Overview on Data Assimilation Activities in COSMO

christoph.schraff@dwd.de
Deutscher Wetterdienst, D-63067 Offenbach, Germany

current DA method: nudging

radar-derived precip:
- latent heat nudging
- 1DVar (better at reducing RR)

radar radial wind:
- VAD (at DWD: no benefit)
- nudging directly V_r

GPS–IWV (new modif., tests)

scatterometer wind (tests)

Satellite radiances, 1DVAR:
- AMSU-A, SEVIRI, IASI (new tests)
- spatial AMSU-A obs errors statistics

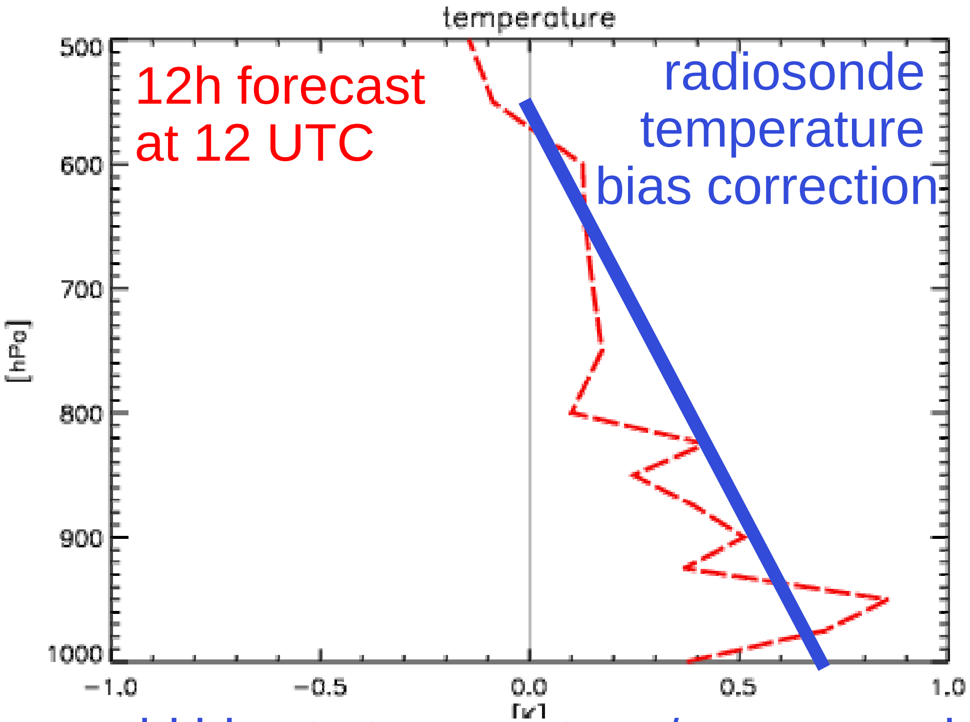
PP KENDA for (1 – 3) km-scale EPS:
LETKF

LETKF for HRM
(28 km, quasi-opr)

influence of biases on convection :
- Vaisala RS-92 humidity obs dry bias
- model warm bias (daytime, low levels)

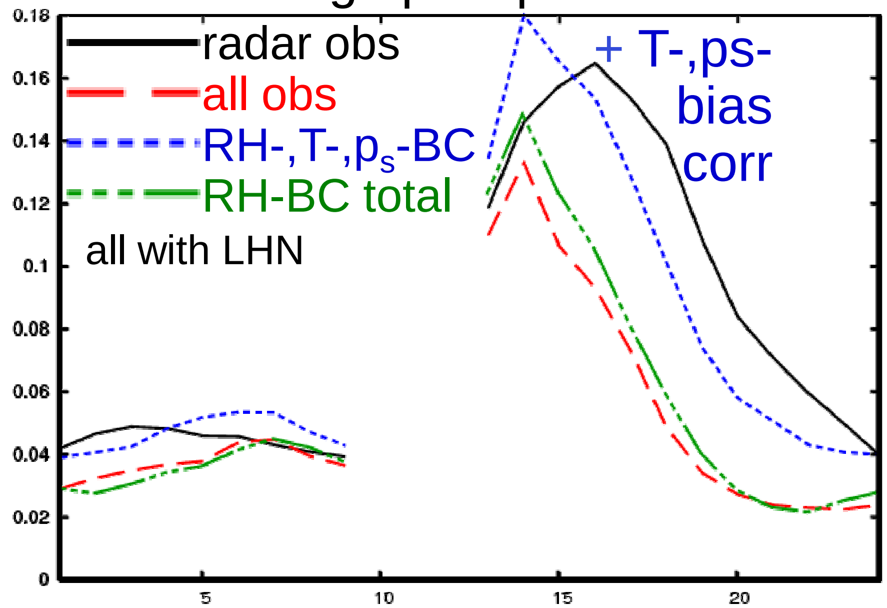
surface (snow …)
→ PP COLOBOC

'new PBL': greatly improves diurnal cycle of convective precip except for 12-UTC runs,
leads to significant warm bias (of forecasts) in low troposphere at noon
i.e. COSMO-DE needs excessive instability on a large scale
to produce sufficient convective precip on its own



