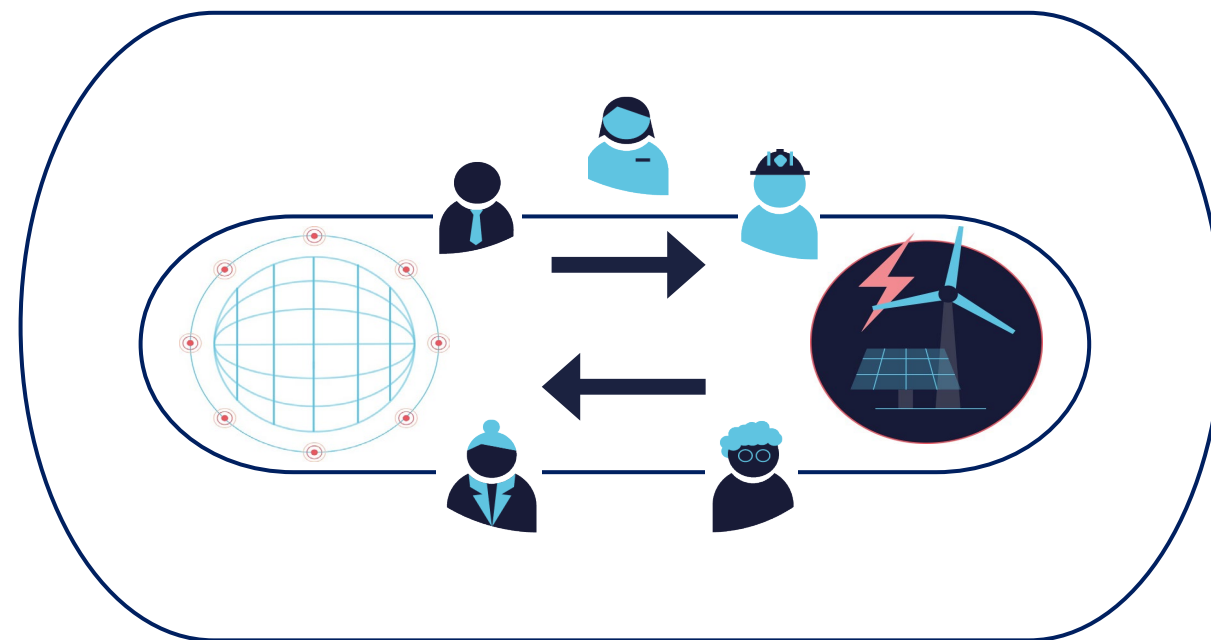
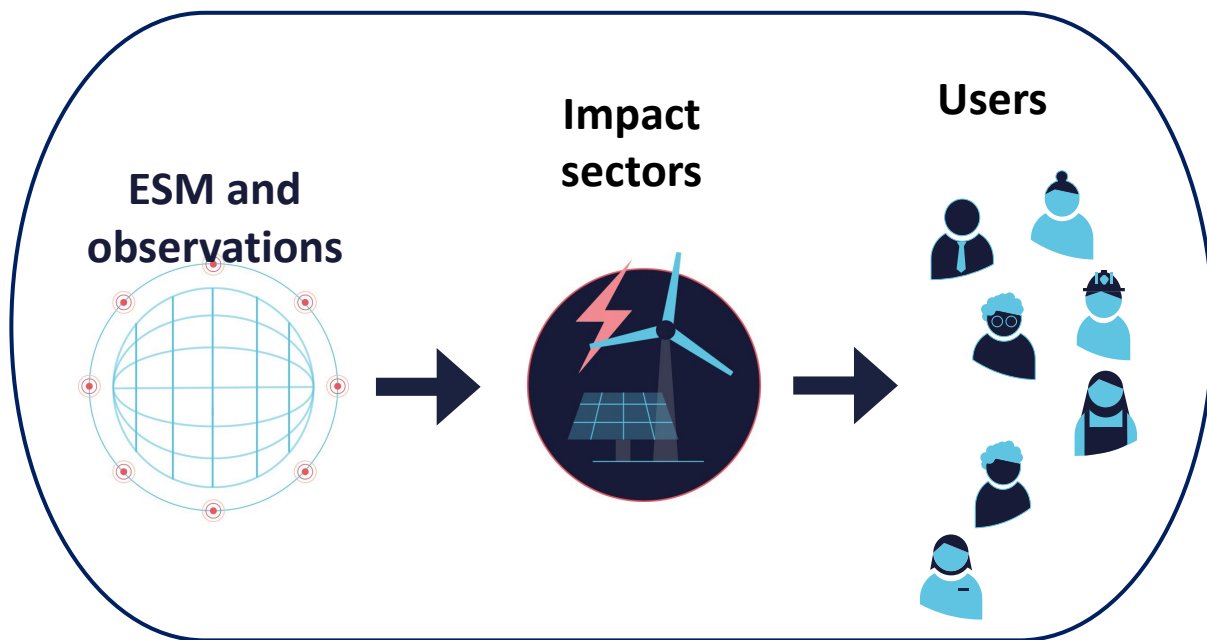




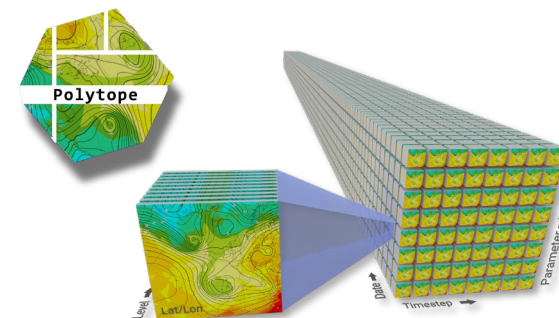
From prediction systems the Earth

to

Digital twins of



- ✓ Enhanced flexibility of simulations and output
- ✓ Flexible access to fields, time series, specific regions, ...
- ✓ On-demand production, frequent updates
- ✓ Integration of sectoral models in the DTs workflow
- ✓ Enhanced spatial and temporal resolutions





DIGITAL TWINS for exploring plausible what-if scenarios

WEATHER-INDUCED EXTREMES DIGITAL TWIN

A few days ahead



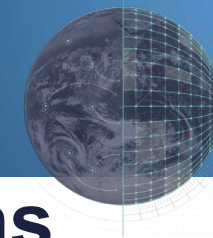
What specific adaption measure can limit the consequences of recent and future events?

