Towards a hybrid ensemble nudging / LETKF regional reanalysis data assimilation system

Lilo Bach[1], Jan Keller[2,3]

Christian Ohlwein[1,2], Andreas Hense[1]

1) Meteorological Institute, University of Bonn
2) Hans-Ertel-Centre for Weather Research
3) German Weather Service, Offenbach

---

collaboration with Christoph Schraff[3], Klaus Stephan[3]

universitätbonn

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

DWD

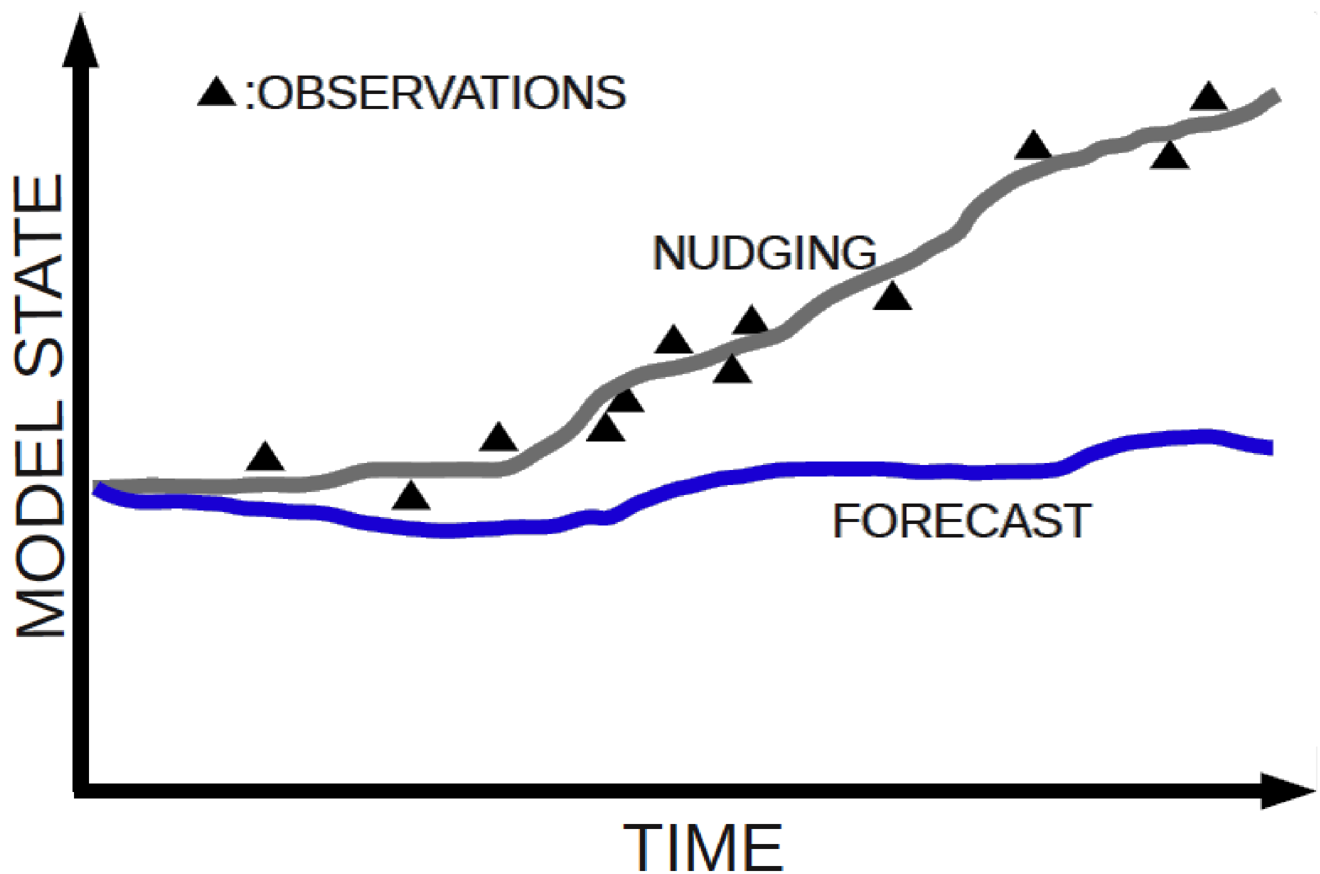
UERRA
Uncertainties in Ensembles of Regional ReAnalyses

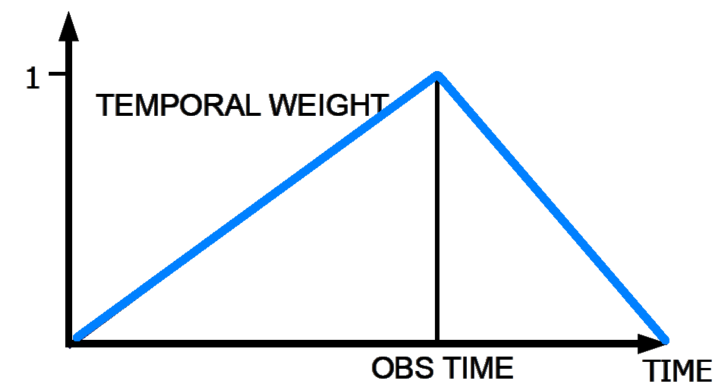
Ensemble nudging

Hybrid ensemble nudging / LETKF

Deterministic nudging

$$\frac{\partial}{\partial t}\psi(\mathbf{x},t) \quad = \quad F(\psi,\mathbf{x},t) \quad + \quad G_\psi \cdot \sum_{k_{(obs)}} W_k(\mathbf{x},t) \cdot [\psi_k^{obs} - \psi(\mathbf{x}_k,t)] \qquad (1)$$