→ add bias to temperature / pressure obs
to match model bias

domain-average precip of 12-UTC runs



– correct RS92 humidity obs
(Miloshevich et al., 2009, *J. Geophys. Res.*)

– temperature, surface pressure:
test **L65** with 'near-old PBL'

PP KENDA (Km-scale ENsemble-based Data Assimilation)

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christoph.schraff@dwd.de
Deutscher Wetterdienst, D-63067 Offenbach, Germany

Contributions / input by:

Hendrik Reich, Andreas Rhodin, Uli Blahak (DWD, Germany) ;
Daniel Leuenberger, Tanja Weusthoff (MeteoSwiss, Switzerland) ;
Mikhail Tsyrulnikov, Vadim Gorin (HMC, Russia) ; Lucio Torrisi (CNMCA, Italy) ; Amalia Iriza (NMA, Romania)

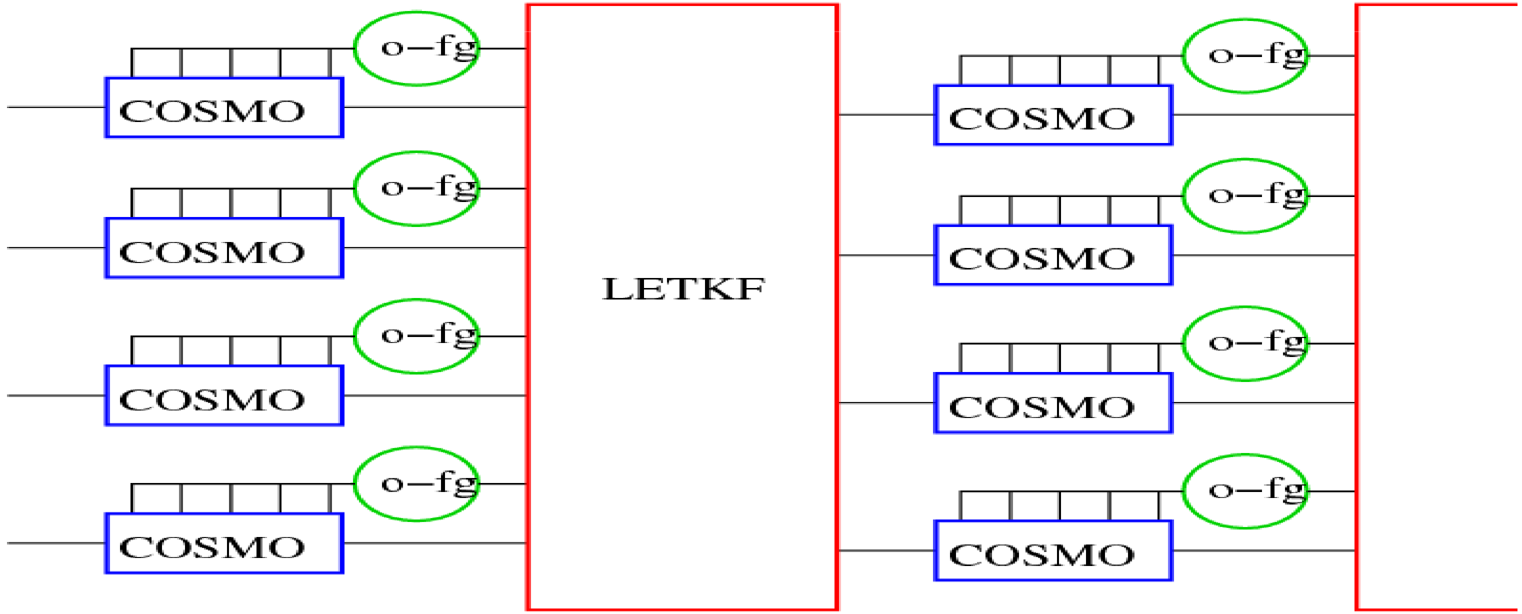
- Task 1: General issues in the convective scale (e.g. non-Gaussianity)
  - obs – f.g. statistics: find variable transformations to get near Gaussianity
    $\rightarrow$ COSMO Met Services focus on LETKF, cease on SIR
  - COSMO-DE EPS: fixed perturbations of model physics param. $\rightarrow$ non-Gauss.
    $\rightarrow$ in LETKF, need more Gaussian perturbations $\rightarrow$ stochastic physics
- Task 2: Technical implementation of an ensemble DA framework / LETKF
- Task 3: Tackling major scientific issues, tuning, comparison with nudging
- Task 4: Inclusion of additional observations in LETKF
- (Task 5: Development of a Sequential Importance Resampling (SIR) filter)

