

# Modelling and monitoring the Earth System: the AI revolution

Matthew Chantry

Strategic Lead for Machine Learning

[matthew.chantry@ecmwf.int](mailto:matthew.chantry@ecmwf.int)

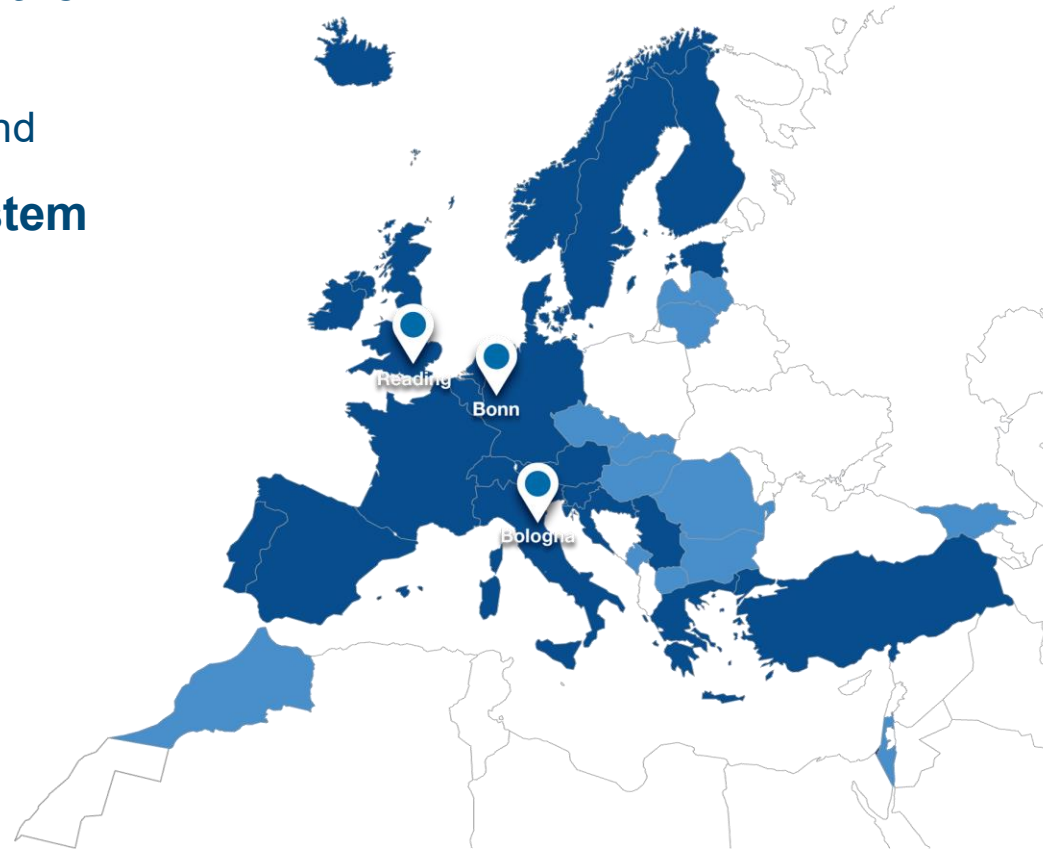
# European Centre for Medium-Range Weather Forecasts

## ECMWF's mission:

Deliver **global numerical weather predictions**

focusing on the medium range and  
**monitoring of the Earth system**

to and with our Member States.



## Key facts

- 23 Member States
- 12 Co-operating States
- > 500 staff - 3 locations
- **24/7 operational service**
- **Research institution**



PROGRAMME OF  
THE EUROPEAN UNION



IMPLEMENTED BY



#EUSpace



Climate  
Change Service

[climate.copernicus.eu](https://climate.copernicus.eu)

**We provide authoritative information about the past, present and future climate in Europe and the rest of the World**



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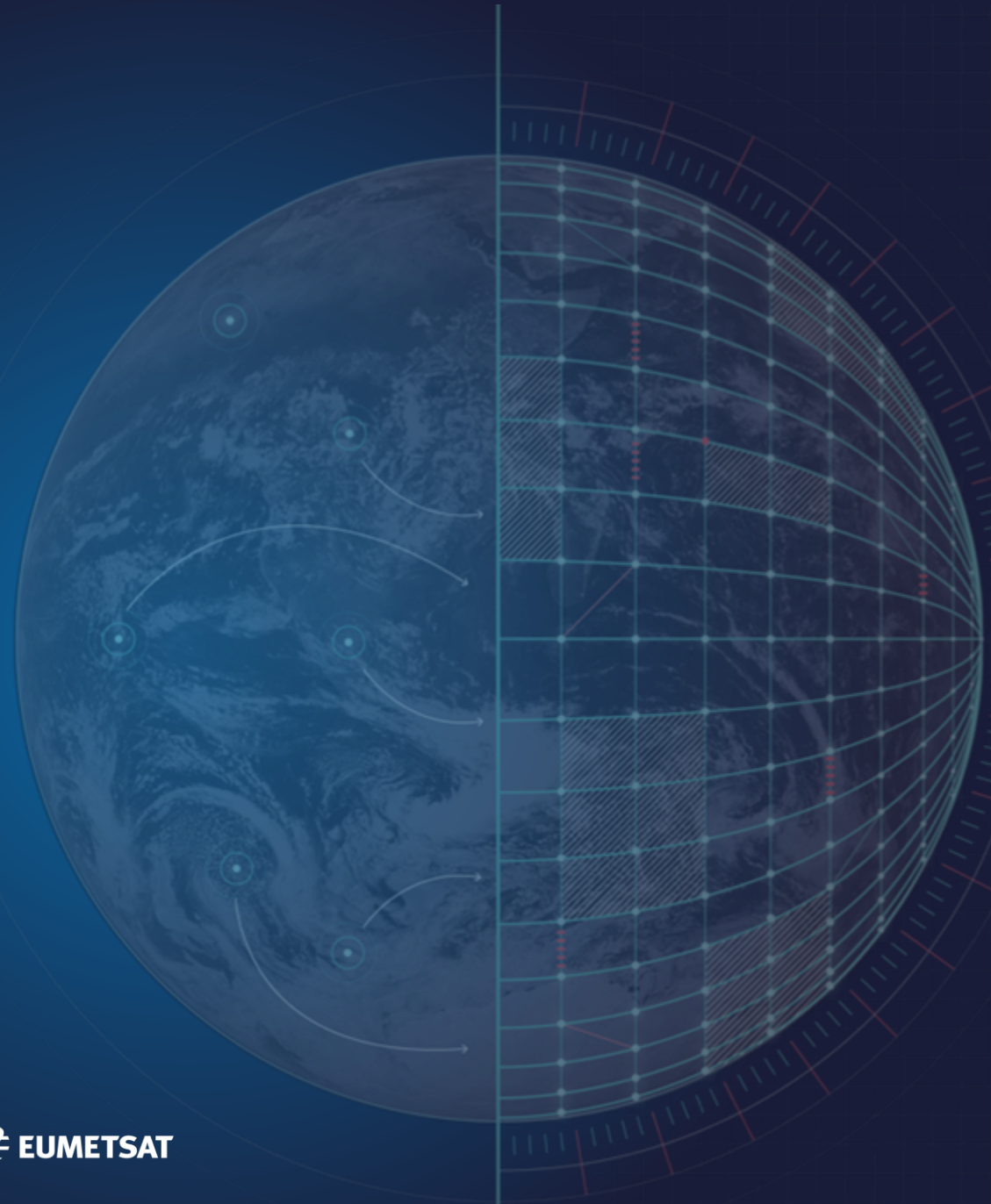
Atmosphere  
Monitoring Service  
[atmosphere.copernicus.eu](https://atmosphere.copernicus.eu)

**We provide consistent and quality-controlled information related to air pollution and health, solar energy, greenhouse gases and climate forcing, everywhere in the World**

