Recent Results in the KENDA Project

Deutscher Wetterdienst DWD

Christoph Schraff

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… and many colleagues from CH, D, I, ROM, RU …
… in particular Hendrik Reich, Theresa Bick (DWD), Daniel Leuenberger (MCH)

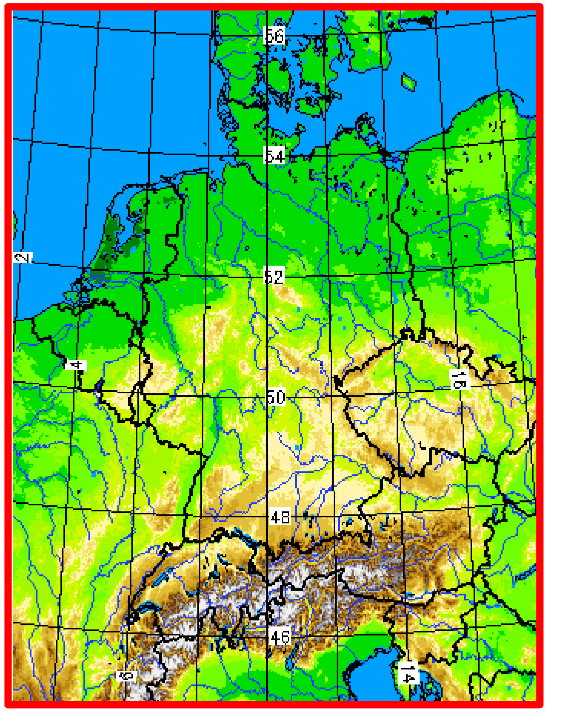
- **K**m-scale **EN**semble-based **D**ata **A**ssimilation : COSMO priority project
- Local Ensemble Transform Kalman Filter (LETKF) system being developed

talk outline:

- LETKF exp. using conventional obs (radiosonde, aircraft, windprof, surface), comparison to nudging (+ LHN: Latent Heat Nudging for assimil. radar precip)
- brief overview on use of high-res obs (radar, cloudy satellite, …)

DWD

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

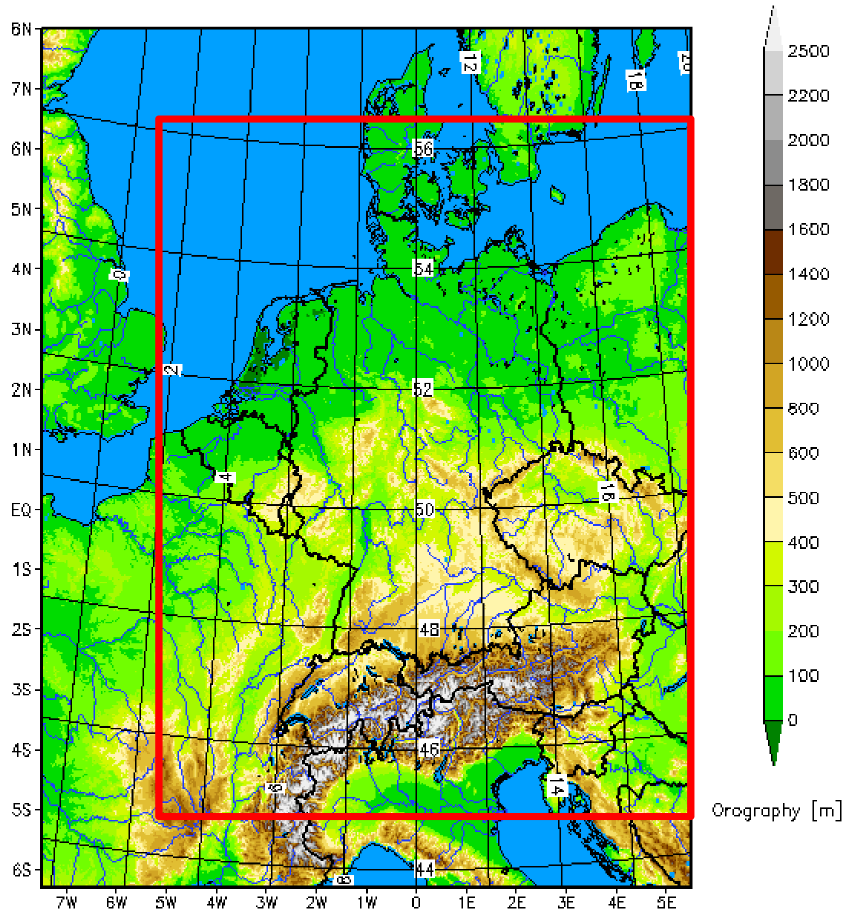


DWD

- 1st goal: replace nudging + LHN with deterministic LETKF analysis
  for COSMO-DE (Δx = 2.8 km)
  / COSMO-D2 (Δx = 2.2 km)
  (operational in summer/autumn 2016)

→ main task for operation-ability:

quality of deterministic forecast
from KENDA (using conventional obs)
as good as nudging + LHN



DWD

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  for COSMO-DE (Δx = 2.8 km)
  / COSMO-D2 (Δx = 2.2 km)
  (operational in summer/autumn 2016)

  → for operation-ability: quality of deterministic fcst. as good as nudging + LHN

  → test period 28 days (18 May – 15 June 2015 : 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)

