“It's The End Of The World As We Know It (And I Feel Fine)"

ECMWF Annual seminar
2025.04.08

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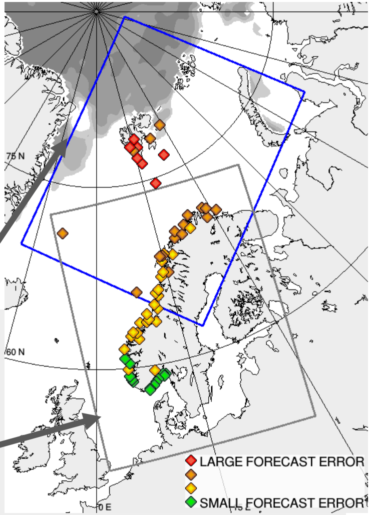
"This work is supported by computing and storage resources provided by Sigma2 – the National Infrastructure for High-Performance Computing and Data Storage in Norway."

Forecasting from now to 21 days

Challenges with merging many models:

- Each model needs different post-processing
- Jumps often occur in transitions between models



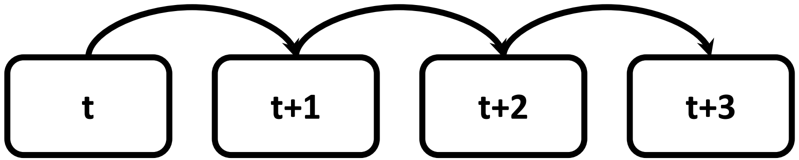
Our current portfolio of models

Global		**Medium range** IFS (0.1°)		
Nordic	**Now** Radar, Cloud Obs, Netatmo	**Short range** MEPS (2.5km)	**Medium range** IFS (0.1°)	**Extended** IFS (0.4°)
	Post-processing (1km)			
Arctic		**Short range** AA (2.5km)	**Medium range** IFS (0.1°)	

The emergence of AI Weather Prediction

- Trained on 40+ years of ERA5 reanalysis
- Highly competitive global models have emerged over the last 2-3 years

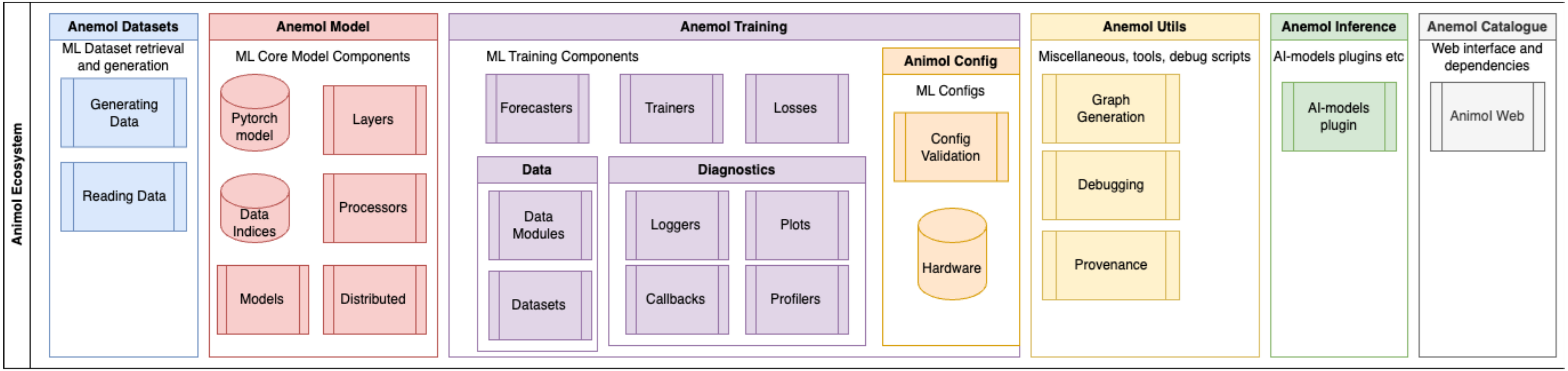
Analyses



AIFS Single operational since Feb 25

The Anemoi framework

- An initiative by ECMWF
- Framework for building global and regional AI-WP models, ex. **AIFS**
- Consists of components for data flow, building, training and running models
- A generic toolbox that is ready to support operational pipelines
- It is not a specific scientific application or machine learning tool



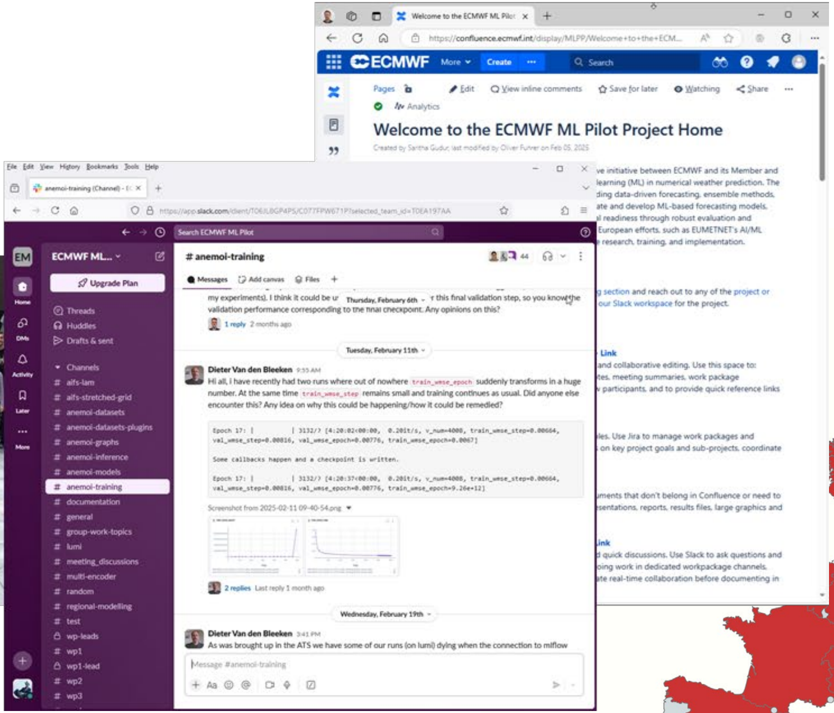
ECMWF Machine Learning Pilot Project

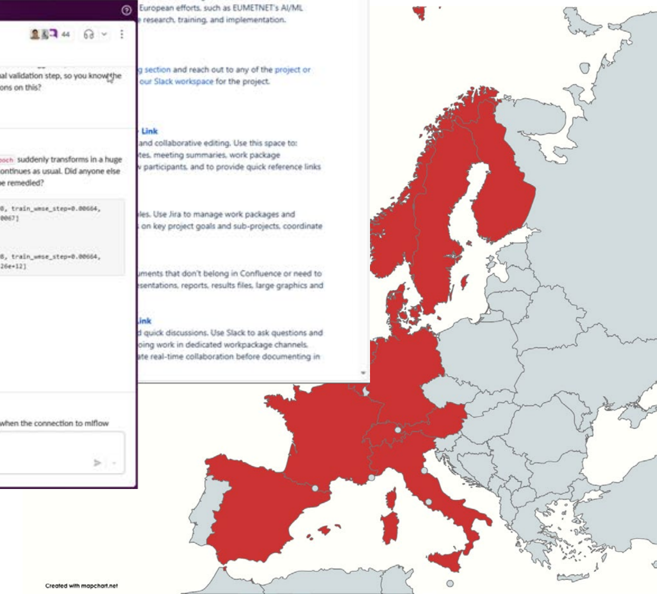
15 European partners

Led by Met Norway and MeteoSwiss

Work Package 1 – Data-driven forecasting
Work Package 2 – Ensemble forecasting
Work Package 3 – Data Assimilation
Work Package 4 – Infrastructure and MLOps

A new European consortium is forming …

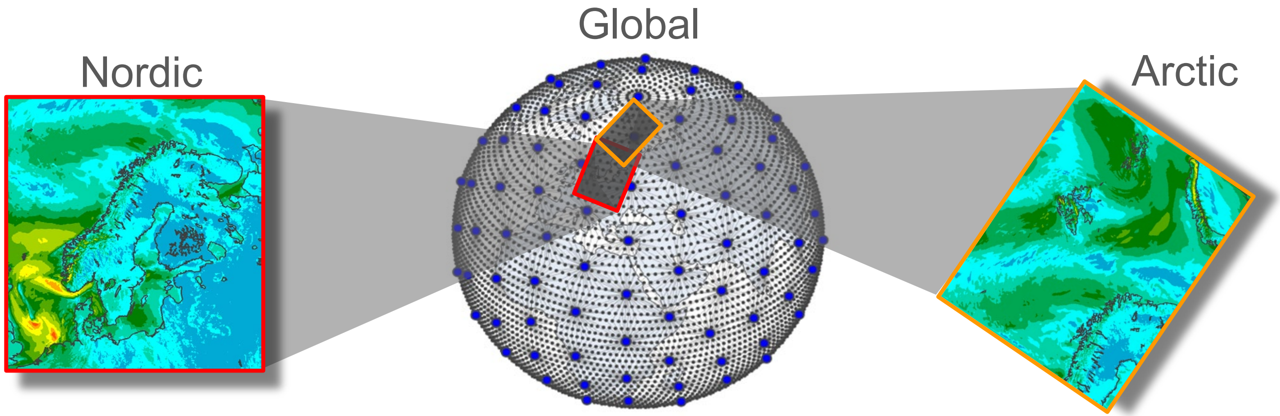




From Oli Fuhrer (MeteoSwiss)

Bris [bri:s] AI-WP

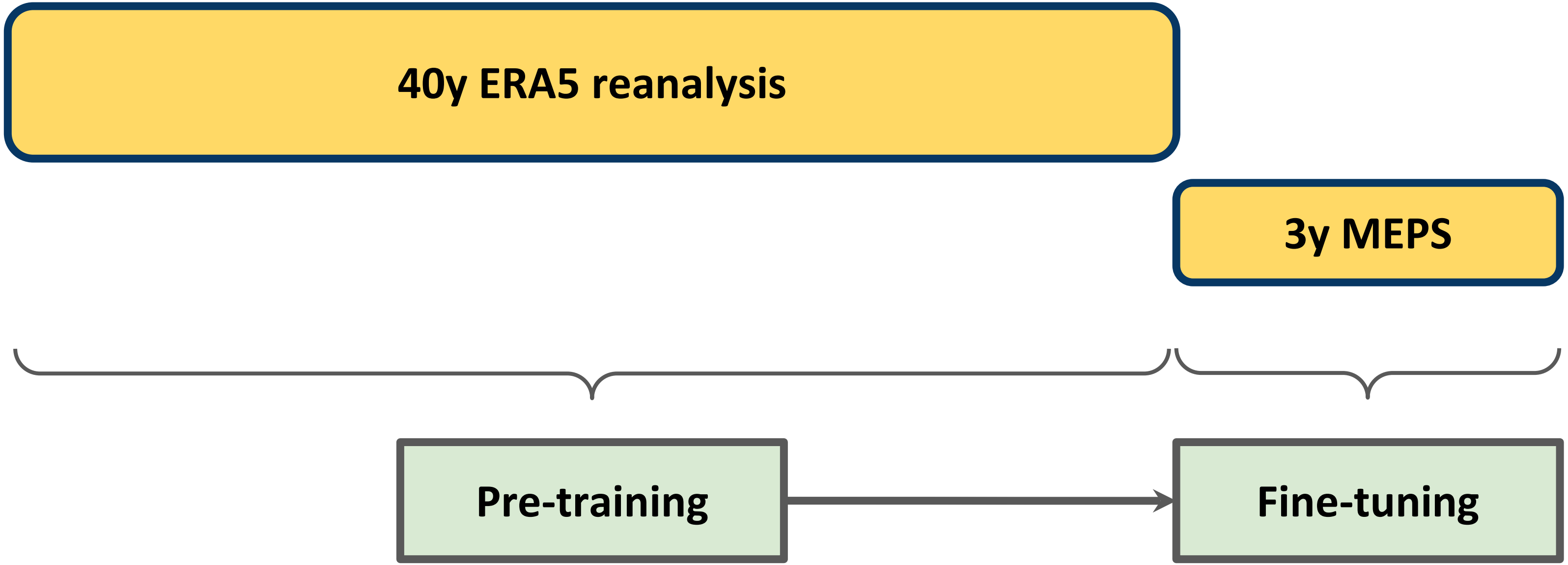
- A global AI-based model with high resolution over our **focus area(s)**
- Idea and initiated by Met Norway
- Developed in **collaboration** with MLPP partners
- **Seamlessly** covering nowcasting (next hour) to long-range (next 21 days)
- Based on ECMWF **AIFS**/GraphCast architecture
- Developed within the **Anemoi** framework



