Research Updates at ECMWF

With contributions from the Research & Forecast Department

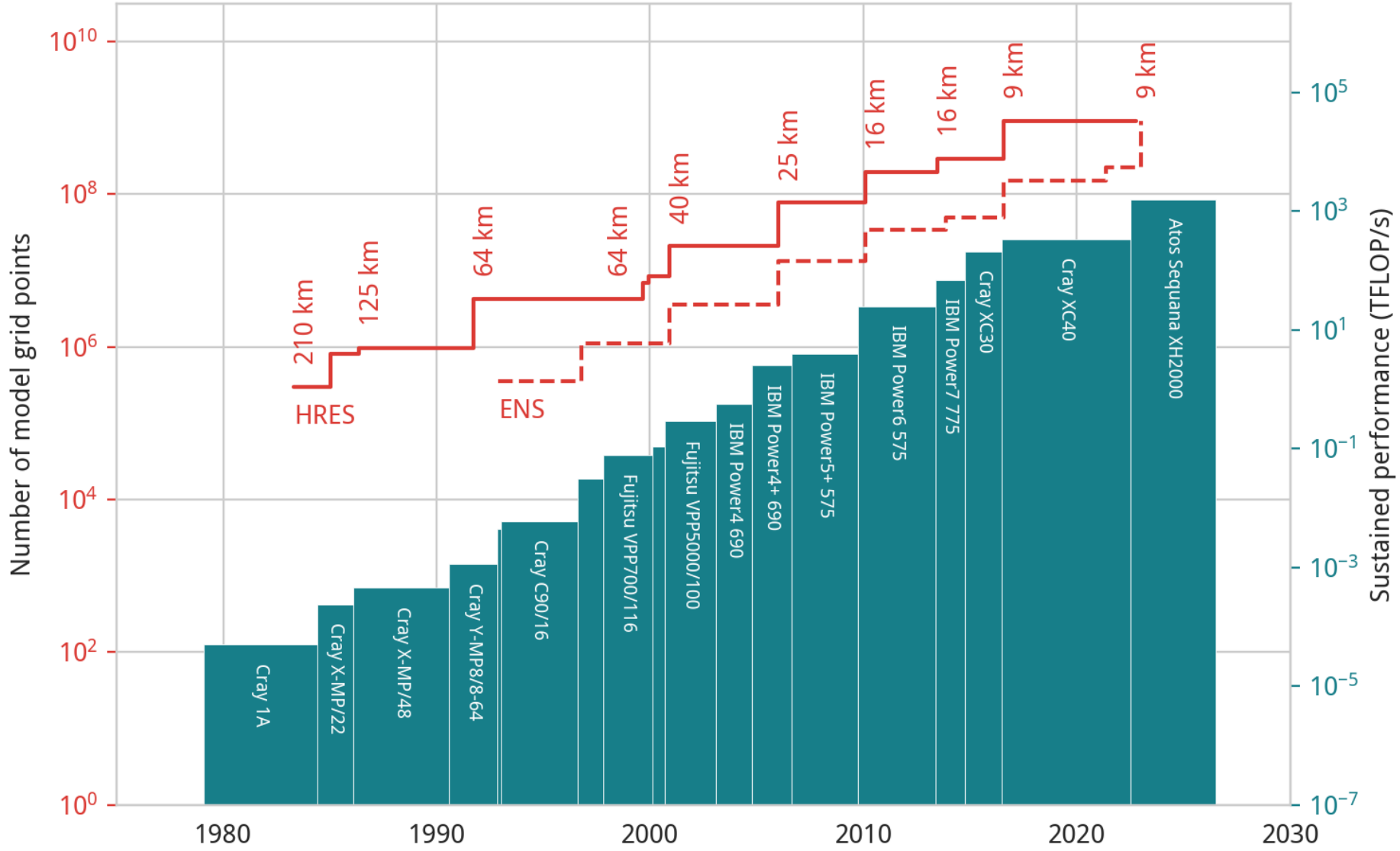
Nils Wedi & Peter Dueben

The strength of a common goal

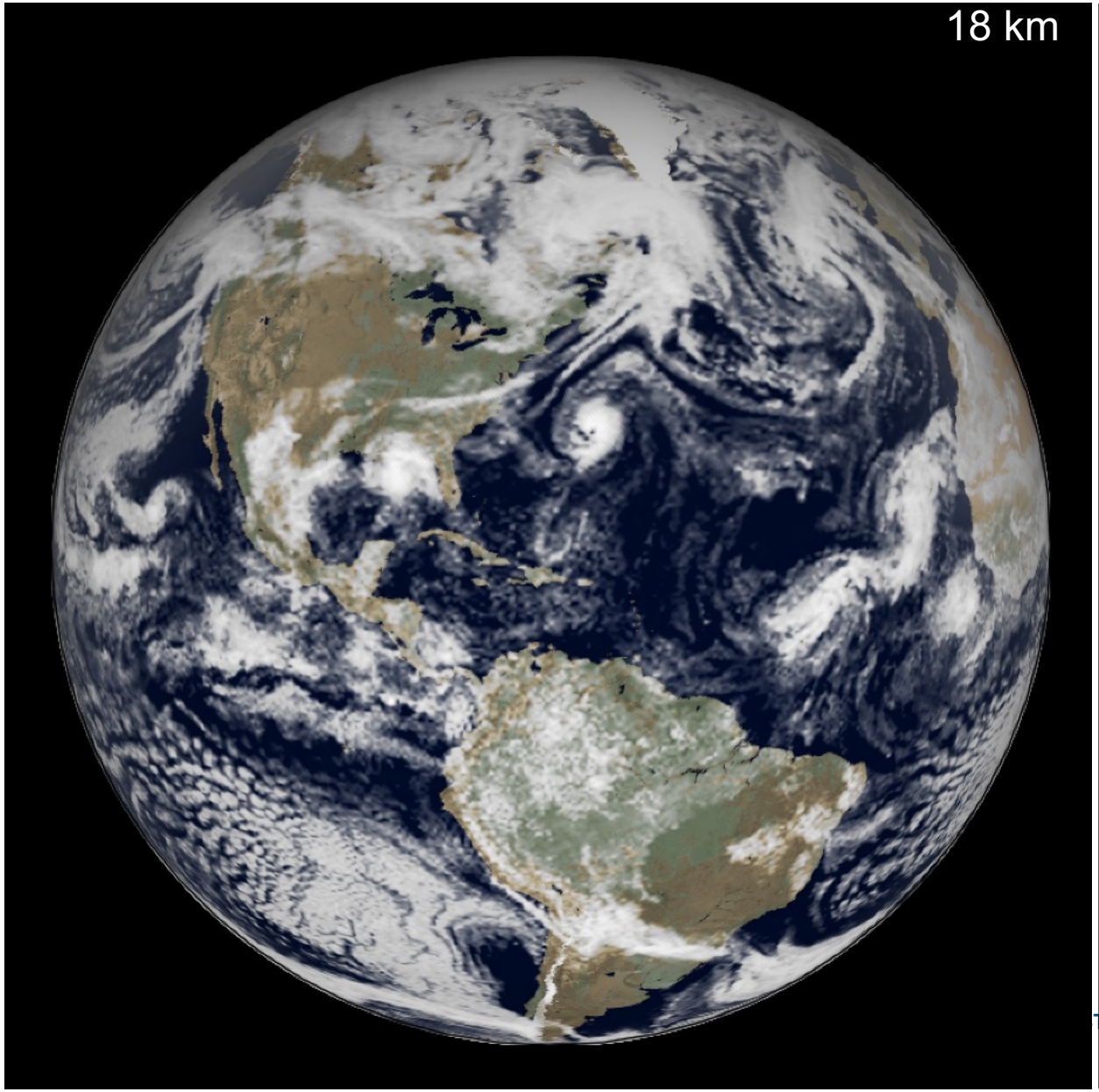
IFS Cycle 48r1

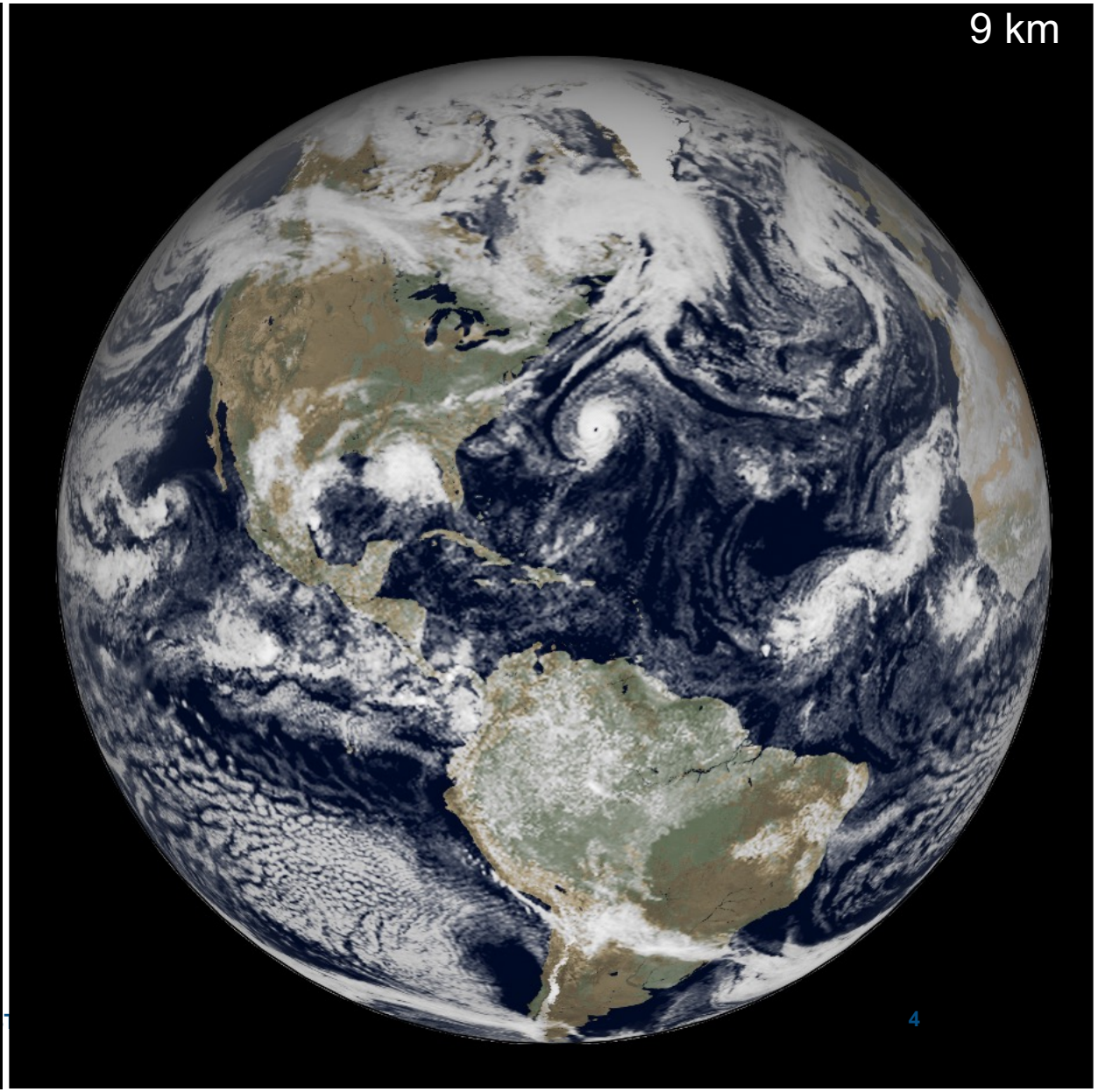
Implemented in June 2023

Evolution of HRES and ENS



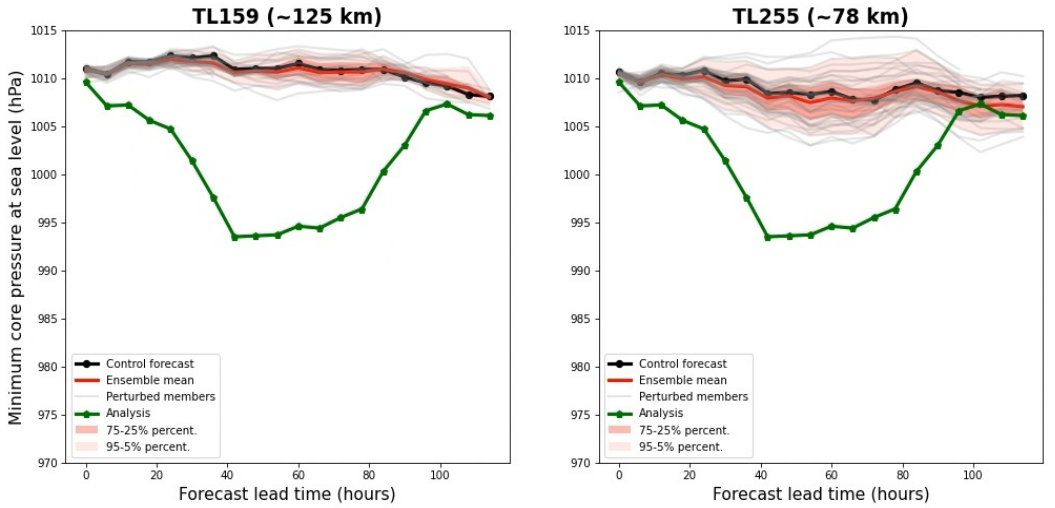
Medium range ensemble : 18 km to 9 km (same as HRES)
