Overview of the COSMO Priority Project **KENDA**
for Km-Scale Ensemble-Based Data Assimilation

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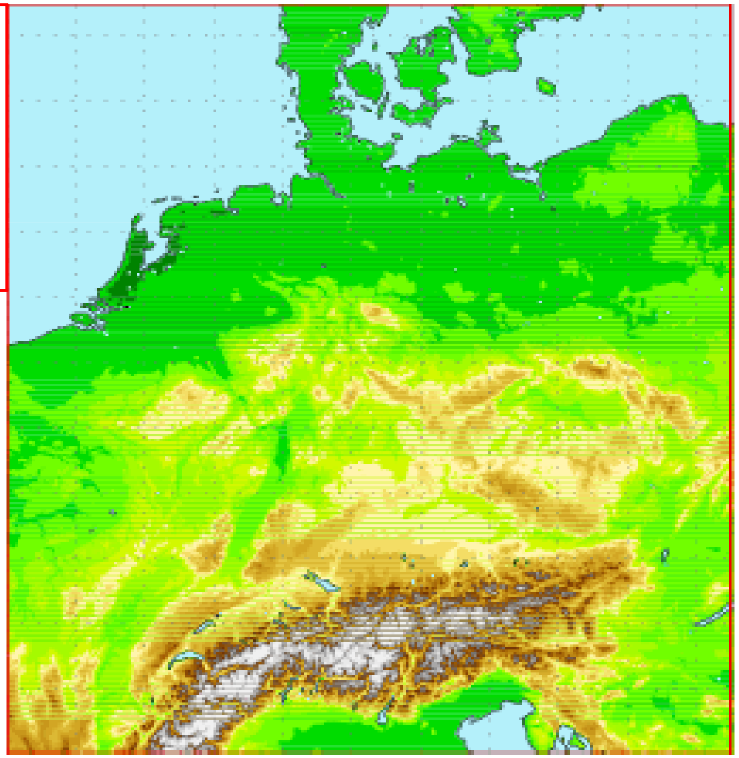
KENDA : Why develop Ensemble-Based Data Assimilation ?

COSMO-DE: Δx = 2.8 km
(deep convection explicit,
shallow convection param.)

domain size : ~ 1250 x 1150 km



convection-permitting NWP:
after ‘few’ hours,
a forecast of convection is a long-term forecast

→ deliver probabilistic (pdf) rather than deterministic forecast

→ need ensemble forecast and data assimilation system

→ forecast component: COSMO-DE EPS

KENDA : Why develop Ensemble-Based Data Assimilation ?

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→ data assimilation: priority project within COSMO consortium
Km-scale ENsemble-based Data Assimilation (**KENDA**):

→ Local Ensemble Transform Kalman Filter (LETKF) ,
(because of its relatively low computational costs)

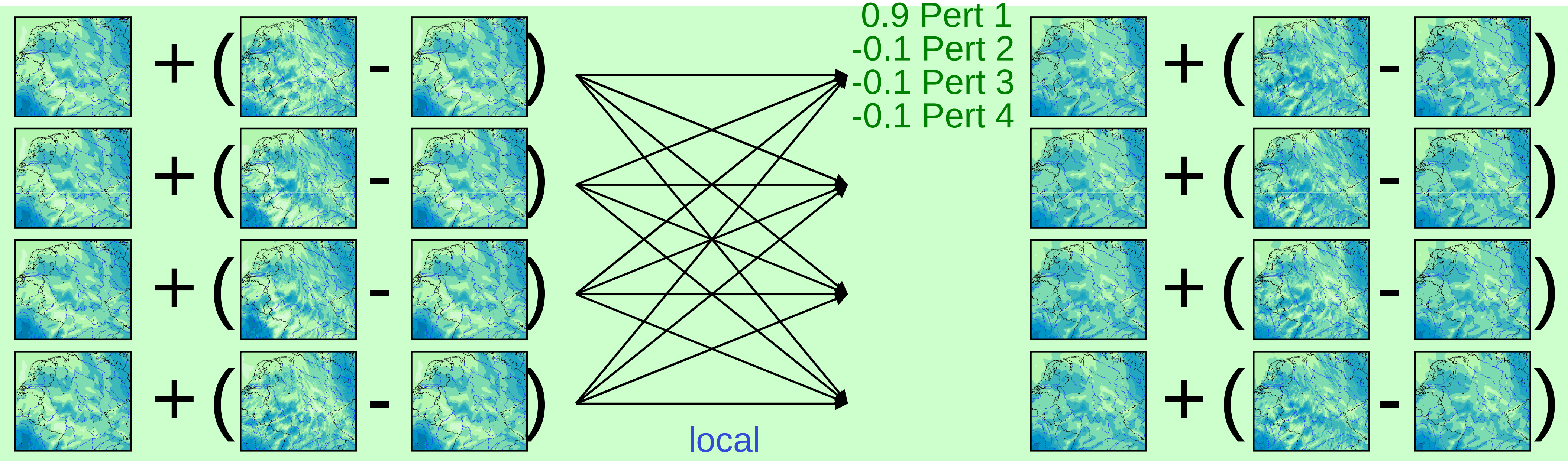
This talk: - method and implementation
- some scientific issues