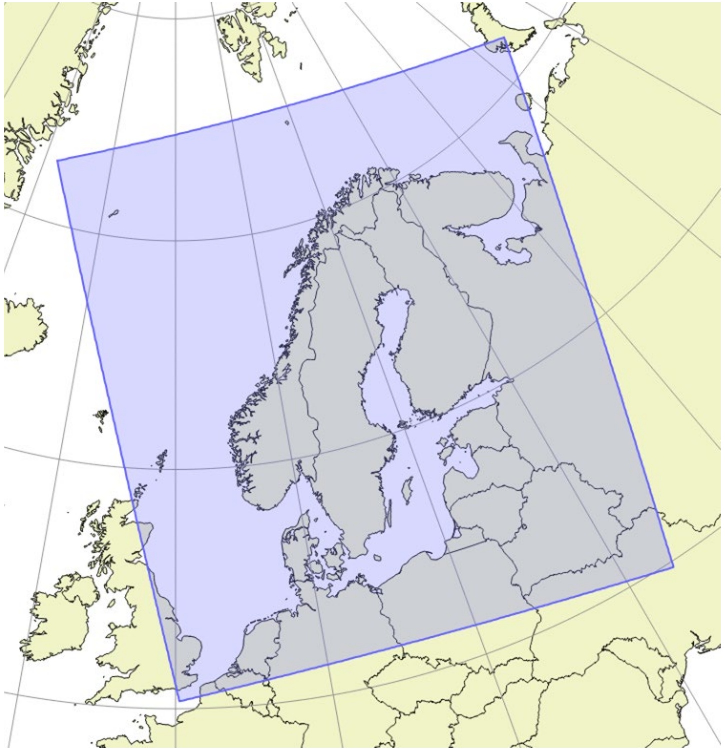
Norwegian Meteorological Institute

Training strategy - transfer learning - Bris

- Useful if:
  - You have a reanalysis on a different grid than your operational grid
  - Pre-train on one grid, fine-tune on another grid



Training data: ERA5 and MEPS 2.5 km

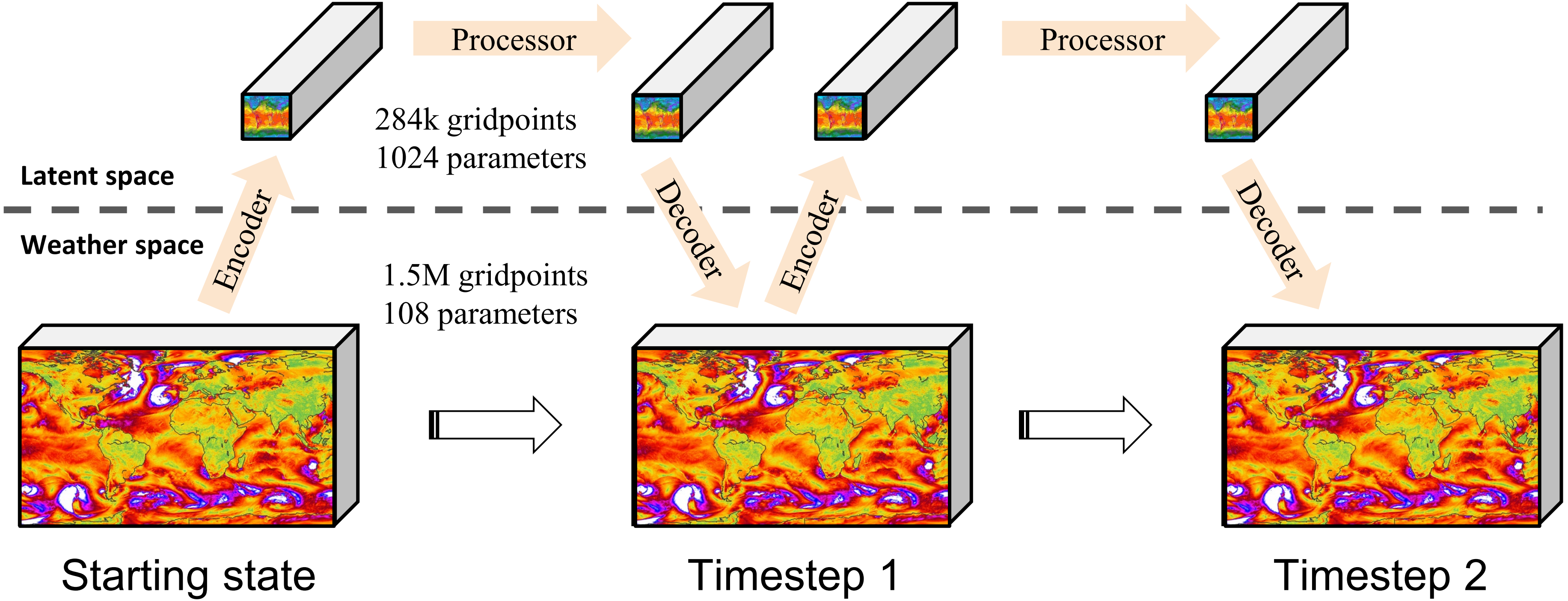


- Input and output variables:
  - 13 pressure levels
  - 6 pressure level variables (T, U, V, Z, W, Q)
  - 13 single level variables (T0, T2, Td2, U10, V10, MSLP, surface pressure, cloud area fraction, …)

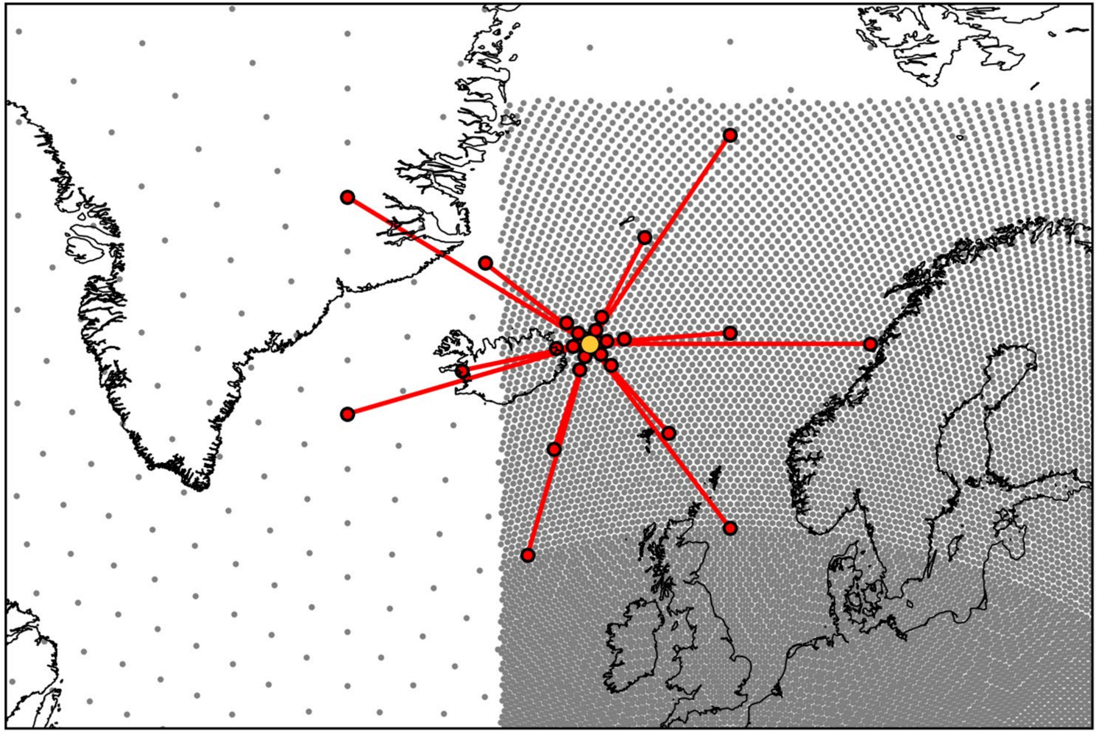
Diagnostic variables: precip, wind gust, visibility, fog

Bris model architecture

- Autoregressive model
- Encoder-processor-decoder architecture



Graph neural network - refined mesh over focus area(s)



Hardware requirements

Training:

250 million trainable parameters

10 TB of training data

Approx 8000 GPU-h to train the model

Generating forecasts:

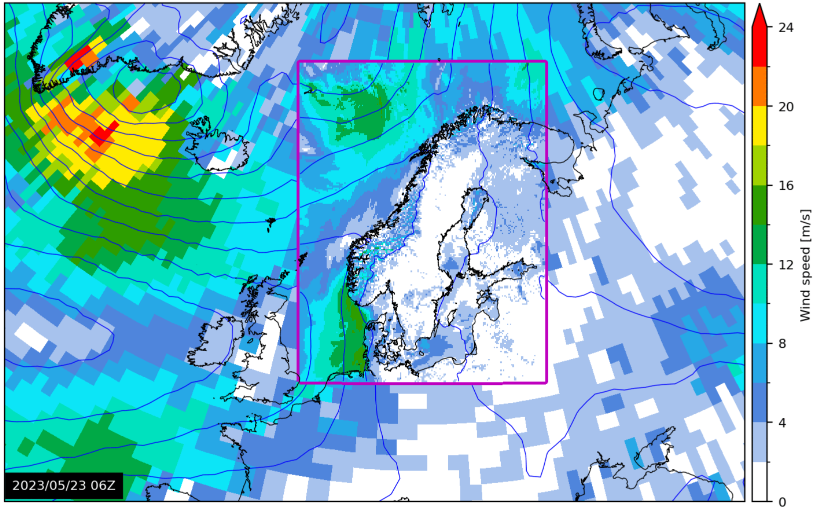
NVIDIA H200   approx 2 min 10 day forecast

