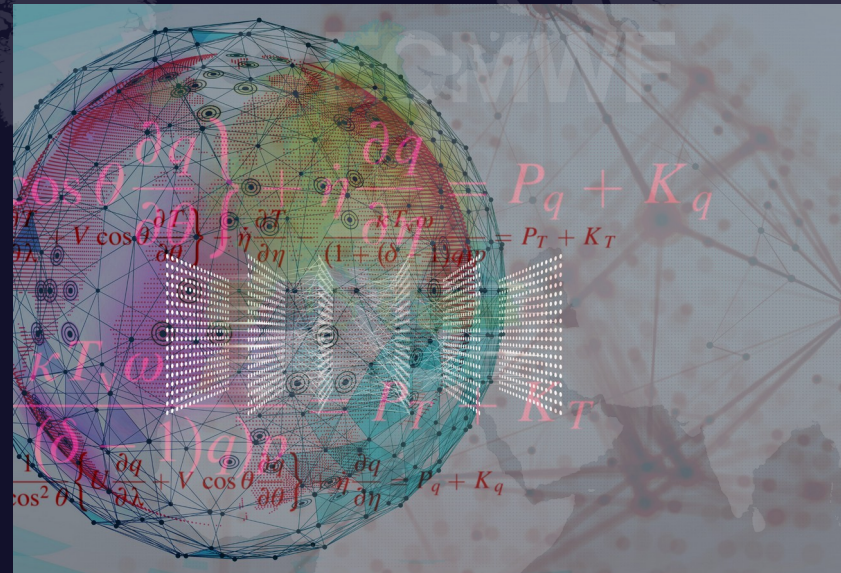


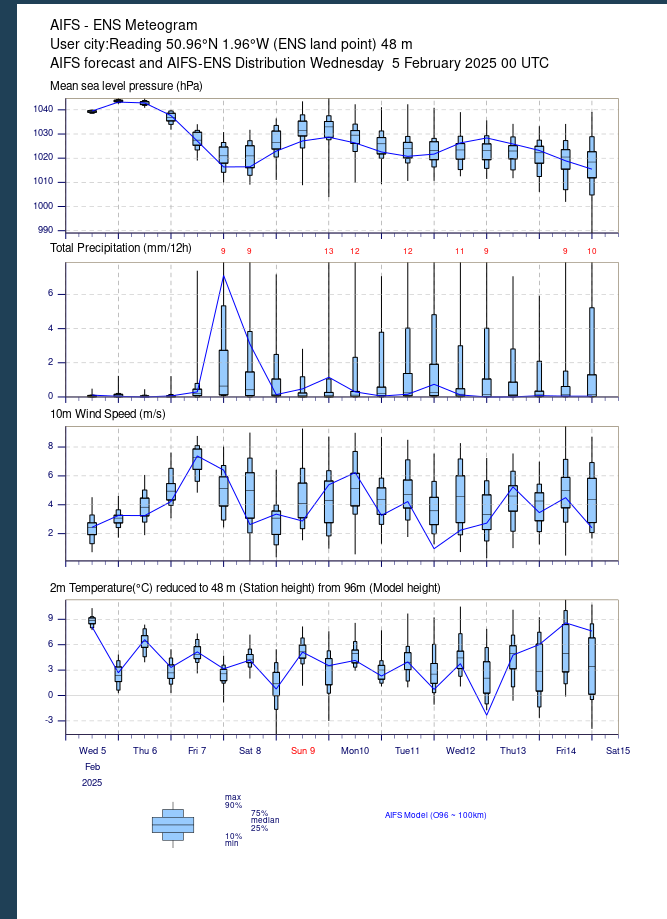
# Machine Learning in NWP: Forecast evaluation

Linus Magnusson and colleagues at ECMWF



# Real-time experimental forecasts available on OpenCharts

The screenshot shows the OpenCharts website interface. On the left, there is a navigation menu with options for 'Home / Charts catalogue', a search bar, and filters for 'Range' (Medium, Extended, Long), 'Type' (Forecasts, Verification), 'Component' (Surface, Atmosphere), and 'Product type' (High resolution forecast, Ensemble forecast, etc.). The main content area displays a grid of eight forecast panels, each with a map and a text box describing the model. The models include AIFS (ECMWF) ML, FourCastNet ML, FuXi ML, GraphCast ML, and Pangu-Weather ML, each providing forecasts for mean sea level pressure, wind speed, and temperature at 850 hPa.



All models are trained on ERA5 reanalysis (~0.25 degree resolution), but some fine-tuned on HRES analysis

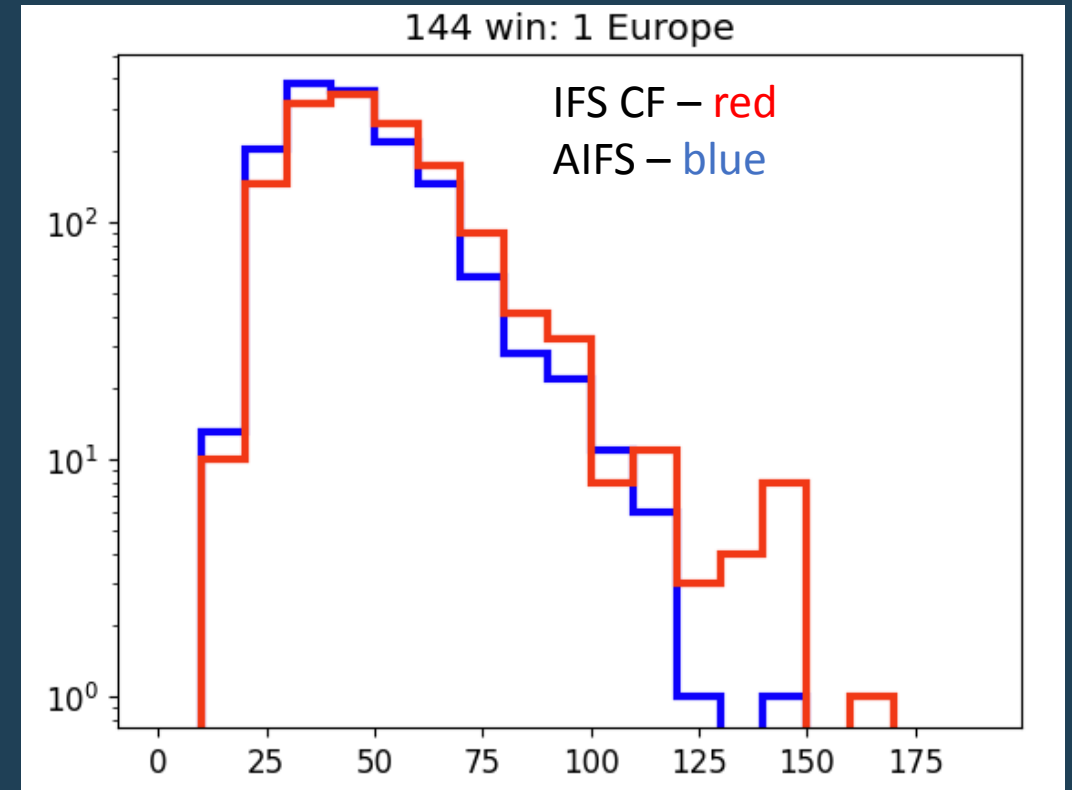
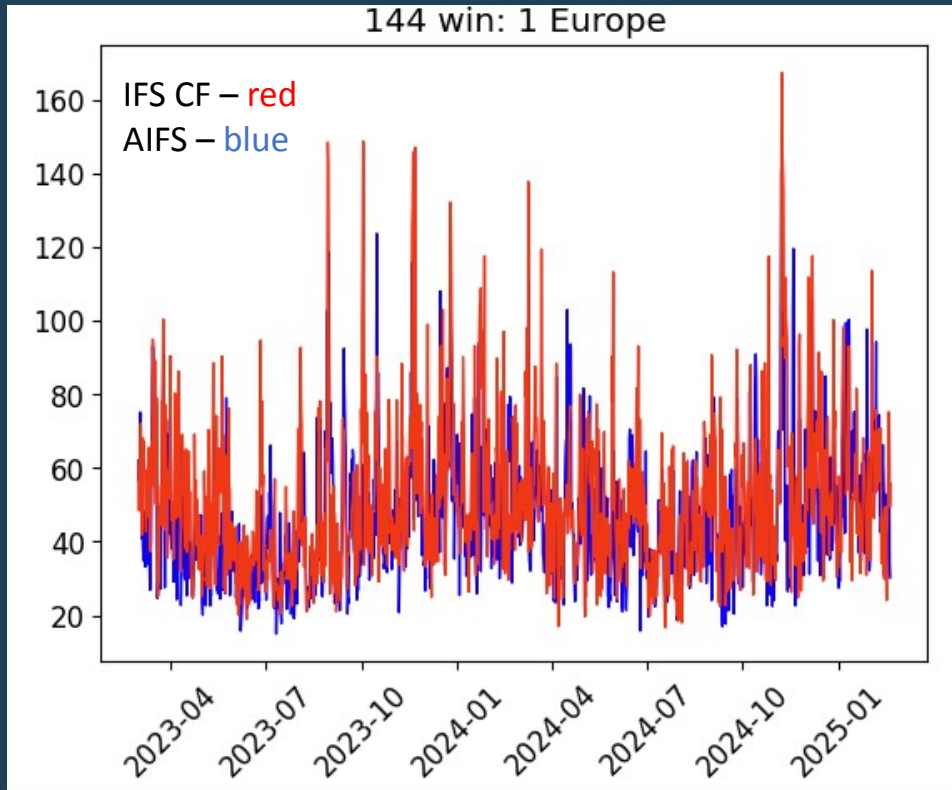
In all experiments below, we have initialised all ML models from ECMWF initial conditions.

# AIFS v1.0

- AIFS-single operational on 25 February with version v1.0
- <https://confluence.ecmwf.int/display/FCST/Implementation+of+AIFS+Single+v1>
- The new version includes new parameters:
  - Snowfall
  - Soil moisture and temperature
  - Cloud cover and radiation
  - Sharper precipitation features
- New AIFS ensemble based on CRPS as loss function and 0.25° resolution in testing and hopefully will be operational during the summer



# Day-to-day z500 RMSE for Europe



Less forecast busts in AIFS compared to HRES

# Extreme weather cases

## Severe Event Catalogue

Created by Florian Pappenberger, last modified by Timothy Hewson on Nov 09, 2022

rgui







On this space we collect material for evaluation of severe/extreme weather events. The focus is on the meteorological conditions and the forecast performance. The amount of material differs from case to case, and we are not claiming to give the full picture of the cases here. Users are welcome to contribute with material for the cases by using the comment function in the bottom of each page. To suggest a new case to evaluate, please contact us at the email address given below. If you have any initial comments and material, please include them in the mail.

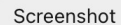
Contact email address [servicedesk@ecmwf.int](mailto:servicedesk@ecmwf.int)

(Please note that some of the links on the pages are only accessible from ECMWF.)