talk by Hendrik Reich : preliminary experiments at DWD

Assume: Gaussian errors

$$J(\mathbf{x}) \;=\; \left(\mathbf{x}-\overline{\mathbf{x}}^{b}\right)^{T}\mathbf{P}^{b^{-1}}\left(\mathbf{x}-\overline{\mathbf{x}}^{b}\right) + \left[\mathbf{y}^{\mathbf{O}}-H(\mathbf{x})\right]^{T}\mathbf{R}^{-1}\left[\mathbf{y}^{\mathbf{O}}-H(\mathbf{x})\right]$$

for $\mathbf{P}^{b} = (k-1)\,\mathbf{X}^{b}(\mathbf{X}^{b})^{T}$, $J(\mathbf{x})$ is well-defined in sub-space S spanned by $\mathbf{X}^{b}$



ensemble mean forecast

k perturbed forecasts

ensemble mean fcst.

forecast perturbations $\mathbf{X}^b$

↓

flow-dep background error cov.

$$\mathbf{P}^b = (k-1)\, \mathbf{X}^b (\mathbf{X}^b)^T$$

↓

transform matrix $\mathbf{w}$

analysis mean $\overline{\mathbf{w}}^a$

analysis perturbations $\mathbf{W}^{a(i)}$

analysis error covariance (computed only in ensemble space)

$$\mathbf{w}^{a(i)} = \overline{\mathbf{w}}^a + \mathbf{W}^{a(i)}$$

perturbed analyses

↑

in the (k-1) -dimensional (!) sub-space S spanned by background perturbations :

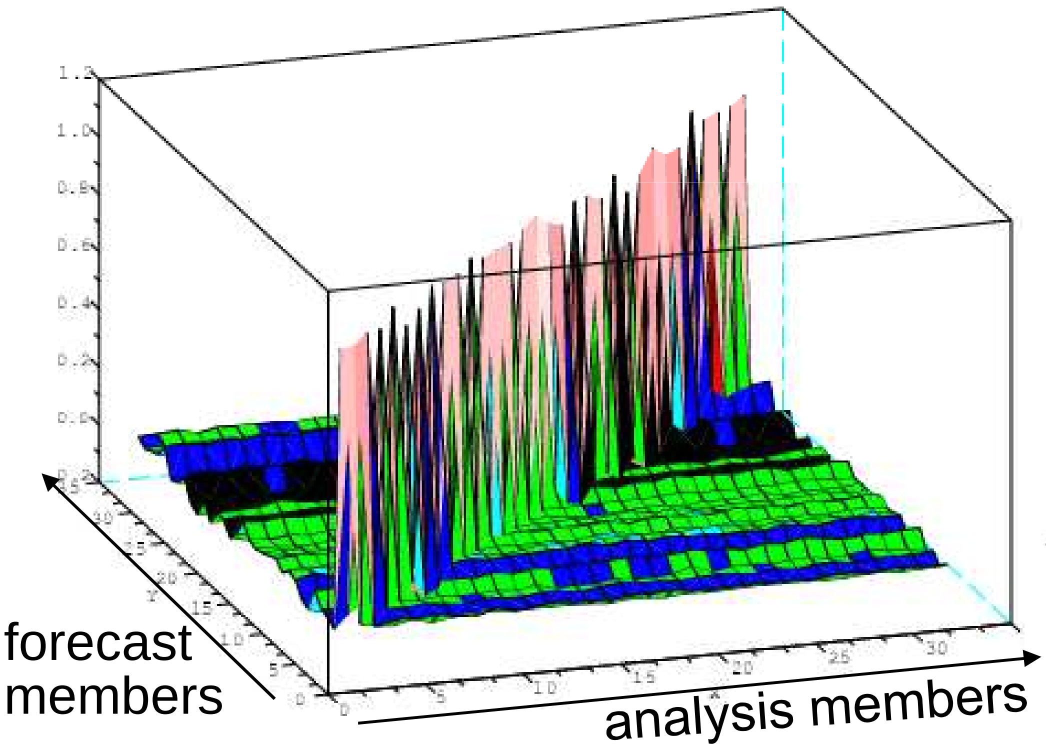
$$\mathbf{x} = \overline{\mathbf{x}}^b + \mathbf{X}^b \mathbf{w}$$

