Hybrid NWP-AI at MétéoFrance
Nudging AIFS large scales in the global NWP operational model ARPEGE

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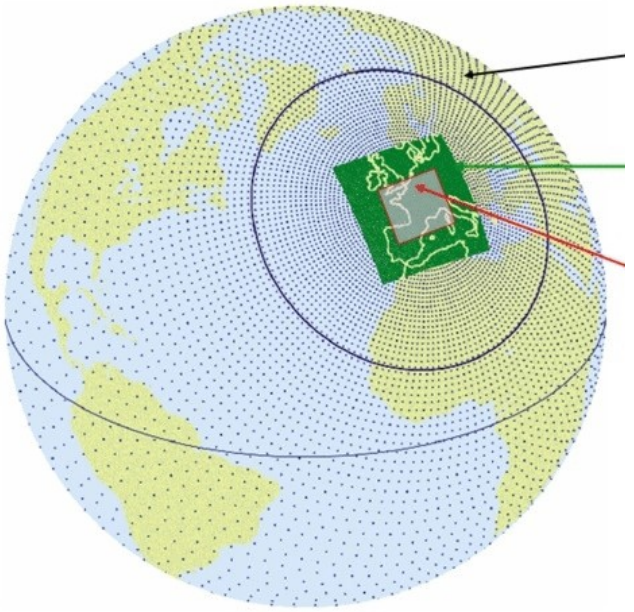
ECMWF Machine Learning Pilot Project

ARPEGE

ARPEGE :

- Streched grid (5km over Europe- ~25km on the antipodes)
- 105 levels
- 4 runs per day
- + 102H to +114H forecast

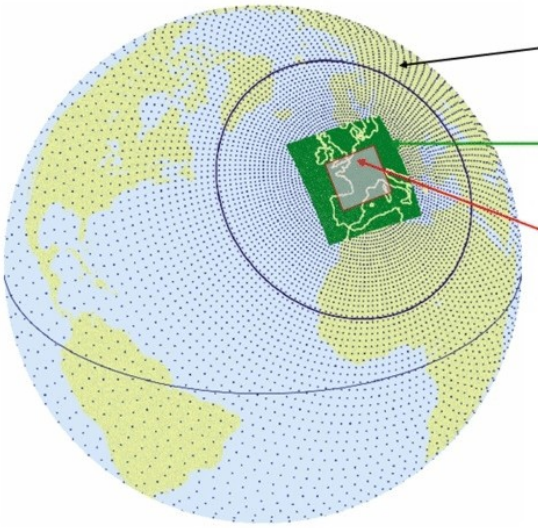


Physical and AI model Hybridation

Can we have the advantage of an AI model inside a physical one ?

ARPEGE :

+ Finescales
+ Physical consistency
+ All variables are produced
+ hourly output



AI Model:

+ Large scale are better forecasted
- Reduced set of variables
- Low resolution
- Smoothed

Can we force ARPEGE large scale to follow those of an AI-model ?

[Husain et al. 2024] Leveraging data-driven weather models for improving numerical weather prediction skill through large-scale spectral nudging.

Constraining ARPEGE « large scale » with AIFS

Following [*Polichtchouk et al. 2026*]

Only « large scales » are constrained from AIFS.

Here , we perform a spectral nudging on ARPEGE streched grid till T63c2.2.

Nudged variables :

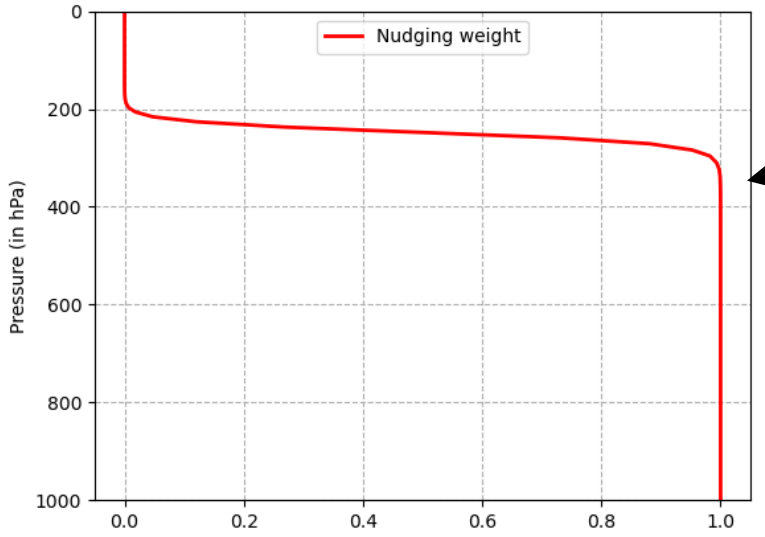
Vorticity, Virtual Temperature, Specific Humidity

$$\frac{\partial x}{\partial t} = ... - a f(t) g(k) (x - x_{ia})$$

$$a = 0.0833$$

$$x : Vor , Tv , q$$

x_{ia} : Linear interpolation between two timestep of the AI model

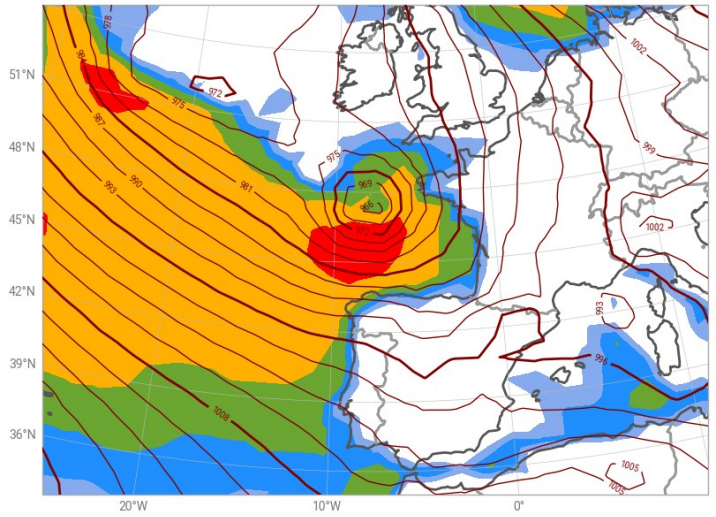


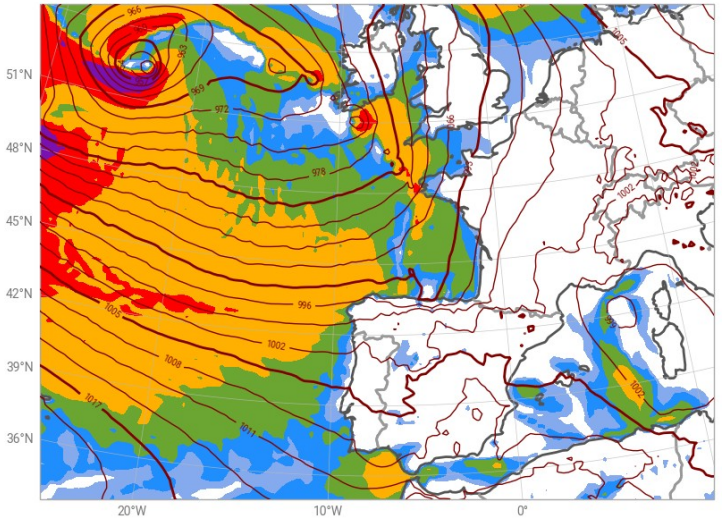
Nudging according to the vertical level (g(k))
From Etienne Arbogast