Extended range ensemble : 50+1 members twice weekly to 100+1 members every day

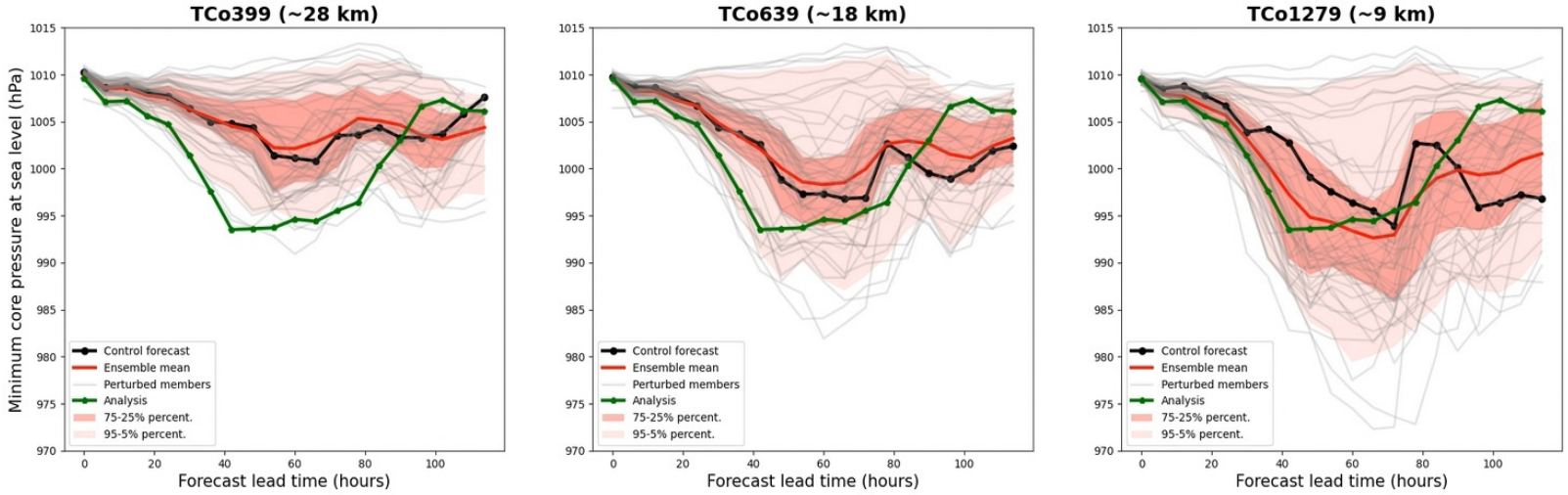




Resolution matters: Core pressure at sea level for Medicane Ianos

- Ensemble prediction systems of older generations (~ 20 years ago) would have been unable to predict this event
- Current (9 km) operational ensemble resolutions can reasonably predict the intensity of the medicane

