Towards an operational use of the KENDA system at DWD

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talk outline

- motivation
- towards operational use of KENDA:
  - deterministic forecasts: comparison KENDA-LETKF vs. nudging + LHN
  - EPS: comparison to COSMO-DE-EPS setup → *Richard Keane*
- use of additional high-resolution observations (outlook)
  → *Michael Bender, Theresa Bick, …*

Motivation : Why develop Ensemble Data Assimilation ?

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convection-permitting NWP:
stochastic nature of (air-mass) convection

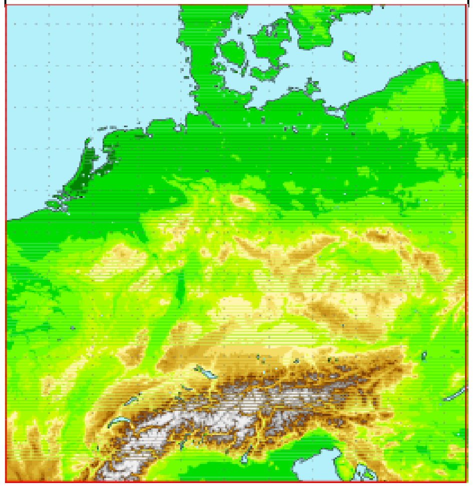
→ deliver probabilistic (pdf) rather than deterministic forecast

→ need ensemble prediction system (EPS)

COSMO-DE EPS operational,
but without data assimilation (DA) cycle

→ develop ensemble DA
to provide suitable **perturbed IC for EPS**

COSMO-DE
(Δx = 2.8 km)
deep convection
simulated explicitkly



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Motivation : Why develop Ensemble Kalman Filter (EnKF) ?

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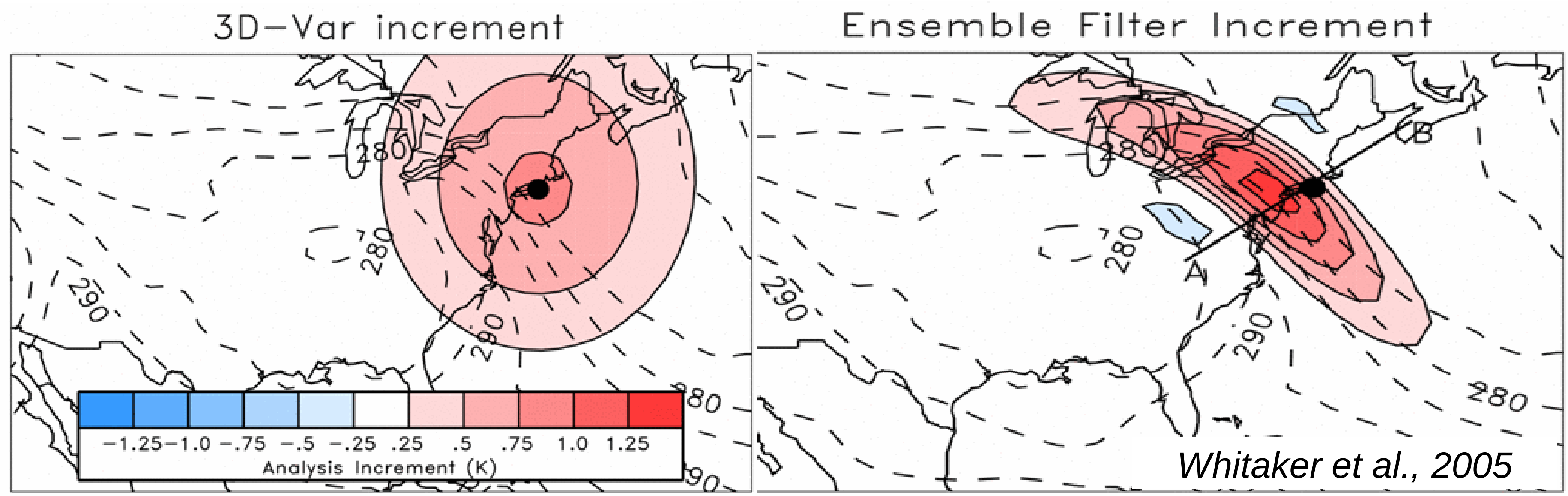
analysis increments given a single observation



→ EnDA / EnKF : uses first guess (1h forecast) ensemble to estimate current, flow-dependent first guess errors + use

→ ensemble spread mainly localised over frontal area, + fcst. errors assumed in EnKF

→ observation causes analysis increments over frontal area

→ advantage esp. in convective scale, where error covariances strongly flow dep.

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Motivation : Why develop EnKF / LETKF ?

1. provide **perturbed IC for EPS**

2. improved analysis / forecast quality by use of **multi-variate, flow-dependent error covariances**

3. better suitable than current operational nudging scheme for use of **indirect observations** (**satellite**, **radar**, etc.):
   - nudging requires retrievals (e.g. T-, q- profiles from satellite radiances)
   - EnKF: apply forward observation operator (→ simulated radiances)

→ Local Ensemble Transform Kalman Filter (**LETKF**, Hunt et al. 2007) , (because of its relatively low computational costs)

developed in COSMO priority project: Km-scale ENsemble DA (**KENDA**)

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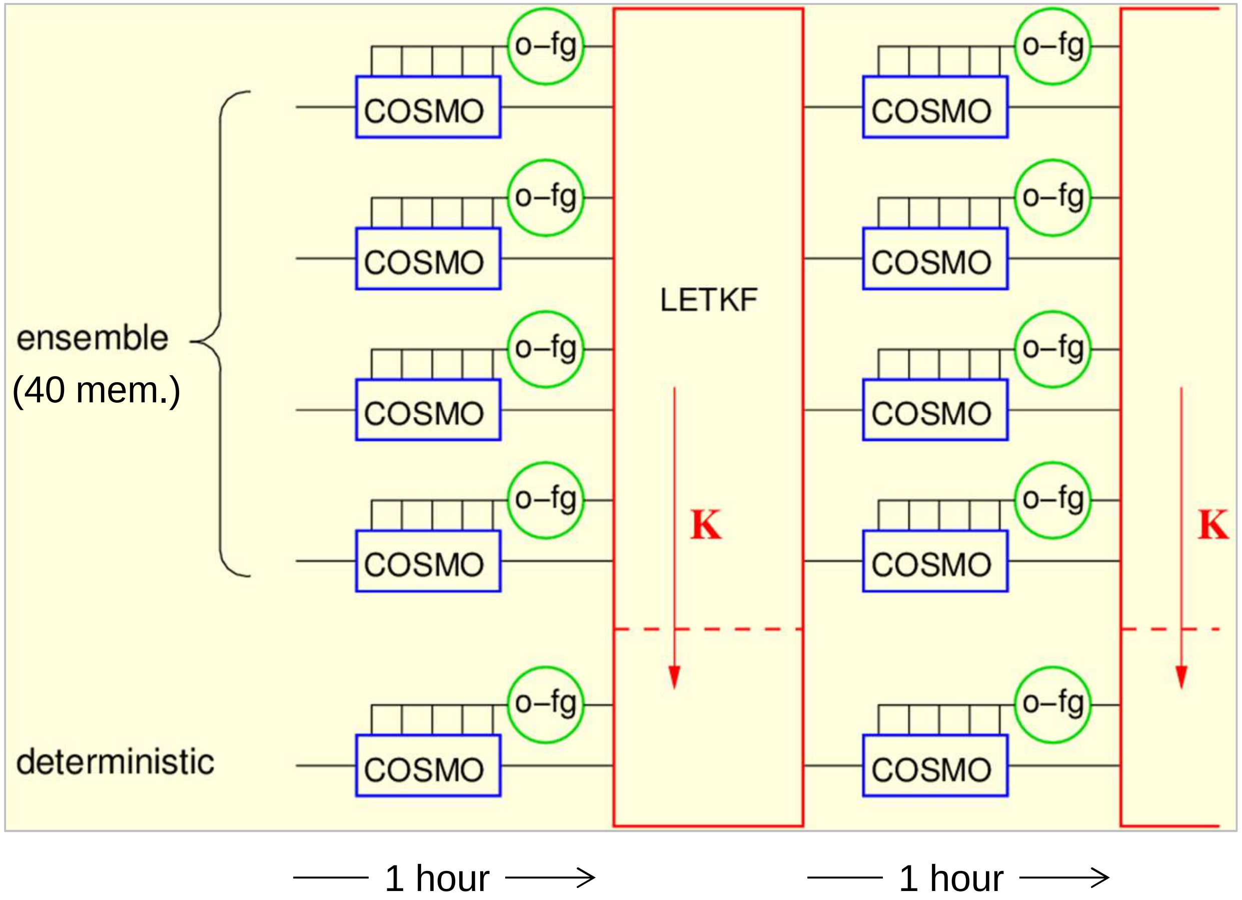
LETKF: **KENDA**



→ **4D** –LETKF

→ **K**: Kalman Gain for ensemble mean (to compute ana incr.)