LETKF (COSMO) : 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

LETKF (COSMO) : technical implementation

- analysis step (LETKF) outside COSMO code
  → ensemble of independent COSMO runs up to next analysis time
  → 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

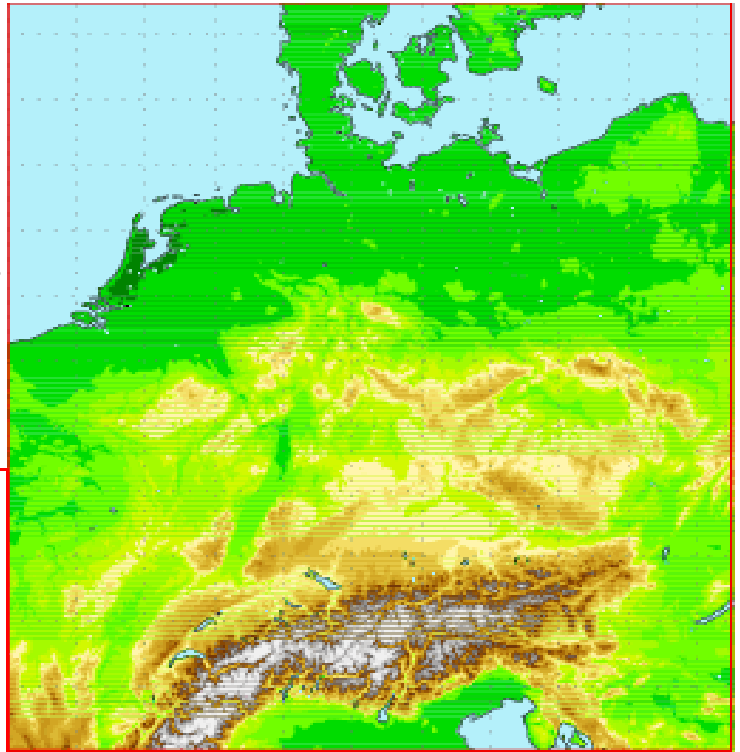
- standard experimentation system not yet adapted to perform LETKF (but soon)
  → stand-alone scripts allow only preliminary LETKF experiments up to now

LETKF (COSMO) : set-up of preliminary experiments

- use **in-situ obs** (TEMP, AIREP, SYNOP) from GME analysis (sparse density)
  → near future: use set of in-situ obs with higher density
- **3-hourly** cycles (and only up to 2 days: 7 – 8 Aug. 2009: quiet + convective day)
  → (near) future: 1-hourly / 30-min / 15-min cycles
- lateral (and upper) boundary conditions (BC)
  – **ensemble BC** from COSMO-SREPS (3 * 4 members),
  – or **deterministic BC** from COSMO-EU
  → future: ens. BC from global LETKF (GME/ICON)
- ensemble size: **32** (→ near future: ~ 40)
- initial ensemble perturbations reflect global 3DVar-**B**
- ensemble mean verified against nudging analysis which used much more obs

COSMO-DE: $\Delta x = 2.8$ km
(deep convection explicit,
shallow convection param.)

domain size : ~ 1250 x 1150 km



christoph.schraff@dwd.de

LETKF (COSMO) , example:
zonal wind at lowest model level

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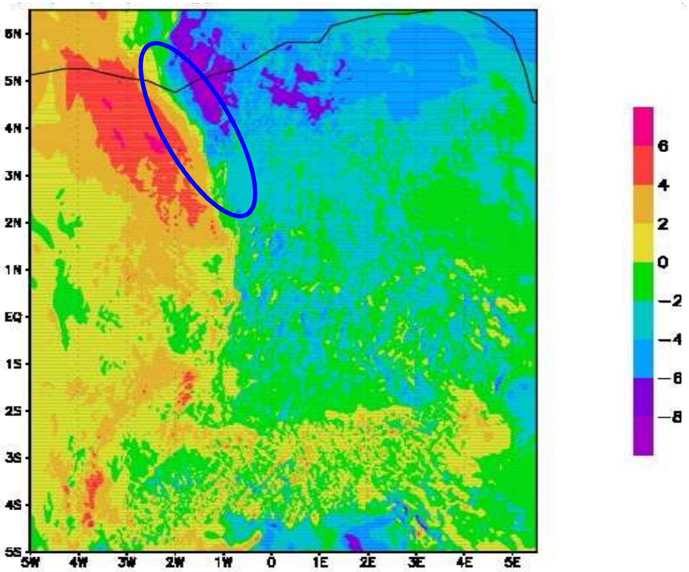
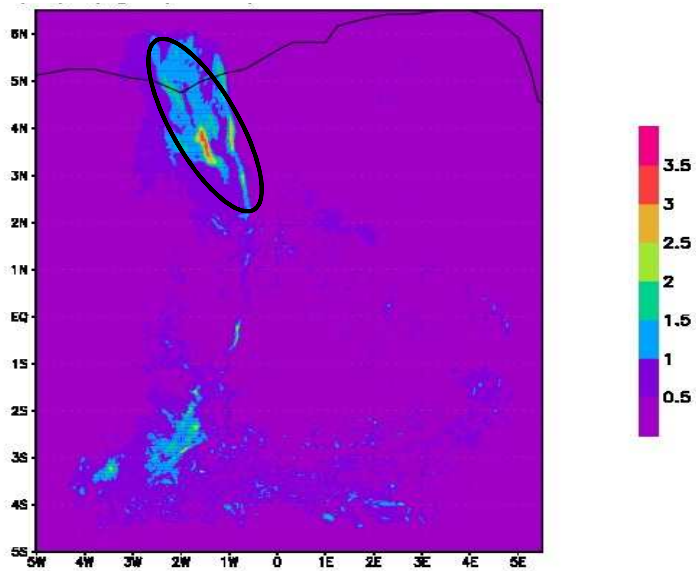
<u>after 1 day of 3-hrly cycling of LETKF</u>