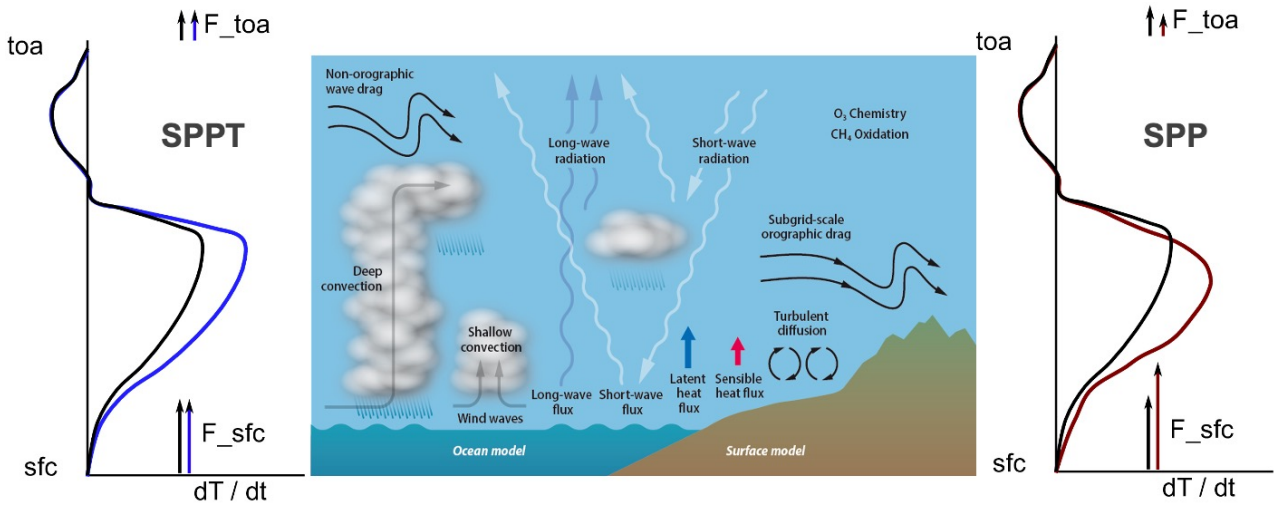




Special thanks to Aristofanis Tsiringakis

SPP replacing SPPT in future upgrade of ensemble system

- A multiyear effort with milestones documented in Ollinaho et al (2017), Leutbecher et al (2017), Lang et al (2021)
- Further developments over the last year to get also good results for extended-range and seasonal forecasts
- Extensive testing of the impact of the switch from SPPT to SPP with CY48R1 on medium-range, extended-range and seasonal ensembles as well as EDA and km-scale extreme cases



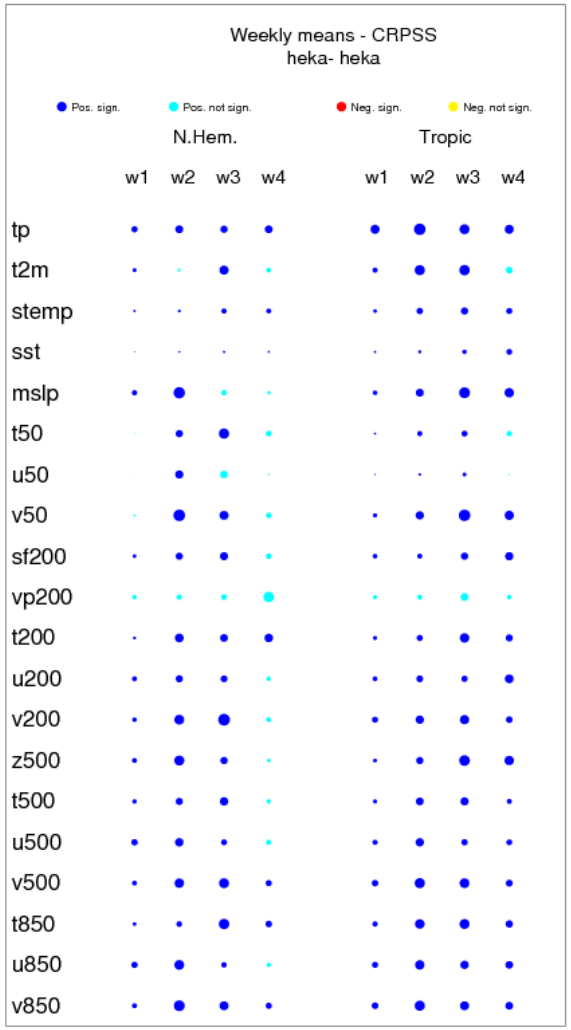
perturbations close to sources of errors

local conservation

consistent flux perturbations

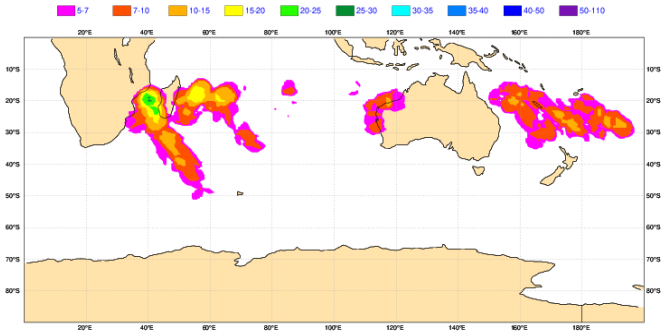
Change to extended-range forecast configuration in 48r1

Impact of increase of ensemble size

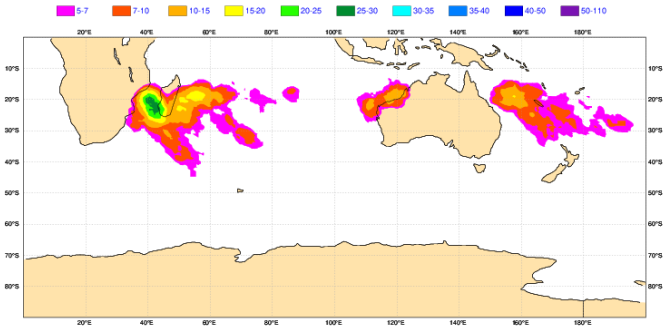


Tropical storm strike probability week 4 forecast
Start date:7/1/2021 – verification 1-7 Feb. 2021

