Assimilation of T2m with Hybrid-3DEnVar over The Alps in AROME-Austria

Kaushambi Jyoti[1], Philipp Griewank[1], Florian Meier[2], and Martin Weissmann[1]

1. Department of Meteorology and Geophysics, University of Vienna
2. Geosphere Austria, Vienna

Generated by ChatGPT

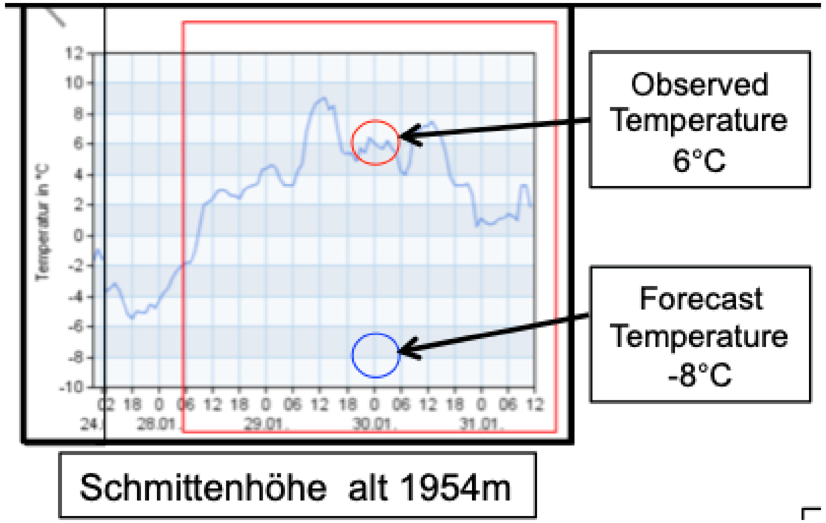
Motivation

- Data assimilation (DA) provides initial conditions to the NWP model
  - GeoSphere is currently using the 3-Dimensional Variational (3DVar, *Courtier et al., 1998*) for DA

- Making use of GeoSphere's Convection-permitting Limited-Area Ensemble Forecasting (C-LAEF, *Wastl et al., 2021*)
  - CLAEF consists 16 members + 1 control
  - at 2.5 km

- We want to improve the T2m forecast
  - Correctly forecasting T2m is hard in complex terrain
  - Specifically in anticyclonic conditions

60-hr lead time valid at 00 UTC 30 Jan 2024



https://confluence.ecmwf.int/display/FUG/Section+9.2.1.1+Causes+of+errors+in+2m+temperature

Data Assimilation

- DA combines past forecasts (background) and observations weighted by the inverse of respective errors
- GeoSphere Austria uses the 3DVar method for DA

(squared deviation of background from model state)

$$\mathbf{J}(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}[\mathbf{y}_{\mathbf{o}} - \mathbf{H}(\mathbf{x})]^{\mathrm{T}}\mathbf{R}^{-1}[\mathbf{y}_{\mathbf{o}} - \mathbf{H}(\mathbf{x})]$$