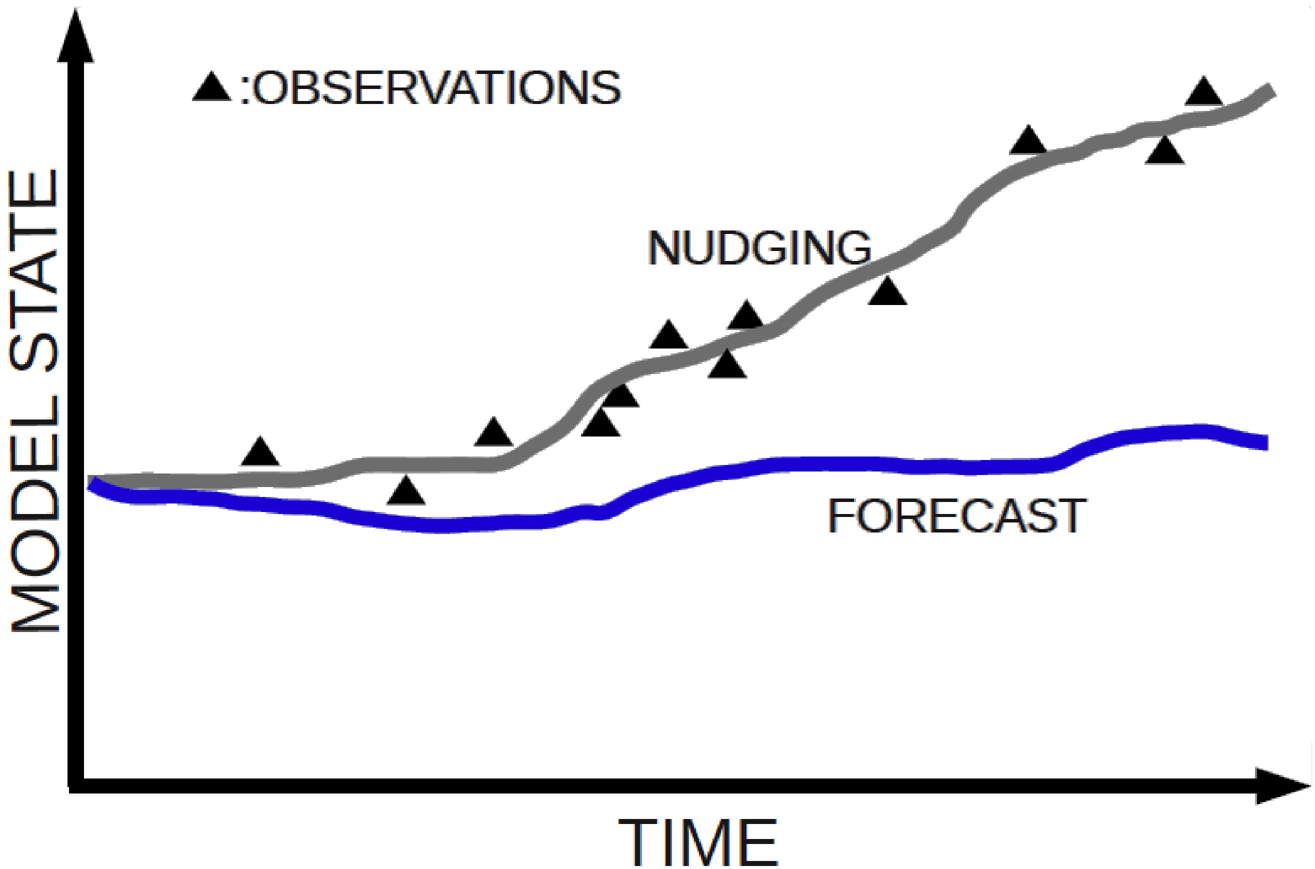


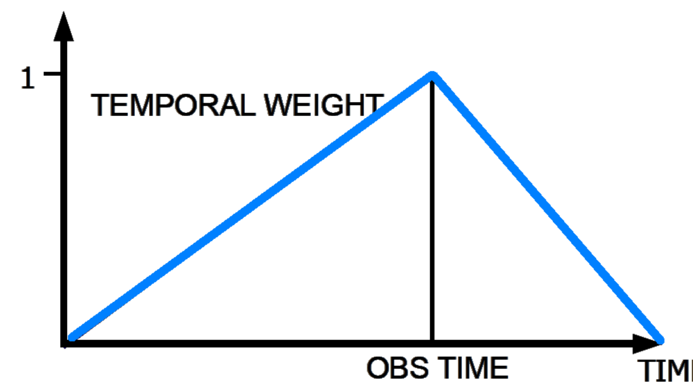
(1) Schraff, 1997

What is the uncertainty of a nudging reanalysis given observation errors?

Deterministic nudging

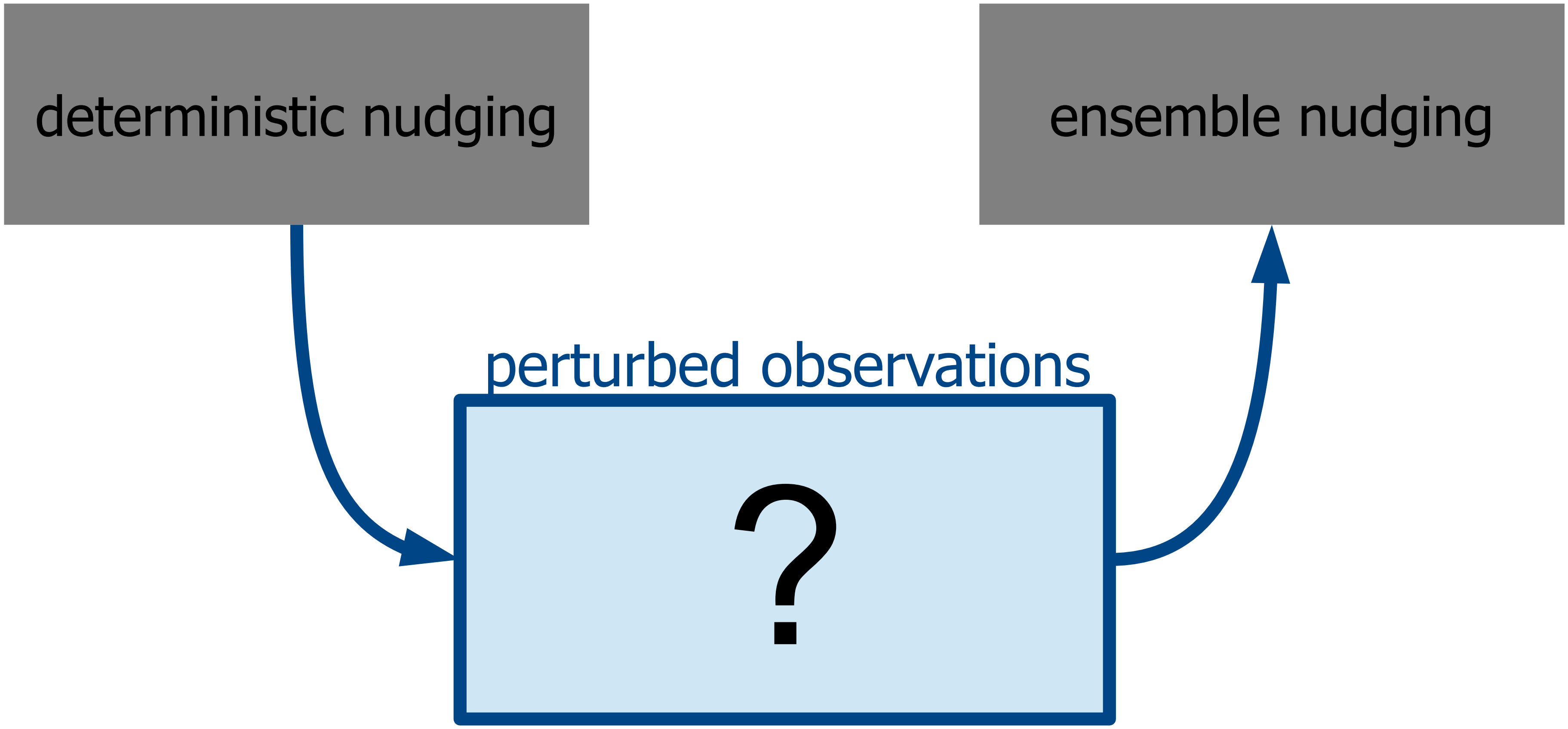
$$\frac{\partial}{\partial t}\psi(\mathbf{x},t) \quad = \quad F(\psi,\mathbf{x},t) \quad + \quad G_\psi \cdot \sum_{k_{(obs)}} W_k(\mathbf{x},t) \cdot \boxed{[\psi_k^{obs}} - \psi(\mathbf{x}_k,t)] \qquad (1)$$