CLIMATE CHANGE ADAPTATION DIGITAL TWIN

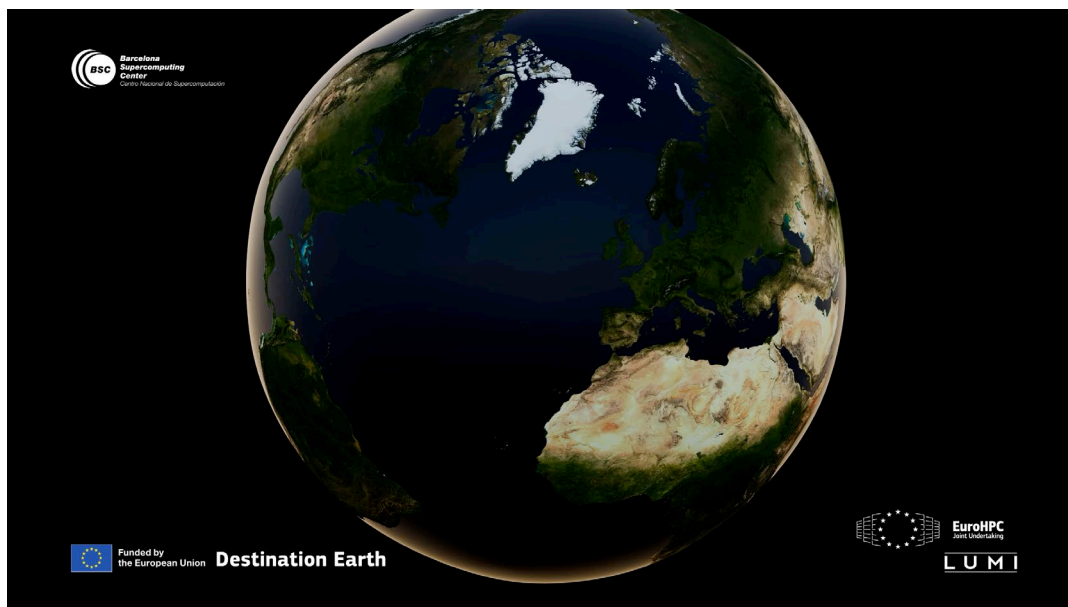
Multi-decadal timescales



*How will different scenarios change droughts and heatwaves ?
How will this impact European food production?*



Climate DT: 1st operational capability for climate projections



3 global climate models at ~5 km

IFS-NEMO
IFS-FESOM
ICON

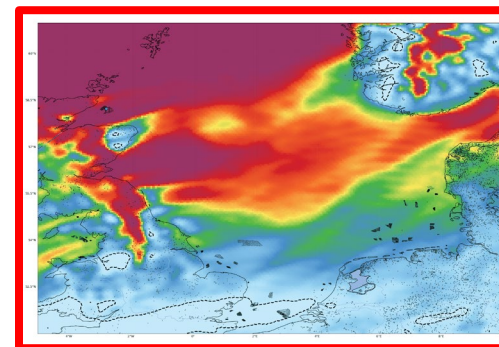


Common format
and data
governance

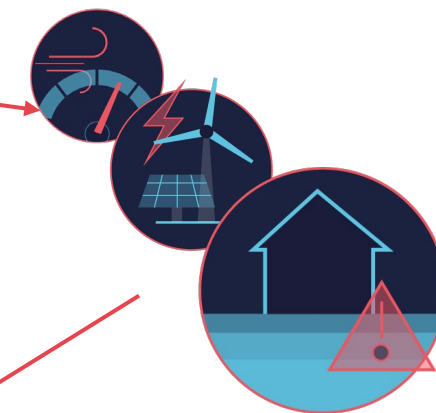
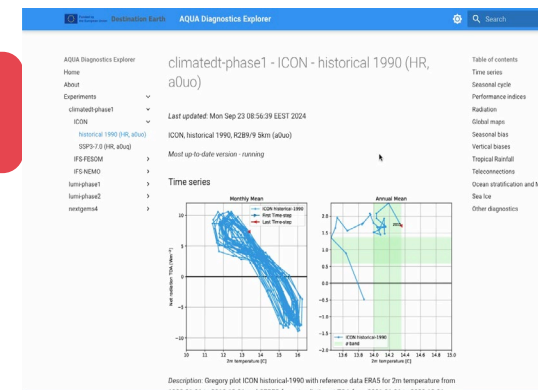
Monitoring &
evaluation

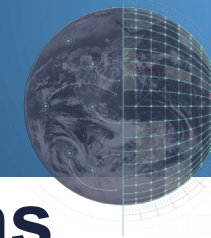
Statistics

e.g Tailored information for wind energy



Impact-sector models





Climate DT: 1st operational capability for climate projections

Current climate projections

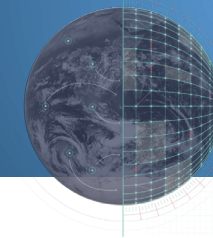
- ✓ Run through research efforts
- ✓ Updated in 7-10 year cycles
- ✓ Limited resolution (~100 km)
- ✓ Small-scale processes not represented
- ✓ Separation of Earth System Models and impact sector models

Climate DT

- ✓ Regular operational production of multi-decadal projections
- ✓ Flexible on-demand operational production
- ✓ Global information with local granularity
- ✓ 5-10 km resolution; allowing to explore the weather of the future
- ✓ Bringing Earth System Models and impact sector models within the same workflow



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

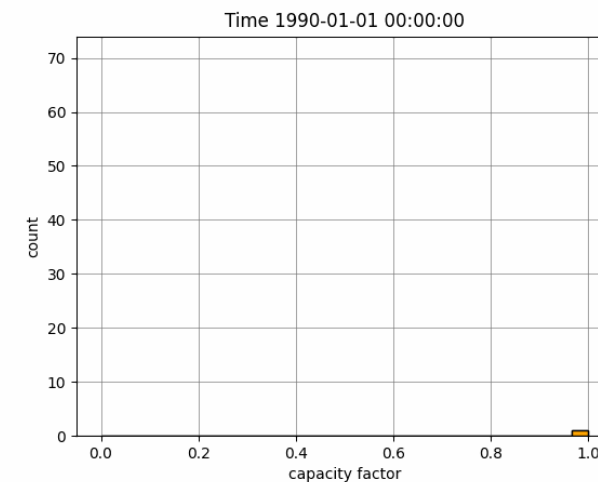
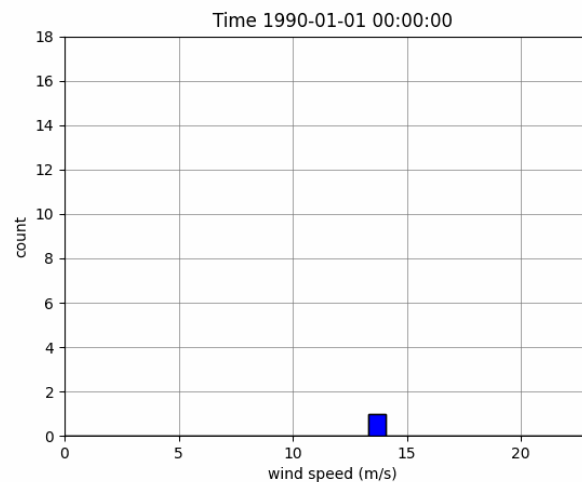
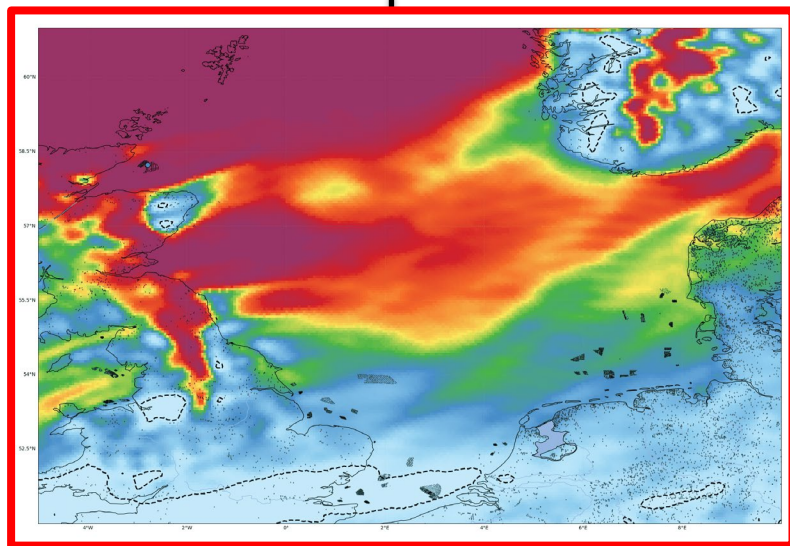