50+1 members

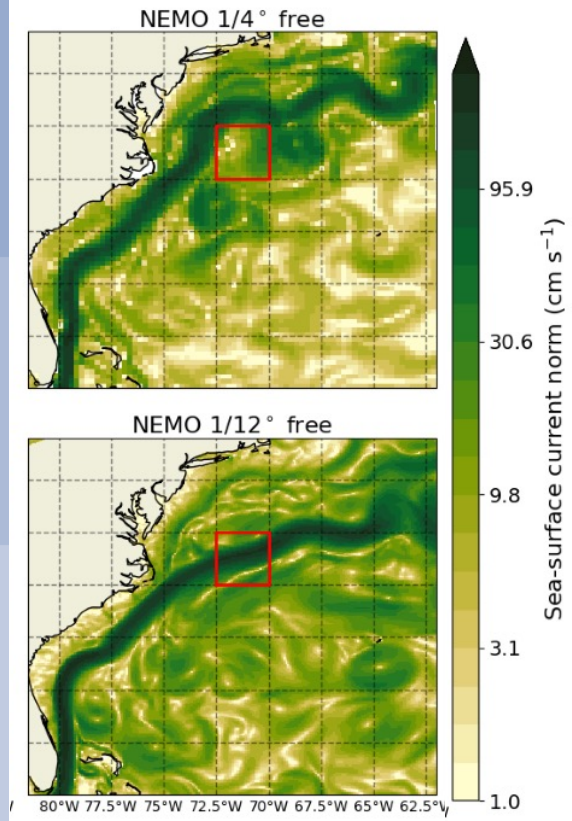


100+1 members

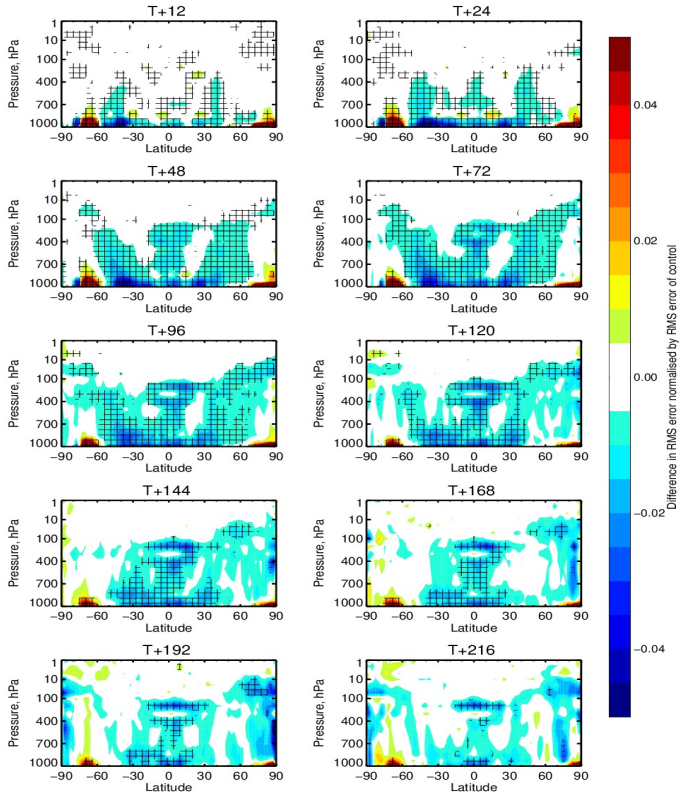


Progress with new ocean model NEMO4-SI3

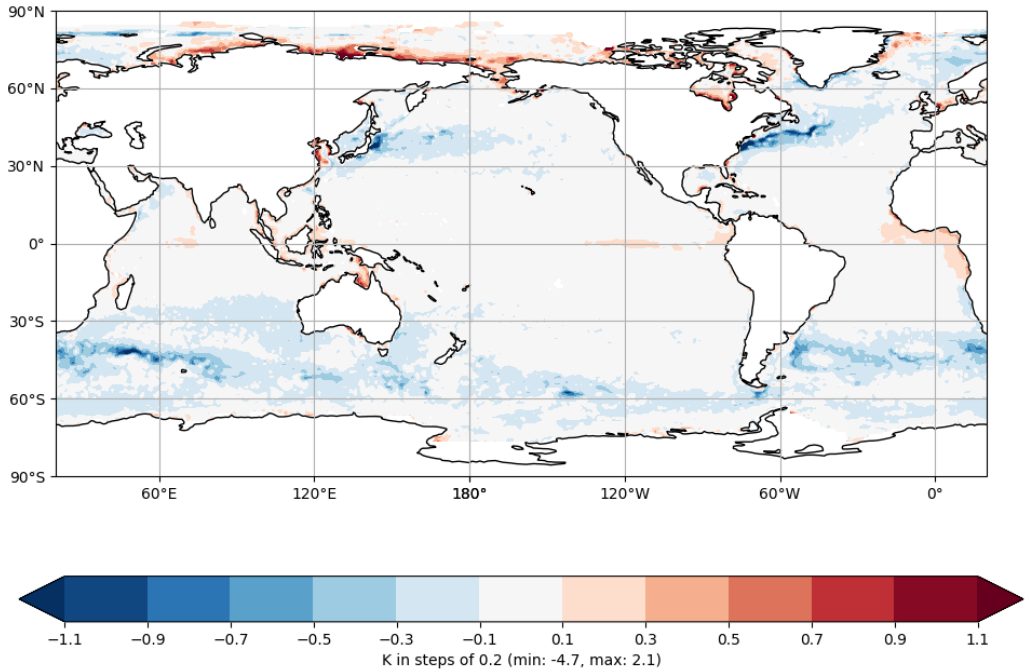
- Updated ocean and multicategory sea ice model for:
  - coupled NWP; ocean analysis (reanalysis)
  - reduced rmse (blue) with improved representation of Gulf Stream and Southern Ocean
  - more responsive sea ice model – winter improved, summer melt in Arctic is too rapid
- Ongoing testing for all forecast systems
- Preparations for 1/12°



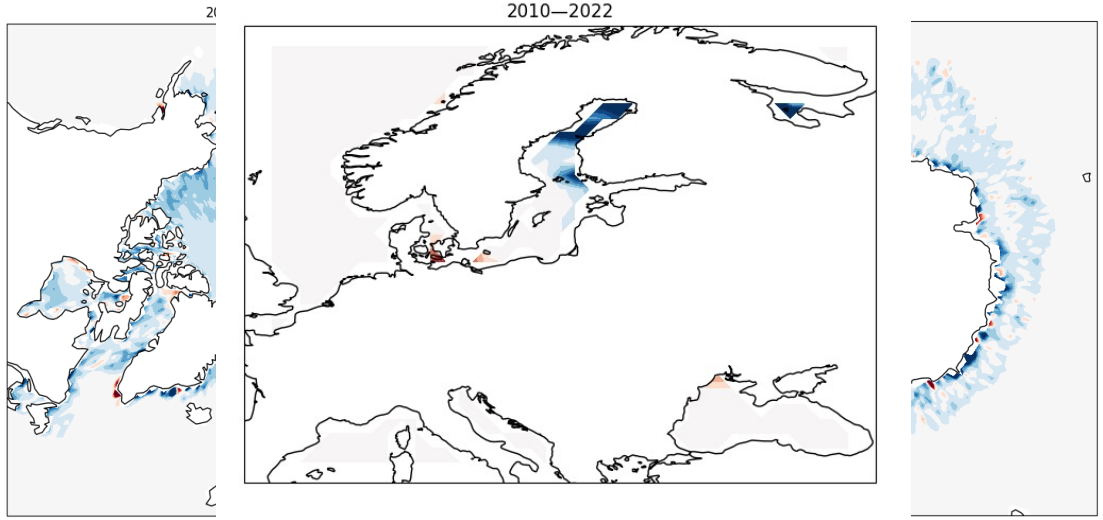
Change in RMS error T (NEMO4 – NEMO3.4)
Verified against ERA5



Change in RMS error SST (NEMO4 – NEMO3.4)
Verified against esa cci SST



Change in RMS error sea ice conc (NEMO4 – NEMO3.4)
Verified against osisaf cdr siconc



Ocean initialisation: addressing context-depending needs

Charles Pelletier & Chris Roberts

NWP/forecasting:

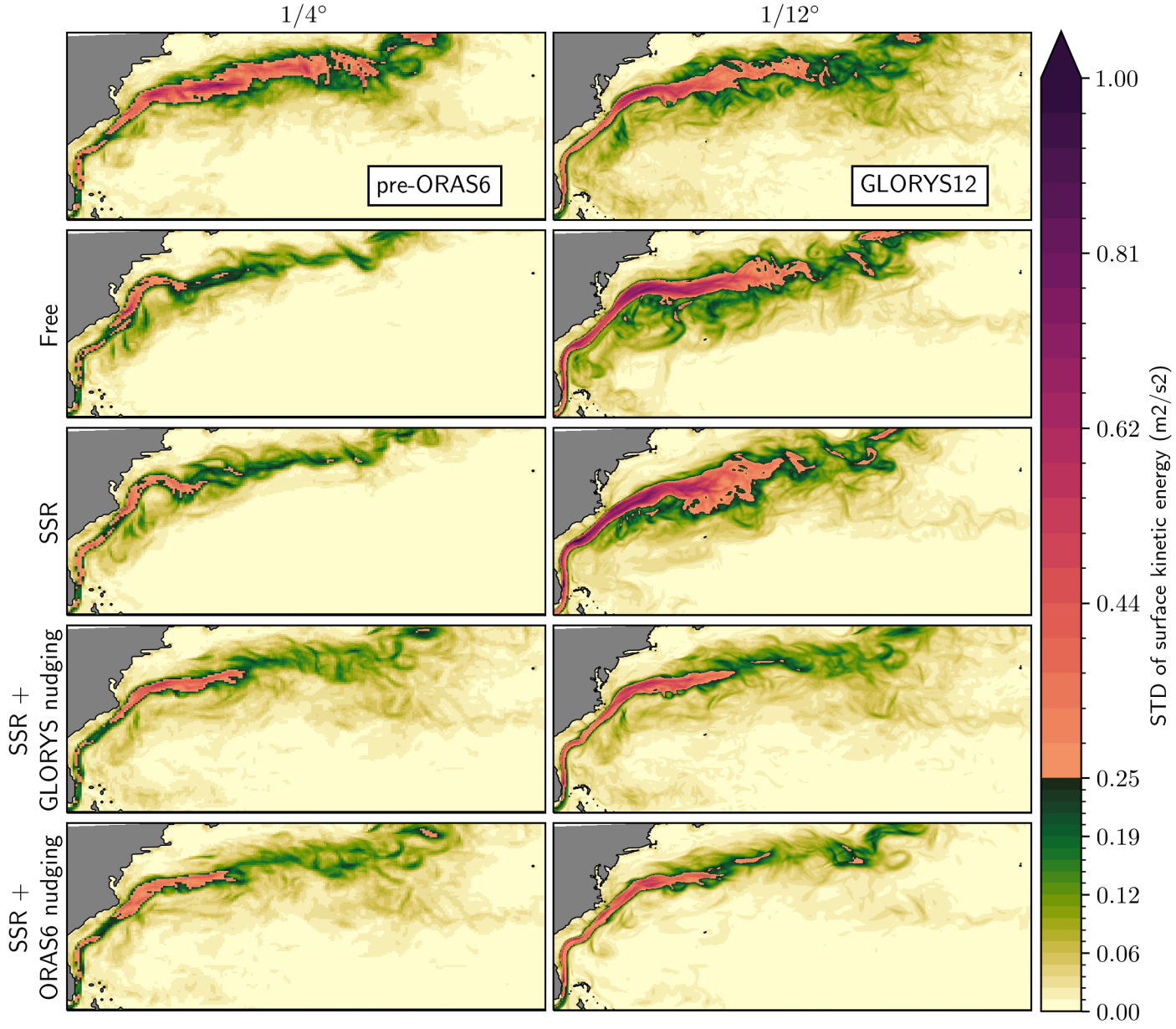
- The objective is to be as **close to "true" ocean state** as possible.
- **Ocean data assimilation** targets optimal fusion of model and data constraints, which may require compromise between realism (observations constraining the state) and balance between model physics-dynamics, leading to comprehensive model state (full restart).
- Ocean spin-up can be reasonably **ignored** for short- to medium-range (up to 2 weeks).
- For longer lead times (e.g., subseasonal up to decadal), reforecasts can be used for **model recalibration** or **bias correction**.

Climate:

- The challenge is to **separate signal** (i.e. response to forcings) **from drift/noise**. Emphasis on **stability** and having a model state that is close to equilibrium.
- The development and stabilisation of model biases (a.k.a. "drift") depends on the variable of interest and physical processes involved. Adjustment times in deep ocean can be **centuries**.
- **Computationally prohibitive** for high-resolution long integrations.
- An alternative is separating signal from model drift in **outputs**, but this depends on diagnostic-specific character of signal/drift/noise and the **linearity (or lack thereof) of the response**, which is difficult to assess.

Plans on ocean high-res initialisation

Context: 1/12º ocean (NEMO) initialisation using nudging as a substitute for DA.

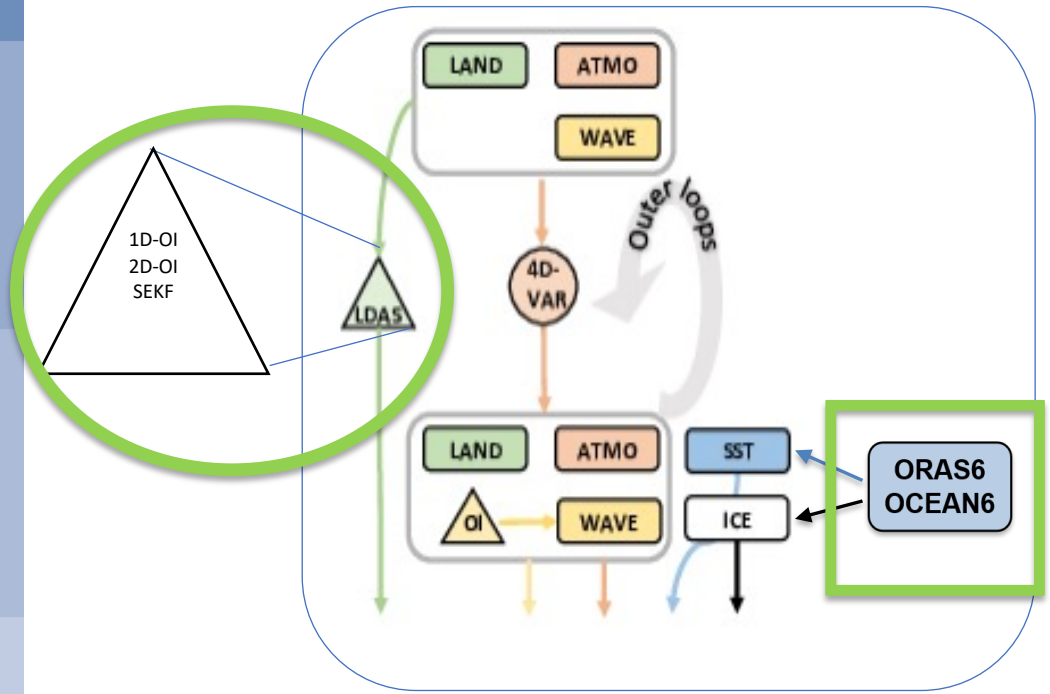


ECMWF coupled data assimilation

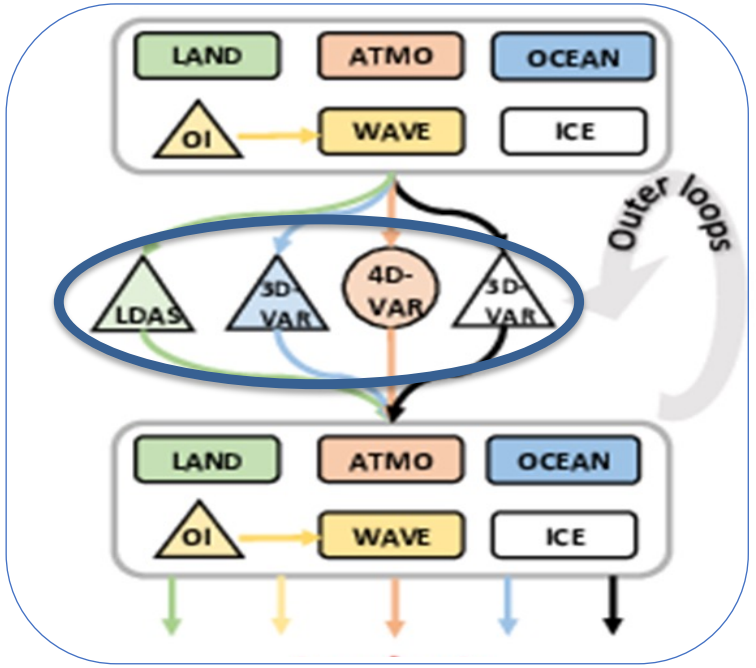
Funded by the European Union

Weakly coupled data assimilation for
- Land-atmosphere-waves (ERA5)
- Land-atmosphere-waves-ocean-sea ice (NWP & ERA6)

Enhanced outer coupled data assimilation for
- Land-atmosphere-waves-ocean-sea ice
→ future NWP and ERA7

