In collaboration with

RIKEN R-CCS Data Assimilation Team

Guidance on optimal vertical covariance localization based on a convection-permitting 1000-member ensemble

AS1.9 EGU22-4413

EGU General Assembly 2022

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Motivation – Why vertical localization?

Ensemble-based background error covariances:

- Key component in convective-scale data assimilation
- Introduce flow-dependence
- Spread information in state space and determine observation weight

Problem: **Sampling error due to under-sampling**

Requires: **Localization to mitigate spurious correlations**
(e.g., distance-dependent damping of covariances)

Challenges for (vertical) localization:

- **Long-distance error correlations** with physical meaning
  --> for example radiative effects of clouds or deep convection
- **Non-linear flow and rapid error growth**
  --> localization on convective scales is non-trivial task

Our approach: **Very large ensembles + subsampling for improving localization**

Localization of error covariances

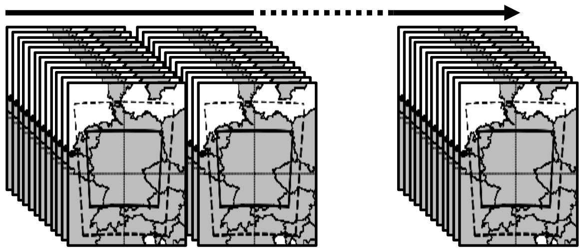
$x_a = x_b + K(y - H\,x_b)$

$K = PH^T(HPH^T + \mathbf{R})^{-1}$

$$\mathbf{P} = \frac{1}{N-1}\sum_{n=1}^{N}(x^n - \overline{x})(x^n - \overline{x})^T$$

$$\mathbf{P}_{loc} = \mathbf{C} \circ \mathbf{P}$$

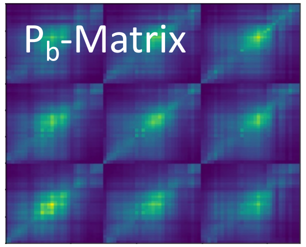
C: Localization matrix (model space)

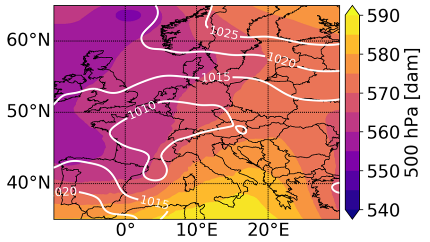


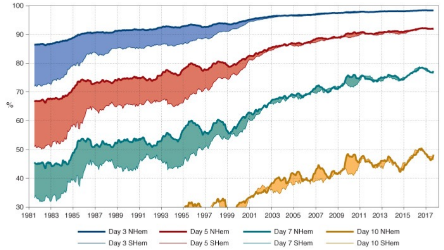
Research goals - Vertical Localization

Goal: Improving localization → Better Error Covariances → Better Initial Conditions → Improved Forecasts → Benefit

1000-member ensemble







Research questions: Improving vertical localization based on 1000-member ensemble data-set

a) How should an **optimal localiaztion** for vertical correlations be constructed?

b) What are **optimal vertical localization scales/functions** for temperature, humidity or wind?

c) How much **error reduction** can be achieved with different vertical localization approaches?