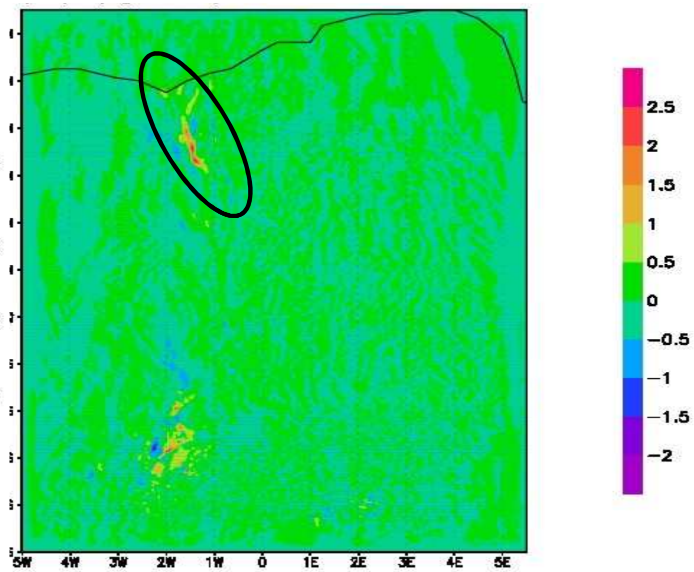
nudging analysis (reference)



first guess ensemble spread



analysis mean – f.g. mean



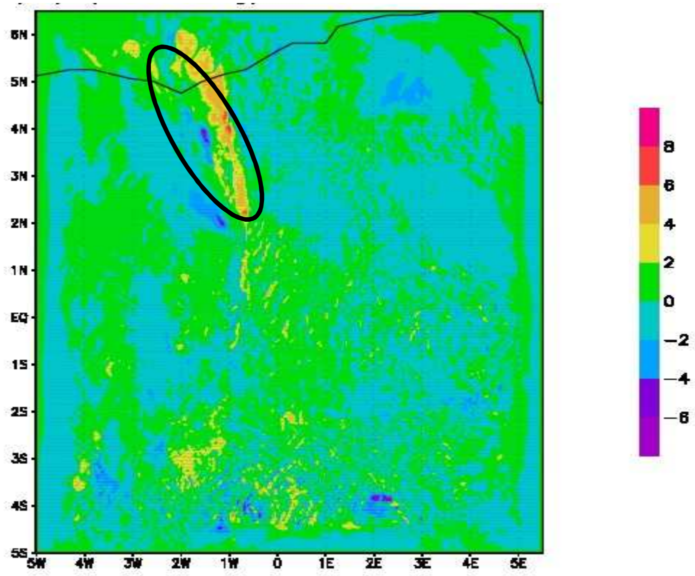
front

= area with large spread, i.e. assumingly with large forecast errors

= area with large analysis increments

= area with differences to nudging analysis

analysis mean – nudging ana.



LETKF, preliminary results: spread compared to RMSE

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deterministic BC

(with vertical localisation, multipl. covariance inflation
$X_b \rightarrow \rho \cdot X_b$, $\rho = 1.15$)