## Navigation

### List of (recent) cases

-  [202404 - Snowfall / Cold - Sweden / Finland](#)
-  [202404 - Rainfall - UAE](#)
-  [202404 - Rainfall - Brazil](#)
-  [202404 - Cold -Europe](#)

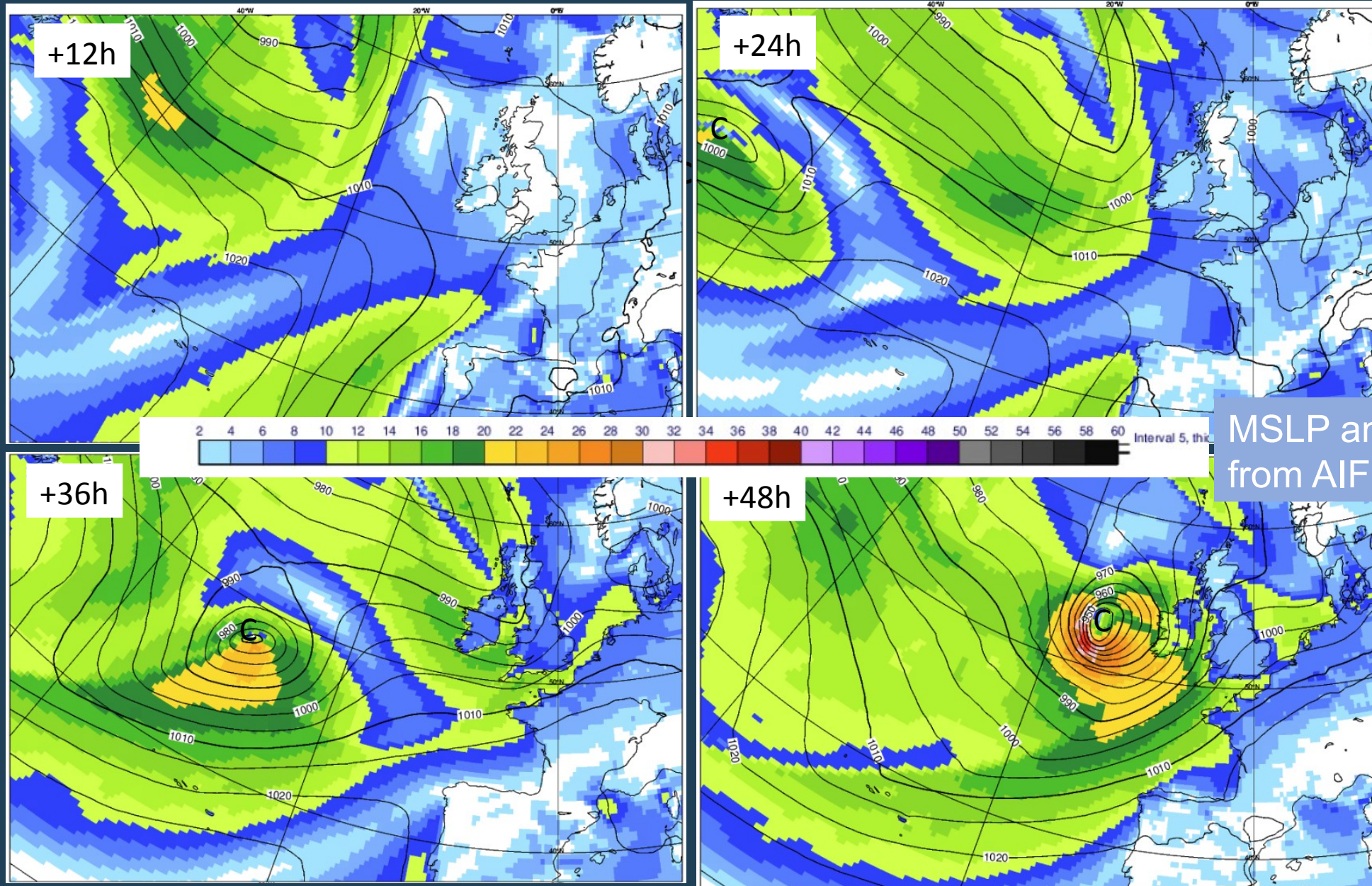
 Screenshot

Search (for old cases enter the year and month of the event, as yyyyymm)

AIFS cases usually included in the ECMWF severe event catalogue  
<https://confluence.ecmwf.int/display/FCST/Severe+Event+Catalogue>

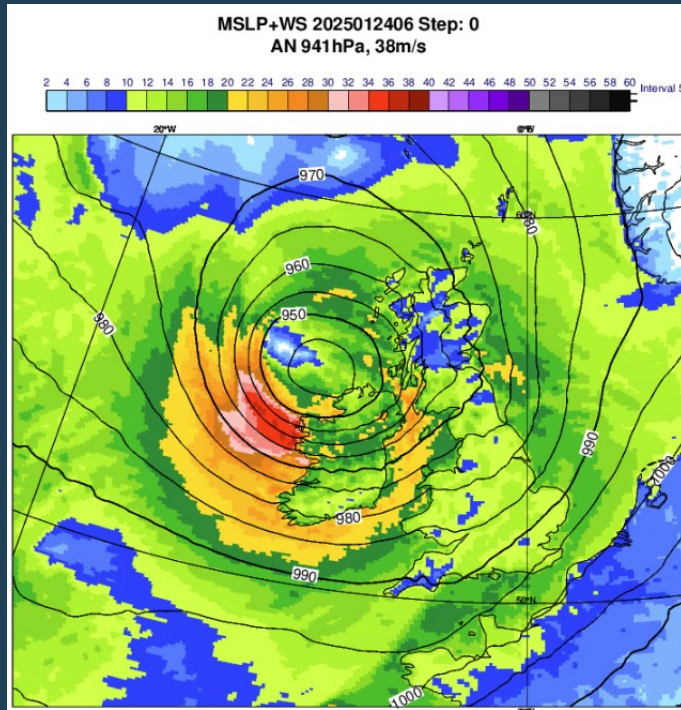
# AIFS: Storm Eowyn (forecast from 22 Jan 2025 00UTC)



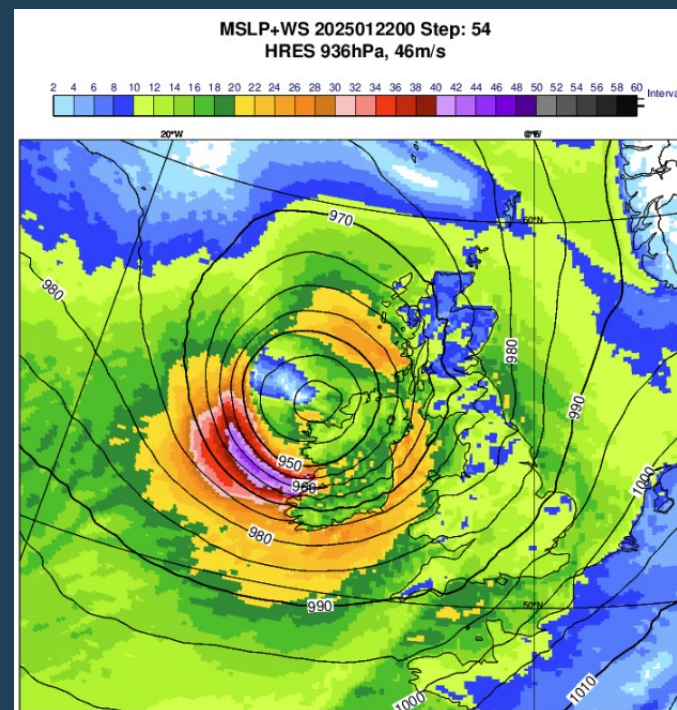
MSLP and wind speed  
from AIFS model

# Storm Evowyn (2-day forecasts valid 24 Jan 2025 06UTC)

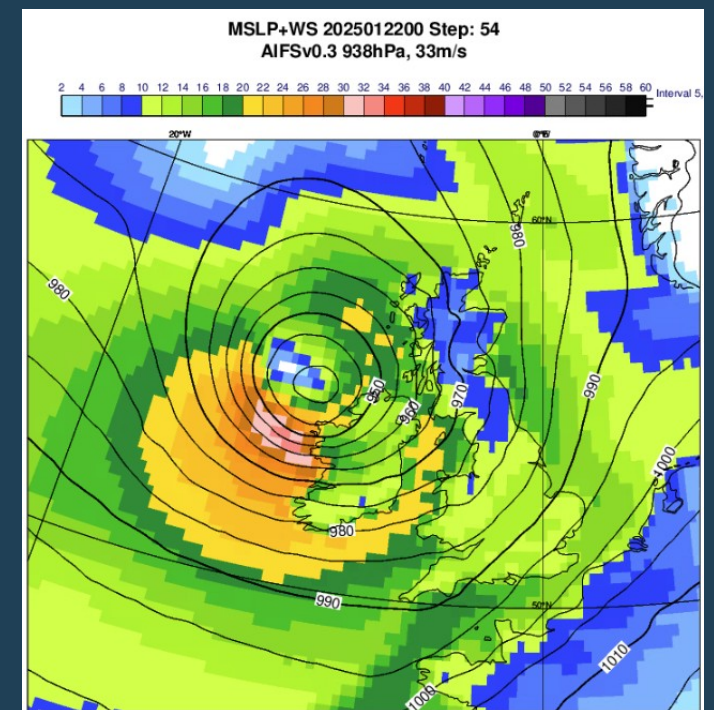
## Analysis



## IFS CF

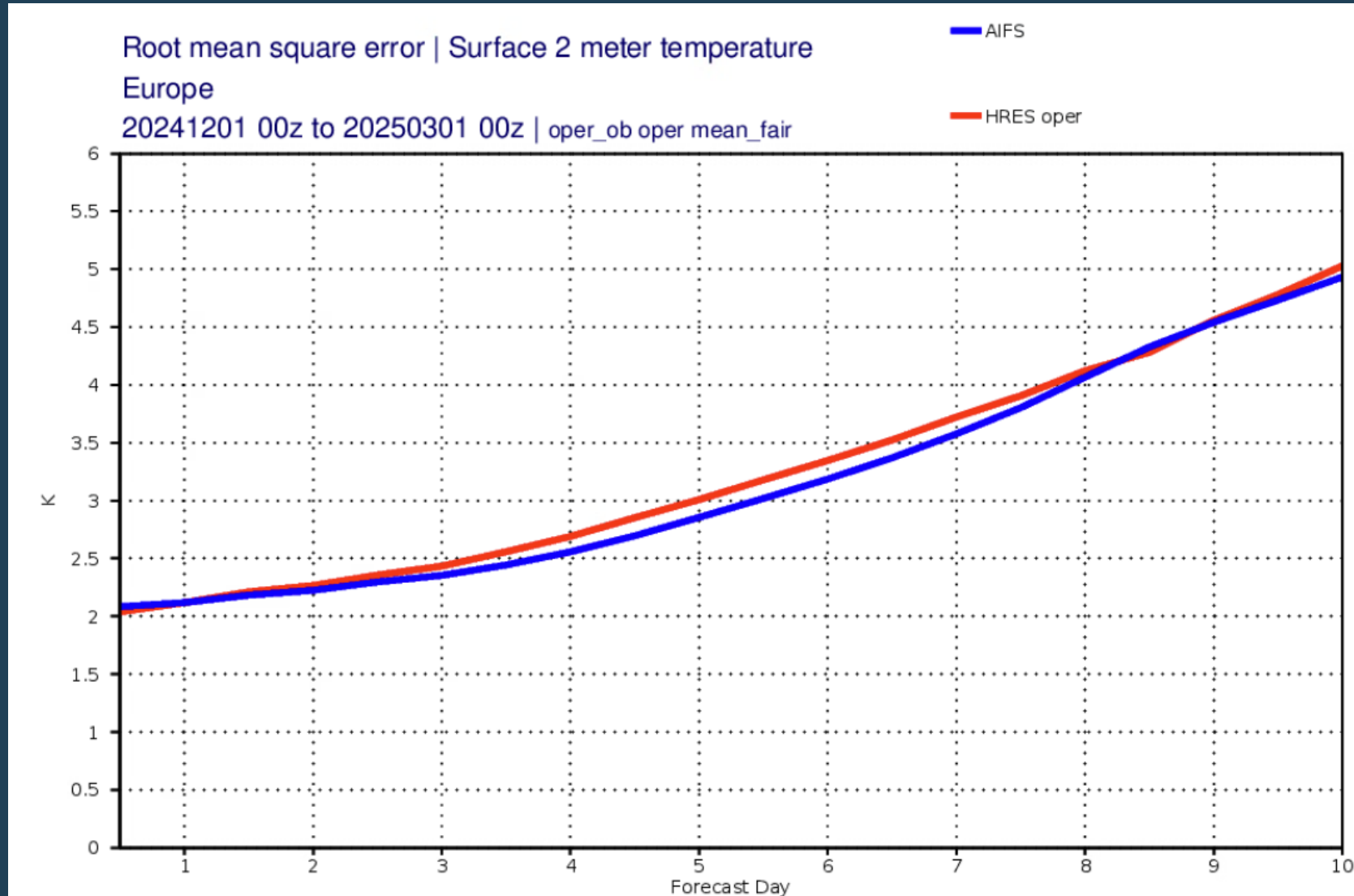


## AIFS v1.0



- Better position forecast in of the maximum wind in AIFS
- Similar minimum pressure 935-940hPa
- Less extreme wind speed in ML models 46 m/s vs. 33 m/s