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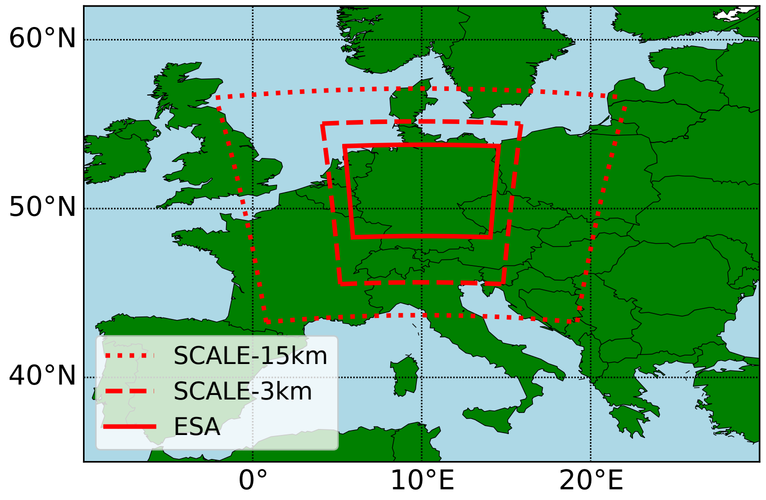
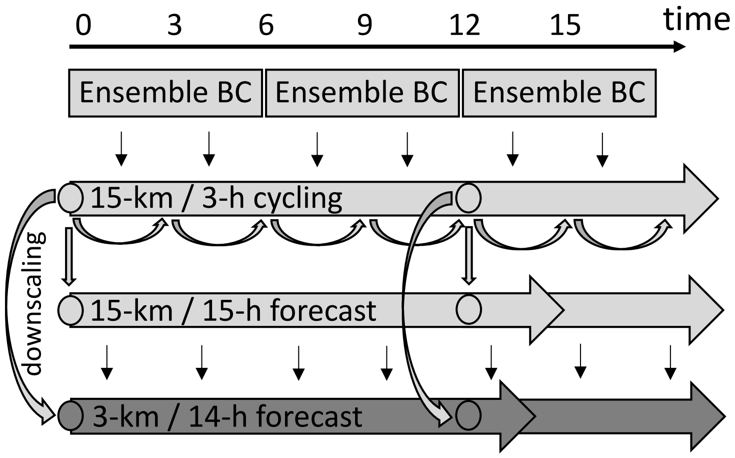
Convective-scale 1000-member ensemble simulation

1000-member ensemble
- **Model**: Japanese "SCALE-RM" model
- **Period:** 5 days / 10 forecasts in Mai/June 2016
- **Resolution:** 3 km grid spacing, 350x250 grid points with 30 levels
- **Boundary conditions:** Global GFS ensemble (20-member, NCEP)
  + 1000 random climatologically scaled perturbations

Experimental setting:
- 1000-member correlation as truth: r^{1000}
- 25 40-member subsample correlations: r^{40}
- 3h first guess background forecast for error correlations
- Focus on vertical correlations on 20 pressure levels





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Necker et al. 2020a (QJRMS)
Necker et al. 2020b (MWR)

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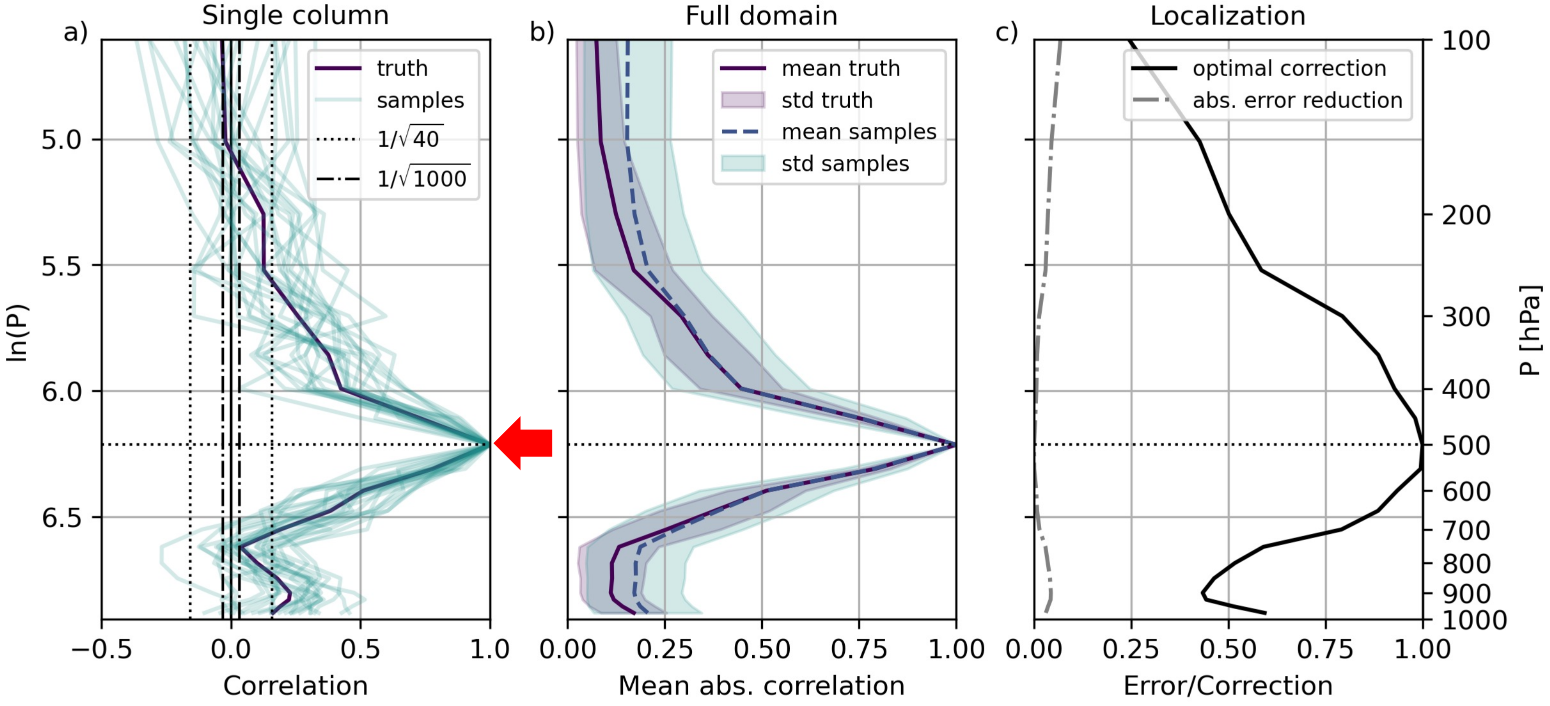
Goal: Finding empirical optimal localization α



