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First Experience with 3DEnVar in Routine Runs of the Claef1k Ensemble

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Introduction

Motivation

- Why explore 3DEnVar in Claef1k? Combine flow-dependent ensemble information with deterministic variational techniques

Objectives

- Assess the feasibility of 3DEnVar with Claef1k members for routine runs
- Study properties of 3DEnVar analysis vs. 3DVar
- Evaluate the impact on forecast performance

Claef1k ensemble system and its DA

Claef1k system

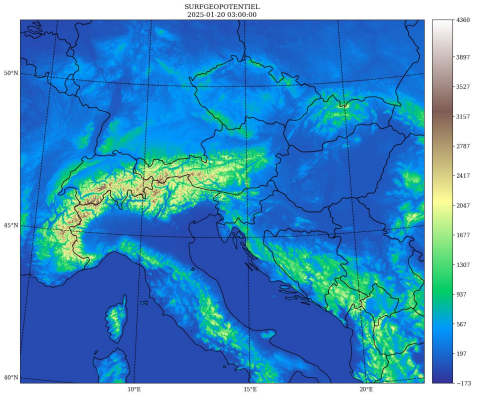
- Successor to C-LAEF system of GeoSphere Austria, cooperation between Austria, Slovenia and Croatia
- Implemented in **cy46t1,** 16 members + control member
- The ensemble implemented in lagged mode to save SBUs - 4 long runs every 3 hours

Perturbation methods

- SPP scheme for model perturbations
- Ensemble-Jk
- EDA and surface EDA (perturbed observations)
- External additional surface perturbation scheme (pertsurf)

Data assimilation

- 3h DA cycle with 3DVar - static B-matrix and V-matrix (mix of different seasons)
- Observations: conventional, GNSS ZTD, Mode-S, radar, AMV, scatterometers



Claef1k domain

Production and dissemination

- Test periods with 4 runs per day to +60h, dissemination to members on post-processed subdomains

3DEnVar ensemble member

3DEnVar:

- Background error covariances **B** directly sampled from the perturbations of the forecasts in reduced ensemble space, with localization **C**

$$\mathbf{B} = \mathbf{C} \circ \mathbf{X}_B \mathbf{X}_B^T \qquad \mathbf{X}_B = [\epsilon_B^1, ..., \epsilon_B^N] \qquad \epsilon_B^i = \frac{1}{\sqrt{N-1}}(\mathbf{X}_B^i - < \mathbf{X}_B >)$$

- Compared to 3DVar, the scheme allows for horizontal inhomogeneity and flow-dependence of background errors and thus analysis increments, and flexibility for the content of control vector.

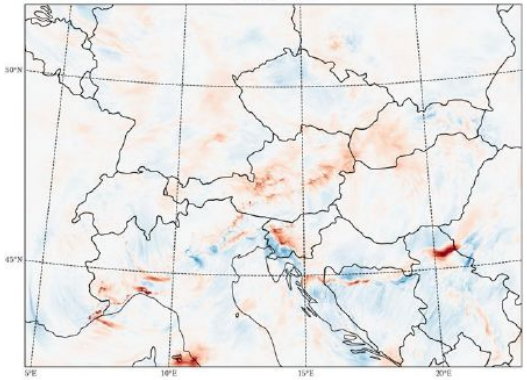
Implementation in Claef1k:

- EnVar as additional, 17th member, following implementation by Meteo France
- Implemented under OOPS in **cy48t3** (very similar to IAL export version cy48t3_bf3)
- Short-range forecasts in DA cycle extended to 6h => duplicate number of perturbations (16 + 16)
- Same observations as in other perturbed and control members
- Height-dependent localization 30 - 150 km
- One long run per day (+60 h at 0 UTC) for comparisons

