Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Plans at DWD for Global Ensemble Data Assimilation

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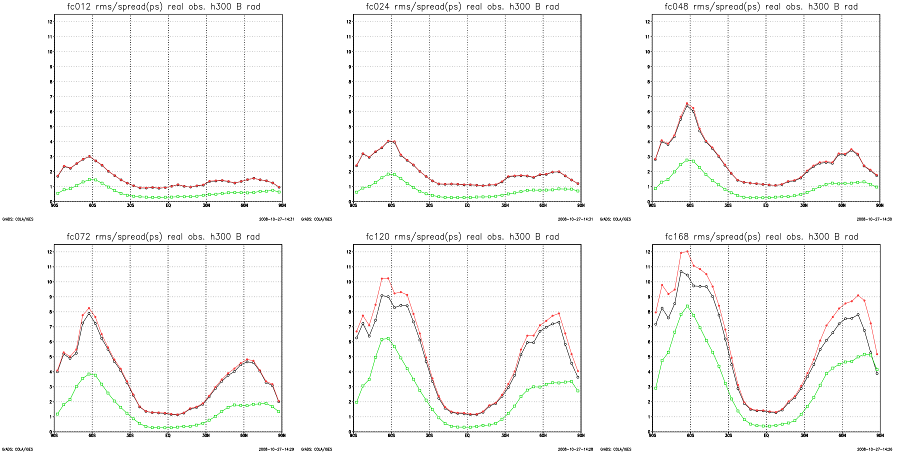
Status

- Operational Forecast System
  - 3dVar, 3 hours cycle
  - GME global model, icosahedral grid, 30 km resolution (ni 256)
- Experimental EnKF
  - Developed within DFG project (*Uni Bonn, MPI Hamburg, DWD*)
  - LETKF (Hunt et al.), 6 hours cycle
  - GME global model, 120 km resolution (ni 64)
  - Assessment and tuning of the ETKF (*Hendrik Reich*) Parameters:
    - Model error: multiplicative inflation, additive 3D-Var B
    - Horizontal localisation radius
  - Results
    - Additive model error performs better than multiplicative inflation
    - Spread is too small but not unreasonable
    - Remote sensing observations are important and reasonably used

Forecast verification (spread and rmse)

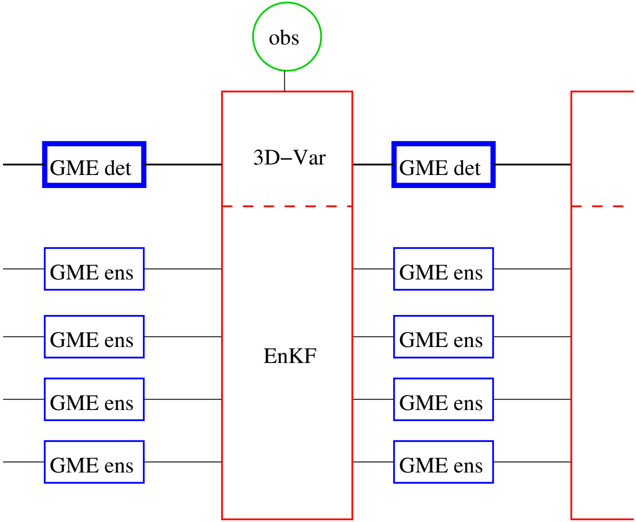


rmse for ensemble mean (black) and deterministic forecast started from ensemble mean (red) and spread (green) (ps in hPa) for 12,24,48,72,120,168h-forecasts.

Plan

- Forecast model: ICON
  - icosahedral grid, non-hydrostatic dynamical core
  - local grid refinment
  - replaces GME, COSMO-EU
- Assimilation System
  - adapt to ICON
  - hybrid 3Dvar-EnKF (VarEnKF)
    additional control variables (Buehner)
    - deterministic high resolution forecast
    - low resolution ensemble

Variational EnKF for GME/ICON



time →

← analysis cycle interval →

Purpose

- use Ensemble information on **B** in the analysis (flow dependence)
- provide initial conditions for global ensemble forecasts
- provide boundary conditions for COSMO

VarEnKF: Formulation

- Introduce additional field of control variables $\mathbf{v}_i$ for each ensemble deviation $\mathbf{x}_i$ in the variational scheme:
  $J_b = 1/2 \sum_i \mathbf{v}_i^T \mathbf{v}_i$
- The analysis increment is:
  $\mathbf{x}_a - \mathbf{x}_b = \sum_i \mathbf{x}_i \circ (\mathbf{C}^{1/2} \mathbf{v}_i)$
  $\mathbf{C}$ is the 'localisation matrix'
  $\circ$ denotes multiplication element by element
- Requires operator implementation for $\mathbf{C}^{1/2}$.
  Candidate:
  - diffusion operator on a hierarchical grid (ICON)

VarEnKF: Advantages and Disadvantages

- Advantages
  - Smooth transition between 3D-Var and EnKF
  - Deterministic analysis using Ensemble B (and 3D-Var B)
  - Variational Quality Control applicable
  - Varational bias correction applicable
  - Consistent handling of remote sensing observations (localisation on **B**)
- Disadvantages
  - Specification of localisation radius is not flexible
  - Additional mechanism for ensemble generation required. Candidates:
    - LETKF
    - independent 3D-Var analyses for each ensemble member