Cost function J –> opt. localization α

„minimize root mean square difference between subsamples and 1000-m truth“

$$J(\alpha, t, p, A) = \sqrt{\sum_{s=1}^{S}\sum_{k=1}^{K}(\alpha r_{s,k}^{40} - r_{k}^{1000})^2}$$

J: Cost function
α: opt. localization
r: correlation
t: time
p: level
A: Variable pair
S: Subsamples
K: Grid points

Optimal localization for vertical correlations

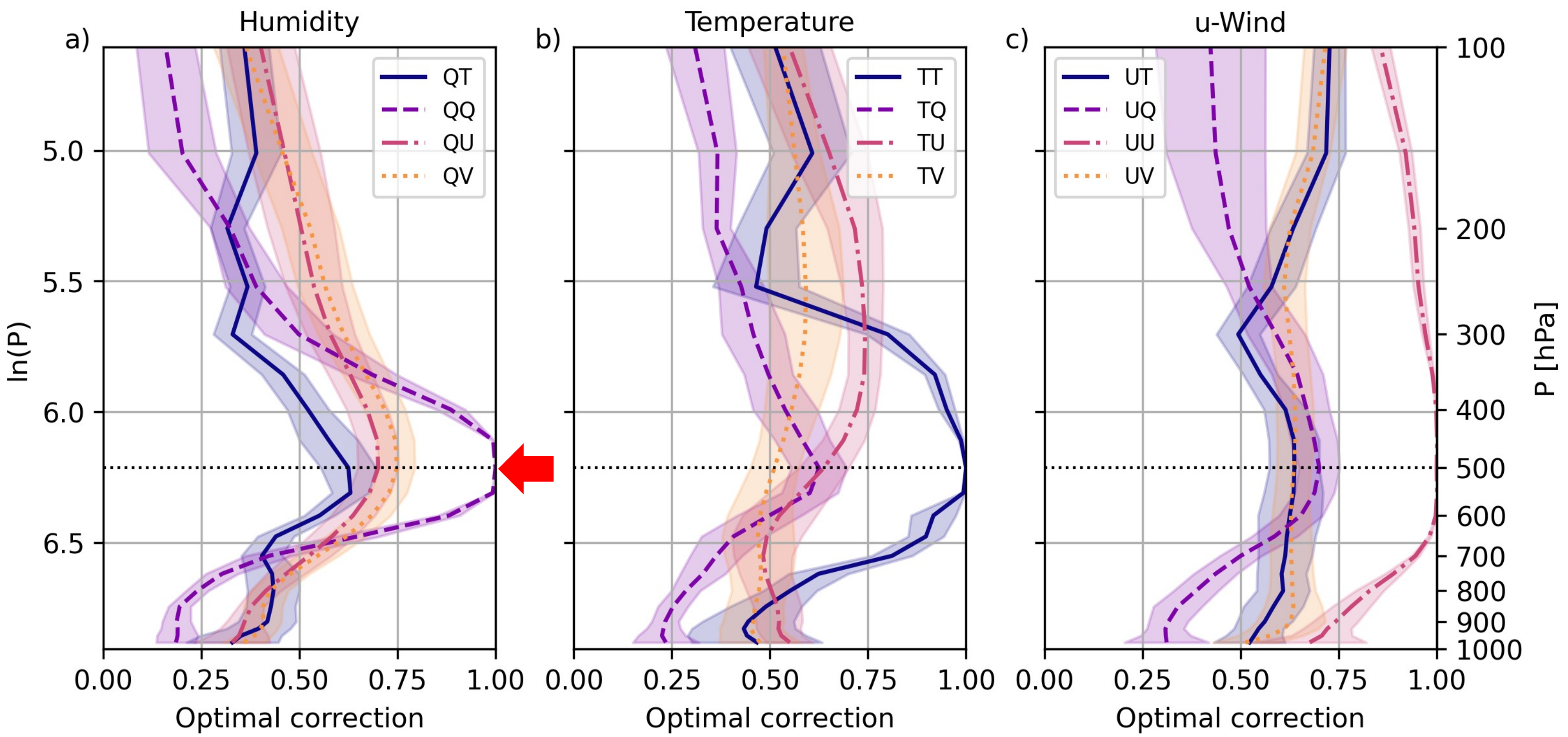
- Domain-uniform / non-adaptive loc.
- **Reference level 500hPa**
- **Temperature-Temperature correlations**