# Destination Earth

Digital Twins of the Earth system

ECMWF & over 100 partner organisations in 26 countries



Funded by  
the European Union

**Destination Earth**

implemented by

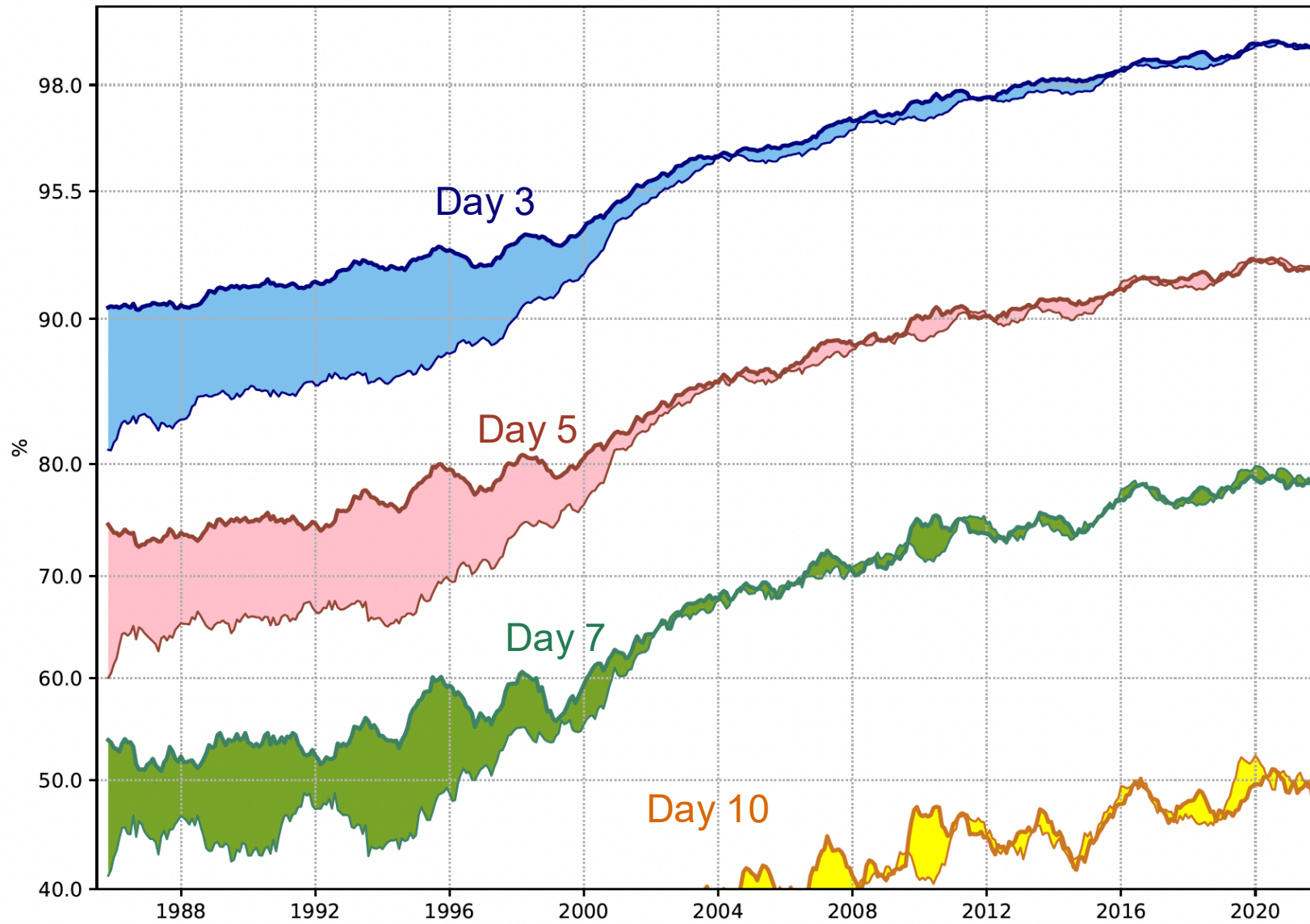


Neural networks as universal approximation systems

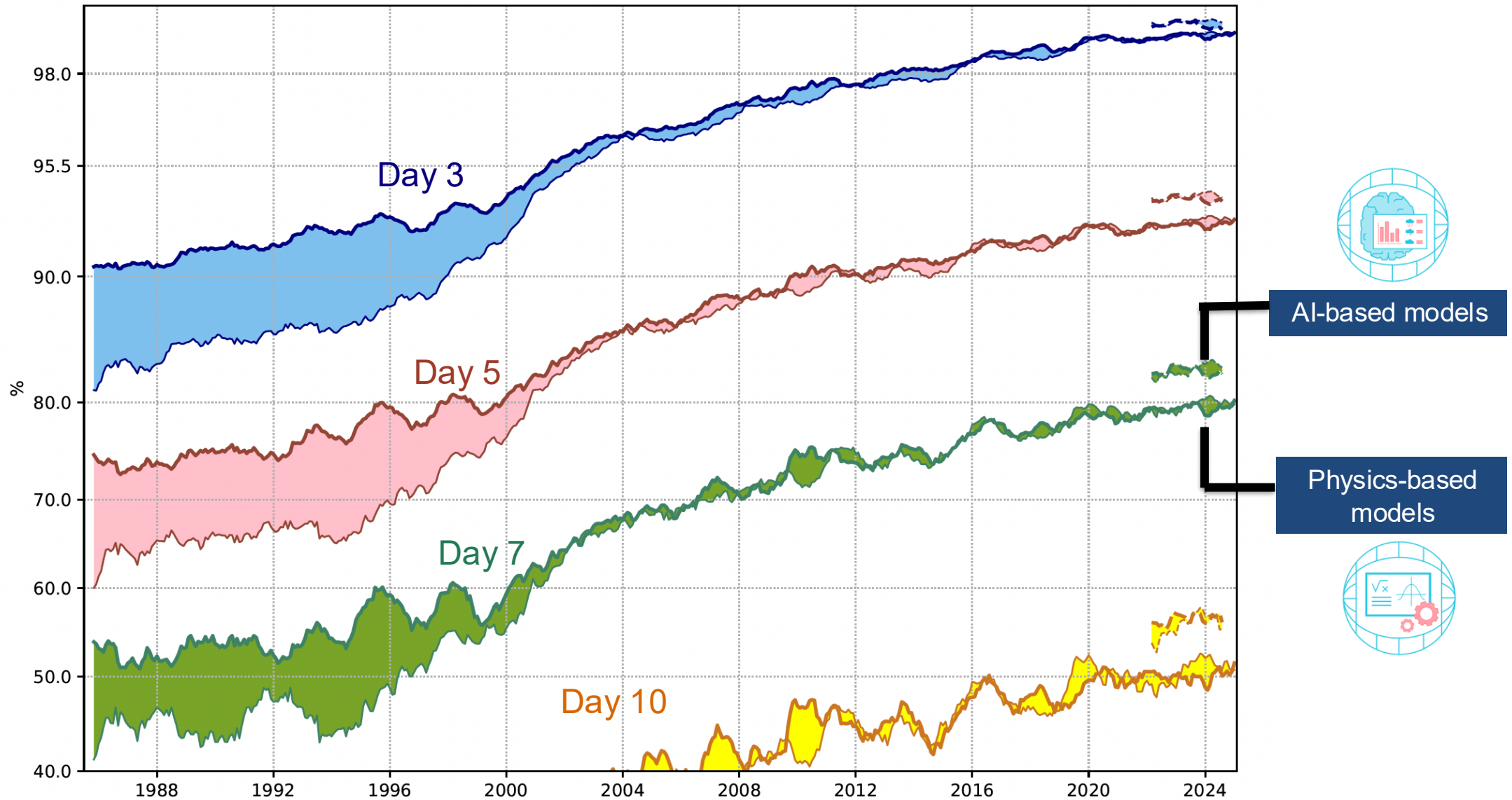
Given enough **compute** and **data** any relationship can be learnt....

For which problems is this true?

# From quiet revolution



# From quiet revolution to noisy revolution



# A short history of data-driven weather forecasting

**February 2022 – First competitive medium-range systems**

- **Keisler** – GraphNN, competitive with GFS (USA)
- **NVIDIA** – **FourCastNet Fourier+**, 0.25°, **O(10<sup>4</sup>) faster & more energy efficient than IFS**

**December 2022**

- **Deepmind** – **GraphCast**

GraphNN  
0.25° **Many parameters with comparable skill to IFS.**

**November 2022**

- **Huawei** – **PanguWeather**

Vision Transformer  
0.25° **“More accurate tropical cyclone tracks” than the IFS.**

**January-June 2023**

- **Microsoft** – **ClimaX**
- **China academia/Shanghai Met** – **FengWu**
- **Alibaba** – **SwinRDM**
- **NVIDIA** – **SFNO**
- ...

**December 2023**

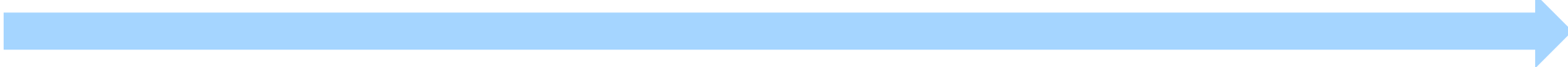
- **Deepmind** – **GenCast**

Probabilistic forecast (ensemble) – 0.25°  
**“Outperforming the leading operational ensemble forecast” (aka ECMWF)**

**June 2024**

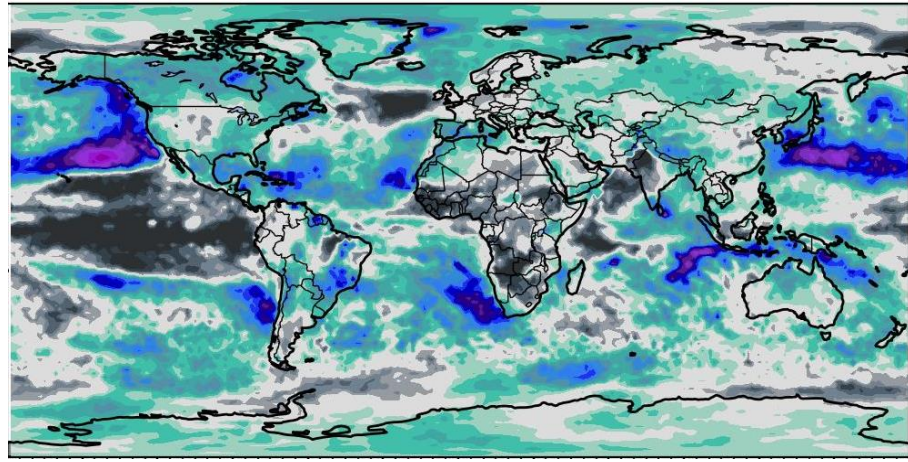
- **Microsoft** – **Aurora**

Higher resolution – 0.1°  
Atmospheric composition

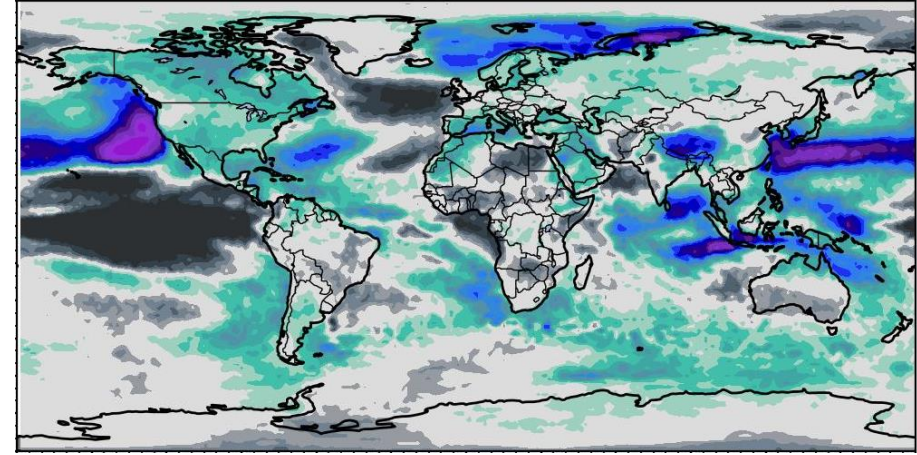


**2018 – Concept explored (ECMWF and others)...**

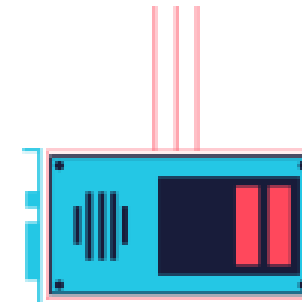
# AI – running a weather forecast on a GPU in minutes



Produced in one hour.