(1) Schraff, 1997

Ensemble nudging



Ensemble nudging

deterministic nudging

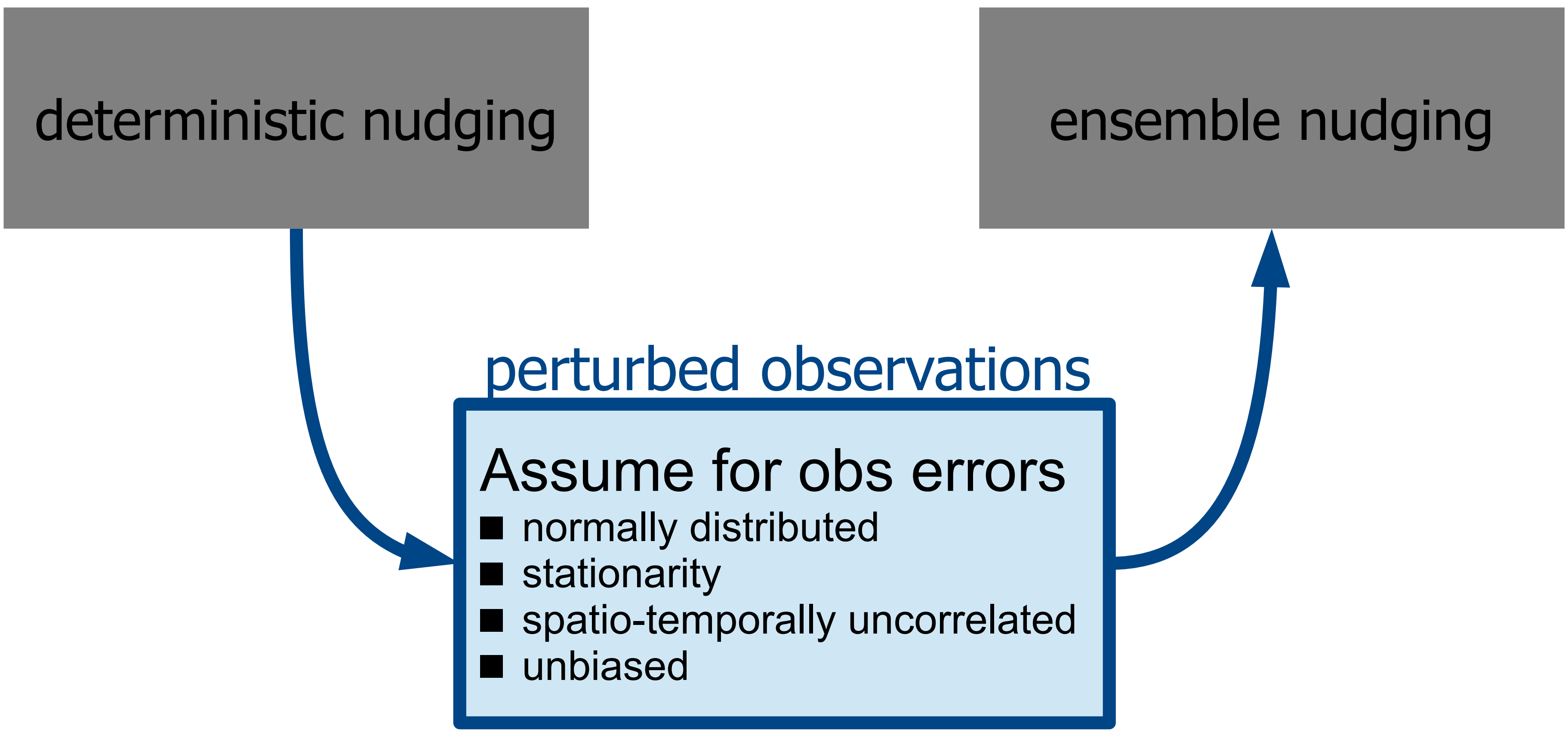
perturbed observations

$o_p = o + o'$ with

$o' \sim \mathcal{N}(0, \sigma_o)$

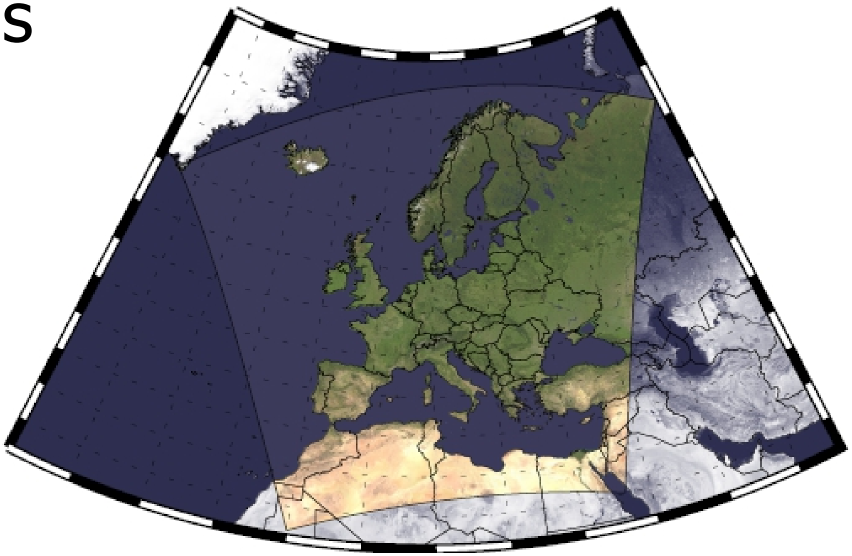
ensemble nudging

Ensemble nudging



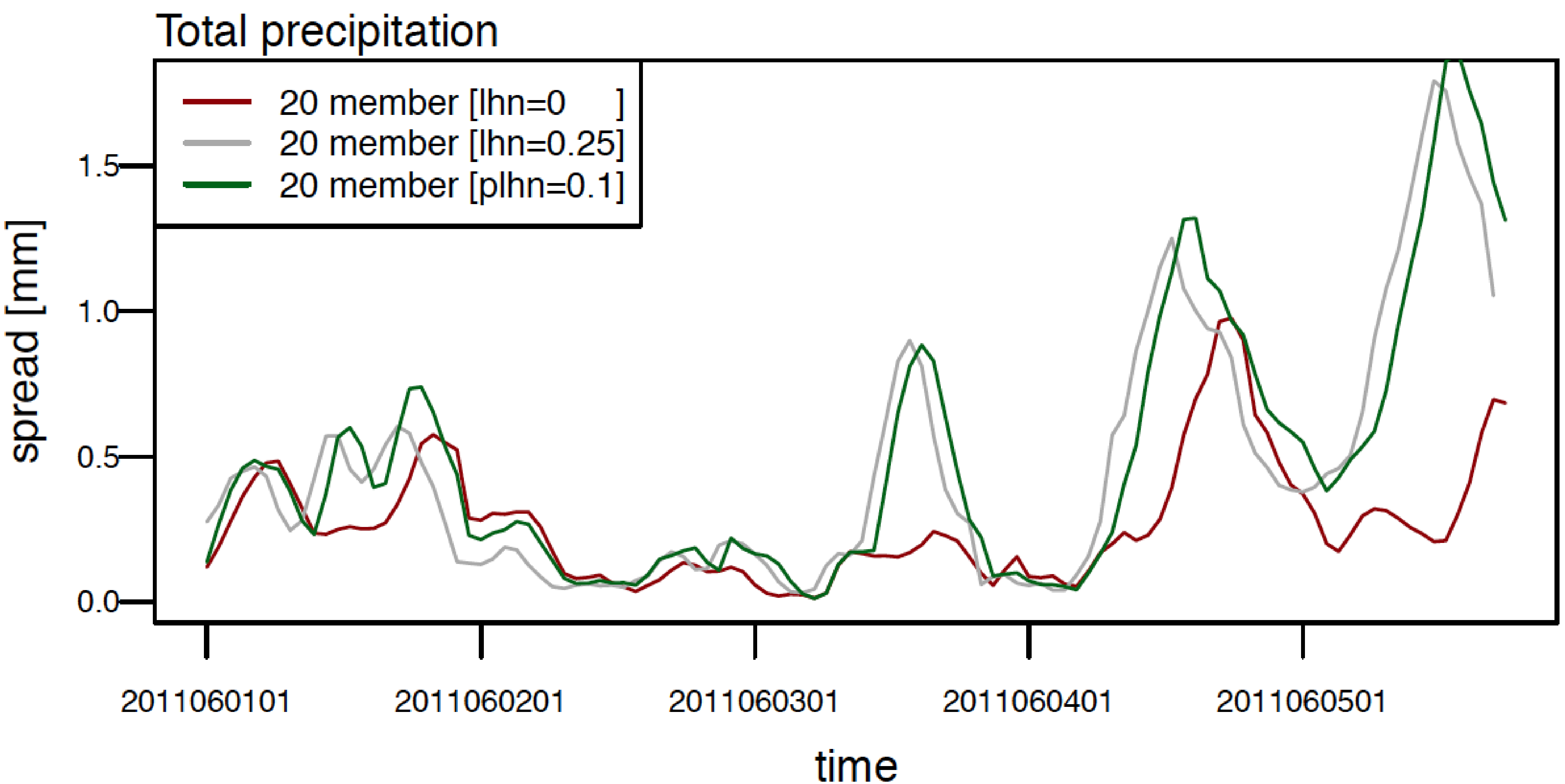
Case studies for CORDEX-EUR11

- COSMO model
- $\Delta x = \Delta y = 0.11°$ / 40 vertical levels
- 01.06. - 06.06.2011
- 15.12. - 21.12.2011
- 20 to 40 ensemble members