→ benchmark: **Nudging**

LETKF: main development + testing
comparison to Nudging + LHN

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- 1st goal: replace nudging + LHN with **deterministic** LETKF analysis for COSMO-DE (Δx = 2.8 km)

→ for operation-ability: quality of deterministic forecast from KENDA
(using conventional obs: radiosonde, aircraft, wind prof, surface)
as good as nudging + LHN (for use of radar precip)

→ test period 28 days (18 May – 15 June 2014 : convection, little advection)

– adaptive localisation & mutliplicative covariance inflation,
  RTPP (relaxation to prior perturbations), soil moisture perturbations

– LBC from 80-km ICON-LETKF / 40-km 3DVar , conv. obs , 1-hrly LETKF cycle

– combine LETKF with LHN, compare with nudging (+ LHN)

- 2nd goal: use KENDA for IC of COSMO-DE-**EPS**
(possibly in combination with other perturbations)

KENDA-LETKF:
setup, with LHN added to LETKF

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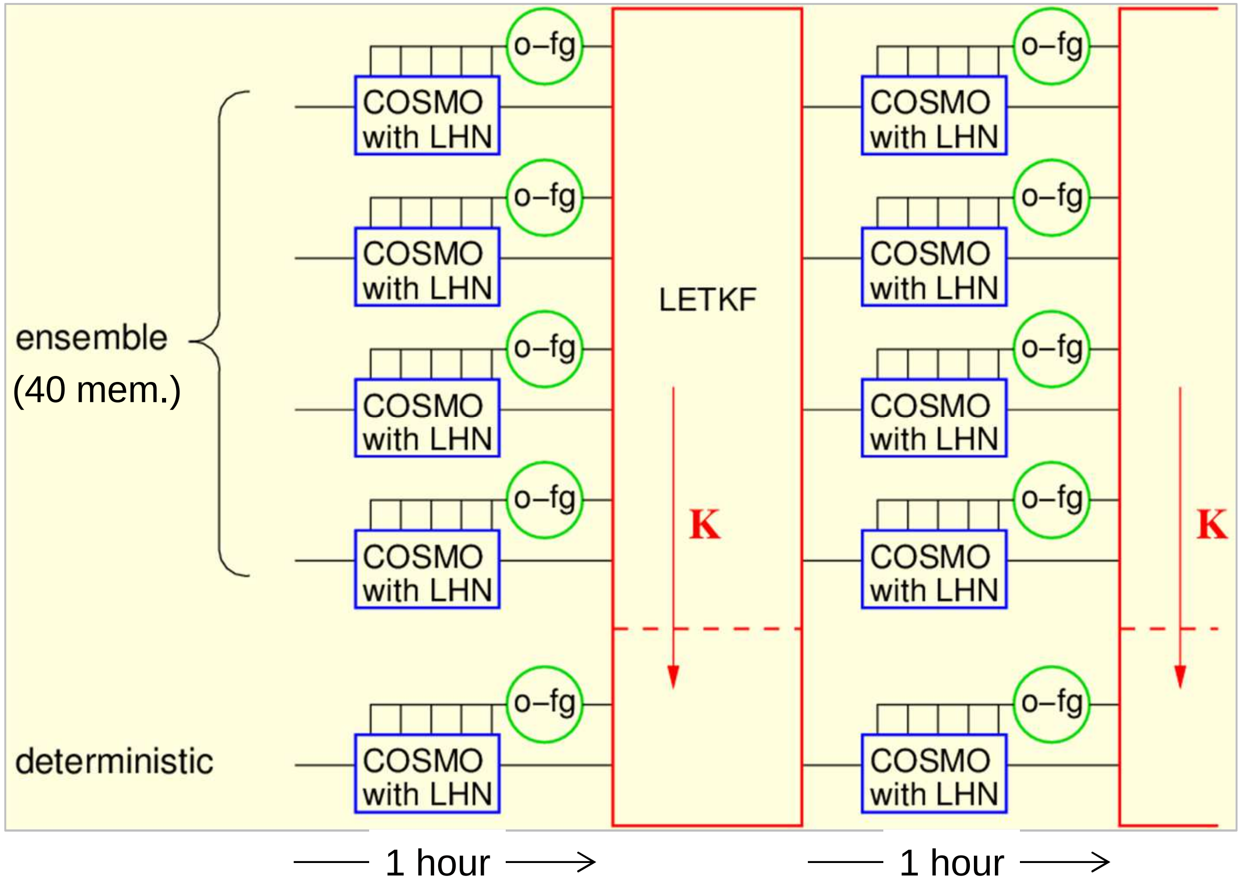
KENDA-LHN



→ benchmark:
Nudging + **LHN**

LETKF + LHN : new approach, does it work ?