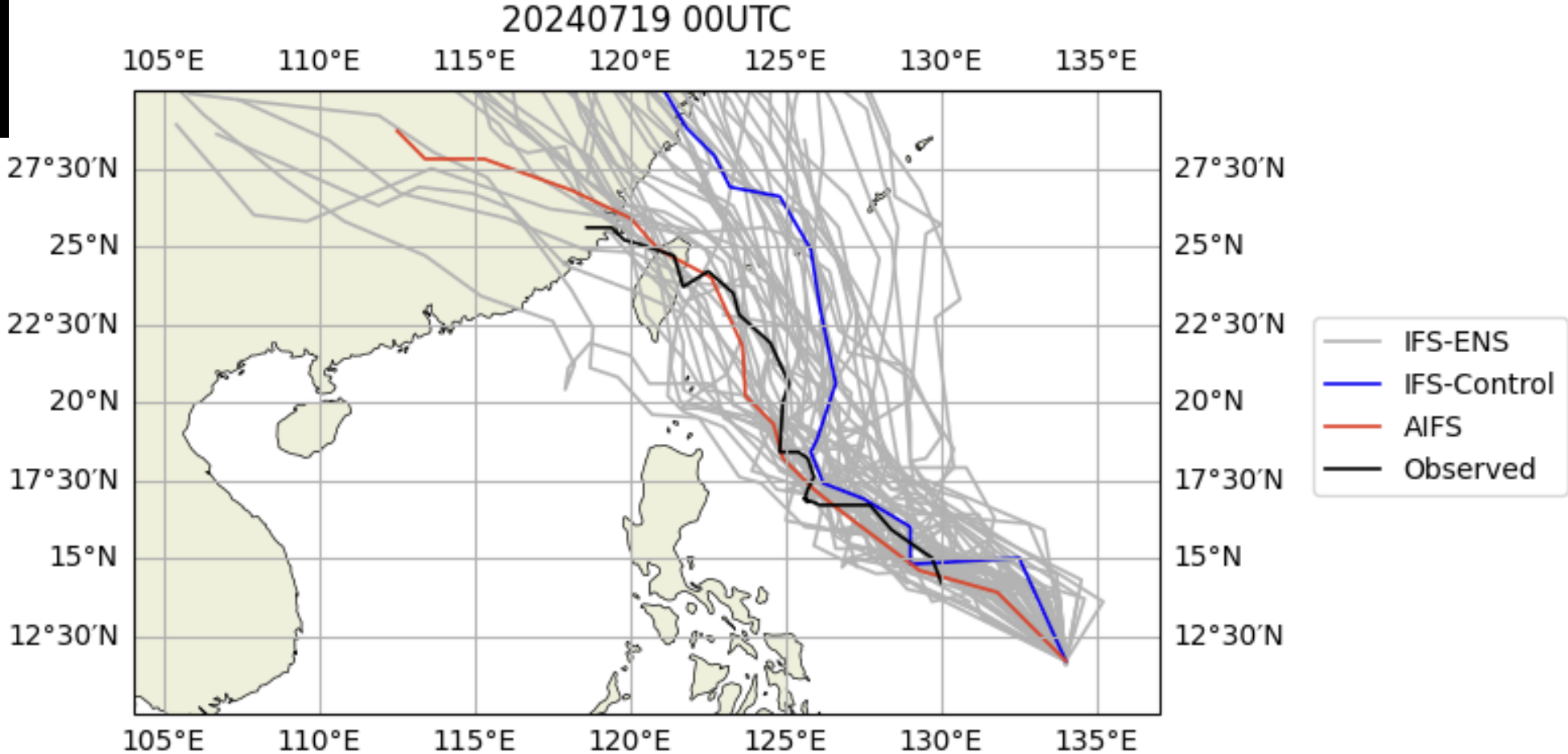


Produced in 2 minutes.



# AI – more skillful predictions of extreme events

12-hour earlier warning on tropical cyclones



Neural networks as universal approximation systems

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For which problems is this true?

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# ERA5: The Foundation of the AI Revolution



Climate  
Change Service

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The global surge in AI-based weather and climate models shares one common foundation: high-quality, physically consistent training data.

ERA5, produced and maintained by ECMWF and C3S, is that standard. It provides the ground truth required to train the next generation of predictive intelligence.



Funded by  
the European Union

**Destination Earth**

implemented by



ECMWF



esa



EUMETSAT



# The Digital Twins: bespoke simulation capability

Kilometer-scale fsimulations on weather and climate timescales



Neural networks as universal approximation systems

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# A short history of data-driven weather forecasting

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- ...

**December 2023**

- **Deepmind** – **GenCast**

Probabilistic forecast (ensemble) – 1°  
**“Outperforming the leading operational ensemble forecast” (aka ECMWF)**

**June 2024**

- **Microsoft** – **Aurora**

Higher resolution – 0.1°  
Atmospheric composition



**2018 – Concept explored (ECMWF and others)...**

**June 2023  
ECMWF – ML project begins**

**Jan/Feb 2024  
AIFS first updates**

**June 2025:  
AIFS ENS 1 operational**

**Early 2023  
Prototype AIFS developments begin**

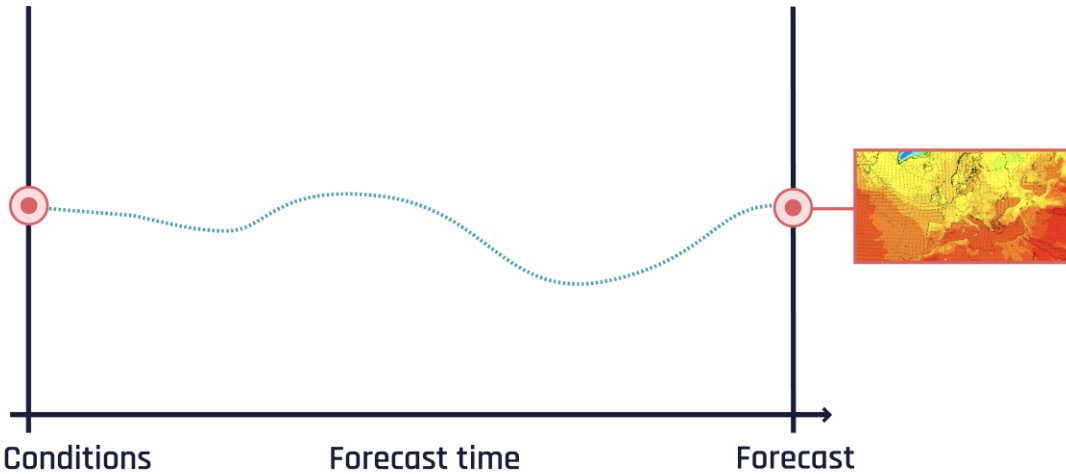
**October 2023  
AIFS experimental forecasts live**

**Feb 2025:  
AIFS Single 1 operational**

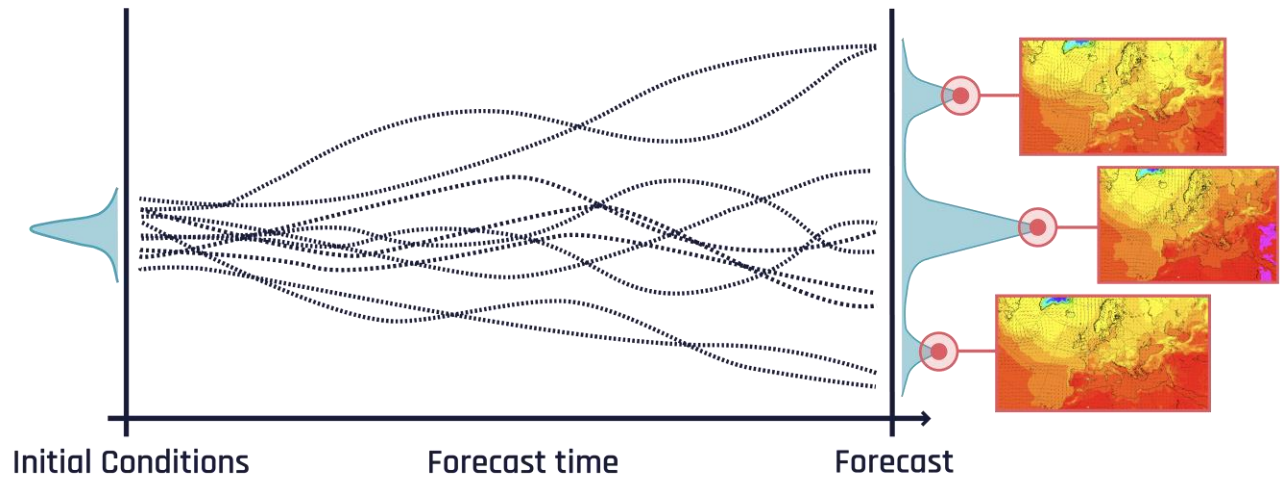
# ECMWF's Artificial Intelligence Forecasting System (AIFS)

Operational machine learning models for medium-range weather forecasting.