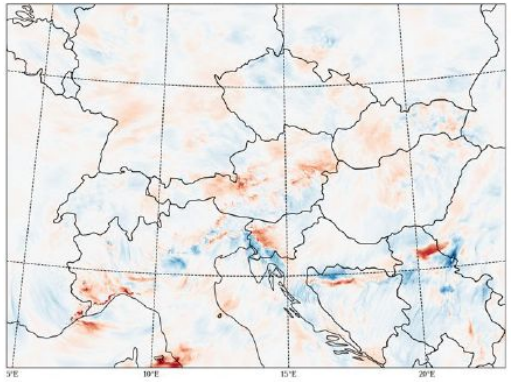
Ensemble perturbations - implementation options

Subjectively evaluated options:

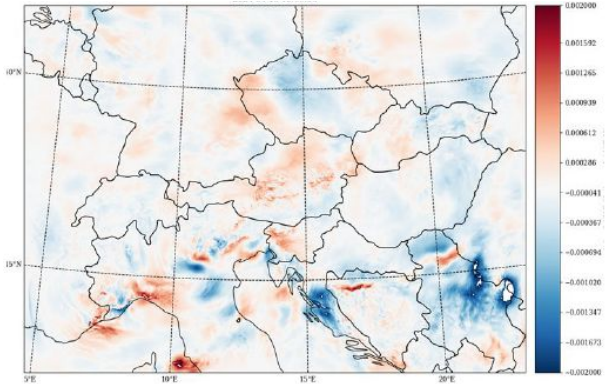
- All available first guesses from ensemble members (16)
- Short-range forecasts extended to 6h - mixed 3h and 6h forecasts as independent ensemble perturbations (16 + 16)
- ENS LBCs members as additional perturbations (16 + 16) or (32 + 16)
- Within lagged Claef1k implementations: recent 3h first guesses + older ens. members (16 + 4 + 4 + 4)



50 LAM EPS pert.



16+16 LAM EPS pert.



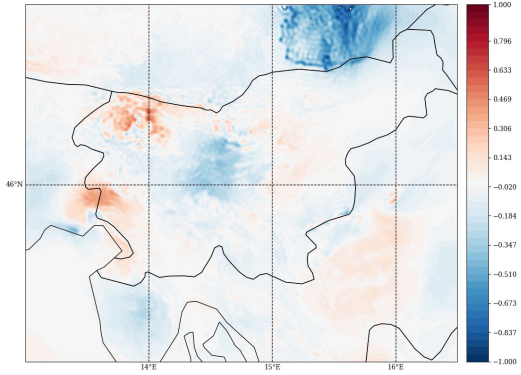
Mixed 16 LAM + 16 global EPS

Treatment of sub-ensembles from different sources

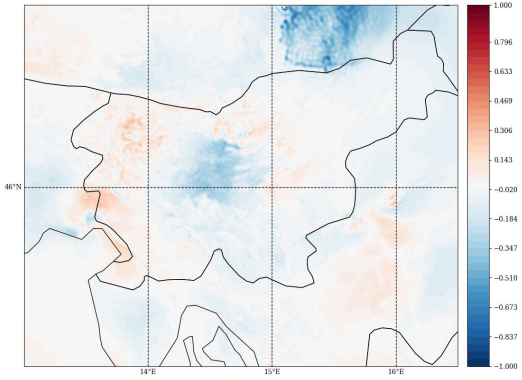
Sub-ensembles in 3DEnVar

- current implementation (OOPS, cy48t3) allows for ensemble subsets of equal sizes
- proposed extension: perturbations
  belong to different sub-ensembles

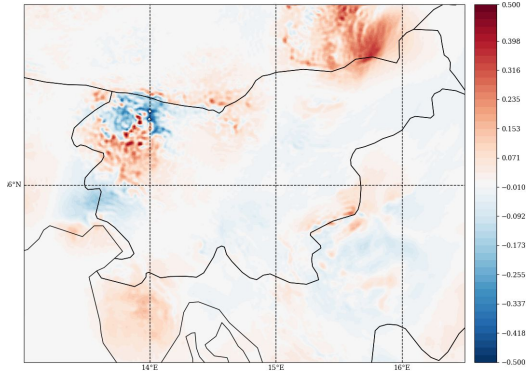
$$\epsilon_B^{i,l} = \frac{1}{\sqrt{N - N_s}}(\mathbf{X}_B^{i,l} - < \mathbf{X}_B >^l)$$



one ensemble (16 + 16)



two sub-ensembles (16)