KENDA-LETKF for deterministic forecasts: impact of LHN

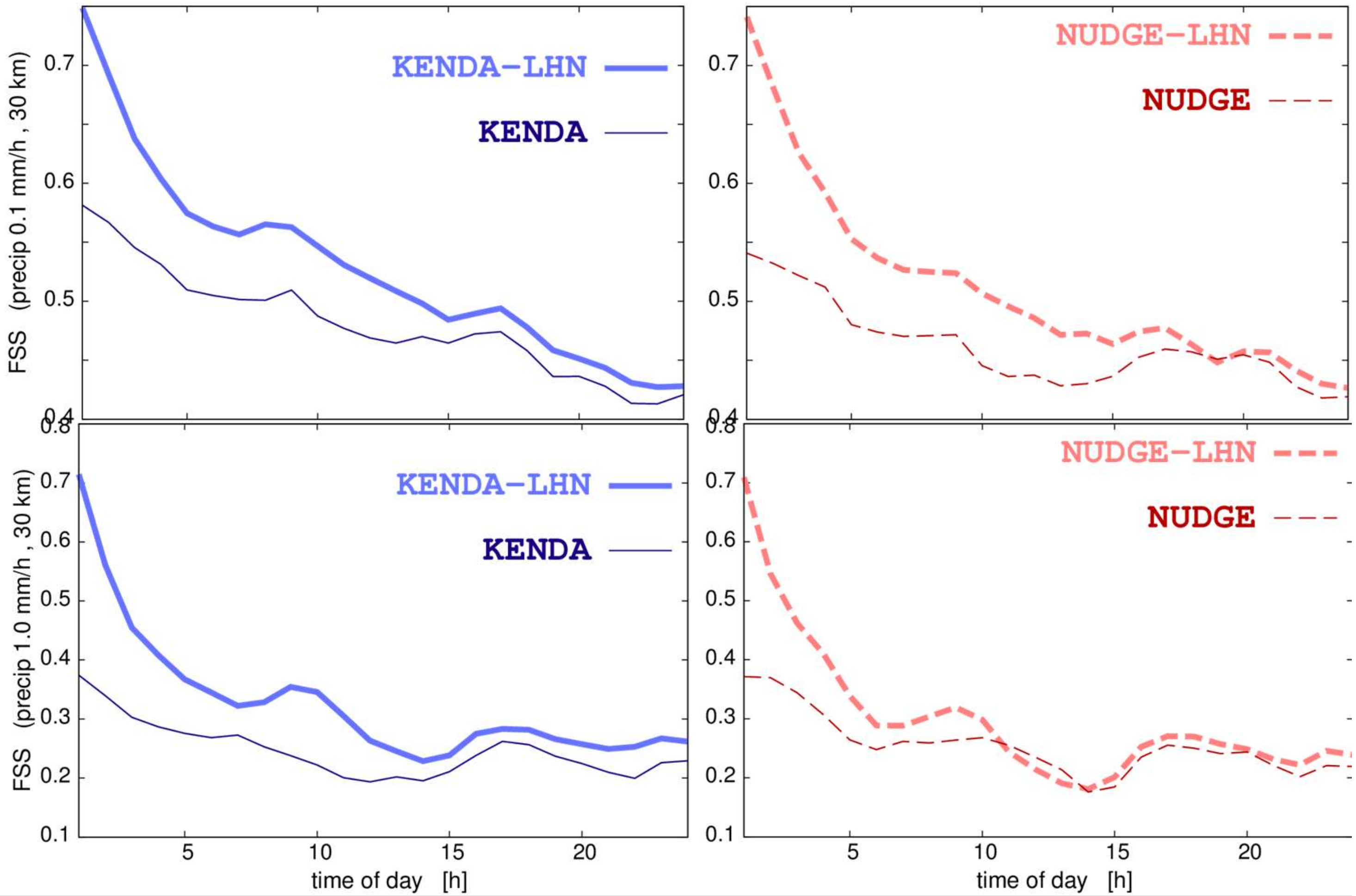
28 days
18.05. – 15.06. 2014

0.1 mm/h

0-UTC runs
precip FSS (30 km)

1 mm/h

LHN added to LETKF	LHN added to Nudging



- ✓ LHN added to LETKF: large, long-lived positive impact from LHN (except 12 UTC run)
- ✓ LHN added to nudging: less (long-lived) positive impact, particularly for higher thresholds

KENDA-LETKF for deterministic forecasts: comparison to Nudging

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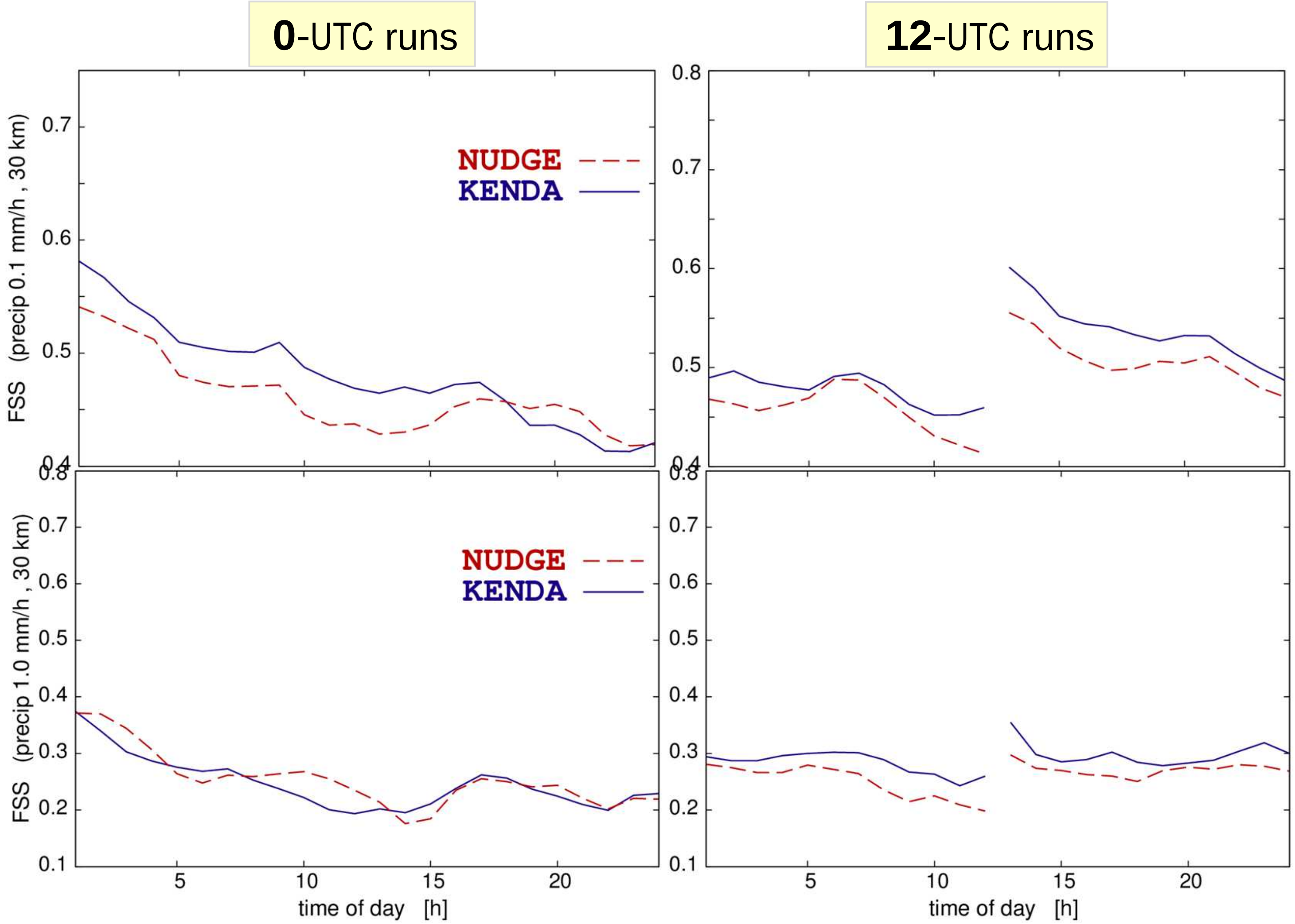
28 days
18.05. – 15.06. 2014

0.1 mm/h

precip FSS (30 km)

1 mm/h



✓ without LHN: usually long-lived advantage of KENDA over nudging

KENDA-LETKF for deterministic forecasts: comparison to Nudging + LHN

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28 days
18.05. – 15.06.
2014

