Towards a data-driven Earth System Model
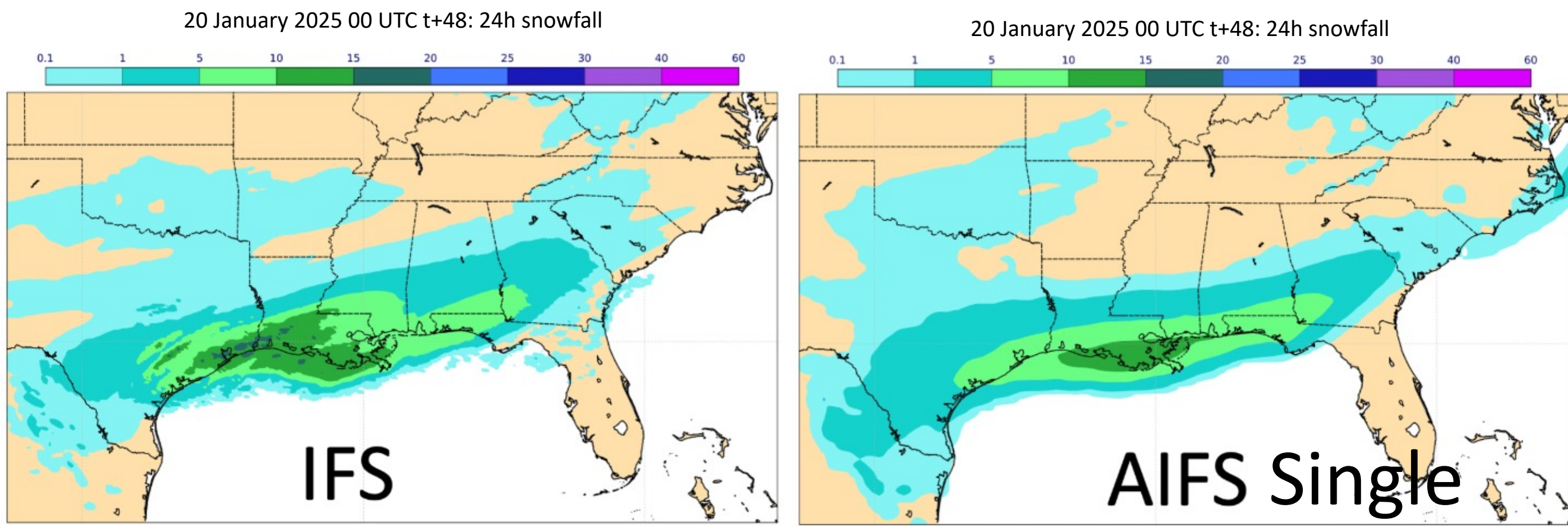
ECMWF