  → encouraging results

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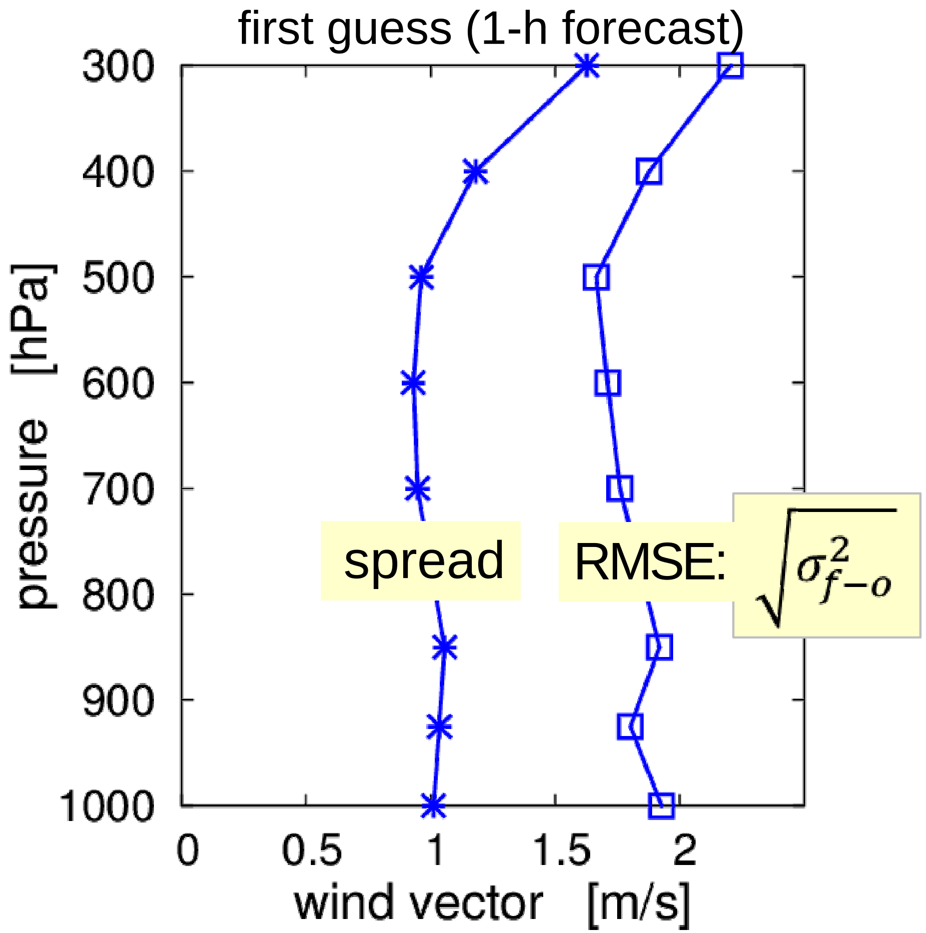
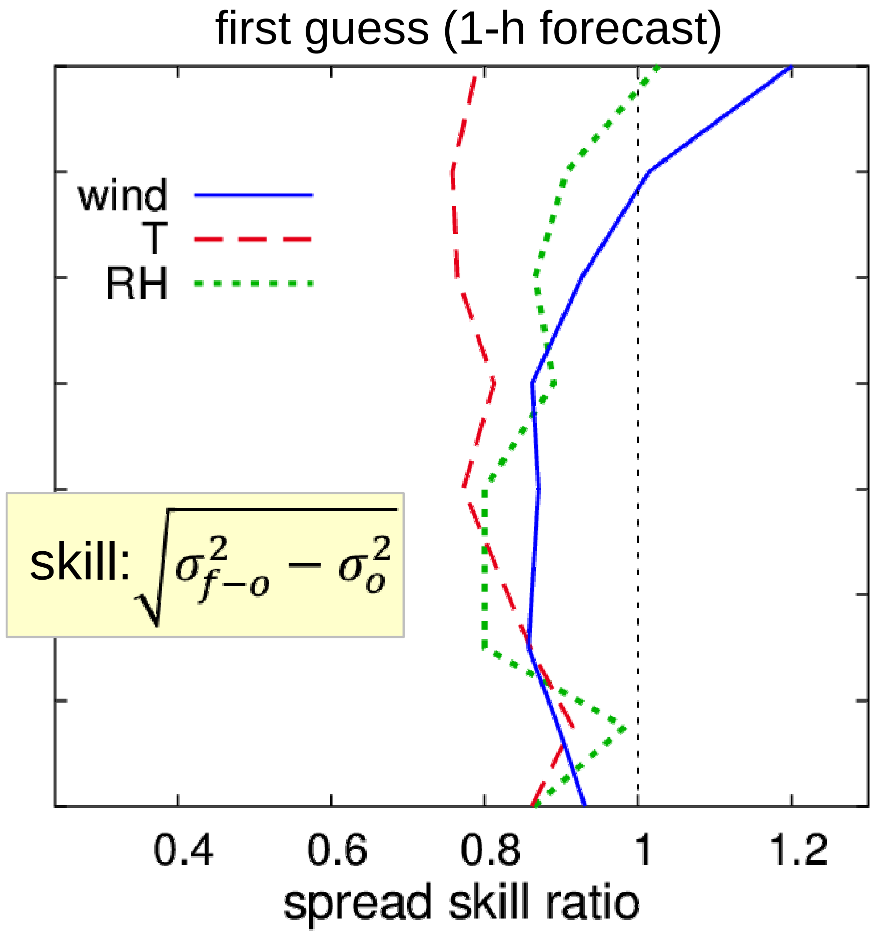
LETKF with adaptive multiplicative cov. inflation + RTPP + soil moisture perturb.

(6-day period in July 2012)

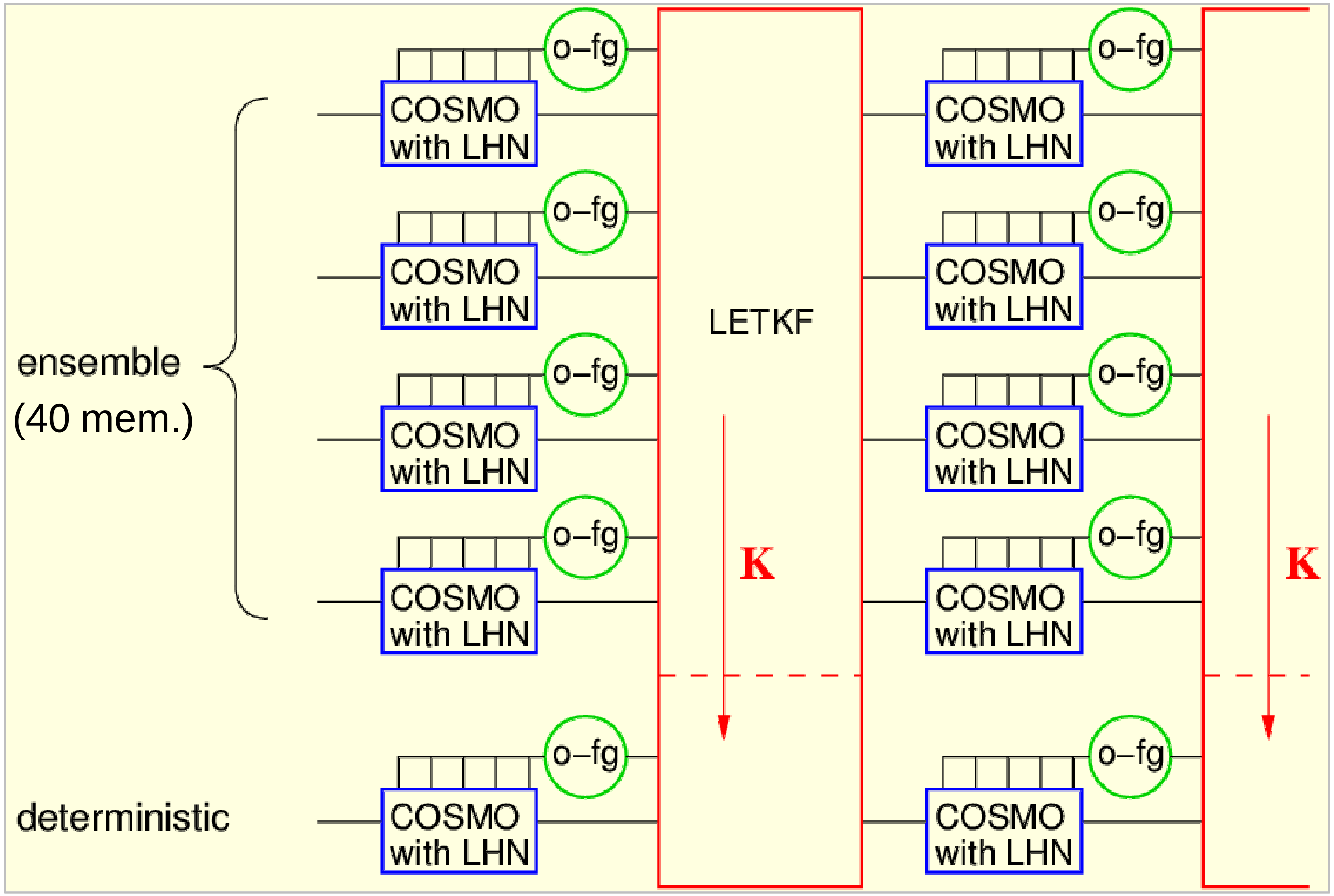




✓ spread-skill ratio of LETKF first guess mostly within 0.8 – 1.0 if (diagnosed) observation errors taken into account

