LETKF for the COSMO-DE model of DWD: latest results

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SRNWP workshop 2013, Offenbach

Outline

- LETKF basics
- setup of LETKF
  - GME-LETKF
  - COSMO-LETKF
- First results
- Localization
- Outlook

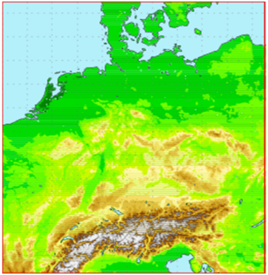
LETKF basics

- Implementation following *Hunt et al., 2007*
- basic idea: do analysis in the space of the ensemble perturbations
  - computational efficient, but also restricts corrections to subspace spanned by the ensemble
  - explicit localization (doing separate analysis at every grid point, select only certain obs)
  - analysis ensemble members are locally linear combination of first guess ensemble members

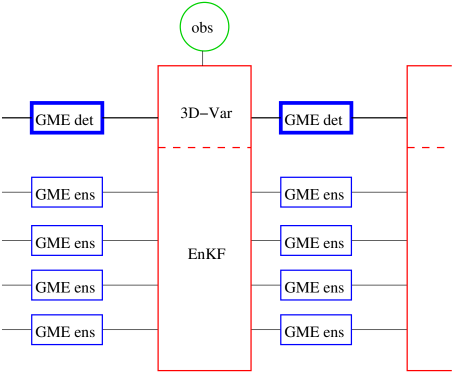
LETKF/KENDA

- LETKF: *Local Ensemble Transform Kalman Filter*
  - GME (ICON): running within NUMEX, delivers boundary conditions
  - hybrid version with 3dVar planned (following *Buehner et al.*)
- *KENDA*: **K**ilometerscale **En**semble **D**ata **A**ssimilation
  - priority project within COSMO consortium
  - LETKF for the nonhydrostatic COSMO-DE model of DWD

COSMO-DE domain (≈ 1200 km x 1200 km)

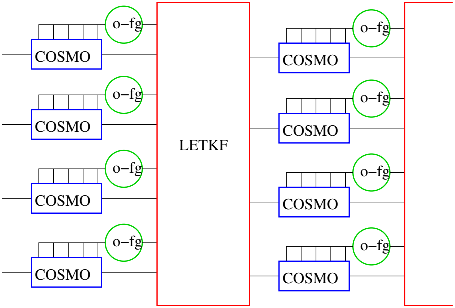


GME-LETKF setup



(obs-fg) computed within LETKF; additional deterministic analysis (currently 3dVar, later hybrid method)

COSMO-LETKF setup



obs-fg (netcdf) and grib files written during integration by COSMO (4D), LETKF reads these files, computes analysis; additional deterministic run (not shown here)

COSMO-LETKF experiments

- old experiments
  - stand-alone LETKF script environment to run COSMO-DE LETKF
  - 3-hourly cycles, up to 2 days (7-8 Aug. 2009: quiet + convective day)
  - lateral boundary conditions (LBC) from COSMO-SREPS (3 * 4 members), 32 ensemble members
- new experiments
  - use of NUMEX: COSMO-LETKF / GME-LETKF running
  - COSMO-LETKF uses LBC's from GME-LETKF
  - but: currently problems with database, experiments very slow!

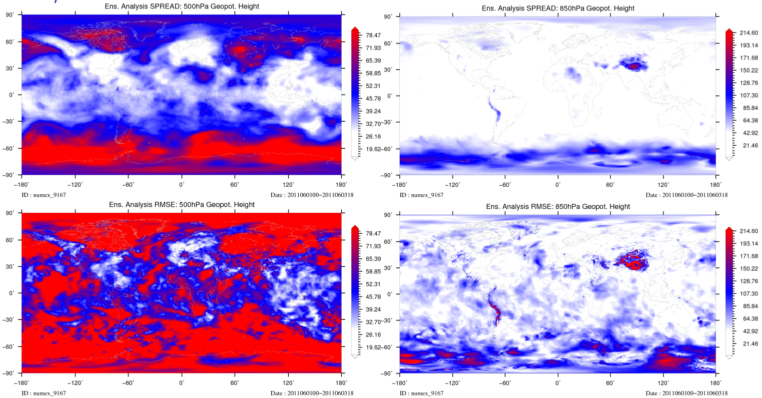
COSMO-LETKF experiments

- analysed variables are $u, v, w, T, pp, qv, qcl, qci$
- analysed means that linear combination is applied to these variables (other variables taken from first guess ensemble / ensemble mean)
- verify LETKF *det run (mean)* against
  - nudging analysis (u, v, w, T, pp)
  - observations (u, v, T, rh)
- COSMO-LETKF: verification tool (against obervations, deterministic/ensemble scores) has been developed by A. Iriza in Romania, will be tested soon
- GME-LETKF analysis/forecast verified against operational analysis