AIFS Single: First fully operational data-driven weather forecasting model
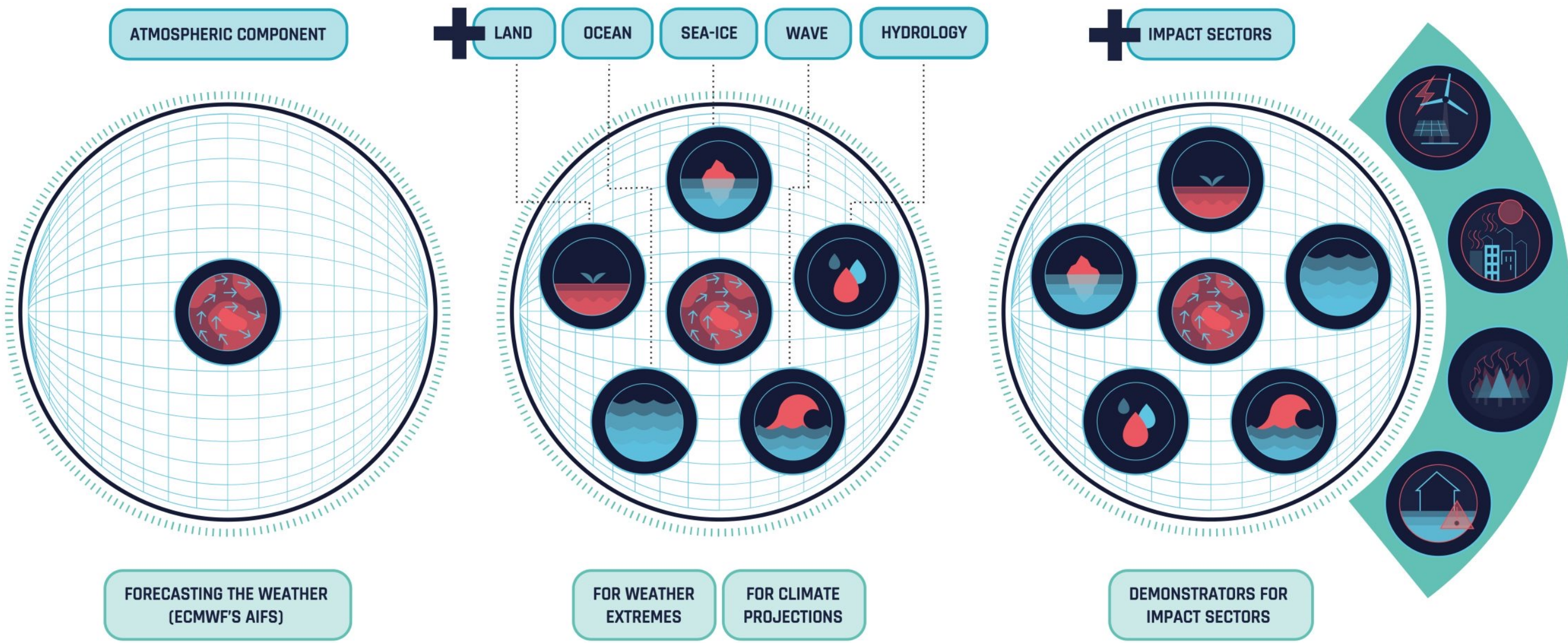
Input
Atmospheric state:
X(t), X(t-6h)

AIFS MODEL

encoder → processor → decoder

Output
Prediction:
X(t+6h)

Graph attention

Graph attention

Transformer blocks and windowed attention

OPERATIONAL AIFS SINGLE

Implemented in
anemoi

(see Lang et al. 2024)
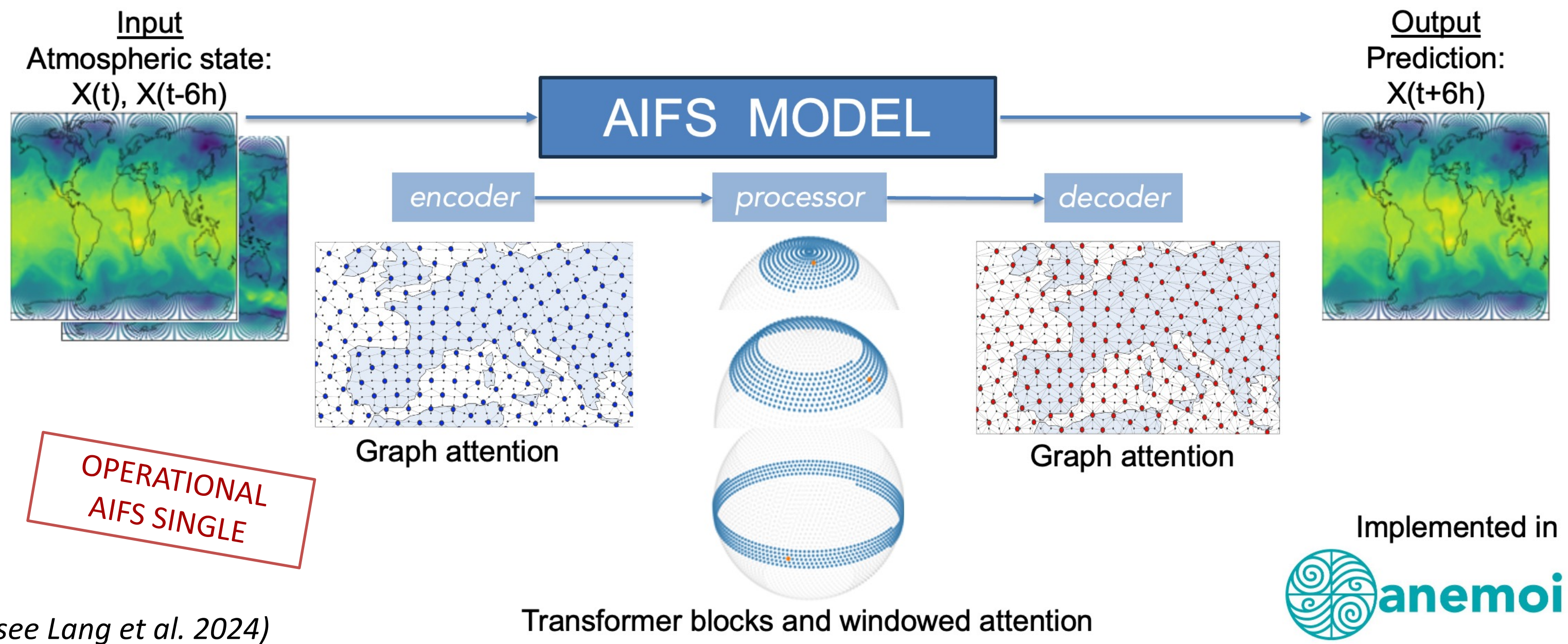
Verification of AIFS Single against IFS: Extreme Event