Nudging effect (FF10m, msl) : Ingrid storm

AIFS
LeadTime 96H

ARPEGE
LeadTime 96H





Nudging effect (FF10m, msl) : Ingrid storm

AIFS
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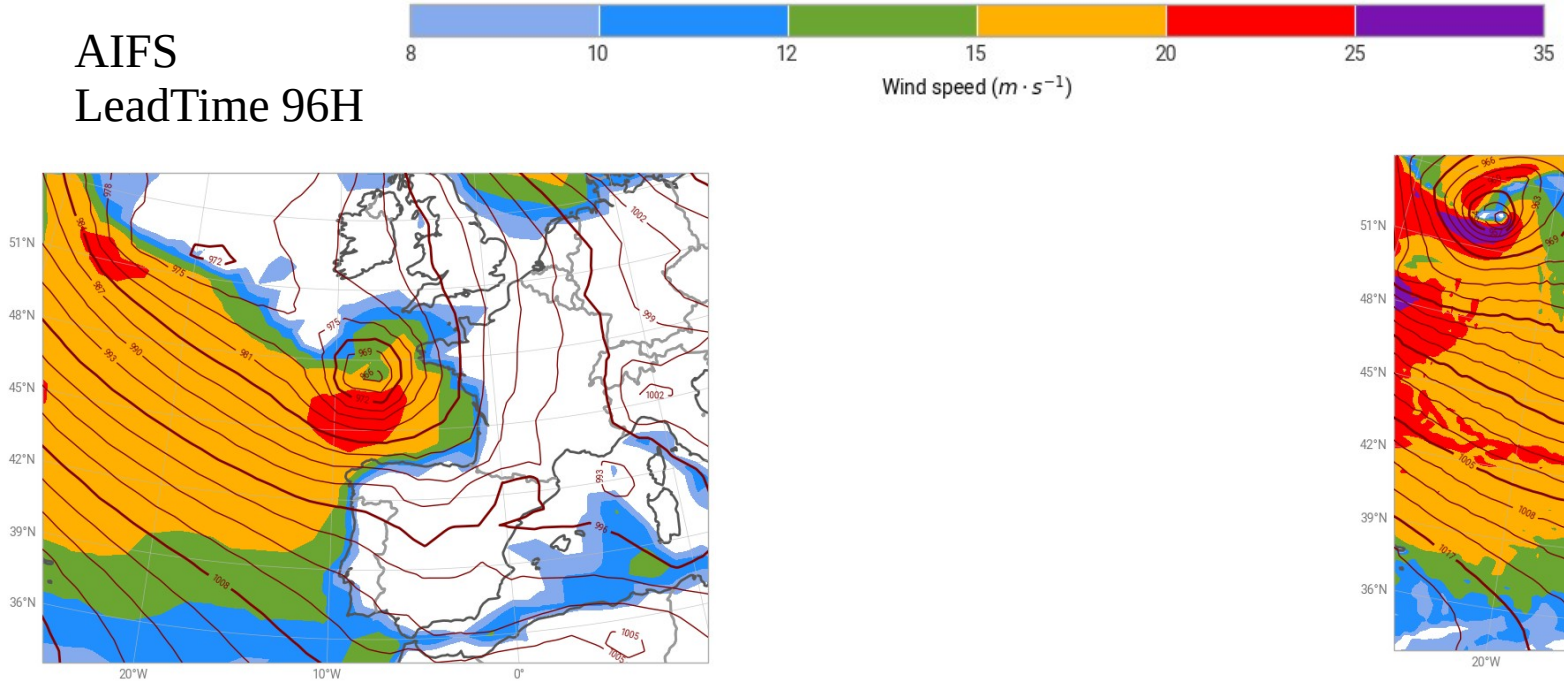
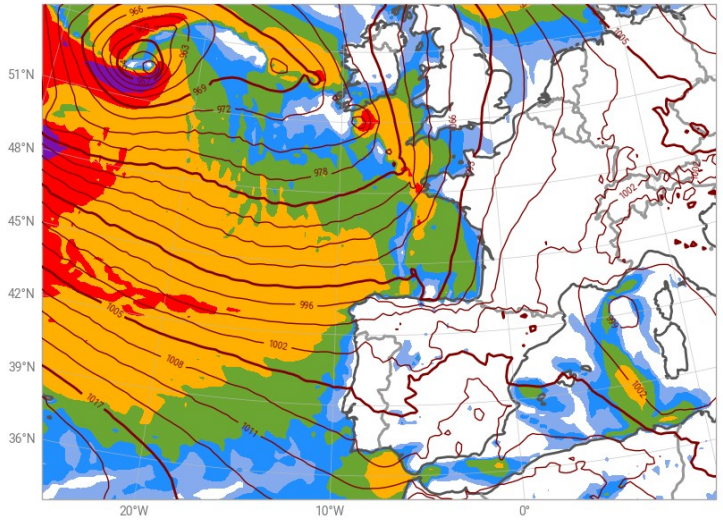
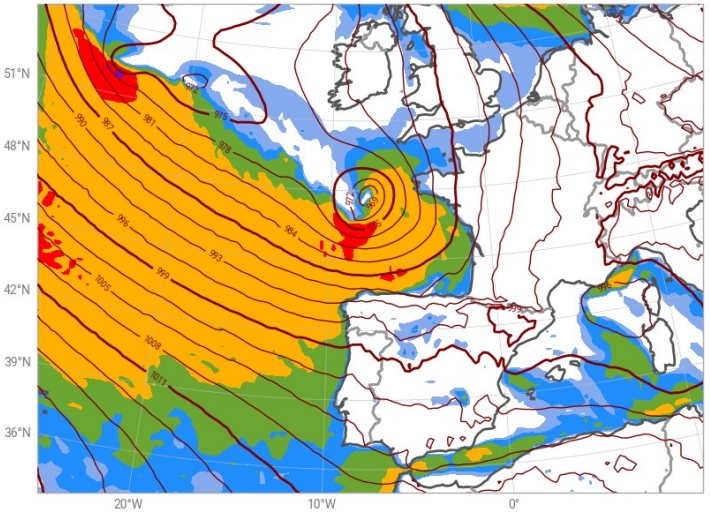


ARPEGE
LeadTime 96H



ARPEGE nudged
LeadTime 96H



Choice of AIFS and finetuning strategy

Horizontal resolution : 1° - O96 (TL191)

Inputs (2 analysis):

- **On sigmaLevel :** u,v,q,T,w
  From the ground to level 60 (IFS vertical geometry).
- **2D Fields:** sp, msl, t2m, td2m, *u850, v850, T500, Z500*, skt, tcw, 10u, 10v
- **Constants :** Orography, StandardDeviation of Orography, Slope , LandSeaMask

Timestep : 6h
Original model trained by ECMWF on ERA5 and finetuned on IFS analysis (Thanks).

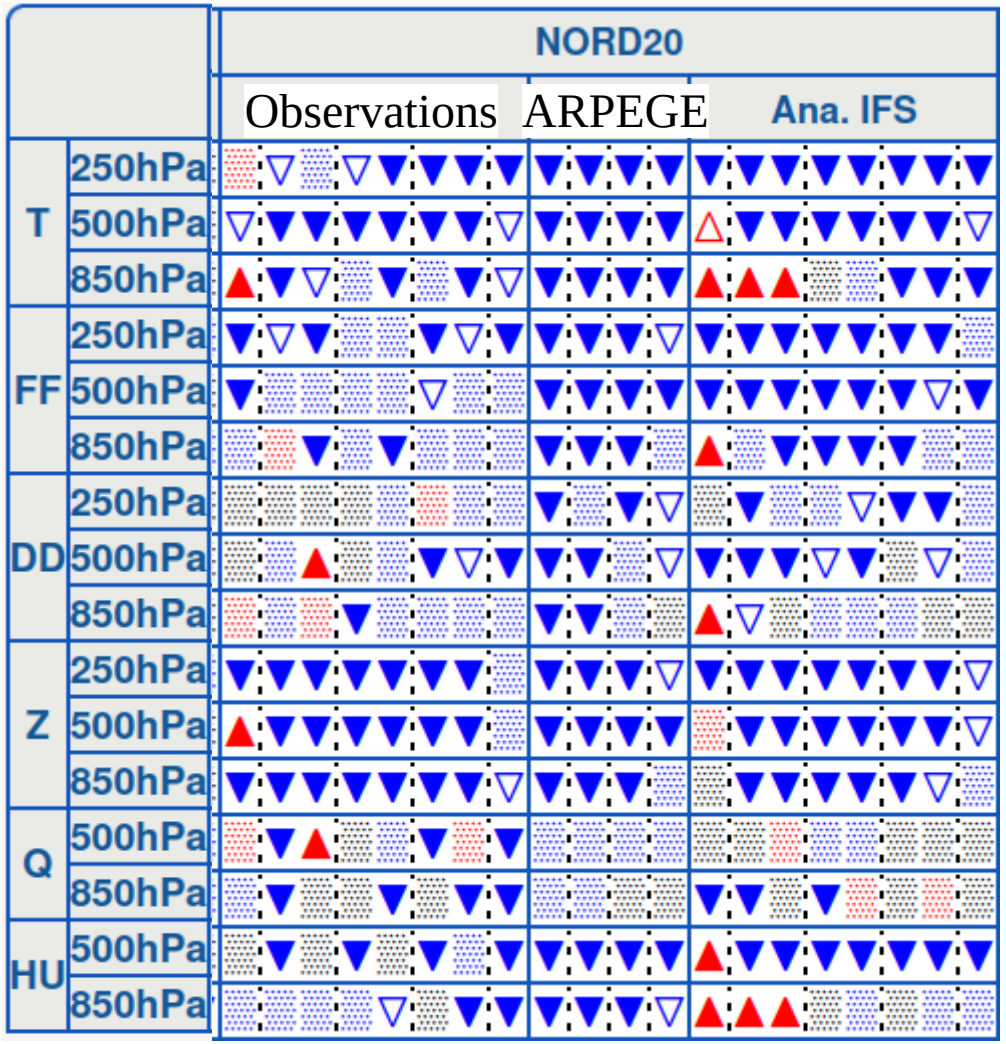
Finetuning (which dataset)