set up cost function $J(\mathbf{w})$ in ensemble space,
explicit solution for minimisation (Hunt et al., 2007)

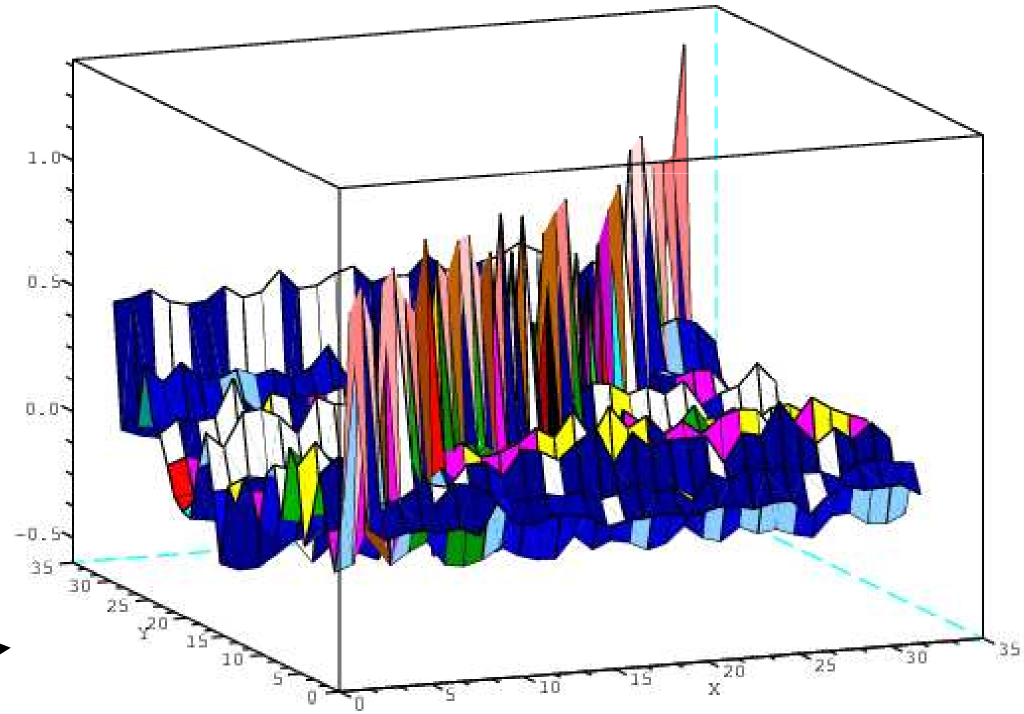
LETKF for COSMO : summary of method

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

weight matrices (transform matrices) : determine linear combination



normal values for obs errors **R**
(for a grid point influenced by
> 200 conventional obs)



R divided by 100
(simulating many more obs)

→ diagonal elements >> off-diagonal elements (→ analysis increments 'small')