2-day forecast of rare snow along the Gulf Coast

20 January 2025 00 UTC t+48: 24h snowfall

IFS

AIFS Single

A full Earth System Model

ATMOSPHERIC COMPONENT

LAND   OCEAN   SEA-ICE   WAVE   HYDROLOGY

IMPACT SECTORS

FORECASTING THE WEATHER (ECMWF'S AIFS)

FOR WEATHER EXTREMES   FOR CLIMATE PROJECTIONS

DEMONSTRATORS FOR IMPACT SECTORS

As part of **Destination Earth** – the ambitious initiative of the European Commission to create digital twins of our planet - ECMWF and its partners aim to expand the AIFS framework to **all components of the Earth System**, including land, ocean, sea ice, waves and hydrology.

Land component represented in operational AIFS Single

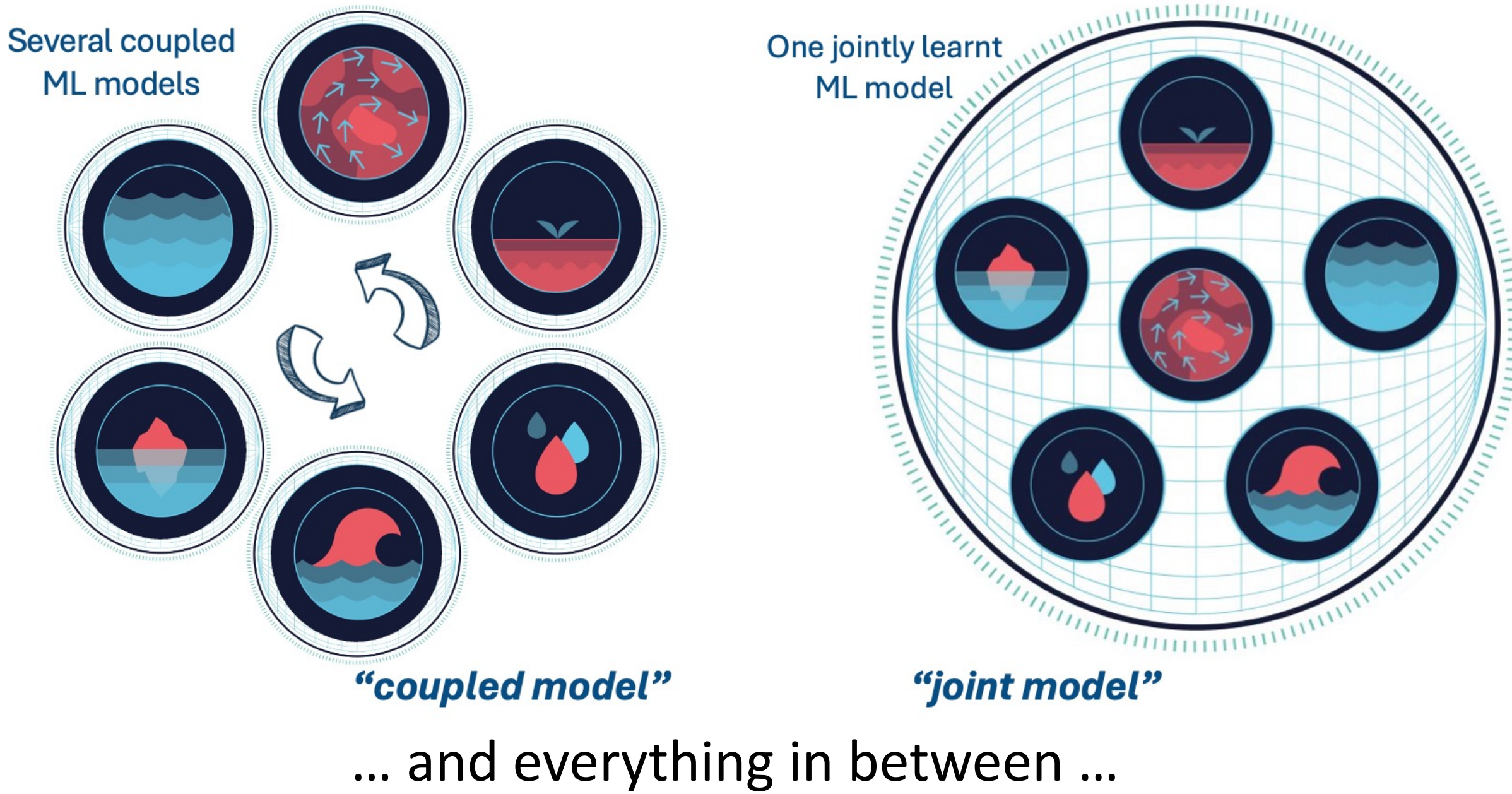*Land variables directly learnt as part of the AIFS Single! → joint model*