- Finetuning on ARPEGE analysis. *Training dataset from January 2020 to December 2023.*

  => currently worse than no finetuning and postprocessed on IFS orography

- Finetuning on ARPEGE analysis postprocessed on IFS orography.
  Training dataset from June 2022 to December 2023.

Impact of finetuning (after nudging)



Training : 06/2022 -12/2023
Validation : 01/2024->12/2024

Best results (after nudging) so far

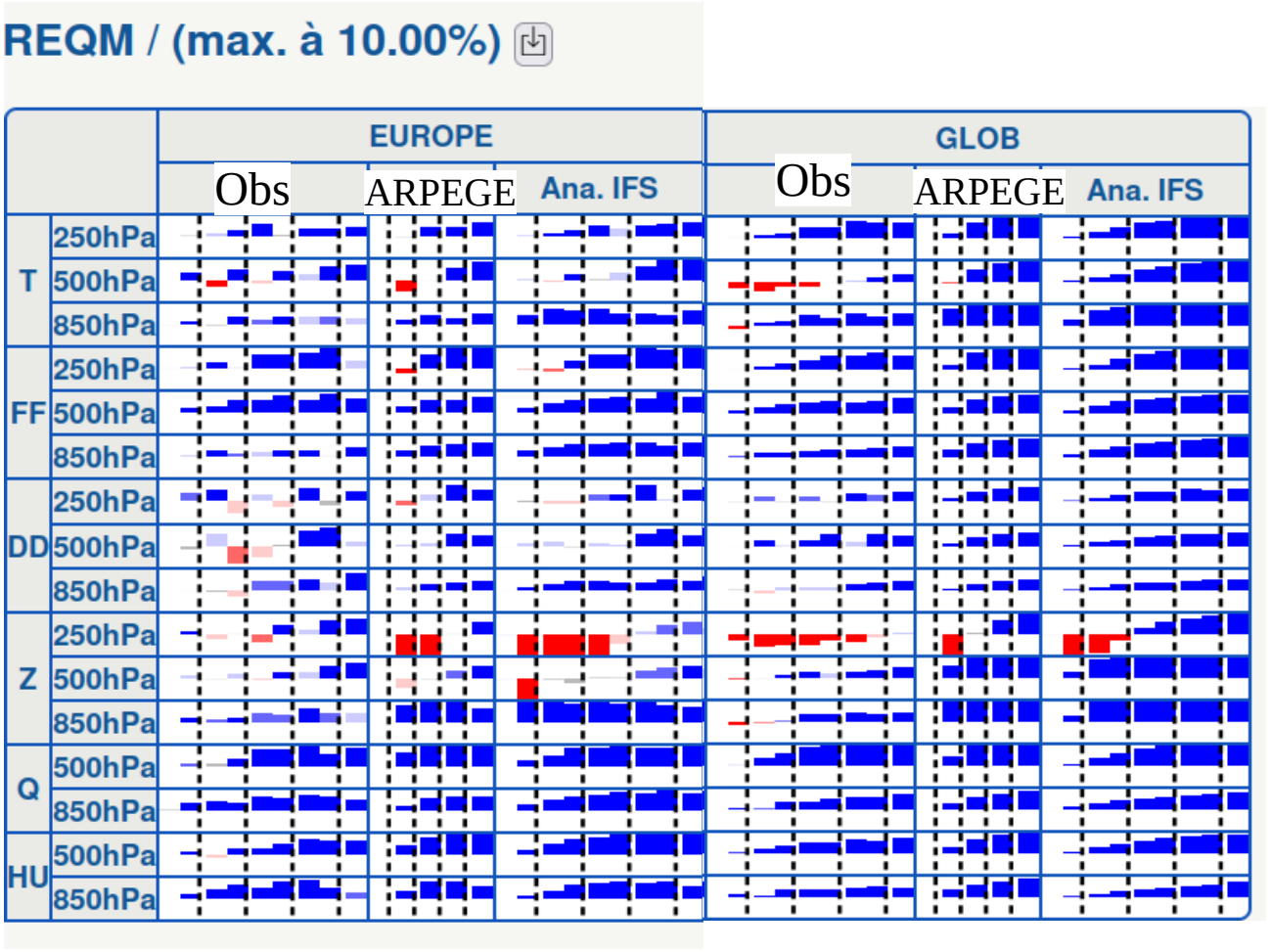
1 Step : 15 epochs lr : 6.25e-06

1 to 6 steps. 7 epoch (in total) lr : 2e-7

Score (after nudging in T21) with respect to d'ARPEGE nudged with the initial AIFS77.

Closer to ARPEGE analysis, IFS analysis and observations.