LETKF: main development + testing
LHN added to LETKF

KENDA-LHN



→ **4D** –LETKF

→ **K**: Kalman Gain for ensemble mean

→ benchmark: Nudging + LHN

→ LHN also applied in ensemble: positive for deterministic forecast

→ LHN influences first guess ensemble perturbations and hence LETKF estimation of first guess error (“B-matrix”) positively

LETKF: main development + testing
impact of LHN added to LETKF

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DWD

28 days
18.05. – 15.06.
2014

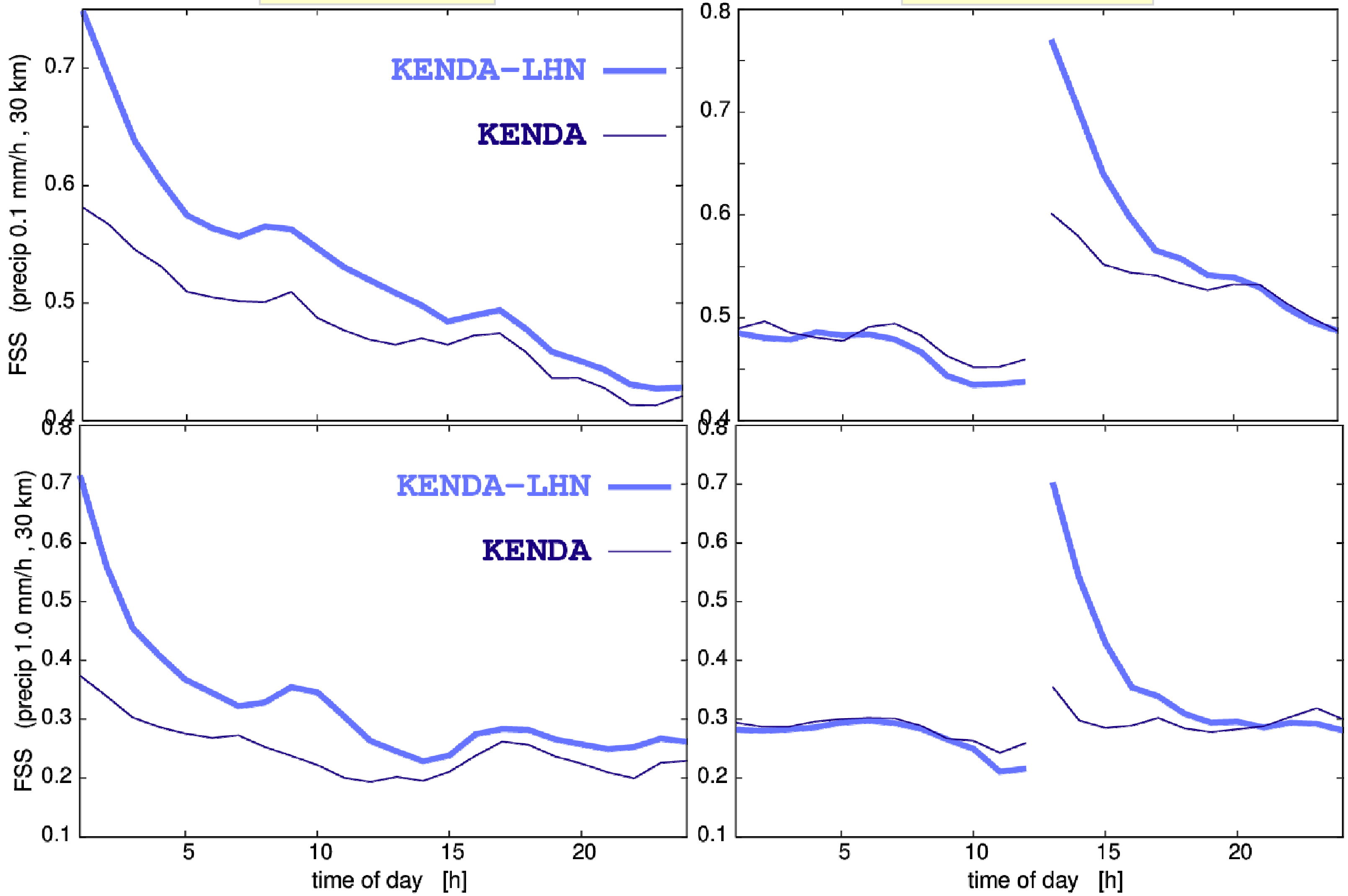
0.1 mm/h

precip
FSS
(30 km)

1 mm/h

0-UTC runs

12-UTC runs



✓ large, long-lived positive impact from LHN (except 12 UTC run)

LETKF: main development + testing
impact of LHN added to Nudging

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28 days
18.05. – 15.06. 2014

precip FSS (30 km)

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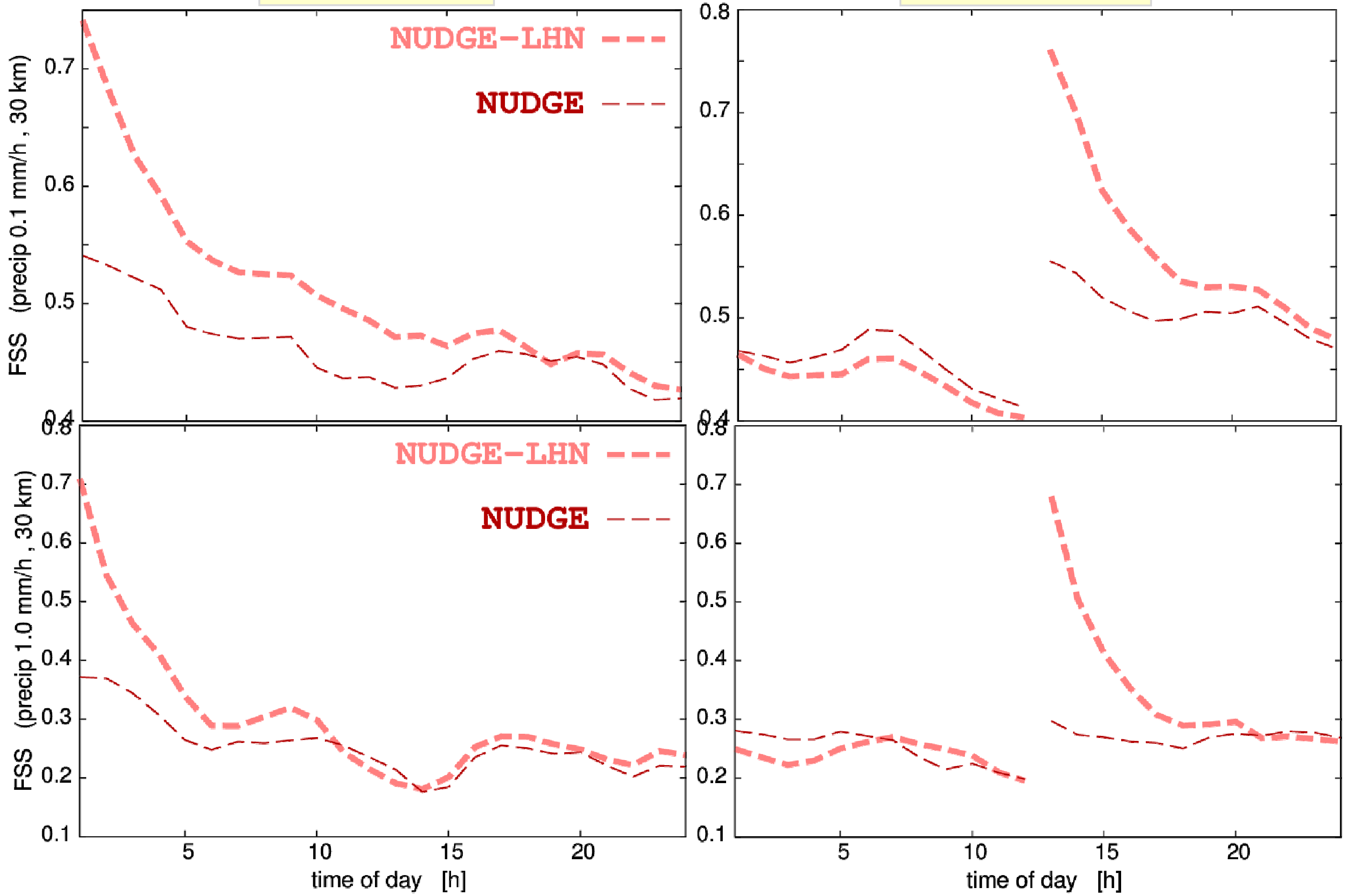