NVIDIA A100   approx 4 min 10 day forecast

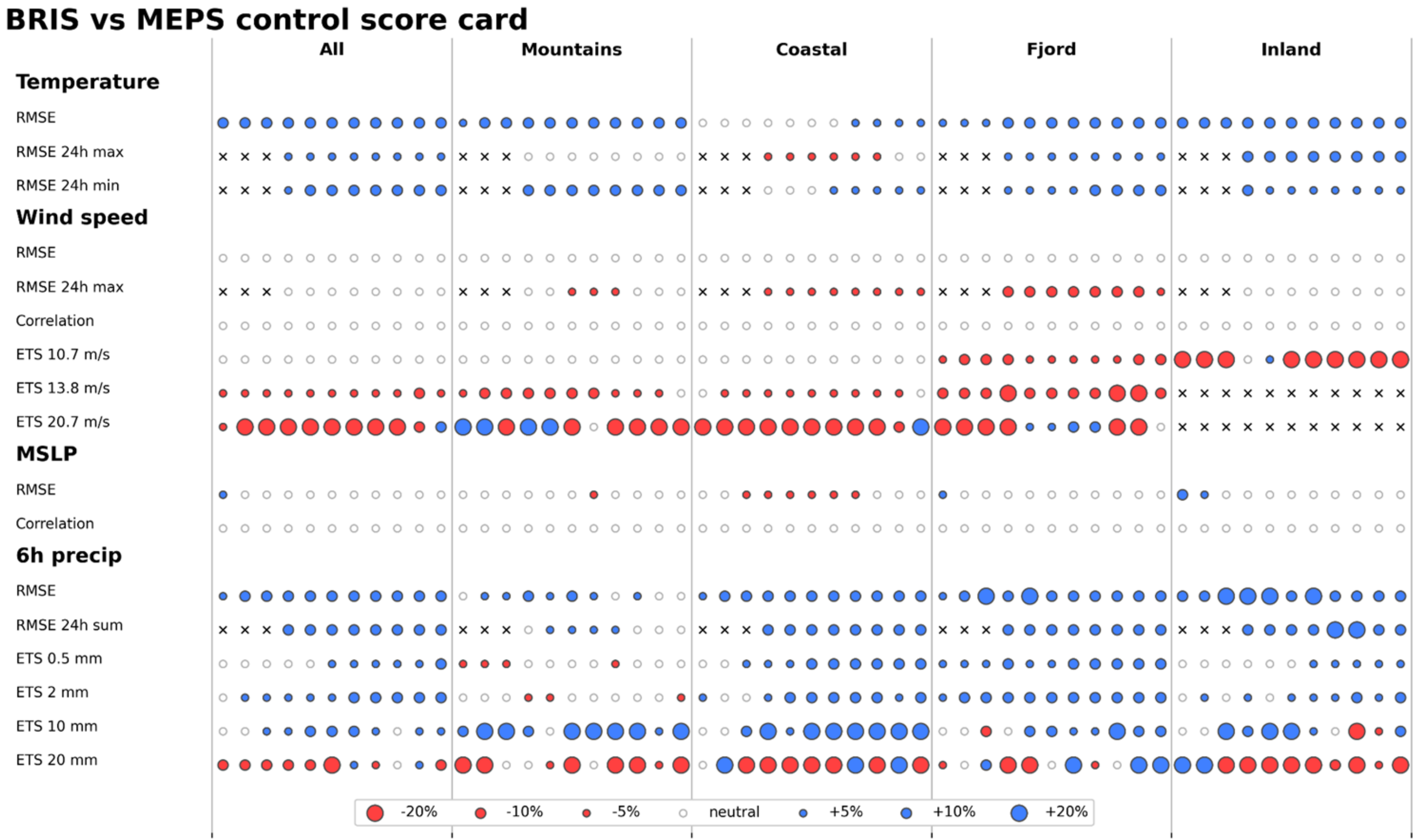
LUMI supercomputer

AI Weather Prediction is going operational…

AIFS Single operational since Feb 25

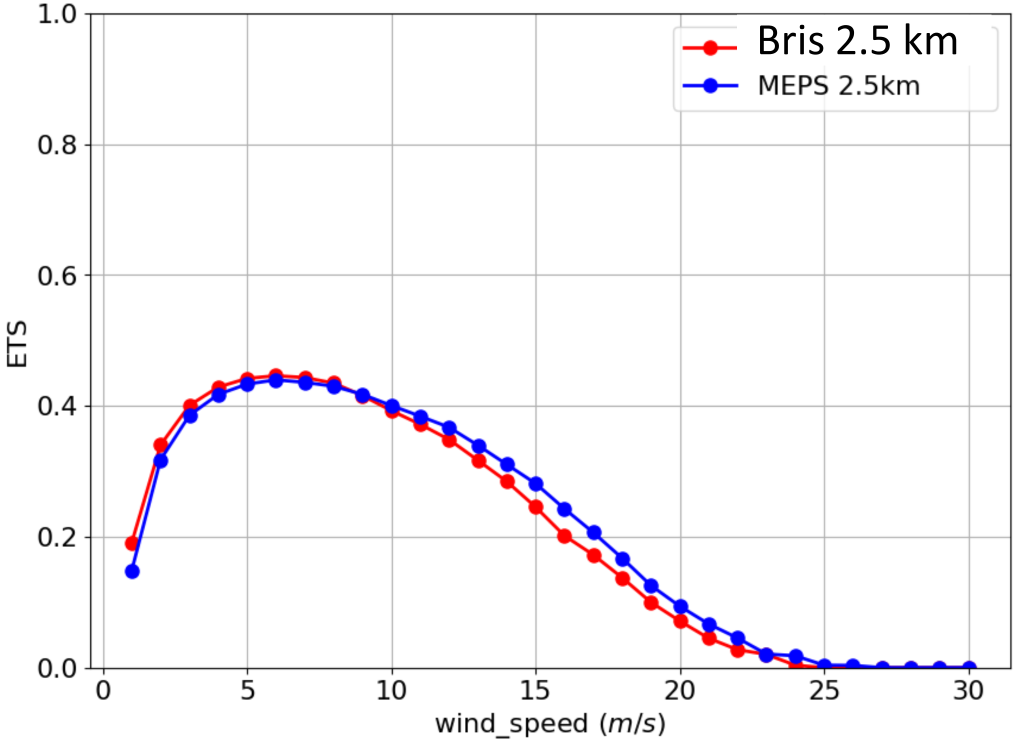


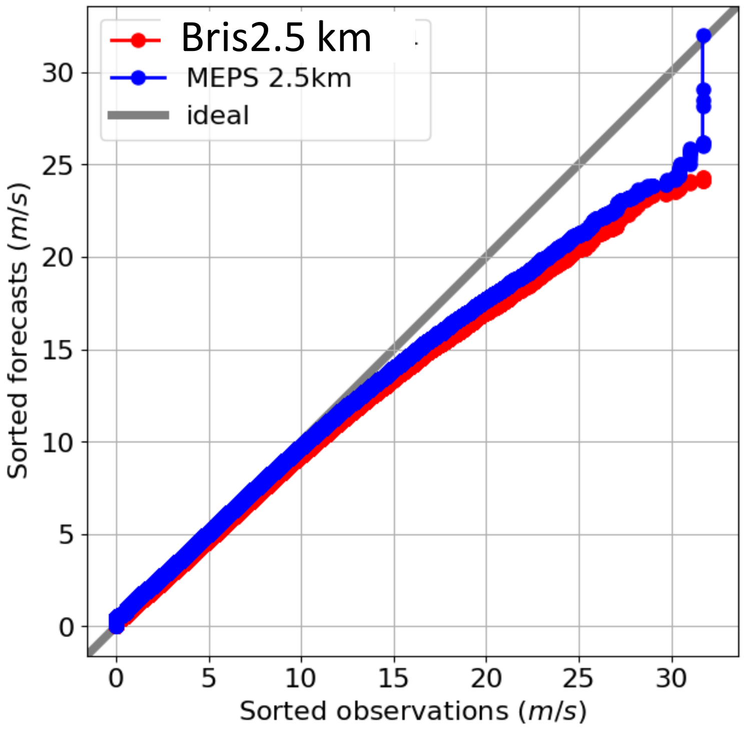
Bris pre-operational since Nov 2024 at Met Norway and since Mar 2025 at FMI, and many more to come



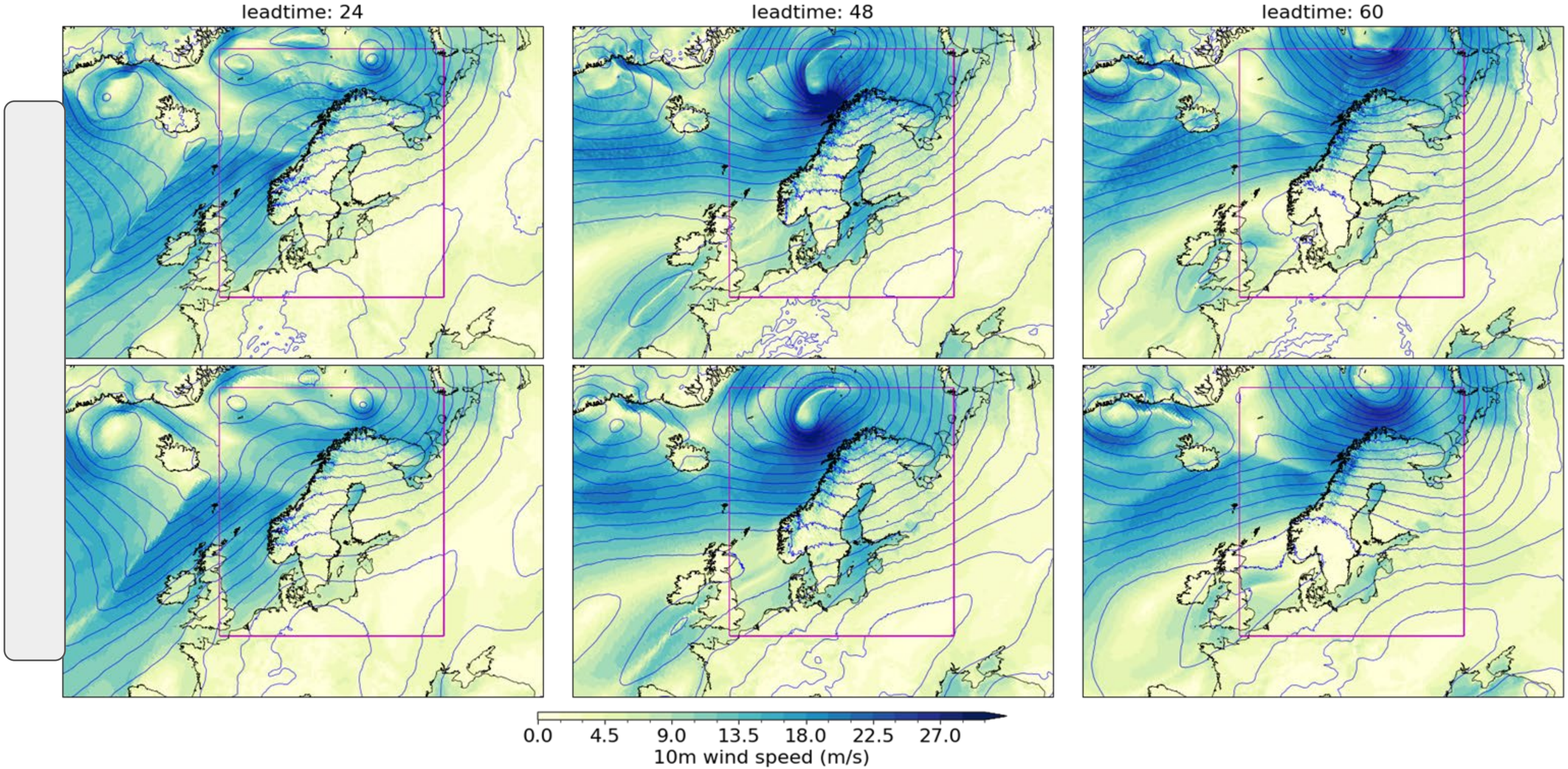
BRIS vs MEPS control score card
All
Mountains
Coastal
Fjord
Inland
Temperature
RMSE
RMSE 24h max
RMSE 24h min
Wind speed
RMSE
RMSE 24h max
Correlation
ETS 10.7 m/s
ETS 13.8 m/s
ETS 20.7 m/s
MSLP
RMSE
Correlation
6h precip
RMSE
RMSE 24h sum
ETS 0.5 mm
ETS 2 mm
ETS 10 mm
ETS 20 mm
-20%
-10%
-5%
neutral
+5%
+10%
+20%