Schedule

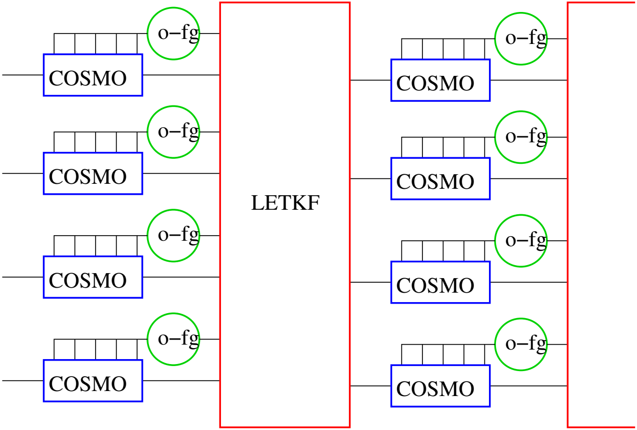
2011/1	Adapt global LETKF/3D-Var to ICON
2011/1	Provide COSMO Boundary conditions by the GME LETKF ensemble
2011/?	VarEnKF (hybrid 3dVar/EnKF)

Spare Slides

KENDA related Software

- LETKF/4dVar implementet in common source code environment
- Fortran 95 (not 200x due to NEC compiler limitations)
- Parallelisation: MPI
- External libraries: NetCDF, BUFR
- Common Utilities for COSMO-LETKF and global 3dVar/EnKF
  - Feedback file interface
    F95 modules to support I/O of feedback files
    - innovation statistics for verification
    - link COSMO and LETKF
  - Proabilistic verification tool (*Amalia Iriza*)
    (reads feedback files)
  - probabilistic LMSTAT (*Tanja Weusthoff . . .*)
    (writes feedback files)

4-D LETKF for COSMO-DE



time →

← analysis cycle interval →

Ensemble Transform Kalman Filter (ETKF)

Perform the analysis using the gain matrix **K**:

$$\mathbf{x}^a - \mathbf{x}^b = \mathbf{K}\,(\mathbf{o} - H(\mathbf{x}^b))$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T\,(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

set

$$\mathbf{B} = \mathbf{X}\mathbf{X}^T \quad \text{with} \quad \mathbf{X}_k = \sqrt{\frac{1}{n_k-1}}\left(\mathbf{x}_k^b - \overline{\mathbf{x}_k^b}\right)$$

and

$$\mathbf{H}{=}\mathbf{Y}\mathbf{X} \quad \text{with} \quad \mathbf{Y}_k = \sqrt{\frac{1}{n_k-1}}\left(H(\mathbf{x}_k^b) - \overline{H(\mathbf{x}_k^b)}\right)$$

Then the gain matrix becomes :

$$\mathbf{K} = \mathbf{X}\mathbf{Y}^T\,(\mathbf{Y}\mathbf{Y}^T + \mathbf{R})^{-1}$$

Finally derive the analysis ensemble deviations **Z** :

$$\mathbf{Z} = \mathbf{Y}^T\,(\mathbf{Y}\mathbf{Y}^T + \mathbf{R})^{-1}(\mathbf{o} - H(\mathbf{x}^b)) \quad \text{with} \quad \mathbf{Z} = \sqrt{\frac{1}{n_k-1}}\left(\mathbf{x}_k^a - \mathbf{x}_k^b\right)$$

Variants of localisation

For computational efficiency :
apply $\mathbf{C}\circ$ on $\mathbf{BH}^T$, $\mathbf{HBH}^T$ or $\mathbf{R}^{-1}$ instead of $\mathbf{B}$

- Kalman Gain matrix

  $$\mathbf{K} = \mathbf{BH}^T\ (\mathbf{HBH}^T + \mathbf{R})^{-1}$$

  or

  $$\mathbf{K} = (\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}\ \mathbf{R}^{-1}$$

- pure EnKF (small set of linear equations)

  $$\mathbf{K} = \mathbf{XY}^T\ (\mathbf{YY}^T + \mathbf{R})^{-1}$$

  or

  $$\mathbf{K} = \mathbf{X}(\mathbf{1} + \mathbf{Y}^T\mathbf{R}^{-1}\mathbf{Y})^{-1}\ \mathbf{Y}^T\mathbf{R}^{-1}$$

- localisation on $\mathbf{B}$ (requires $\mathbf{H}$)

  $$\mathbf{K} = \mathbf{C}\circ\mathbf{XX}^T\mathbf{H}^T\ (\mathbf{H}\,\mathbf{C}\circ\mathbf{XX}^T\mathbf{H}^T + \mathbf{R})^{-1}$$

- localisation on $\mathbf{BH}^T$, $\mathbf{HBH}^T$

  $$\mathbf{K} = \mathbf{C}\circ\mathbf{XY}^T\ (\mathbf{C}\circ\mathbf{YY}^T + \mathbf{R})^{-1}$$

- localisation on $\mathbf{R}^{-1}$ (LETKF, Hunt et al. 2007)

  $$\mathbf{K} = \mathbf{X}\,(\mathbf{1} + \mathbf{Y}^T\mathbf{C}\circ\mathbf{R}^{-1}\,\mathbf{Y})^{-1}\ \mathbf{Y}^T\mathbf{C}\circ\mathbf{R}^{-1}$$

Pros and Cons

algorithm to be used for localisation	patches $\mathbf{B}$	EnSRF $\mathbf{HBH}^T$	LETKF COSMO $\mathbf{R}^{-1}$	Var-EnKF GME/ICON $\mathbf{B}$	3D-Var $\mathbf{B}(p)$
requirements					
requires $\mathbf{H}$	no	no	no	yes	yes
iterates $H(\mathbf{x})$	yes	no	no	yes	yes
requires $\mathbf{B}(p)$	no	no	no	no	yes
is fast	no?	?	yes	no?	no?
functionality					
consistent $\mathbf{C}\circ\mathbf{HBH}^T$	yes	?	no	yes	yes
localisation in $\triangle x$	yes	yes	yes	no	no
nonlinear H	no	no	no	yes	yes