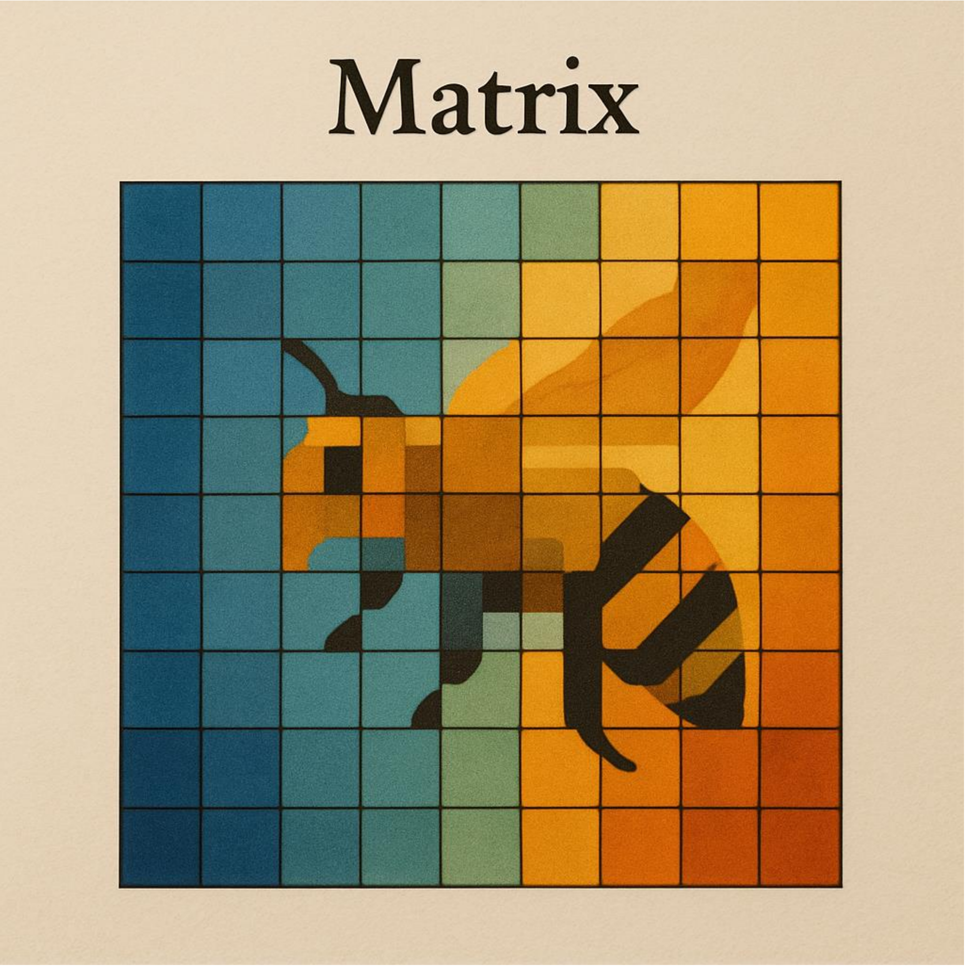
(squared deviation of observations from model state)

- Precise representation of forecast errors **(B)** is crucial for accurate ICs

$\mathbf{x}$ = model state vector
$\mathbf{x}_b$ = background state vector

$\mathbf{y}_{\mathbf{o}}$ = observation state vector
H = forward observation operator

B = background error covariance matrix
R = observation error covariance matrix



a picture of a bee in the form of a matrix

Ways of estimating B

$$\mathbf{B} = \begin{pmatrix} \sigma_1^2 & cov(\sigma_2\sigma_1) \dots & & \\ cov(\sigma_1\sigma_2) & \sigma_2^2 & & \\ \vdots & & \ddots & \\ cov(\sigma_1\sigma_m) & & \cdots & \sigma_m^2 \end{pmatrix}$$

- Symmetric positive semi-definite 10^15
- variances on the diagonal
- covariances (correlations) at off-diagonal

$\mathbf{B} = \mathbf{B_c}$

3DVar (Climatology)