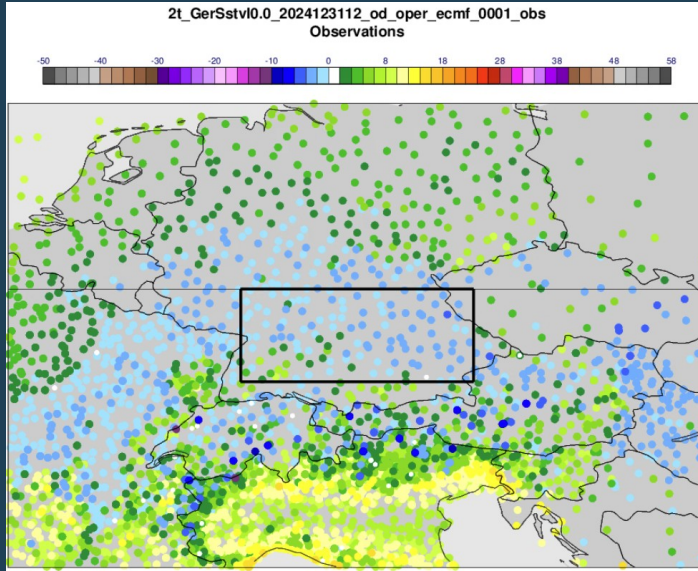
# 2-metre temperature verification for DJF 2024/2025



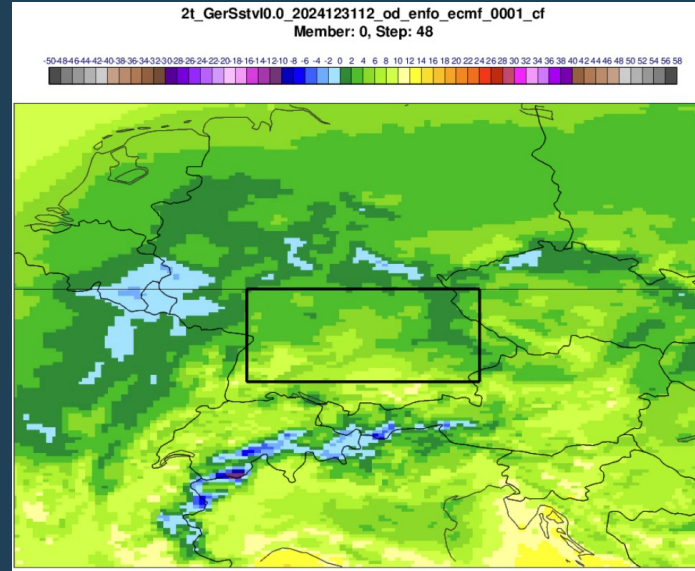
# Problem in IFS with 2-metre temperature over Europe, Winter 2024/2025

2-metre temperature 31 December 2024 12UTC

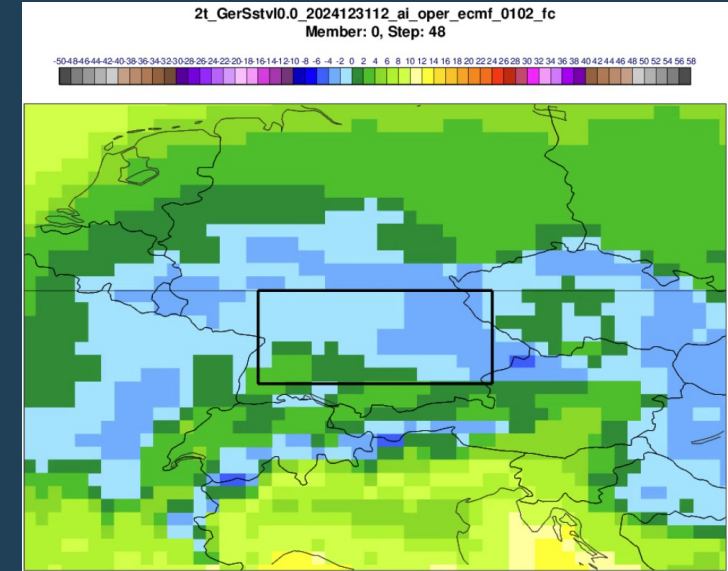
Observations



IFS control (48h)



AIFSv1.0 (48h)

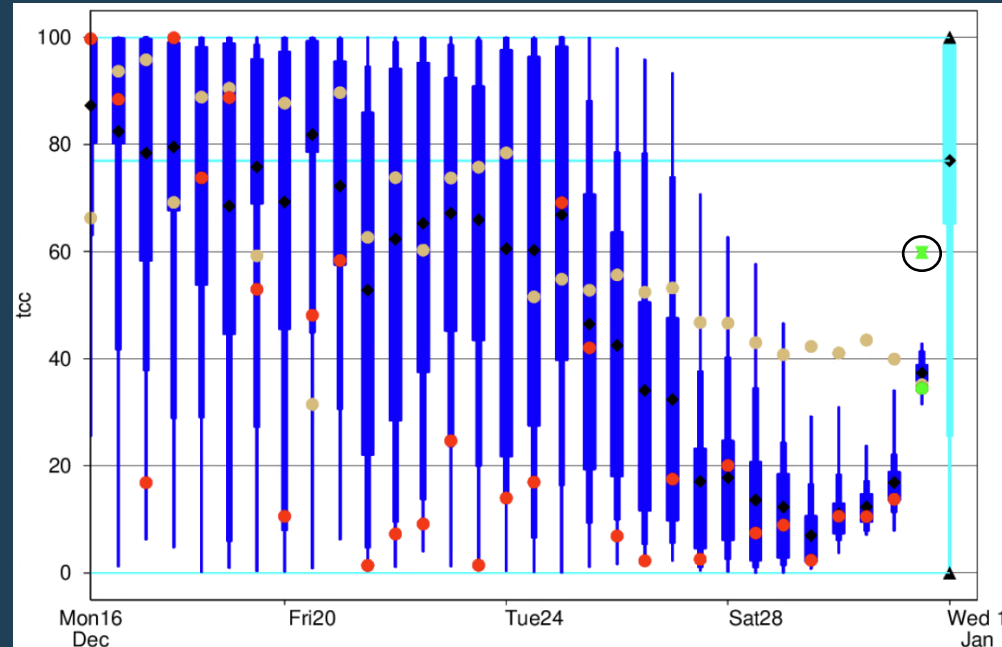
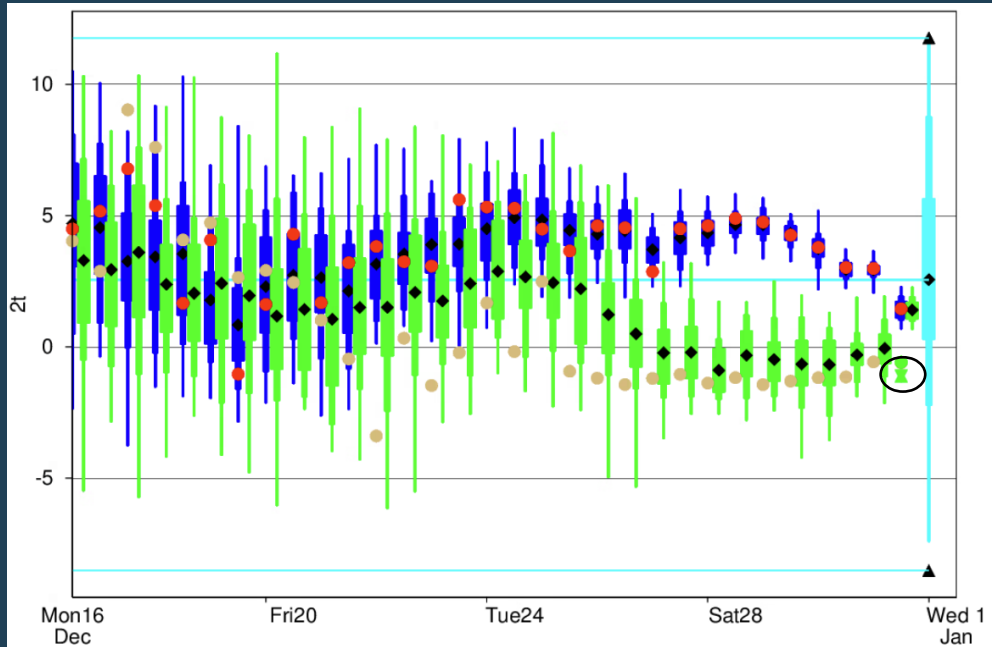


- IFS too warm, much better captured in AIFS

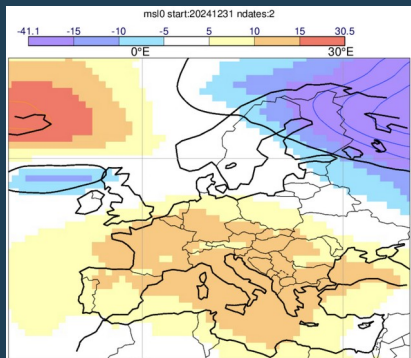
# Problem in IFS with low clouds over Europe, Winter 2024/2025

2-metre temperature valid 31 December 2024 12UTC

Total cloud cover valid 31 December 2024 12UTC

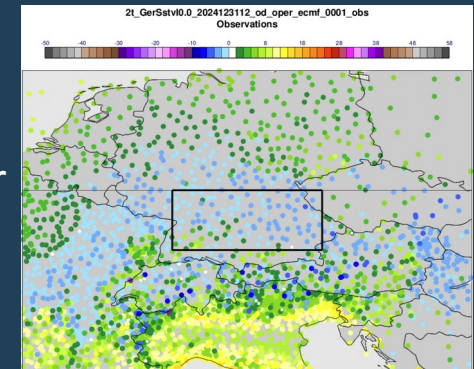


Observations –green hourglass, IFS analysis – green dot IFS CF – red dot, AIFS-single v1.0 – light brown  
 IFS ENS – blue, AIFS-CRPS ENS – green, IFS model climate - cyan



MSLP anomaly

Averaged over station locations inside the box



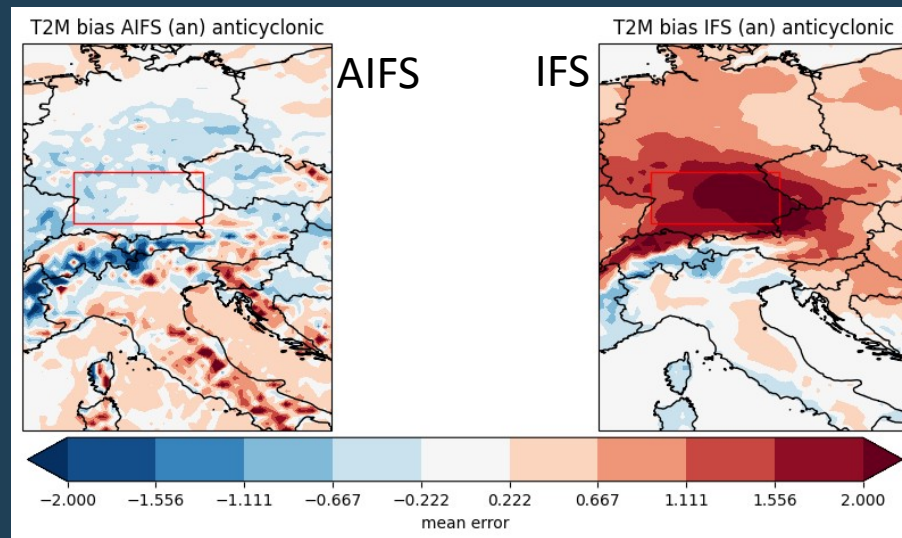
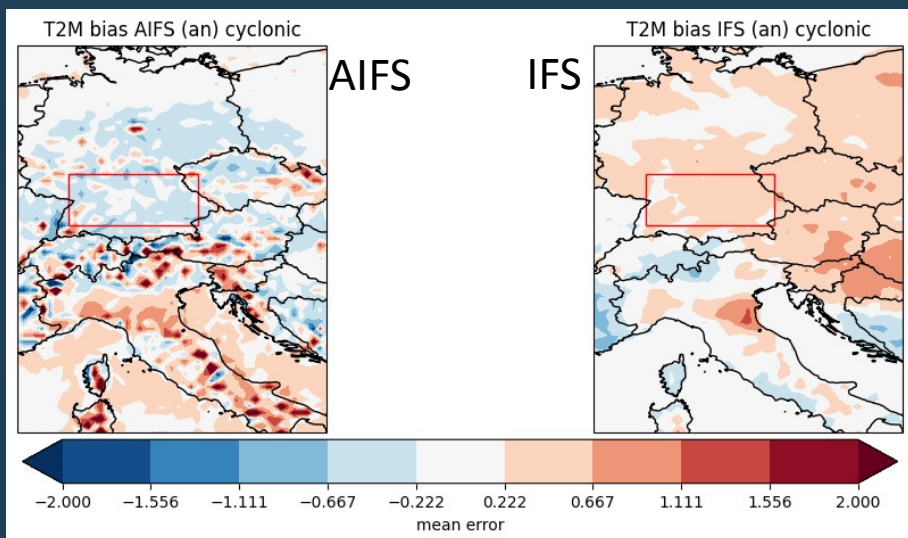
# Conditional verification based on flow pattern, Winter 2024/2025