free forecast
LETKF first guess mean

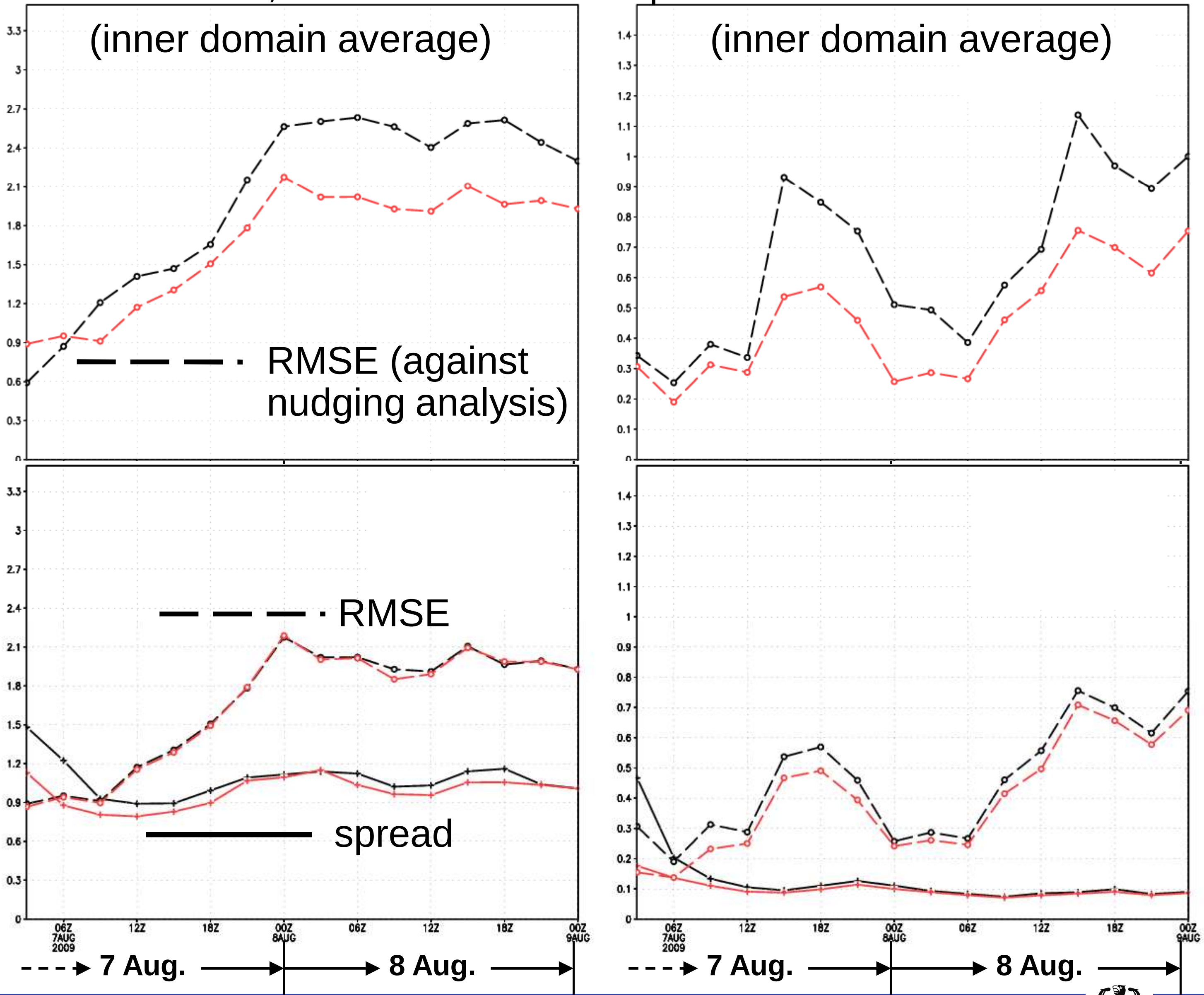
→ obs info is assimilated

first guess mean
analysis mean

→ analysis and f.g. have similar RMSE
→ underdispersive

zonal wind, at ~ 570 hPa

pressure at lowest model level



christoph.schraff@dwd.de

LETKF, preliminary results: spread compared to RMSE

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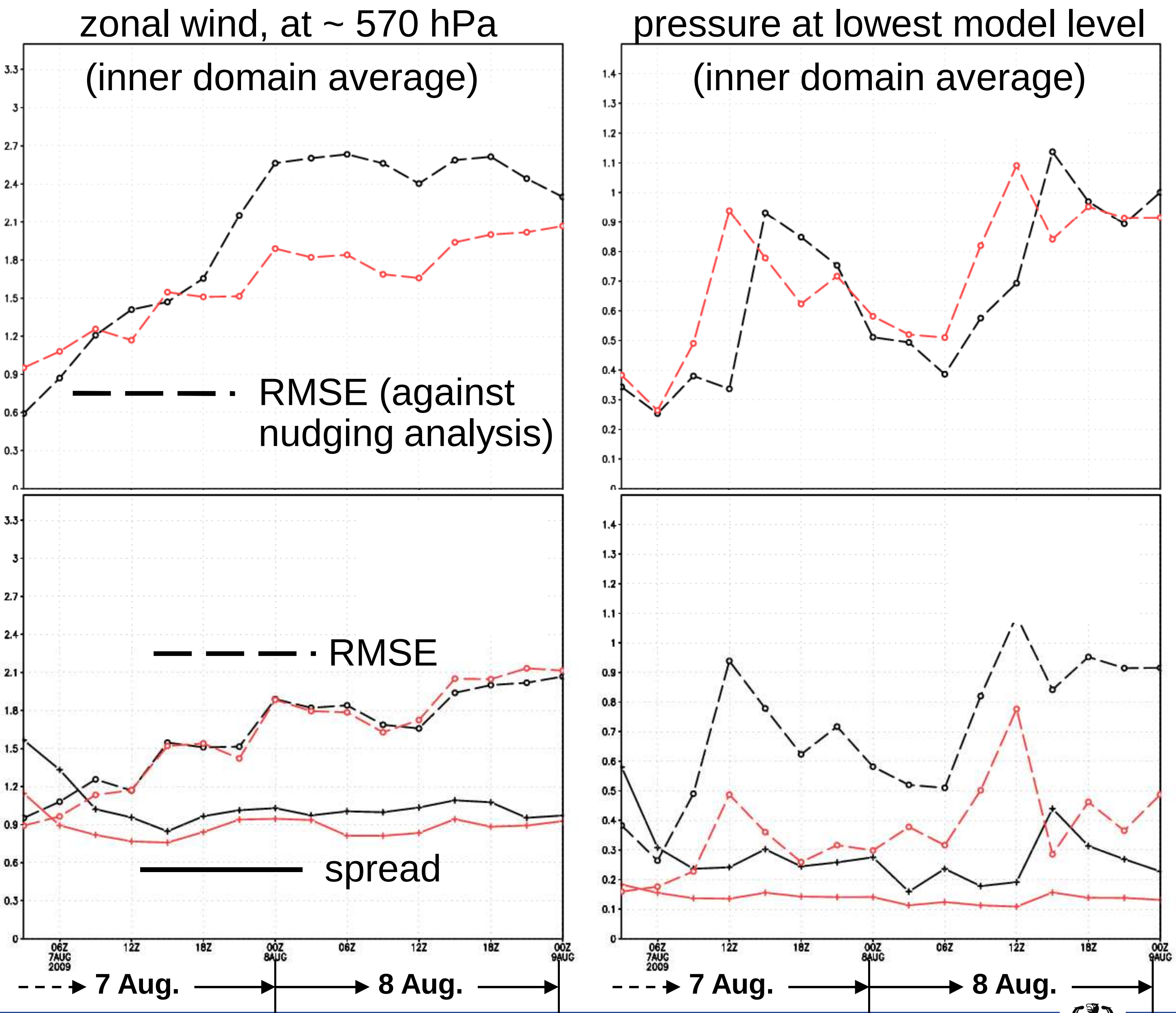
ensemble BC
(with vertical localisation, adaptive **R**, ρ = 1.15)