Data-driven Deterministic Forecast  
(AIFS Single)



Data-driven Ensemble Forecast  
(AIFS ENS CRPS)

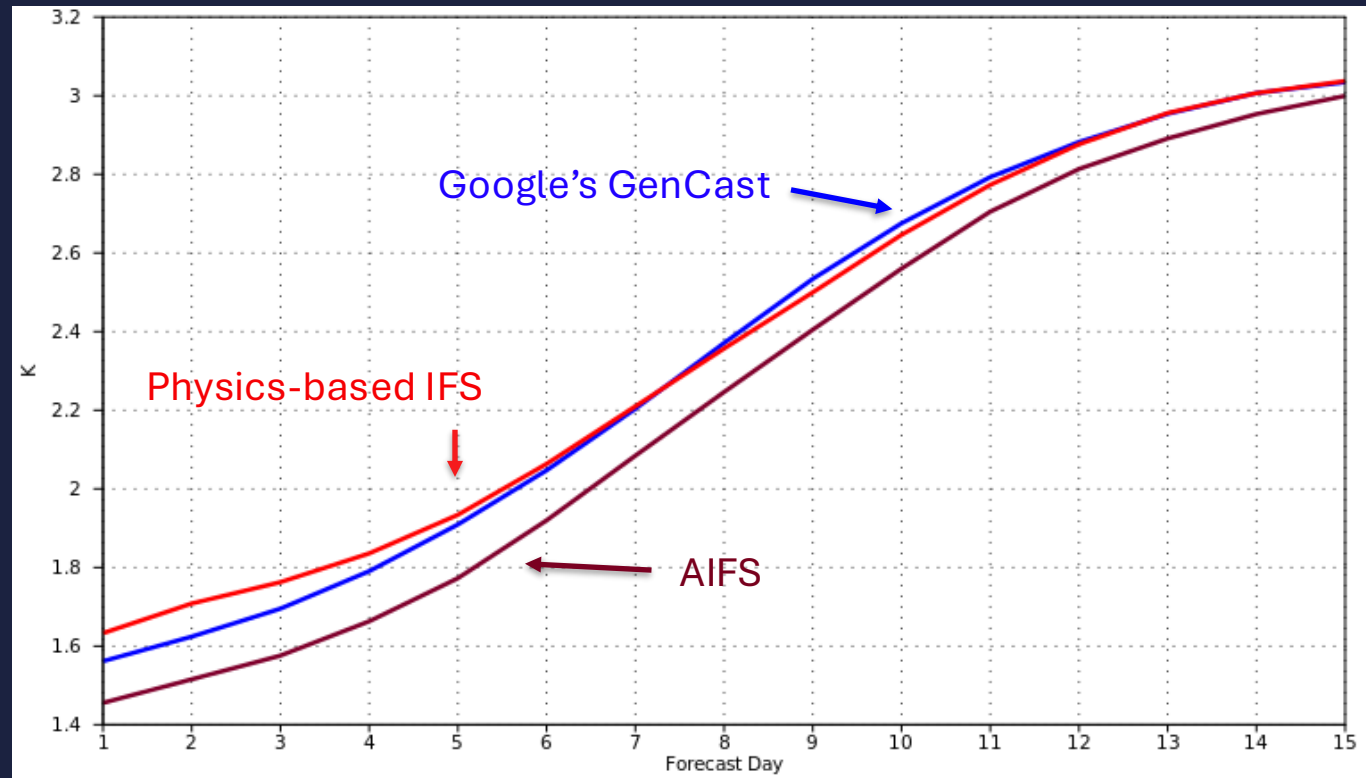


More accurate probabilistic forecasts

# ECMWF Artificial Intelligence Forecasting System (AIFS)

Showing improved skill in the medium-range compared to the physics-based IFS.

## AIFS Probabilistic forecast

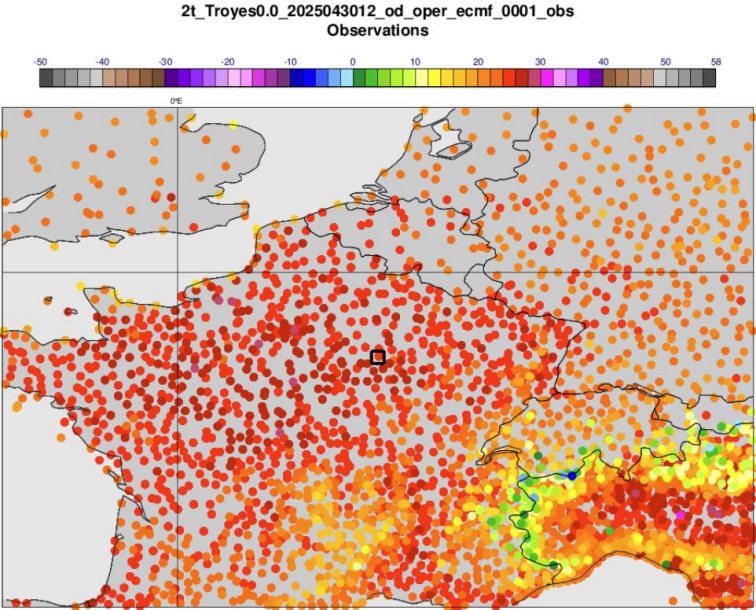


Surface temperature accuracy

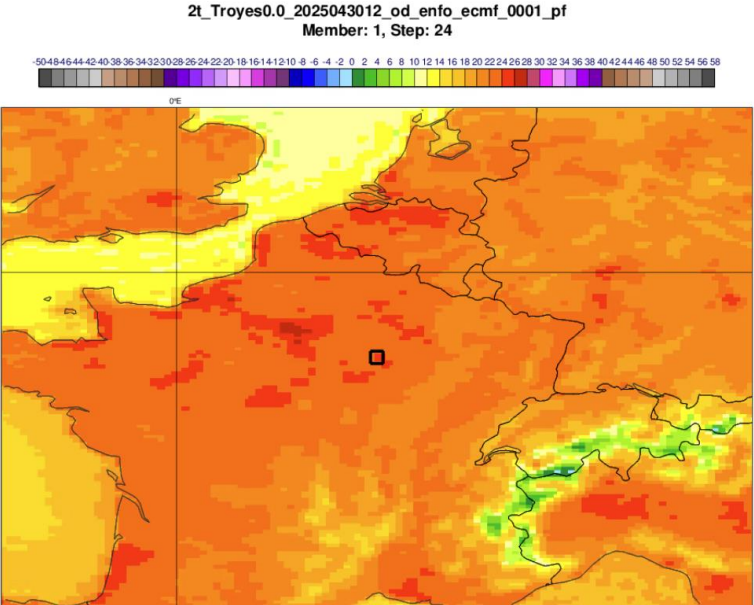
# AI – more skillful predictions of extreme events