✓ combined with nudging, LHN has less long-lived positive impact and generally less impact for higher threshold (except 12 UTC run)

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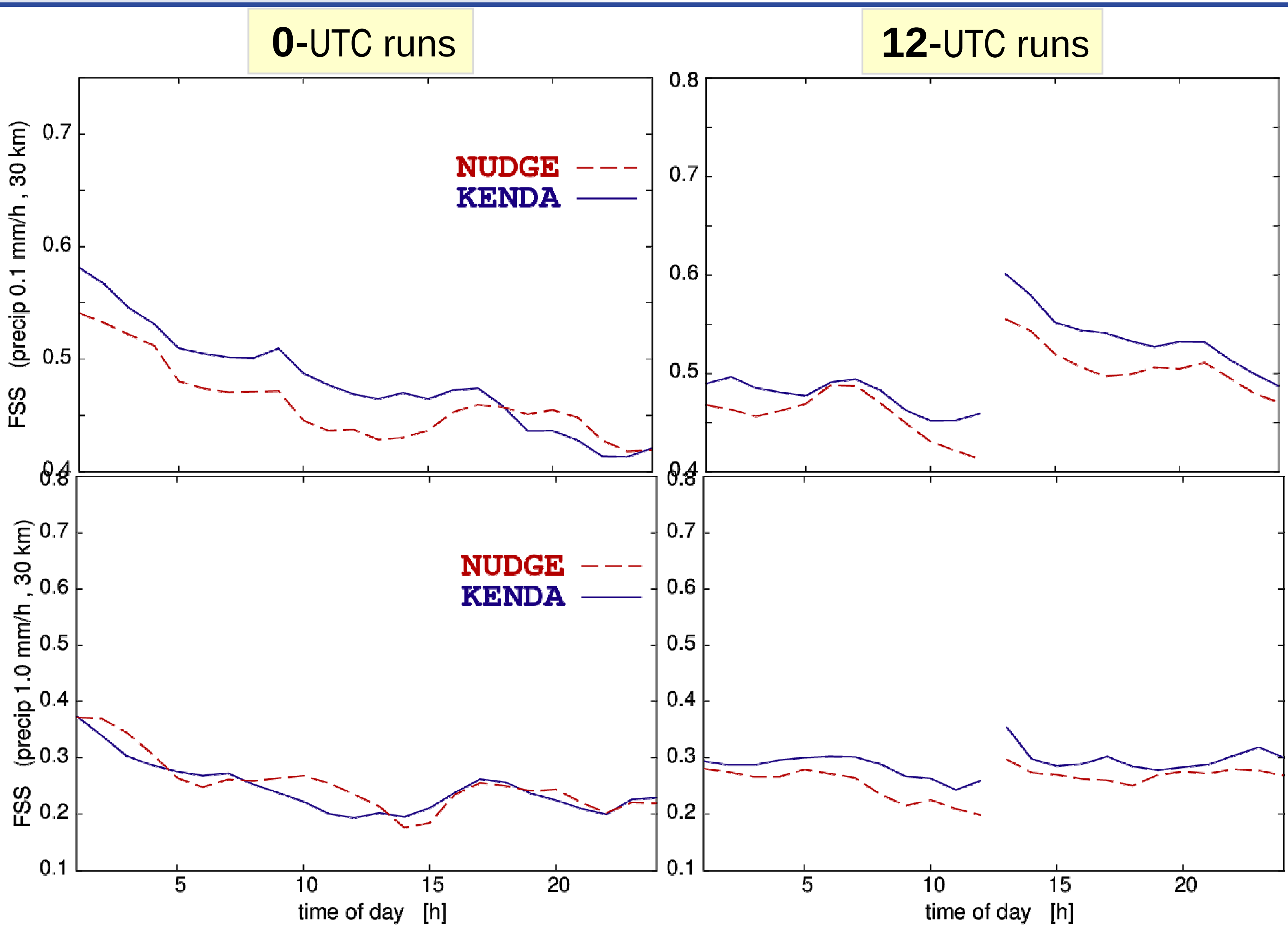
28 days
18.05. – 15.06.
2014

0.1 mm/h

precip FSS (30 km)

