Deutscher Wetterdienst
Wetter und Klima aus einer Hand

KENDA: latest results

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Outline

- General overview on BACY experiments
- summary of old setup (GME BC)
- new setup (ICON BC)
- results from new setup
- discussion of results
- next steps, outlook

KENDA experiments: general overview

- stand-alone script environment used for basic cycling (BACY)
- BACY for ICON-LETKF and KENDA
- avoids data base use, fast cycling (speed 1.5 for KENDA, 3 for ICON), but needs large hard disk storage (now available)
- ICON-BACY: LETKF + 3dVar analysis, incl. SMA, verify against analysis and obs, comparison of ens mean (up to now no det run) with 3dVar analysis, also forecasts (ens + ens mean, up to 7 days)
- ICON-BACY produces BC for KENDA (3h cycle)
- KENDA-BACY: LETKF incl. det analysis, nudg cycle with same obs set; forecasts: nudgecast (nudg analysis), free fc, det LETKF, verify against obs (surface/upper air)
- nudg forecast and det forecast use same BC

KENDA experiments: general overview

- old setup: BC from GME-LETKF (NUMEX), period: 20110601-20110607
- new setup: BC from ICON-BACY, period: 20120719-20120725
- first goal: replace nudging with deterministic LETKF analysis
- $\rightarrow$ focus on quality of deterministic analysis/forecast

KENDA old 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	+/-
additive model error | RTPP	+ (3dVar **B**) | +	- | +/-
(adapt.) inflation | R	+ | -	+ | +/-
conventional obs	+	+
Radiances	+ (AMSU-A)	-
GPS-RO	+	-
Radar data	-	oper. impl.
cloud height	-	first tests done
update frequency	3h	1h

KENDA new setup

	ICON	**COSMO**
ensemble member	40 + 1 (3dVar)	40 + 1 (det run)
horizontal resolution (ens)	R02B06 ($\approx$ 80 km)	2.8 km
horizontal resolution (det)	R02B05 ($\approx$ 40 km)	2.8 km
horiz. local. length scale	300 km	100 km
vert. local. length scale (ln p)	0.3 (0.075-0.5)	(0.075-0.5)
adapt. horiz. local.	not tested	+
additive model error | RTPP	- | +	- | +
(adapt.) inflation | R	- | -	+ | -
conventional obs	+	+
Radiances | GPS-RO	+ (AMSU-A) | +	- | -
Radar data	-	oper. impl.
LHN	-	+/-
surface pert (SST/SOIL)	-	+/-
update frequency	3h	1h

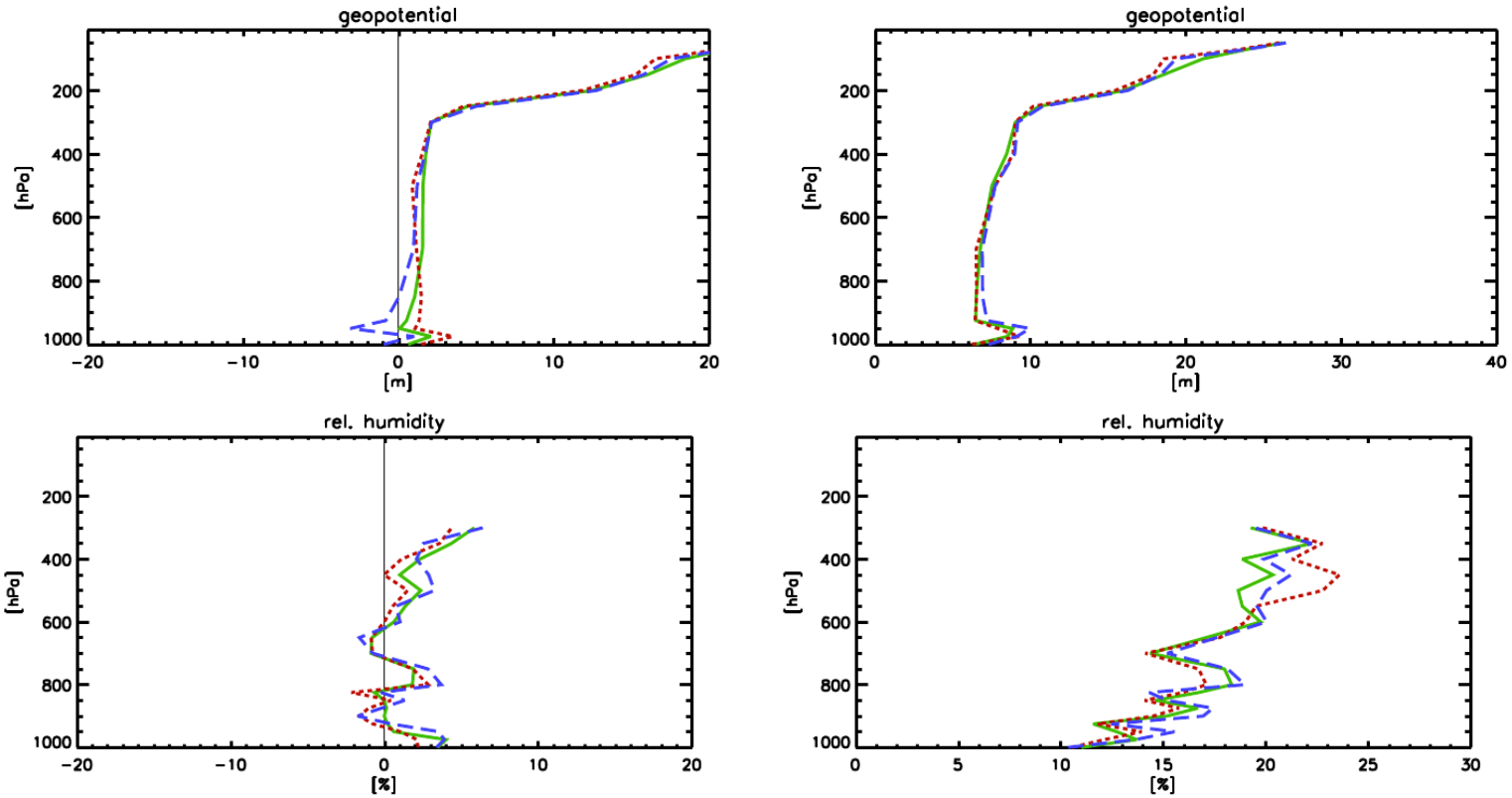
KENDA experiments (old setup)

- 5 experiments for 2011060100 to 2011060700 period
- BC from GME-LETKF

EXP	**adap R**	**adap loc**	**RTPP**
0000.01	-	+	-
0000.02	+	+	-
0000.03	+	-	-
0000.04	-	-	-
0000.07	-	+	+

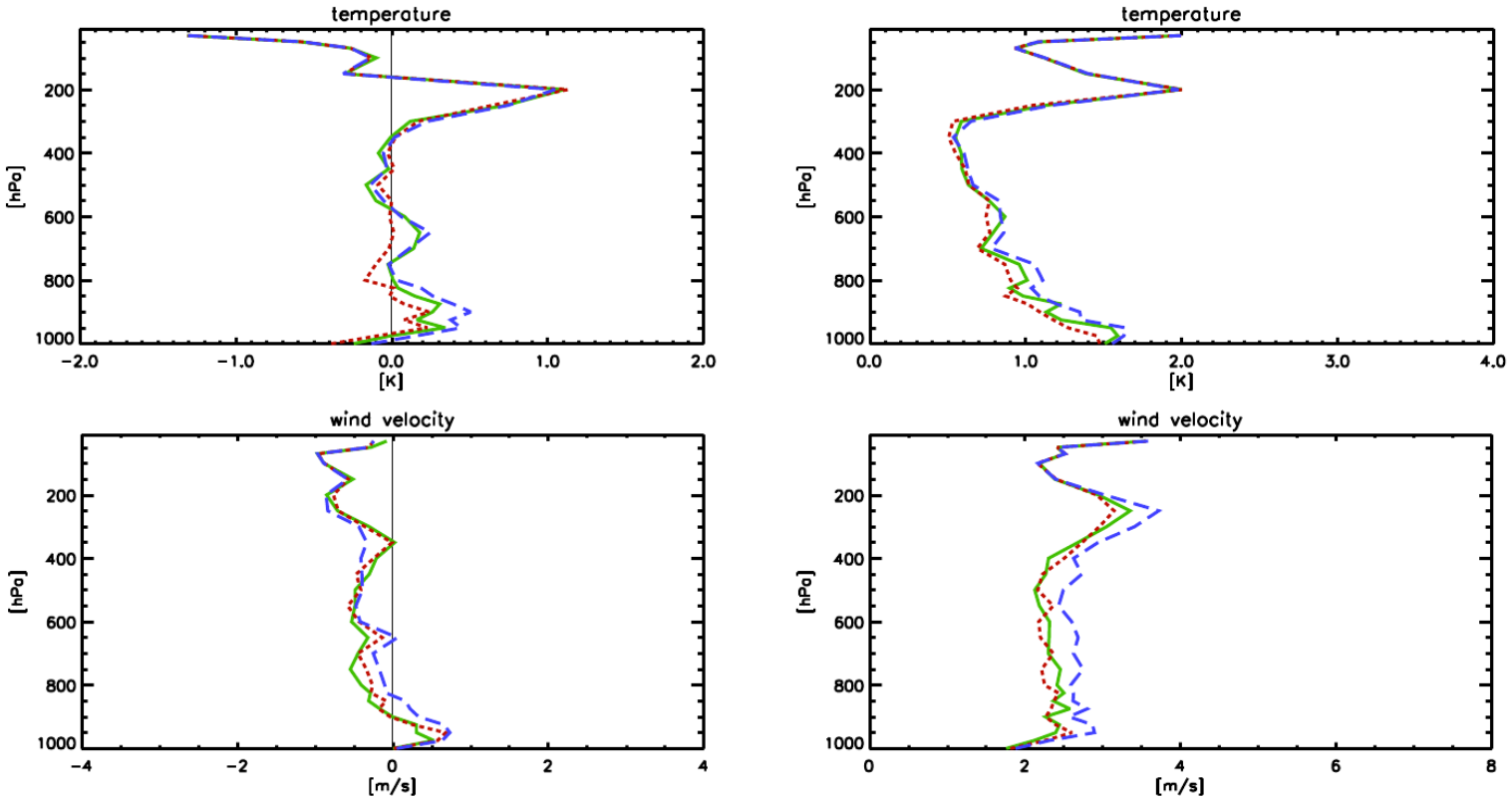
- Compute deterministic forecast (24 h forecast time, every 6 h), starting from deterministic LETKF analysis
- standard DWD scripts for upperair verification
- test several methods to increase spread