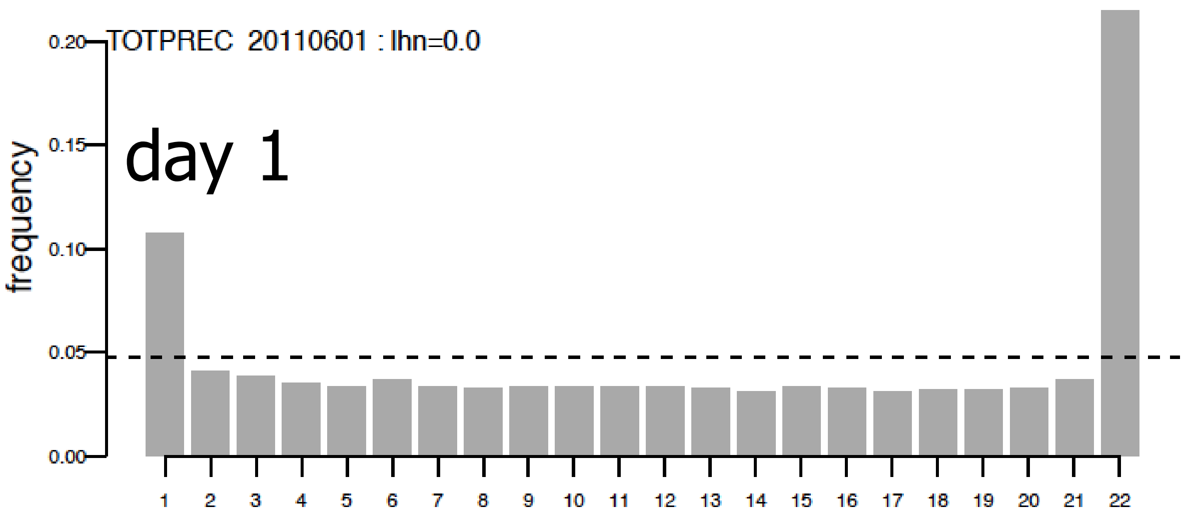


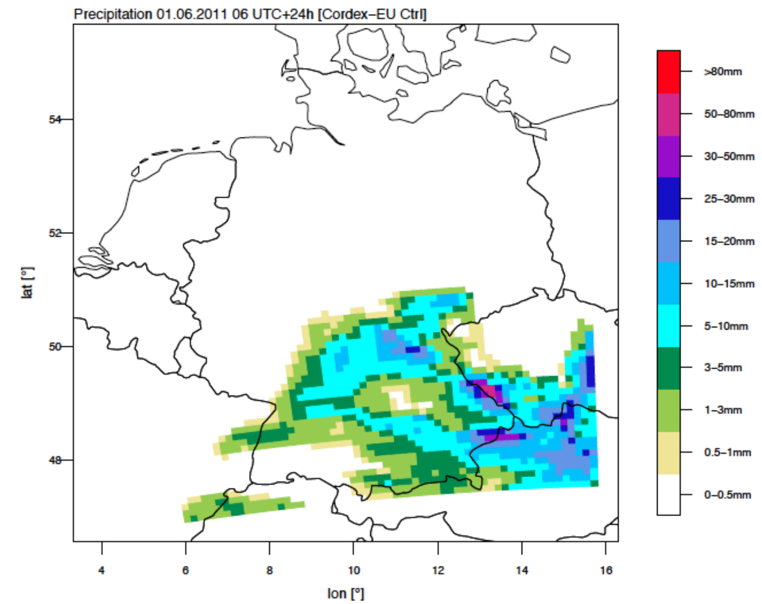
- REPORTS: TEMP, PILOT, DRIBU, ACARS, AMDAR, SYNOP, WIND PROFILER, SHIP

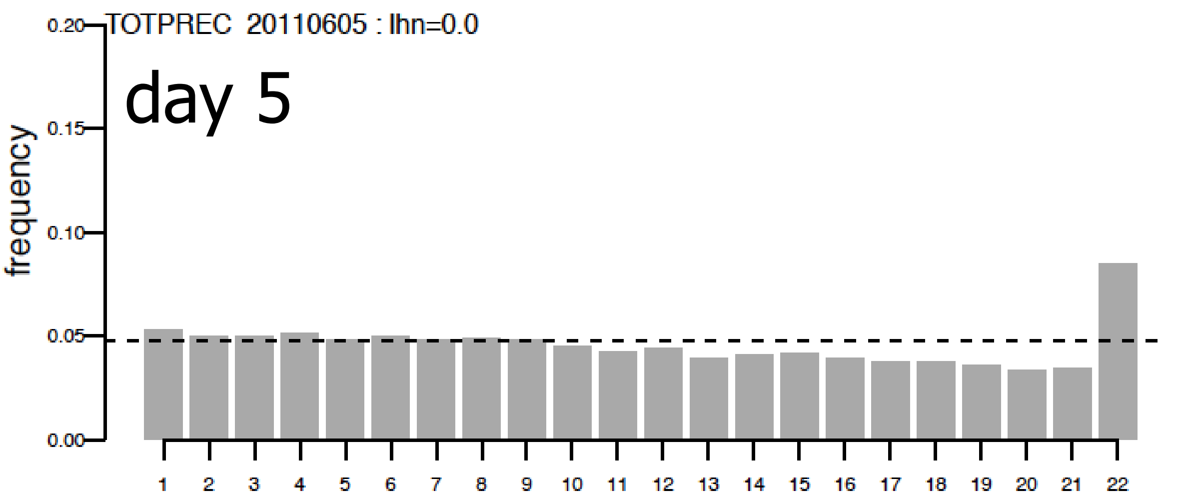
Spread

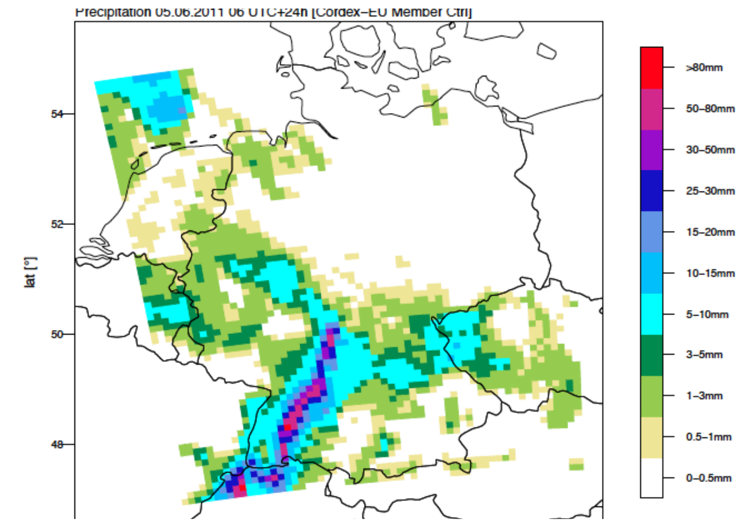

Total precipitation
20 member [lhn=0]
20 member [lhn=0.25]
20 member [plhn=0.1]
spread [mm]
0.0
0.5
1.0
1.5
2011060101
2011060201
2011060301
2011060401
2011060501
time

Ensemble calibration

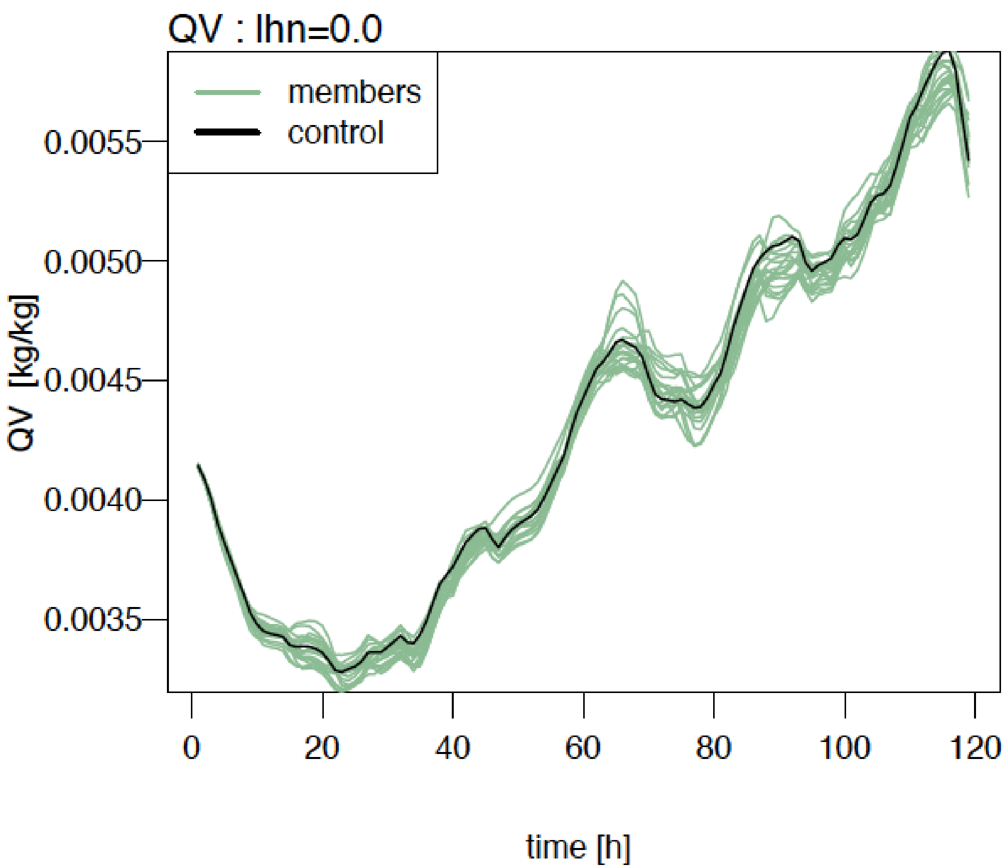


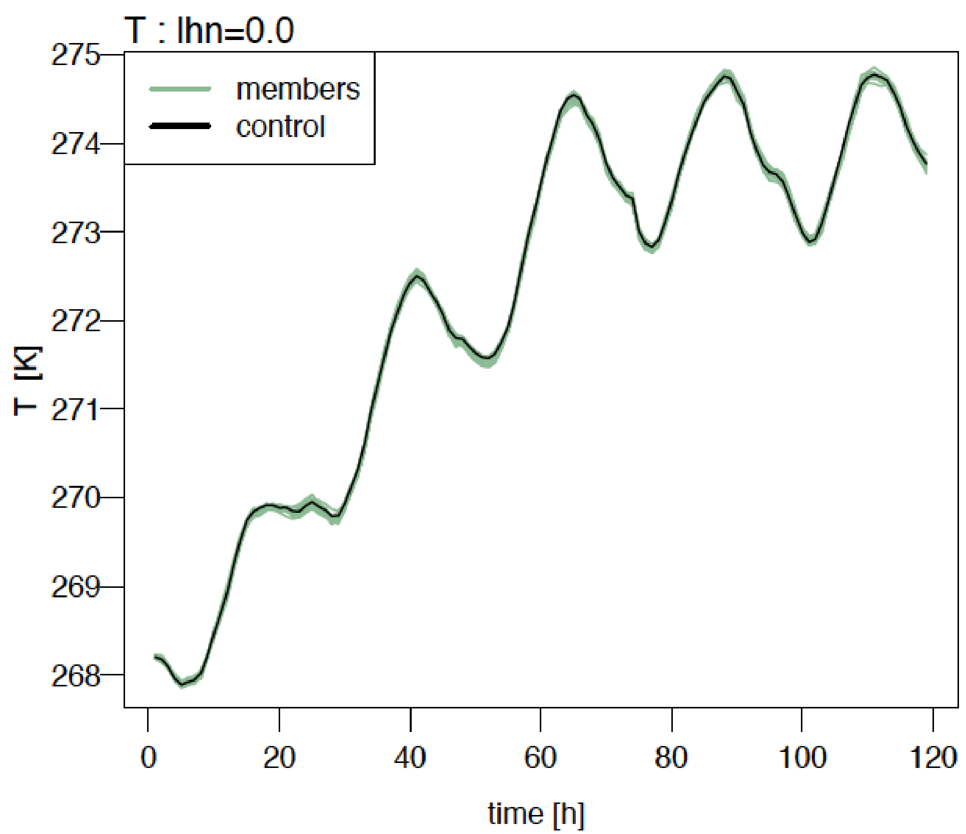






Evolution of ensemble members





Further investigations

- impact of perturbed obs on convection

  → strong projection of obs errors on convective events

- latent heat nudging

  → positive impact on precipitation

  → suspension point for pseudo-observations

Next steps

- perform longer experiments (~ 3 months)
- verification

  → data available on 1-hourly resolution?
- latent heat nudging for whole CORDEX domain

  → radar data for whole European CORDEX domain?
- enhance spread of T2m by perturbing SMA
- assimilation of pseudo-observations
- enhance nudging coefficients by means of background covariance matrix
- technique for perturbing boundary conditions?