CLimate dt: streaming data to applications

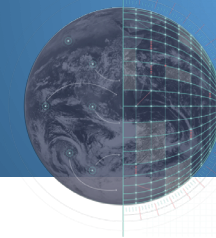
Model outputs **raw**
climate variables
(e.g., 100u, 100v)

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

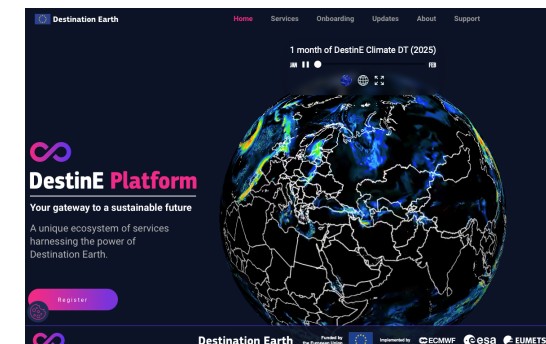
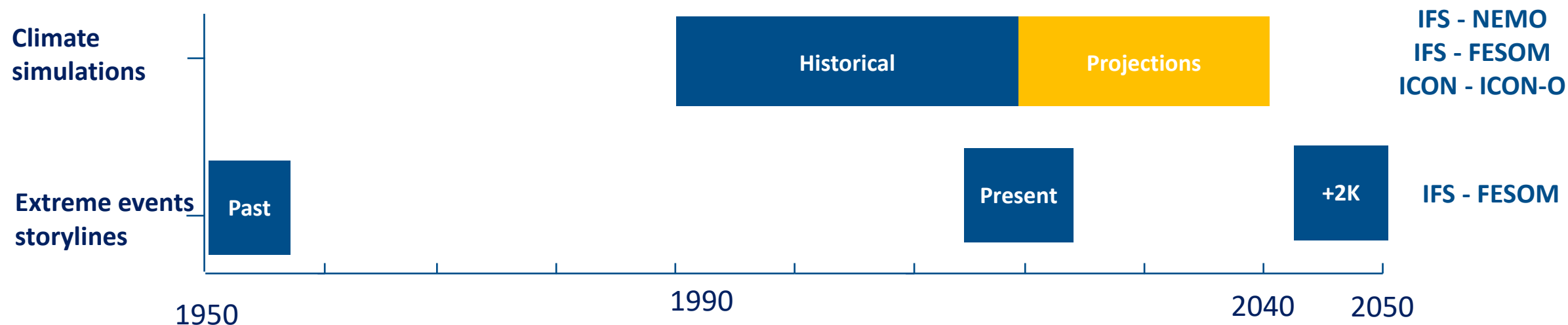
Computation of climate
indicators anywhere in the
world (e.g., weekly capacity
factor of any turbine)

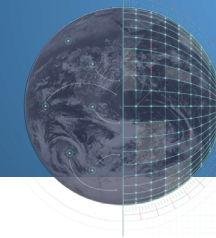


North Sea - Moray East wind farm: 58°N, -2°E



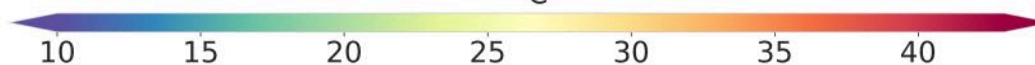
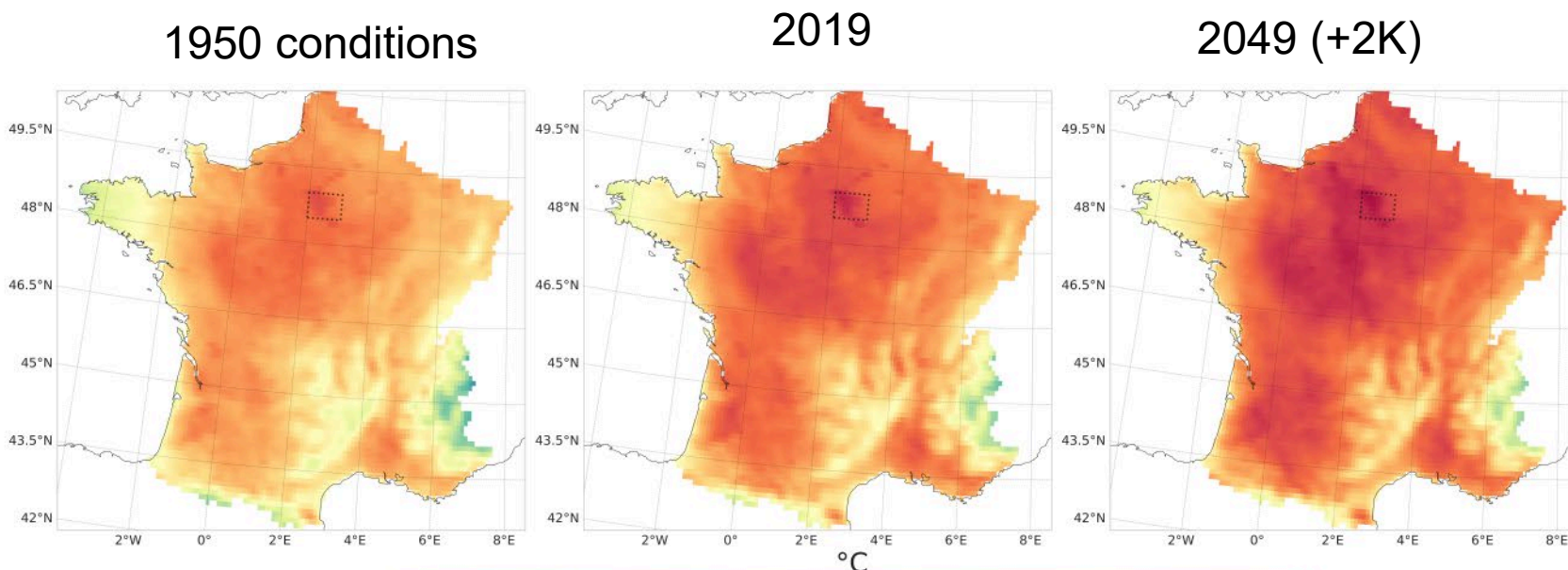
CLIMATE DT: 90+ simulated years





CLIMATE DT: storylines of extreme events – 2019 heatwave

“What-if” the
2019 heatwave
occurred in
1950 or 2049 ?