## Early heatwave in April 2025: 2-metre temperature 30 April 12UTC

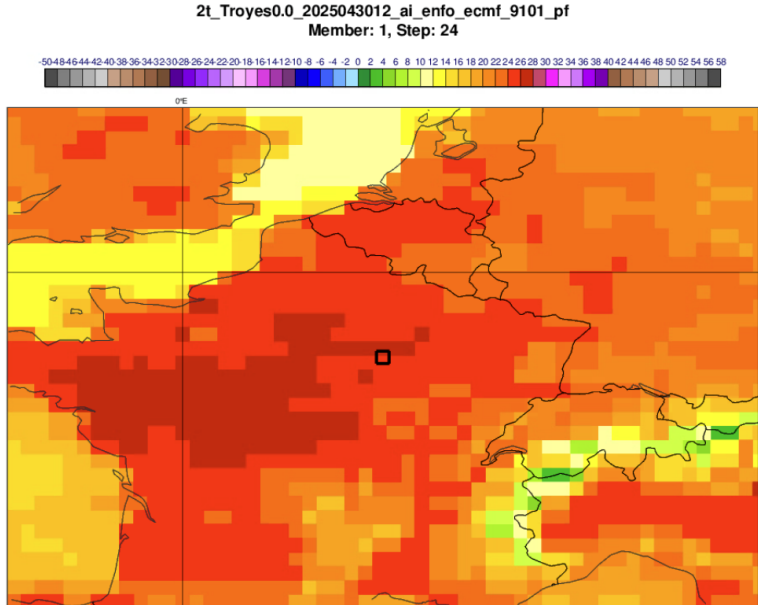
Observations



24h forecast from IFS-ENS Mem 1

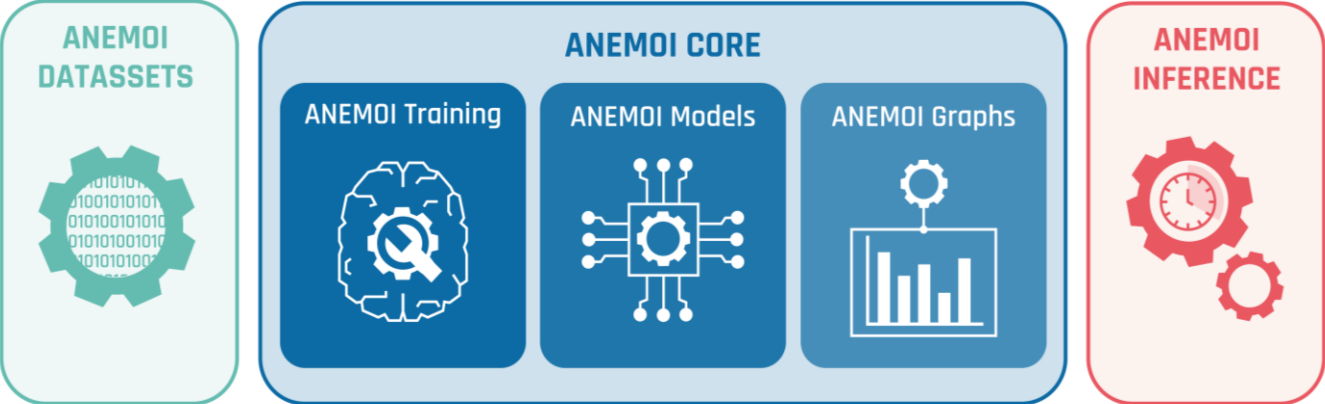


24h forecast from AIFS-ENS Mem 1



# Anemoi: ECMWF & Member States AI software framework

## ANEMOI COLLABORATIVE OPEN SOURCE ECOSYSTEM



**The EuroHPC**

**SUPERCOMPUTERS**

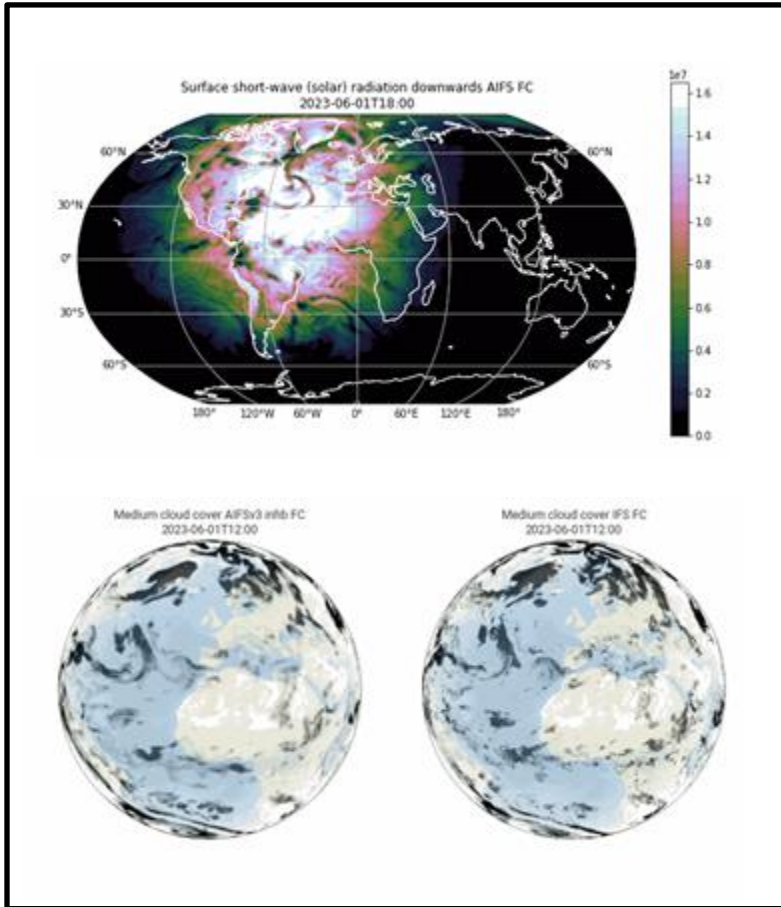
The infographic features a map of Europe with four supercomputer locations highlighted by colored pins and connected to small images of the facilities:

- LUMI** (Ljubljana, Slovenia)
- MareNostrum 5** (Barcelona, Spain)
- Leonardo** (Graz, Austria)
- Meluxina** (Ljubljana, Slovenia)