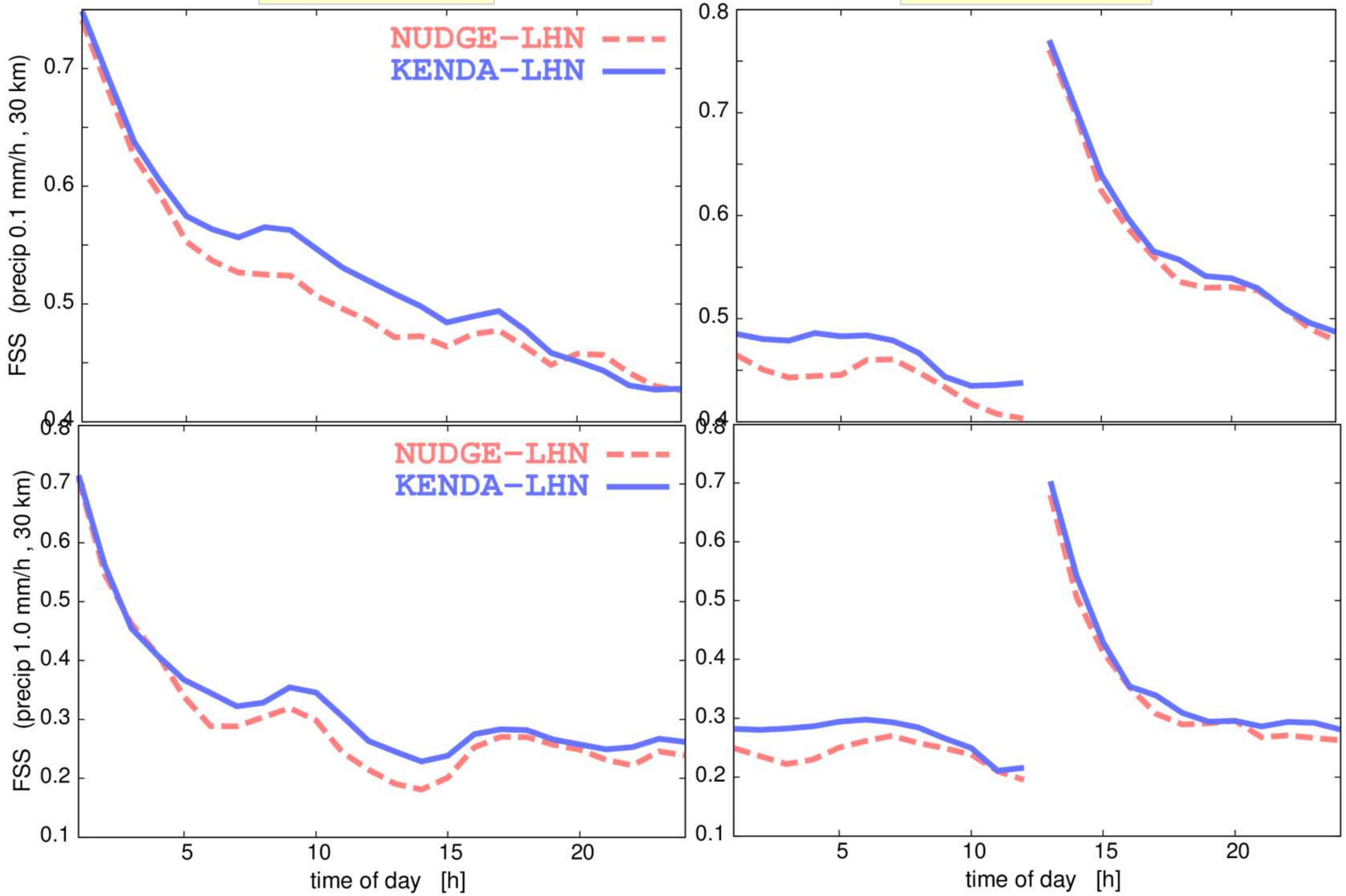
0-UTC runs

12-UTC runs

0.1 mm/h

precip FSS (30 km)

1 mm/h



- ✓ with LHN: small difference in first 4 hours due to dominating influence of LHN, thereafter, advantage of KENDA over nudging tends to be larger than without LHN

KENDA-LETKF for deterministic forecasts: comparison to Nudging + LHN

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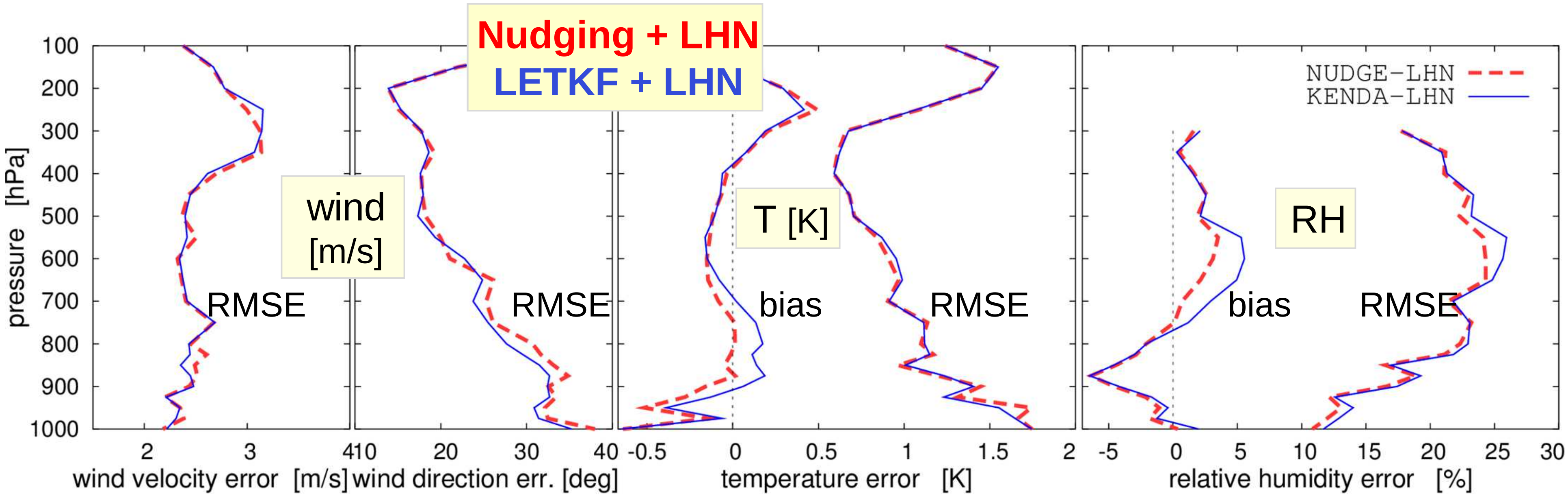
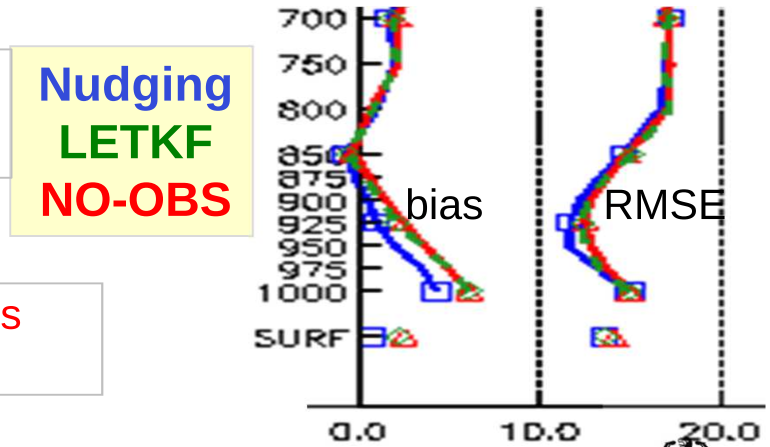
verification of **6-h** forecasts against radiosondes , 28 days (18.05. – 15.06. 2014)



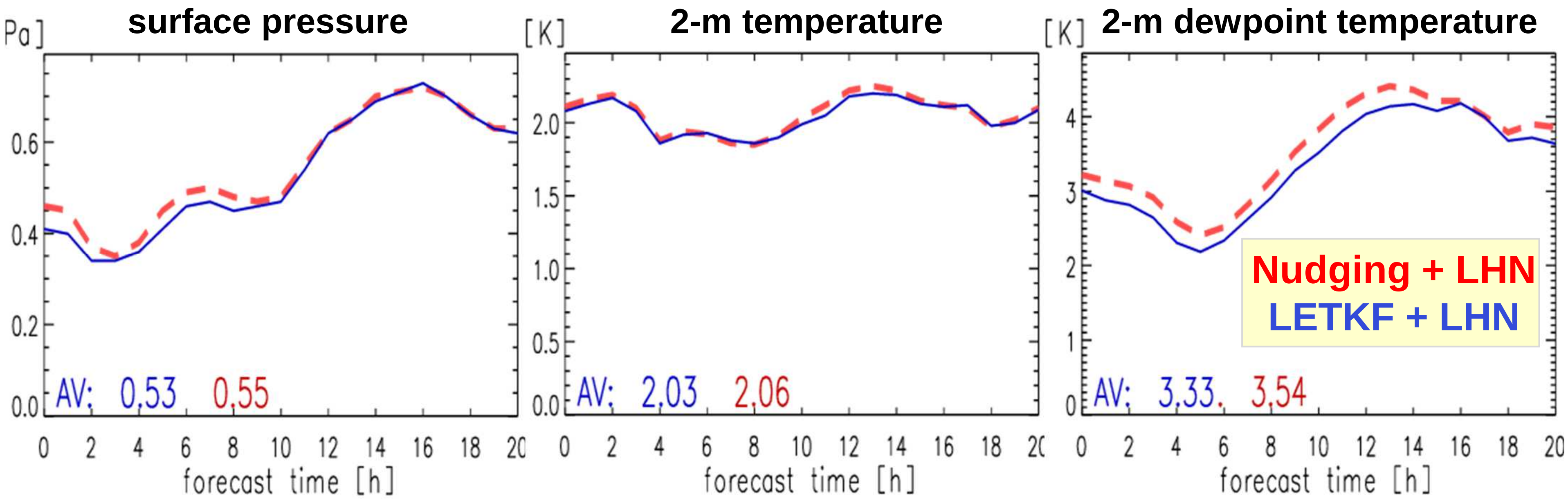
MeteoSwiss: 2 months (March + April 2015)