LETKF setup

	GME	COSMO
ensemble member	40 + 1 (3dVar)	40 + 1 (det run)
horizontal resolution (ens)	ni128 ($\approx$ 60 km)	2.8 km
horizontal resolution (det)	ni256 ($\approx$ 30 km)	2.8 km
horiz. local. length scale	300 km	100 km
vert. local. length scale (ln p)	0.3 (0.075-0.5)	0.3 (0.075-0.5)
adapt. horiz. local.	not tested	tested (new exp)
additive model error	T (3dVar **B**)	F
(adaptive) inflation	T	T
conventional obs	T	T
Radiances	T (AMSU-A)	F
GPS-RO	new exps	F
Radar data	F	operator implemented
cloud height	F	Annika's talk
update frequency	3h	1h ($\rightarrow$ 30/15 min)

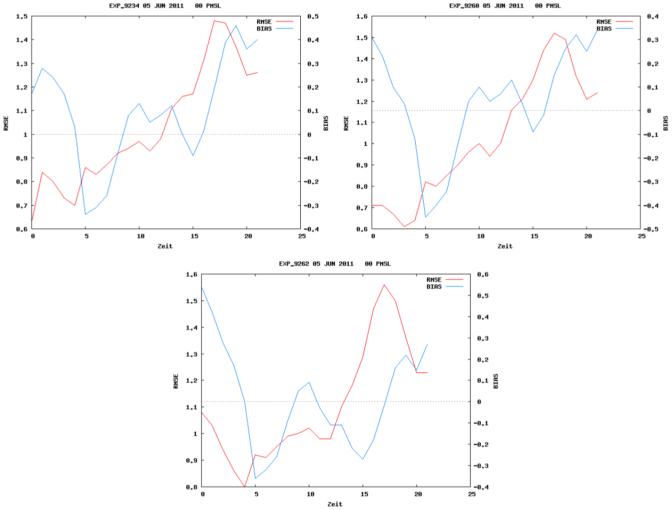
RMSE/SPREAD of GME-LETKF



SPREAD and RMSE of GME-LETKF analysis (geop. height, 500 and 850 hPa)

very low SPREAD over Europe and other data-rich areas → BC for COSMO-LETKF will also suffer from lack of spread; test/tune adaptive methods

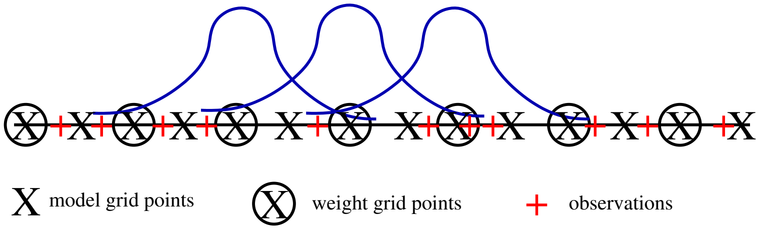
RMSE/BIAS of COSMO-LETKF



RMSE and BIAS of surface pressure, verified against SYNOP stations for LETKF, nudging and free forecast

LETKF slightly worse than nudging

Localization, weight grid and noise



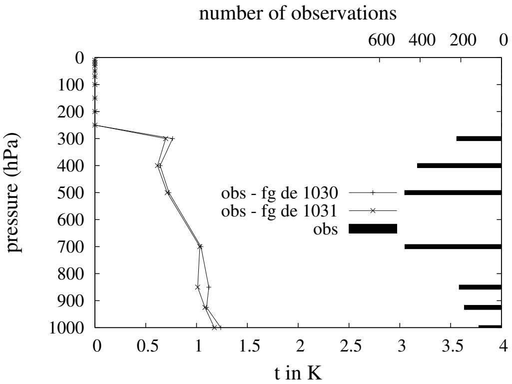
localization function, observations, model and weight gridpoints