EXP04/nudg/free old, 06h, gp/rh



geopotential (upper row), relative humidity (lower row) for exp0000.04/nudg/free fc; bias (left), rmse (right), 6h forecast; det run, nudging, free fc

EXP04/nudg/free old, 06h, t/wv



temperature (upper row), wind velocity (lower row) for exp0000.04/nudg/free fc; bias (left), rmse (right), 6h forecast; det run, nudging, free fc

model error: inflation/relaxation methods

- (1): compare "observed" with "expected" quantities:

$$\left\langle (y - H(x_b))(y - H(x_b))^T \right\rangle = \mathbf{R} + \rho \mathbf{H} \mathbf{P_b} \mathbf{H^T}$$

$$\left\langle (H(x_a) - H(x_b))(y - H(x_b))^T \right\rangle = \rho \mathbf{H} \mathbf{P_b} \mathbf{H^T}$$

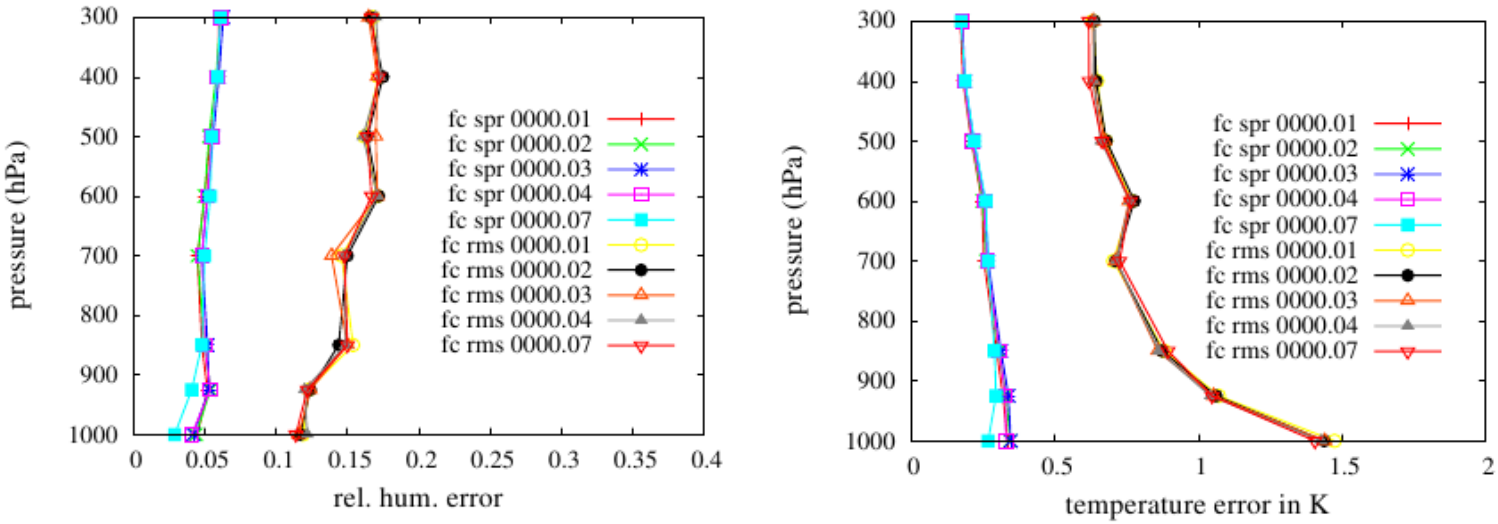
- idea (2): "relaxation" methods:
  - e.g. relaxation to prior spread (RTPS):
  - $\rho = \sqrt{\alpha \frac{\sigma_b - \sigma_a}{\sigma_a} + 1}$, $X_a^{i,infl} = \rho X_a^i$
  - or relaxation to prior perturbation (RTPP): $X_a^{i,infl} = (1 - \alpha) X_a^i + \alpha X_b^i$
- (1) works in observation space; tries to increase/decrease spread to fulfill statistical relations
- (2) works in model space; "corrects" reduction of spread due to assimilation of observations (RTPP: similar to additive pert., "directions" of fg pert partly remain; RTPS: inflates ana pert directions)

model error: inflation/relaxation methods

- → EXP 0000.07: test RTPP
- combine with adaptive rho
- settings used:

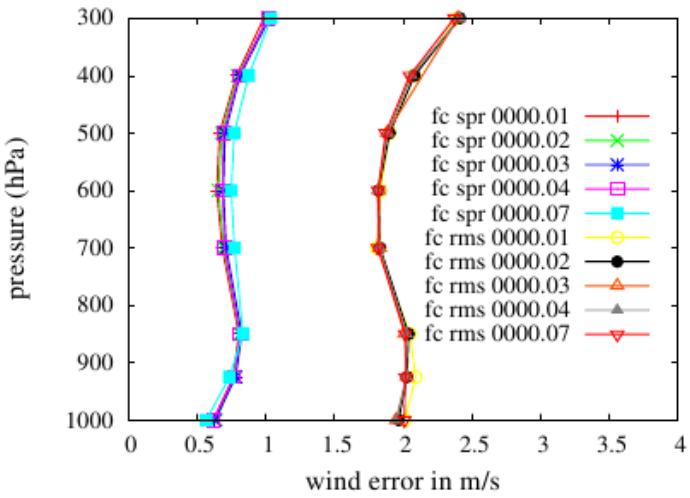
```
adap_rho    = T
apply_rho   = 2
alpha       = 0.1
adap_rho_l  = 0.5
adap_rho_u  = 3.0
adap_R      = F
adap_loc    = T
apply_rtpp  = T
apply_rtps  = F
rtpp_alpha  = 0.75
```

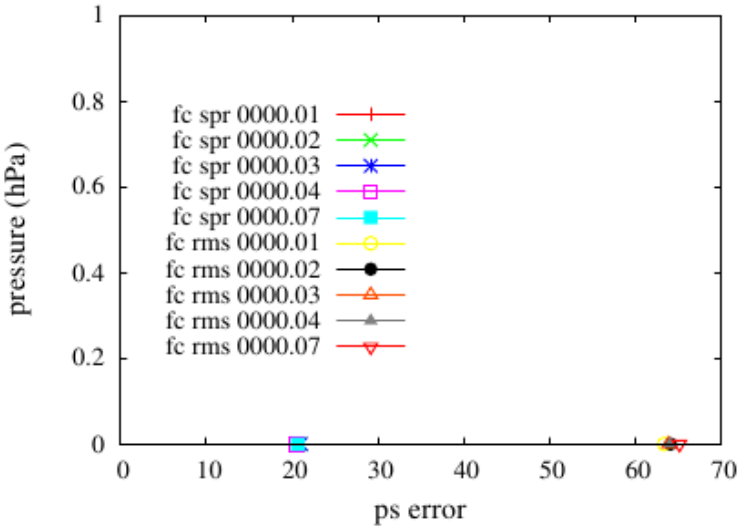
Analysis cycle old: rmse/spread



spread and rmse (against obs) for relative humidity (left), temperature (right), all exp

Analysis cycle old: rmse/spread



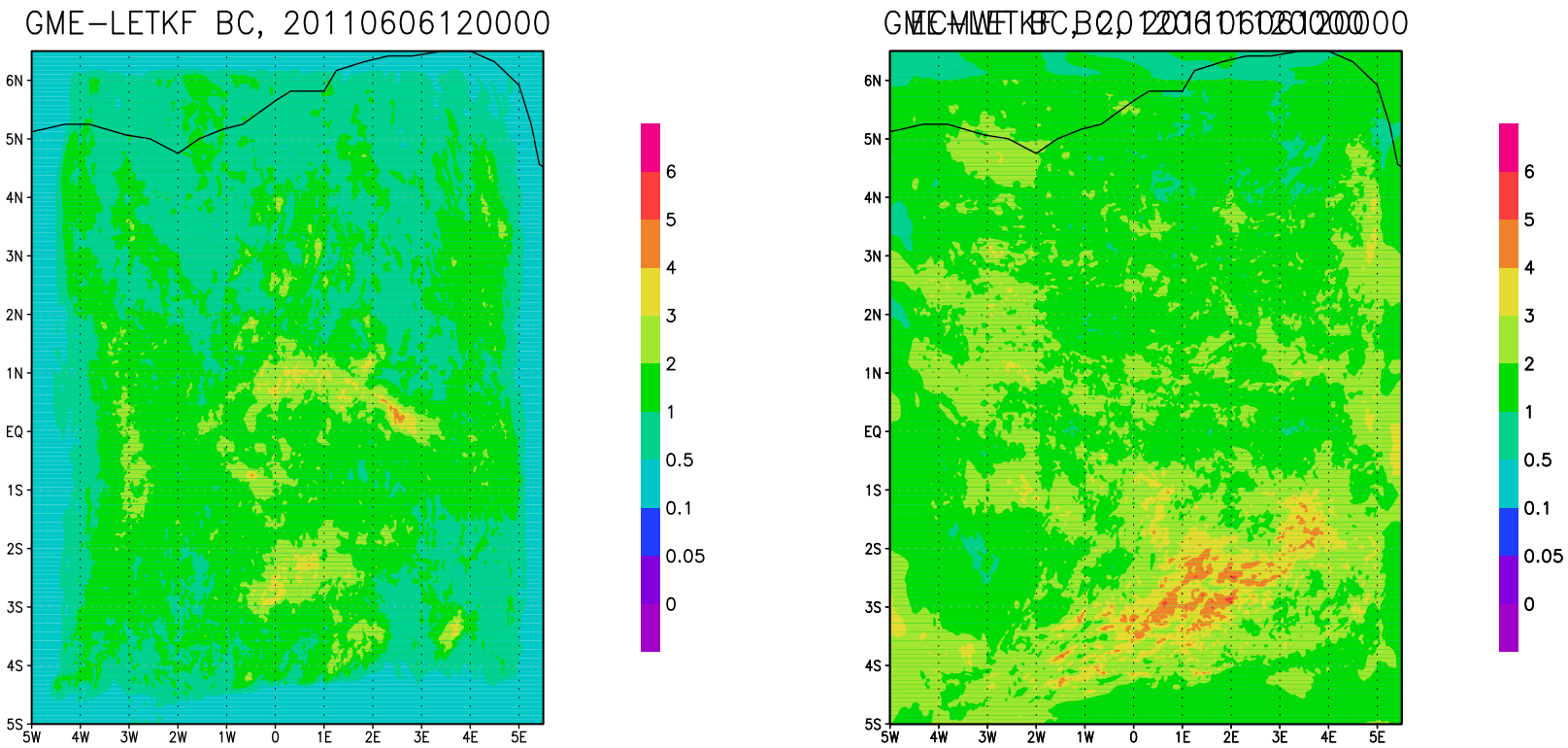


spread and rmse (against obs) for wind (left), surface pressure (right), all exp

Effect of RTPP

- small impact on spread; slightly larger spread on higher levels for wind, spread reduced close to surface
- no / partially negative impact on rmse
- Florian Harnisch obtained good results (esp. on spread / Talagrand diagrams) (using ECMWF BC)
- RTPP gives weight to first guess perturbations which are strongly influenced by BC
- $\rightarrow$ look at BC used (ECMWF/GME)