Cyclonic

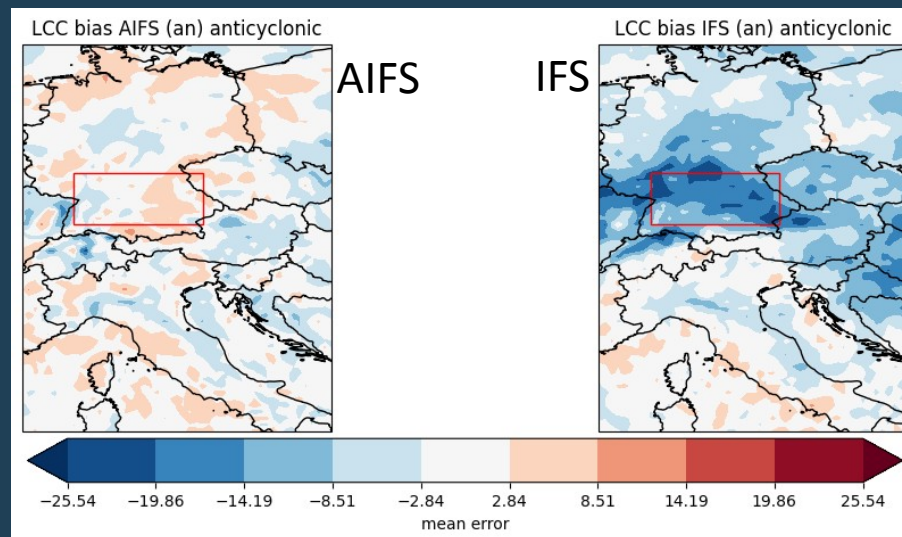
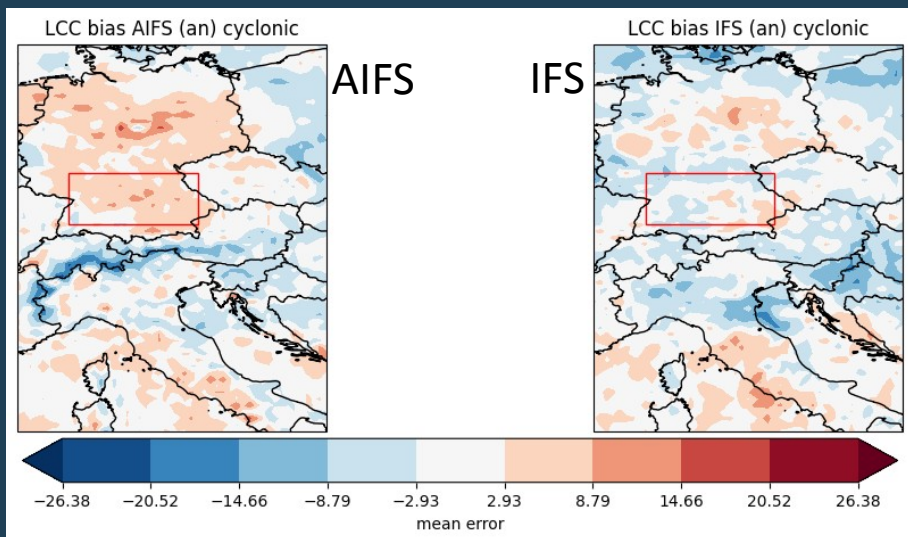
(verified against ECMWF analysis)

Anticyclonic

2-metre temperature



Low cloud cover



Bias, step +36h, validity dates (2024-10-02 12UTC - 2025-02-25 12UTC)

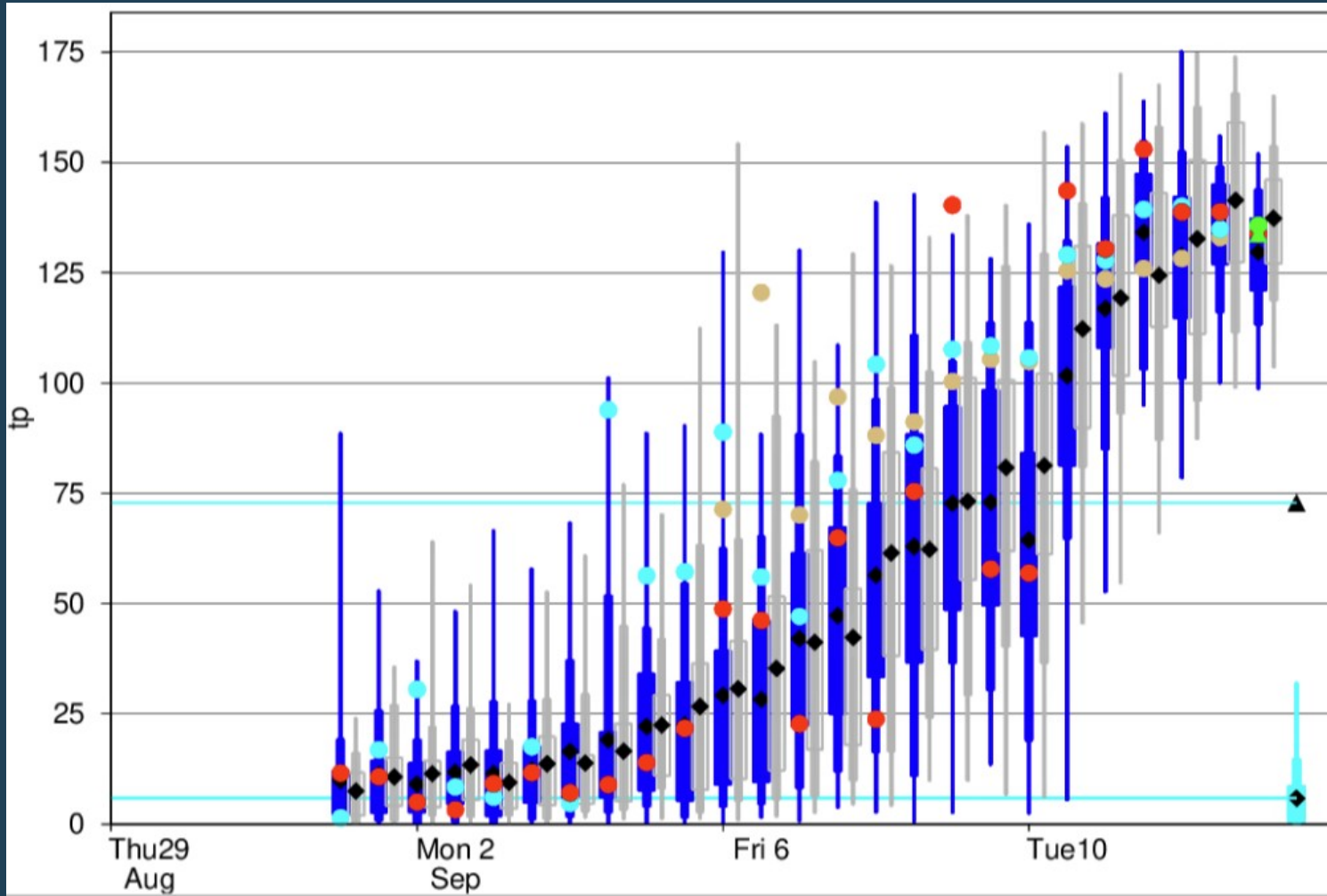
Flow conditions based on CURV index developed by Nigel Roberts, ECMWF

Thanks to Soufiane Karmouche, ECMWF



# Extreme precipitation during Storm Boris in central Europe, September 2024

72-hour precipitation 13 September 00UTC – 16 September 00UTC for the box



Observation mean: Green hourglass

IFS CF: red

AIFS v02.1: Cyan

AIFS v1.0: Beige

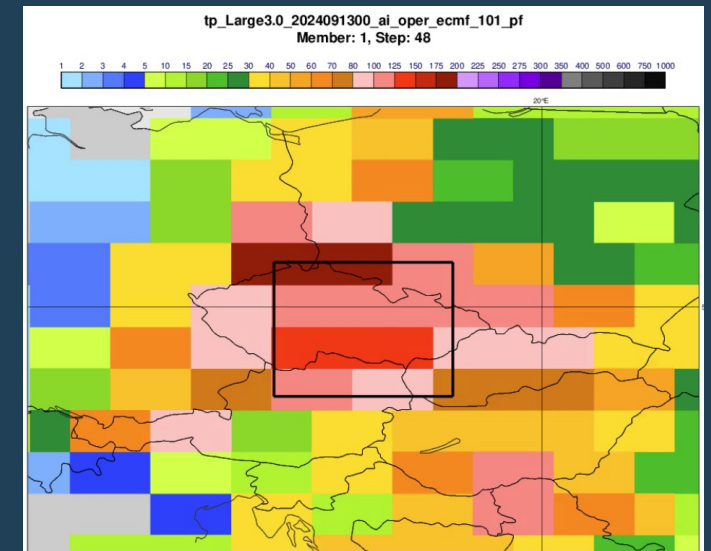
IFS-ENS : blue box-and-whisker

AIFS-ENS (diffusion, 1 degree): grey box-and-whisker

M-climate: cyan box-and-whisker

M-climate max: black triangle

AIFS ensemble member (48-120h)