1 mm/h



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

LETKF: main development + testing comparison to Nudging + LHN

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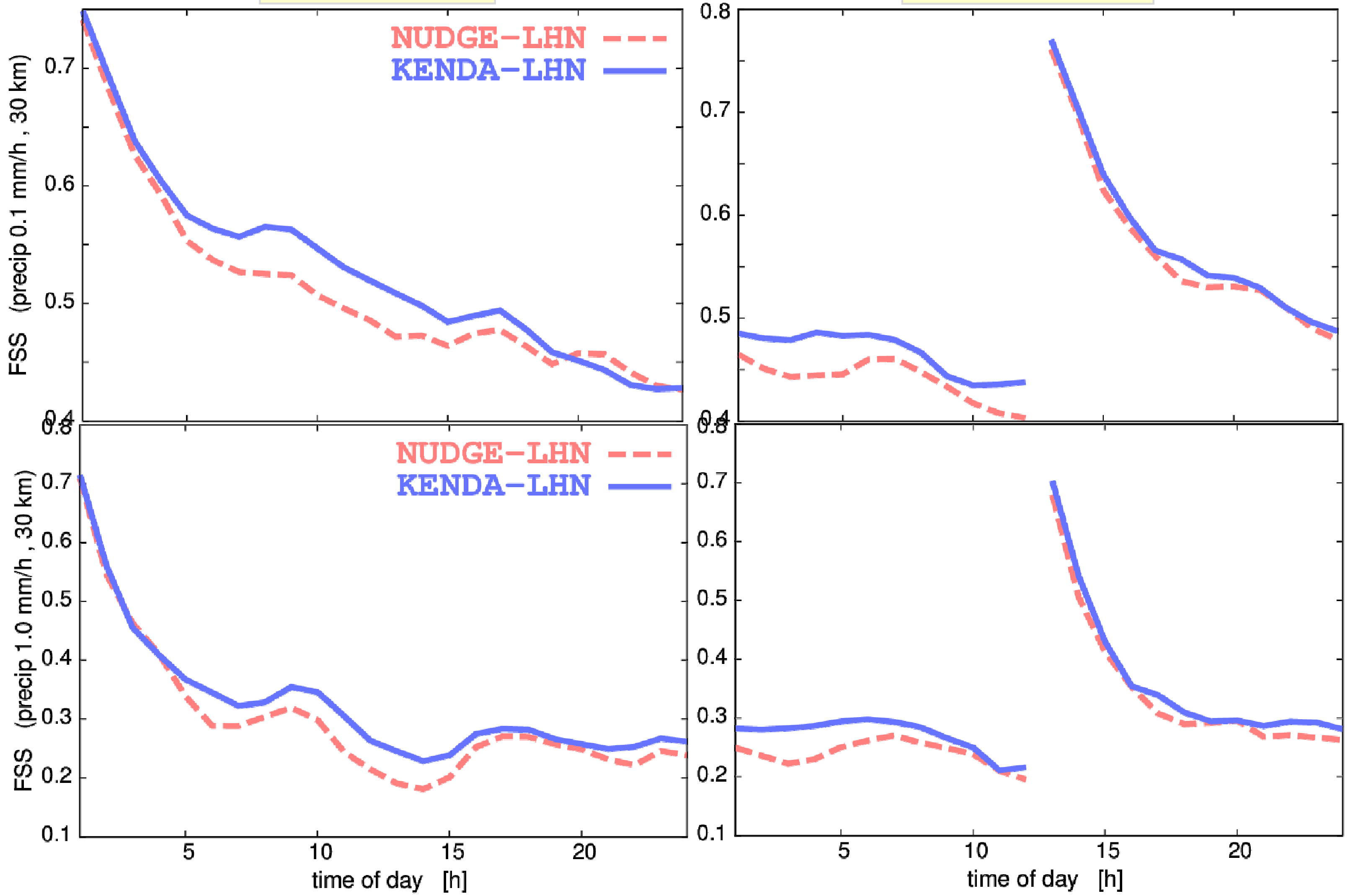
28 days
18.05. – 15.06. 2014

precip FSS (30 km)

0-UTC runs | **12**-UTC runs

0.1 mm/h

1 mm/h

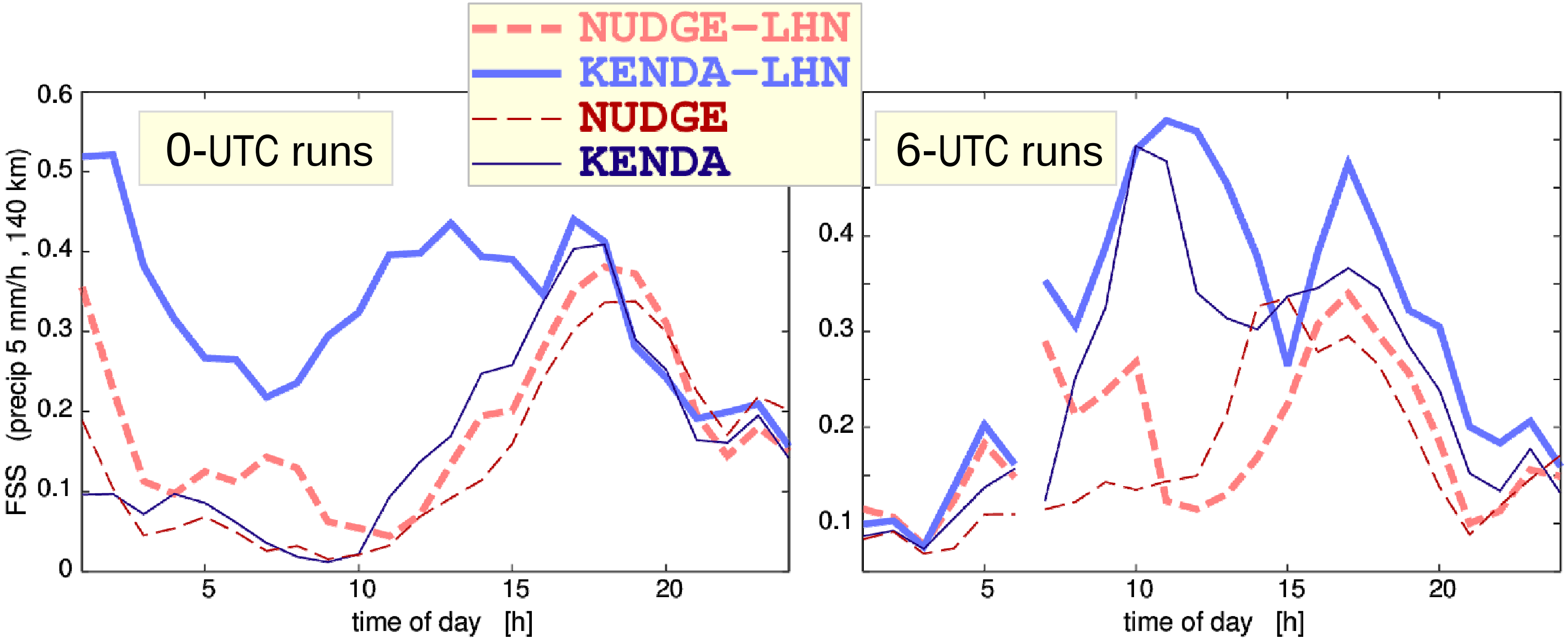


✓ with LHN: small difference in first 4 hours due to dominating influence of LHN, thereafter, advantage of KENDA over nudging tends to be larger than without LHN

28 days
18.05. – 15.06.
2014

examples where KENDA + LHN is even more clearly better:
high threshold 5 mm/h

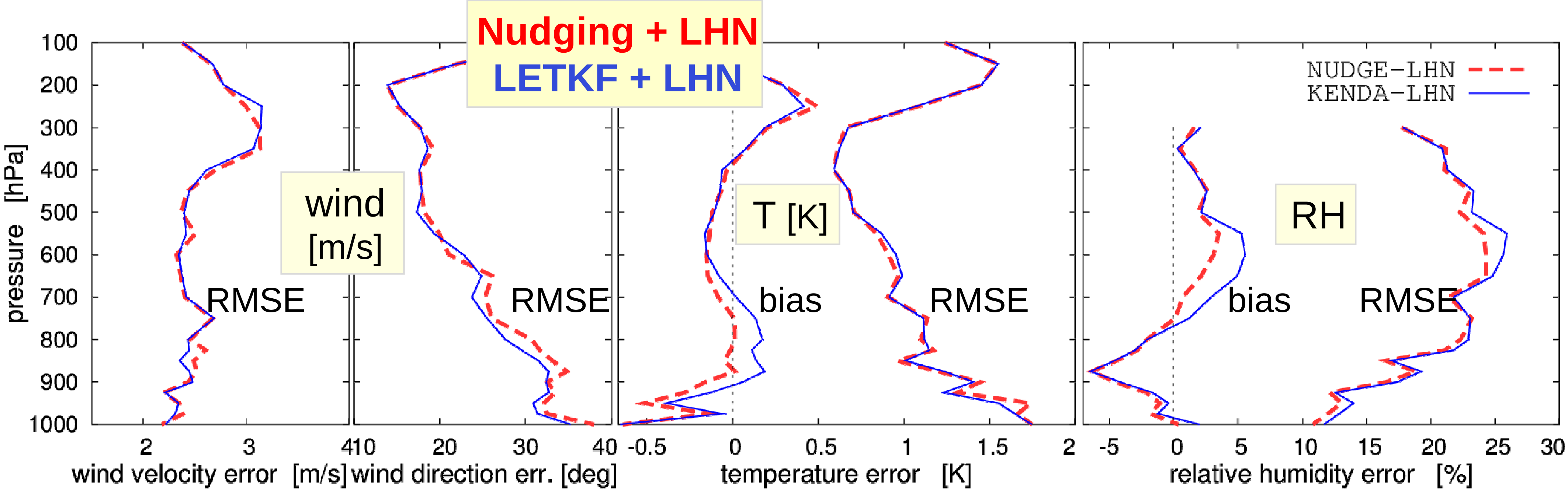
1-hrly precip
FSS
(140 km ,
5 mm/h)