GME / ECMWF BC

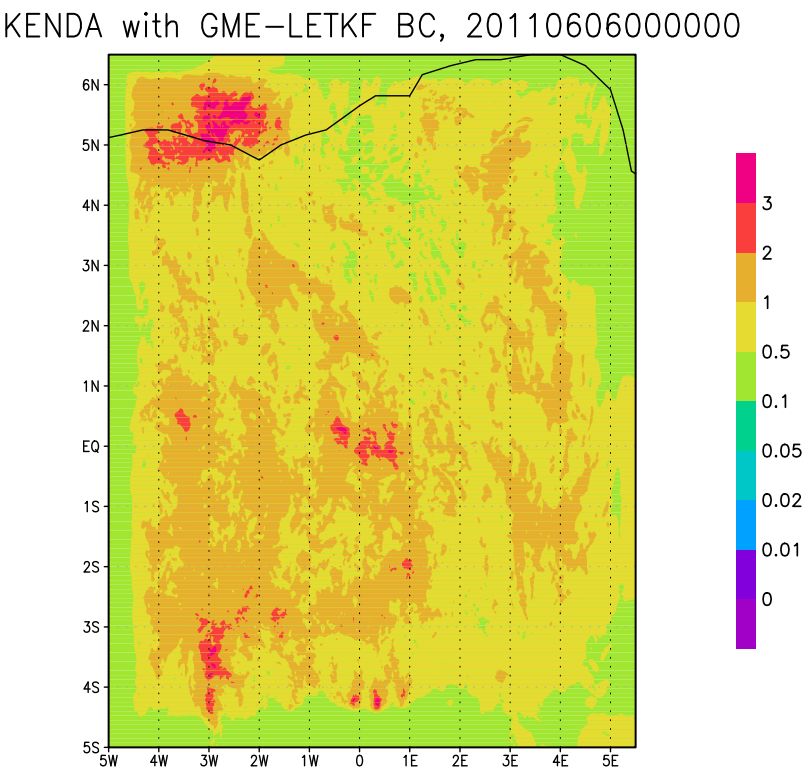


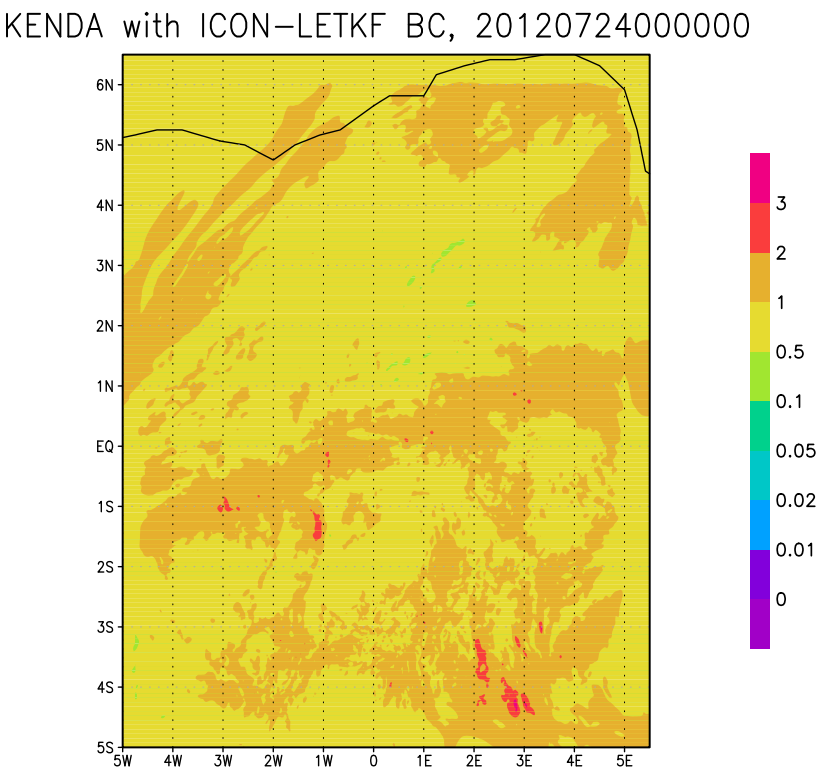
first guess spread of *u*-wind component at model level 25, 2011060612 UTC, from GME-LETKF (left); same for 2012061112 UTC, with ECMWF BC (right)

KENDA experiments (new setup)

- 12 experiments for 2012071900 to 2012072500 period
- BC from ICON-LETKF
- Compute deterministic forecast (24 h forecast time, every 6 h), starting from deterministic LETKF analysis
- standard DWD scripts for upperair + surface verification
- compare with free fc and nudging (similar to operational setup, but different BC)
- free fc, LETKF det and nudging use same BC, obs set the same for det and nudg
- BC from ICON-LETKF: LETKF depends on "2 ways" frm BC: direct and via **B**-matrix
- ICON-LETKF uses RTPP (latest results: increases spread, slightly decreases RMSE)
- $\rightarrow$ look at spread of ICON-BC first

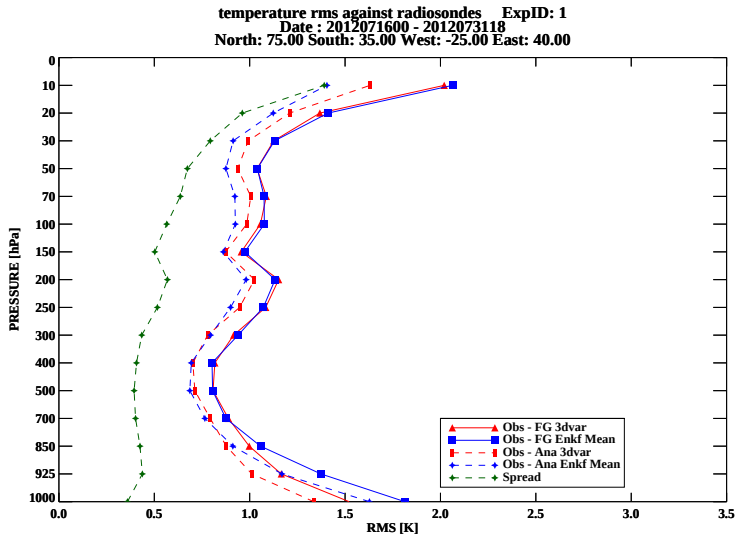
GME / ICON BC

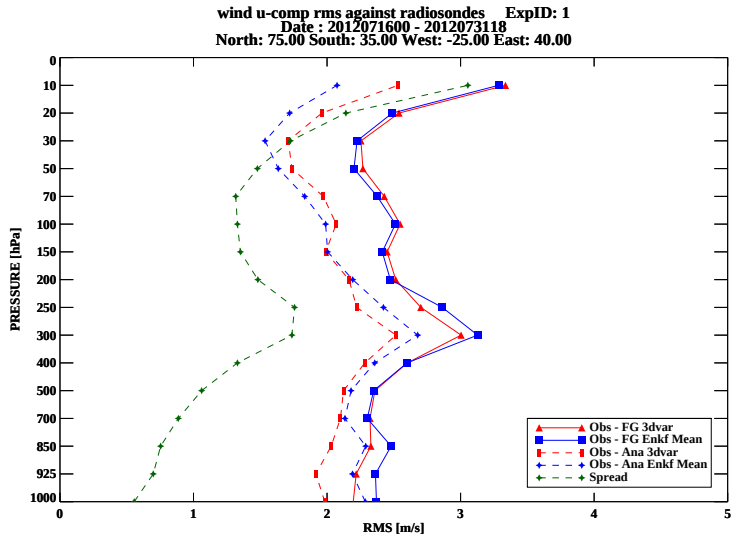




spread of first guess with GME/ICON BC at 2011060600/2012072400 UTC (u-wind component, z=25)

RMSE ICON





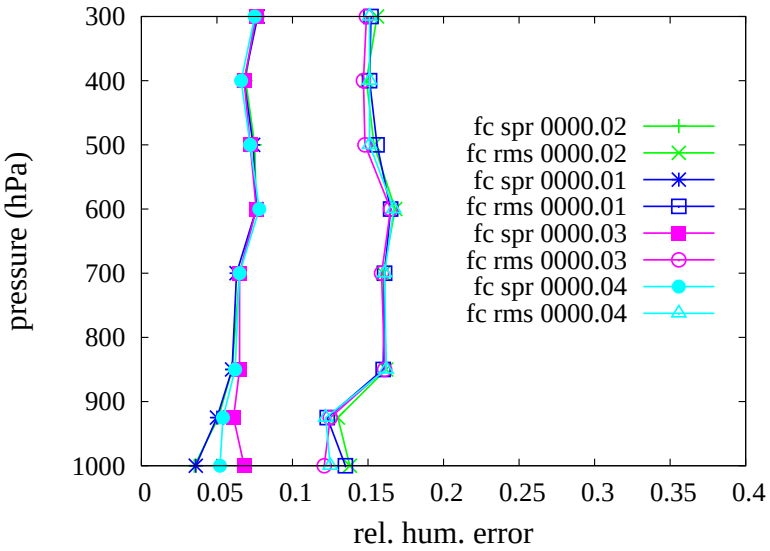
rmse and spread of ICON 3dVar and LETKF for Europe, verified against radiosondes, temperature (left) and u-wind component (right)