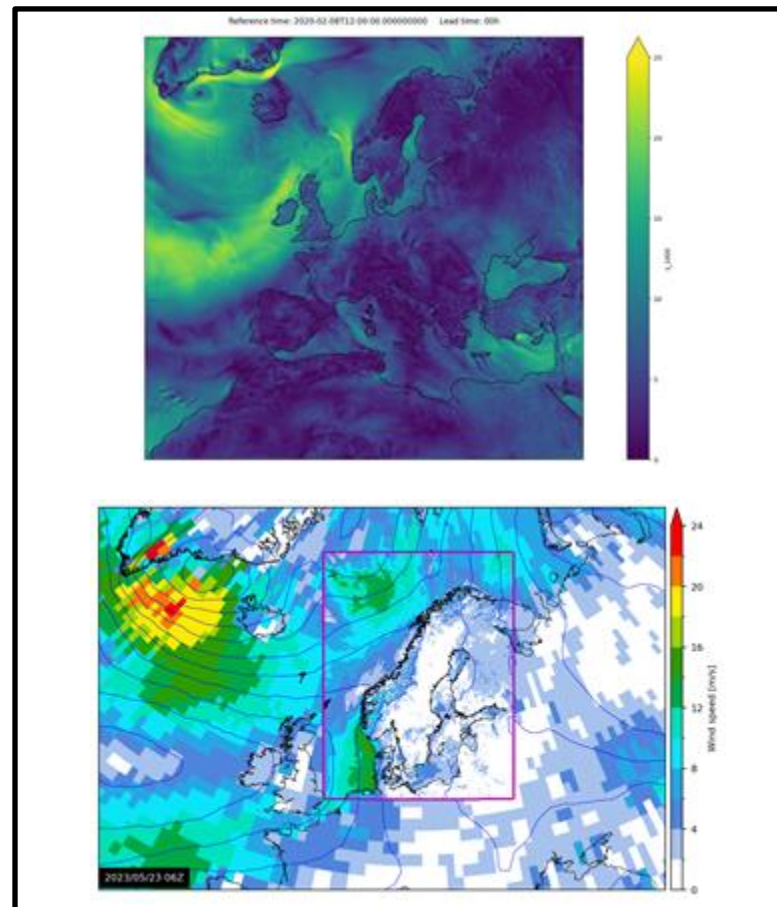
Europe's leading supercomputers with

# Anemoi: numerous operational AI applications in weather & climate

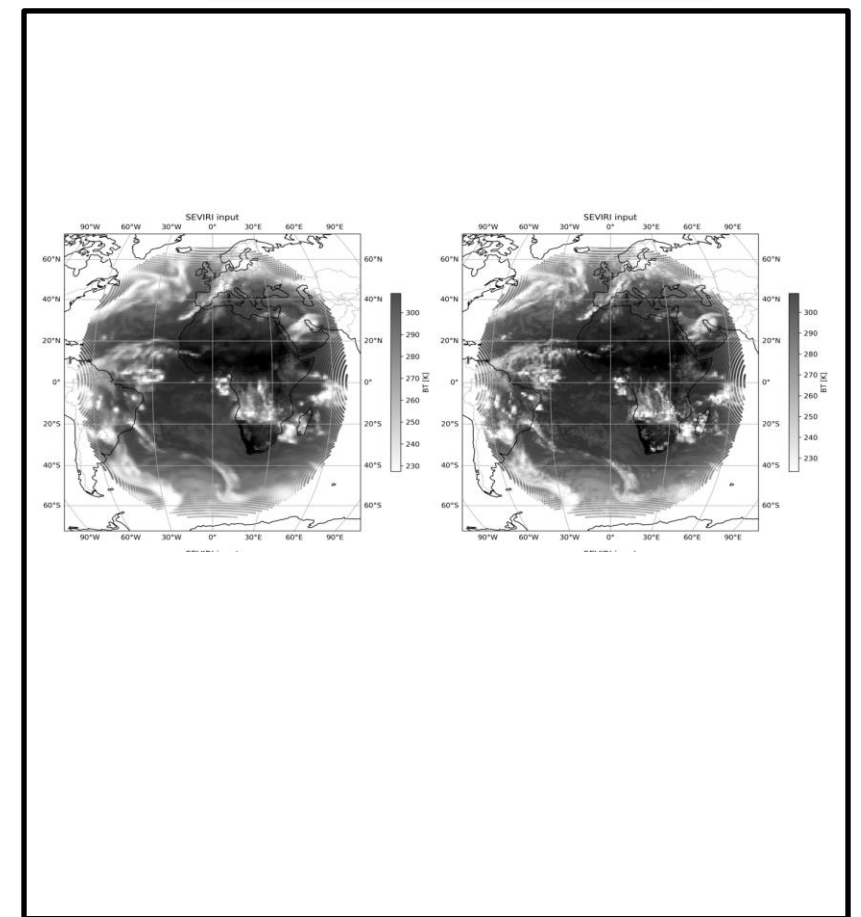
## Global



## Limited area



## Direct observation prediction





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**Destination Earth**

implemented by



ECMWF



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EUMETSAT

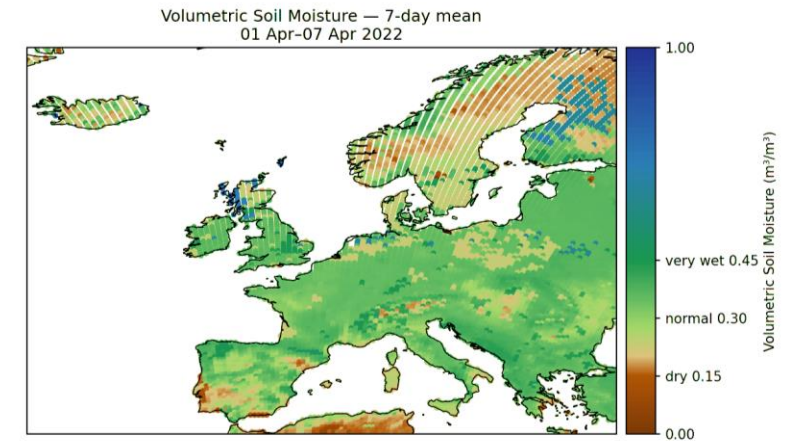
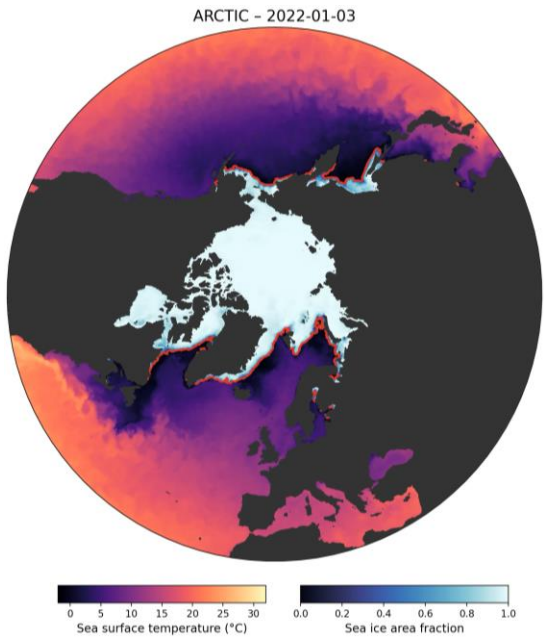
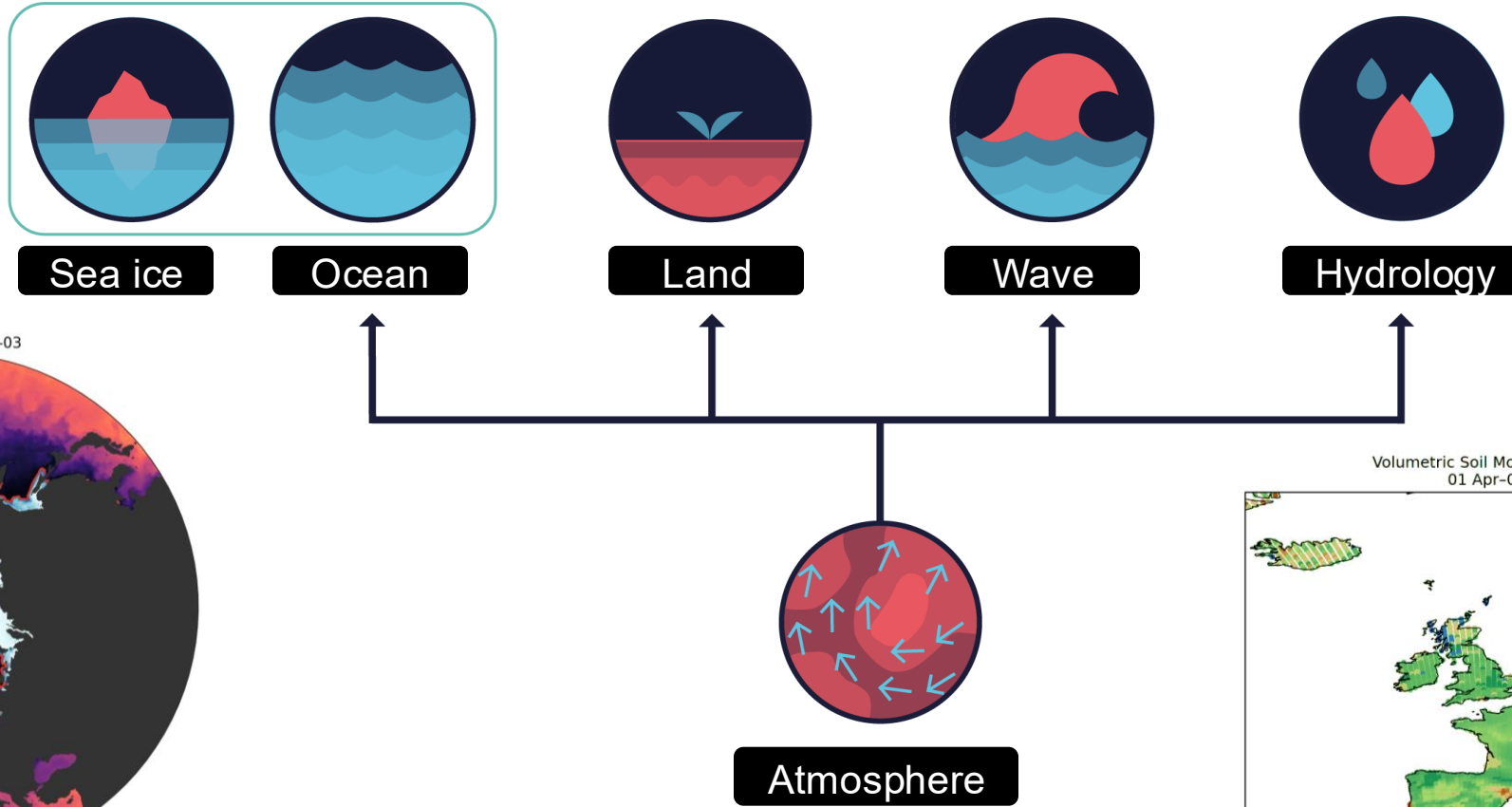


# Delivering AI in Destination Earth





# Towards an AI Earth system model



# An AI Forecast-in-a-box



Prepare Initial  
Conditions

Run the  
Model

Create User  
Products

Visualise



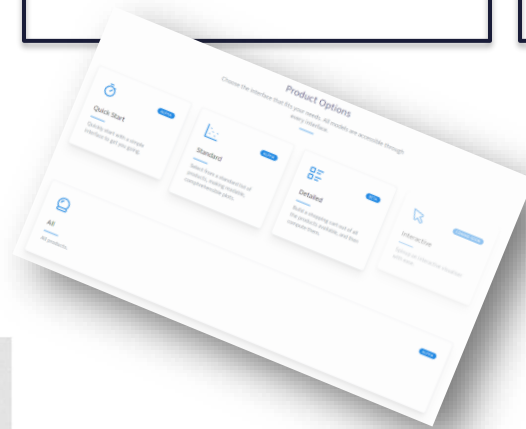
# An AI Forecast-in-a-box



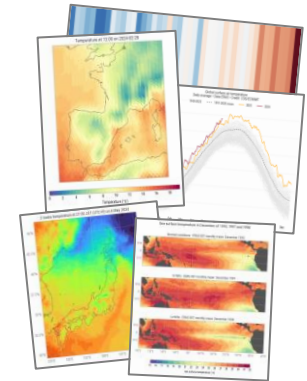
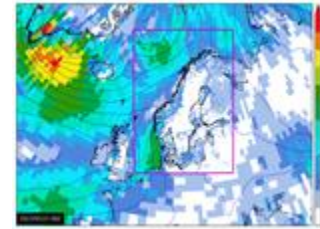
Deploy  
Anywhere

Easy to run

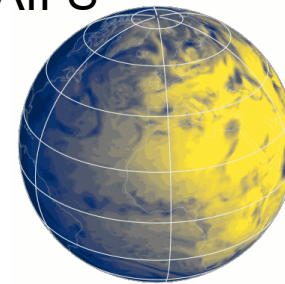
Choose your  
own model



BRIS



AIFS





# Chatbot: Digital Twin assistant

Tell me briefly what you can help me with.

I can assist you with the following:

### Accessing Climate and Weather Data

- Find environmental parameters (e.g., temperature, precipitation, salinity, wind speed, etc.).
- Retrieve and plot data for specific dates, regions, or global coverage from ECMWF's Destination Earth (DestinE) Digital Twins, including:
  - High-resolution global climate projections.
  - Historical climate simulations.
  - Weather and oceanographic data.

### Generating Data Requests

- Construct Polytope requests to fetch data for:
  - Maps (spatial plots for a specific date).
  - Time series (data over a period for a location).
  - Vertical profiles (atmospheric or oceanic data at different depths/altitudes).

### Answering Questions About DestinE

Provide context on:

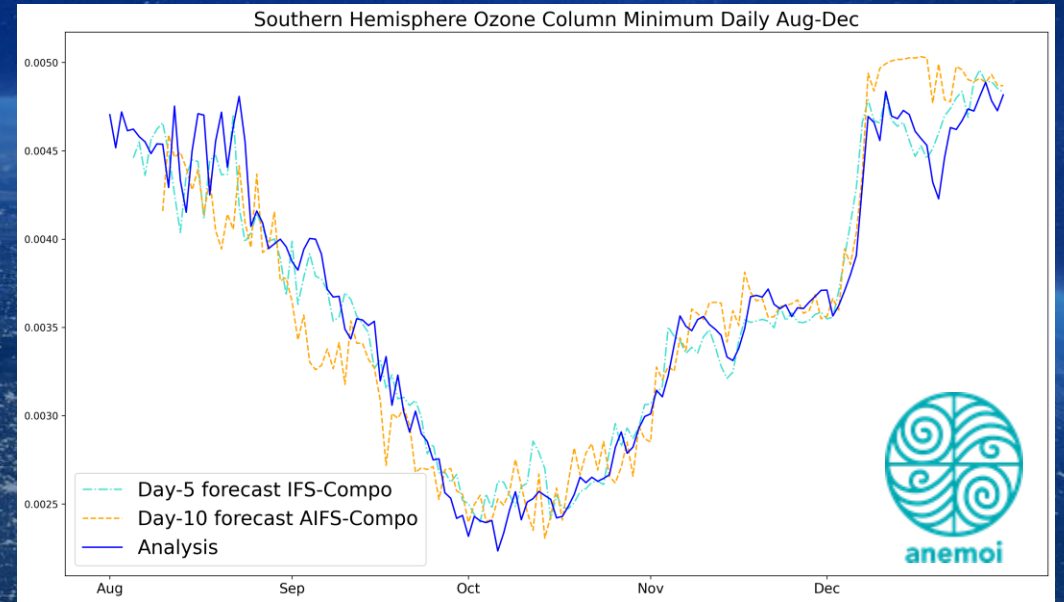
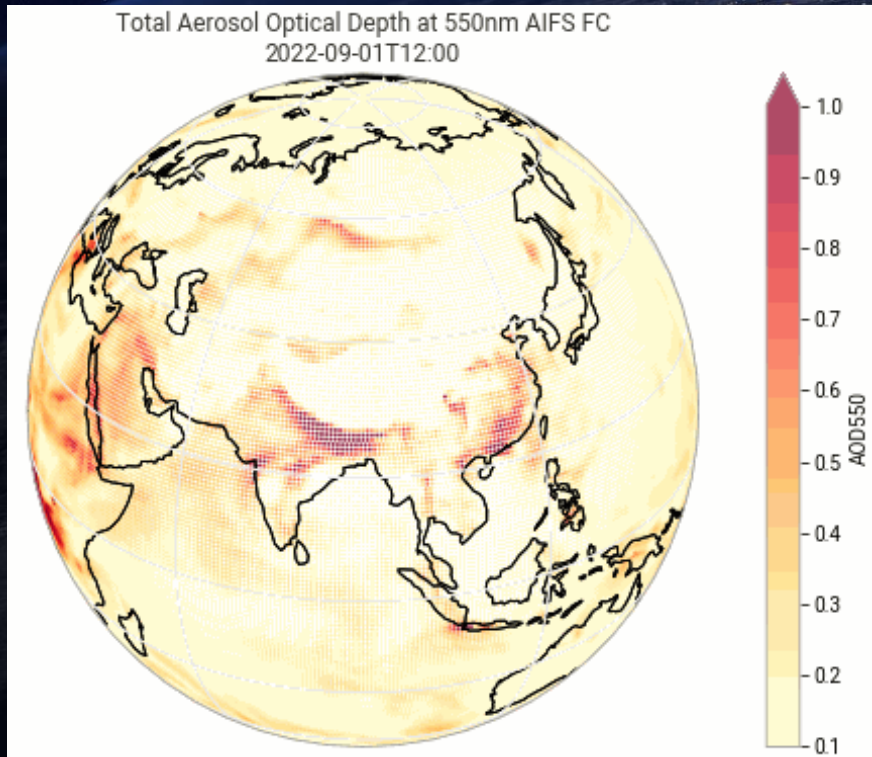
Ask about DestinE climate and weather data... >