free forecast (perfect BC)
LETKF first guess mean

→ obs info is assimilated

first guess mean
analysis mean

→ RMSE ana << f.g. for pressure
→ still underdispersive

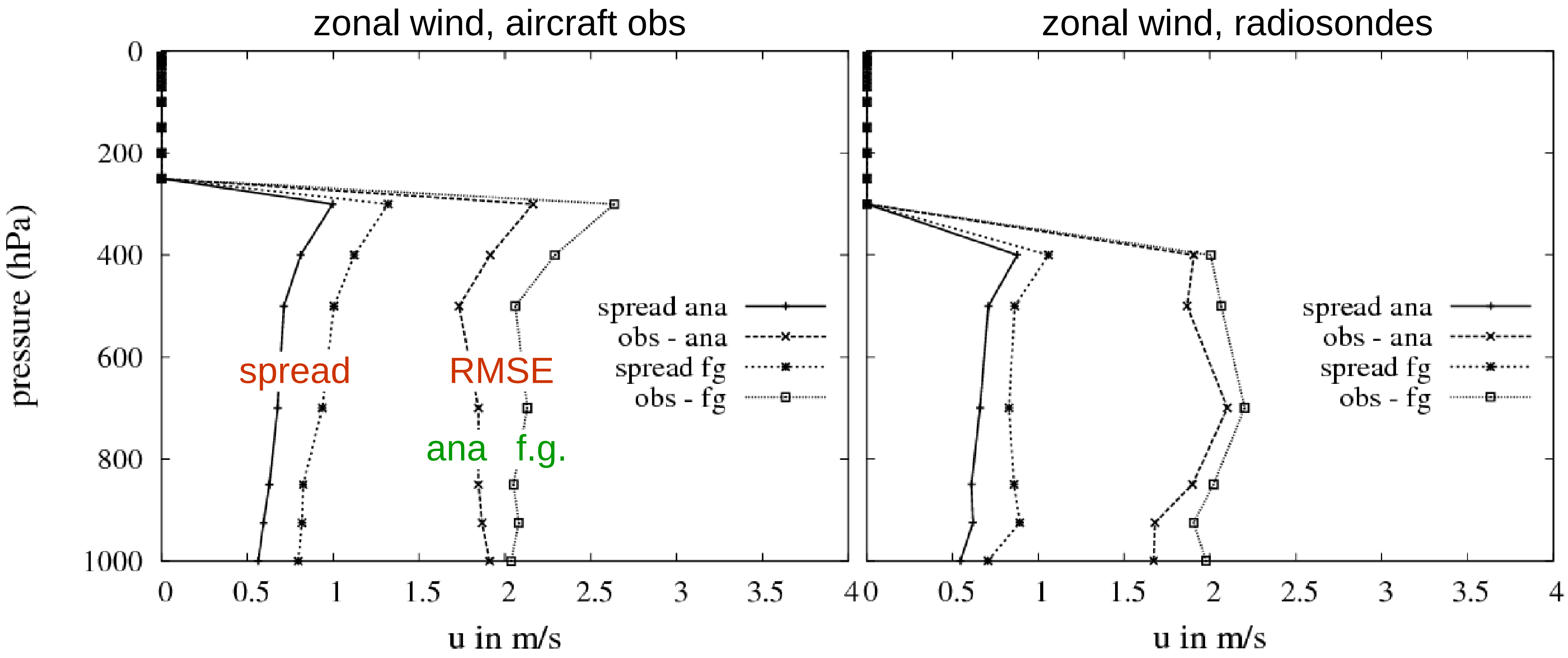


christoph.schraff@dwd.de

LETKF, preliminary results: spread compared to RMSE

time average of RMSE against **obs** , and spread (7 Aug, 15 UTC – 9 Aug, 0 UTC)

(ensemble BC, with vertical localisation, adaptive **R**, ρ = 1.15)



→ larger differences between analysis and first guess at observation locations

→ underdispersive

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

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- lack of spread: (partly ?) due to model error and limited ensemble size which is not accounted for so far

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