Ensemble nudging

Hybrid ensemble nudging / LETKF

Local ensemble transform Kalman filter (LETKF)

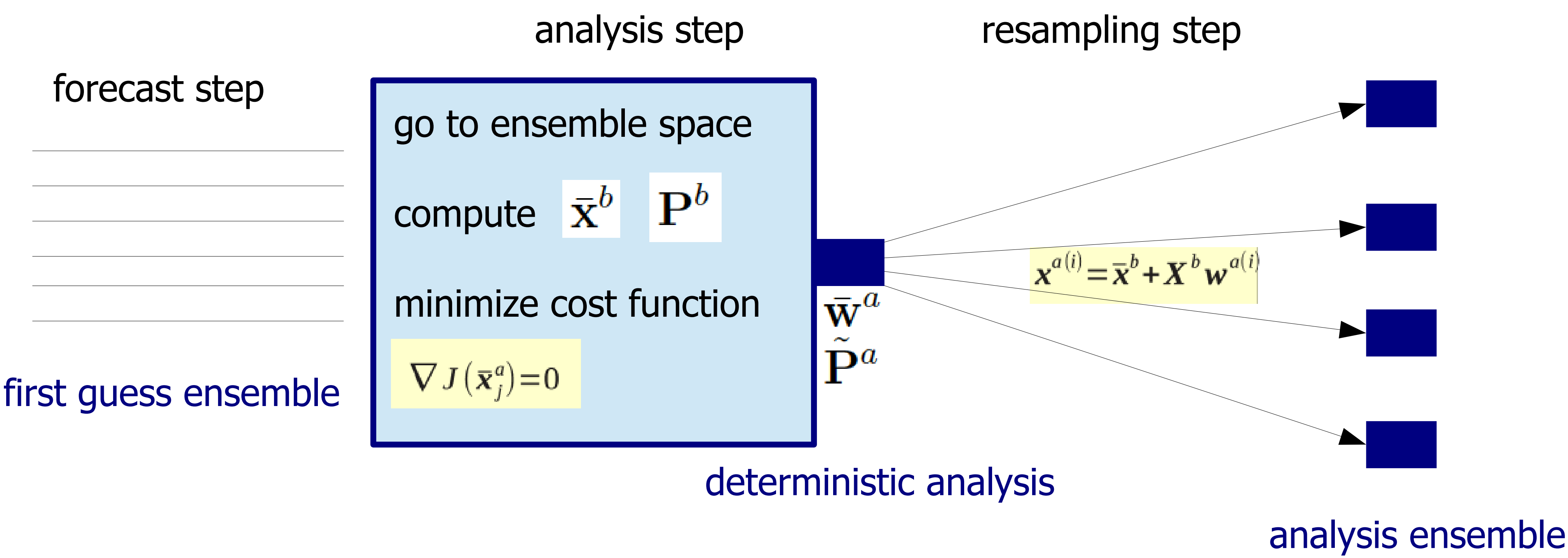
- perform analysis in space of ensemble perturbations[1]

- explicit localization, i.e. analysis for each grid point separately

- analysis ensemble members are linear combinations of first guess ensemble members

(1) Hunt et al, 2007

LETKF steps



analysis step
resampling step
forecast step
go to ensemble space
compute $\bar{\mathbf{x}}^b$ $\mathbf{P}^b$
minimize cost function
$\nabla J(\bar{\mathbf{x}}_j^a)=0$
$\bar{\mathbf{w}}^a$
$\tilde{\mathbf{P}}^a$
$\boldsymbol{x}^{a(i)}=\bar{\mathbf{x}}^b+\boldsymbol{X}^b\boldsymbol{w}^{a(i)}$
first guess ensemble
deterministic analysis
analysis ensemble

HENLETKF

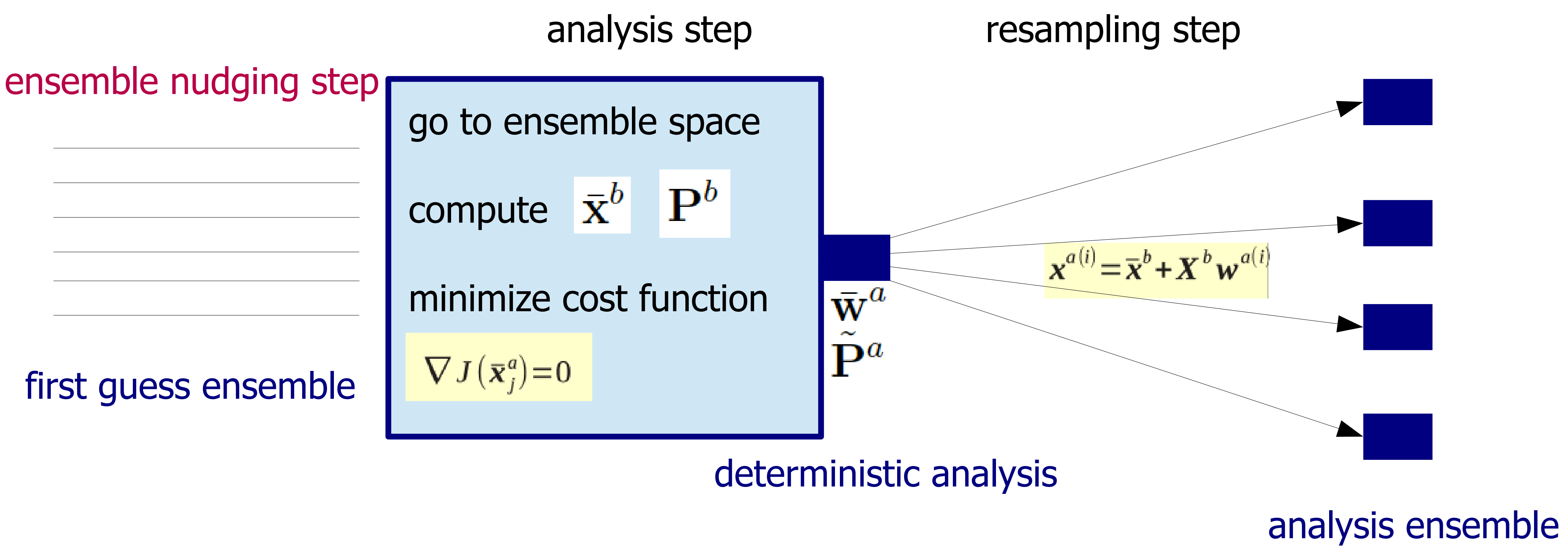
- provide nudging ensemble as first guess to LETKF
- alternate components temporally
- conventional obs in ensemble nudging, new ones in LETKF

- advantages of combination

  → new observations in LETKF component

  → enhancement of spread using ensemble nudging component → less covariance inflation

HENLETKF



analysis step
resampling step
ensemble nudging step
go to ensemble space
compute $\bar{\mathbf{x}}^b$ $\mathbf{P}^b$
minimize cost function
$\nabla J(\bar{\mathbf{x}}_j^a)=0$
$\bar{\mathbf{w}}^a$
$\tilde{\mathbf{P}}^a$
$\boldsymbol{x}^{a(i)}=\bar{\mathbf{x}}^b+\boldsymbol{X}^b\boldsymbol{w}^{a(i)}$
first guess ensemble
deterministic analysis
analysis ensemble