Wind speed

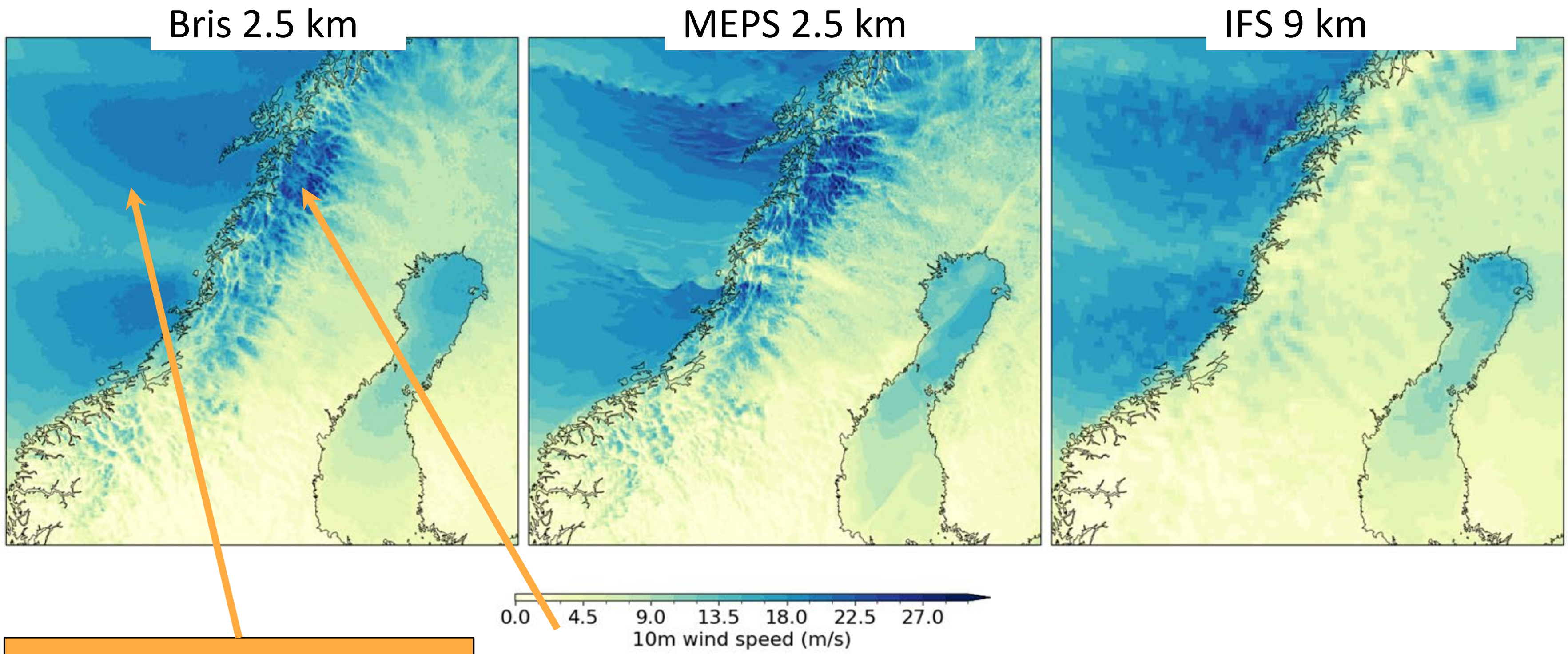

Bris 2.5 km
MEPS 2.5km
ETS
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
wind_speed (m/s)


Bris2.5 km
MEPS 2.5km
ideal
Sorted forecasts (m/s)
30
25
20
15
10
5
0
Sorted observations (m/s)

Extreme weather Ingunn - Jan 2024



Wind speed forecasts

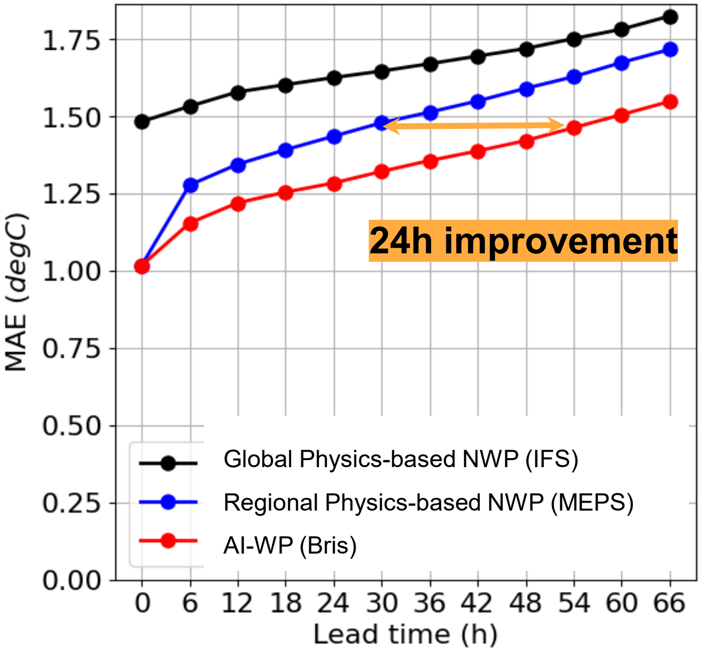


Smoother forecast over ocean

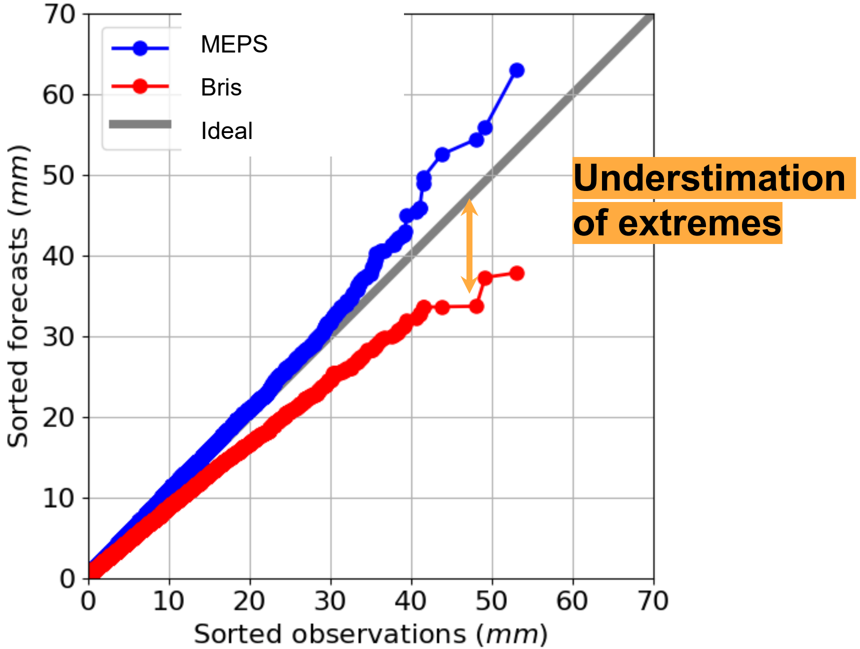
Sharper forecasts in areas with topographically steered winds

Deterministic Bris forecasts

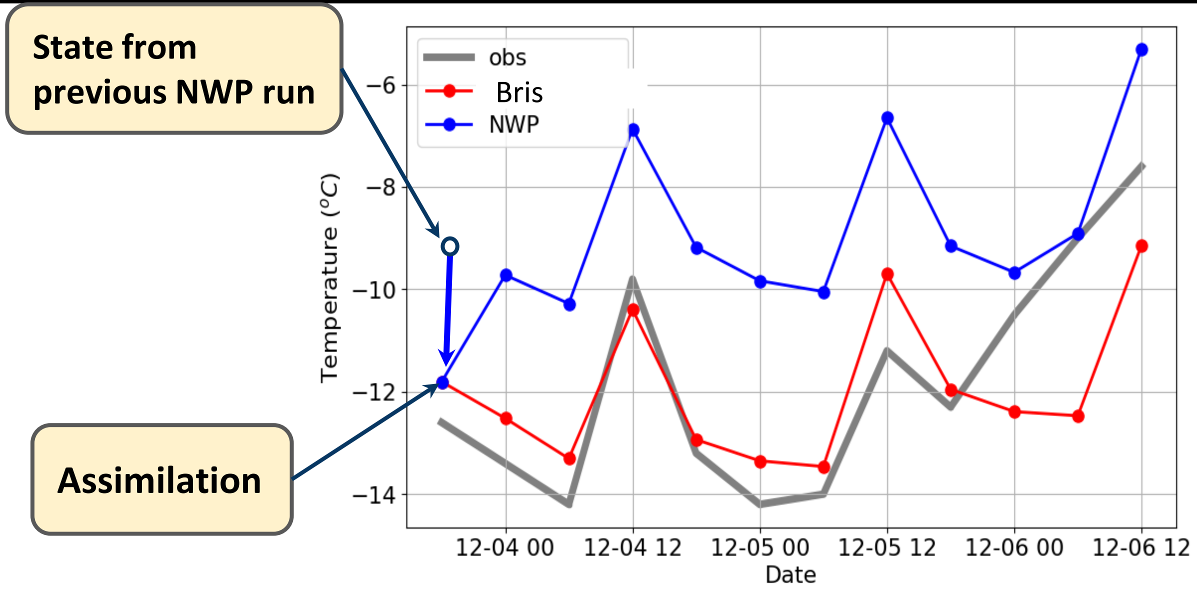
Temperature forecasts



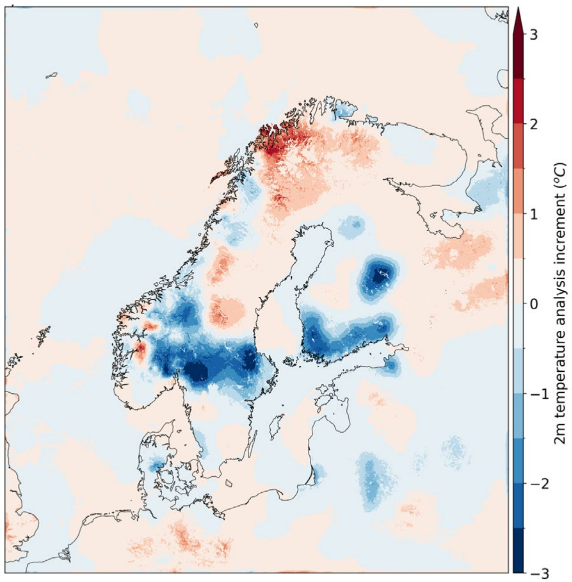
Precipitation forecasts



Explaining (?) the temperature skill
Training data from assimilation vs prediction



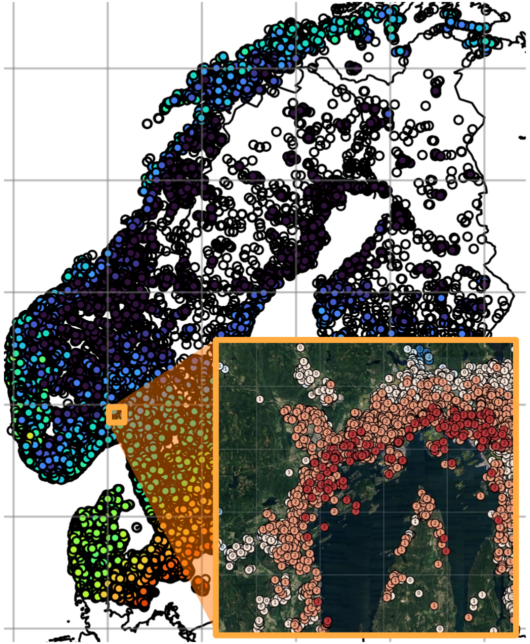
Analysis increments



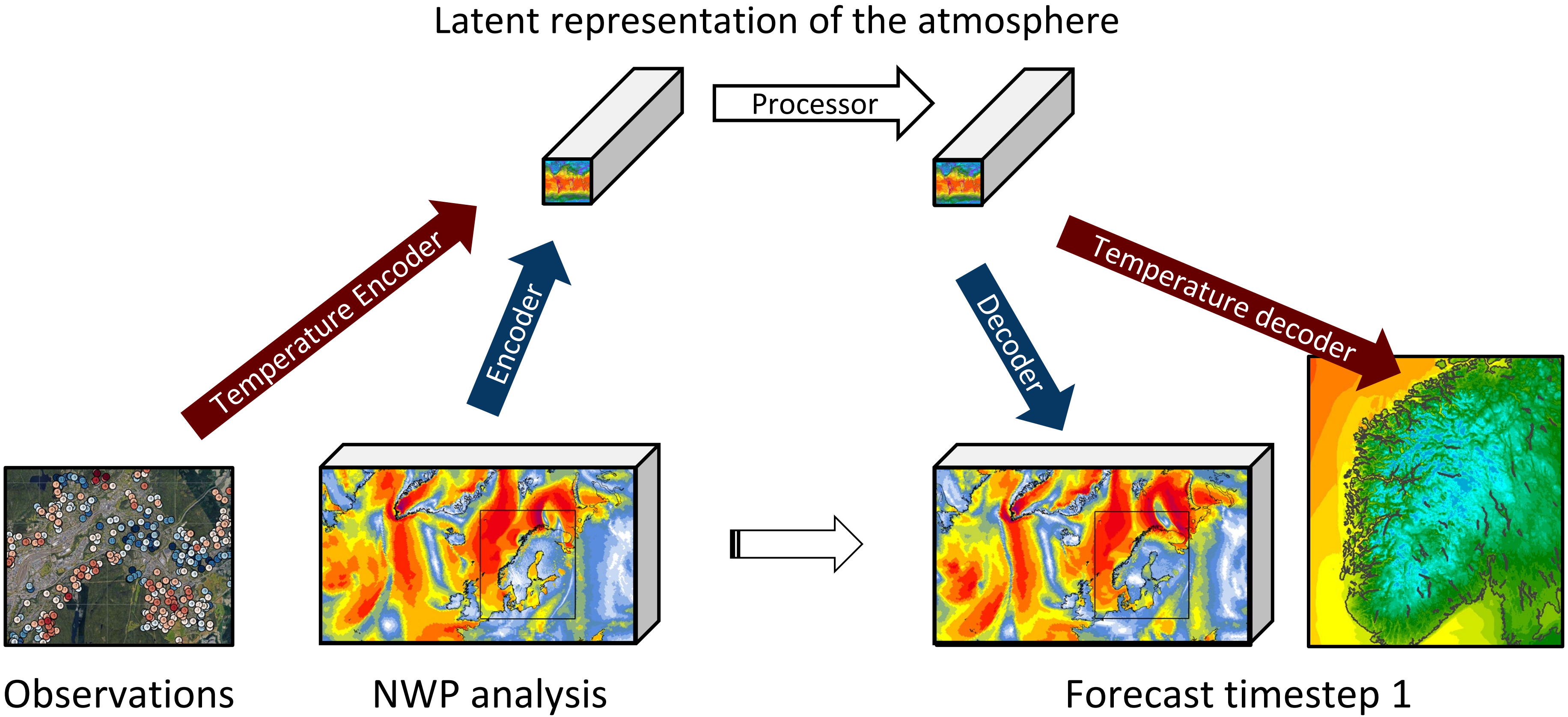
Emerging data sources

- Crowdsourced data from off-the-shelf instruments
- Owned and maintained by private individuals
- High redundancy makes up for lower quality equipment
- 50-100 times denser network than our own