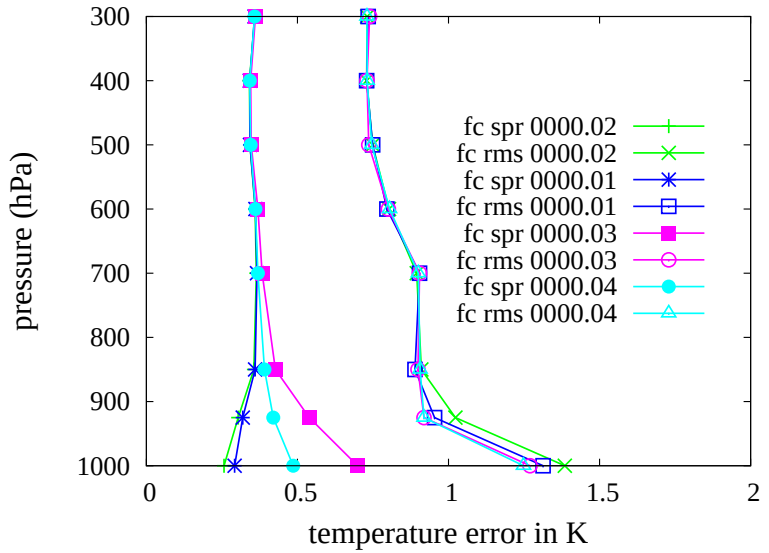
KENDA experiments (new setup)

EXP	**settings**	EXP	**settings**
02	no soil cycling	05	free fcst
01	soil cycling	06	nudg
03	strong soil pert	07	LHN ens+det
04	weak soil pert	08	nudg LHN

EXP	**settings**
09	LHN det
10	nudg soil oper
11	new ps obs err
12	LETKF soil oper
13	nudgecast

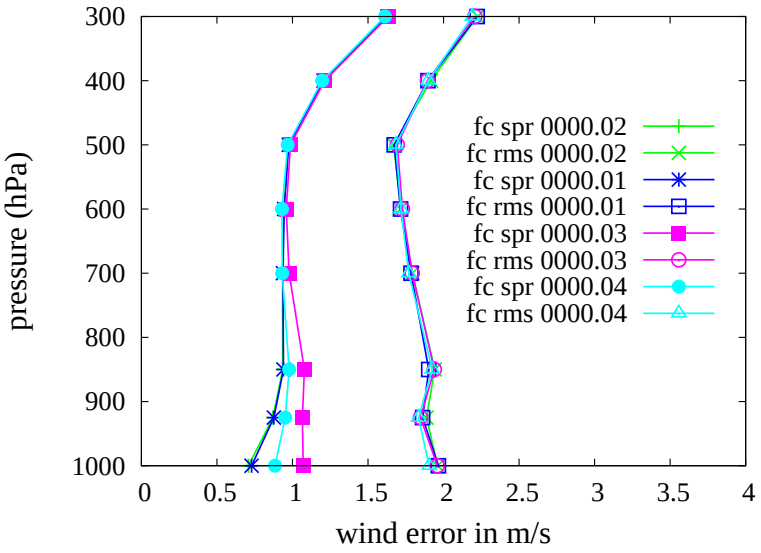
Effect of soil perturbations: analysis cycle

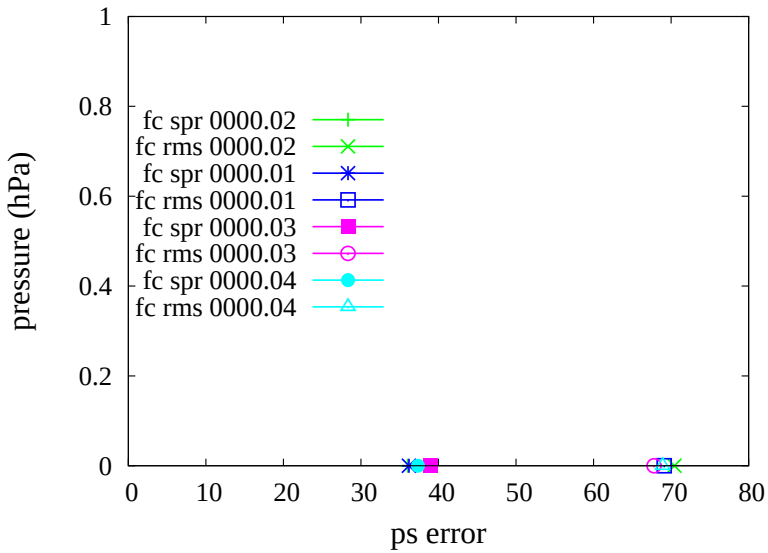




spread and rmse (against obs) for relative humidity (left), temperature (right); shown are exp without soil cycling (02), soil cycling (01), strong (03) and weak (04) soil moisture perturbations

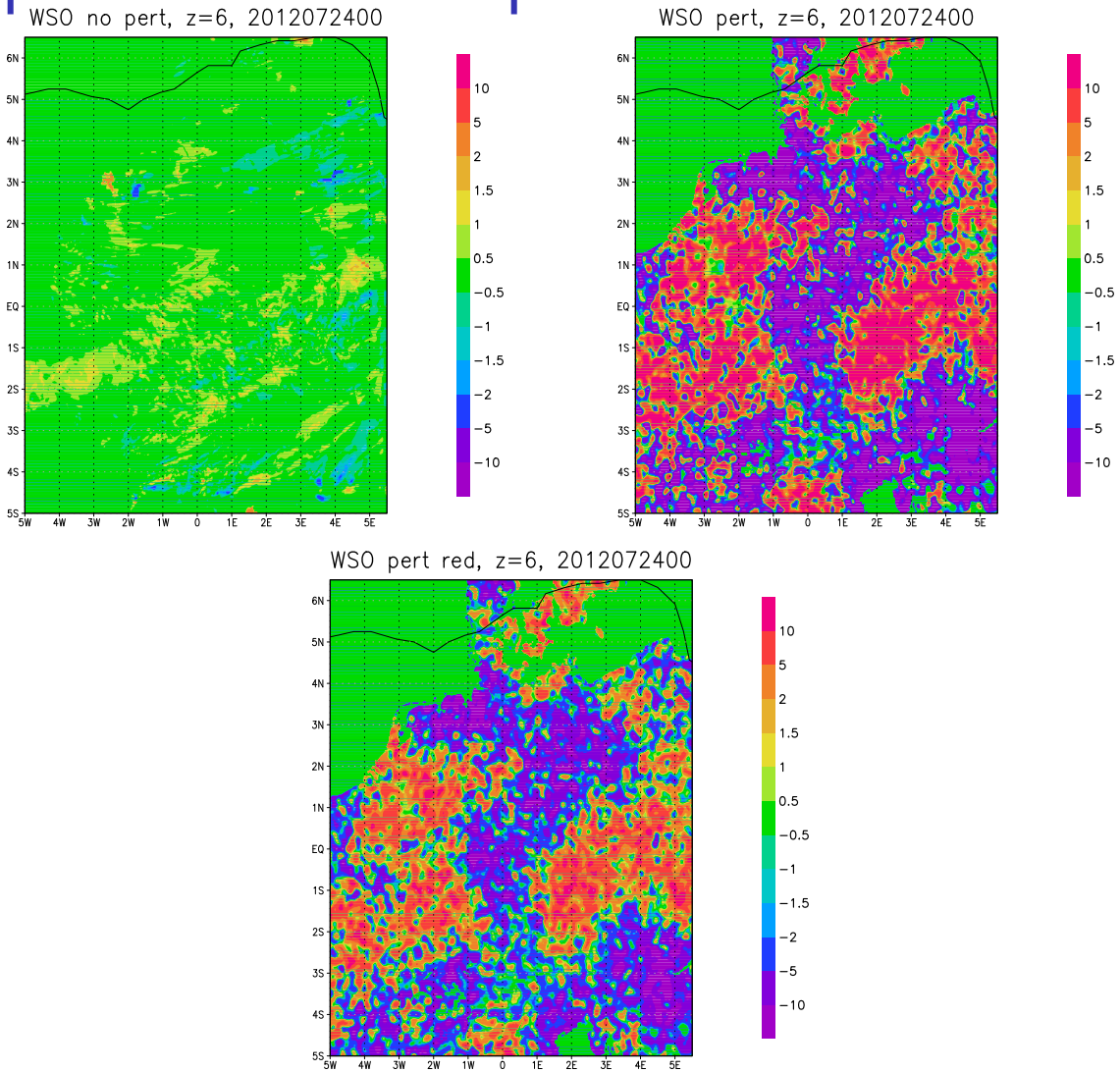
Effect of soil perturbations: analysis cycle





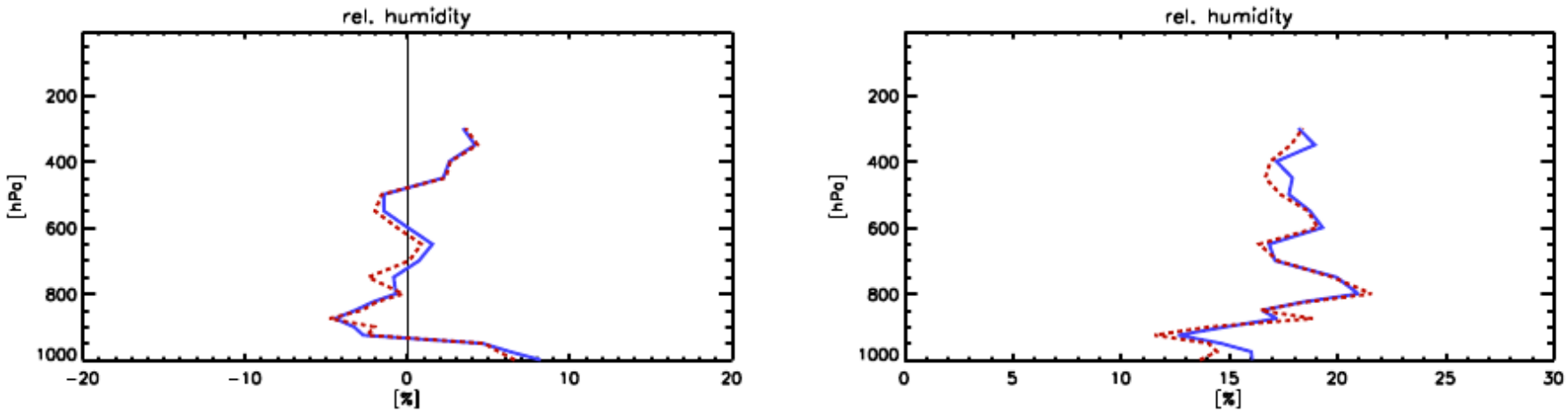
spread and rmse (against obs) for wind (left), surface pressure (right); shown are exp without soil cycling (02), soil cycling (01), strong (03) and weak (04) soil moisture perturbations