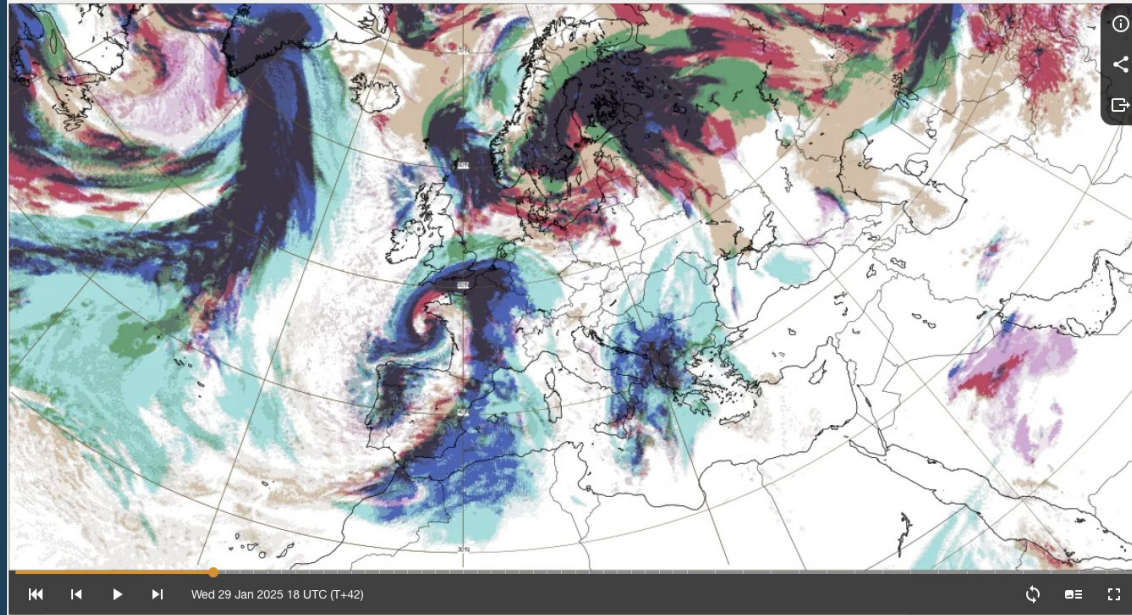


# Precipitation verification for JJA 2024

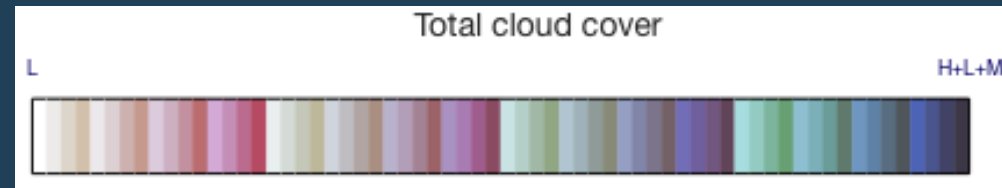
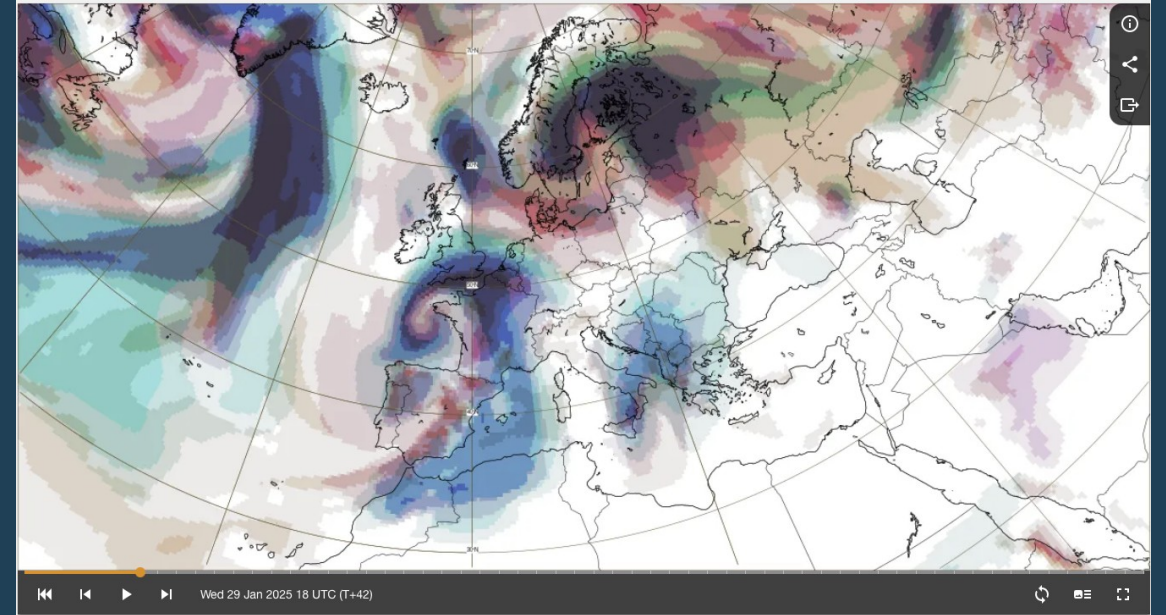
---

# Example of cloud forecasts, 29 January 2025 00UTC+48h

IFS CF



AIFS v1.0



# Summary

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- From our daily monitoring of AIFS and IFS we continue to learn about strengths and weaknesses of the system
- Better large-scale scores for AIFS compared to IFS – fewer forecast busts
- Problem for AIFS to capture maximum winds also in extra-tropical cyclones
- AIFS do not suffer as much from the long-standing issue with low clouds during anti-cyclonic conditions in the winter

# Further reading

aifs v.01, Lang et al., AIFS: a new ECMWF forecasting system

<https://www.ecmwf.int/en/newsletter/178/news/aifs-new-ecmwf-forecasting-system>

aifs v.021, Lang et al., AIFS -- ECMWF's data-driven forecasting system

<https://arxiv.org/abs/2406.01465>

Lang et al., Enter the ensembles :

<https://www.ecmwf.int/en/about/media-centre/aifs-blog/2024/enter-ensembles>

Lang et al., AIFS-CRPS: Ensemble forecasting using a model trained with a loss function based on the Continuous Ranked Probability Score

<https://arxiv.org/html/2412.15832v1>

Alexe et al., Data-driven ensemble forecasting with the AIFS :

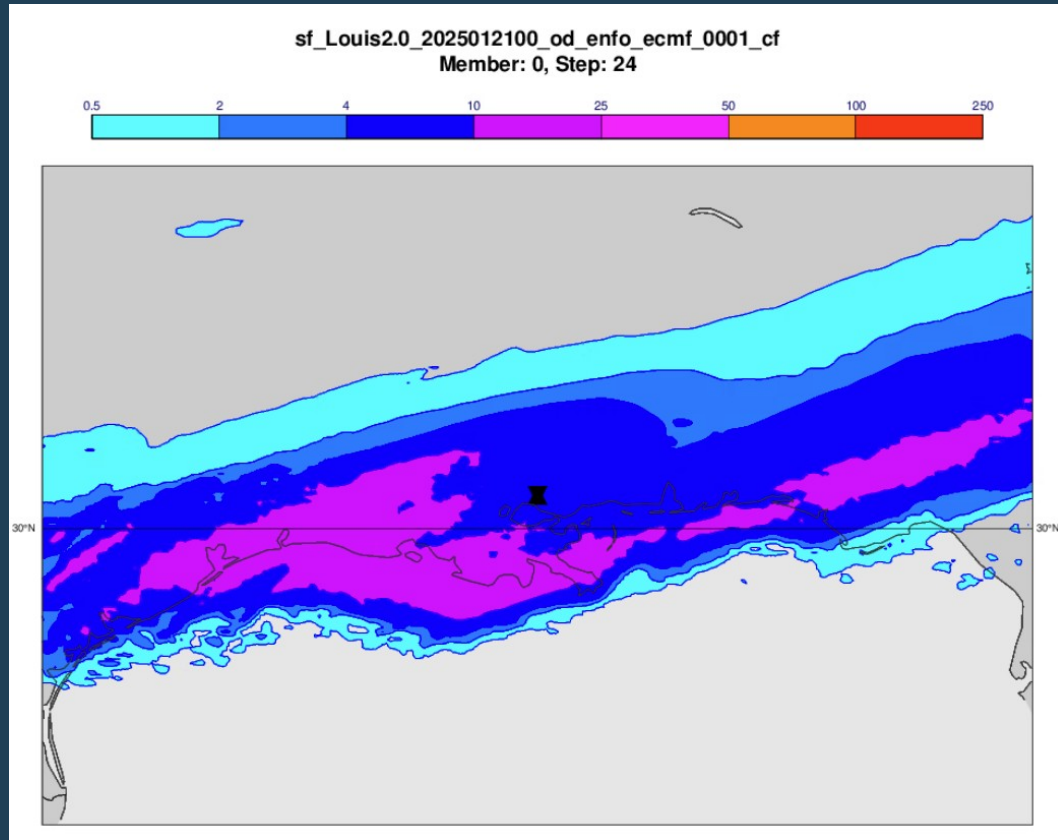
<https://www.ecmwf.int/en/newsletter/181/earth-system-science/data-driven-ensemble-forecasting-aifs>

Ben Bouallègue et al., The Rise of Data-Driven Weather Forecasting: A First Statistical Assessment of Machine Learning–Based Weather Forecasts in an Operational-Like Context:

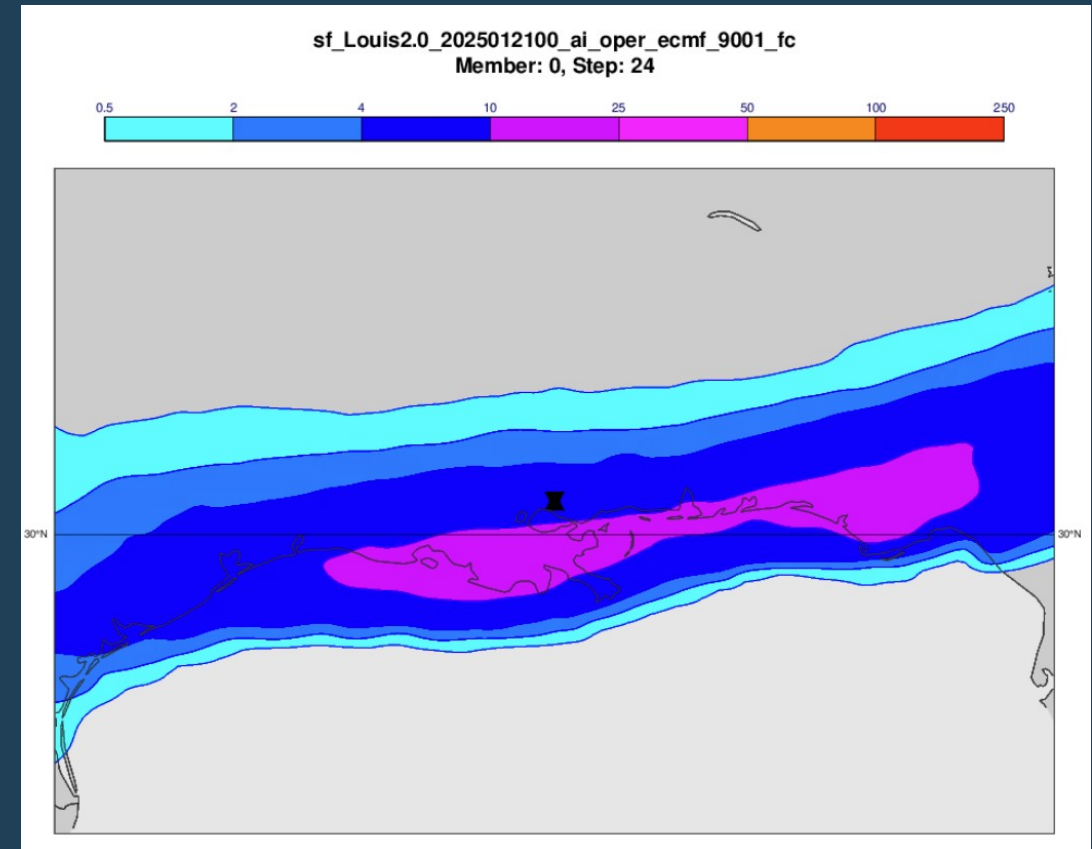
<https://doi.org/10.1175/BAMS-D-23-0162.1>

# Extreme snowfall over Louisiana, 24-72h forecast from 00UTC 21 January 2025

ENS CF



AIFS v1.0

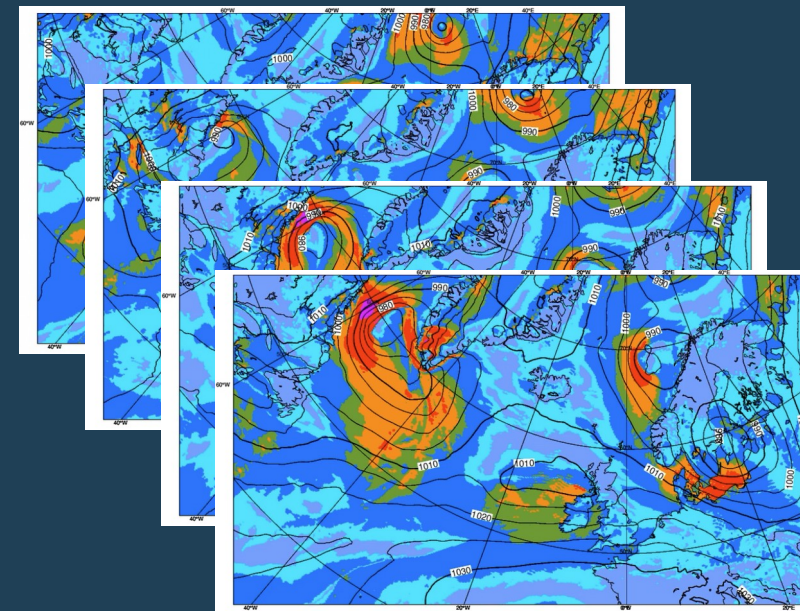


# Experimental forecasts available from ECMWF web:

- AIFS (ECMWF experimental AI model)
- FourCastNet (NVIDIA)
- PanguWeather (Huawei)
- Graphcast (Google Deepmind)
- Aurora (Microsoft)

All models are trained on ERA5 reanalysis (~0.25 degree resolution), but some fine-tuned on HRES analysis

In all experiments below, we have initialised all ML models from ECMWF initial conditions.