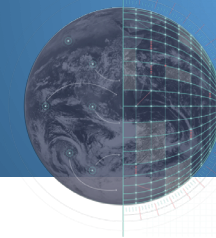


d) Maximum 2m-temperature (Paris)

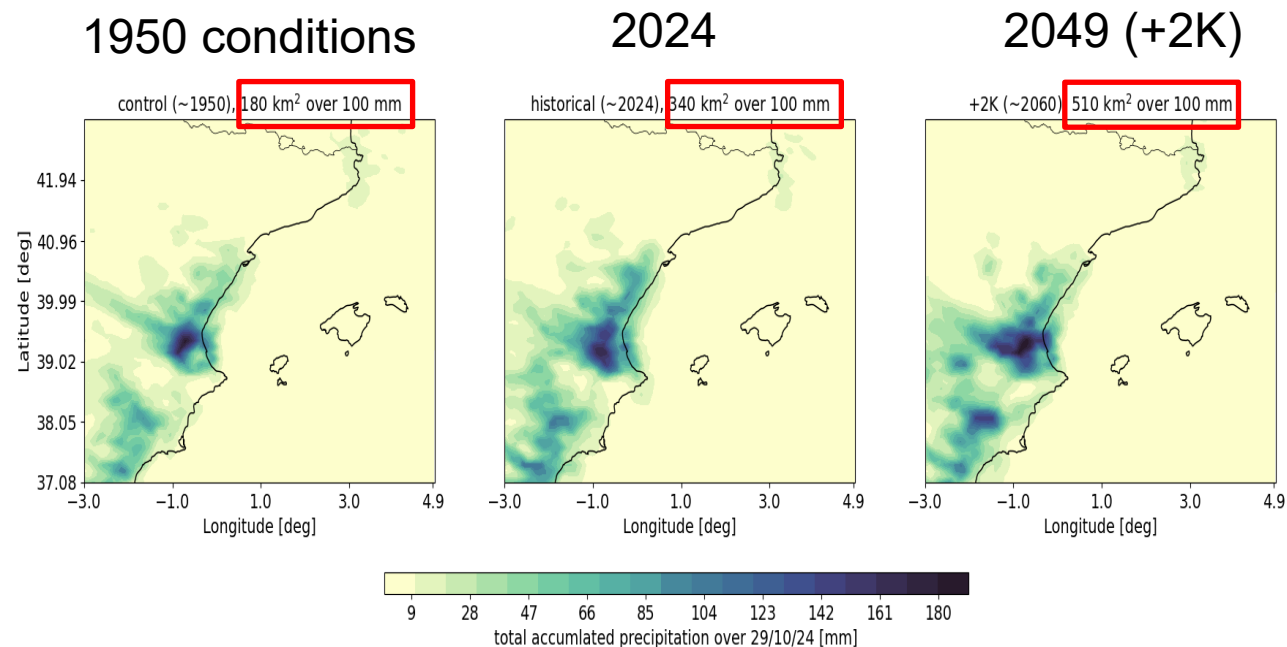
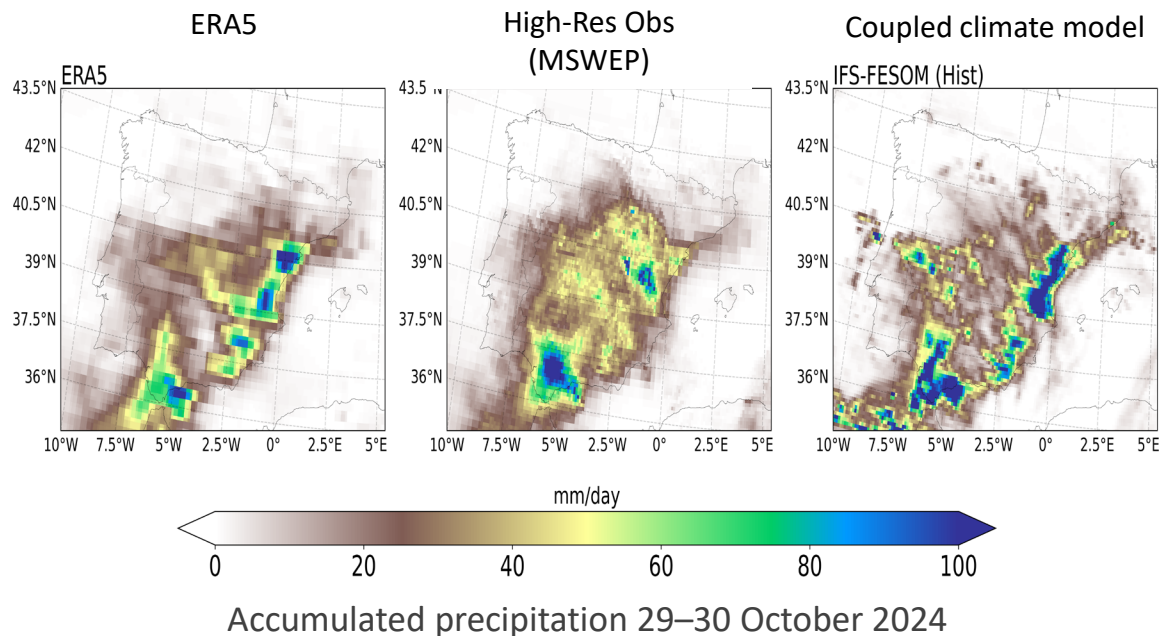
2049	29.5	28.8	28.2	27.9	27.7	27.7	29.0	31.0	33.4	35.9	38.1	39.9	41.0	41.8	42.1	41.8	41.8	40.4	38.9	36.9	34.8	33.5	31.9	30.6
2019	30.1	29.2	28.5	28.0	27.4	27.1	28.1	29.9	32.4	35.0	37.2	38.8	39.8	40.5	40.8	40.9	40.5	39.4	38.8	37.3	35.5	34.1	32.8	31.5
1950	27.1	26.4	25.7	25.2	24.5	24.3	25.3	27.3	29.6	31.9	34.2	35.9	37.2	37.9	38.2	38.3	37.1	37.0	36.7	35.4	33.1	31.4	30.1	29.1
	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00