→ 'good' forecast members get larger weight in all analysis members

LETKF for COSMO : technical implementation

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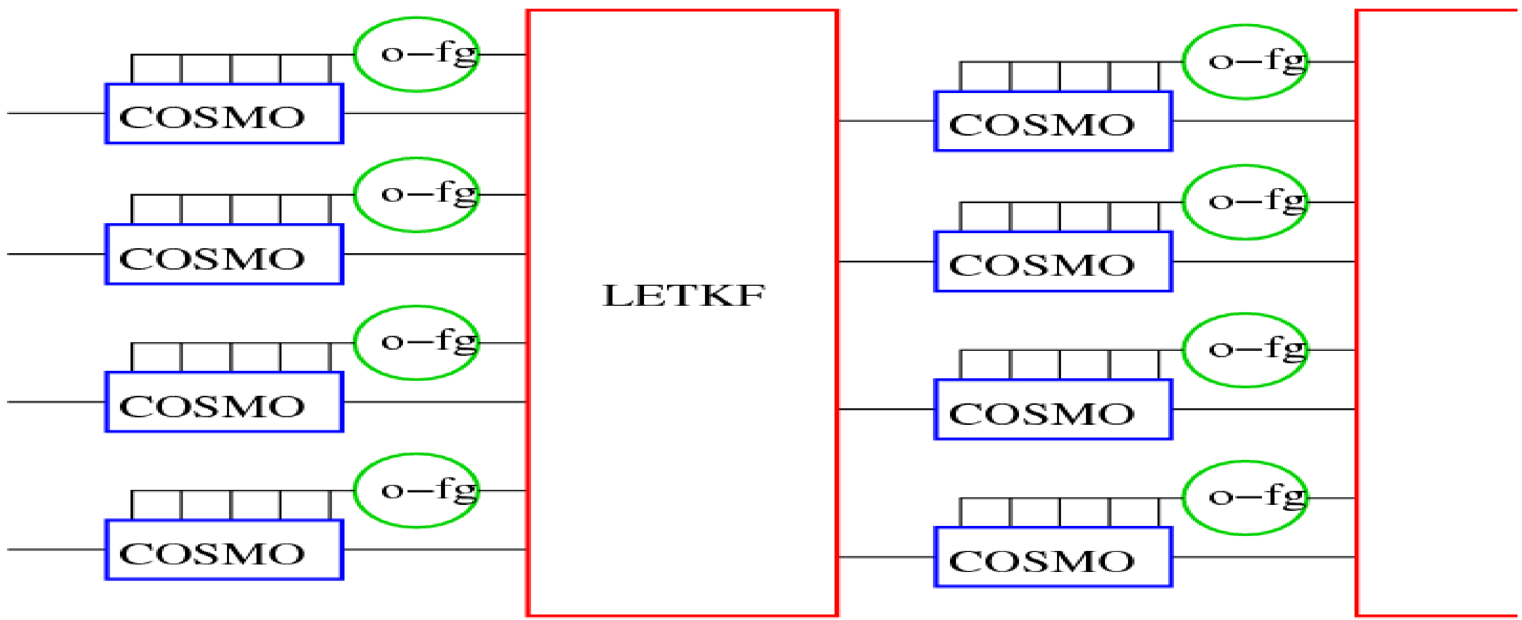
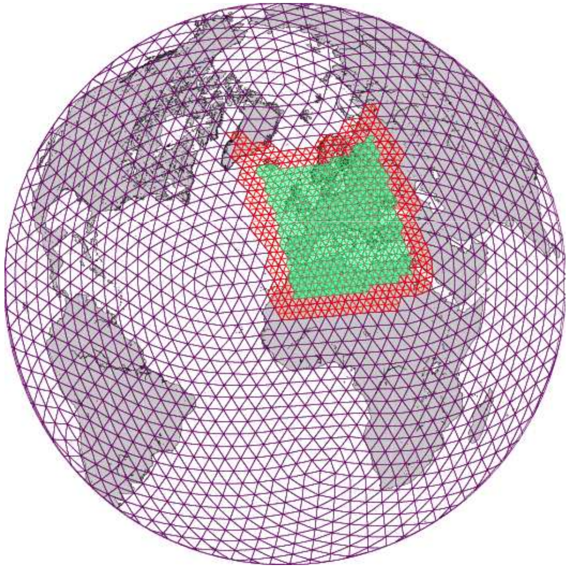
- analysis step (LETKF) outside COSMO code
  - → ensemble of independent COSMO runs up to next analysis time (collecting obs – f.g. → 4D -LETKF)
  - → separate analysis step code, LETKF included in 3DVAR package of DWD