Since last summer:  
Experimental AIFS ensemble with 1 degree resolution, based on diffusion model

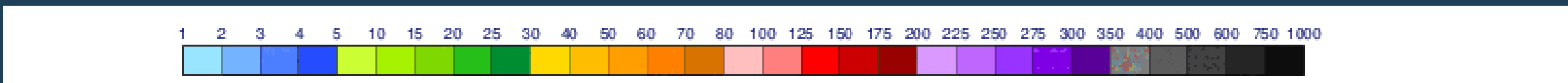
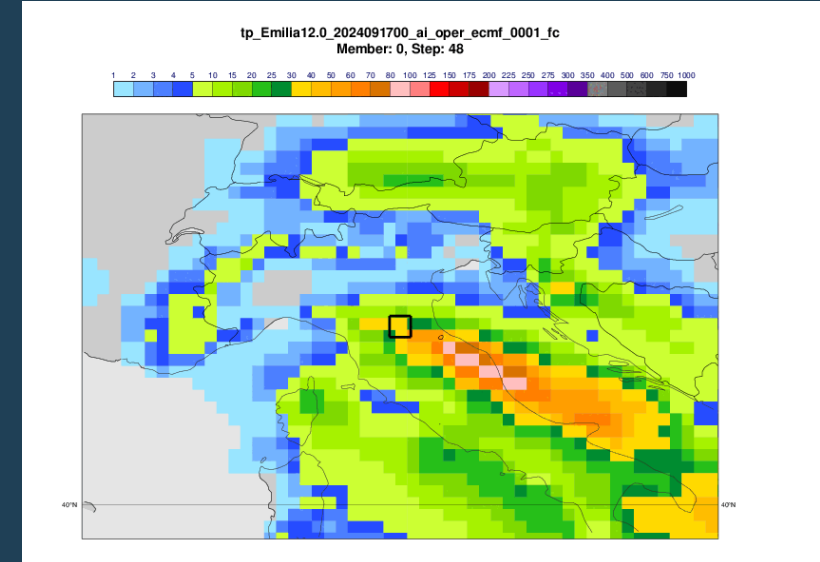
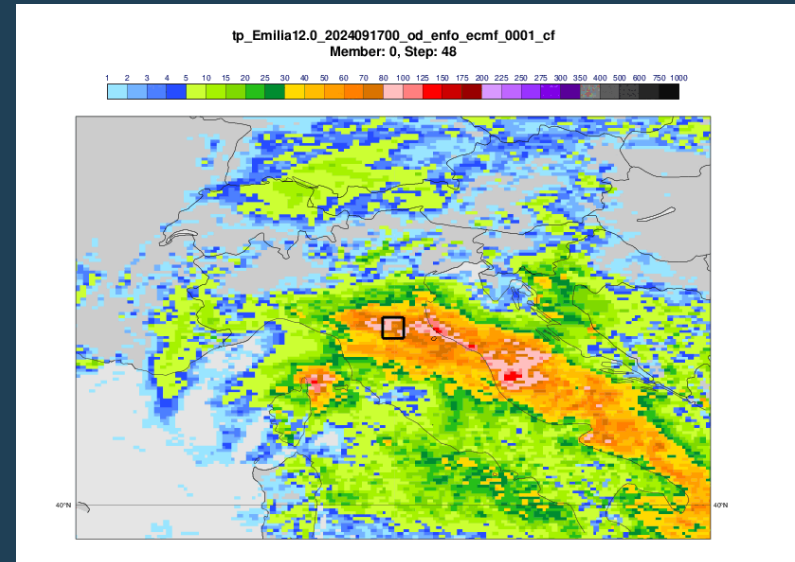
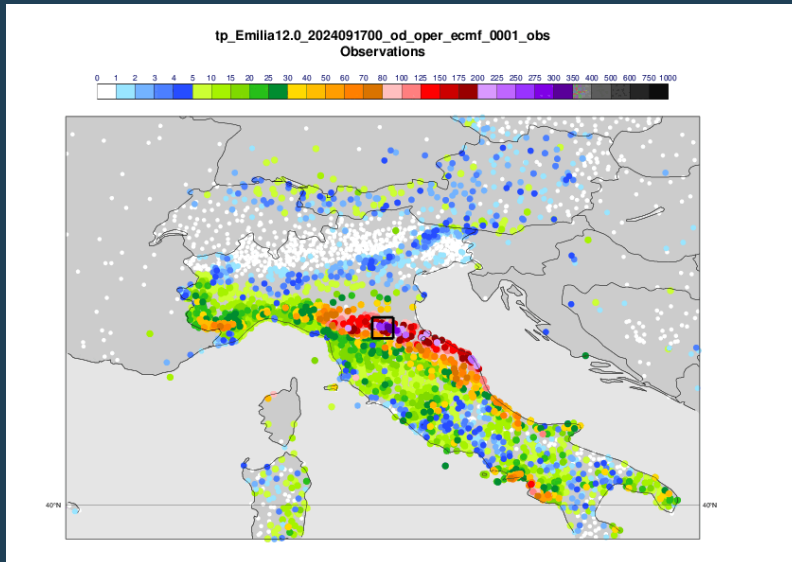
# Boris Part 2 - Italy

24-hour precipitation 17 September 00UTC – 18 September 00UTC

Observations

IFS control (48-72h)

AIFS (48-72h)



- Smooth precipitation field from AIFS (do not capture local structures)



# Scores from the recent winter – z500 over Northern Hemisphere (N.Hem)

Root-mean-square error (RMSE)

Anomaly correlation (ACC)

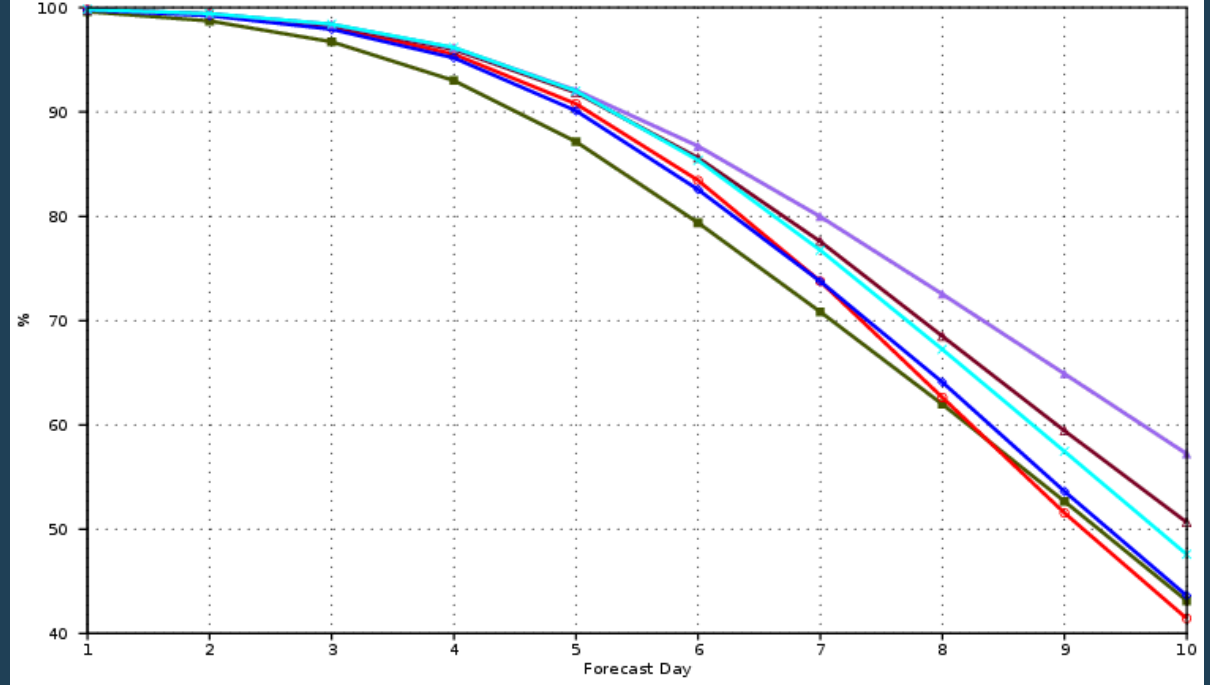
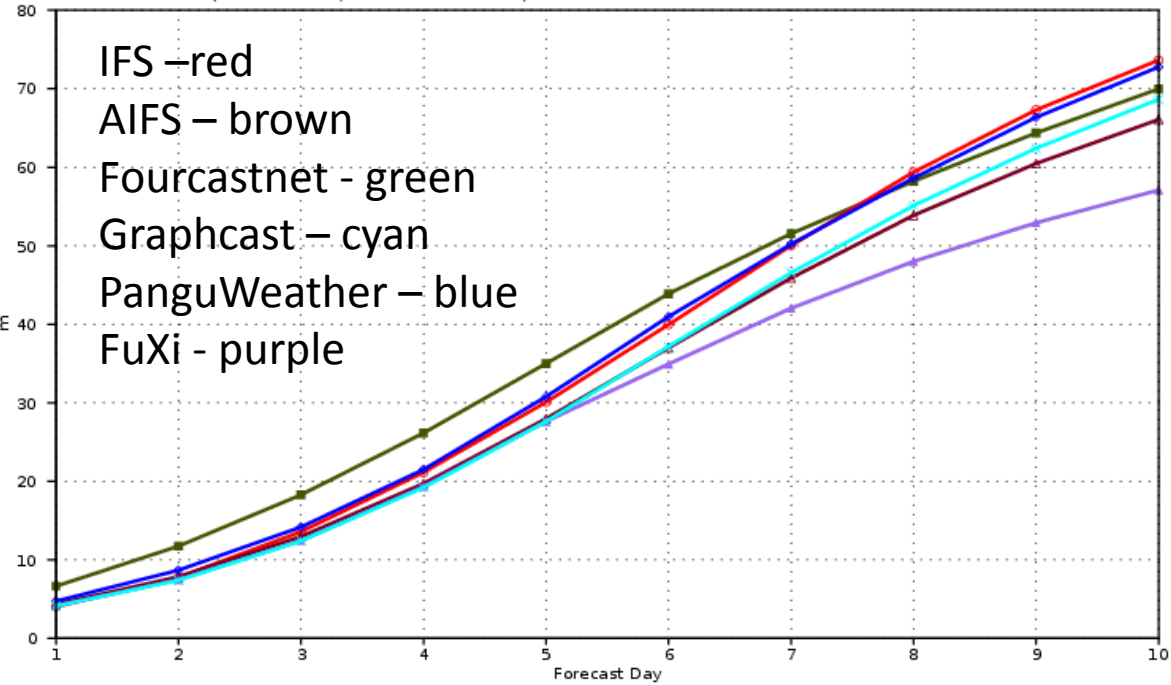
Season: JJA 2024  
500hPa geopotential  
Root mean square error | NHem Extratropics

Season: JJA 2024  
500hPa geopotential  
Anomaly correlation | NHem Extratropics

—●— AIFS  
—●— GraphCast  
—●— IFS  
—●— FuXi  
—●— FourCastNet  
—●— Pangu-Weather

—●— AIFS  
—●— GraphCast  
—●— IFS  
—●— FuXi  
—●— FourCastNet  
—●— Pangu-Weather