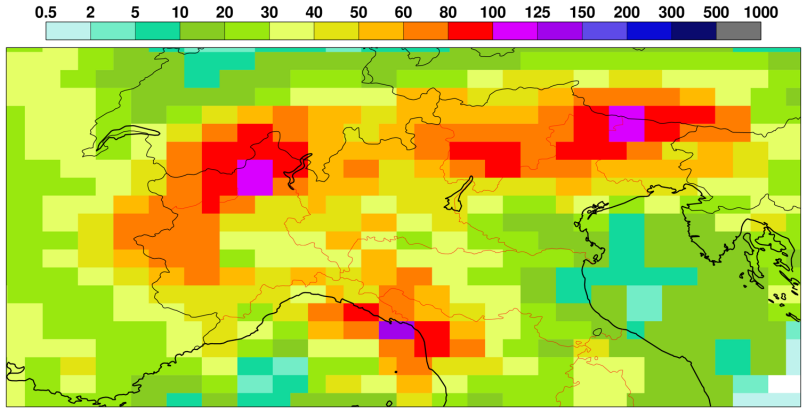


Current → Future

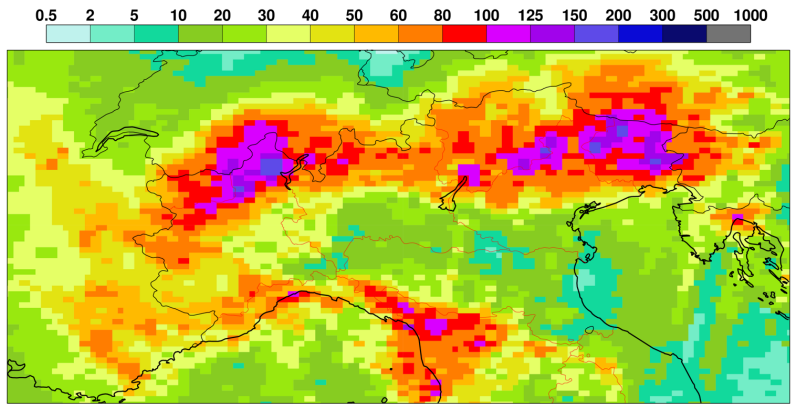


Km-scale simulations: Storm Adrian (Oct 2018)

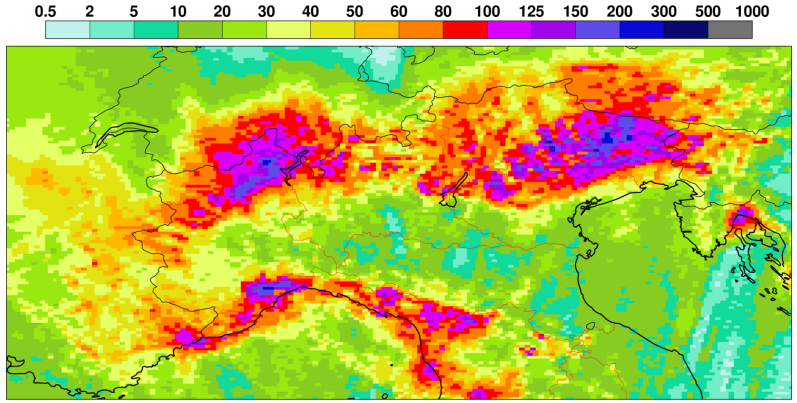
24h accumulated precipitation (T+54h - T+78h)