Balanced, Long-range correlations

Fixed

Hybrid

$\mathbf{B} = \beta_e^2\,\mathbf{B_e} + \beta_c^2\,\mathbf{B_c}$

where $\beta_e^2 + \beta_c^2 = 1$

$\mathbf{B} = \mathbf{B_e}$

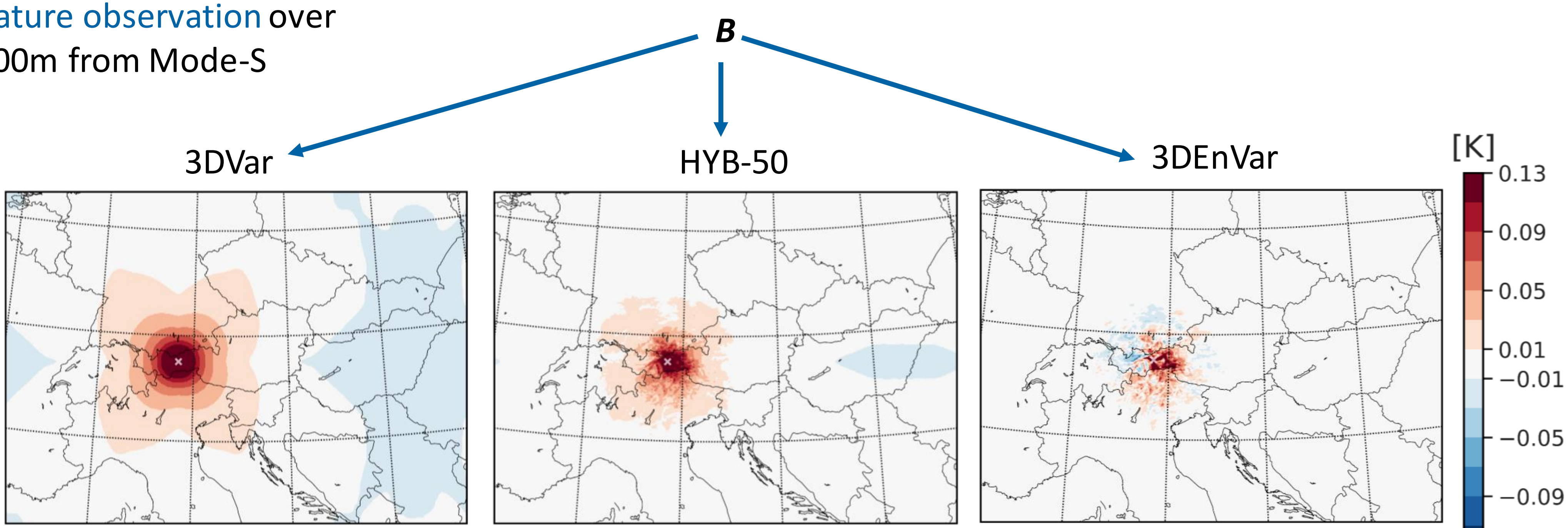
3DEnVar (*Lorenc, 2013; Montmerle et al. 2018*)

Information on recent flow regime

Noisy correlations (sampling errors)

Different B provide different increments (ICs – background)

- a single temperature observation over Innsbruck at 1600m from Mode-S



Smooth, long-range,
Nearly symmetric and isotropic

Small scale + long range

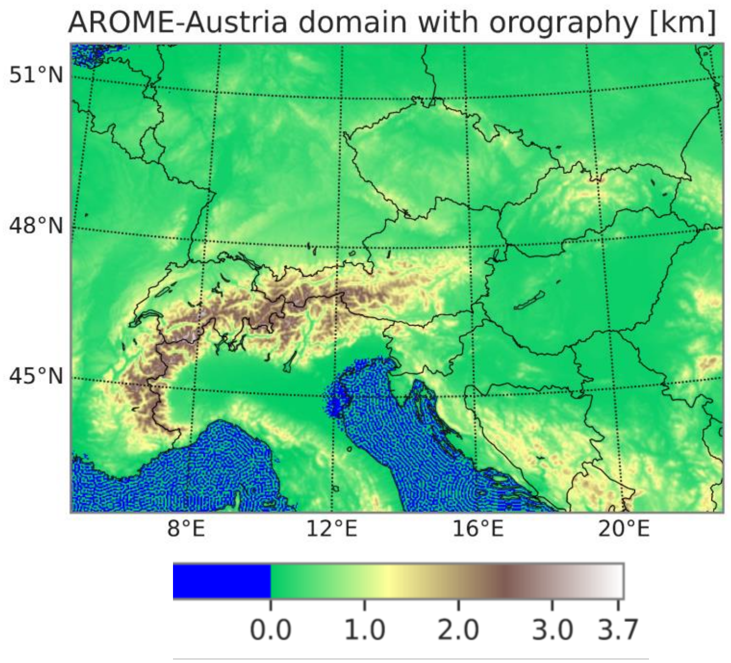
Small scale, Inhomogeneous
Orographic footprint