Effect of soil perturbations: spatial structure



soil moisture at level 6 (6 cm), 2012072400: no perturbations, strong perturbations, weaker perturbations

Effect of soil perturbations: upper air, LETKF strong soil pert, no pert, - EXP03/01

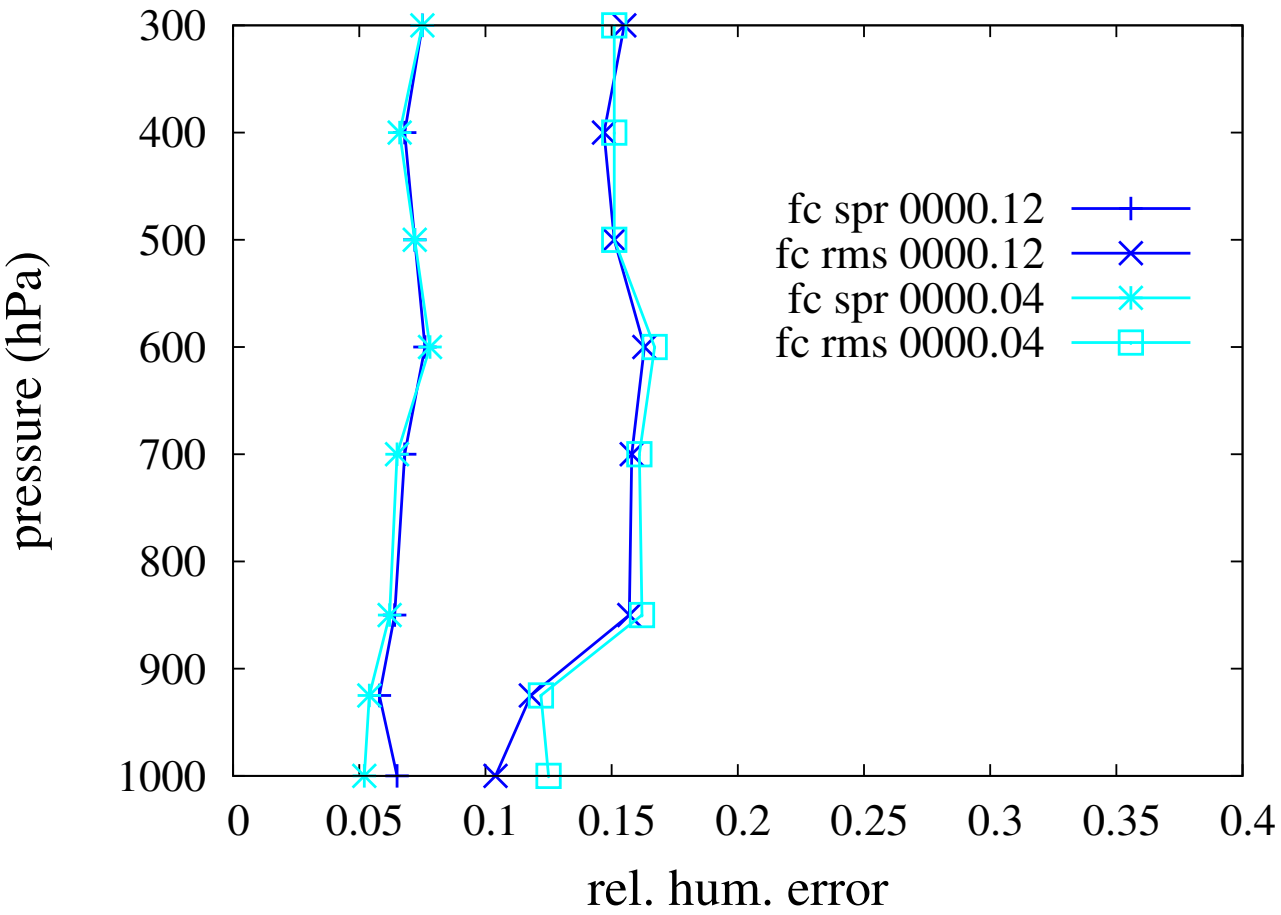


(upper air) verification against observations; relative humidity; bias (left), rmse (right), 6h forecasts; no pert, pert; positive impact close to surface!

Effect of soil perturbations: LETKF strong pert vs. LETKF no pert - EXP 03/01

Variable	RMSE	BIAS
Geopotential	=	=
Temperature	=	=
Relative Humidity	(+)	=
Wind Speed	=	=
Wind Direction	=	=
Total Cloud	+	+
Low Cloud	(+)	=
Mid Level Cloud	+	+
High Cloud	=	=
Surface Pressure	+	=
2m Dew Point	+	=
2m Temperature	=	=
10m Wind	=	=

Effect of ICON/COSMO-DE soil: analysis cycle

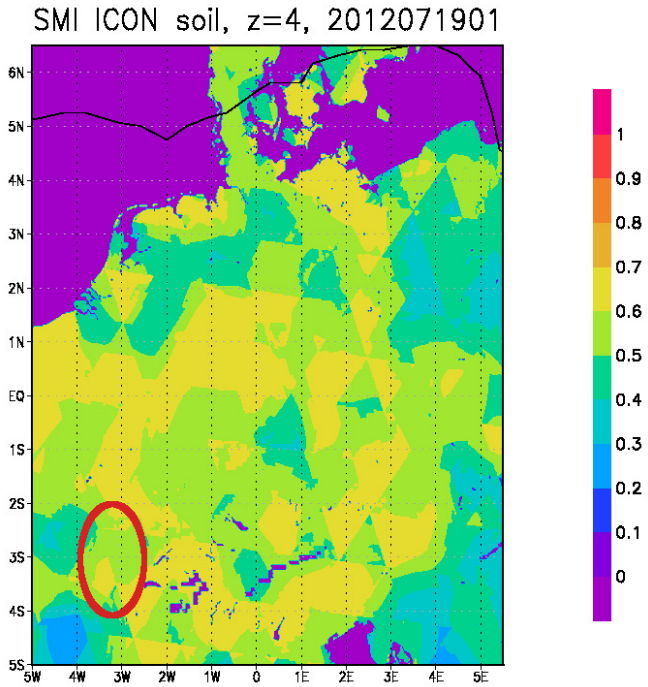


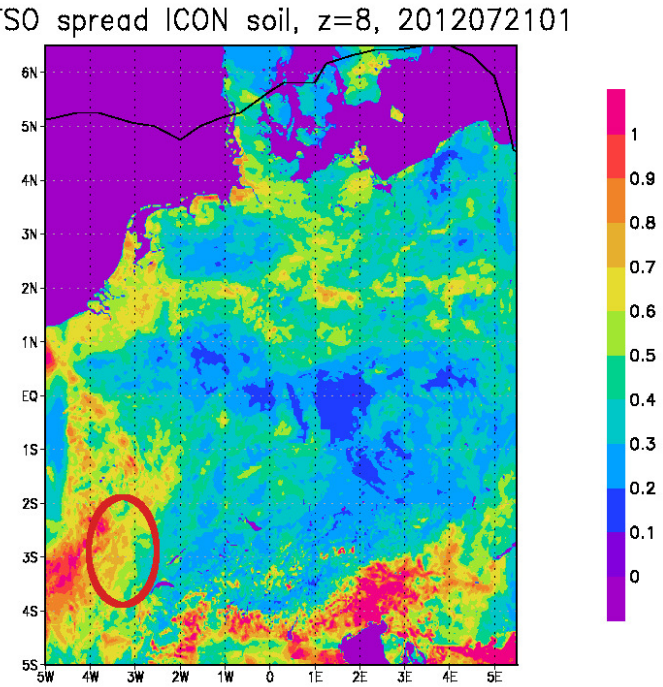
spread and rmse (against obs) for relative humidity with ICON (0000.04) and COSMO-DE (0000.12) soil; spread increases!

Effect of ICON/COSMO-DE soil

- Why the spread increases when using operational COSMO-DE soil?
- Perturbations are zero at the beginning (as we use the same soil for all ensemble members) of period with operational COSMO-DE soil
- the perturbations added are the same as in the case of ICON soil.
- Possible explanation: plants (roots) are more sensitive to changes (induced by the the perturbations) if soil moisture is low; this leads to more spread in areas with low soil moisture.

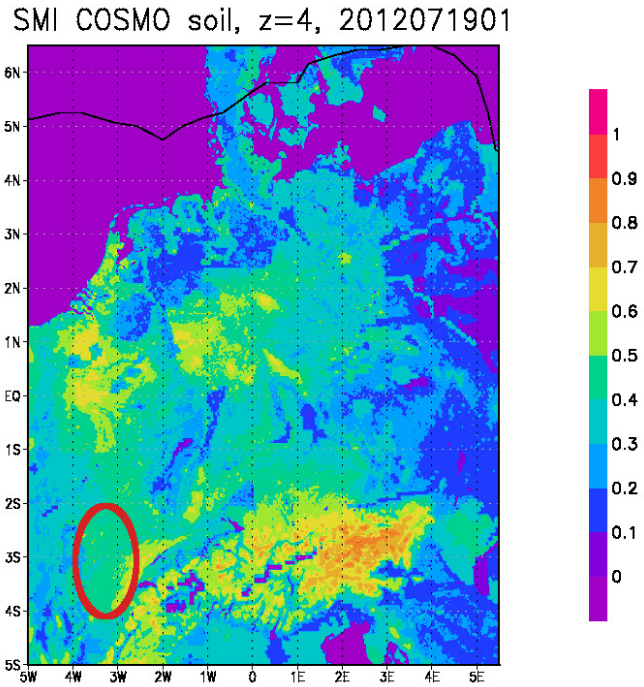
Effect of ICON/COSMO-DE soil

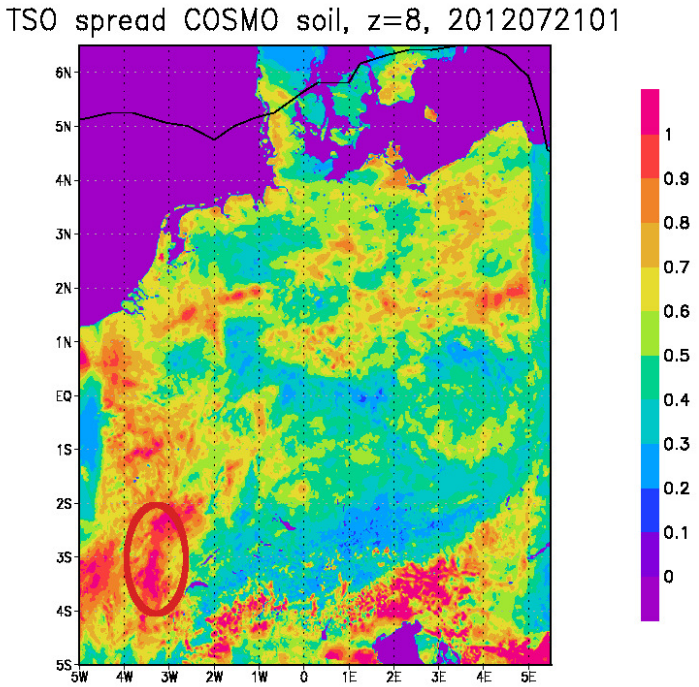




soil moisture index (smi) with ICON soil at 2012071901, level 4 (54cm,left) and tso spread at 2012072101, level 8 (1cm,right)