- Solar radiation ☀️
- 100m winds 🌬️
- Snow fall ❄️
- Soil moisture 💦
- Soil temperature 🌡️
- Runoff 💧
- Cloud cover ☁️

Soon:
- Snow depth ❄️
- Snow cover ❄️

4-day forecast of soil temperature level 1

Destination Earth blog
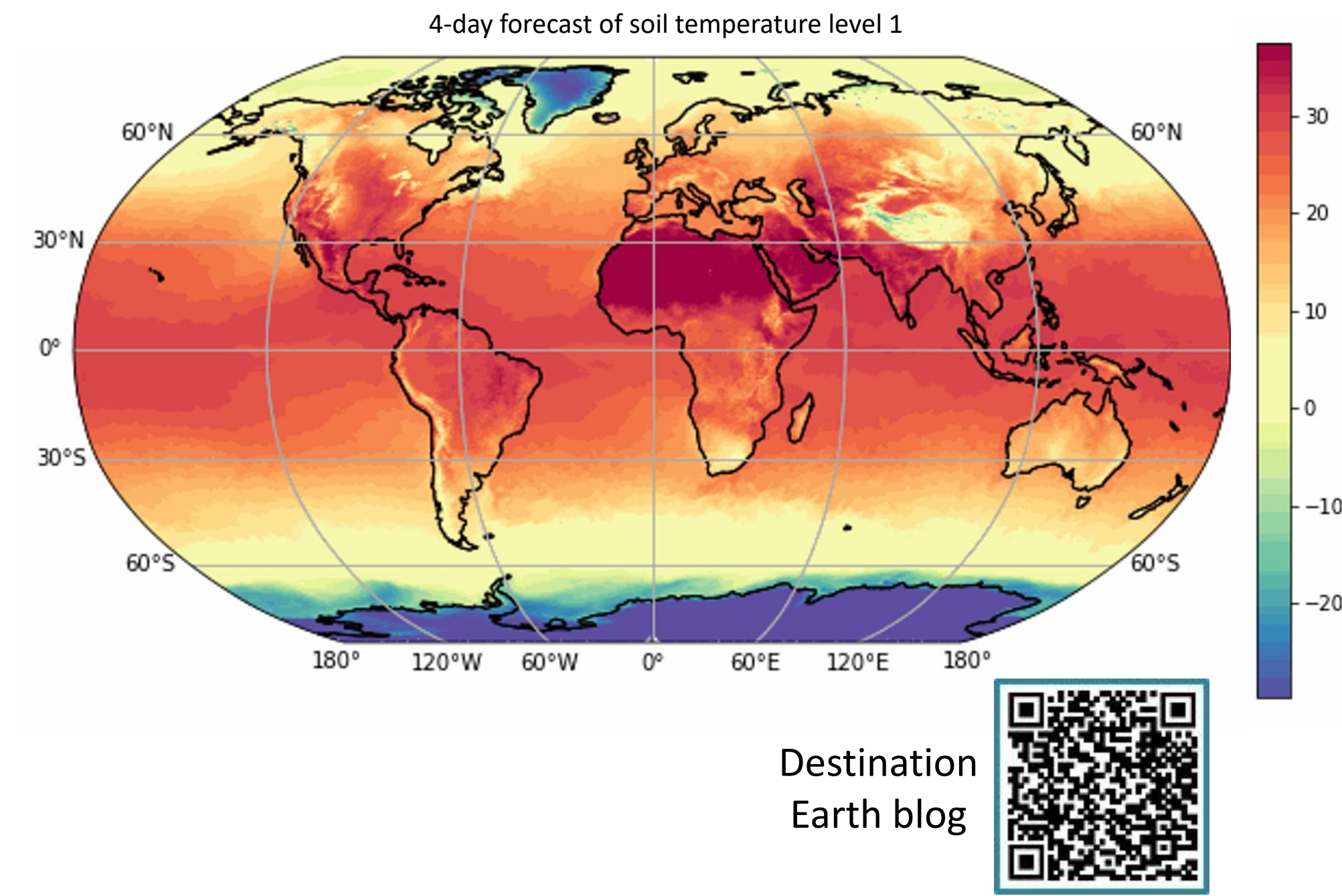
Coupling data-driven models