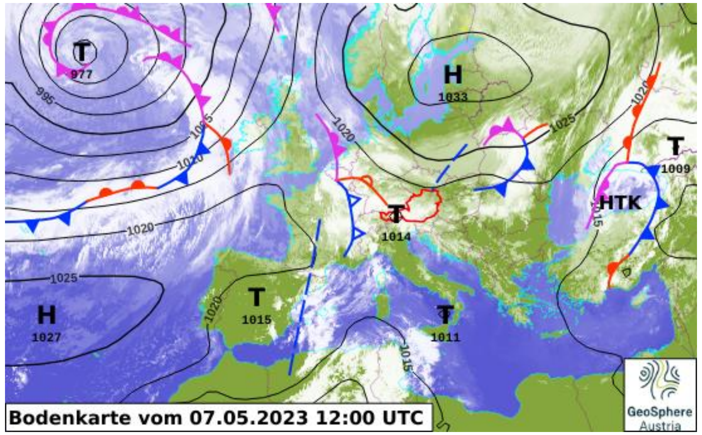
Nearby valleys and mountain tops can have different weather, leading to different degrees of small-scale correlation, even negative correlations in atmospheric variables.

Does assimilation of T2m with Hybrid-3DEnVar improve the forecast, particularly over Alpine terrain?

AROME-Austria

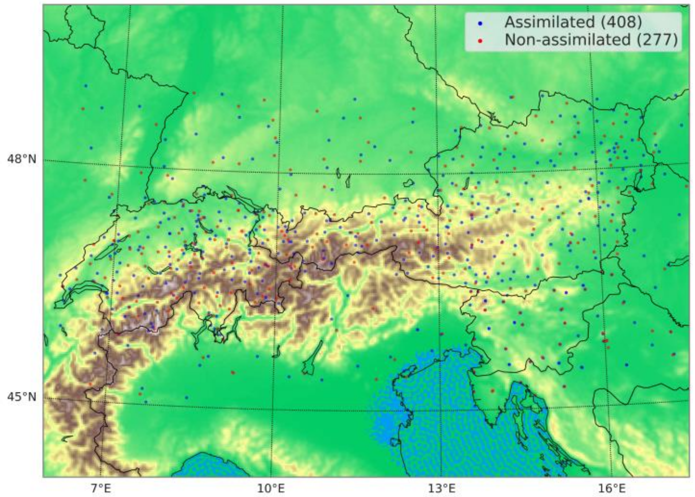
- Convective-scale at 2.5 km grid spacing
- Assumed to allow deep convection
- 600x432x90 grid-points
- 50-member ensemble from C-LAEF at 2.5 km.
- Test case: 1200 UTC, 07-05-2023





Method

- Experiments
  - 3DVar $(\boldsymbol{B_c})$
  - HYB-50 $0.5(\boldsymbol{B_c} + \boldsymbol{B_e})$
  - 3DEnVar $(\boldsymbol{B_e})$