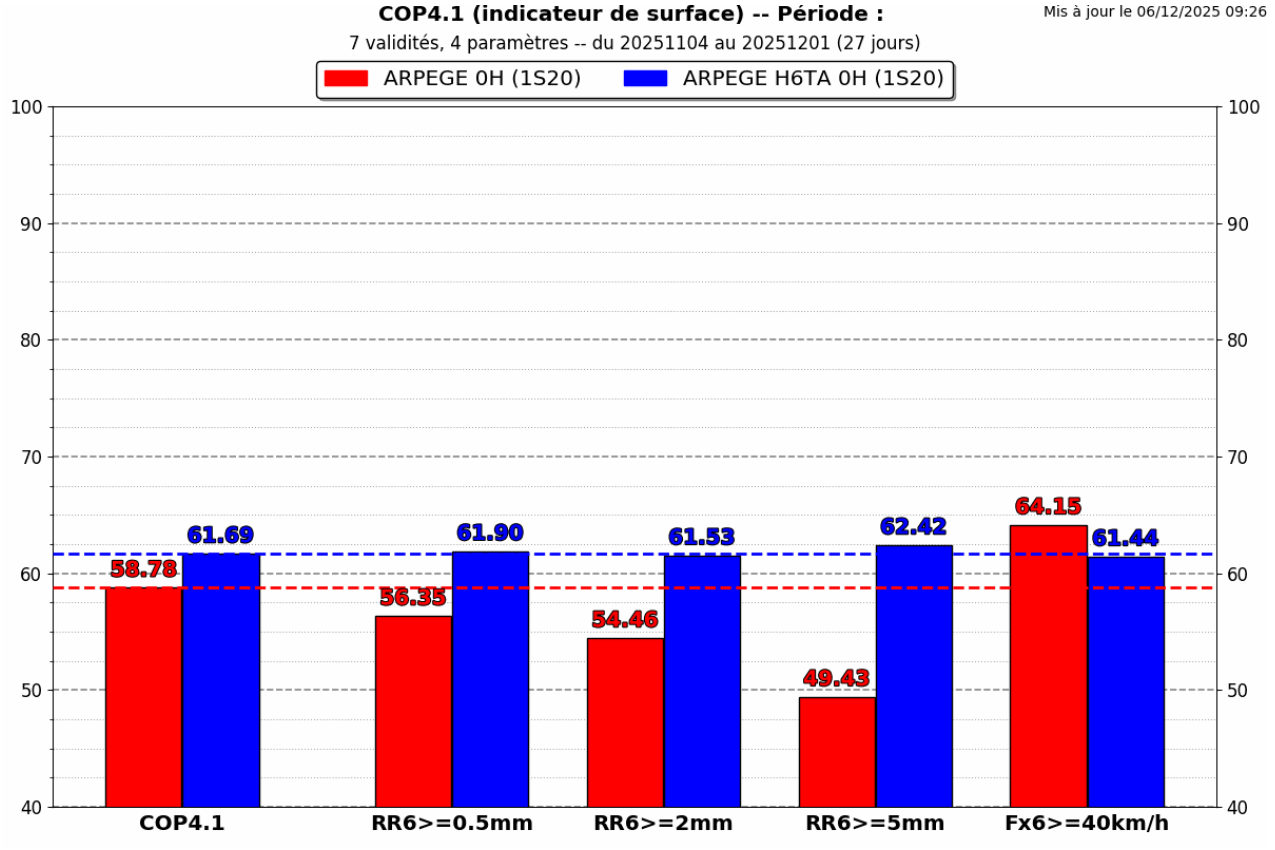
Nudged vs ARPEGE OPER



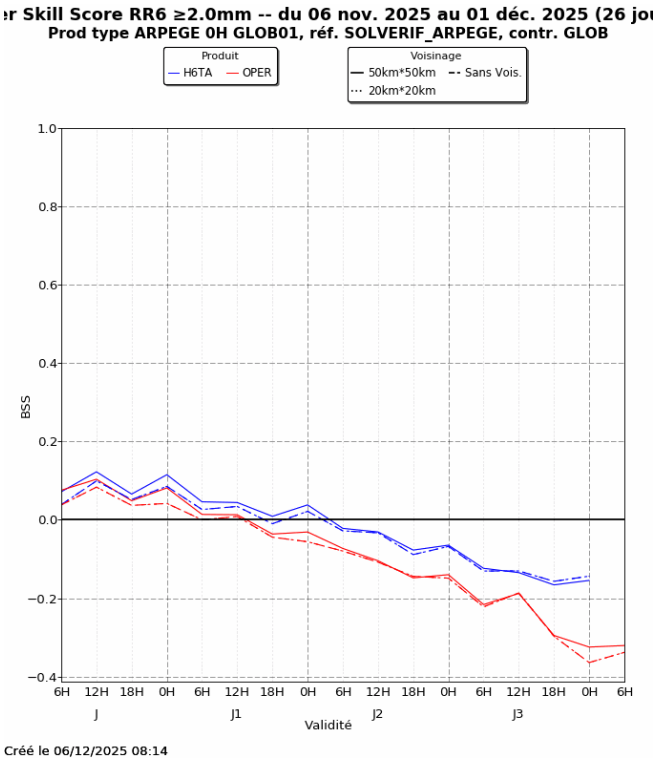
November 2025

Very good, either with respect to radiosounding or analysis.
Problem for Temperature over Himalaya.

Impact on surface fields

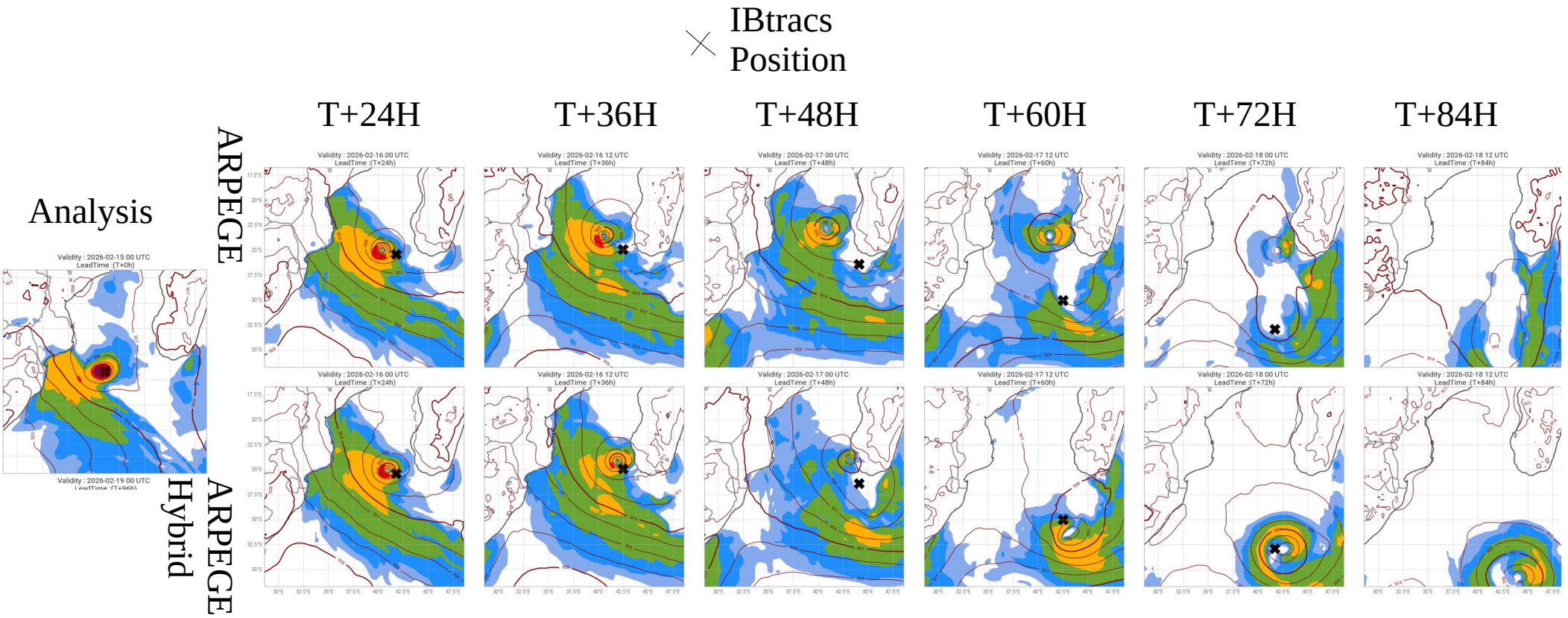


GLOB BSS RR6>=2mm



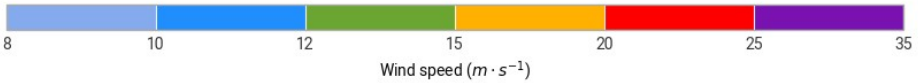
High positive impact on MeteoFrance surface indicator.
Mainly due to a positive impact on BSS.

Cyclone GEZANI : ARPEGE / ARPEGE Hybrid Initiate on 15/02/2026



ARPEGE forecast go through Mozambique channel, while ARPEGE hybrid forecast was closer to the cyclone track.
A few successives run of ARPEGE had this behavour.

INGRID storm : ARPEGE / ARPEGE Hybrid – Different run – ValidTime : 23/01/2026



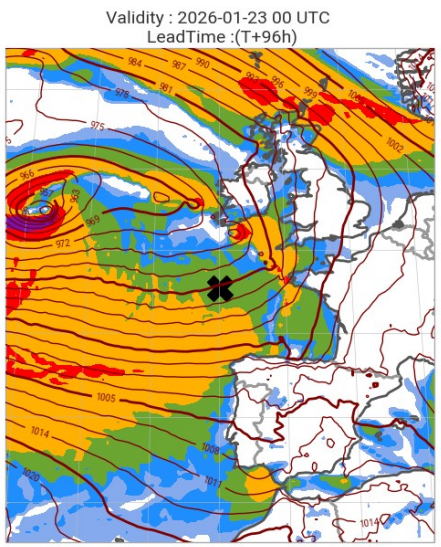
Position (forecaster)