  → multiplicative $X_b \rightarrow \rho \cdot X_b$ (adaptive (y – **H**(x) ~ **R** + $\mathbf{H}^T \mathbf{P}_b \mathbf{H}$), Li et al., QJRMS 09)

  → additive (stochastic physics , statistical 3DVAR-**B** , etc.)
- model bias
- **localisation** (multi-scale data assimilation, 2 successive LETKF steps with different obs / localisation ?)
- update frequency
- noise control:
  - how to deal with **perturbed lateral** (upper ?) **BC** (distort implicit error covariances in filter → limit use of obs ?)
  - hydrostatic imbalance by vertical localisation
  - digital filter initialisation ?
- non-linear aspects, **convection initiation** (latent heat nudging ?)

  (→ CH project submitted: OSSE, investigate / reduce spin-up (‘outer loop’))

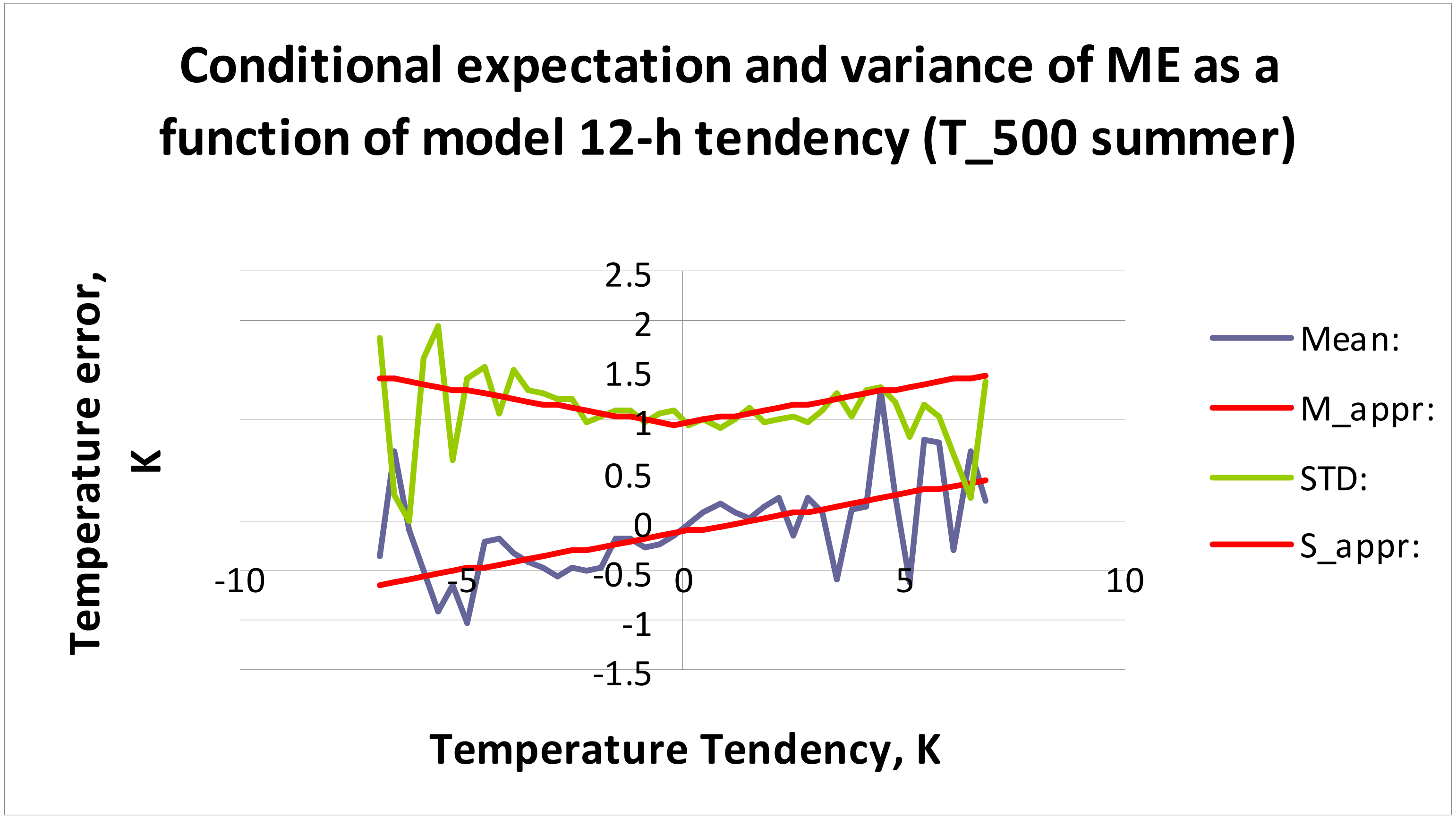
end of 2011: (‘pre-operational’) LETKF suite