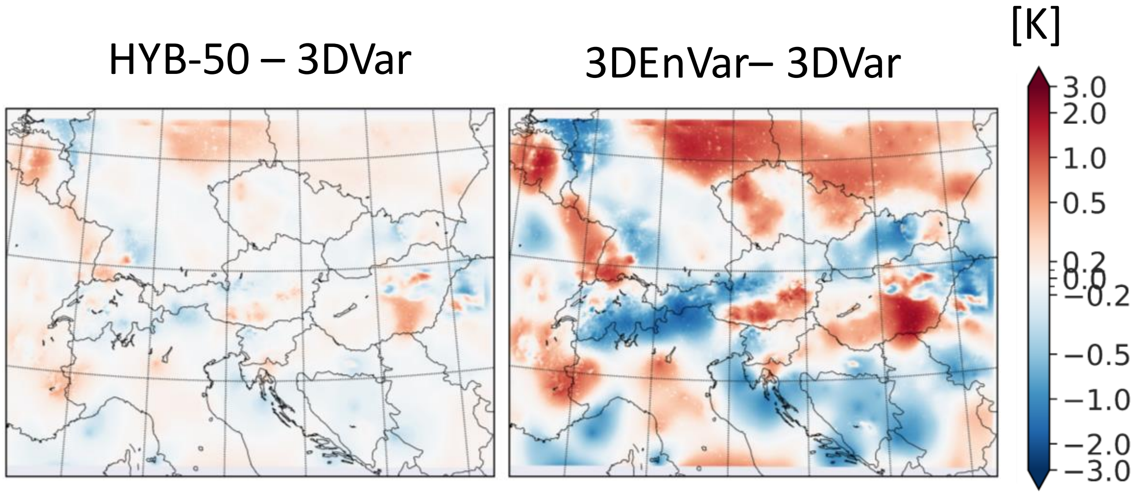


- 408 stations are assimilated
- 277 stations for verification

- Verification

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(F_i - O_i)^2}$$

Evaluation of T2m forecast at 0-hr lead time

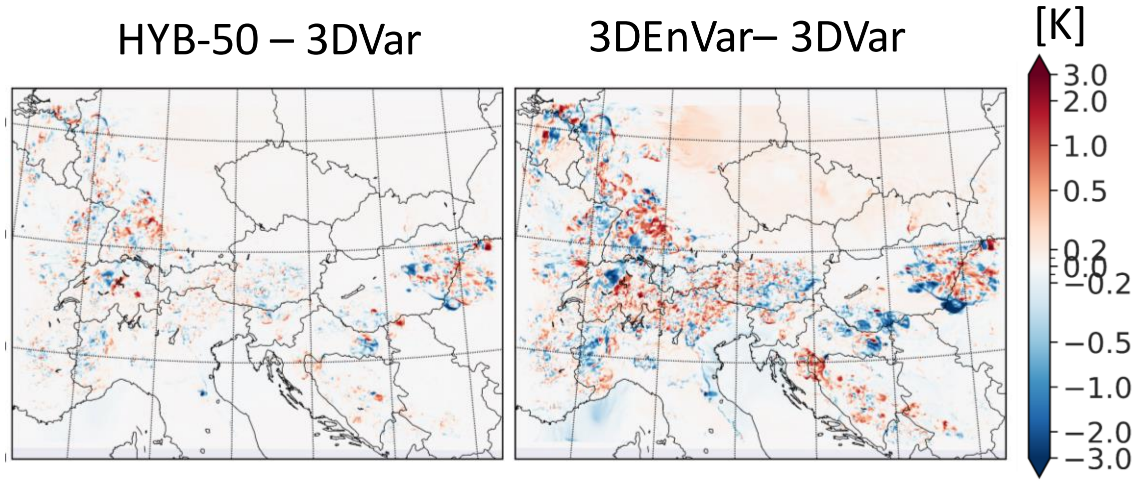


- Substantial differences in the forecasts

No-assimilation	3DVar	HYB-50	3DEnVar
2.20	1.92	1.93	2.06

- Assimilating T2m improves the 0-hr forecast in all experiments

Evaluation at 3hr lead time



Differences are still present at a 3-hr lead time and are adjusted as the model evolves

Evaluation at 3hr lead time

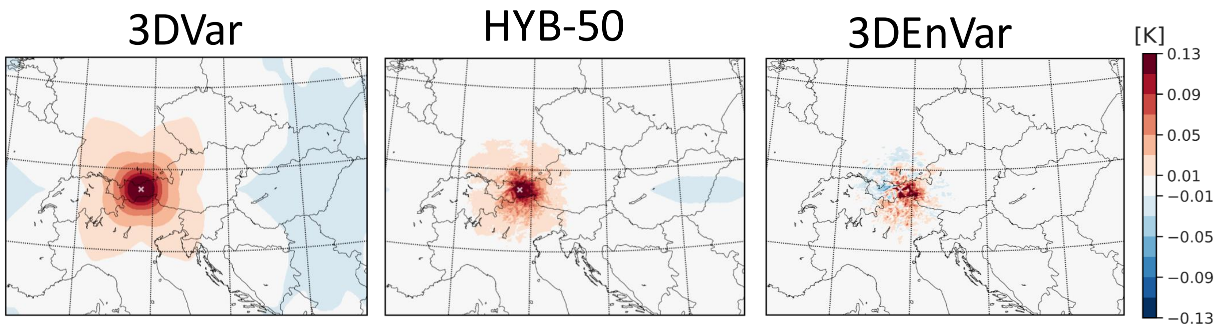
Valley (z< 800 m)
Mid-altitude (z = 1000 to 2000 m)
Mountain (z> 2000 m)