- basically for verification purposes, COSMO obs operators incl. quality control will be implemented in 3DVAR / LETKF environment
  - → future: hybrid 3DVAR-EnKF approaches in principle applicable to COSMO

LETKF (km-scale COSMO) : implementation



- lateral BC :
  - future: from global EnKF / EPS based on
    ICON (non-hydrostatic,
    with regional grid refinement)
  - currently: COSMO-SREPS (or deterministic)
- standard experimentation system not yet adapted to perform LETKF (but soon)
  $\rightarrow$ stand-alone scripts, only preliminary LETKF experiments up to now

$\rightarrow$ talk by Hendrik Reich

LETKF (km-scale COSMO) : scientific issues / refinement

(forecast / analysis) ensemble spread 'characterises' (forecast / analysis) error, but

- ensemble size is limited, ensemble can only sample but not fully represent errors
- model error is not accounted for by algorithm

→ lack of spread: (partly) due to model error and limited ensemble size
which is not accounted directly by the algorithm

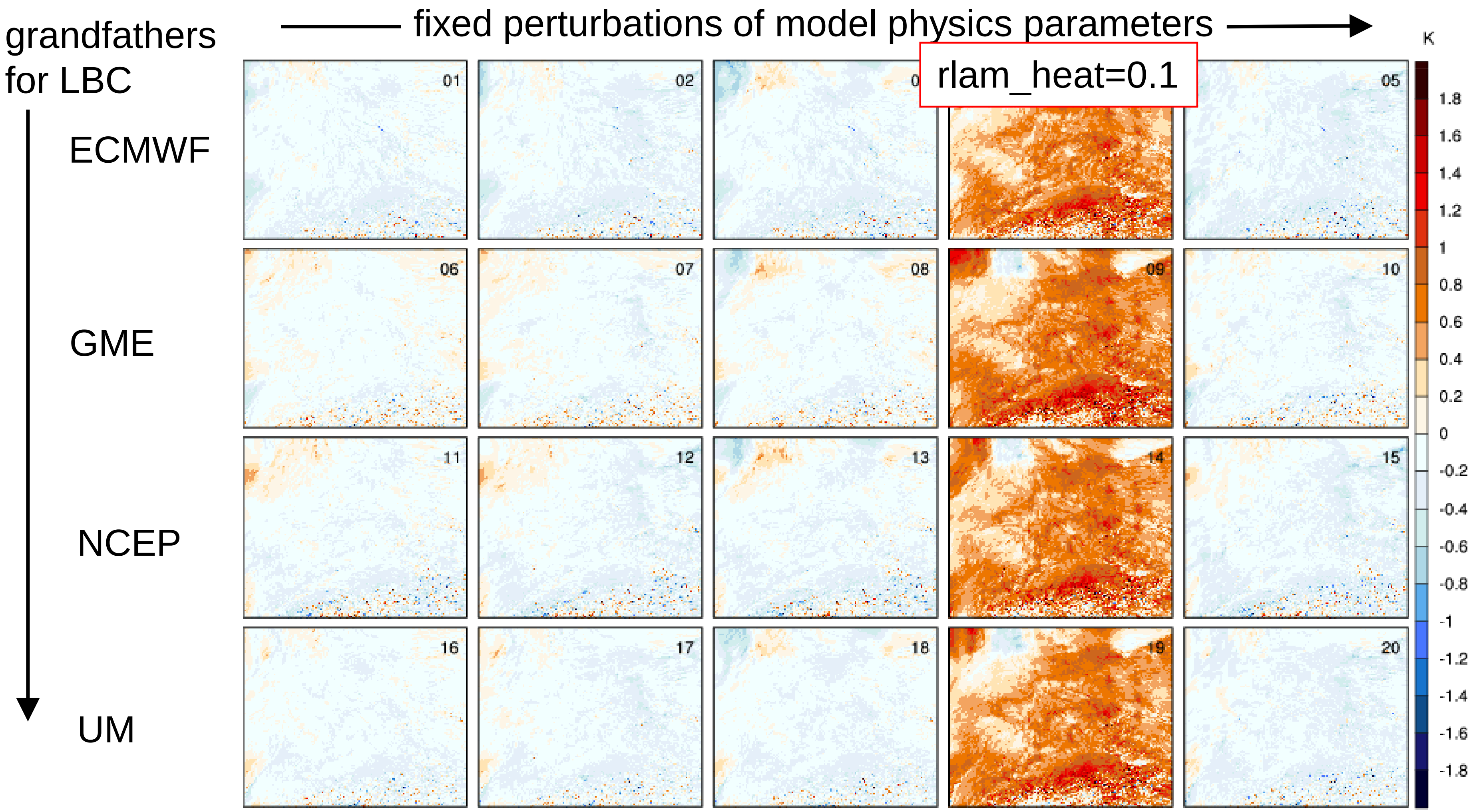
to account for it: covariance inflation, what is needed ?