christoph.schraff@dwd.de

- **stochastic physics (Palmer et al., 2009)** (by Lucio Torrisi, for Jan. 2011)
- **estimation and modelling of model-errors**
  (by M. Tsyrulnikov, V. Gorin (Russia), for 2 years, start in June 2010)

1. develop an objective estimation technique for model (tendency) errors (not to be confused with forecast errors), and set up stochastic model (parameterisation) for model error : $e = u * M(\mathbf{x}) + e_{add}$
   involves stochastic physics ($u * M(\mathbf{x})$) and additive components e_{add} and includes multi-variate and spatio-temporal aspects
   - build statistics of forecast tendencies minus observation tendencies d (using pairs of lagged obs (increments) at nearly the same location)
     $\text{cov}(d) = (\text{cov}(u)\, M(\mathbf{x}_i)\, M(\mathbf{x}_j) + \text{cov}(\delta M(\mathbf{x})) + \text{cov}(e_{add})) * \Delta t^{2} + 2\,R$
     where $\delta M(\mathbf{x})$ = error in the model tendency due to the analysis error, $\text{cov}(\delta M(\mathbf{x}))$ estimated by sample covariance of the ens. tendencies
     Obs: p, T, u,v, q: Synop, ship, buoy; aircraft; wind profiler (?); radar (?)
2. estimate parameters for model error by fitting to statistics
3. develop a model-error generator and embed it in the COSMO code
4. validate: apply MEM to COSMO forecasts and check resulting EPS spread

Statistics: 2 months in winter and in summer. T, u, v fields, 1000-100 hPa. SYNOP & TEMP obs. on COSMO-RU domain



the upper curves imply a non-zero var(u), the lower curves E[u].

For most cases, both conditional mean and conditional variance are present.

LETKF (km-scale COSMO) : inclusion of additional observations

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

  observation operators (2 PhD’s, started summer 2010, DWD funding) .

  – implement full, sophisticated observation operators

  – then develop different approximations and test their validity in order to obtain sufficiently accurate and efficient operators

  Particular issues for use in LETKF: obs error variances and correlations, superobbing, thinning, localisation

- **ground-based GNSS slant path delay** (after 2010, N.N.)

  – implement non-local obs operator in parallel model environment

  – test and possibly compare with using GNSS data in the form of IWV or of tomographic refractivity profiles

  Particular issue: localisation for (vertically and horizontally) non-local obs

LETKF (km-scale COSMO) : inclusion of additional observations

- **cloud information based on satellite and conventional data**

  → DWD: **Eumetsat fellowship, closing date for applications: 14 October**

  – 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

  – use SEVIRI brightness temperature directly in LETKF in cloudy (+ cloud-free) conditions, in view of improving the horizontal distribution of cloud and the height of its top

  – compare approaches

Particular issues: non-linear observation operators,
non-Gaussian distribution of observation increments

thank you for your attention