- ✓ LETKF: smaller wind errors, larger humidity errors
- ✓ LEKTF less able to correct (model) biases

KENDA-LETKF for deterministic forecasts: comparison to Nudging + LHN

SYNOP verification (RMSE) of **0-UTC** forecast runs , 28 days (18.05. – 15.06. 2014)



✓ LETKF: neutral or smaller errors, particularly pressure and humidity

DWD : **LETKF outperforms nudging** , in particular if both **combined with LHN**, in test periods (→ Schraff et al., QJRMS 2016, in press)

most critical criterion for operationability fulfilled (still more periods required)

remaining issues:

- upper-air humidity verifies slightly worse, mainly in PBL
  (also MeteoSwiss → talk by Leuenberger et al)
  - → should be investigated (non-Gaussianity of relative humidity ? sampling noise in LETKF cross-covariance ?)
  - → tolerable, considering benefits for other variables (precip !) (DWD)

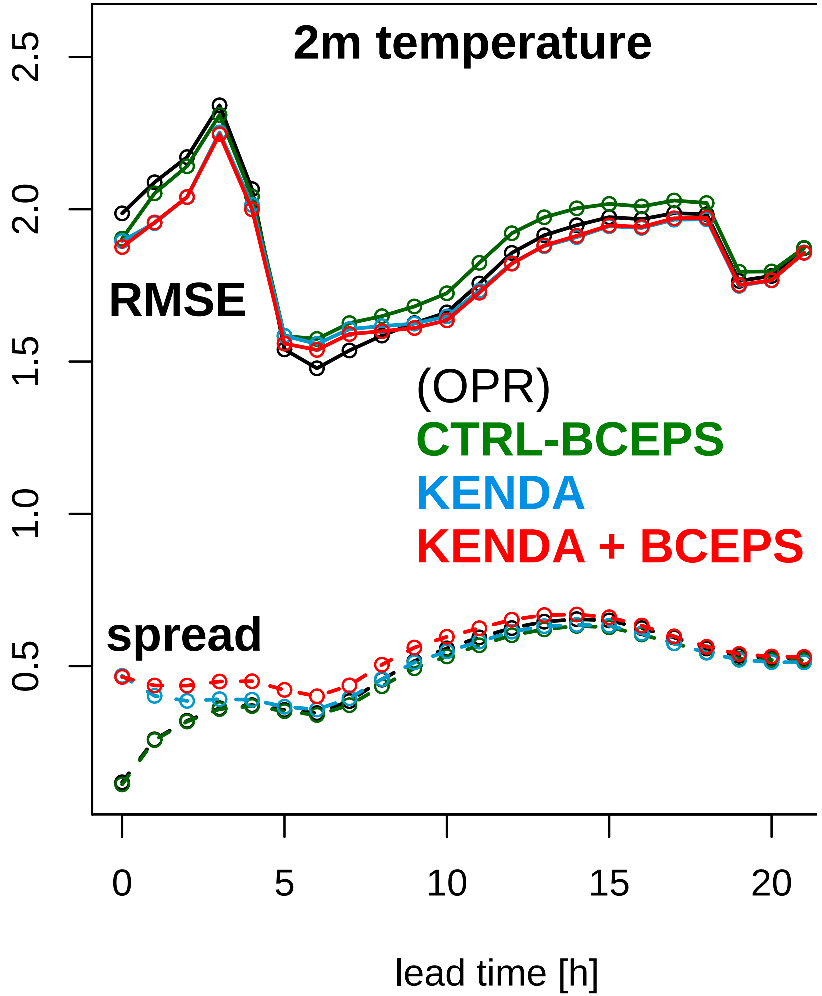
- LETKF less able than nudging to correct (temperature, humidity) model biases
  - → inherent, difficult to solve in LETKF
  - → needs improvement of model itself

OPR: IC: C-DE operational determin. analysis (nudging + LHN; LBC from 7km C-EU)
+ perturbations from 4 global models
LBC: BCEPS (reflecting 4 global models)

CTRL-BCEPS: as OPR, but
C-DE det. ana with LBC
from 40-km ICON-3DVar

KENDA : IC from KENDA (i.e. LBC
from 80-km ICON-LETKF
40-km ICON-3DVar)

KENDA + BCEPS: 15 IC from KENDA
+ 5 IC from reference 40km



- ✓ KENDA: smaller RMSE, initially larger spread than CTRL-BCEPS
- ✓ KENDA + BCEPS: even better

KENDA-LETKF for COSMO-DE-**EPS**

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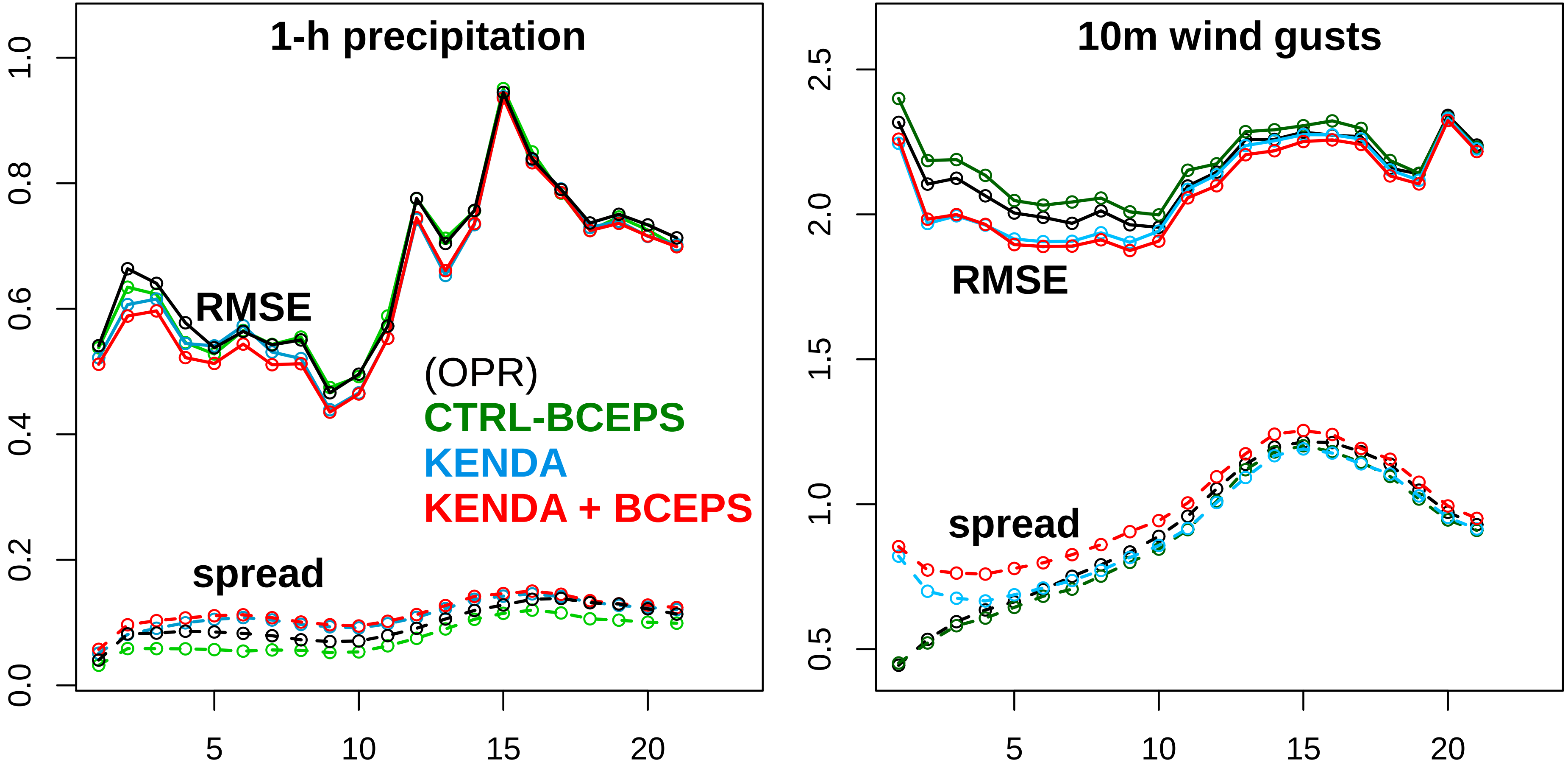