development interface! a user-friendly web app is in the making





# Extending AIFS to Atmospheric Composition



Atmosphere Monitoring Service

[atmosphere.copernicus.eu](http://atmosphere.copernicus.eu)



# Regional climate model ML downscaling

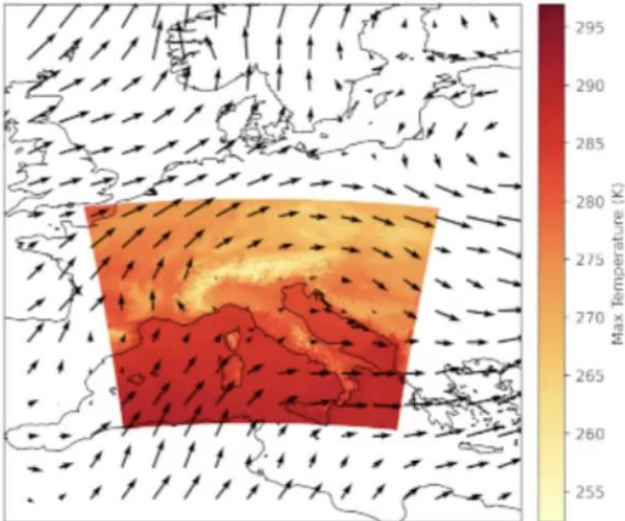
Leverage CORDEX regional climate datasets and downscaling to deliver enhanced regional uncertainty quantification



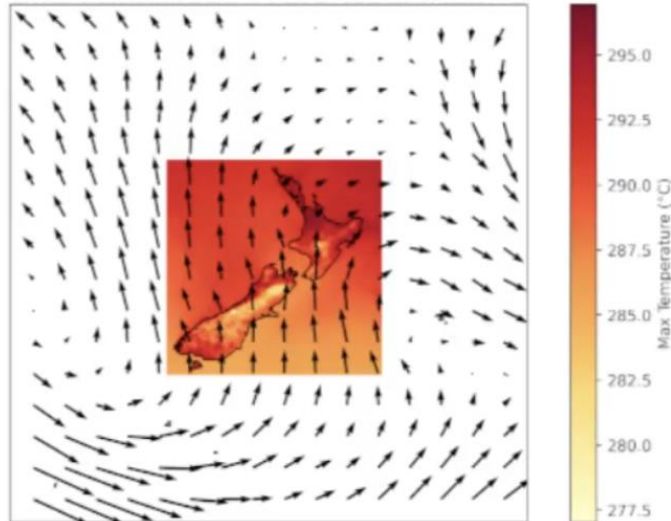
Climate Change Service

[climate.copernicus.eu](http://climate.copernicus.eu)

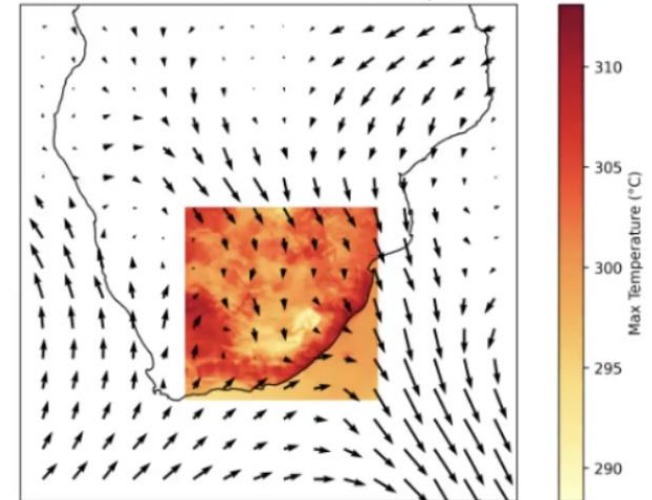
850 hPa Wind Vectors and Surface Max Temperature