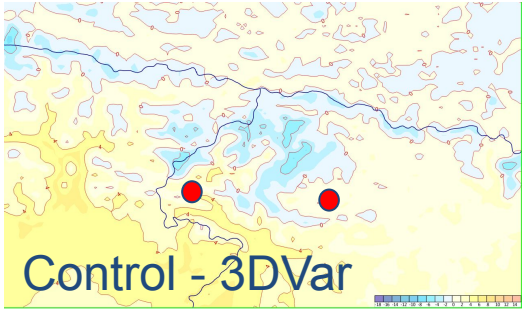


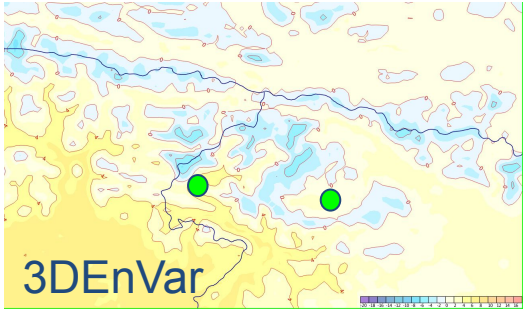
difference

Analysis increment of low-level (L88) temperature

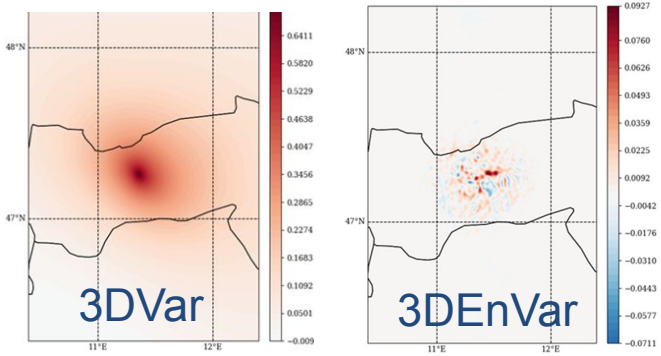
Properties of 3DEnVar vs. 3DVar analysis