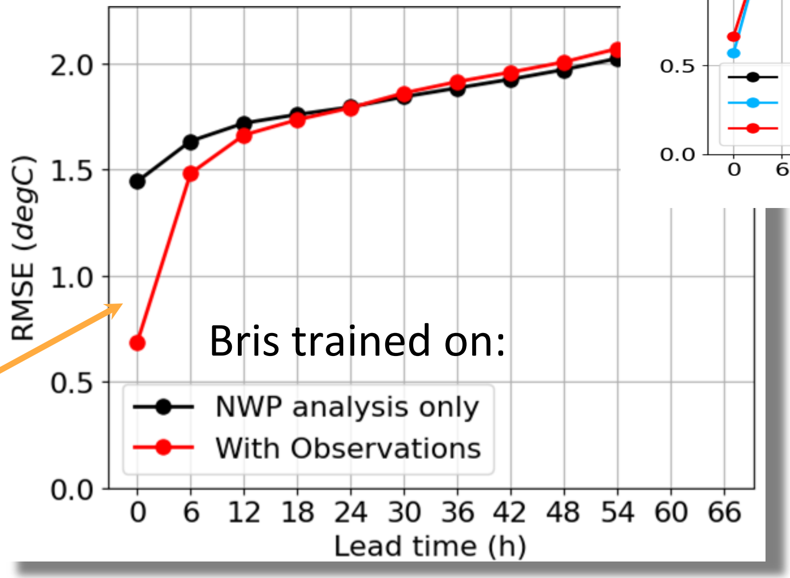
Netatmo's network of private weather stations

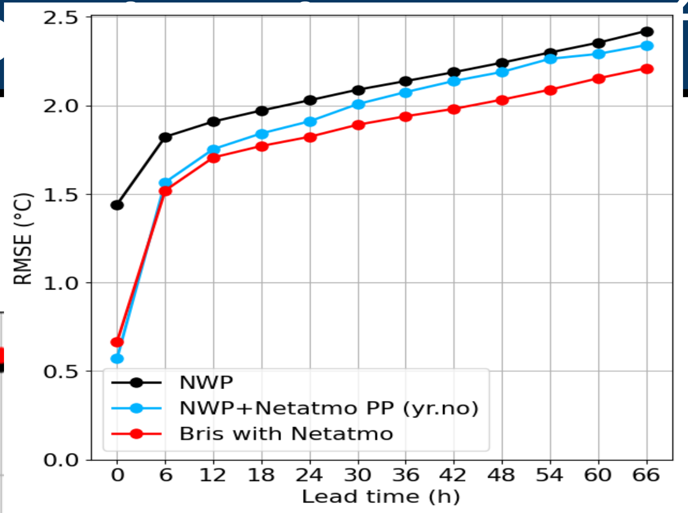


Integrating gridded observations in Bris



Integrating observatio



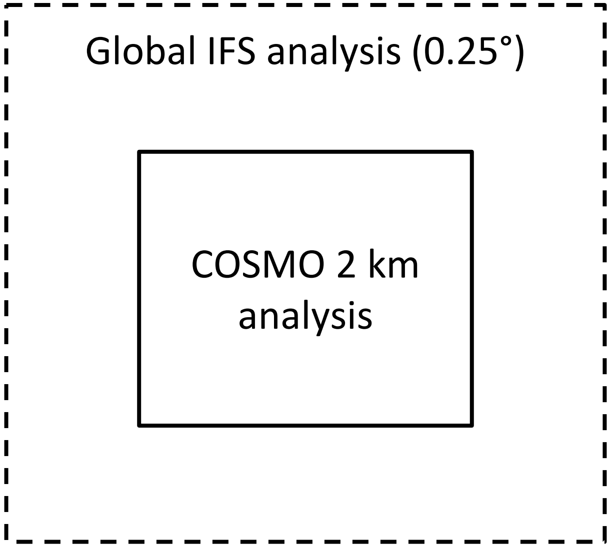


Improvement from fusing Netatmo observations

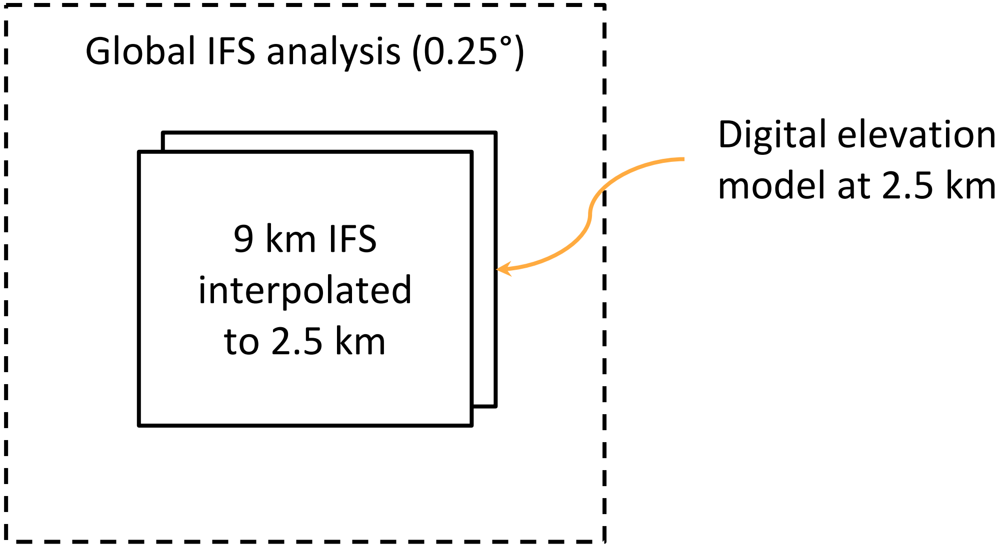
Still some work to do…

Does Bris trained on high-res Nordic data generalize to other regions?

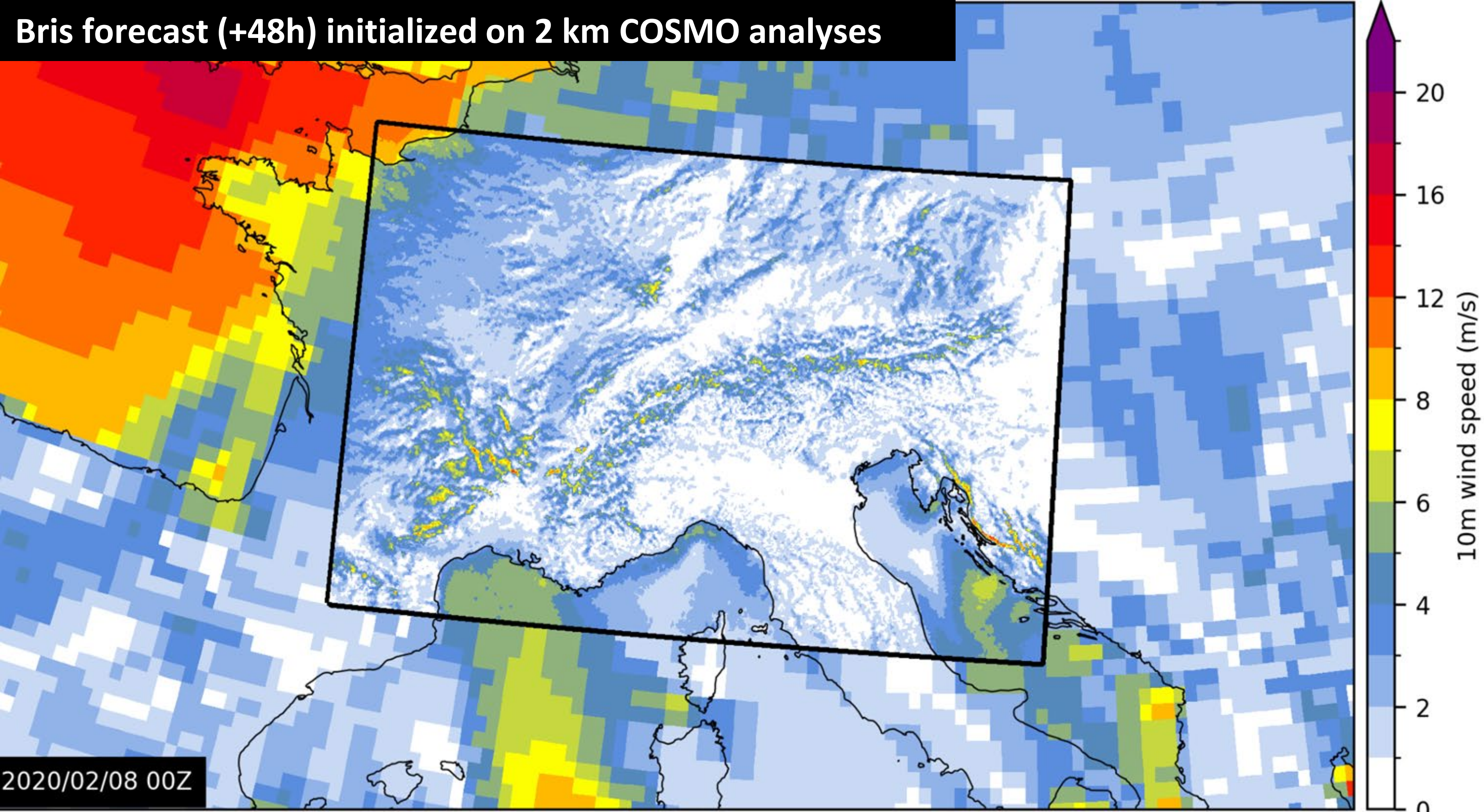
Experiment 1: Bris initialized from regional analyses (ex. Meteo Swiss)



Experiment 2: Bris initialized from global analyses (ex. ECMWF)