Effect of ICON/COSMO soil



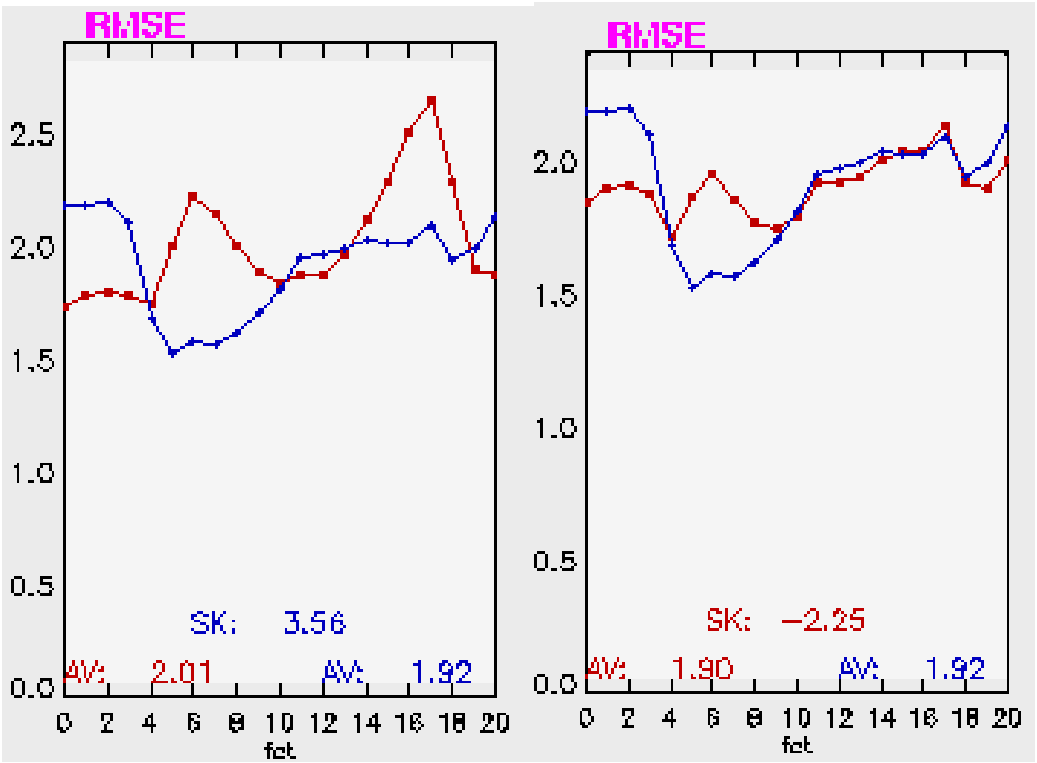


COSMO-DE soil, smi at 2012071901, level 4 (54cm,left) and tso spread at 2012072101, level 8 (1cm,right)

Effect of ICON/COSMO-DE soil; LETKF COSMO-DE soil vs. LETKF ICON soil (LHN) - EXP 12/07

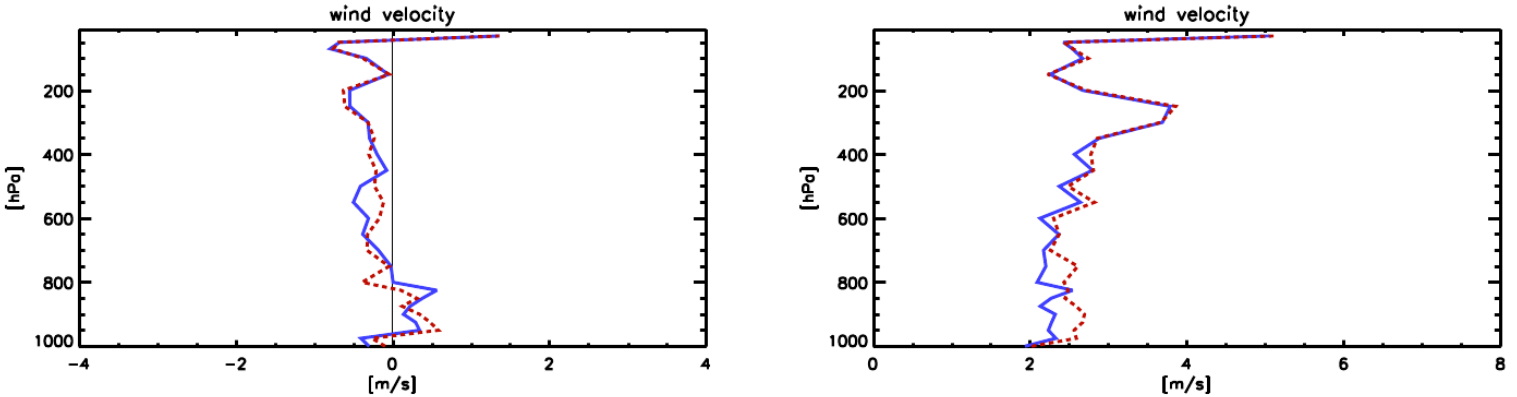
Variable	RMSE	BIAS
Geopotential	=	=
Temperature	+	+
Relative Humidity	+	+
Wind Speed	=	=
Wind Direction	=	=
Total Cloud	-	=
Low Cloud	+	-
Mid Level Cloud	(+)	=
High Cloud	=	=
Surface Pressure	=	=
2m Dew Point	=	+
2m Temperature	+	+
10m Wind	-	(+)

Effect of ICON/COSMO-DE soil



surface verification: 2m temperature for LETKF exp07 (ICON soil, lhn) (red curve,left), LETKF det 12 (COSMO-DE soil) (red curve, right). Blue curve is routine.

Effect of ICON/COSMO-DE soil, comparison with nudging

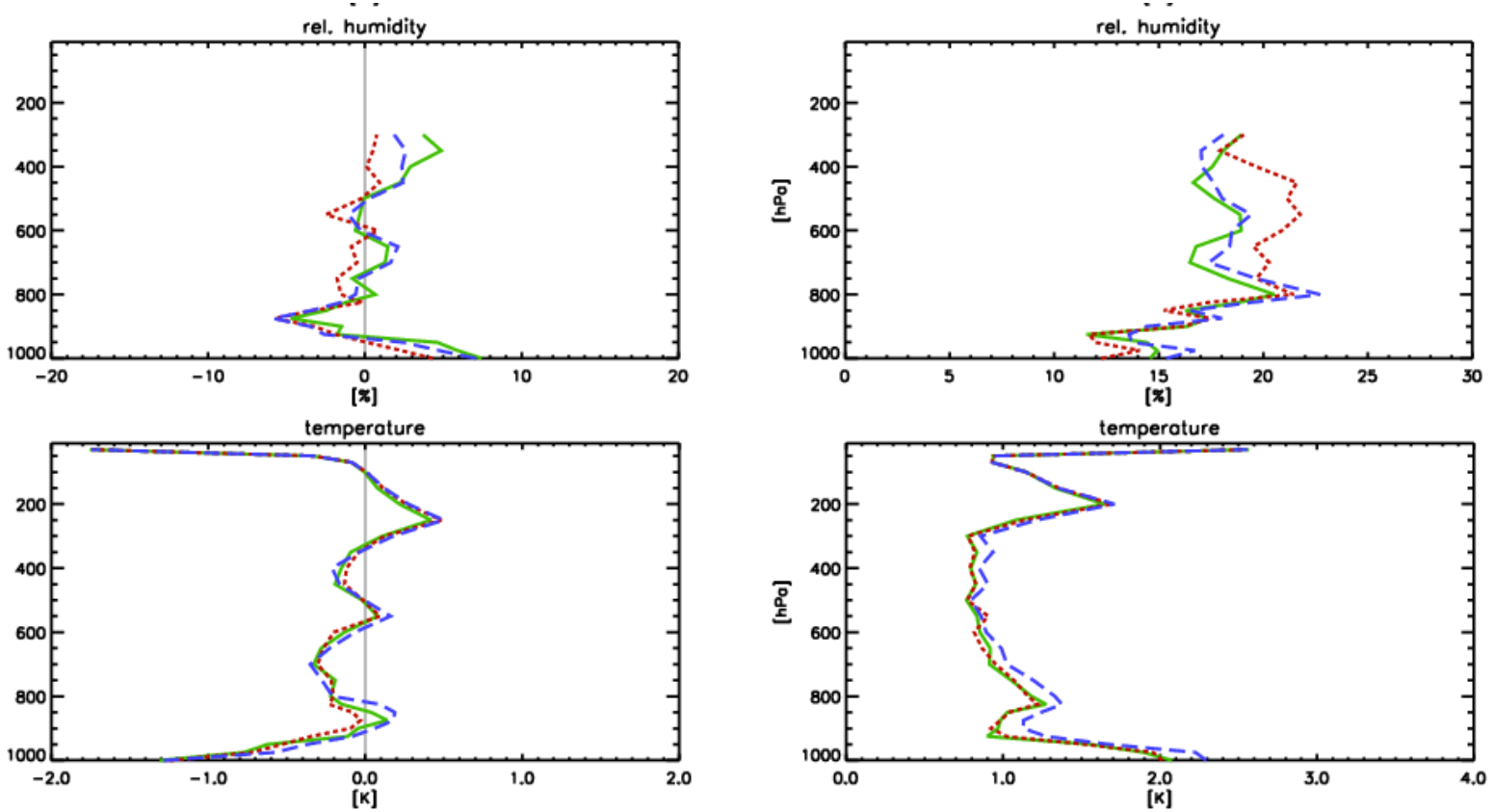


wind velocity; bias (left), rmse (right), 6h forecast; nudg soil COSMO-DE, LETKF soil COSMO-DE