- Improved topographic features in the analysis increments

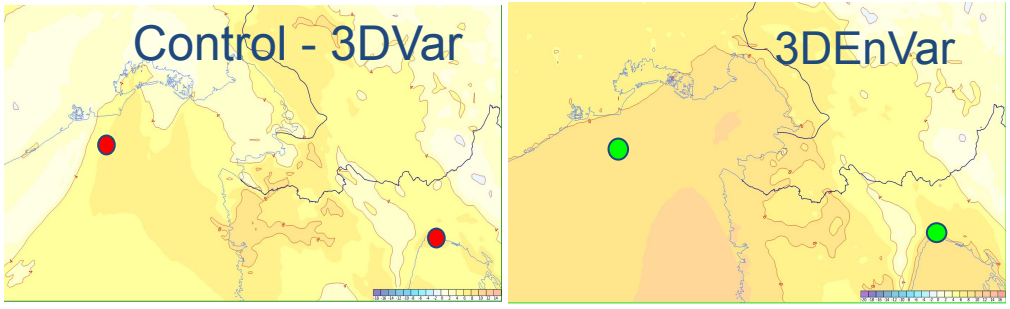




Single obs. u-wind in Alpine valley

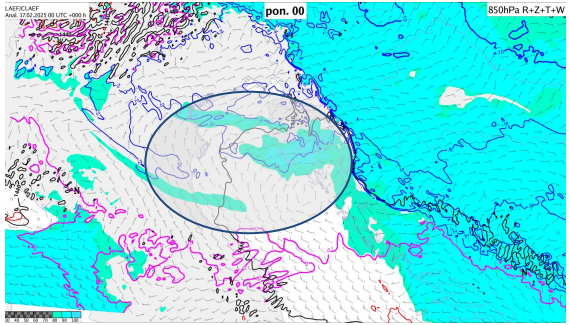


- More consistent analysis across land-sea boundaries

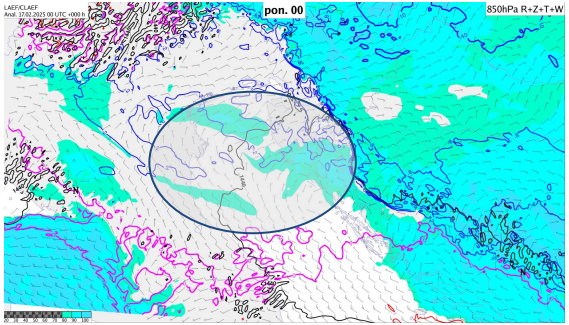


Properties of 3DEnVar vs. 3DVar analysis

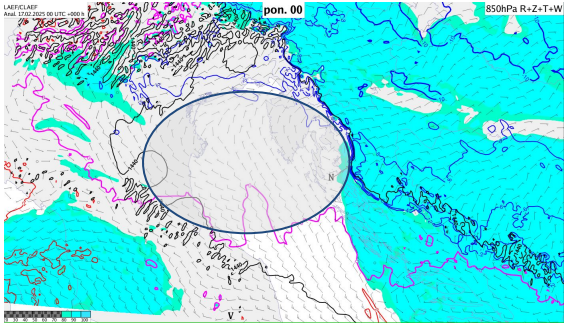
- Better representation of horizontal gradients in upper-air fields, e.g. mountain flows



3D-Var (Control)



3DVar (member 1)

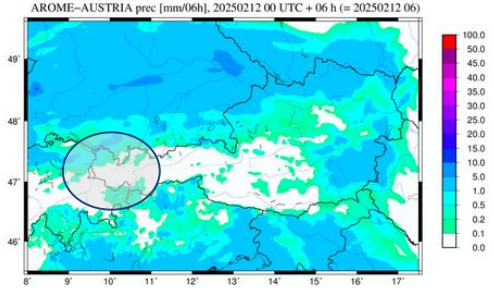


3DEnVar

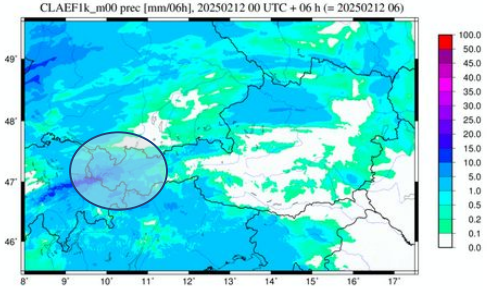
EnVar is better at preserving sharp horizontal gradients in the 3D analysis. Case of Bora/Foehn event over the Dynaric Alps, Fanuary 2025.

