Rapid observation system experiments for observation impact in the ensemble space

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Introduction

- Forecast trajectories are influenced by data assimilation
  → different experiments are not comparable
- Difficult to understand the analysis and its components
- Observation system experiments experiments are:
  computationally expensive
  time consuming

How can we analyse the ensemble space to get insights about the ensemble system and the observation impact?

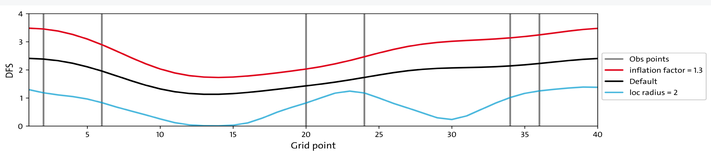
Degrees of freedom in ensemble space

$$\mathrm{DF}^{\mathrm{S}} = k - (k-1)\mathrm{tr}(\tilde{\mathbf{P}}^{\mathbf{a}})$$

where $\tilde{\mathbf{P}}^{a}$ is the covariance matrix of ensemble weights at analysis

- In ensemble space, ensemble members are independent
  → space has k degrees of freedom (k = number of members)
- Data assimilation constrains the background to the observations
  → decreased degrees of freedom in ensemble space
  → collapsed ensemble is lower limit
- Degrees of freedom is trace (tr) of an influence matrix
  → degrees of freedom for noise: $\mathrm{DF}^{\mathrm{a}} = \mathrm{tr}((\tilde{\mathbf{P}}^{b})^{-1}\tilde{\mathbf{P}}^{a}) = (k-1)\mathrm{tr}(\tilde{\mathbf{P}}^{a})$
  → degrees of freedom for signal (DFS) is difference between maximum number (k) and degrees of freedom for noise
- Assumption: covariances are specified correctly
- In ETKF, inexpensive to calculate because eigenvalues are reused

Usable to estimate data assimilation and tuning parameter impact

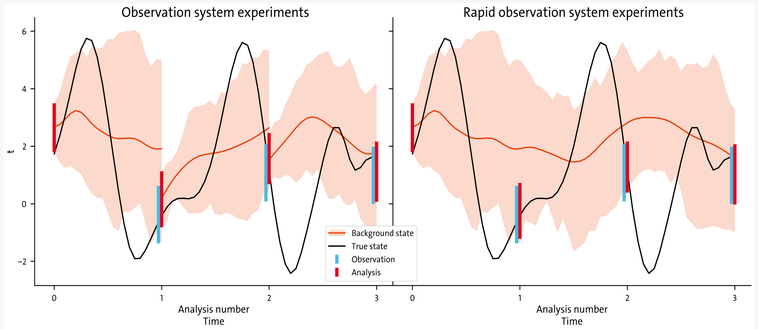


Degrees of freedom for signal for every grid point at an arbitrary time point with different localization radius (blue, default=5) and multiplicative inflation (red, default=None) calculated with LETKF and Lorenz 96 model

Rapid observation system experiments

Do not propagate the analysis to the next background, replace it by an open loop

	Observation system experiments (OSEs)	Rapid observation system experiments (ROSEs)
State trajectories	influenced by DA	not influenced
Experiments comparable	no comparability	yes
Separablity between analysis and propagation	no separability	only analysis
Experimentation speed	slow	rapid

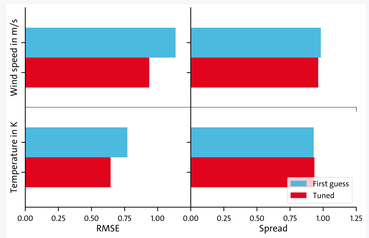


Schematic difference between OSEs and ROSEs at an arbitrary time period calculated with LETKF and the Lorenz 96 model

- Similar methods are already used in paleoclimatology, which are called “offline data assimilation”
- Rapid observation system experiments solve problems of OSEs, but have several drawbacks:
  - no decreased forecast error because analysis is not propagated
    → error in base state trajectory needs to be bounded, otherwise we would get exploding increments
    → but limited area models are constrained by boundary data
  - overestimation of background covariance and obs impact
  - only obs impact on analysis and not on forecasts

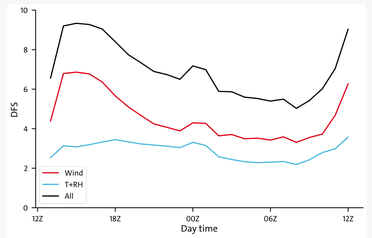
Real world applications

ROSEs for LETKF tuning



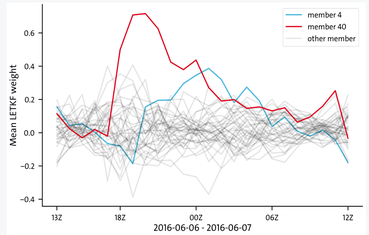
Differences due to observation error and multiplicative inflation factor tuning

ROSEs and DFS for obs impact



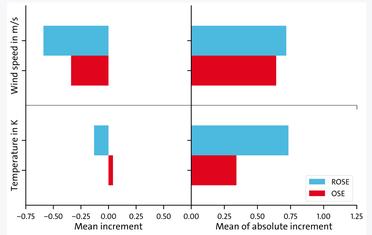
Wind observations have the highest average impact among tower observations

ROSEs for weight analysis



We can trace LETKF weights of single ensemble members through the whole run

OSEs and ROSEs comparison



Overestimation of observation impact for all variables on analysis compared to OSEs

- COSMO around Hamburg with LETKF and single tower observations

Conclusion

- Two new methods (ROSEs and DFS) to analyze the impact of EnKFs
  → together they can be used to estimate a relative obs impact
- Degrees of freedom in ensemble space
  - measures the observation impact on ensemble space
  - usable to visualize parameter impact on ETKF
- Rapid observation system experiments for rapid experimentation
  - different experiments are comparable
  - usable to analyse the data assimilation system behaviour

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References:
Bhend, Jonas et al. (2012). “An ensemble-based approach to climate reconstructions”. Climate of the Past
Bishop, Craig et al.(2001). “Adaptive sampling with the ensemble transform Kalman filter. Part I: Theoretical aspects”. MWR
Cardinali, Carla, et al. (2004). “Influence matrix diagnostic of a data assimilation system”. QJRMS
Schraff, Christoph, et al. (2016). “Kilometre-scale ensemble data assimilation for the COSMO model (KENDA)”. QJRMS