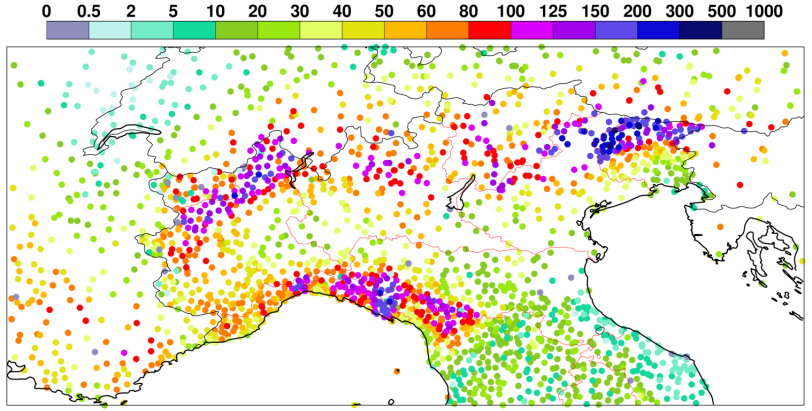
IFS 48r1 29 km



IFS 48r1 9 km



IFS 48r1 4.5 km

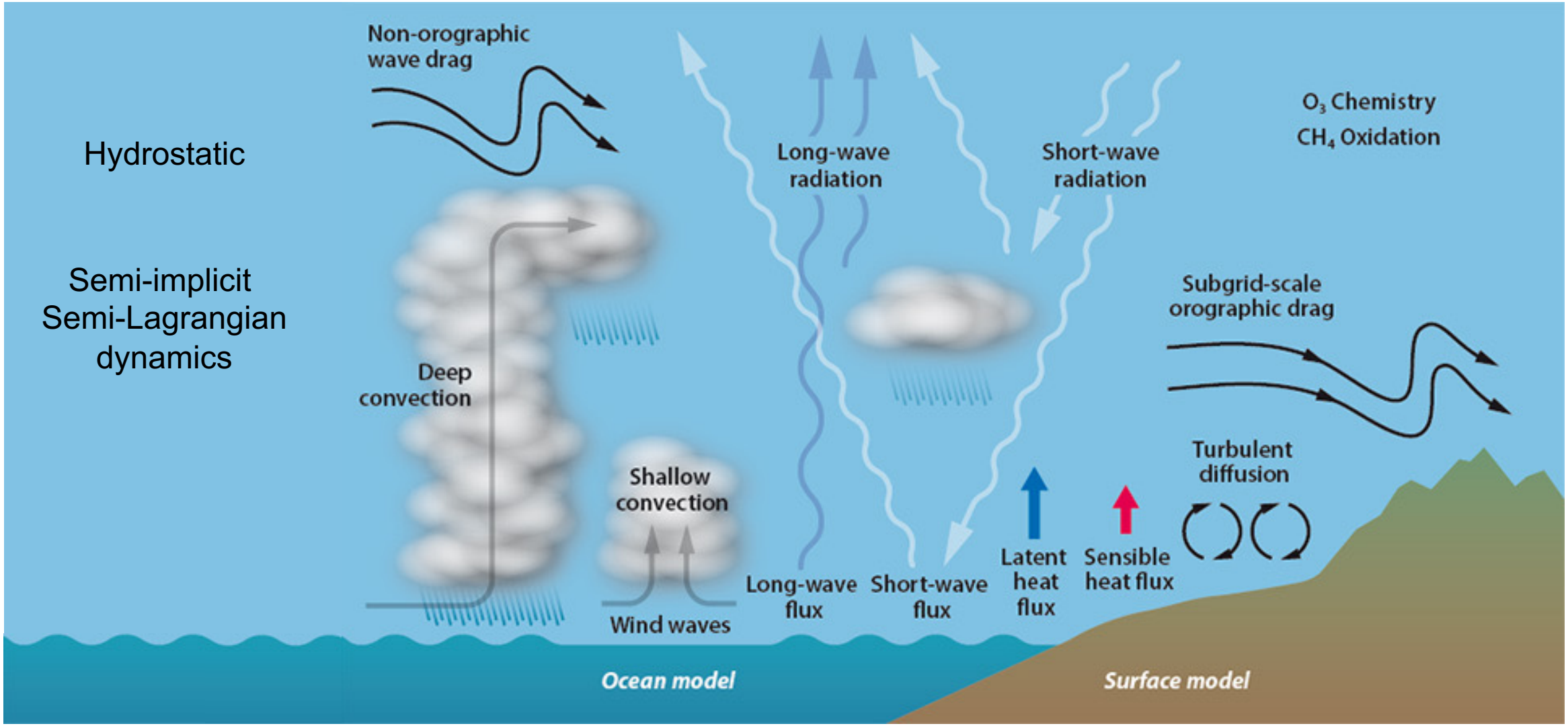


Observations

Next 4 years of km-scale modelling at ECMWF

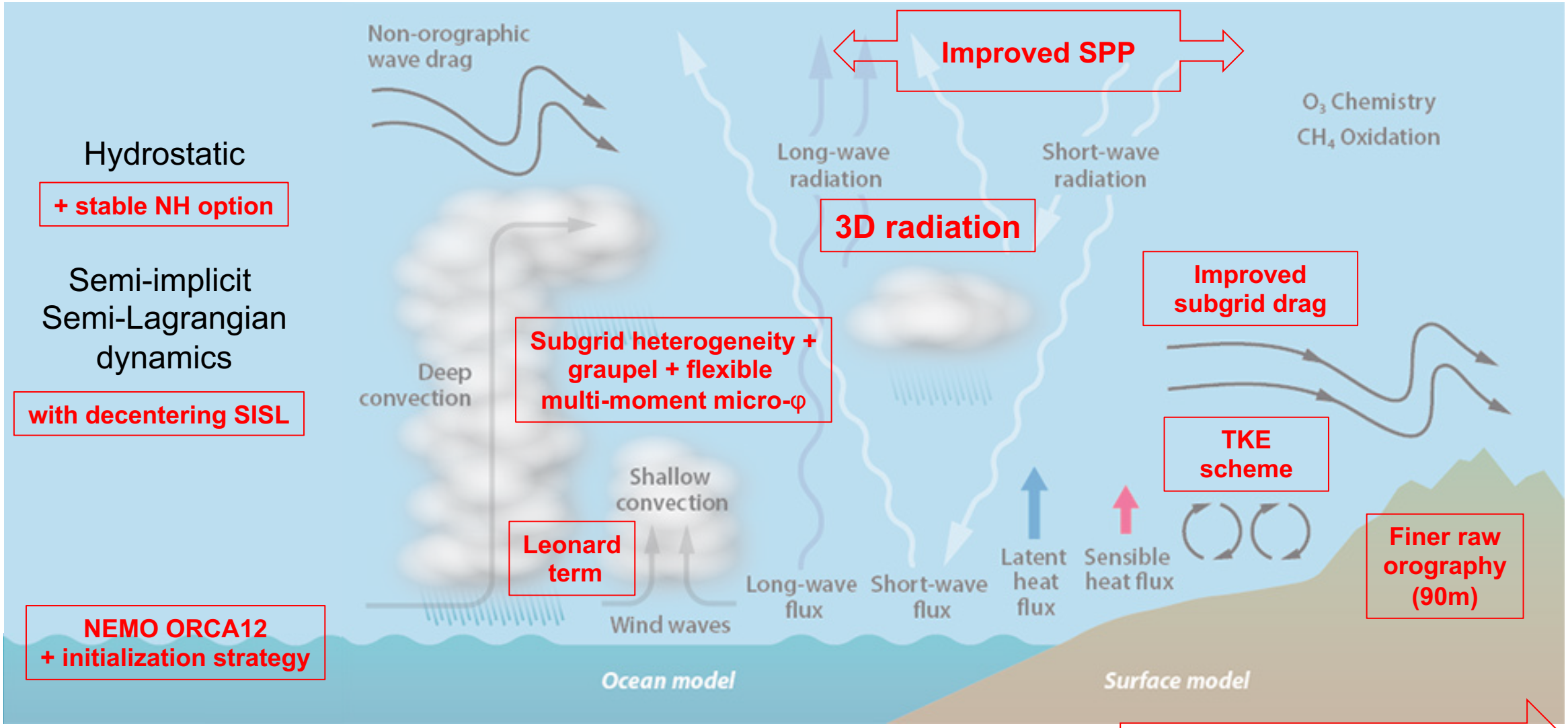
Hydrostatic

Semi-implicit
Semi-Lagrangian
dynamics



ECMWF

Next 4 years of km-scale modelling at ECMWF



ECMWF

The rise of data-driven forecasting …
… in 2023

THE RISE OF DATA-DRIVEN WEATHER FORECASTING

A FIRST STATISTICAL ASSESSMENT OF MACHINE LEARNING-BASED WEATHER FORECASTS IN AN OPERATIONAL-LIKE CONTEXT

A PREPRINT

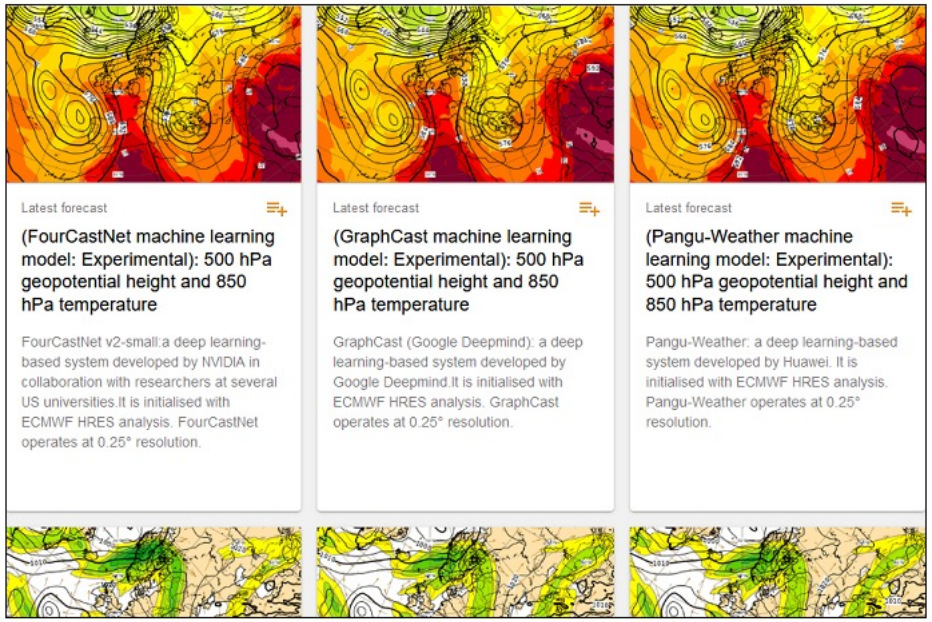
Zied Ben Bouallègue, Mariana C A Clare, Linus Magnusson, Estibaliz Gascón, Michael Maier-Gerber, Martin Janoušek, Mark Rodwell, Florian Pinault, Jesper S Dramsch, Baudouin Raoult, Florence Rabier, Matthieu Chevallier, Irina Sandu, Peter Dueben, Matthew Chantry, Florian Pappenberger

ECMWF

ABSTRACT

Data-driven modeling based on machine learning (ML) is showing enormous potential for weather forecasting. Rapid progress has been made with impressive results for some applications. The uptake of ML methods could be a game-changer for the incremental progress in traditional numerical weather