→ multiplicative $X_b \rightarrow \rho \cdot X_b$ (tuning, or adaptive ($y - \mathbf{H}(x) \sim \mathbf{R} + \mathbf{H}^T \mathbf{P}_b \mathbf{H}$))

→ additive : perturbing the NWP model
  – fixed perturbations of model physics parameters

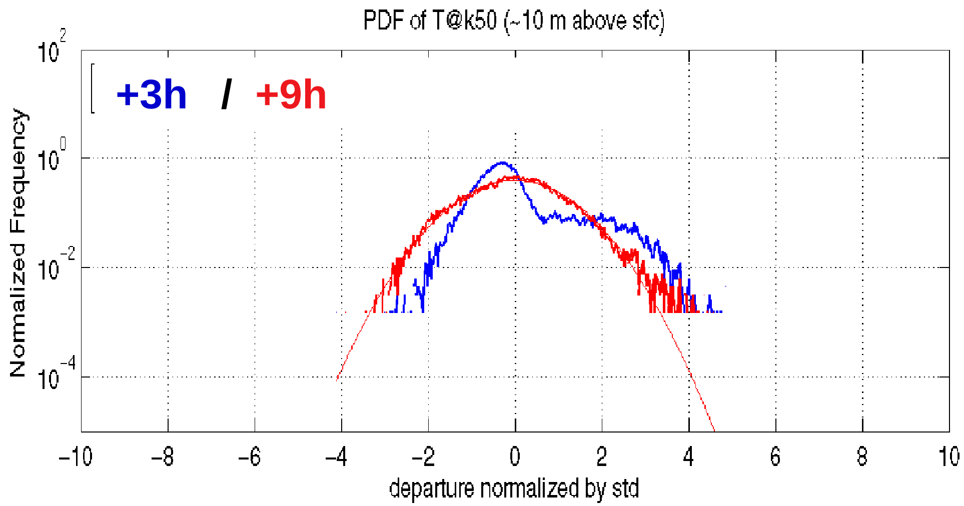
additive covariance inflation:
model perturbations

ensemble forecast perturbations from COSMO-DE-EPS
here: a result from an old version without initial perturbations



temperature at ~10m, +3h (03 UTC)

additive covariance inflation: model perturbations



ensemble forecast perturbations, statistics over 9 days
$T_{10\ m}$ over Northern Germany

→ ≤ +3h : bi-modal pdf
but EnKF optimal
only for Gaussian pdf

→ physics perturbations that may be appropriate for the forecast component of an EPS need not be appropriate for DA (EnKF)

- additive covariance inflation: perturbing the NWP model
  - fixed perturbations of model physics parameters : no
  - stochastic physics (will be implemented)
  - statistical 3DVAR-**B** → hybrid schemes !
  - additive inflation which reflects model error as estimated by statistics (comparing forecast tendencies with observed tendencies, Gorin & Tsyrulnikov)

LETKF (km-scale COSMO) : scientific issues / refinement

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- localisation (multi-scale data assimilation,
  successive LETKF steps with different obs / localisation ?)