Experiment	z<800 m (valley)	z=1000-2000 m (mid-altitude)	z>2000 m (mountain)
3DVar	1.90	4.37	2.50
HYB-50	1.92	4.33	2.49
3DEnVar	1.89	4.30	2.43

Forecast from HYB-50 and 3DEnVar improved compared to 3DVar

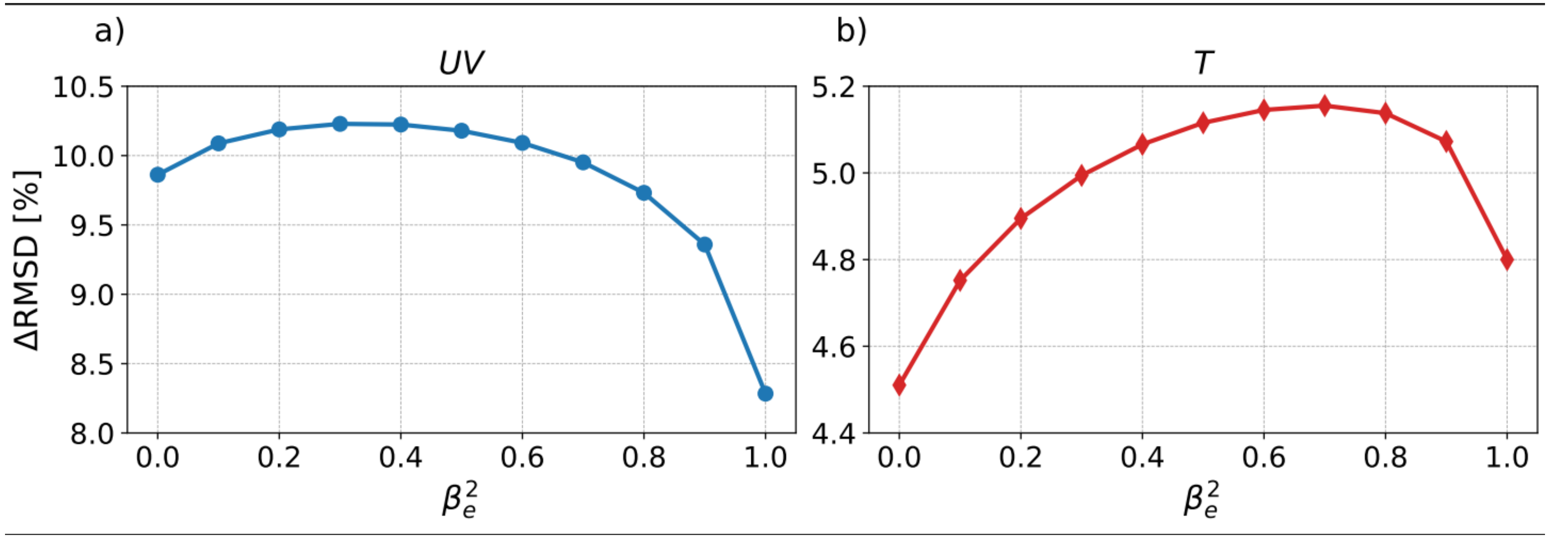
Conclusions

- Successful use of C-LAEF in 3DVar data assimilation while assimilating T2m in AROME-Austria.
- 3DEnVar and HYB-50 can be a suitable alternative over 3DVar in the Alps.



- T2m Forecast from 3DEnVar improves compared to 3DVar. HYB-50 slightly degrade forecast in valleys.

Experiment	*z*<800 m (valley)	*z*=1000-2000 m (mid-altitude)	*z*>2000 m (mountain)
3DVar	1.90	4.37	2.50
HYB-50	1.92	4.33	2.49
3DEnVar	1.89	4.30	2.43


a)
UV
ΔRMSD [%]
10.5
10.0
9.5
9.0
8.5
8.0
0.0
0.2
0.4
0.6
0.8
1.0
β_e^2
b)
T
5.2
5.0
4.8
4.6
4.4
0.0
0.2
0.4
0.6
0.8
1.0
β_e^2