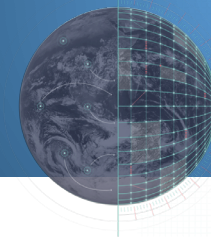
Maximum 2m temperature (Paris)

IFS-FESOM
with large-scale
nudged towards
ERA5 (2017-2023)



CLIMATE DT: storylines of extreme events – DANA





EXTREMES DT : A MAGNIFYING GLASS on EXTREME WEATHER

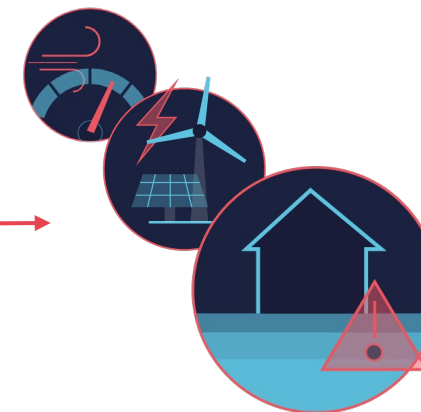


GLOBAL

S

DETECTION/
TRIGGERING

REGIONAL



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

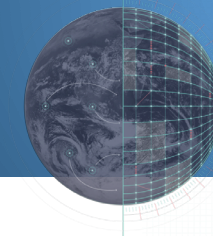
Regional simulations
2 days ahead at **750m** to **500m**

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

IFS-NEMO

Arome
Harmonie-Arome
Alaro





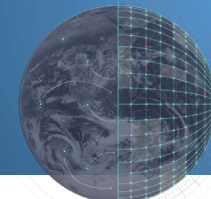
EXTREMES DT : A MAGNIFYING GLASS ON EXTREME WEATHER EVENTS

Current weather forecasts

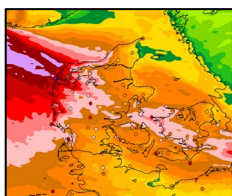
- ✓ Operational production of daily forecasts
- ✓ Fixed configurations, domains, outputs
- ✓ Still limited resolution (~10 km global, 2.5km regional)
- ✓ Separation of Earth System Models and impact sector models

Extremes DT

- ✓ Operational capability to run simulations both regularly and on-demand for past, present and future extreme events
- ✓ Flexible configurations, domain, outputs allowing to respond to evolving extreme events by triggering tailored simulations
- ✓ 4.4 km resolution globally; 500 - 750 m regional
- ✓ Bringing Earth System Models and impact sector models within the same workflow



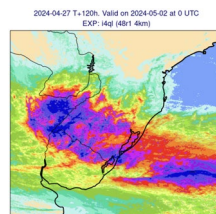
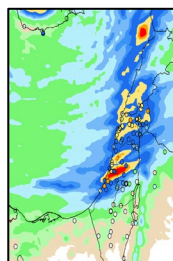
EXTREMES DT : CONTINUOUS EVALUATION OF EXTREMES



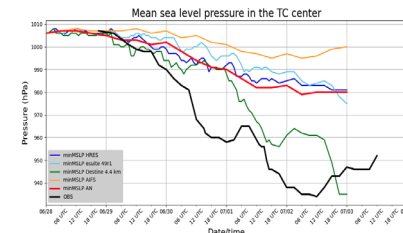
Storm Pia

(20/12)
Wind gust in
Denmark

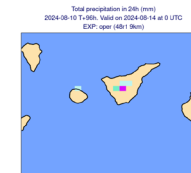
Heavy rain
(27/01) Israel



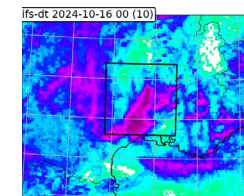
Floods
(28/04-02/05)
Brazil



TC Beryl
(26/06-06/07)
Caribbean



Extreme precipitation
False alarms
(10-08) Canary Islands



Mediterranean event
(17/10) France

Nov

Dec

Jan

Feb

Mar

Apr

May

June

July

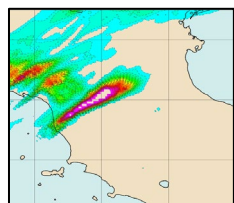
Aug

Sep

Oct

2023

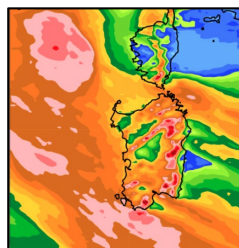
2024



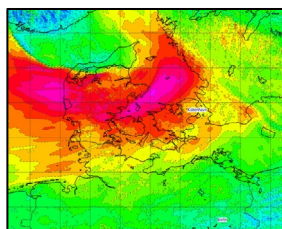
Storm Ciaran

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

Wind gust
(23/12)
Corsica



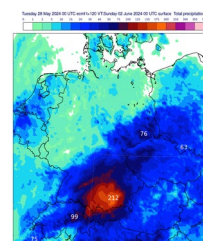
TC Belal
(14/01)
La Réunion



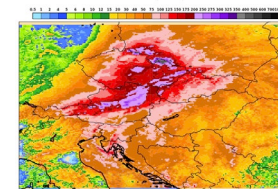
Storm Rolf
(23/02)
Denmark

Floods
(10/03)
South of France

Extreme
precipitation
(01/06)
South Germany



Strong wind
gusts and
floods
(24/06)
Italy and Croatia



Storm Boris
(26/06-06/07)

Austria, Czech Republic



REGIONAL EXTREMES: OPTIMIZED THRESHOLD-BASED EVENT DETECTION

Input data

Forecast data (e.g. from ECMWF ensemble prediction system or operational data from other regional or global NWP models)

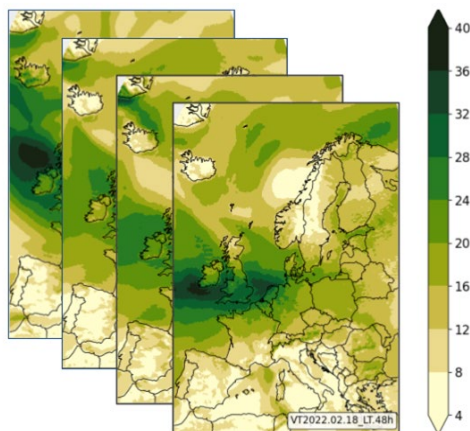
Detection method

Threshold based methods calculated from climatological information

Output information

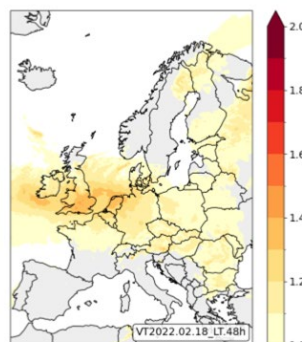
Output information categorized in 1 to 5 triggering priorities based on EPS agreement and intensity

a) Daily maximum wind gust (m/s) from ensemble of forecasts

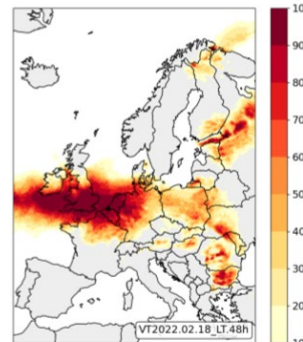


OPTI-THRED triggering applied on Storm Eunice (18 February 2022)