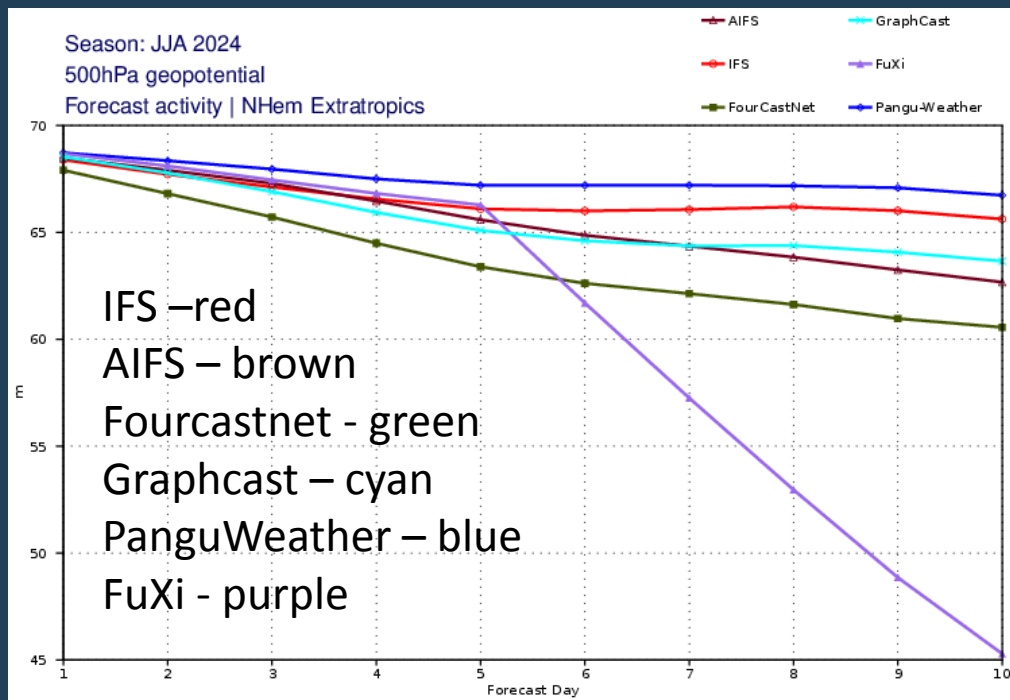
IFS – red  
 AIFS – brown  
 Fourcastnet - green  
 Graphcast – cyan  
 PanguWeather – blue  
 FuXi - purple



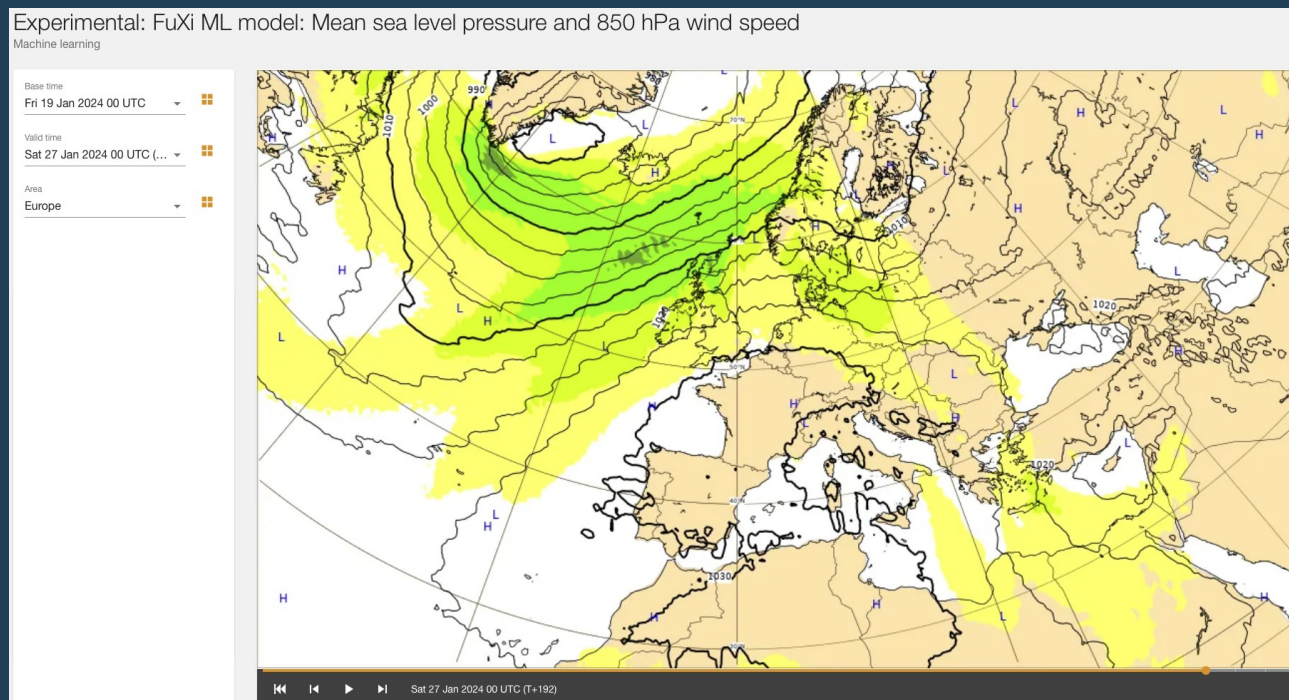
Verification plots available from OpenCharts

# Scores are not telling everything!

Forecast activity (measure of smoothness)



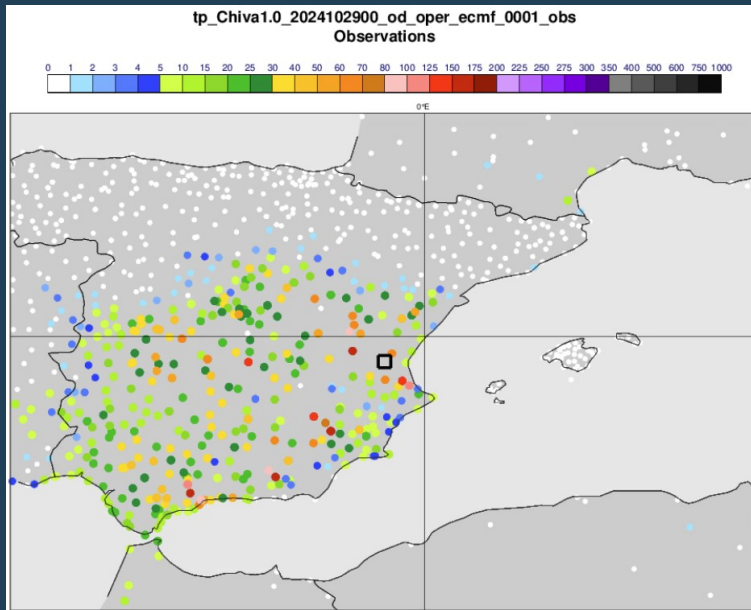
Example of MSLP and 850hPa wind speed from FuXi



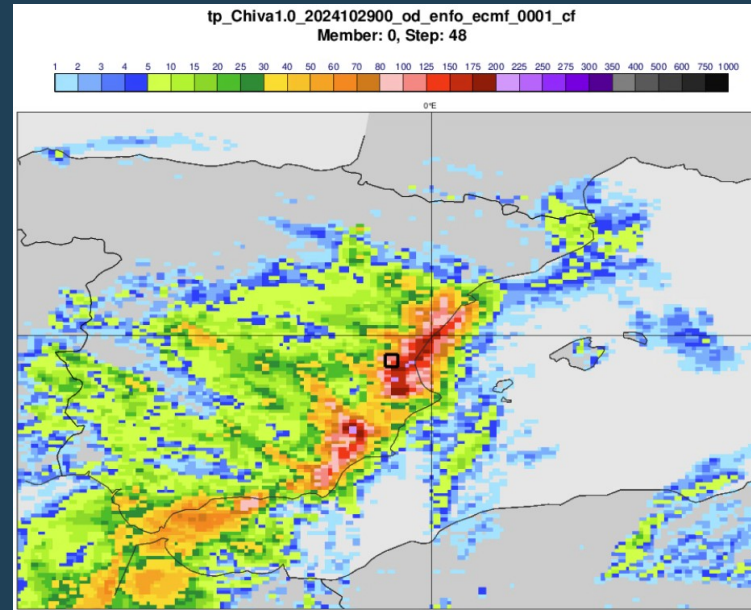
# Extreme precipitation during Valencia flood, October 2024

24-hour precipitation 29 October 00UTC – 30 October 00UTC

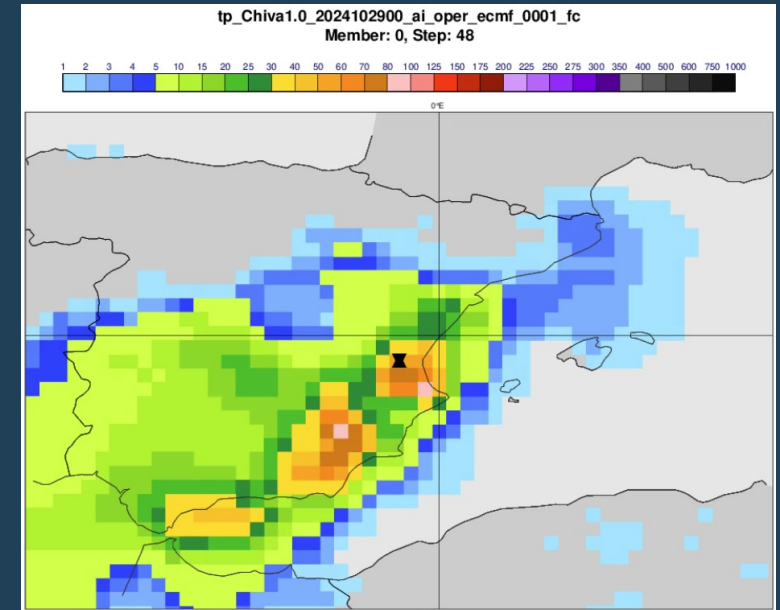
Observations



IFS control (48-72h)



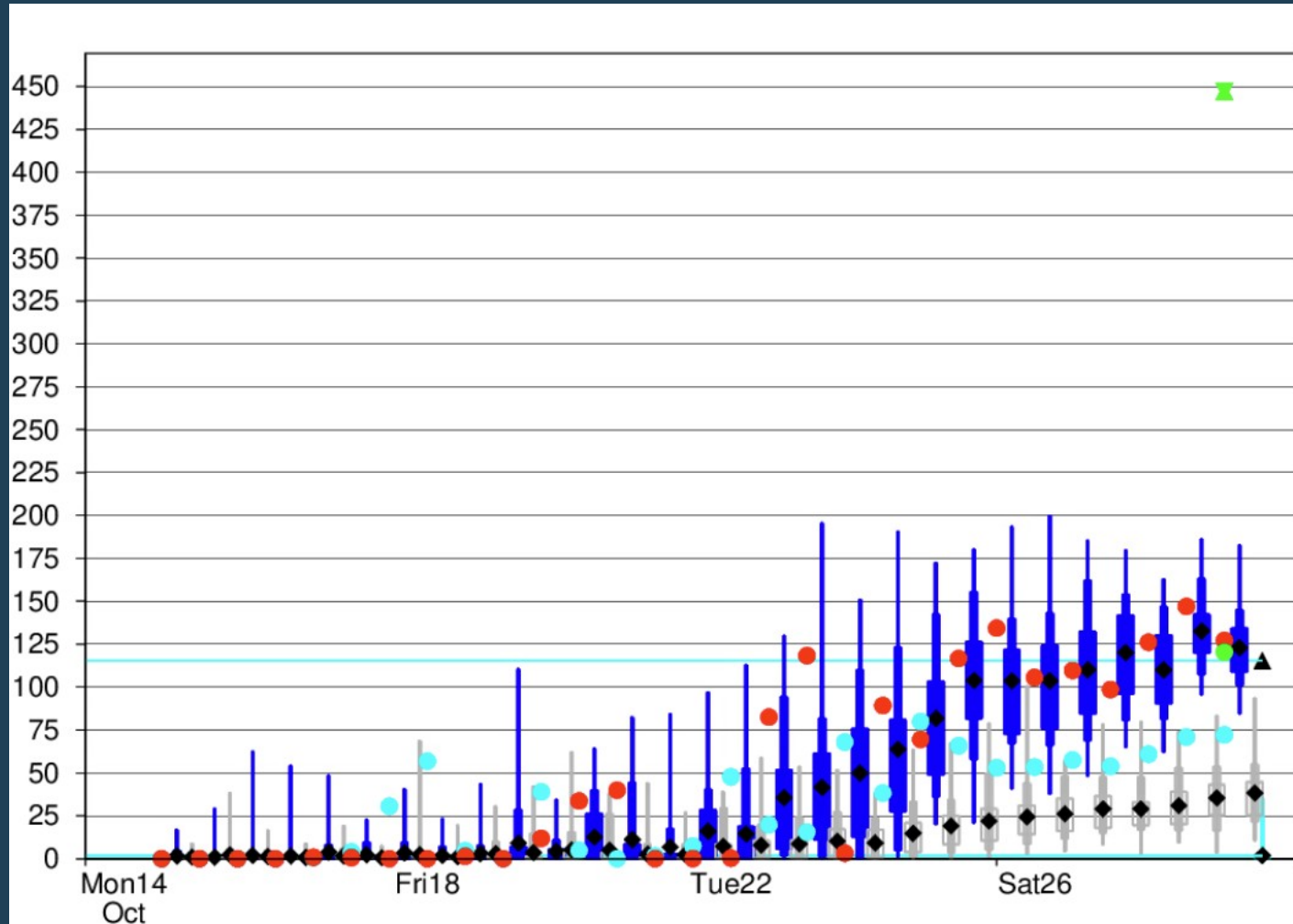
AIFS (48-72h)