charts.ecmwf.int

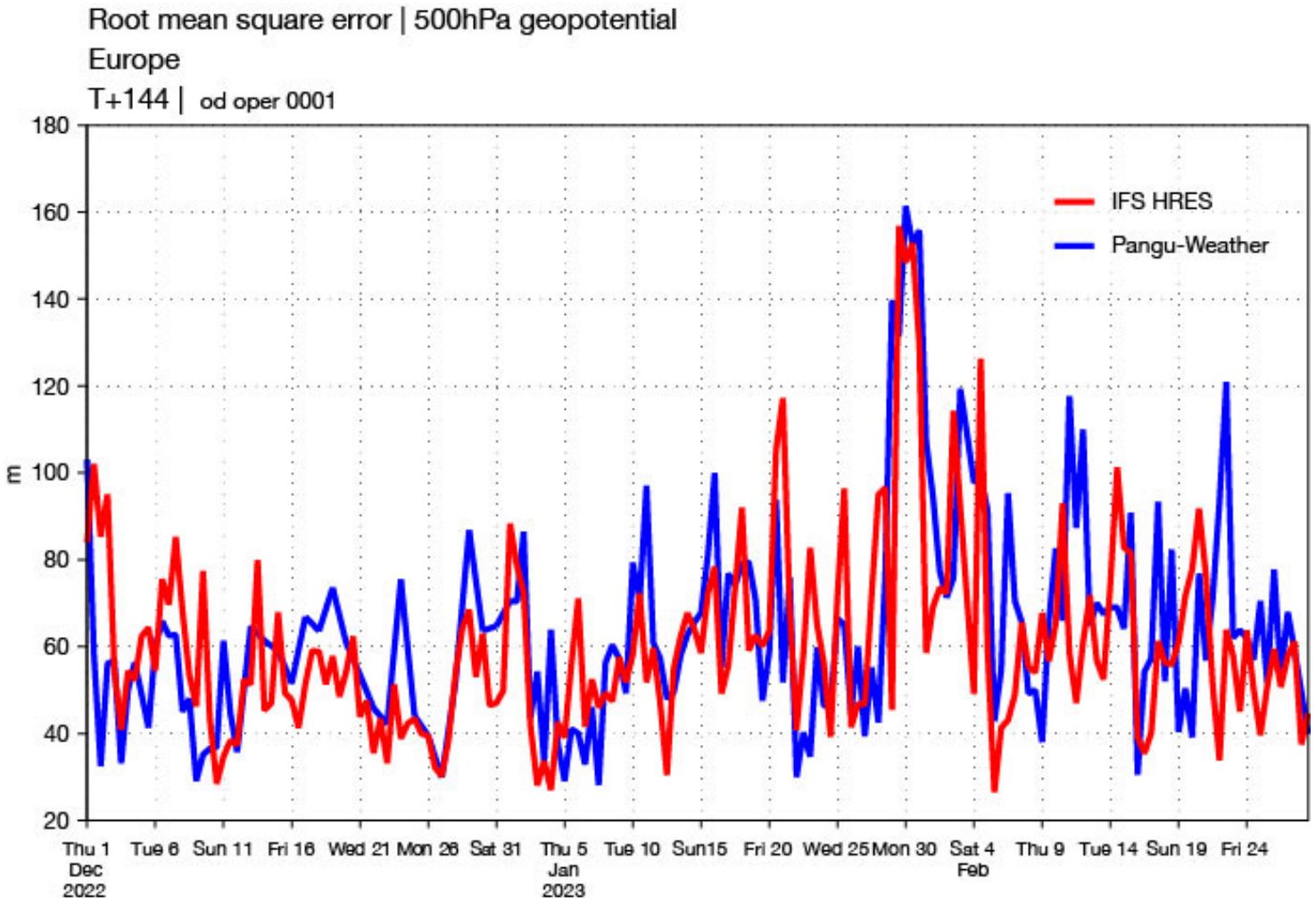


ECMWF unveils alpha version of new ML model

13 October 2023
The AIFS team

https://www.ecmwf.int/en/about/media-centre/aifs-blog

What results are showing
Time-series of RMSE over Europe, day 6



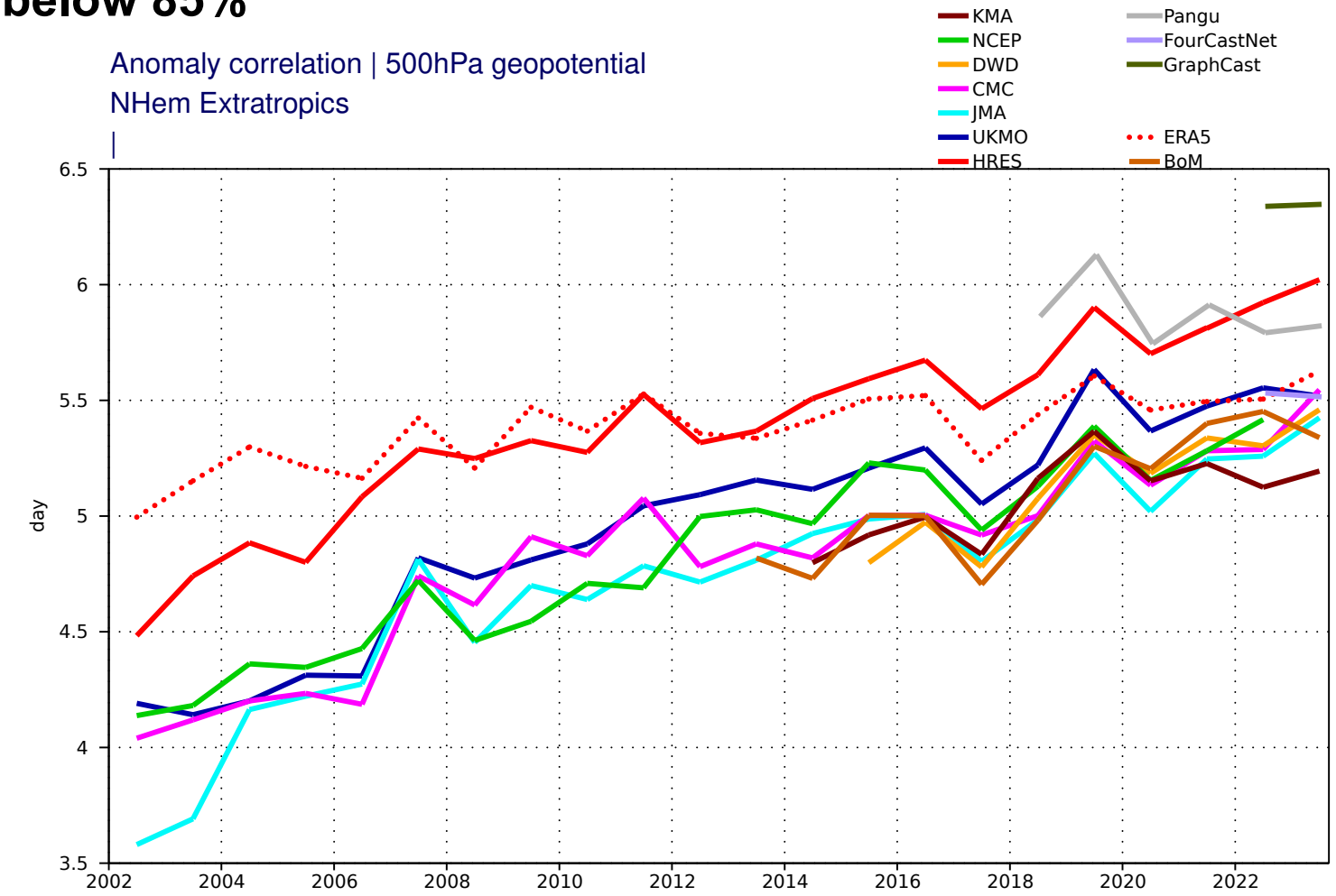
PanguWeather (initialised with ECMWF operational analysis) vs ECMWF HRES forecasts

- Results extremely close...
- ‘forecast busts’ at similar time
  – more ‘physical’ than one might think

WMO IMO-WMO

What results are showing
Headline score - 500hPa geopotential

Anomaly correlation of 500hPa geopotential over Northern Hemisphere Extratropics, falling below 85%



ML models (initialised with ECMWF HRES analysis)

Summary

- Selective overview of research activities

- Cycle 48r1 was a strong cycle in particular due to the increase in resolution of the ensemble

- Upcoming ESM changes:
  - new land cover and orography, surface data assimilation, SPP replacing SPPT and other components
  - NEMOv4 for the ocean and SI3 for sea ice and revise the ocean data assimilation
  - Destination Earth km-scale modelling and GPU adaptation

- ECMWF will increase efforts in machine learning building the AIFS as an ensemble prediction model based on deep learning

Additional: cycle 48r1 features

- …higher inner-loop resolution in the data assimilation system of 40 km and assimilation of surface-sensitive microwave imager channels over land and cold ocean surfaces;
- …a multi-layer snow scheme and updated IFS climate fields for orography, land–sea mask, lake depth and glaciers mask;
- … a major change in the partitioning of low-level orographic drag processes to the surface drag which includes revisions of the subgrid orography fields and the orographic low-level flow blocking, and gravity wave drag parametrizations;
- … the new Hybrid Linear Ozone (HLO) scheme which improves stratospheric wind forecasts;
- …a switch to the Object-Oriented Prediction System (OOPS) which will facilitate the development of ECMWF's data assimilation capabilities in the future.
- …a revised parametrization of microphysical processes to allow supercooled drizzle drops to be formed;
- …a new vertical Finite Element discretisation which is applicable to both the hydrostatic and non-hydrostatic dynamical core;
- …improved water and energy conservation properties in the IFS dynamics via global mass fixers;
- …a shallower sponge layer at the top of the forecast model, starting at 0.7 hPa instead of 10 hPa;
- …a new streamlined algorithm for the computation of semi-Lagrangian advection departure points.