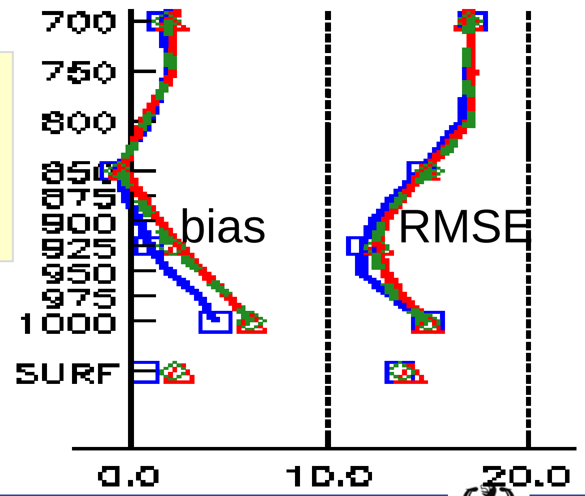
LETKF: main development + testing
comparison to Nudging + LHN

- applying LHN also to ensemble better than applying it only to deterministic run
  - → main difference: B-matrix of LETKF is influenced only in KENDA-LHN
- LHN has more (longer-lasting) benefit if combined with LETKF than with nudging
  - → main difference: LHN influences B-matrix in LETKF, but not weighting functions in nudging

→ LHN tends to influence B-matrix of LETKF positively (rather than adversely) verification of **6-h** forecasts against radiosondes , 28 days (18.05. – 15.06. 2014)



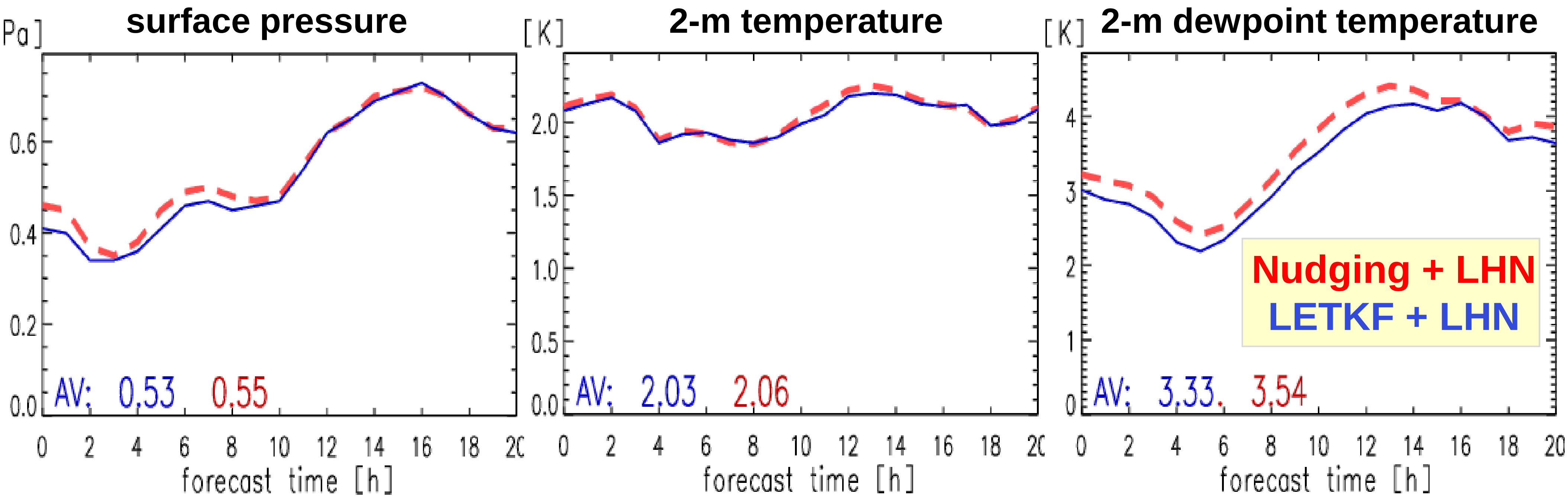
MeteoSwiss: 2 months (March + April 2015)



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

LETKF: main development + testing comparison to Nudging + LHN

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



- ✓ LETKF: smaller errors, particularly pressure and humidity
- ✓ (also slightly smaller error for 10-m wind, neutral for cloud cover)

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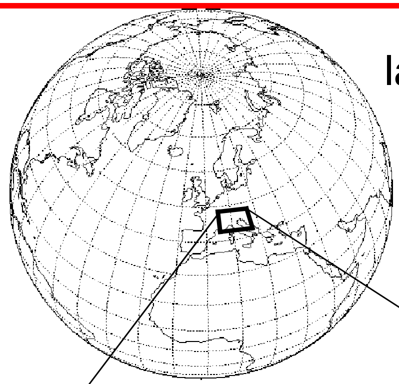
DWD : **LETKF outperforms nudging** , in particular if both **combined with LHN**, in test periods (→ KENDA paper submitted to QJRMS)

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

remaining problems:

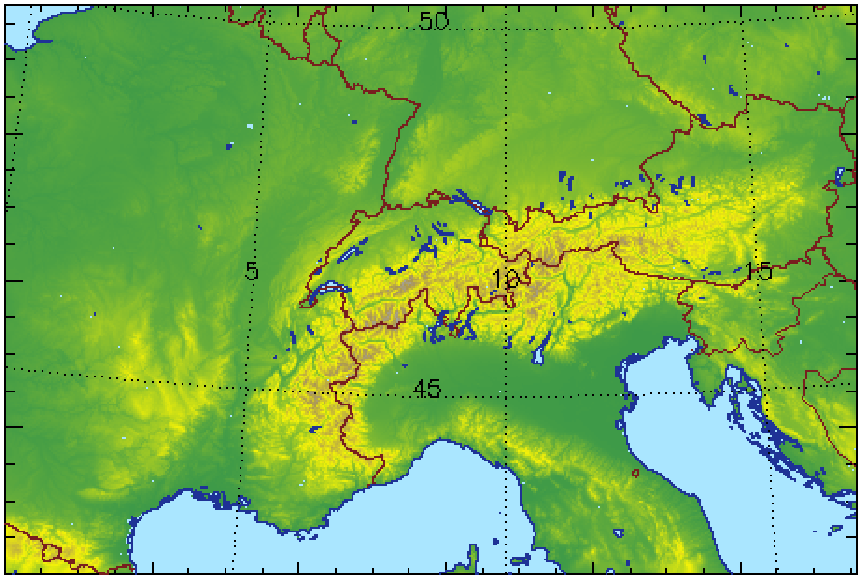
- upper-air humidity verifies slightly worse, mainly in PBL
  - → should be investigated (non-Gaussianity of relative humidity ? sampling noise in LETKF cross-covariance ?)
  - → tolerable, considering benefits for other variables (precip !) (DWD)
- LETKF less able than nudging to correct (temperature, humidity) model biases
  - → inherent, difficult to solve in LETKF
  - → needs improvement of model itself