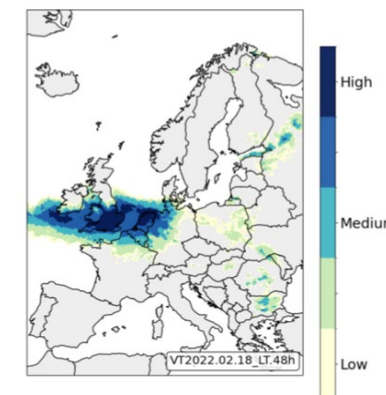
b) Measure of intensity (fraction over threshold)



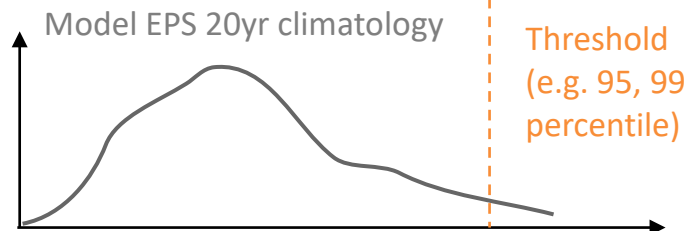
c) Measure of probability (%)



d) Triggering information (priority)

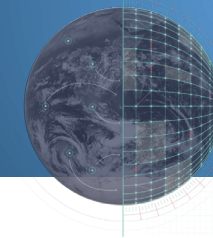


Model EPS 20yr climatology



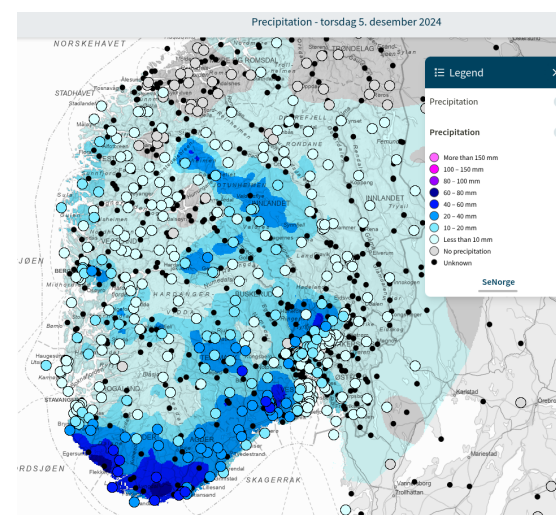
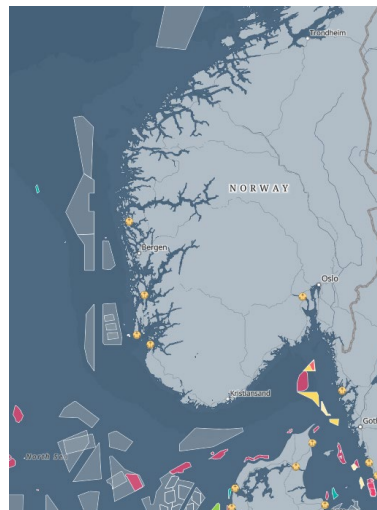
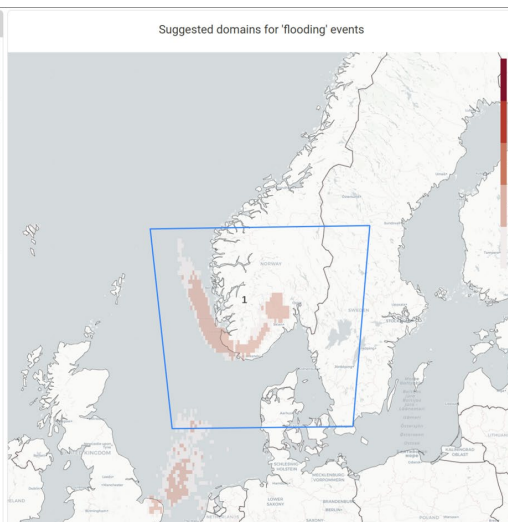
Threshold
(e.g. 95, 99
percentile)

So far tested on single variables, daily statistics (avg/max/min):
Precipitation (total and convective), CAPE, 2m-temp, 10m-wind (speed and gust)



EXTREMES DT: GLOBAL AND REGIONAL EXTREMES INFORMATION

Obs 05/06 dec 2024

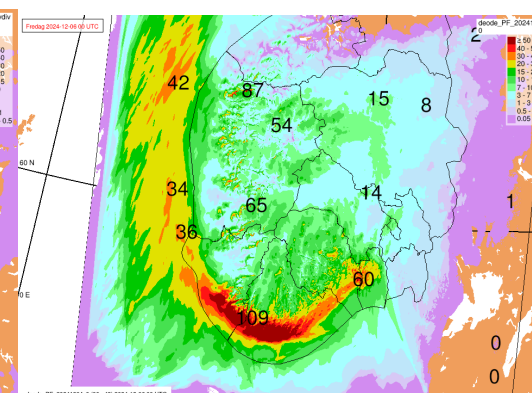
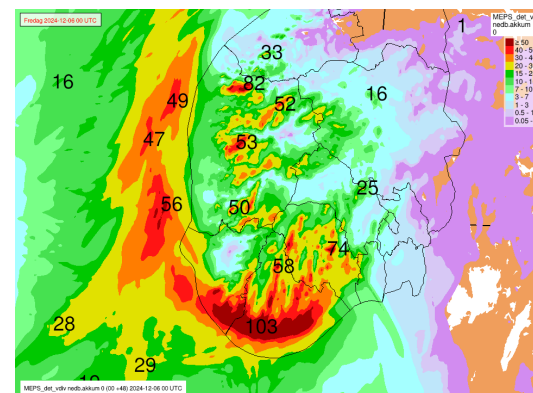
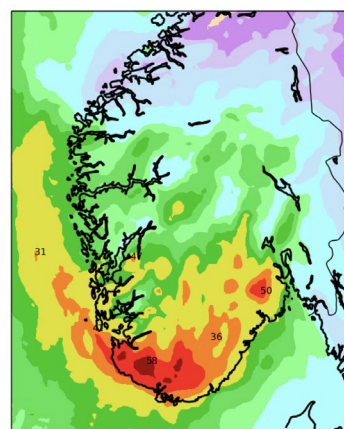
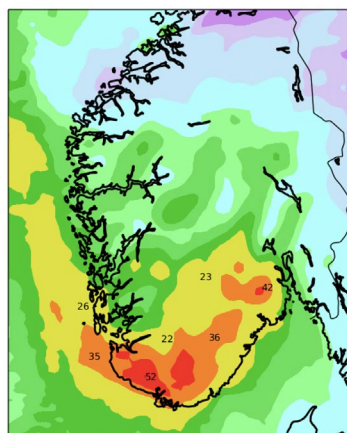