Which coupling strategy for earth system components in the AIFS framework?

Several coupled ML models

One jointly learnt ML model

"coupled model"   *"joint model"*

... and everything in between ...

Joint atmosphere-wave model

Add wave variables to the atmospheric AIFS Single

Improve significant wave height forecast accuracy by 10% at medium-range timescales in comparison to operational wave forecasts

Northern Hemisphere Significant Wave Height

Standard deviation of forecast error
June – August 2023

Operational ecWAM

AIFS Single + waves

Forecast Day

(the lower the better)
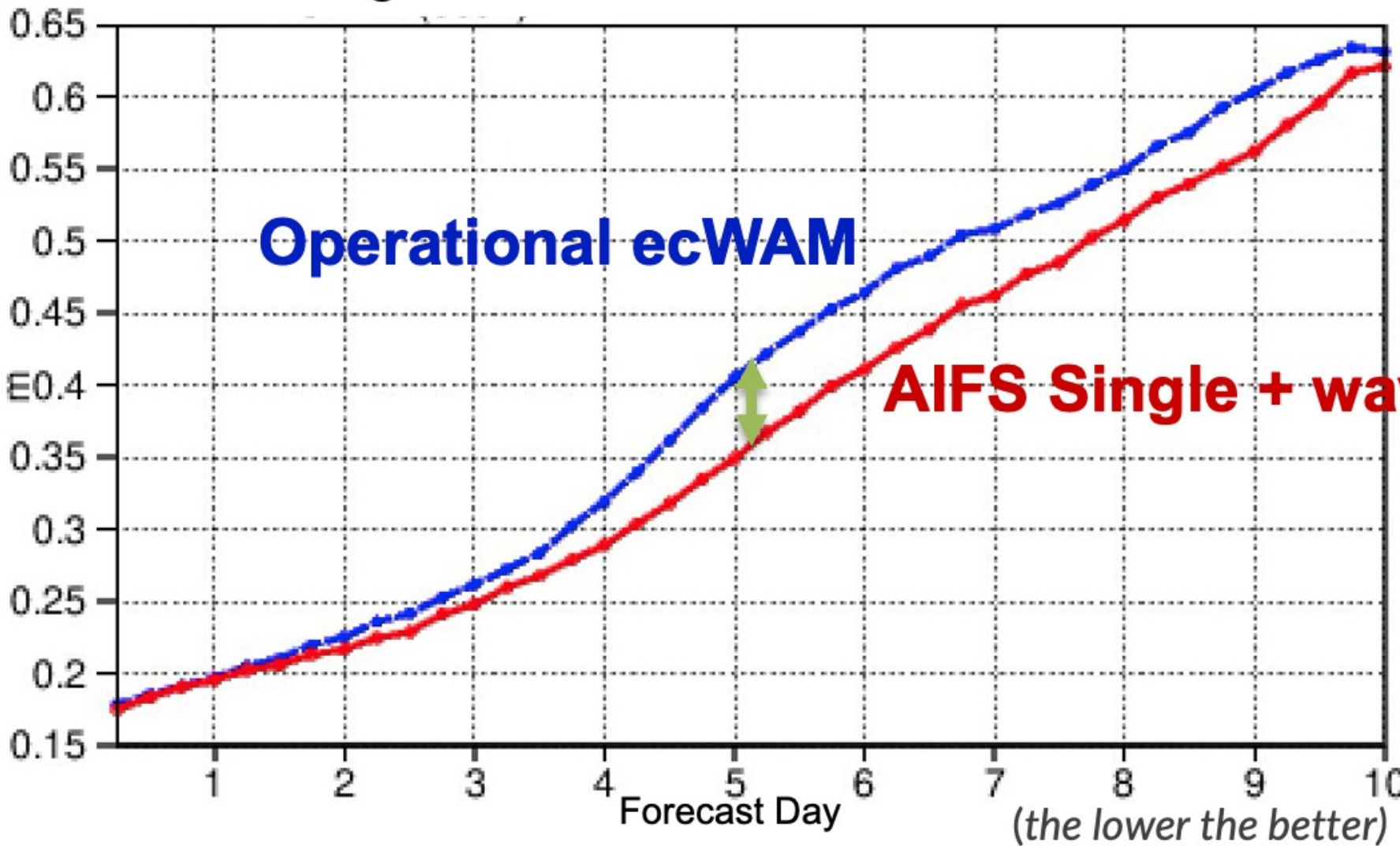
Wave **Blog Post** with more details and animations
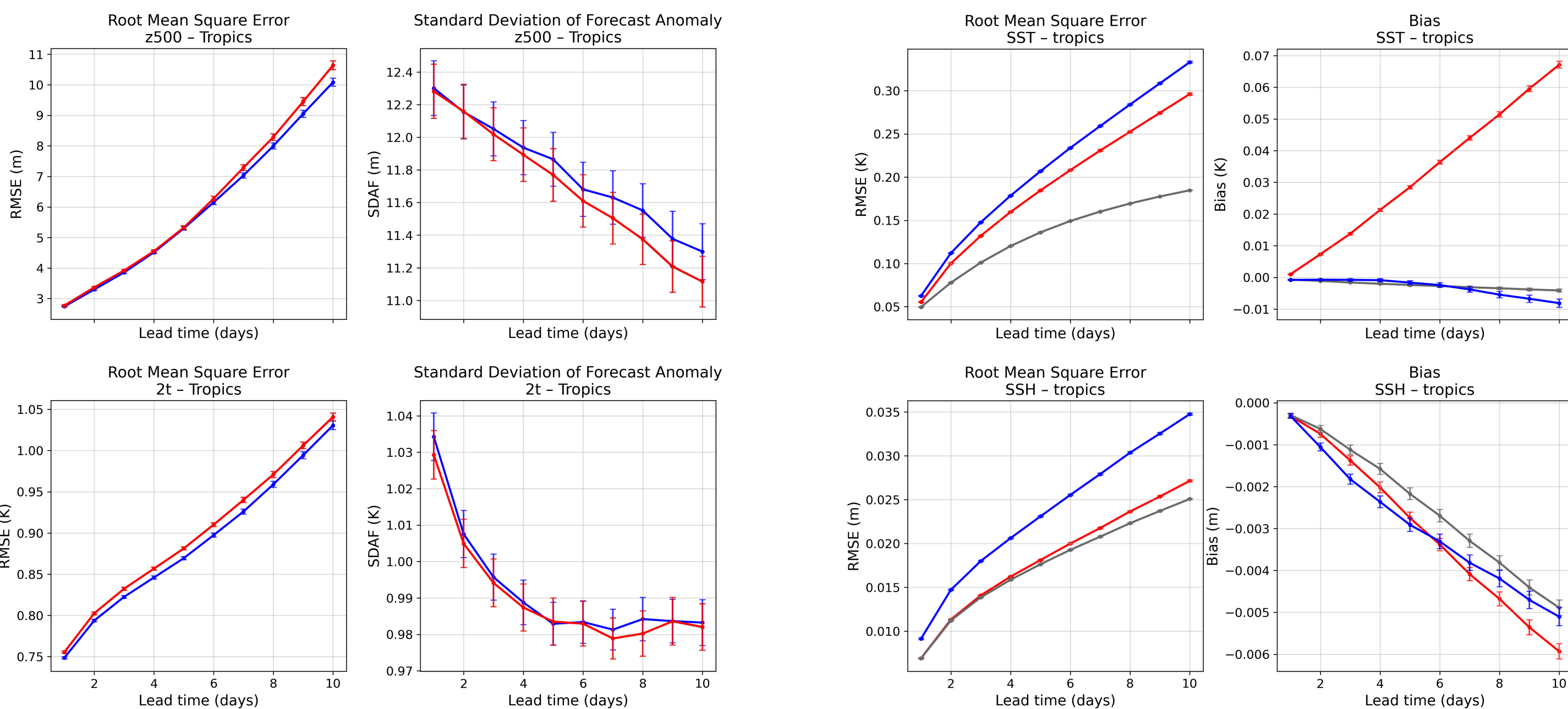
Ocean-atmosphere model: coupled vs joint model