- update frequency $\Delta_a t$? 1 hr $\geq \Delta_a t \geq$ 15 min
  non-linearity vs. noise / lack of spread / 4D property ?

- perturbed lateral BC , how to deal with it ?
  ($\rightarrow$ source of noise)
  (distort implicit error covariances in filter $\rightarrow$ limit use of obs ?)

  note: shorter data cut-off & higher analysis frequency
  for COSMO-DE than for driving global system ICON

- non-linear aspects, convection initiation (outer loop , (latent heat nudging) ?)

LETKF (km-scale COSMO) : current work : new observation types

- **radar : radial velocity and (3-D) reflectivity**

- **ground-based GPS slant path delay** (direct use in LETKF , or tomography)

- **cloud information based on satellite and conventional data**
  - derive incomplete analysis of cloud top + cloud base, using conventional obs (synop, radiosonde, ceilometer) and NWC-SAF cloud products from SEVIRI, use obs increments of cloud or cloud top / base height or derived humidity
  - or use SEVIRI radiances directly

(Issues in LETKF: **non-Gaussian** distribution of obs increments, non-linear obs opr, non-local obs, obs error correlations / thinning …)

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thank you for your attention

$$J(\mathbf{x}) \;=\; \left(\mathbf{x}-\overline{\mathbf{x}}^b\right)^T \mathbf{P}^{b^{-1}} \left(\mathbf{x}-\overline{\mathbf{x}}^b\right) + \left[\mathbf{y}^{\mathbf{O}} - H(\mathbf{x})\right]^T \mathbf{R}^{-1} \left[\mathbf{y}^{\mathbf{O}} - H(\mathbf{x})\right]$$

for $\mathbf{P}^b = (k-1)\,\mathbf{X}^b\,(\mathbf{X}^b)^T$, $J(\mathbf{x})$ is well-defined in sub-space S spanned by $\mathbf{X}^b$

- if $\mathbf{w}$ is Gaussian random vector with mean 0 and covariance $(k-1)\,\mathbf{I}$,
  then $\mathbf{x} = \overline{\mathbf{x}}^b + \mathbf{X}^b\mathbf{w}$ is Gaussian with mean $\overline{\mathbf{x}}^b$ and cov. $(k-1)\,\mathbf{X}^b\,(\mathbf{X}^b)^T$

  → set up cost function in (low-dimensional !) ensemble space

  $$J(\mathbf{w}) \;=\; (k-1)\mathbf{w}^T\mathbf{w} + \left[\mathbf{y}^{\mathbf{O}} - H(\overline{\mathbf{x}}^b + \mathbf{X}^b\mathbf{w})\right]^T \mathbf{R}^{-1} \left[\mathbf{y}^{\mathbf{O}} - H(\overline{\mathbf{x}}^b + \mathbf{X}^b\mathbf{w})\right]$$

  → apply nonlinear H to all forecast members
  and linearize around ensemble mean in observation space $\overline{H\left(\mathbf{x}^{b(i)}\right)}$

  → normal KF eq. in low-dim ensemble space, solve explicitly

  → analysis error cov. $\mathbf{P}_w^{\,a} = \left[(k-1)\,\mathbf{I} + \left(\mathbf{Y}^b\right)^T \mathbf{R}^{-1}\mathbf{Y}^b\right]^{-1}$

  and analysis mean $\overline{\mathbf{w}}^a = \mathbf{P}_w^{\,a}\left(\mathbf{Y}^b\right)^T \mathbf{R}^{-1}\left[\mathbf{y}^{\mathbf{O}} - \overline{\mathbf{y}}^b\right]$

- need analysis ensemble members, with ensemble spread $(k-1)\,\mathbf{X}^a\,(\mathbf{X}^a)^T = \mathbf{P}^a$,
  choose: $\mathbf{X}^a = \mathbf{X}^b\mathbf{W}^a$, where $\mathbf{W}^a = \left[(k-1)\mathbf{P}_w^{\,a}\right]^{1/2}$