Summary

- implementation of ensemble nudging with online perturbation of observations
    - calibrated ensemble
    - no bias introduced to members compared to control
    - control run reasonable realization of ensemble
    - precipiation and surface temperature verified
- first steps with LETKF
- statistical models for artificial radiosondes and precipitation information

Towards a hybrid ensemble nudging / LETKF regional reanalysis data assimilation system

Lilo Bach[1], Jan Keller[2,3]

Christian Ohlwein[1,2], Andreas Hense[1]

1) Meteorological Institute, University of Bonn
2) Hans-Ertel-Centre for Weather Research
3) German Weather Service, Offenbach

---

collaboration with Christoph Schraff[3], Klaus Stephan[3]

universitätbonn

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

DWD

UERRA
Uncertainties in Ensembles of Regional ReAnalyses

Pseudo observations

- observing network sparse in earlier reanalysis time spans

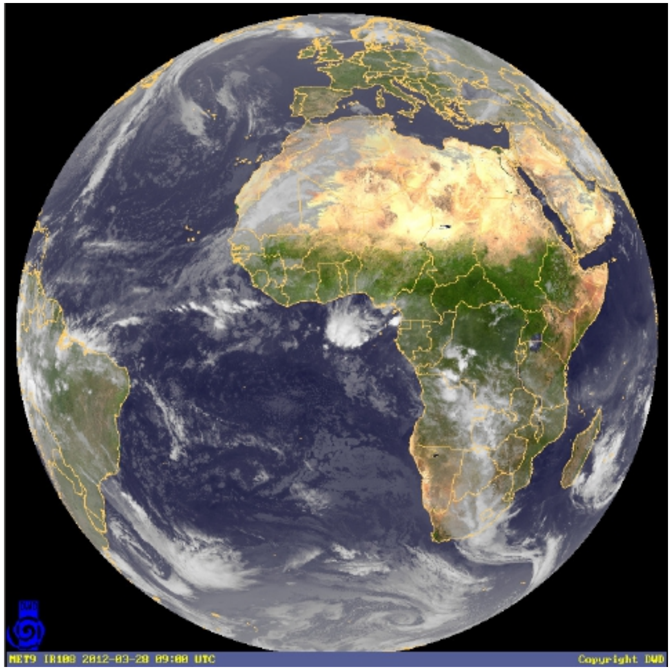
  → Do artificial observations have a positive impact when being assimilated into reanalyses?

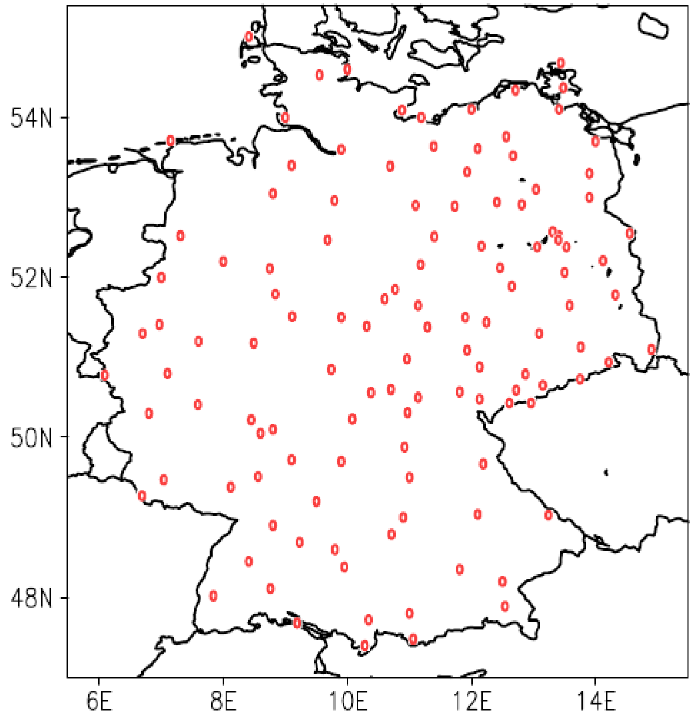
- explore statistical methods
  - vertical temperature profiles / pseudo radiosondes
  - precipitation information

Data

ieda.pscheidt@uni-bonn.de

- hourly precipitation data
- 15-min brightness temperature from MSG





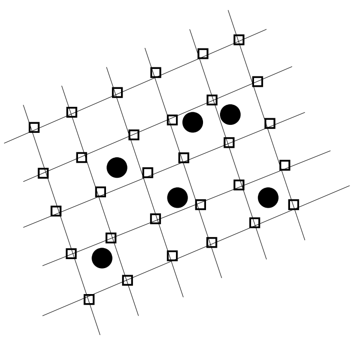
spatial resolution ~4km

10.8 µm

Bayesian Spatial Generalized Linear Model

$$Y=(Y(x_1),\ldots,Y(x_n)) \xrightarrow{\text{threshold}}$$

Observations in Space
Y ε [0,1]



$$S=(S(x_1),\ldots,S(x_n),S(x_{n+1}),\ldots,S(x_q))$$

$$\log\left(\frac{\mu}{1-\mu}\right)=S$$

$$S_i=\beta_0+\Sigma_{k=1}^{m}\beta_k d_{ki}+U_i$$

$$MVN(0,\Sigma)$$

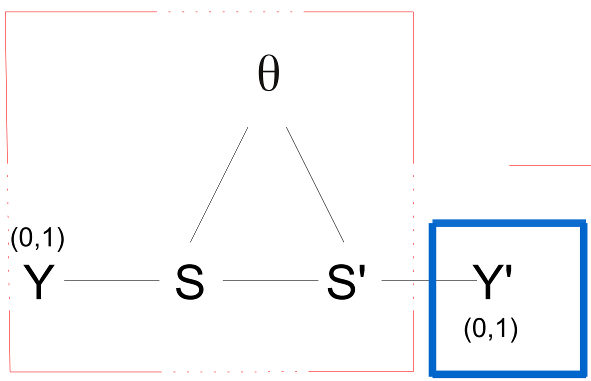
$$Cov(S(x_i),S(x_j))=\sigma^2\rho$$

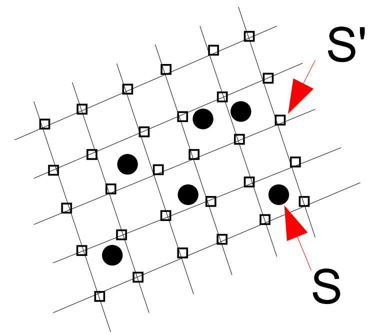
$$\rho(x_i-x_j;\phi)$$

$$\rho=\exp\left(\frac{-h}{\phi}\right)$$

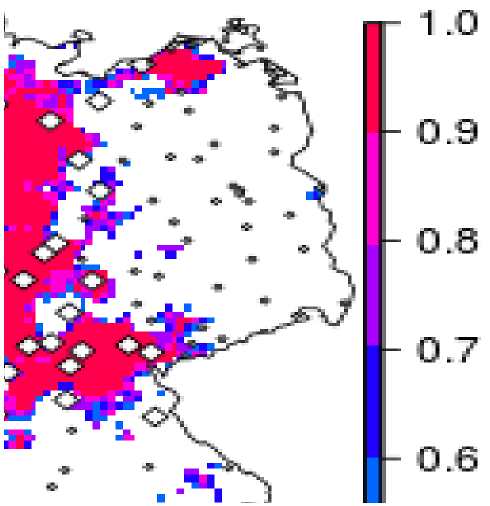
$$prob_i=\mu_i=\frac{\exp(S_i)}{1+\exp(S_i)}$$