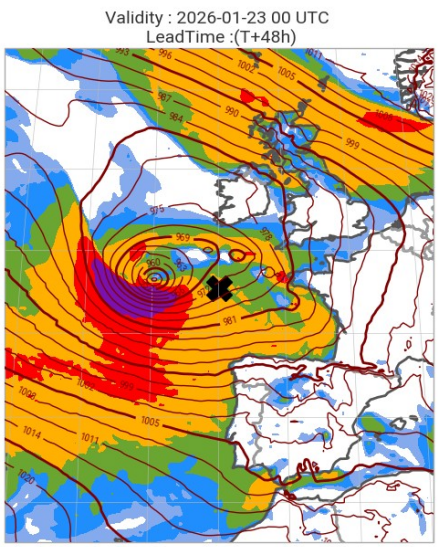
T+96H

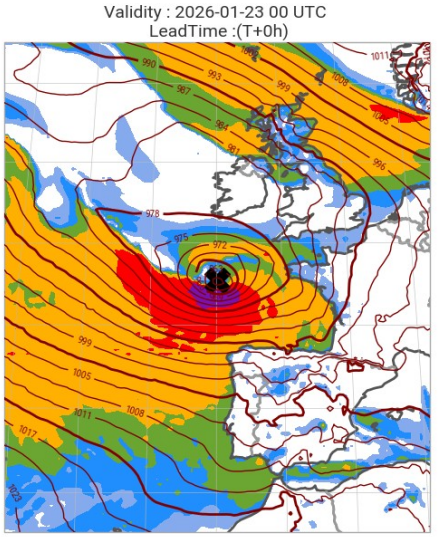
T+48H

Analysis

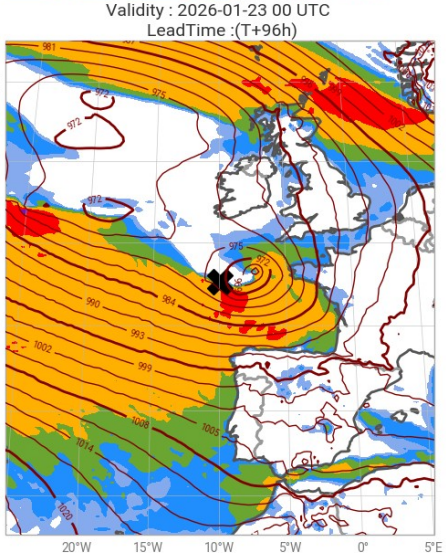
ARPEGE

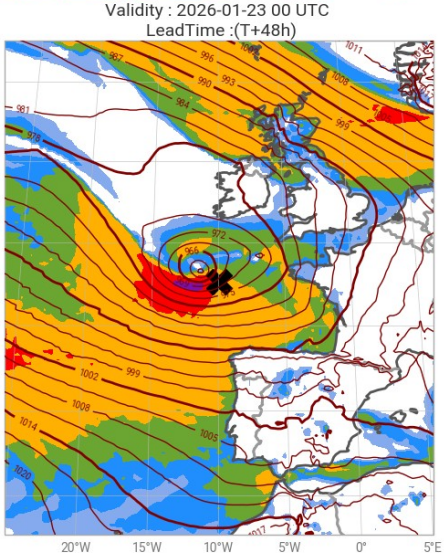






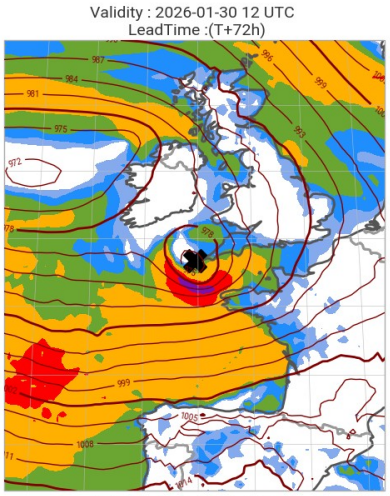
ARPEGE Hybrid



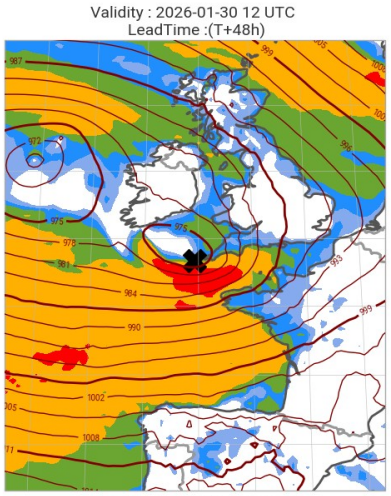


Low Pressure system : ARPEGE / ARPEGE Nudged Different run – Validity : 30/01/2026 at 12H

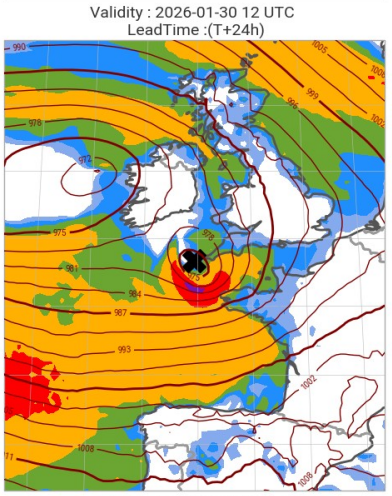
T+72H



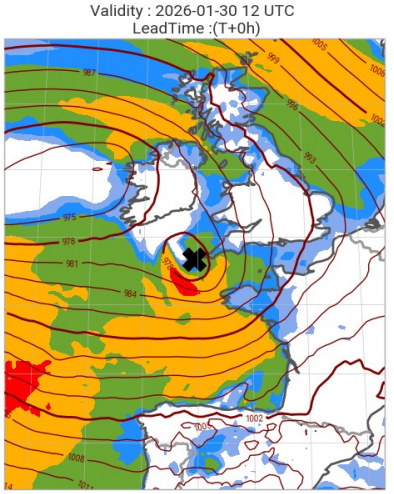
T+48H



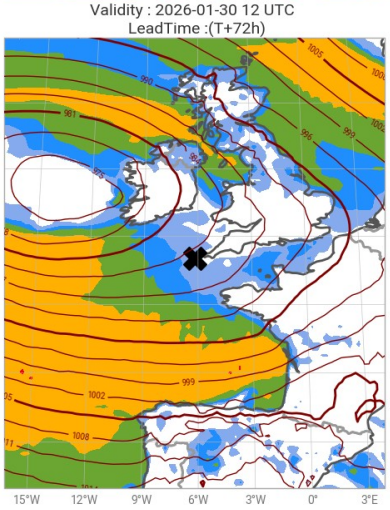
T+24H

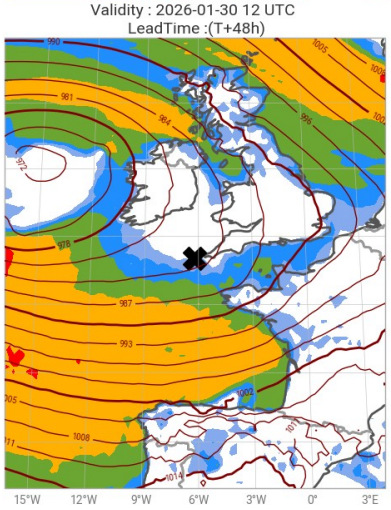


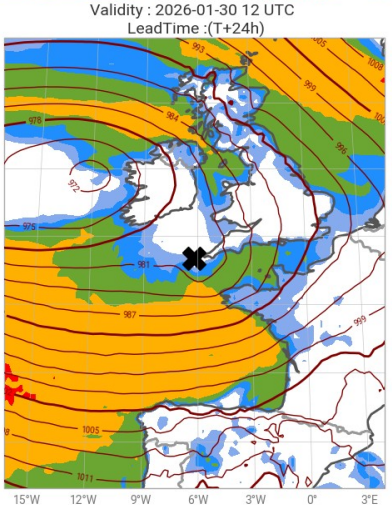
Analysis



ARPEGE





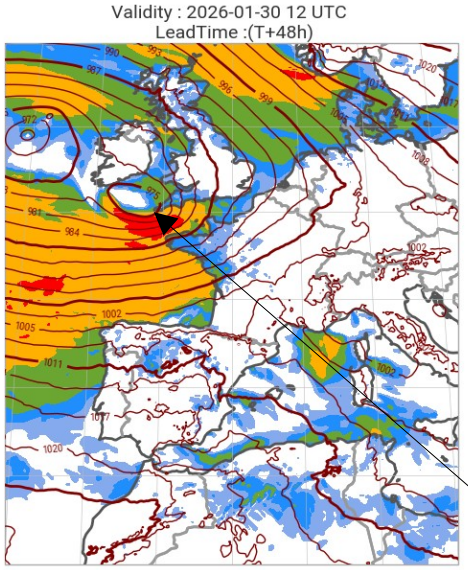


ARPEGE Hybrid

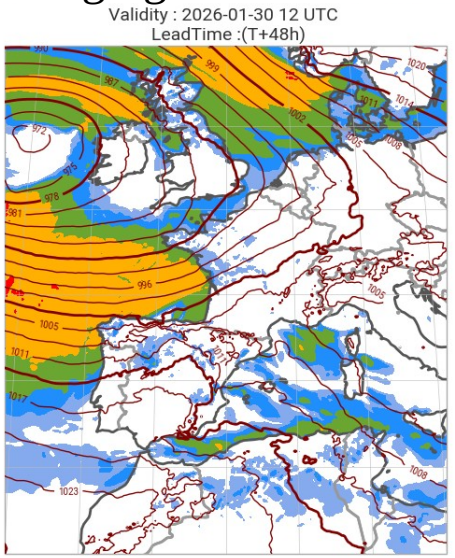
Low pressure near Britany present in ARPEGE.
As never been forecasted in ARPEGE Hybrid, even when present at analysis time.