✓ KENDA + BCEPS > KENDA > CTRL-BCEPS

→ KENDA-IC better than IC from nudging + perturbations from global models, but adding a few members with perturbations from global models allows the EPS to cover a larger part of the true forecast uncertainty, without increasing forecast errors

DWD

- **parallel** (pre-operational) **suite** with KENDA for COSMO-DE in March / April 2016
  - DA cycle: LBC from operational ICON-EnVar 40km/ **20km** + det 13km/ **6.5km**
  - deterministic forecast
  - 20-mem. EPS, KENDA IC, LBC from ICON-EU-EPS
  - 20-mem. EPS, KENDA IC; LBC from BC-EPS (like COSMO-DE-EPS)
- KENDA **operational** (at least replacing nudging)
  in autumn 2016 or in 2017, dep. on IT (data base…) (and forecast quality)
- (COSMO-D2: postponed for technical reasons)

outlook: KENDA-O

main aim for next years:

increase quality of KENDA-4D-LETKF analyses + forecasts (deterministic + EPS)
particularly of cloud + precipitation in very SR (towards nowcasting)

→ increase use of high-resolution obs for convective scale
(cloud, precip, humidity, PBL, surface → remote sensing)

→ new project **KENDA-O**: Km-scale ENsemble-based Data Assimilation for high-resolution **O**bservations
(09/2015 – 08/2020)

high-resolution obs: GNSS Slant Total Delay (STD)
→ *Michael Bender (DWD/IAFE)*

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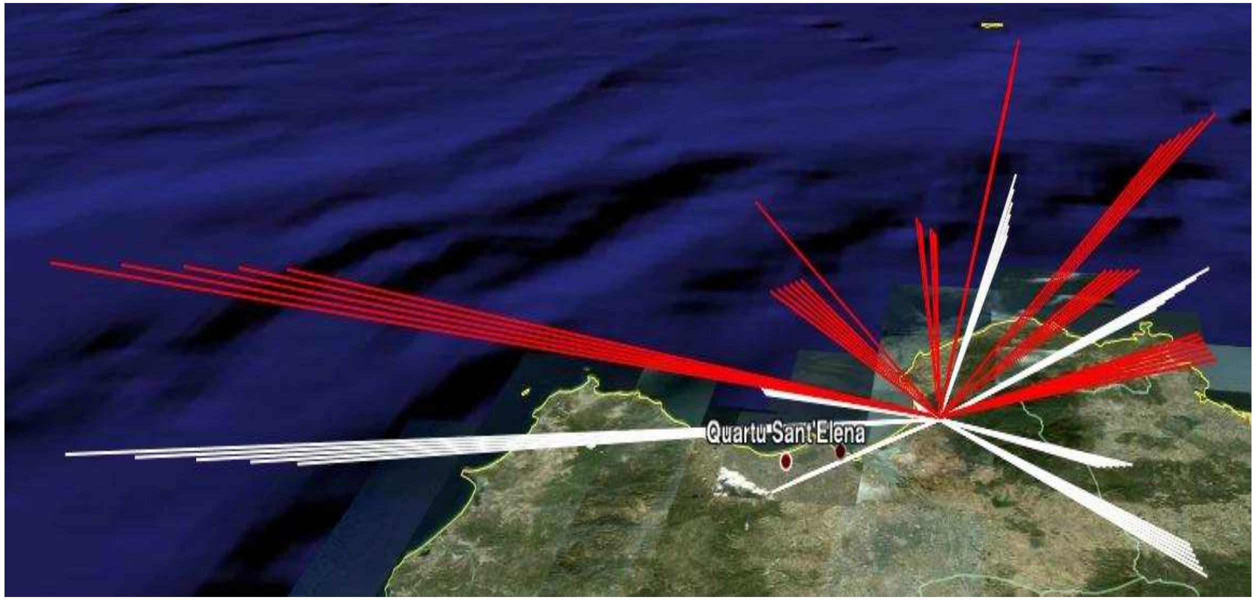
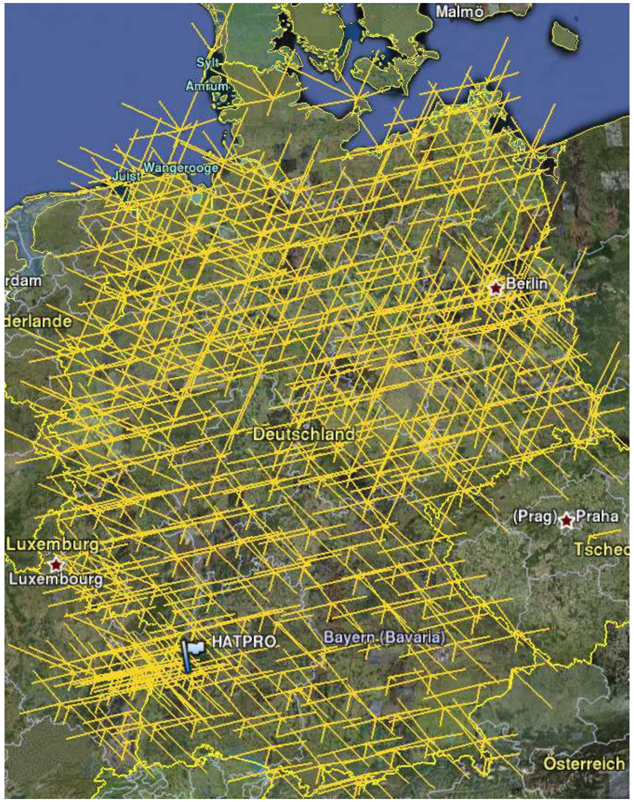
→ GNSS (GPS) Slant Path Delay : **humidity** integrated over path from ground station to GNSS (GPS) satellite, all weather obs

(45) GPS obs from 1 station / 9 satellites in 15 min.