- length scale of localization function $>$ distance between weight grid points
- "smooth" localization function to reduce effect of changes in observation sets
- but in any case localization induces noise! $\rightarrow$ hydrostatic balancing of analysis *increments*

adaptive horizontal localization

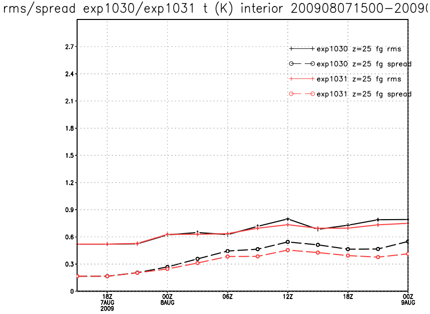
- localization length scales depend on weather situation, observation density ...
- simple adaptive method: keep number of *effective observations* fixed, vary localization radius
- *effective observations*: sum of **observation weights**
- up to now only implemented in horizontal direction
- one has to define minimum / maximum radius, number of *effective observations*
- ideal number of effective observations depends on ensemble size!
- again we have some tuning parameters ...

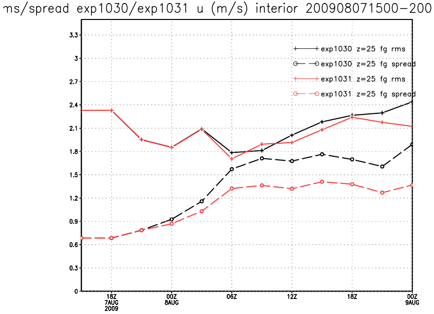
(old) experiments: adaptive horizontal localization



exp1030: adaptive horizontal localization not used, exp1031: adaptive horizontal localization used

(old) experiments: adaptive horizontal localization





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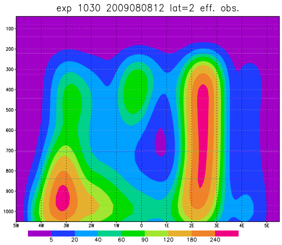

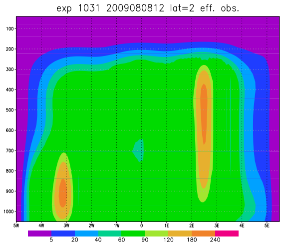

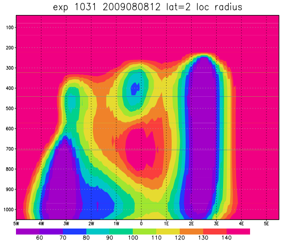

exp1030: adaptive horizontal localization not used, exp1031: adaptive horizontal localization used

Outlook

- *lack of spread* (GME/LETKF): tune adaptive covariance inflation and localization, model error
- *additional observations*: radar obs (radial winds, reflectivity), cloud height (Annika's talk)
- *multi-step analysis* to deal with different observation densities
- *technical (data base) problems* need to be solved to run experiments...

LETKF Theory

- do analysis in the k-dimensional ensemble space

$$\bar{\mathbf{w}}^a = \tilde{\mathbf{P}}^a(\mathbf{Y}^b)^T\mathbf{R}^{-1}(\mathbf{y} - \bar{\mathbf{y}}^b)$$
$$\tilde{\mathbf{P}}^a = [(k-1)\mathbf{I} + (\mathbf{Y}^b)^T\mathbf{R}^{-1}\mathbf{Y}^b]^{-1}$$

- in model space we have

$$\bar{\mathbf{x}}^a = \bar{\mathbf{x}}^b + \mathbf{X}^b\bar{\mathbf{w}}^a$$
$$\mathbf{P}^a = \mathbf{X}^b\tilde{\mathbf{P}}^a(\mathbf{X}^b)^T$$

- Now the analysis ensemble perturbations - with $\mathbf{P}^a$ given above - are obtained via

$$\mathbf{X}^a = \mathbf{X}^b\mathbf{W}^a,$$

where $\mathbf{W}^a = [(k-1)\tilde{\mathbf{P}}^a]^{1/2}$

LETKF Theory

- it's possible to obtain a *deterministic run* via

$$\mathbf{x}_a^{det} = \mathbf{x}_b^{det} + \mathbf{K}\left[\mathbf{y} - H(\mathbf{x}_b^{det})\right]$$

with the *Kalman gain* **K**:

$$\mathbf{K} = \mathbf{X}_b\left[(k-1)\mathbf{I} + \mathbf{Y}_b^T\mathbf{R}^{-1}\mathbf{Y}_b\right]^{-1}\mathbf{Y}_b^T\mathbf{R}^{-1}$$

- the deterministic analysis is obtained on the same grid as the ensemble is running on; the *analysis increments* can be interpolated to a higher resolution