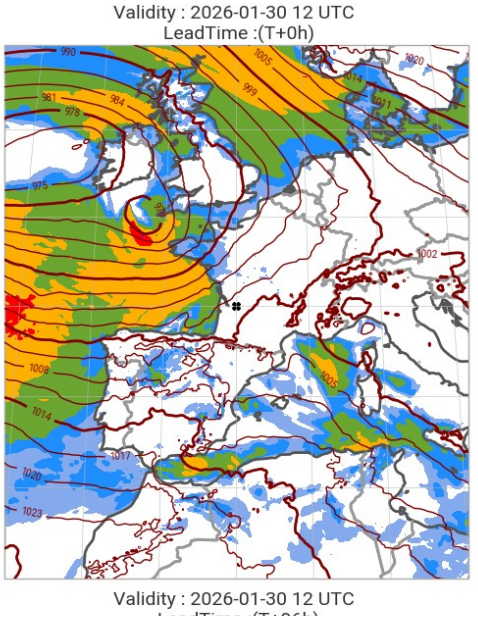
Impact of the nudging choice
LeadTime : 48H

ARPEGE



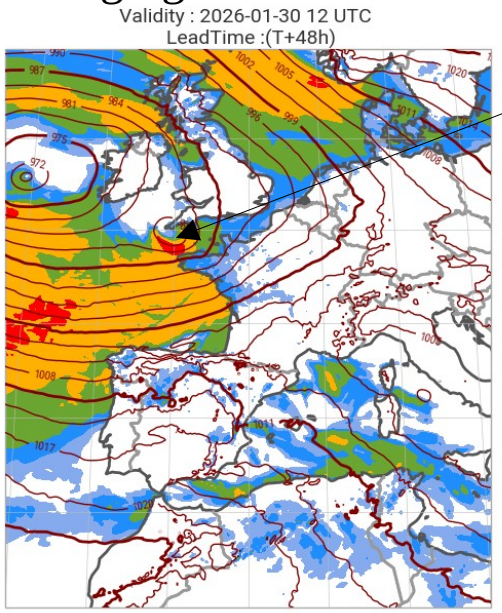
Nudging T63



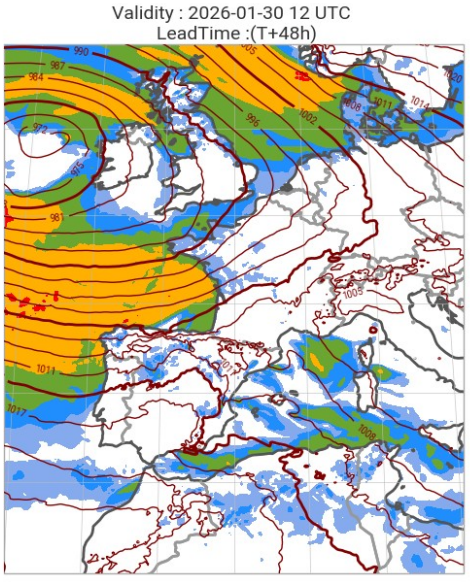


Analysis

Nudging T21



Nudging T42



When nudging less scales we are able to preserve this low pressure system.

METEO FRANCE

Conclusions and future prospects

Conclusion

- ARPEGE nudged delivers promising results

- Dependent on AI model quality as well as the nudging choice

- It is easier to finetune with data closer to the original ones, even if we need more postprocessing operations.

- Production in NearRealTime at MétéoFrance since January.

Future prospects

- Improve the AI-Model (spatial and temporal resolution, …)

- Work on the nudging strategy (scales, vertical levels, …)

- Adapt/Improve ARPEGE initial condition to AIFS

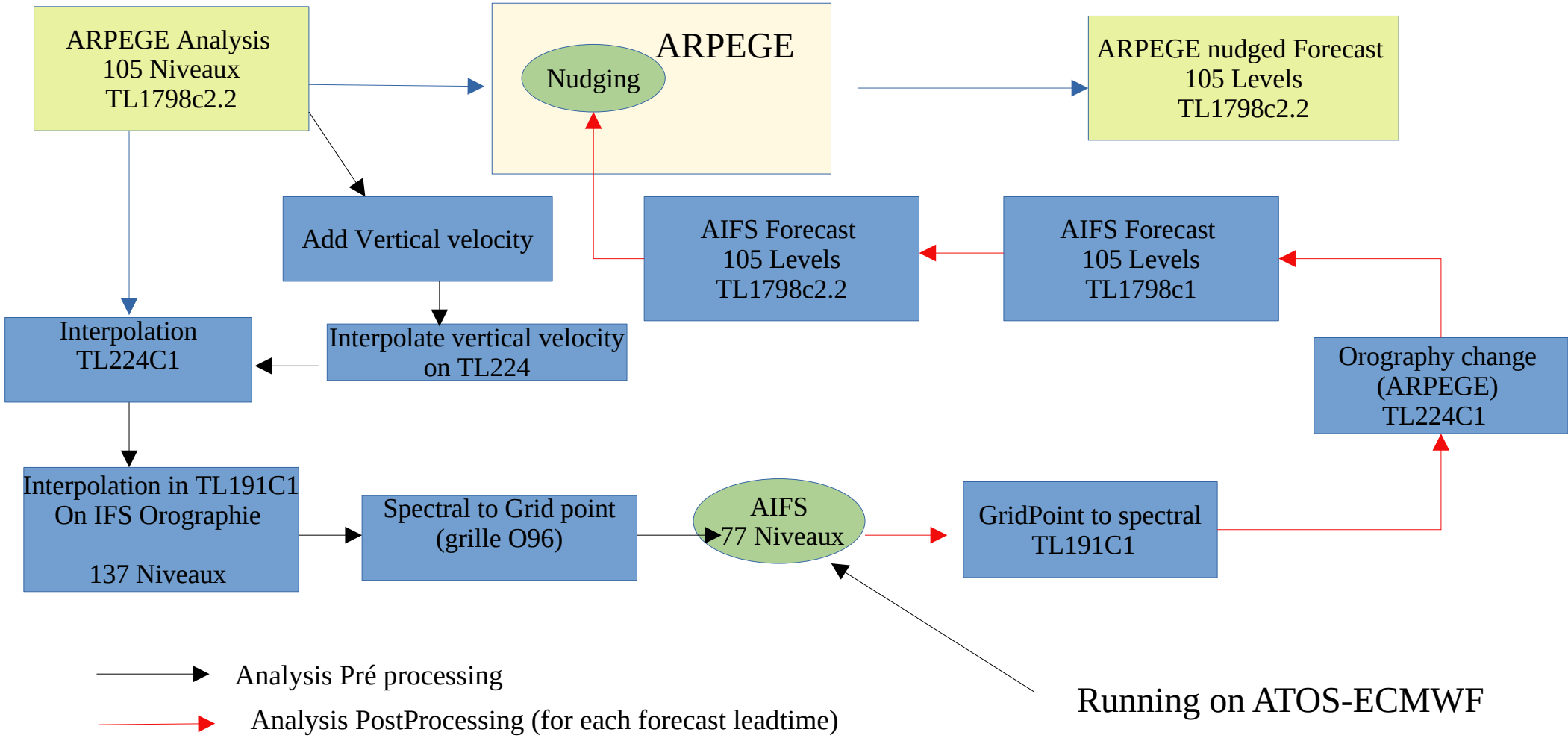
- Nudging for Ensemble forecast

- Study the impact on AROME

Thank you for your attention

Questions ?