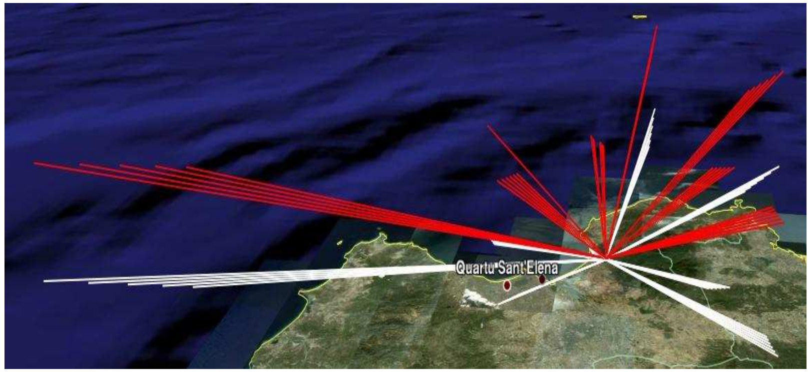
elevation angles 90° - 5

→ many stations → 3-D information on humidity, but !

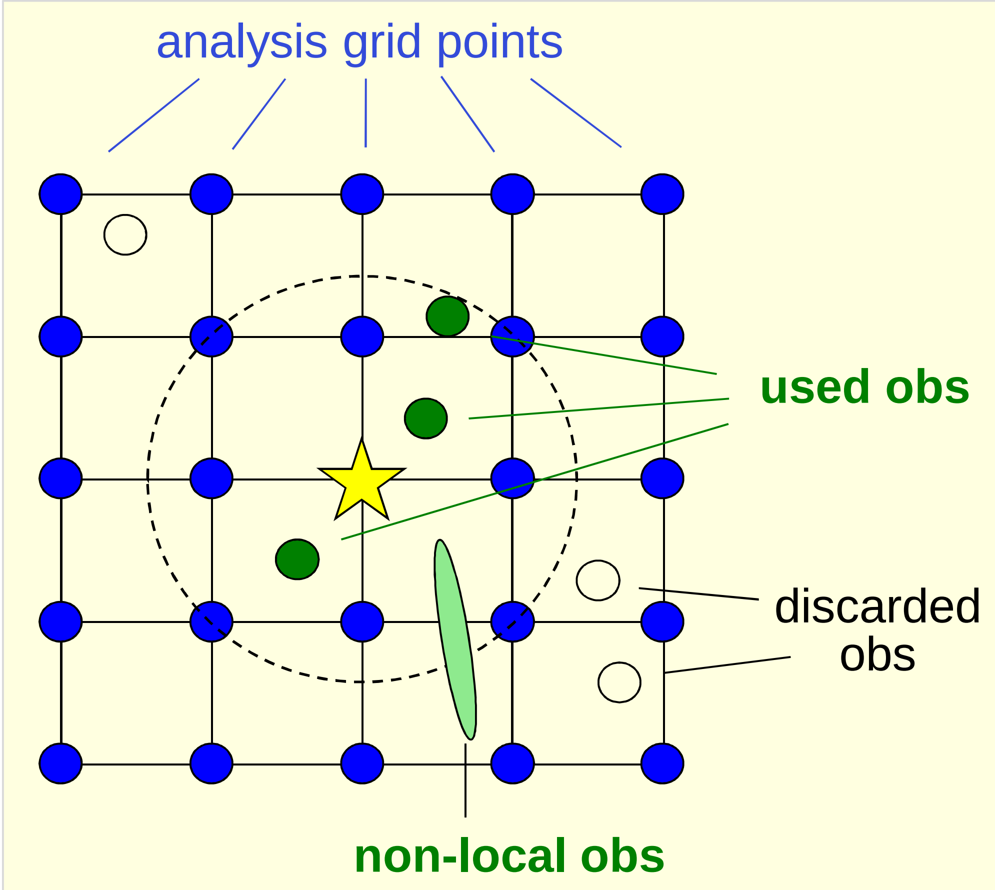
→ at 5° (7°), path reaches height of 10 km at ~ 100 (80) km distance

→ vert. + horiz. non-local obs (not point measurements)

Slant Total Delay :
humidity integrated over path
from ground station to satellite



elevation angles 90° - 5



→ vert. + horiz. non-local obs

→ difficult to use in LETKF:

explicit localization (doing separate analysis at every analysis grid point, select only obs in vicinity and scale $\mathbf{R}^{-1}$)

high-resolution obs:
GNSS-STD, first trial for use in KENDA

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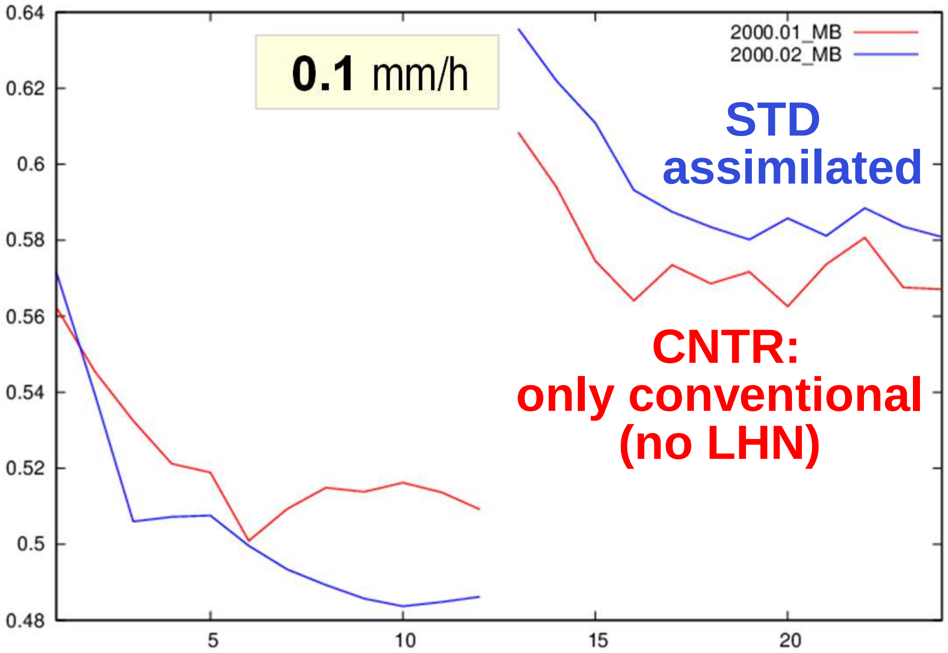
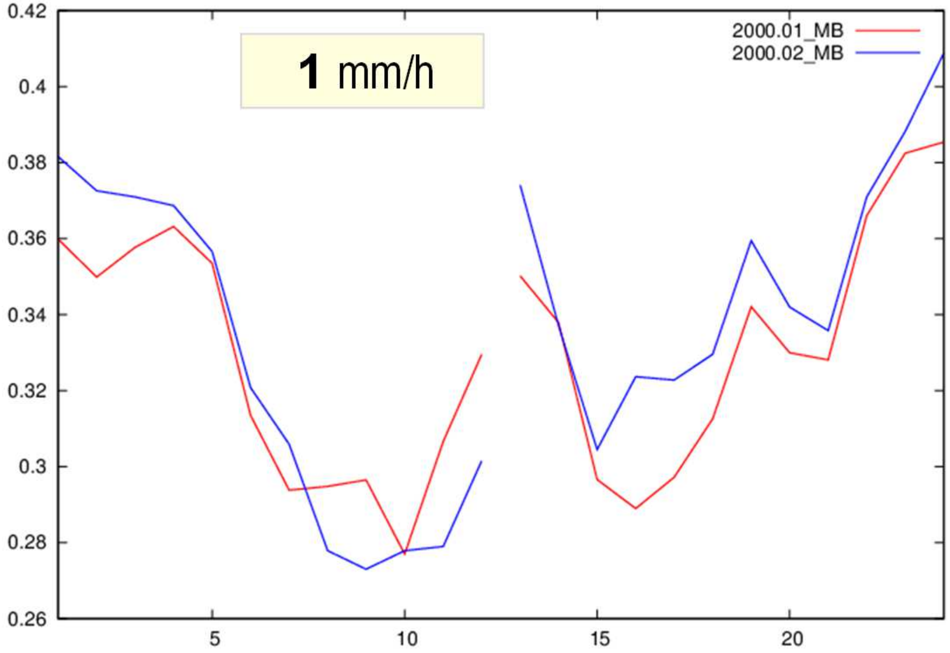
13 days
17. – 29.06.
2014