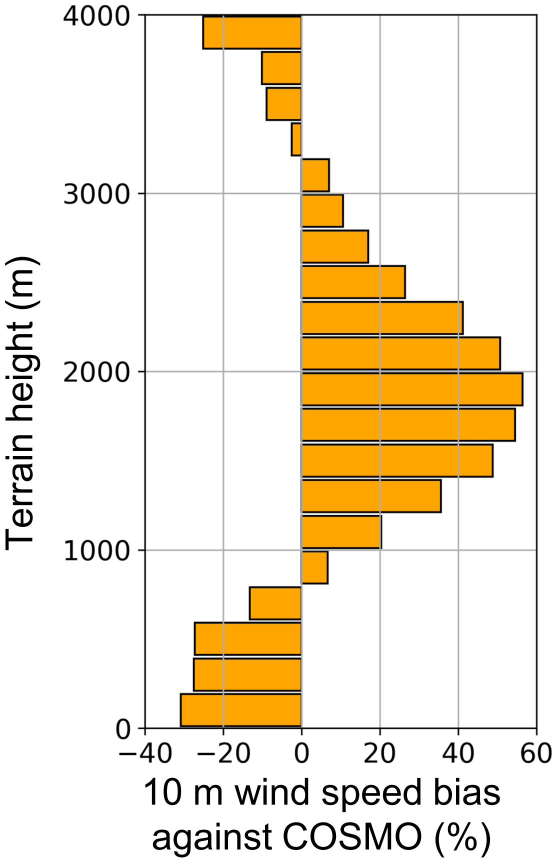


Bris forecast (+48h) initialized on 2 km COSMO analyses

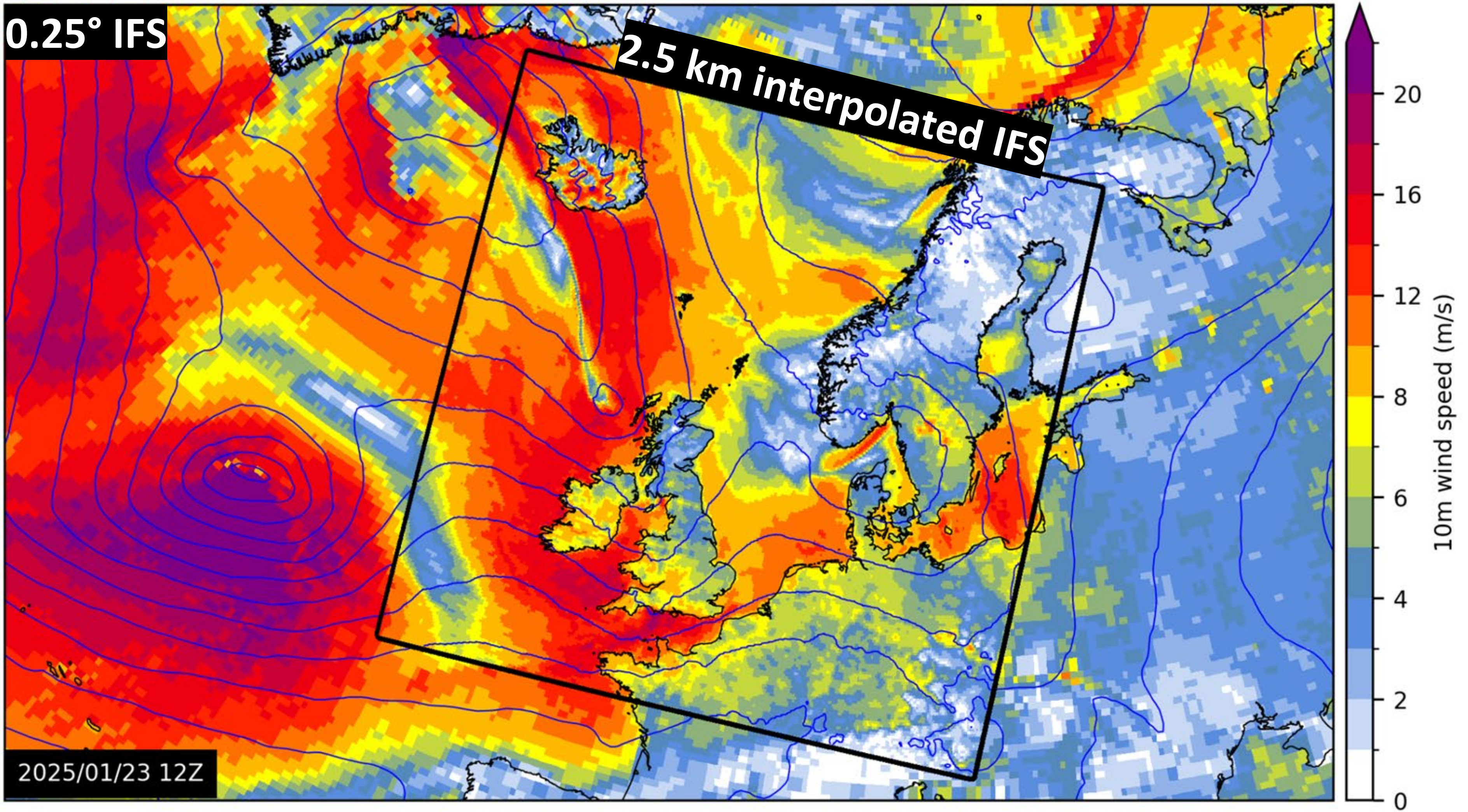


*Thanks to MeteoSwiss for providing data

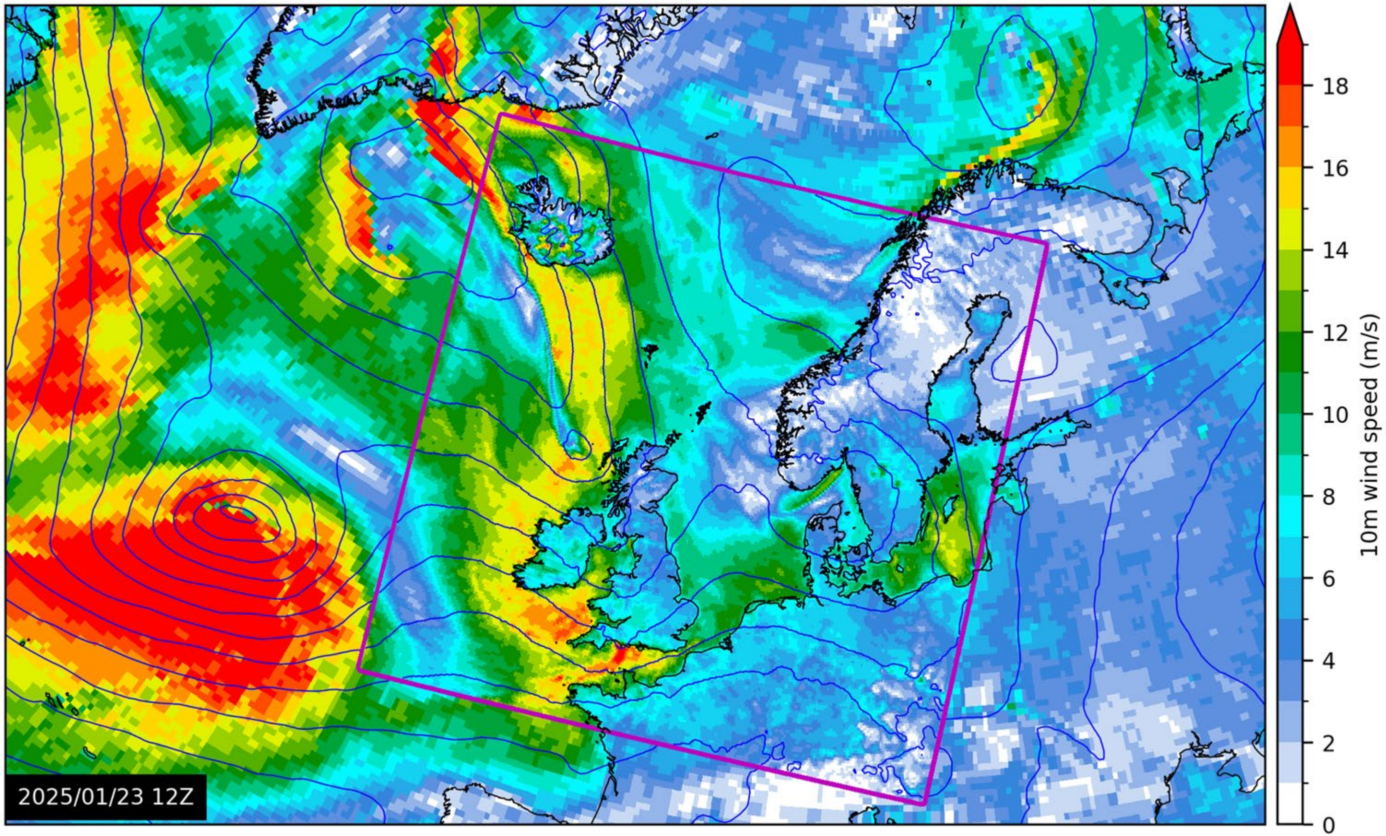
Bris’ winds are too strong in the mountains…



*Thanks to MeteoSwiss for providing data


0.25° IFS
2.5 km interpolated IFS
2025/01/23 12Z
10m wind speed (m/s)
0
2
4
6
8
12
16
20

EOWYN - Initialized with downscaled IFS



Data-driven modelling in Destination Earth

- Developing an AI-WP model in the On-demand Extremes Digital Twin project
- Probabilistic, high-resolution, on-demand, extremes
- We need a model that generalizes to new domains

Multi-domain dynamical graph training

The architecture is made grid-independent such that multiple regional datasets can be alternated as batch input

Advantages:

- **Flexibility:** Support handling datasets from different **domains, grid-sizes, temporal sizes** and **resolutions**
- Increase the **generalizability** of the model
- Preventing **catastrophic forgetting**

From Sophie Buurman (KNMI)