- Lack of observations in our verification system
- Smooth precipitation field from AIFS (do not capture local structures)

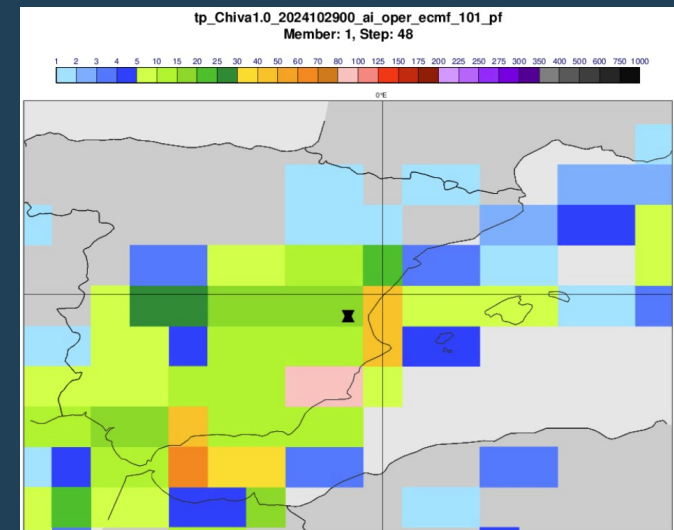
# Extreme precipitation during Valencia flood, October 2024

24-hour precipitation 29 October 00UTC – 30 October 00UTC

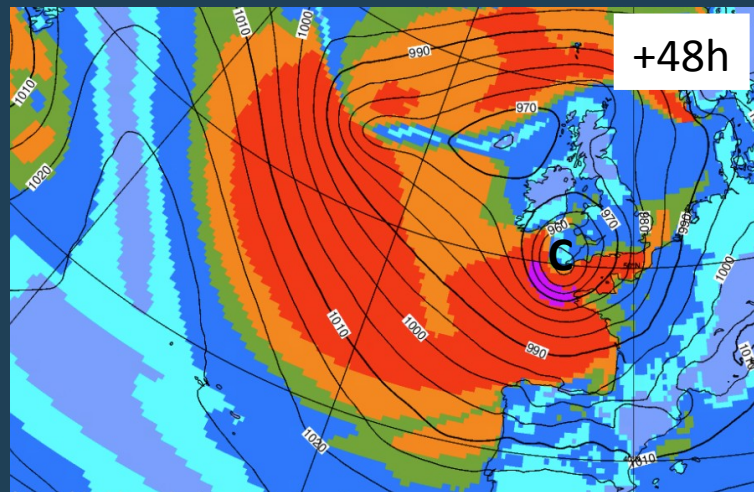
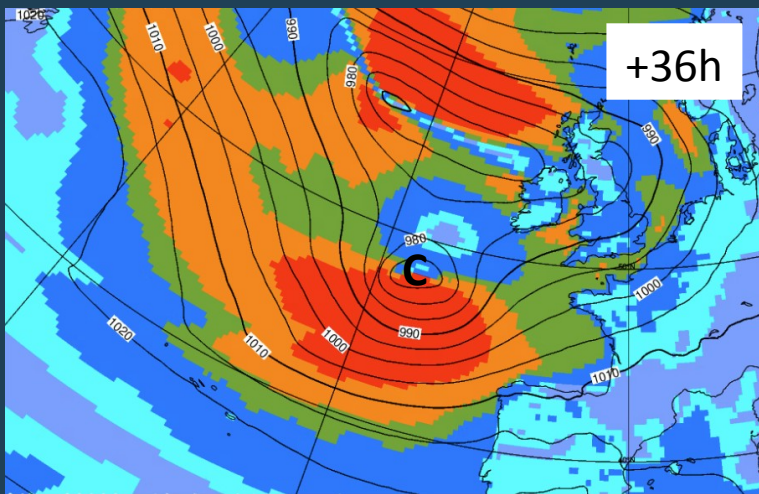
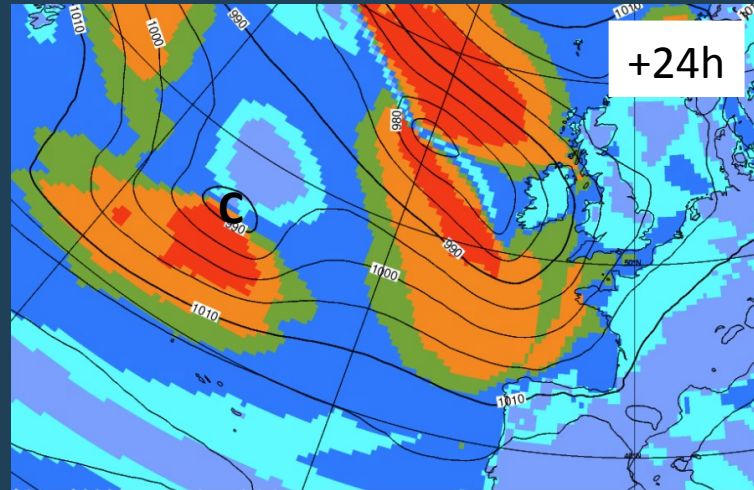
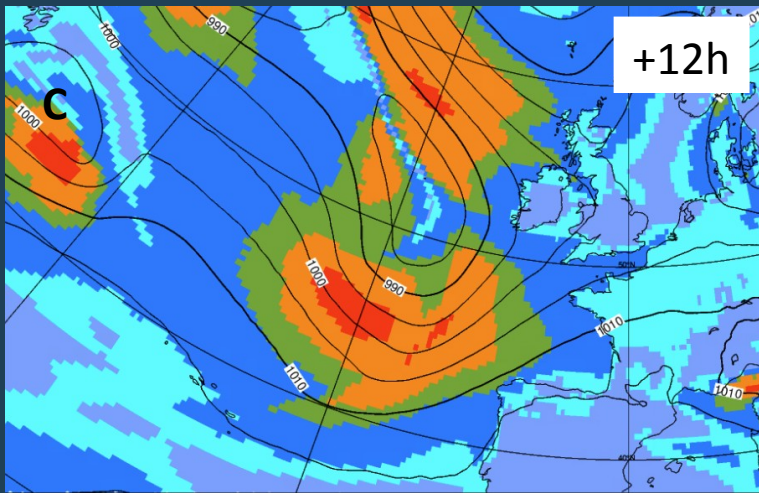


Observation mean: Green hourglass  
IFS control: red  
AIFS: Cyan  
IFS-ENS : blue box-and-whisker  
AIFS-ENS: grey box-and-whisker  
M-climate: cyan box-and-whisker  
M-climate max: black triangle

AIFS ensemble member (48-72h)



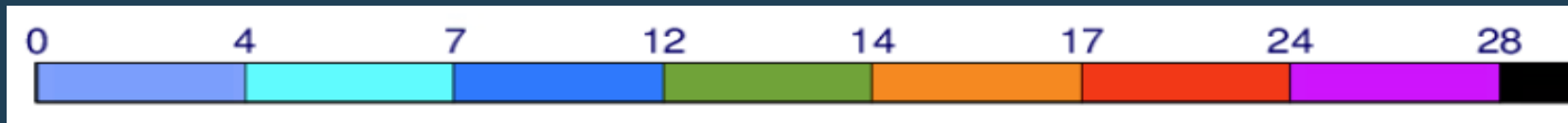
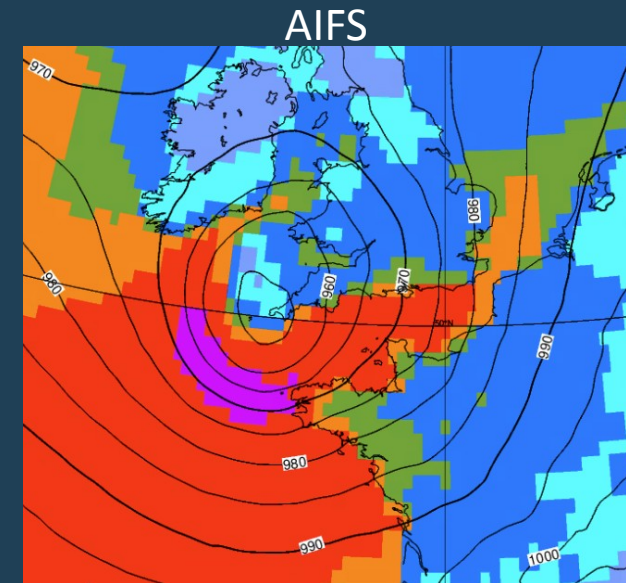
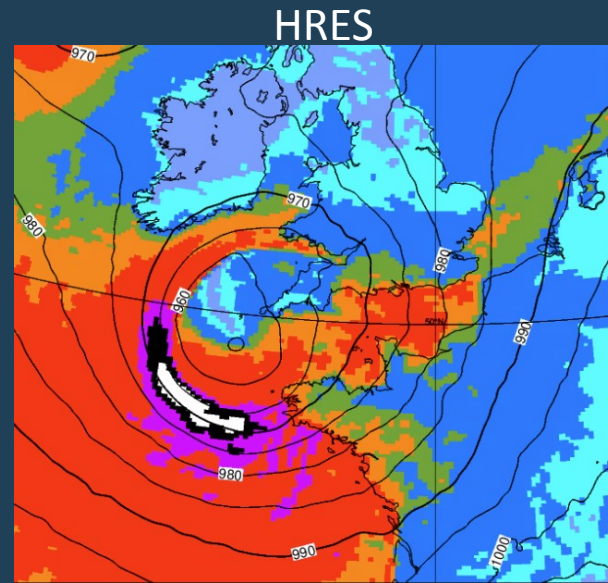
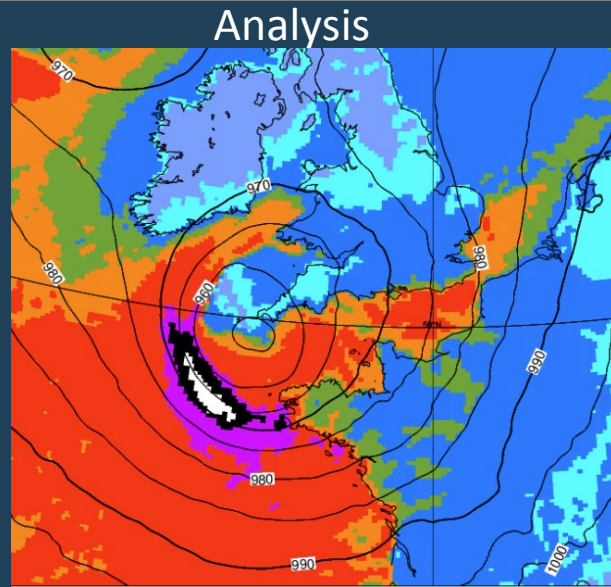
# AIFS: Storm Ciaran (forecast from 31 Oct 2023 00UTC)



MSLP and wind speed  
from AIFS model



# Storm Ciaran (2-day forecasts valid 2<sup>nd</sup> Nov 2023 00UTC)



- Better position forecast in the ML models
- Similar minimum pressure 960-965hPa
- Less extreme wind speed in ML models
- See Charlton-Perez et al. (2024, Nature)