Gaussian spatial process





$$prob = \mu = \frac{\exp(S')}{1+\exp(S')}$$



$$[S'|Y] \propto [S'|S,\theta][S,\theta|Y]$$

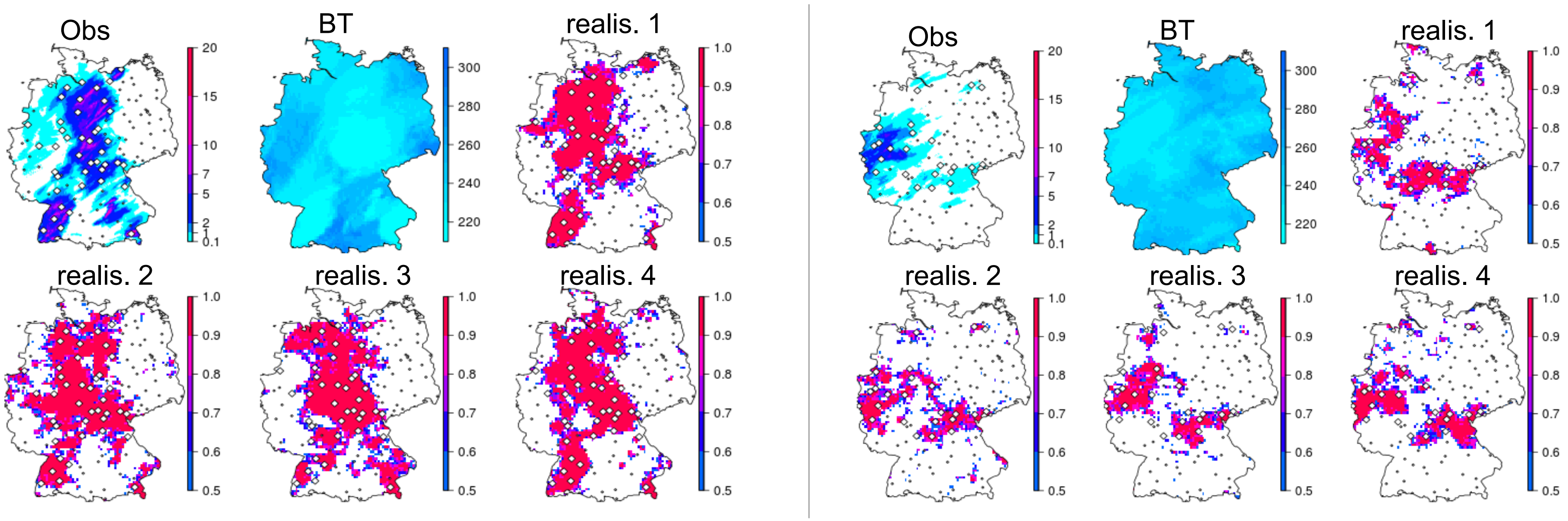
$$[S'|Y] \propto \int\int \underbrace{[S'|S,\phi]}_{t(\mu_s,\, S_1^2\Sigma_s)}\underbrace{[S,\phi|Y]}_{\textbf{MCMC}}\, ds\, d\phi$$

$t(\mu_s, S_1^2 \Sigma_s)$ **MCMC**

Simulate from it

Probability of precipitation

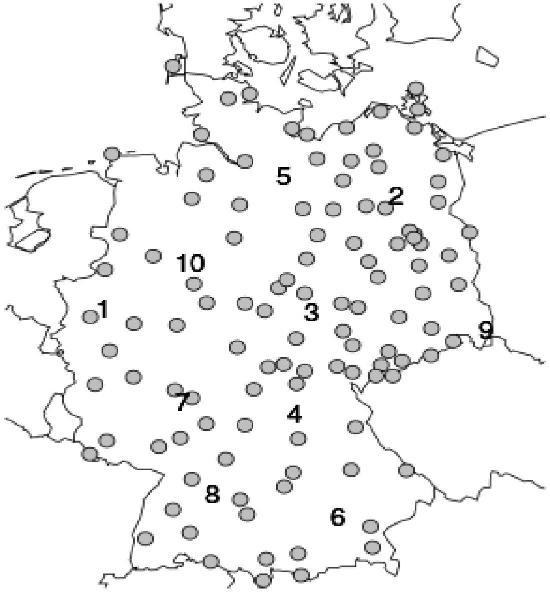
(precip >= 0.1mm/h)

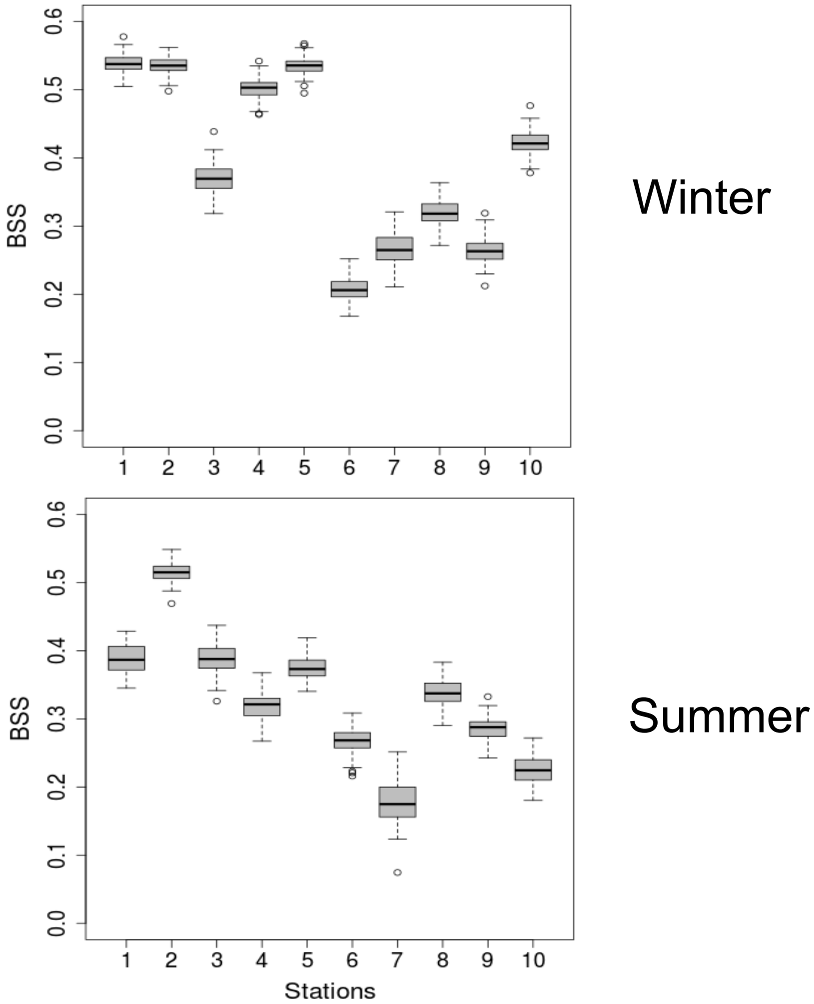


Brier skill score

$$BSS = 1 - \frac{BS}{RS} \qquad BS = \frac{1}{N}\Sigma_k (f_k - o_k)^2$$

Perfect forecast, BSS=1





High-resolution probability fields for precip yes/no