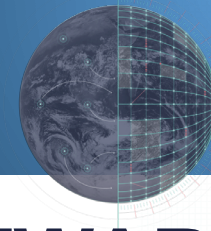
OPER 9 km

DestinE 4.5 km

METCOOP 2.5 km

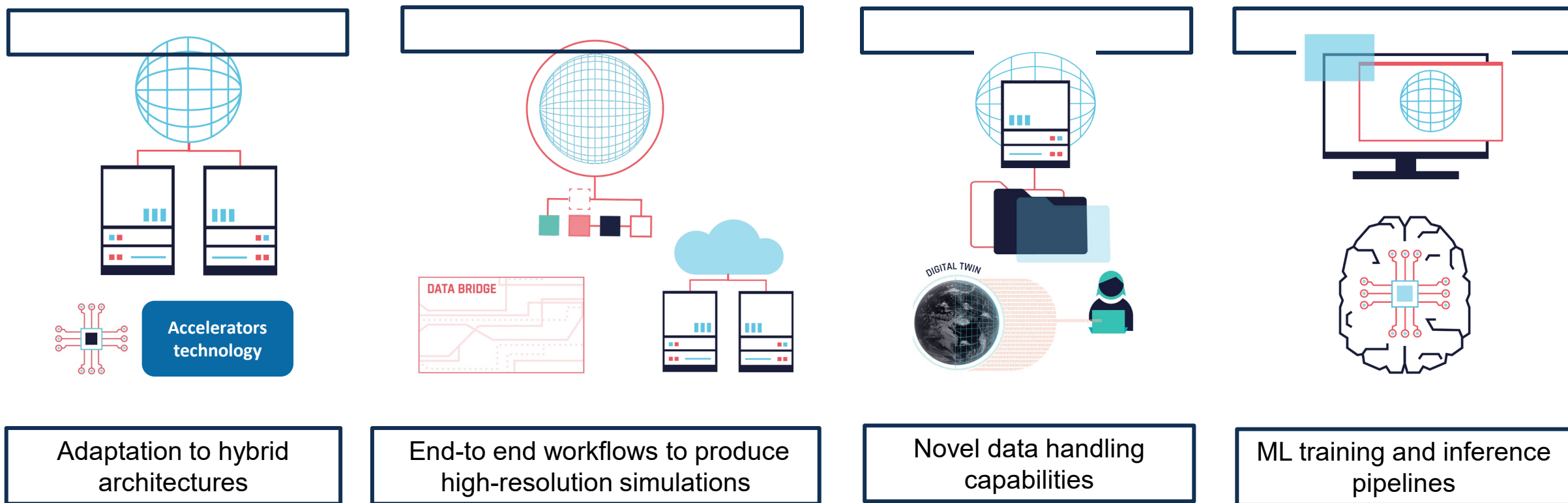
DestinE 500 m

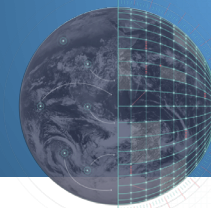




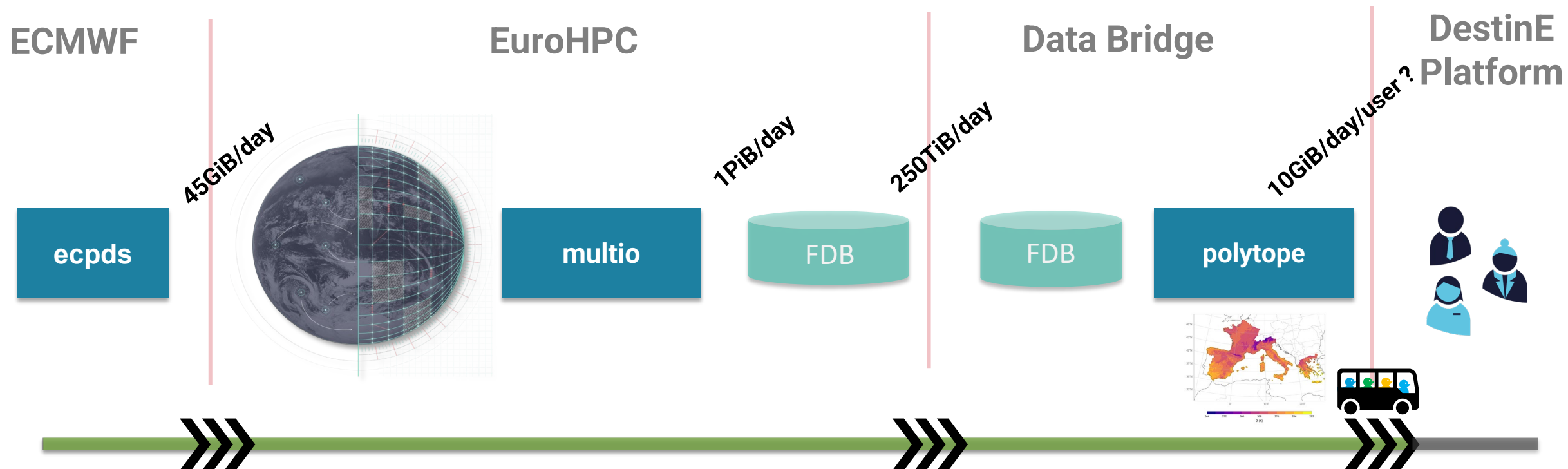
DIGITAL TWIN ENGINE: A KEY PART OF ECMWF SOFTWARE ENGINE

To operate complex Earth-system and impact-sector workflows on EuroHPC, and provide software solutions and services for accessing, handling and interacting with the digital twins and their data