Properties of 3DEnVar vs. 3DVar - improved precipitation bias

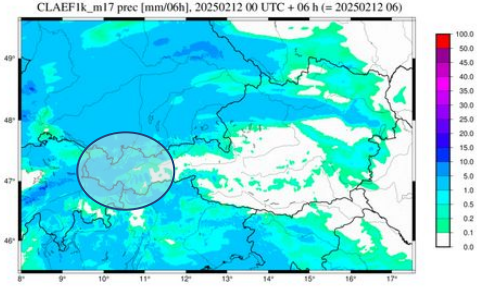
3D-Var AROME-Austria



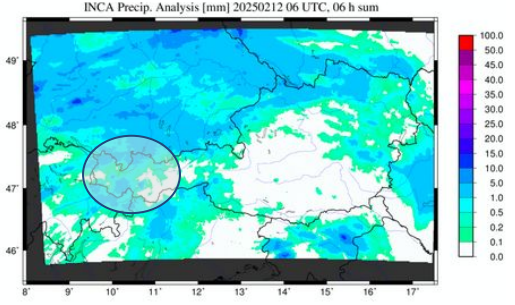
3D-Var - Claef1k



3DEnVar



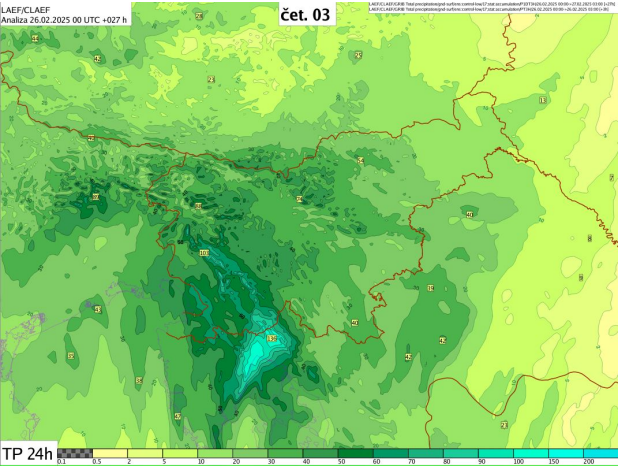
- Precipitation amounts in Claef1k often exceeds the AROME-AUT (2.5 km)
- 3DEnVar member in Claef1k more consistent with ground truth (INCA) on several cases



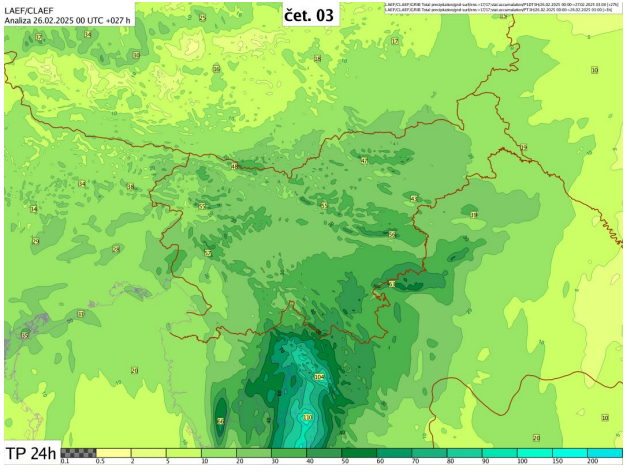
INCA analysis

Properties of 3DEnVar vs. 3DVar - precipitation patterns

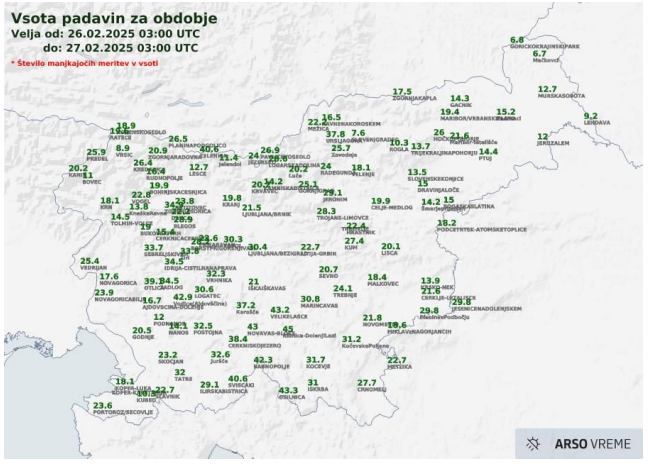
A heavy precipitation case with 3DEnVar decreasing overestimation of 24h precipitation.