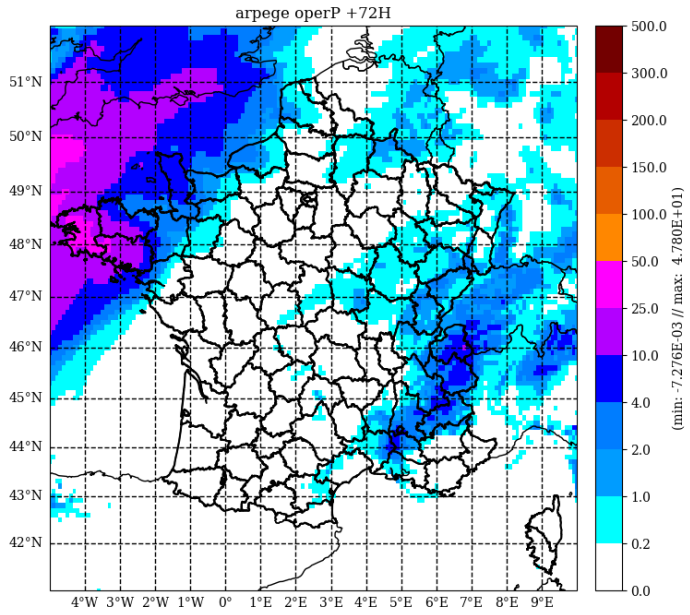
What does the pipeline look like ?
An interpolation story …



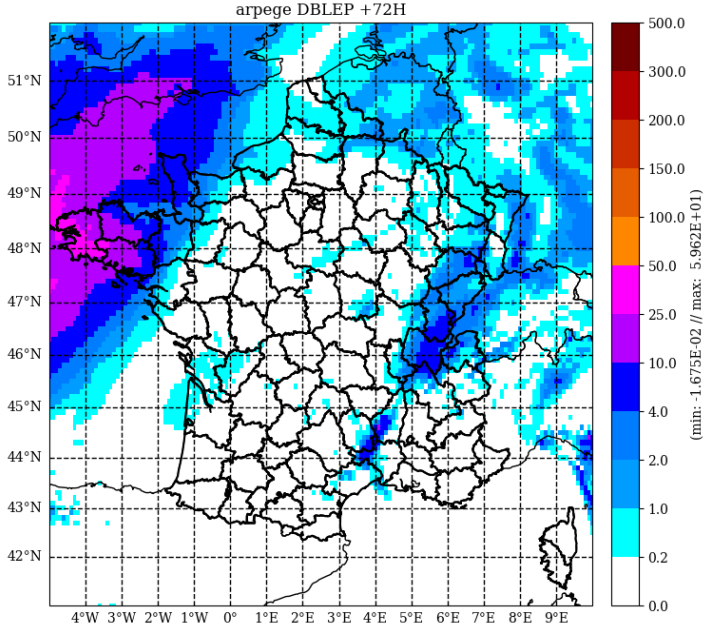
Merci à Etienne Arbogast !