DIGITAL TWIN ENGINE: PRODUCE, ACCESS, HANDLE DIGITAL TWIN DATA



Webinar by Tiago Quintino on the Digital Twin Engine

<https://www.youtube.com/watch?v=9dPyCfbobKc>



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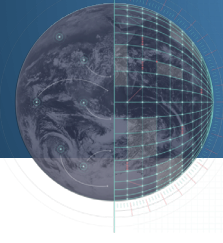
ECMWF



esa



EUMETSAT



Use cases/demonstrators: domains





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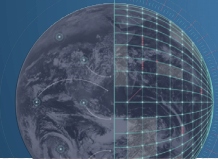
ECMWF



esa



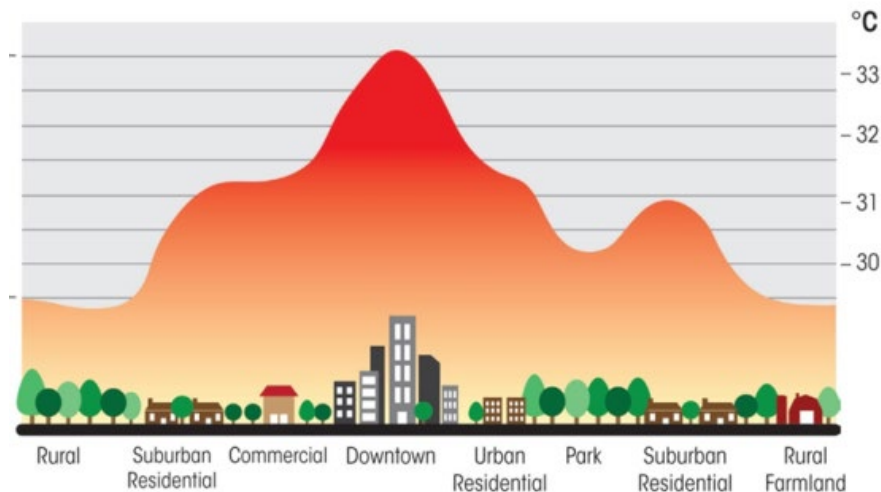
EUMETSAT



Pilot service: Urban Heat

Background

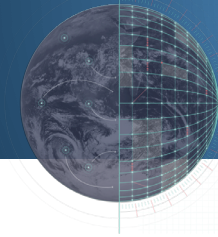
- Climate change leads to increasingly frequent and intense heatwaves in Europe
- Cities are especially at risk because of the urban heat island (UHI) phenomenon



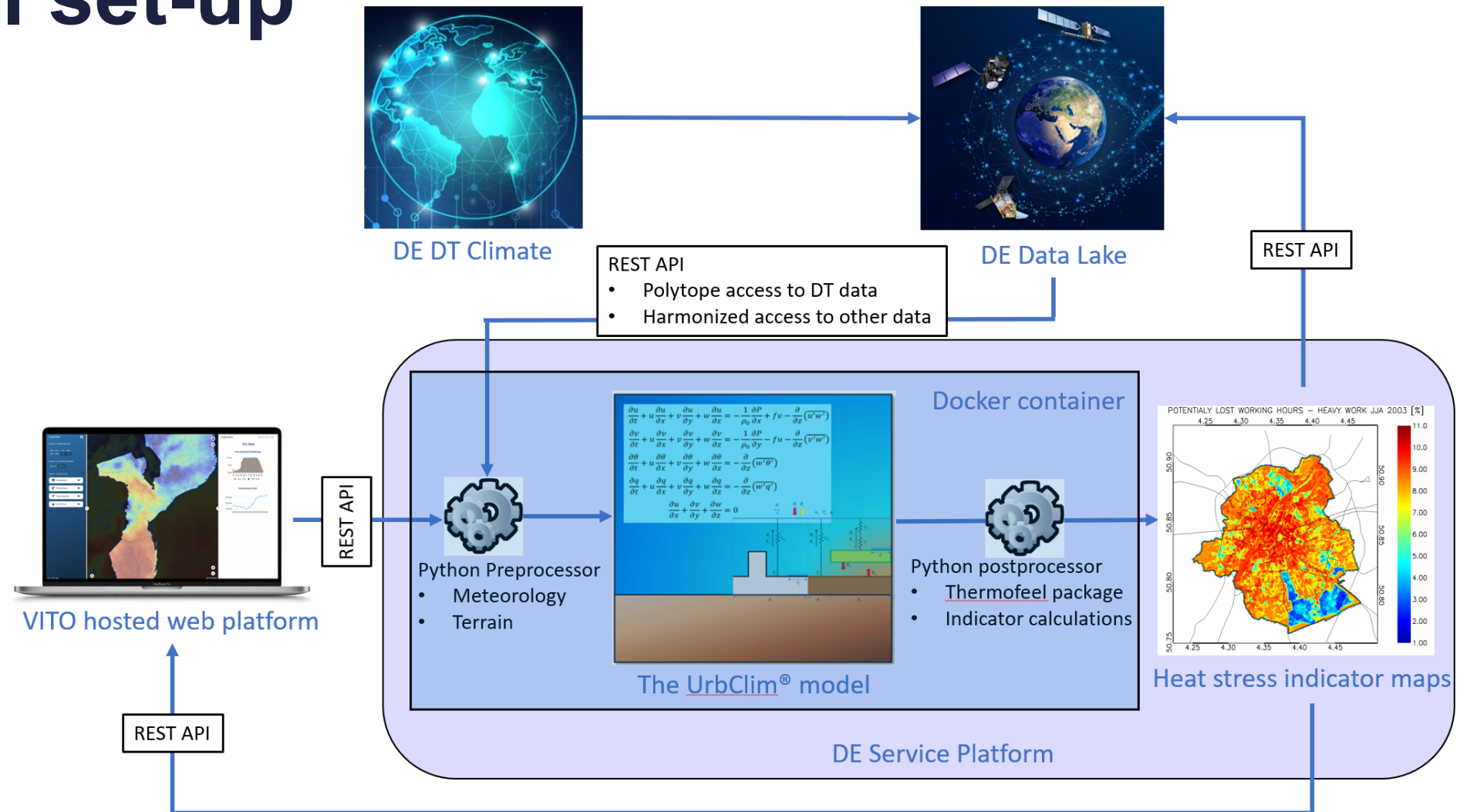
Late afternoon air temperatures across a city. Source:

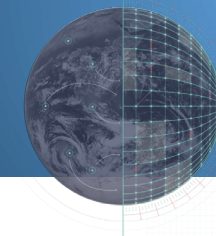
[web](#)





Technical set-up





New ML demonstrators

Energy Systems

Renewables
Grid Initiative

TRÄNSNET BW

Tennet

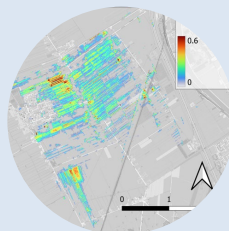
 Stadtwerke Ulm/Neu-Ulm
Netze GmbH

Flood risk management

HydroLogic



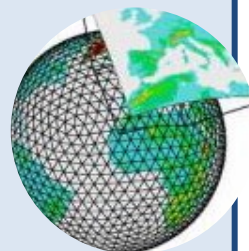
Weather Impact



Fusion of forecasts



CINECA



Water resilience

open

Agriculture

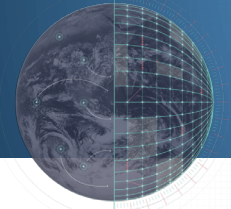
Fusion of climate projections



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Destination Earth

implemented by



Thank you!

www.destination-earth.eu

<https://digital-strategy.ec.europa.eu/en/policies/destination-earth>

<https://destine.ecmwf.int/>

https://www.esa.int/Applications/Observing_the_Earth/Destination_Earth

<https://www.eumetsat.int/who-we-work/destine>