Coupling of components inspired by traditional modelling

ATMOSPHERIC Perspective

OCEAN Perspective

Root Mean Square Error
z500 – Tropics

Standard Deviation of Forecast Anomaly
z500 – Tropics

Root Mean Square Error
SST – tropics

Bias
SST – tropics

Root Mean Square Error
2t – Tropics

Standard Deviation of Forecast Anomaly
2t – Tropics

Root Mean Square Error
SSH – tropics

Bias
SSH – tropics

Experiment Configuration :

— Atmosphere (786) + ocean (512), **coupled model** — 174 forecasts
— Atmosphere (786) **forced model** — 174 forecasts
— Atmosphere + ocean (1024), **joint model** — 174 forecasts

Coupling timestep : 6h (also the forecast timestep)
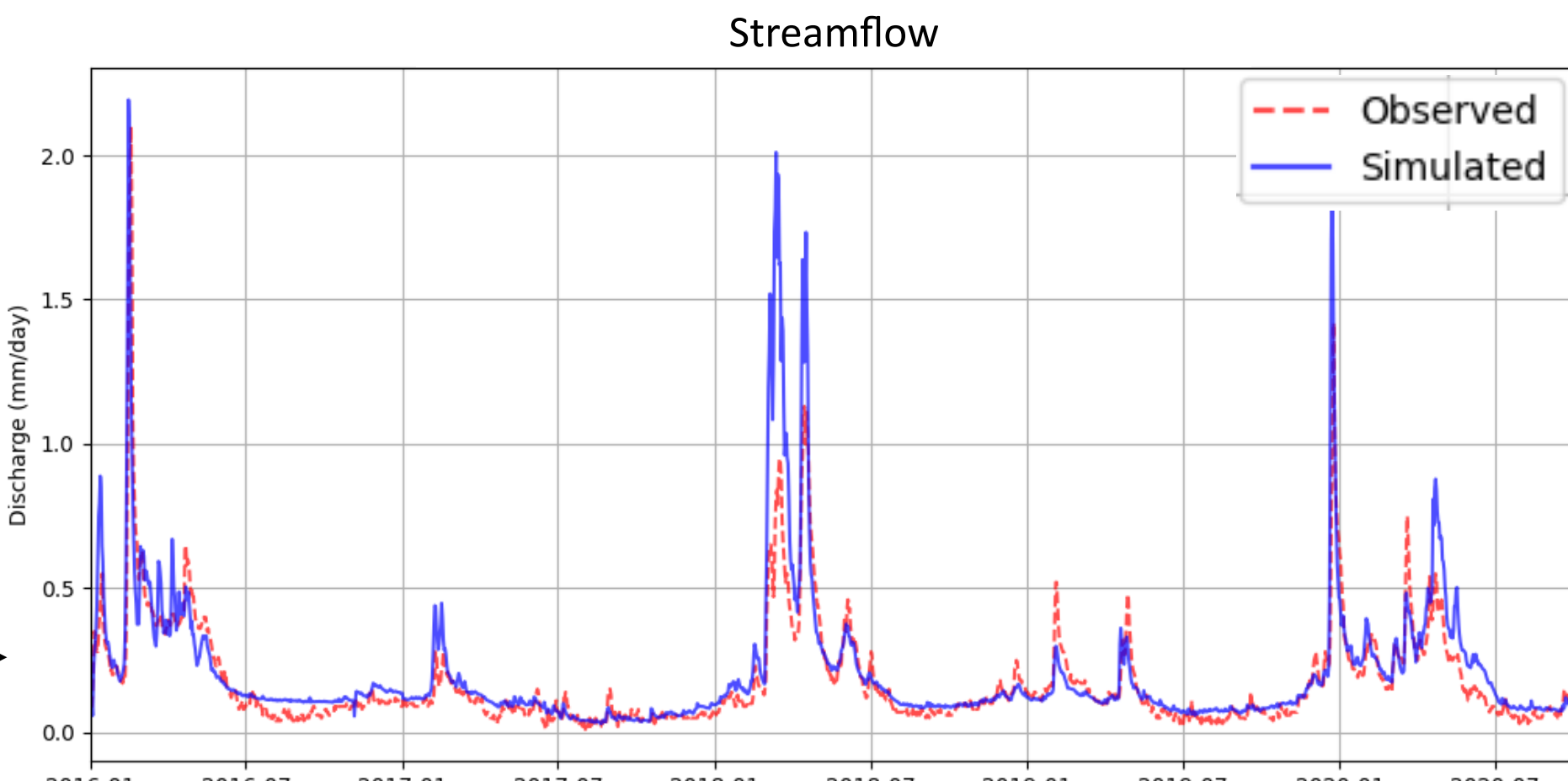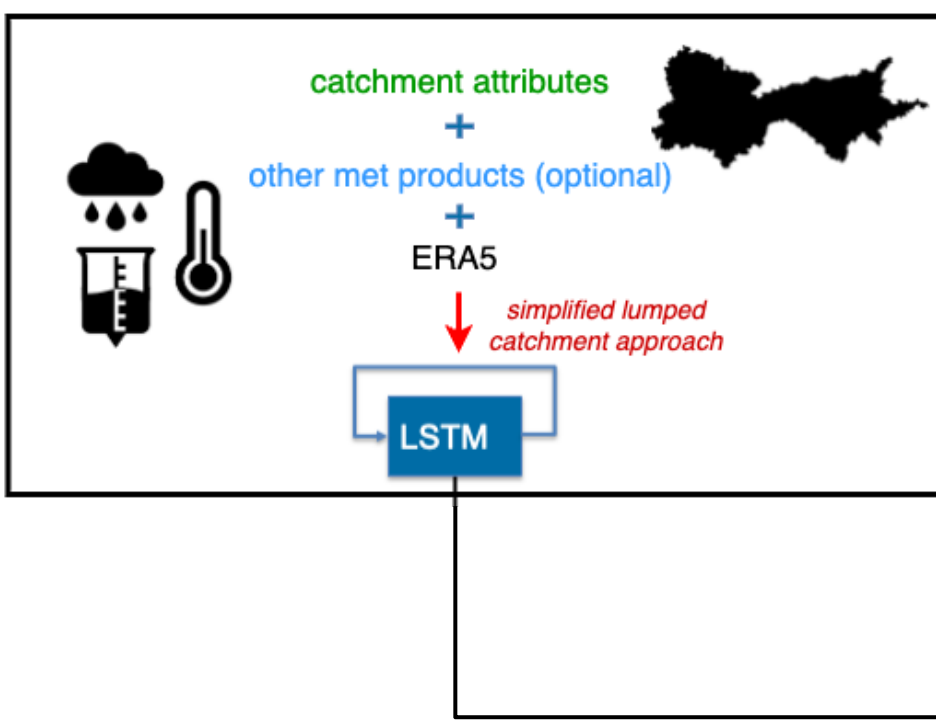**Verification year :** 2023

Key References

- Lang, S., Alexe, M., Chantry, M., Dramsch, J., Pinault, F., Raoult, B., Clare, M. C. A., Lessig, C., Maier-Gerber, M., Magnusson, L., Ben Bouallègue, Z., Prieto Nemesio, A., Dueben, P. D., Brown, A., Pappenberger, F., & Rabier, F. **(2024a)**. AIFS: ECMWF's data-driven forecasting system. *arXiv preprint*. Retrieved from https://arxiv.org/abs/2406.01465

Hydrology: Towards ECMWF's data-driven flood forecasting system

LSTM-based time series model trained on global daily streamflow observations, meteorological reanalysis, and forecasts.

Destination Earth blog

catchment attributes
+
other met products (optional)
+
ERA5
simplified lumped catchment approach
LSTM

Streamflow

--- Observed
— Simulated