Precipitations – Cumul 72-84H
Alpes – Cumul from 15/01/2026 00H to 12H

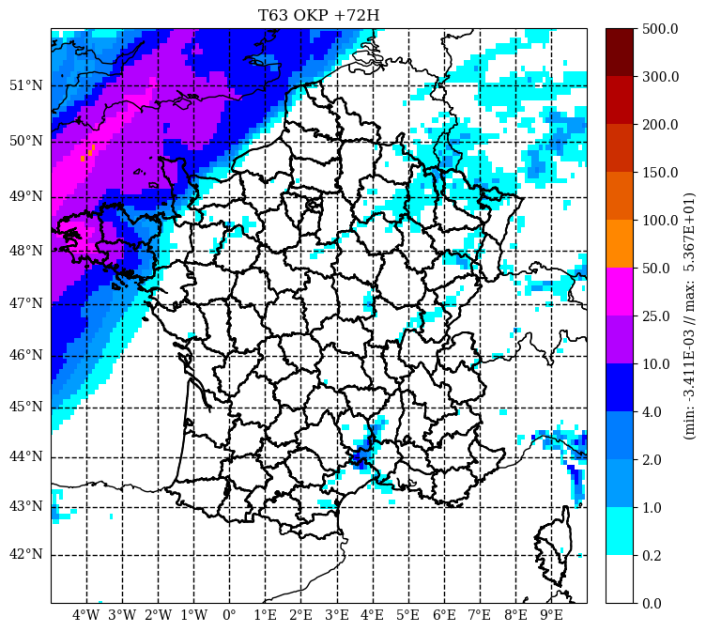
OPER



DOUBLE



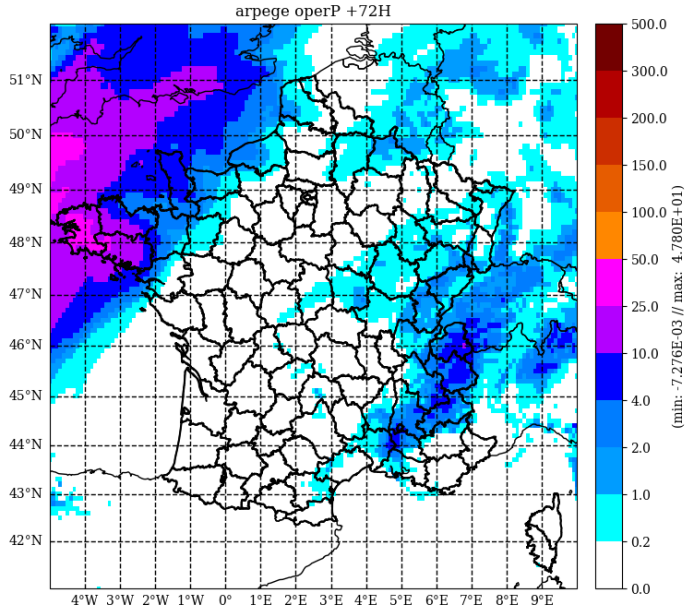
NUDGED



Cumuls 72-84H

Precipitations – Cumul 72-84H
Alpes – Cumul from 15/01/2026 00H to 12H

OPER



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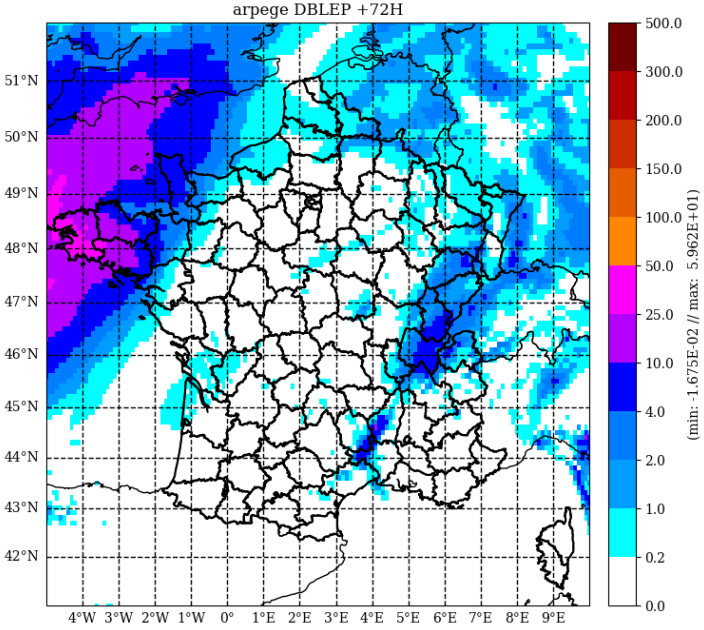
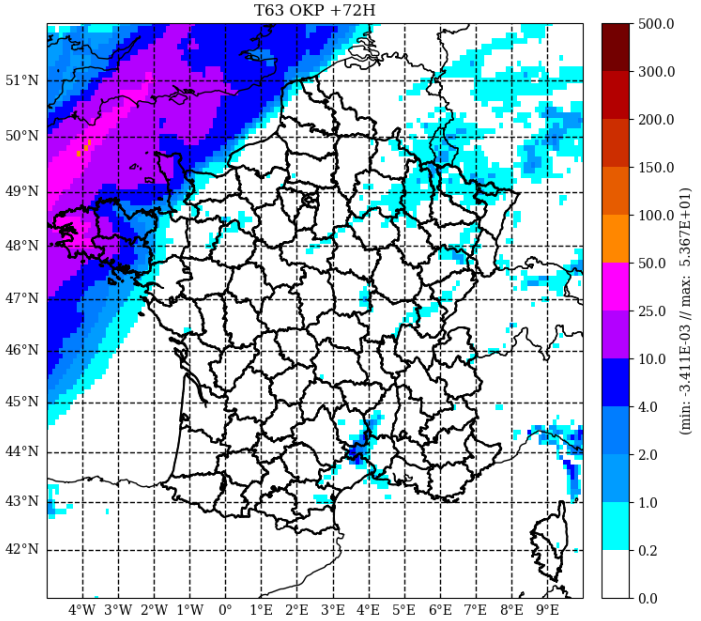
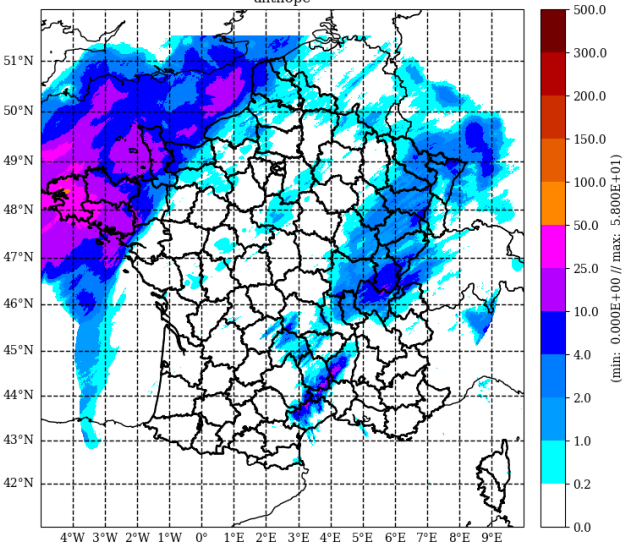


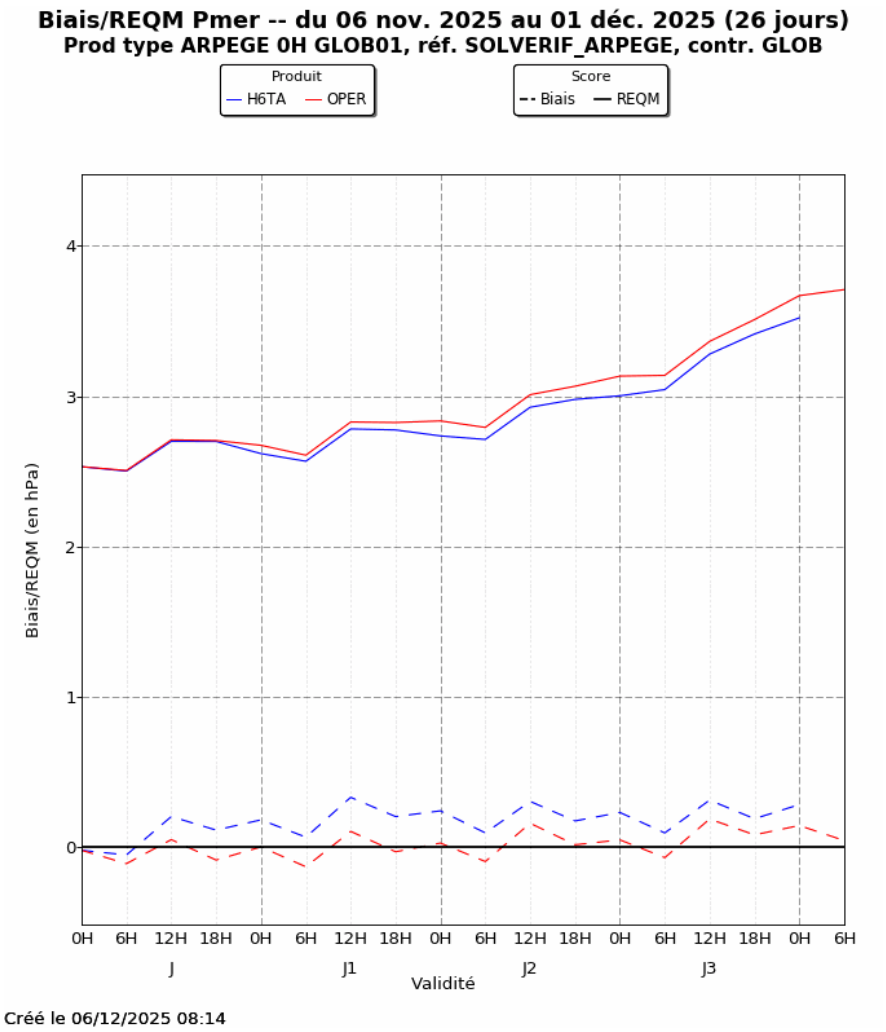
NUDGED



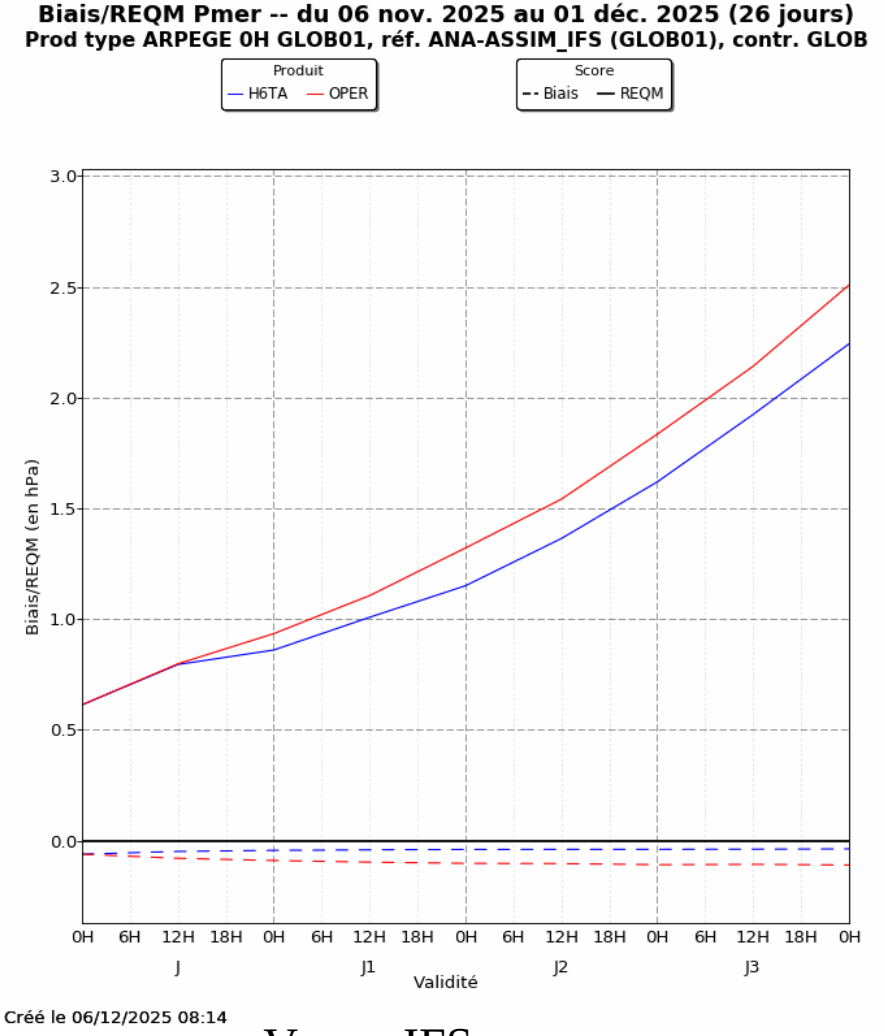
ANTILOPE (Observation)



MSL scores



Versus Observation



Versus IFS