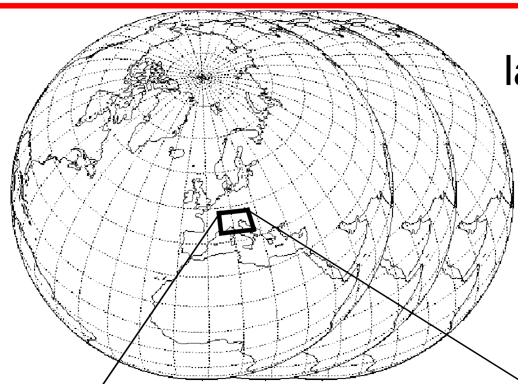
Next Generation MeteoSwiss NWP System



lateral BCs:
IFS-HRES
8-10km
4x per day

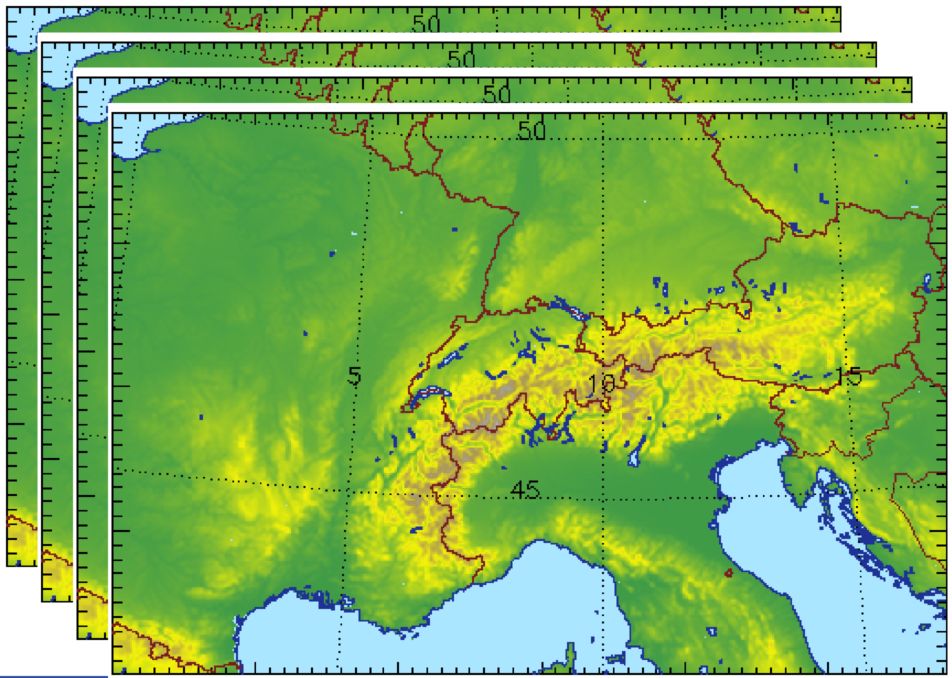
COSMO-1: **24h forecasts, 8x per day**
1.1km grid size (convection permitting)





lateral BCs:
IFS-ENS
20km
4x per day

COSMO-E: **5 day forecasts, 2x per day**
2.2km grid size, 21 ensemble members



KENDA development at MeteoSwiss
→ *Daniel Leuenberger, Simon Förster, André Walser*

- use of KENDA for IC for:
  - COSMO-E: plans to use KENDA IC when going operational in Spring 2016
  - deterministic COSMO-1 (but will first use nudging IC)

- real-time LETKF assimilation cycle:
  - Δx = 2.2 km (40 memb. + det. analysis) since mid Jan. 2015 , runs very stably’
  - Δx = 1.1 km deterministic analysis since end August 2015

- test forecasts (March + April 2015)
  - deterministic **2.2 km** forecasts:
    performance similar to nudging (+ wind, + precip, - humidity, - T-bias)
  - COSMO-E ensemble forecasts started from KENDA:
    compare mostly favourably to those downscaled from IFS-ENS (reduced spin-up)

- recent test forecasts in summer (1.5 months)

  → performance worse than nudging, too little precip

DWD: LETKF outperforms nudging

MeteoSwiss: mostly neutral for deterministic forecast in spring, negative in summer

→ possible reasons for different performance (being investigated at MCH):

- test period (summer period with little advection vs. regular spring / summer)
- lateral boundary conditions (ICON-LETKF vs. IFS)
- model configuration + domain (smaller at MCH)
- soil moisture perturbations, soil state, …

LETKF, high-resolution obs

- **GPS slant path delay** *(Bender)*
  - → obs operator implemented, technically ready for DA experiments
- **direct use of satellite radiances for assimilation of cloud info** *(Perianez)*
  - → prelim. DA exp. over few days : benefit for f.g. simulated radiances
- **cloud top height (CTH) derived from satellite (SEVIRI) data** *(Schomburg)*
  - → sensitivity tests and impact studies for low-stratus periods : some positive impact on forecast of cloud cover, sometimes long lasting
- **3-D radar radial velocity + reflectivity Z** *(Zeng ; Bick)*
  - → tuning, sensitivity tests with LETKF , impact studies (on Z)