1-hrly precip
FSS
(30 km)

12-UTC
forecast runs

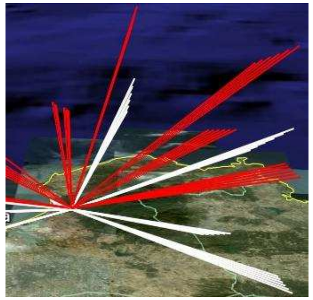




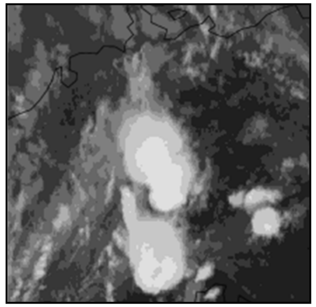
preliminary (!) results (no LHN):

- ✓ improved precip forecast in first 8 – 16 hours
- ✓ precip forecasts tend to be degraded for longer lead times

high-resolution obs
in the context of convection

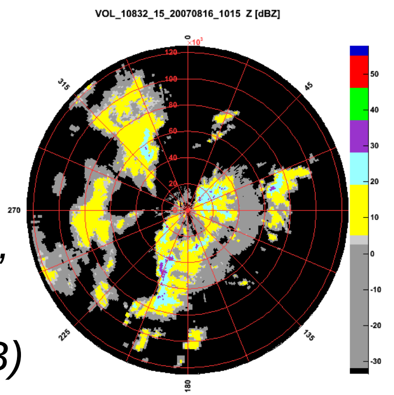


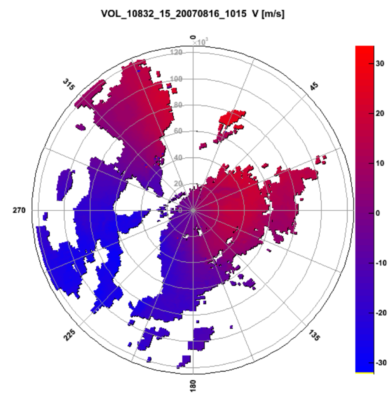
- pre-convective environment: no clouds
  → GNSS **Slant Total Delay** : humidity integrated over path from ground station to GNSS satellite, all weather obs
  → *Michael Bender (DWD/IAFE)*



- developing convection: clouds
  → cloud top height from satellite data (Meteosat / SEVIRI)
  → **cloudy SEVIRI** radiances (**IR** window + **WV** channels)
  → *Axel Hutt (DWD/IAFE) ; Florian Harnisch (LMU/HErZ)*
  (some positive impact on cloud / radiances)

- mature convection: precipitation
  → **radar**: 3-dim. **reflectivity**
  3-dim. **radial velocity**
  → *Elisabeth Bauernschubert (DWD/IAFE),*
  Virginia Poli (ARPAE-SIMC) → talk
  (until March: Theresa Bick (DWD/MIUB)



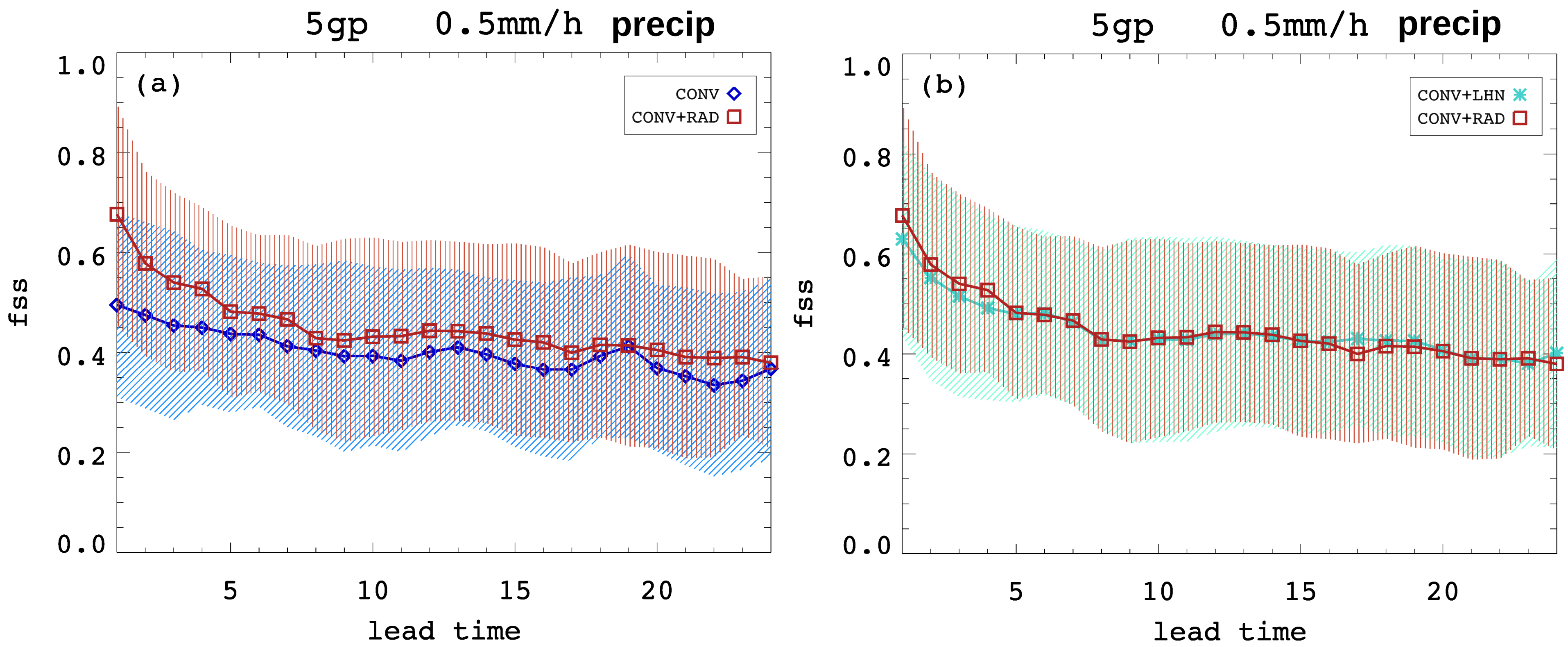


7 days / 29 forecasts
(22 – 29 May 2014)

CONV
CONV + RAD

FSS precip
– ens. mean
– std dev.

CONV + LHN
CONV + RAD



- ✓ rather large, long-lived positive impact from use of radar reflectivity in LETKF
- ✓ use of radar reflectivity in LETKF slightly better than LHN in first 4 hours

Outlook: KENDA-O

- (high-res) observations
  - 3D radar radial velocity + 3D radar reflectivity
  - GPS Slant Path Delay
  - direct use of cloudy SEVIRI IR window + WV channels (for cloud info) / Cloud Top Height (CTH) derived from SEVIRI
  - screen-level observations (q2m, T2m, uv10m) → poster by Tobias Necker
  - Mode-S (aircraft high-resolution) wind + temperature (LMU: Lange & Janjic, QJ 2015)
  - ground-based remote-sensing (microwave radiometer, lidar (wind, Raman), …)
  - AMSU-A, ATMS, IASI
- satellite soil moisture for soil moisture analysis (in LETKF) (Cardinali, COMET)
- refine 4D-LETKF (e.g. additive covariance inflation, multi-scale DA (variable localis.),…)
- to address non-Gaussianity: Particle Filters (PF) + hybrid LETKF-PF
- KENDA for ICON-regional: porting from COSMO to ICON (start 2017)