Control - 3DVar
(~10 mm over-estimation)



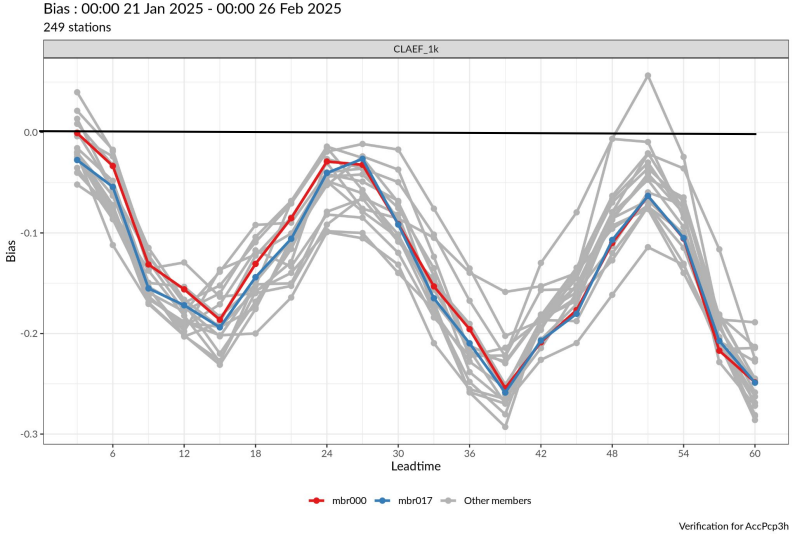
3DEnVar

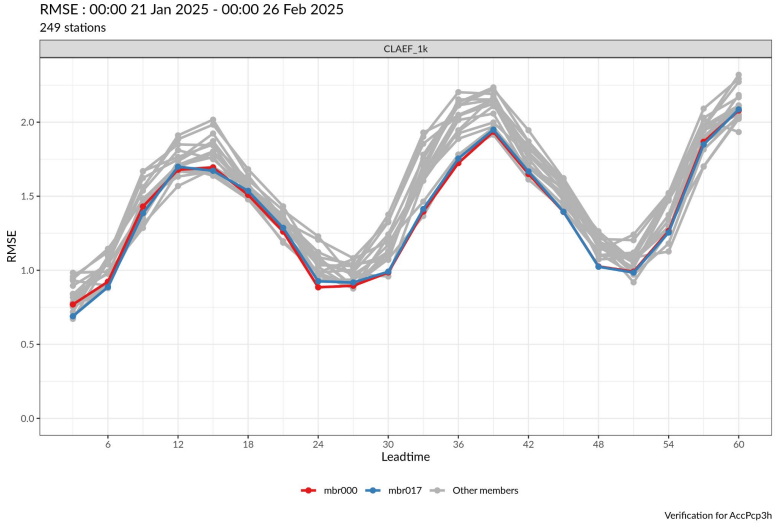


Observed 24h precipitation

Impact on forecast - precipitation

- Systematic verification from January 2025.
- Scores comparing individual members, the control run, and 3DEnVar.

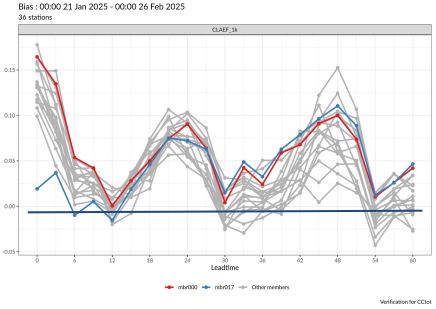




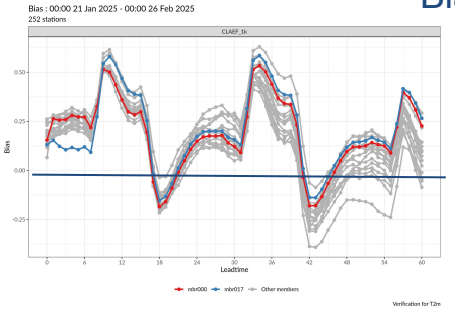
Mostly neutral in 3h precipitation but few cases, slightly negative bias