Funded by the European Union **Destination Earth**

Training data

1

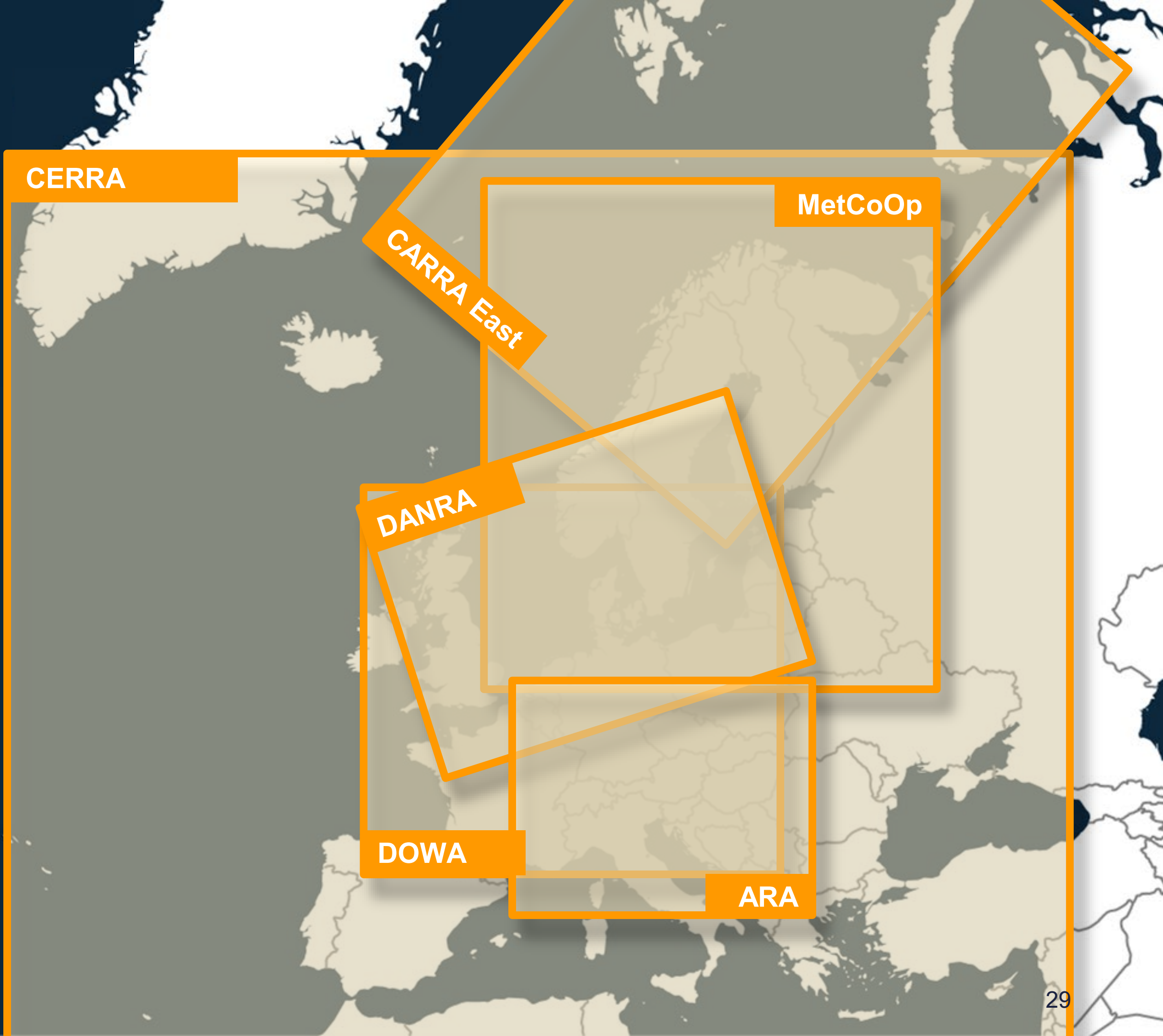
European reanalyses
5.5 km

5

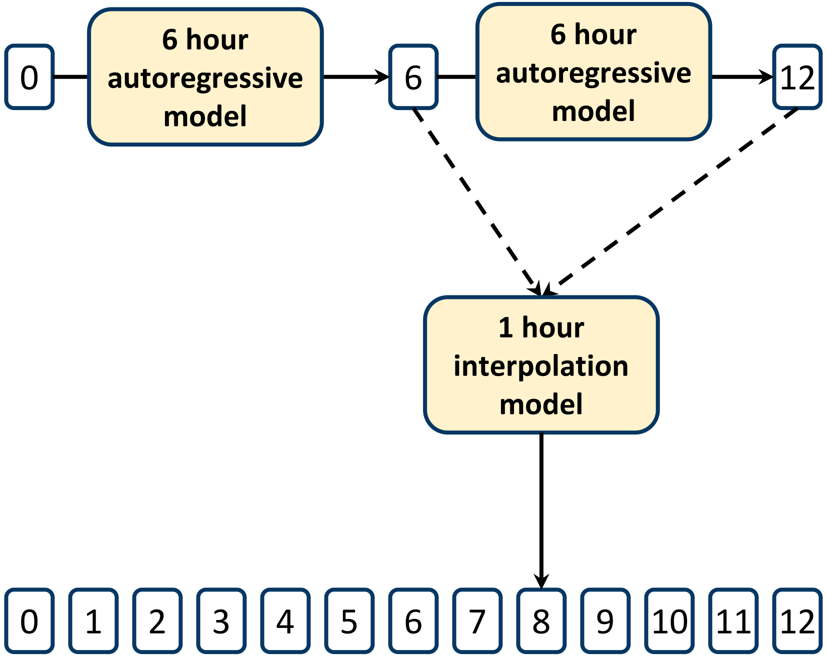
Regional reanalyses
2.5 km

400+

DE330 extreme event simulations
250-750m

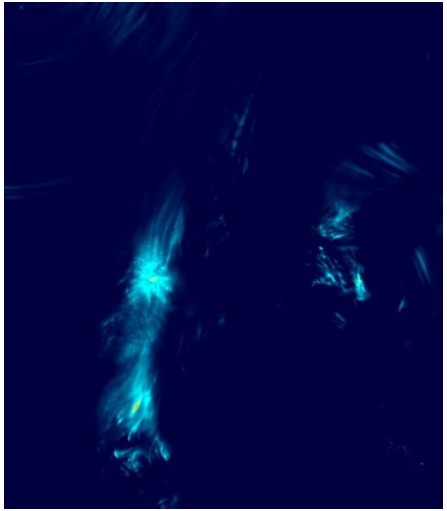


Temporal resolution - hourly forecasts

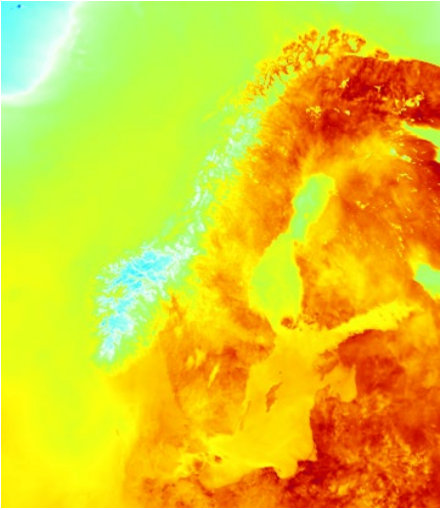


Trained on forecast data, uses full state of model for 0 and 6 hours

6h precip



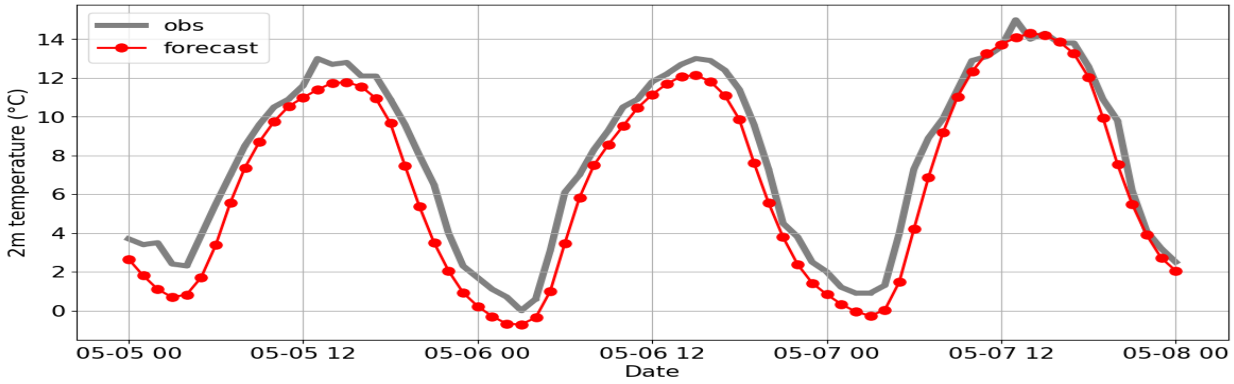
2m air temperature



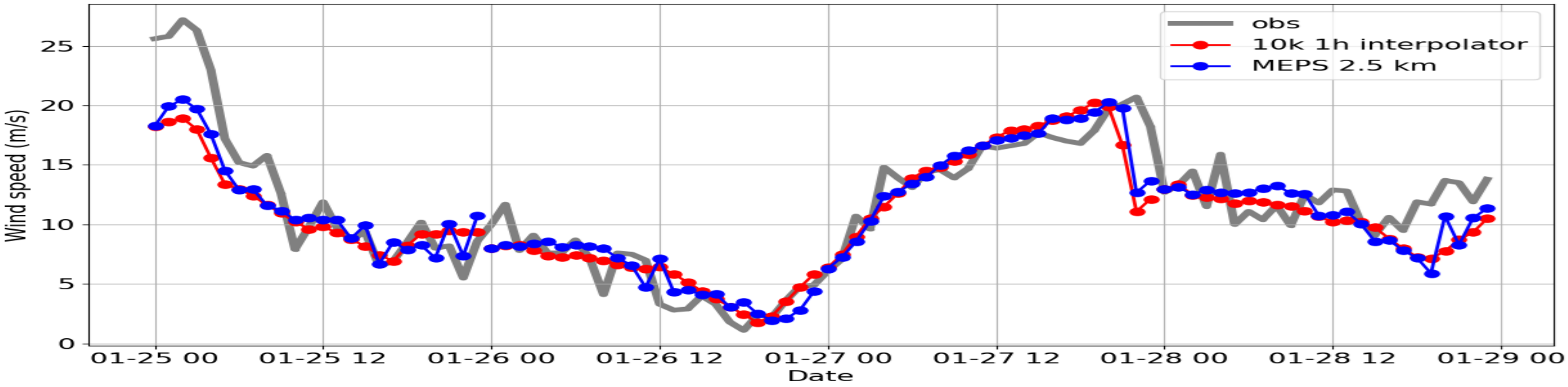
Available as a feature in anemoi-core

Example time series of temperature and wind speed

Air temperature

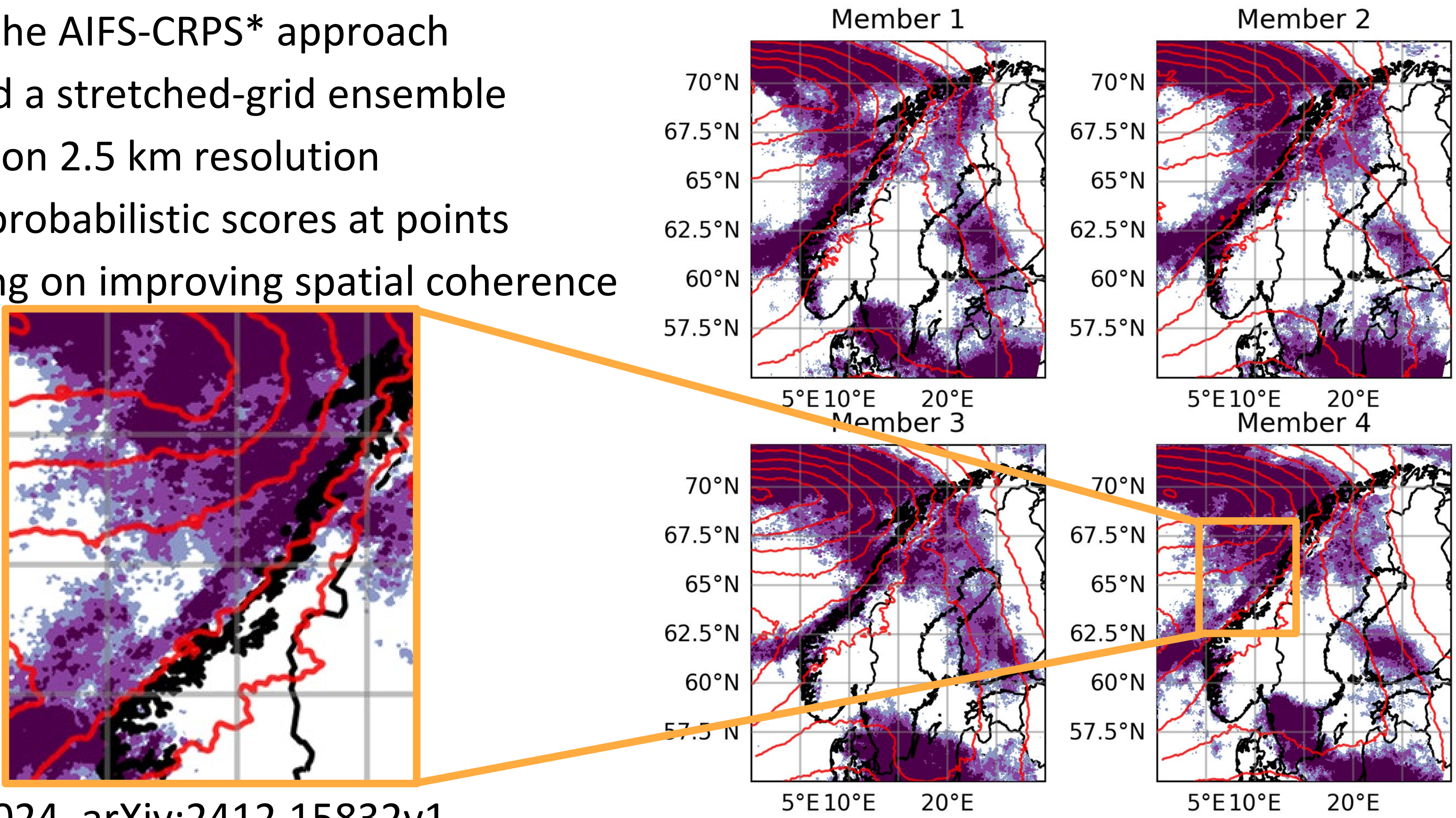


Wind speed



Ensemble generation

- Using the AIFS-CRPS* approach
- Trained a stretched-grid ensemble model on 2.5 km resolution
- Good probabilistic scores at points
- Working on improving spatial coherence