We focus on correlations as sampling error in variances is small

$$cov(x_1, x_2) = \boxed{r(x_1, x_2)}\sigma(x_1)\sigma(x_2)$$

Preliminary results / Publication in preparation

Teaser result - Optimal vertical localization α



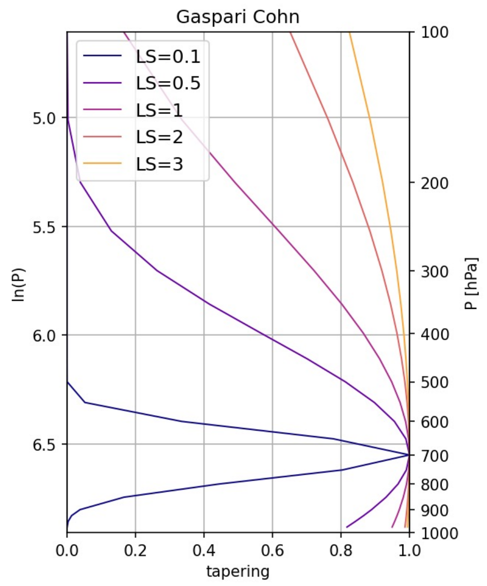
T: Temperature / Q: Spec. humidity / U: Zonal wind / V: Meridional wind

Shading: forecast-to-forecast variability

Reference level 500hPa

Conclusions

- Different localization scales: humindity, temperature, and wind
- Different requirements for self-/ and cross-correlations
- Different localization shapes: Exponential, Gaussian, or linear



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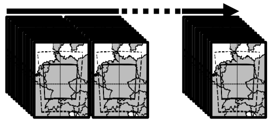
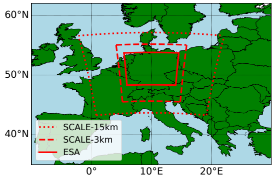
Summary



What can we learn from a convective-scale 1000-member ensemble?

- Quantify sampling errors and evaluate existing localization methods
- Derive optimal localization approaches independent of algorithmic constraints



Research Questions

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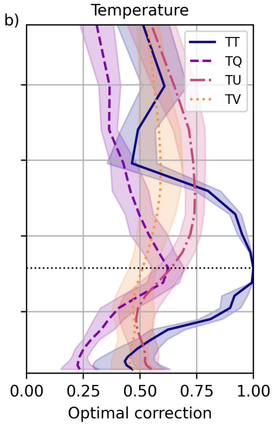
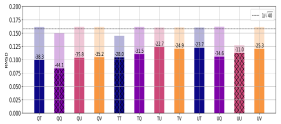


Necker et al. 2022 (NPG / Copernicus - Submission soon)
Guidance on how to improve vertical covariance localization based on a 1000-member ensemble.

Necker et al. 2020a (QJRMS) A convective-scale 1,000-member ensemble simulation and potential applications.
Q. J. R. Meteorol. Soc. 2020, 146, 1423– 1442. https://doi.org/10.1002/qj.3744



Necker et al. 2020b (MWR) Sampling Error Correction Evaluated Using a Convective-Scale 1000-Member Ensemble.
Mon. Wea. Rev., 148, 1229-1249. https://doi.org/10.1175/mwr-d-19-0154.1

Thank You!

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