Effect of ICON/COSMO-DE soil: LETKF vs. nudg (COSMO-DE soil) - EXP 12/10

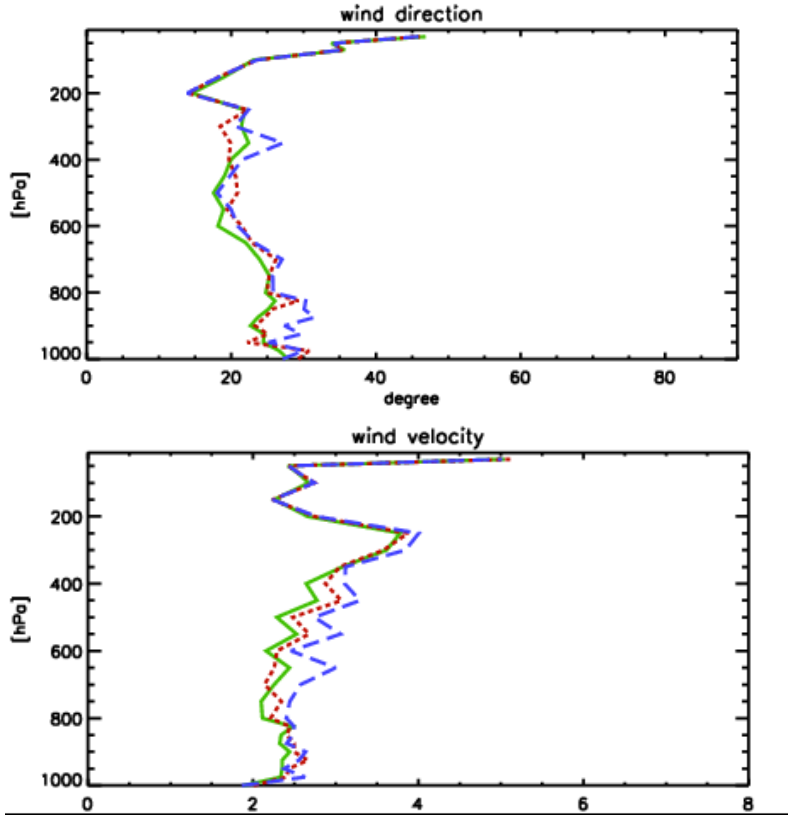
Variable	RMSE	BIAS
Geopotential	=	=
Temperature	=	=
Relative Humidity	+	=
Wind Speed	+	=
Wind Direction	(+)	=
Total Cloud	=	=
Low Cloud	+	+
Mid Level Cloud	+	(+)
High Cloud	-	(-)
Surface Pressure	–	=
2m Dew Point	=	=
2m Temperature	(+)	=
10m Wind	=	=

Effect of LHN: LETKF / nudg LHN, free fc - EXP07/08



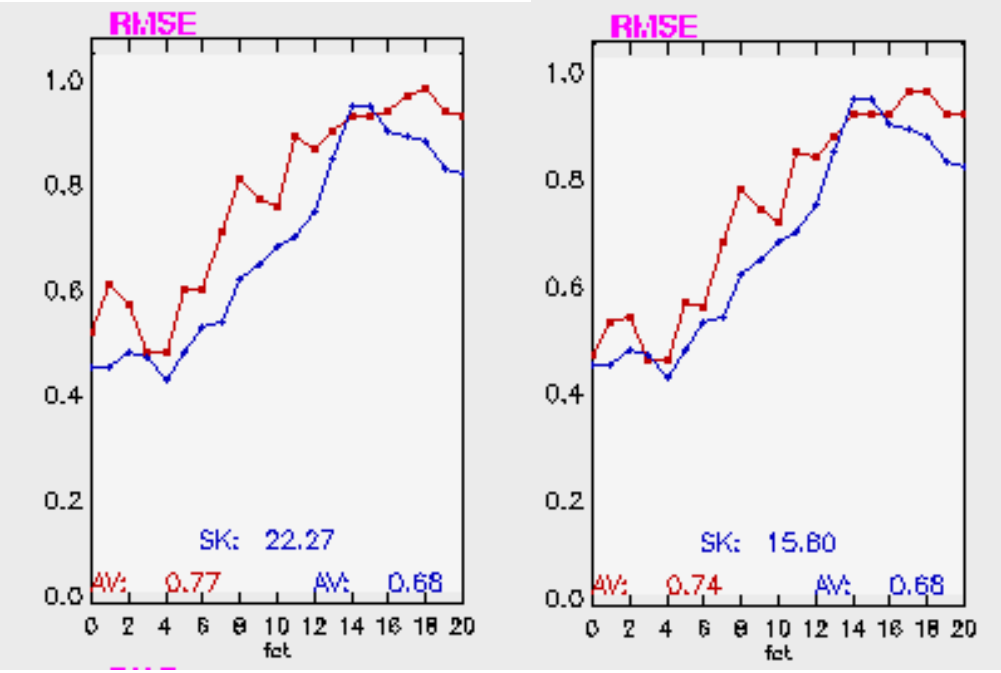
relative humidity (upper row), temperature (lower row); bias (left), rmse (right), 6h forecast; LETKF det, nudg, free fc

Effect of LHN: LETKF / nudg LHN, free fc - EXP07/08



wind velocity (upper row), wind direction (lower row); rmse, 6h forecast; LETKF det, nudg, free fc

Effect of LHN, comparison with nudging



surface verification: surface pressure for LETKF exp07 (LHN for ens+det) (red curve,left), nudging exp08 (LHN) (red curve,right). Blue line is routine.

Effect of LHN: LETKF LHN vs. NUDG LHN - EXP 07/08

Variable	RMSE	BIAS
Geopotential	=	=
Temperature	+	+
Relative Humidity	+	-
Wind Speed	+	=
Wind Direction	+	=
Total Cloud	=	=
Low Cloud	(+)	+
Mid Level Cloud	+	=
High Cloud	-	(-)
Surface Pressure	-	=
2m Dew Point	=	=
2m Temperature	=	=
10m Wind	=	=

Effect of LHN: LETKF LHN (ens/det) vs. LETKF strong soil pert - EXP 07/03

Variable	**RMSE**	**BIAS**
Geopotential	=	=
Temperature	=	=
Relative Humidity	=	=
Wind Speed	=	=
Wind Direction	=	=
Total Cloud	=	=
Low Cloud	=	=
Mid Level Cloud	=	=
High Cloud	=	=
Surface Pressure	=	=
2m Dew Point	=	=
2m Temperature	=	=
10m Wind	=	=

RADAR verification, LETKF LHN ens+det vs. LHN det - EXP 07/09

Variable	**FSS at 11gp**	**FBI**
Precip. 00 UTC, 0.1 mm	+	=
Precip. 12 UTC, 0.1 mm	+	=
Precip. 00 UTC, 1.0 mm	+	=
Precip. 12 UTC, 1.0 mm	+	=

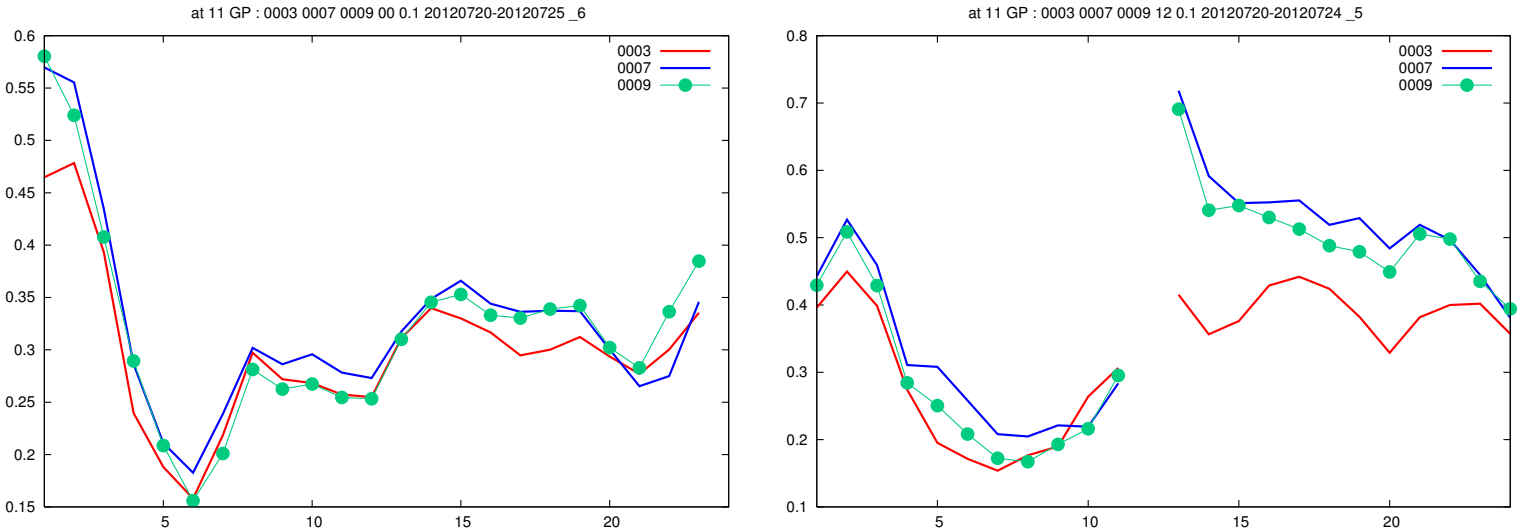
RADAR verification, LETKF LHN ens+det vs. no LHN (strong pert) - EXP 09/03

Variable	**FSS at 11gp**	**FBI**
Precip. 00 UTC, 0.1 mm	=	=
Precip. 12 UTC, 0.1 mm	+	+
Precip. 00 UTC, 1.0 mm	=	=
Precip. 12 UTC, 1.0 mm	+	(+)