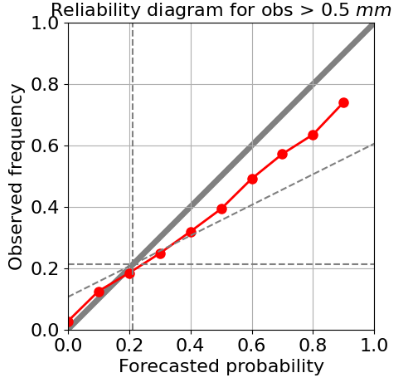


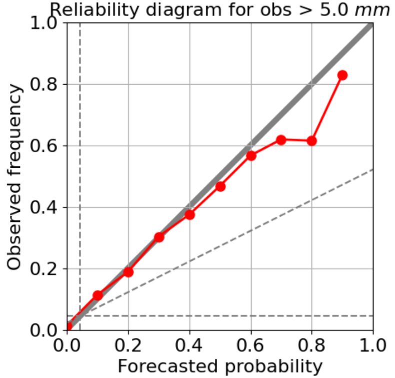
*Lang et al 2024, arXiv:2412.15832v1

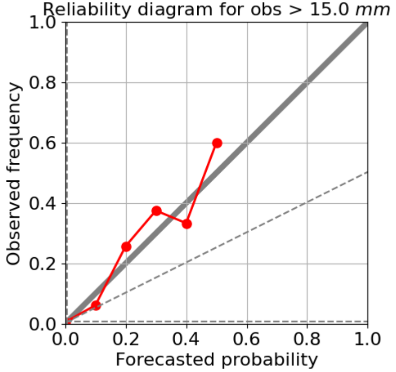
Ensemble generation

Verification against point observations over Norway (lead times 24h-96h)

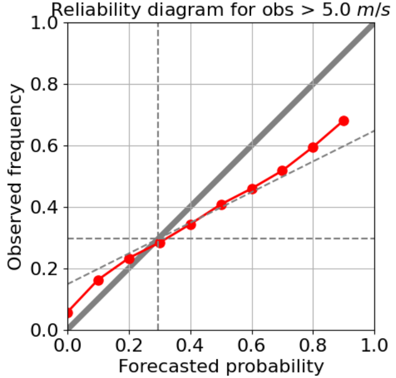
Precipitation

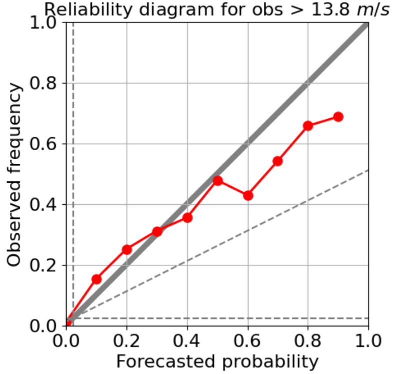


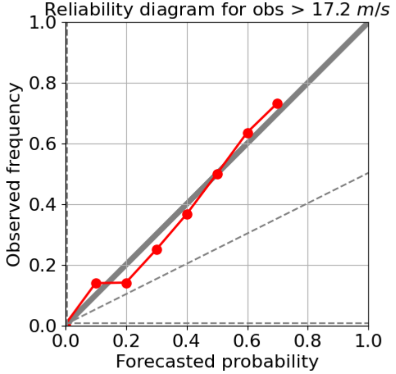




Wind speed







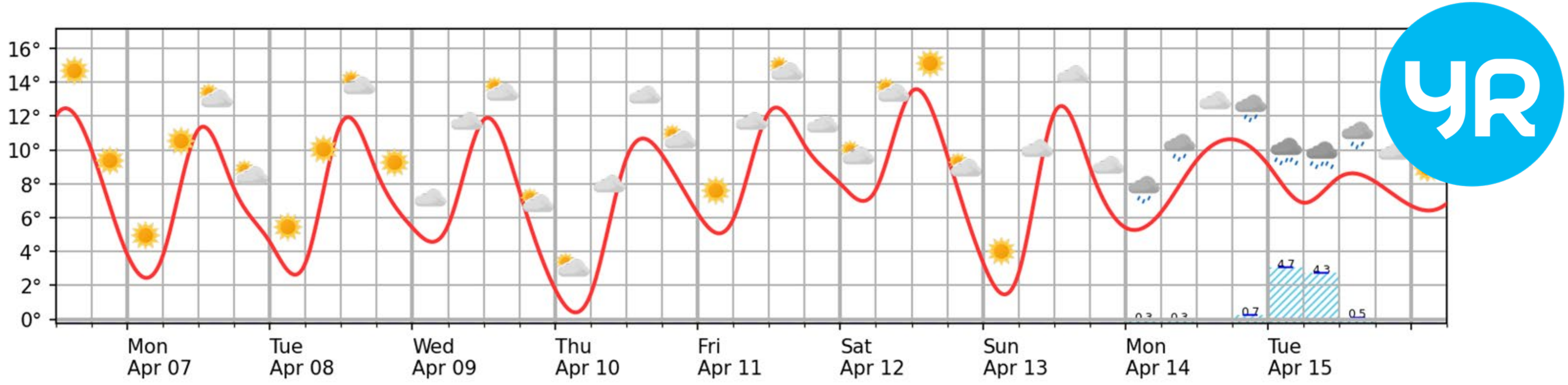
Why AI-WP and Bris?

- Potentially more **accurate** and **reliable** than NWP
- Forecasts available **earlier**
- **Learn** from weather events from all around the globe
- Integrate (even more) relevant **(local) data** sources
- **High-resolution** where it matters
- Long **seamless** forecasts
- Much **faster** to validate new model configurations
- Domain **expertise** and (increased) **collaboration** across Europe
- Reduced **computing cost** (probably)
- “**Different**”!

Warmest congratulations to ECMWF on 50 years!

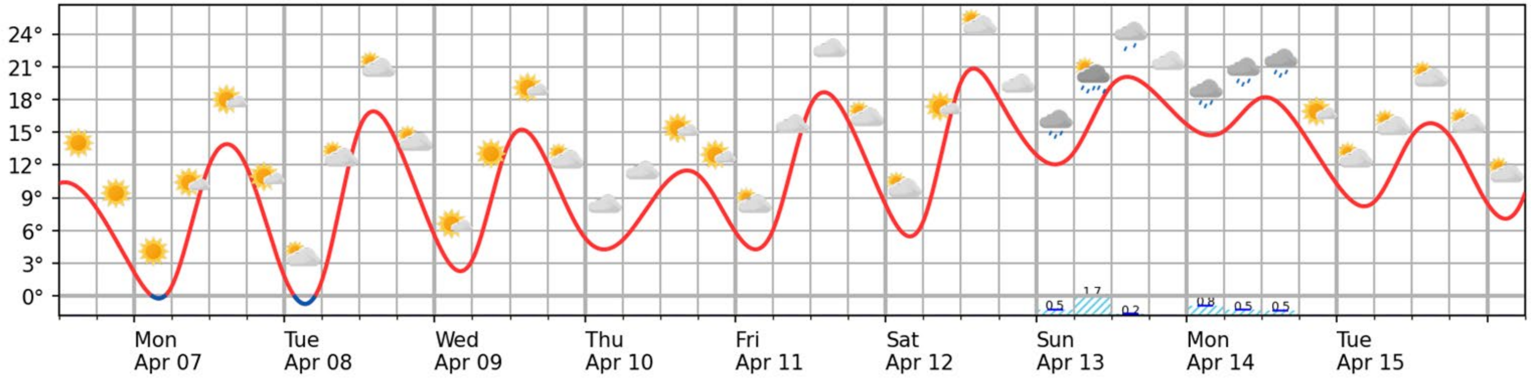
From

Oslo

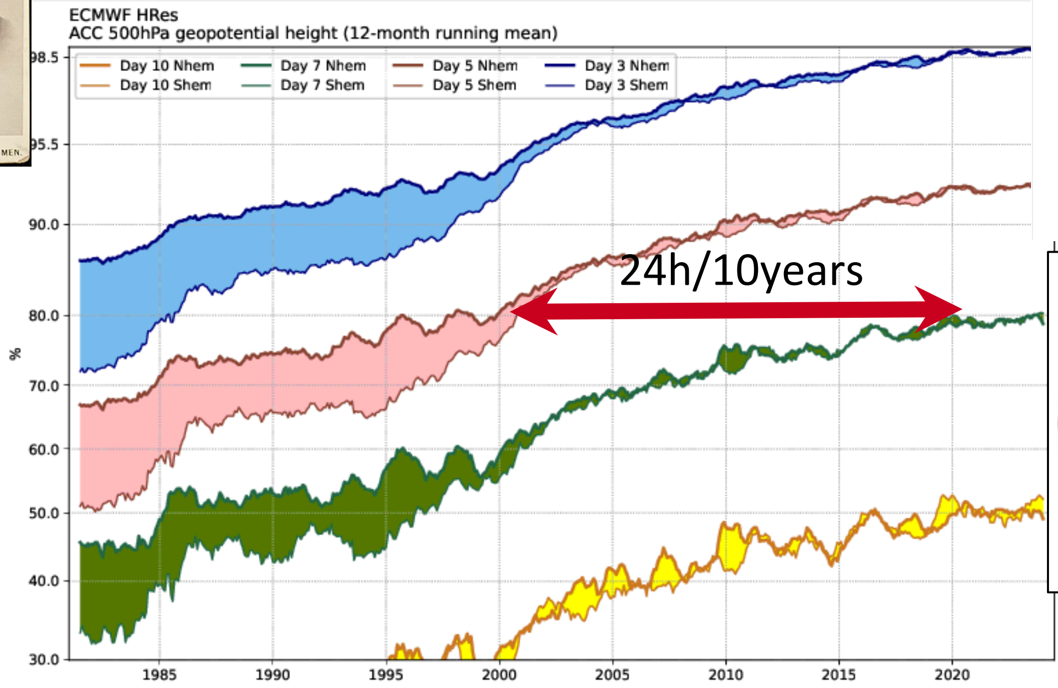


to

Bonn



with Bris



REVIEW

doi:10.1038/nature14956

The quiet revolution of numerical weather prediction

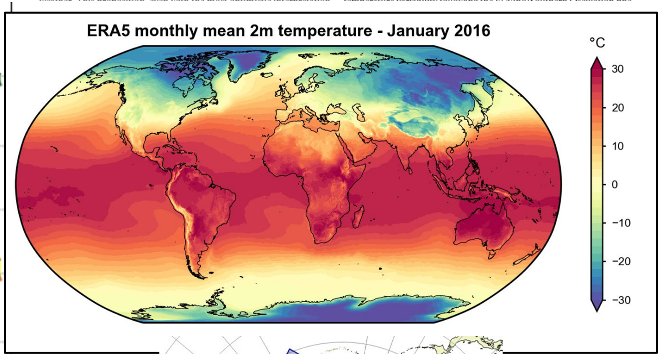
Peter Bauer[1], Alan Thorpe[1] & Gilbert Brunet[2]

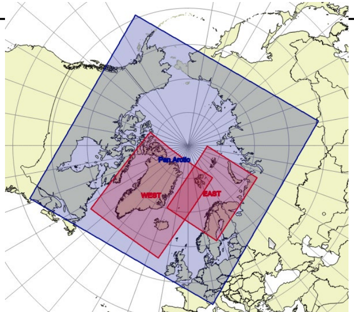
Advances in numerical weather prediction represent a quiet revolution because they have resulted from a steady accumulation of scientific knowledge and technological advances over many years that, with only a few exceptions, have not been associated with the aura of fundamental physics breakthroughs. Nonetheless, the impact of numerical weather prediction is among the greatest of any area of physical science. As a computational problem, global weather prediction is comparable to the simulation of the human brain and of the evolution of the early Universe, and it is performed every day at major operational centres across the world.

At the turn of the twentieth century, Abbe[1] and Bjerknes[2] proposed that the laws of physics could be used to forecast the weather; they recognized that predicting the state of the atmosphere could be treated as an initial value problem of mathematical physics, wherein future weather is determined by integrating the governing partial differential equations, starting from the observed current

use of observational information from satellite data providing global coverage.

More visible to society, however, are extreme events. The unusual path and intensification of hurricane Sandy in October 2012 was predicted 8 days ahead, the 2010 Russian heat-wave and the 2013 US cold spell were forecast with 1–2 weeks lead time, and tropical sea surface





Climate Change Service