Impact on forecast - other variables

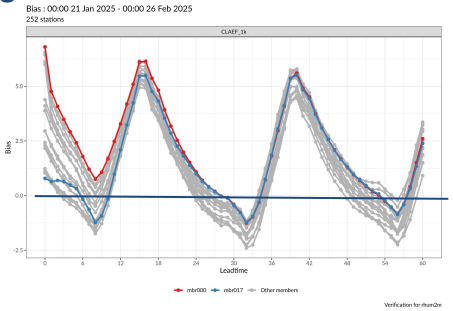
Bias



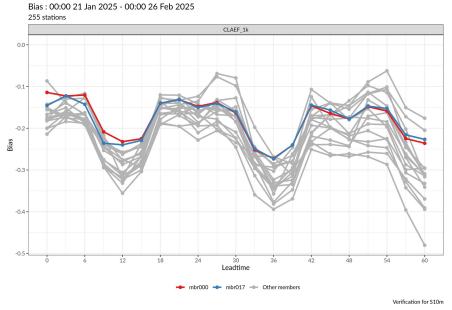
Total clouds



T2M bias

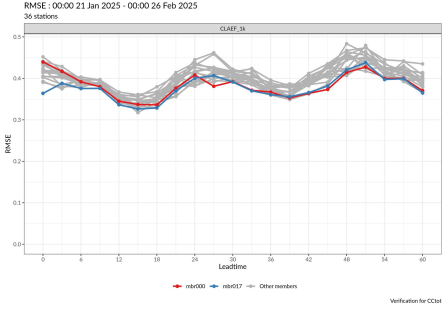


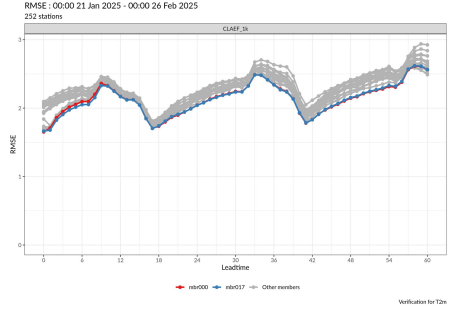
RH2m

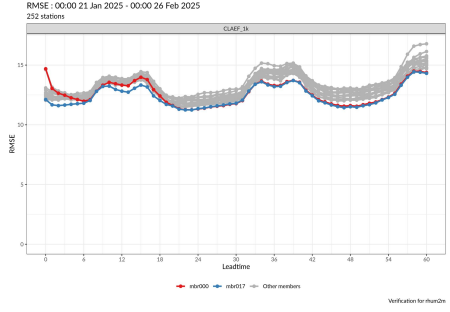


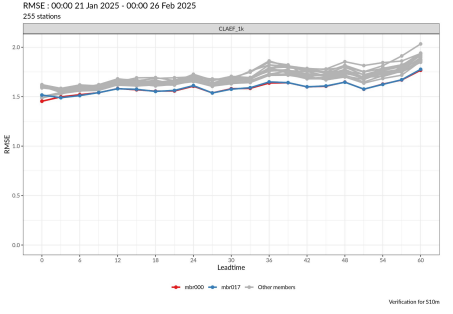
10m Wind

RMSE









A 4DEnVar prototype for Claef1k

- 4DEnVar allows for spatial and **temporal** correlations (diagnosed from the ensemble)
- First setup made during a DAWW (October 2024), with help from MF
- Slots using 2h, 3h and 4h forecast perturbations, with 0.5h, 1h and 0.5 h window length
- Implemented as option in Claef1k scripting, full-observation tests to be performed

Conclusions

- 3DEnVar added as another control member of Claef1k
- Design of perturbations challenging, using lagged approach
- Encouraging performance in winter 2025 with respect to ensemble Control
  - Desirable features seen in analysis (increments)
  - Better forecast performance (cases, scores)
- Increased cost (+3 forecast integrations in assimilation cycle, minimization) and complexity (requires previous runs members) wrt. 3DVar