RADAR verification, LETKF LHN ens+det vs. nudg LHN - EXP 07/08

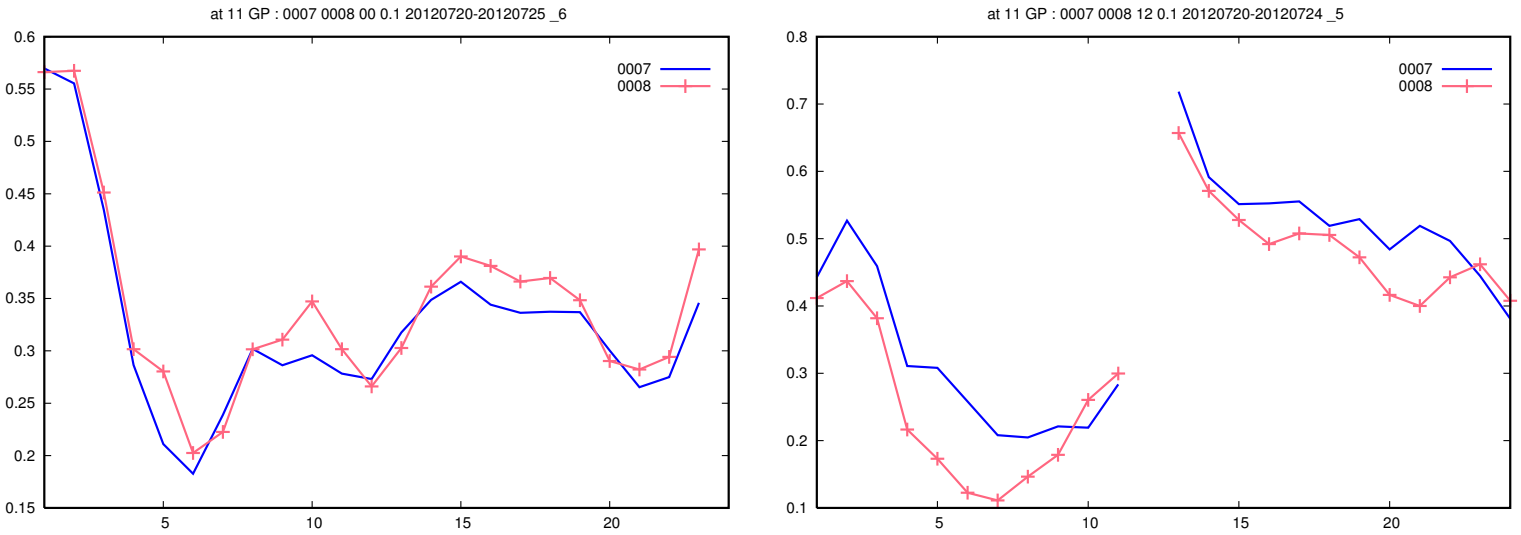
Variable	**FSS at 11gp**	**FBI**
Precip. 00 UTC, 0.1 mm	-	=
Precip. 12 UTC, 0.1 mm	+	(+)
Precip. 00 UTC, 1.0 mm	-	+
Precip. 12 UTC, 1.0 mm	+	=

RADAR verification: FSS LETKF, effect of LHN



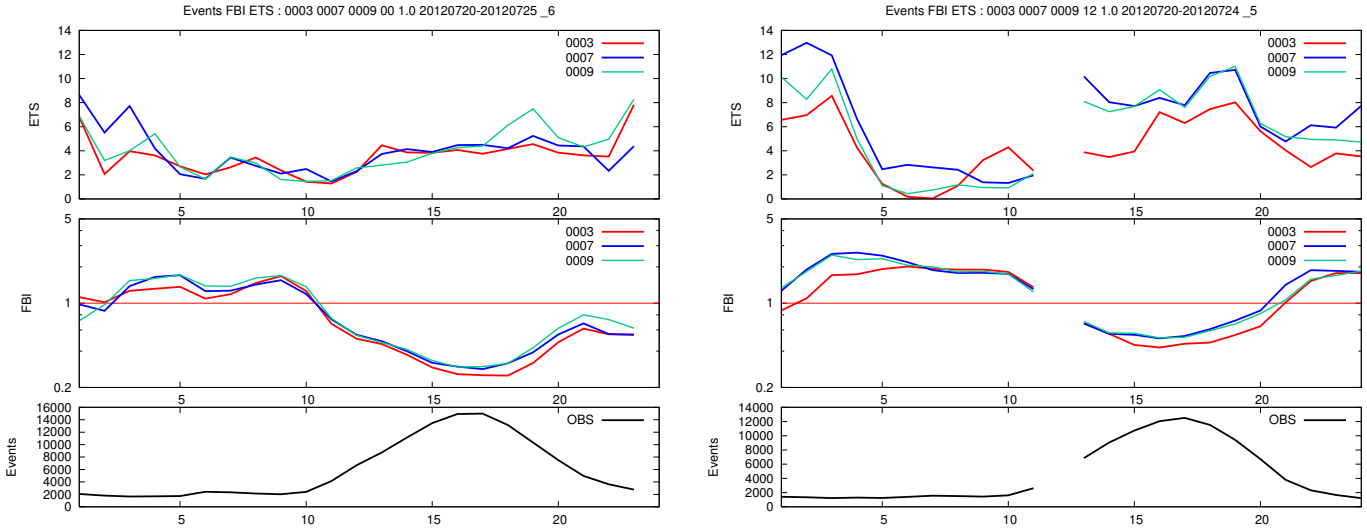
FSS at 11 gp, 0.1 mm, 00 UTC (left), 12 UTC (right) for LETKF without LHN (03), LHN ens+det (07) and LHN ens (09)

RADAR verification: FSS LETKF/nudg with LHN



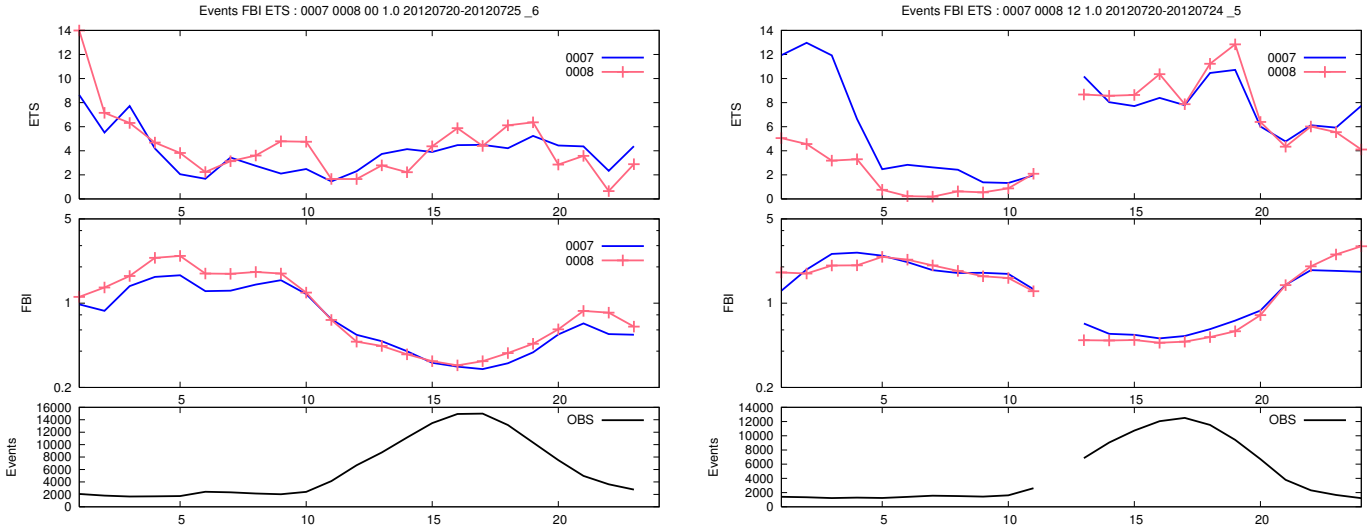
FSS at 11 gp, 0.1 mm, 00 UTC (left), 12 UTC (right) for LETKF LHN ens+det(07) and nudh with LHN (08)

RADAR verification: FBI LETKF, effect of LHN



FBI for 1mm at 00 UTC (left), 12 UTC (right)

RADAR verification: FBI LETKF/nudg with LHN



FBI for 1mm at 00 UTC (left), 12 UTC (right)

Summary, discussion, remarks

- The results shown are *preliminary* because of
  - Quality control in LETKF was very restrictive (observations must be accepted in all ensemble members); large effect for relative humidity observations (Daniel Leuenberger): implement option for less restrictive setiing
  - no alignment of observations (unfair for nudg, esp. relative humidity?)
  - (technical) problems with experiment with weak soil perturbations, repeat
  - run experiment with "no RTPP" to test effect in ICON-setup
  - nudgecast was switched off (test for one nudging experiment: no effect), but we will repeat all nudging forecasts
  - we have different periods for GME/ICON setup
  - longer forecasts needed

Conclusions, next steps

- new setup with ICON-BC: larger spread (except surface pressure)
- 24 h forecast of det run, nudging, free fc: deterministic LETKF forecast of similar /slightly better quality as nudging forecast (except surface pressure)
- plots shown are for 6h forecasts, but results also hold for 12h, 18h forecasts (differences get smaller)
- LHN: no influence on upper air verification; slightly better for Radar (precipitation, 12 UTC)
- soil moisture perturbations: positive impact on spread/rmse close to surface
- use of COSMO-DE-soil: positive impact on 2m temperature forecast
- compute 10-14 days period in May/June 2014
- use neffprove; ensemble forecasts; additional observations

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* $\mathbf{K}$:

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

- 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

Soil moisture perturbations

- perturb soil moisture (and SST) with defined spatial and temporal length scales and amplitude
- soil moisture: 2 length scales, 100 km (synoptic), 10 km (convection)
- cut-off if moisture is below zero or above capacity ($\rightarrow$ bias)
- next step: for soil moisture, limit perturbation amplitude to "available capacity" (avoid bias)

```
name = 'W_SO'                ! disturb soil moisture
scales = 0.002 100 1 24      ! 0.004 of soil capacity, 100km,
                             ! 1m vertical, 24 hour
         0.002 10 1 24       ! 0.004 of soil capacity, 10km,
                             ! 1m vertical, 24 hour
name = 'SST'               ! disturb SST
scales = 1  100 0 24       ! 1K +  100 km length scale pattern,
                           ! 24 hour
```