850 hPa Wind Vectors and Surface Max Temperature

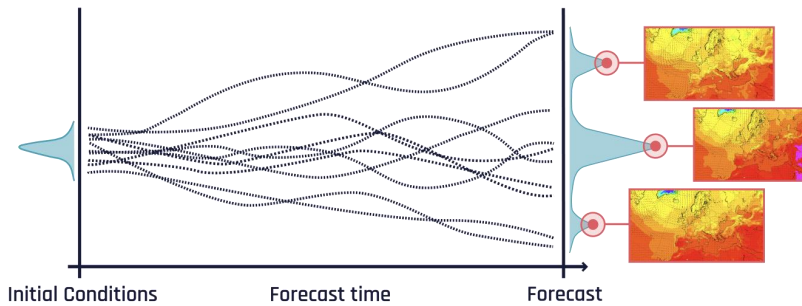


850 hPa Wind Vectors and Surface Max Temperature

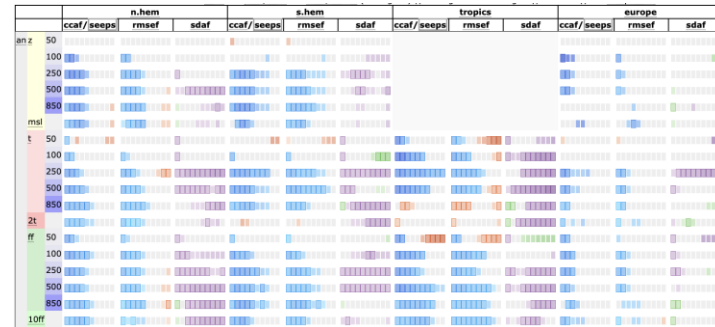


# How can we use AI in an operational setting?

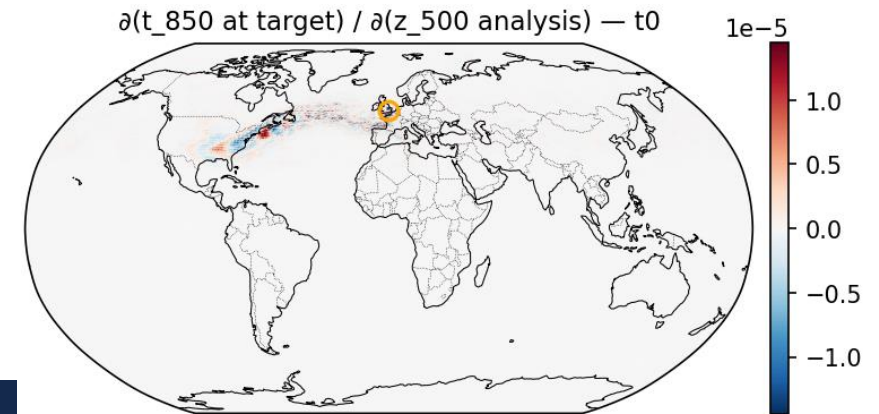
Robust uncertainty quantification



Extensive verification



Explainability



# Where next?



# ERA5: The Foundation of the AI Revolution



Climate  
Change Service

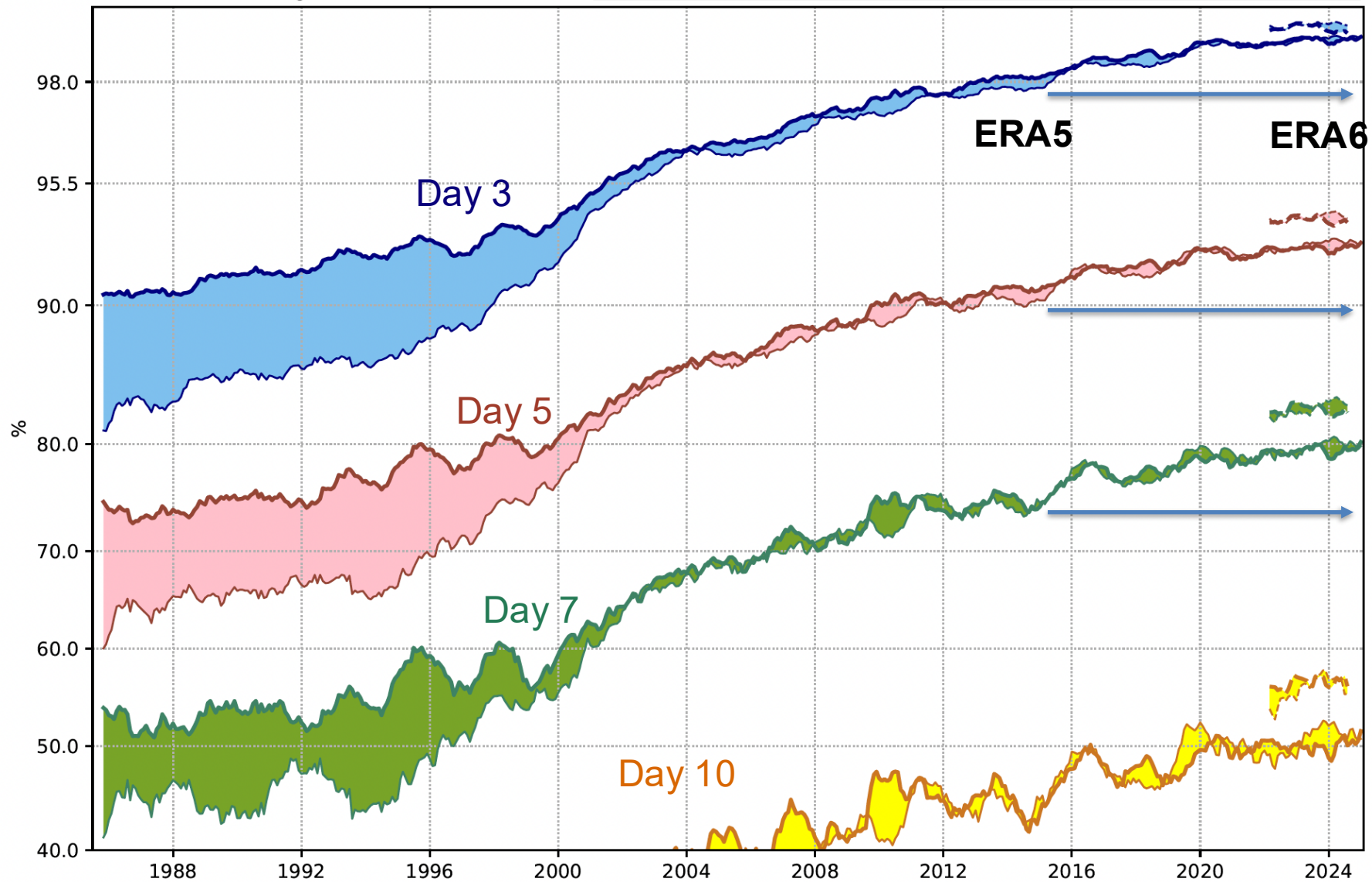
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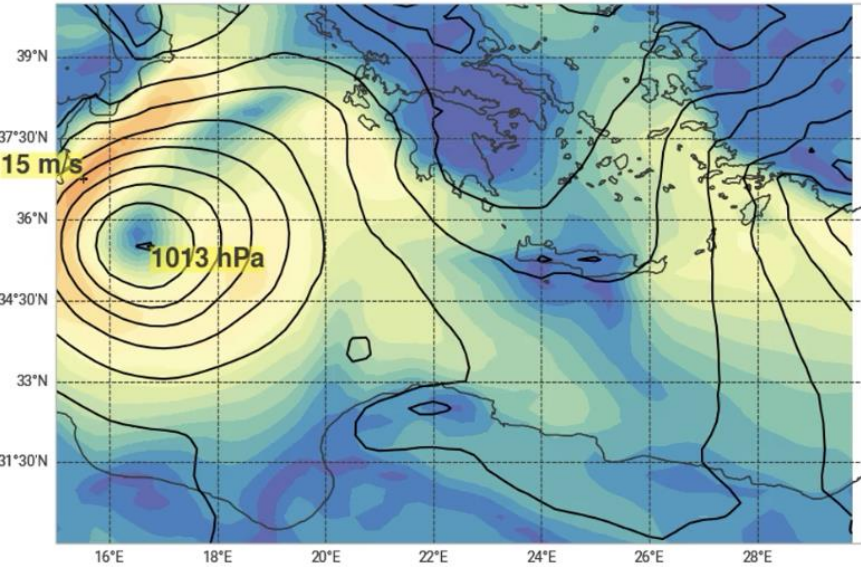
# A decade of investment in physics models



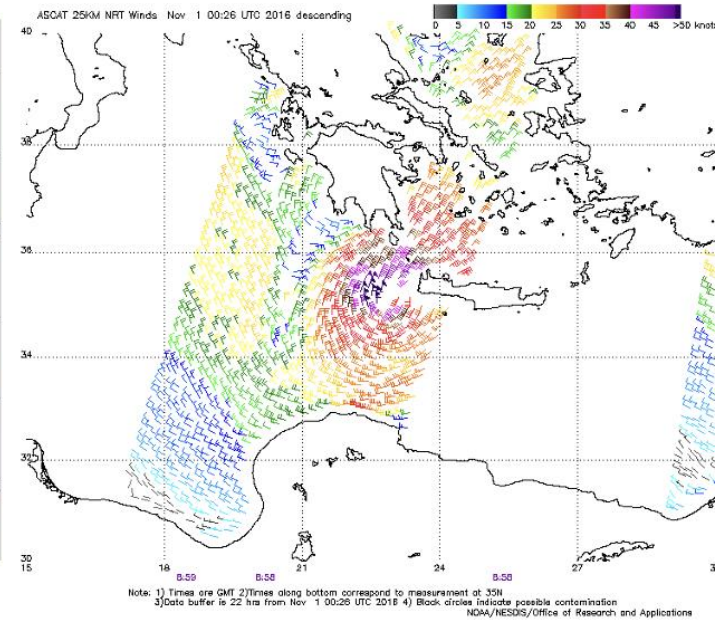
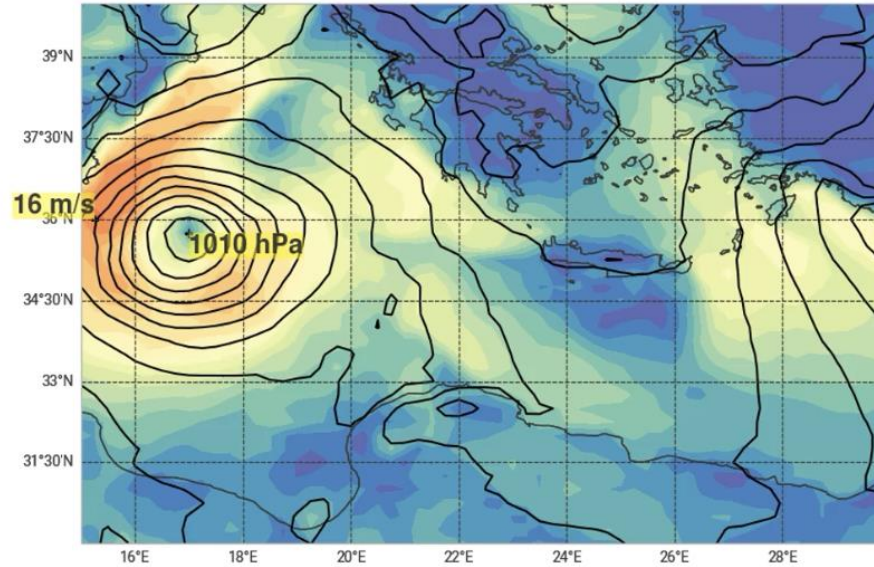


# From ERA5 to ERA6: Increasing Resolution

ERA5  
10m-Wind.Sp, MSLP  
valid on 2016-10-30 00 UTC



ERA6SpinUp  
10m-Wind.Sp, MSLP  
valid on 2016-10-30 00 UTC



ERA5 Horizontal resolution:  
31 km deterministic for atmos., 40 km for waves  
63 km 10-member ensemble

ERA6 Horizontal resolution:  
14 km deterministic  
28 km 11-member ensemble  
¼ deg (approx 25 km) ocean (initialized from ORAS6)

Source, for ASCAT wind map:  
<https://cimss.ssec.wisc.edu/satellite-blog/archives/22492>

## Strengthening Early Warning in Africa (SEWA)

Enhance hazardous weather warnings through Impact-based Forecasting pilots, better data access & cloud deployment and governance

Assess gaps and needs, foster use of Copernicus/Destine data, link with EW4All

Co-develop and co-design digital tools using cloud technologies

Downscale global AI models to regional needs



Creating sustained African ownership:  
Trainings  
Fellowships  
Knowledge Transfer

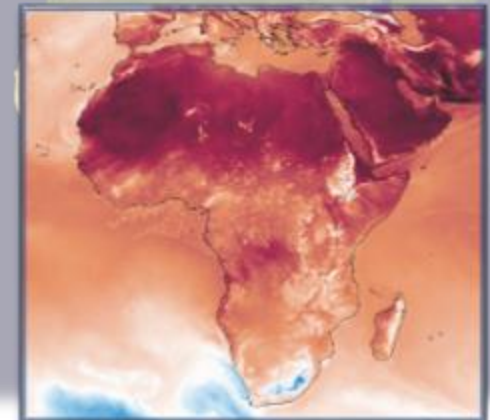
## African Regional Centers of Excellence (ArcX) on climate change resilience

Strengthen ArcX via capability development, innovation and AI-driven tools in support of climate change resilience.

Support capacity to observations AI ready

Use AI models to improve sub-seasonal to seasonal prediction

Foster use of Destine/ Copernicus through society relevant demo cases



## Neural networks as universal approximation systems

Given enough compute and data any relationship can be learnt.....

Europe will continue to lead in this space  
Through continued investment in:  
– Compute – Physics-based Systems – AI