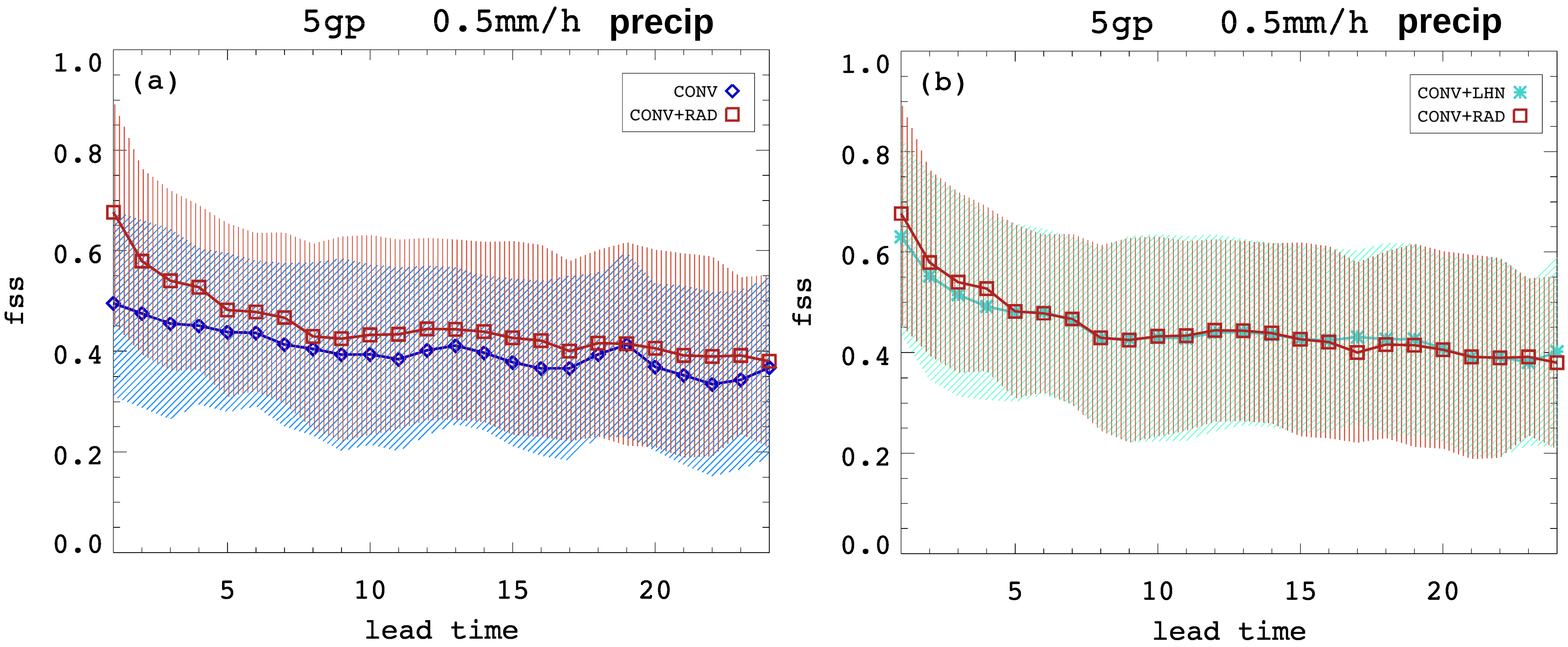
LETKF: use of radar reflectivity impact study → *Theresa Bick et al.*

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

FSS precip
– ens. mean
– std dev.

CONV
CONV + RAD

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

The end of project KENDA …

… but not end of the KENDA system !

Thanks to:

Hendrik Reich, Andreas Rhodin, Roland Potthast, Klaus Stephan, Ulrich Blahak, Yuefei Zeng, **Theresa Bick** , Annika Schomburg, Africa Perianez, Michael Bender, … (DWD)

Daniel Leuenberger, Simon Förster, André Walser, Alexander Haefele (MeteoSwiss)

Chiara Marsigli, Virginia Poli, Tiziana Paccagnella (ARPA-SIM)

Lucio Torrisi, Francesca Marcucci (CNMCA)

Amalia Iriza (NMA)

Mikhail Tsyrulnikov, Dmitri Gayfullin (HMC) 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
(5 years)

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 (T2m, q2m, uv10m)
  - Mode-S (high-resolution) wind and temperature data (from aircraft).
  - ground-based remote-sensing (microwave radiometer, lidar (wind, Raman), …)
  - AMSU-A, ATMS, IASI
- satellite soil moisture for soil moisture analysis (in LETKF)
- 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

Outlook: KENDA-O

LETKF: main development + testing
impact of LHN added to LETKF

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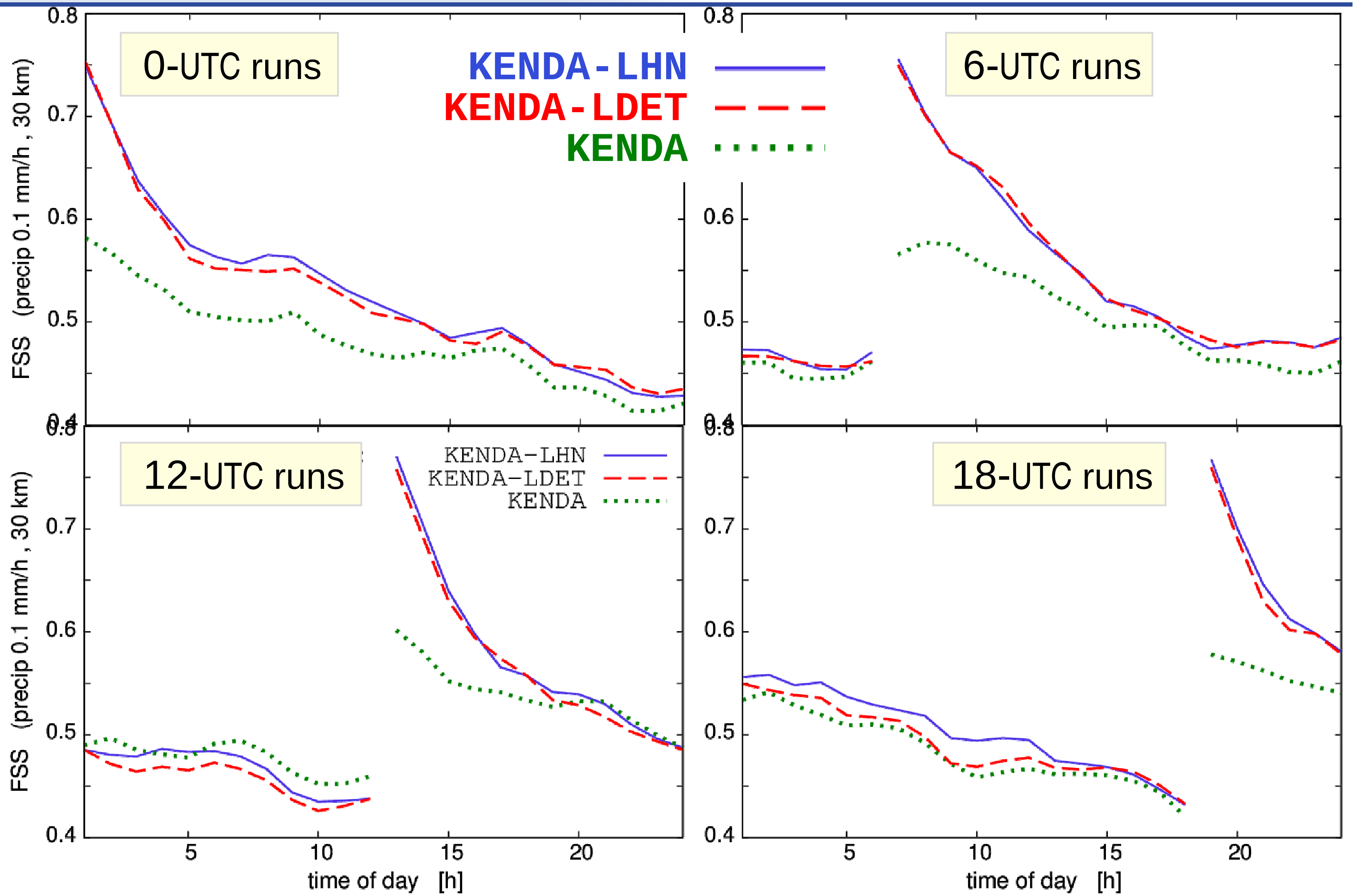
T2014:
28 days
18.05. – 15.06. 2014

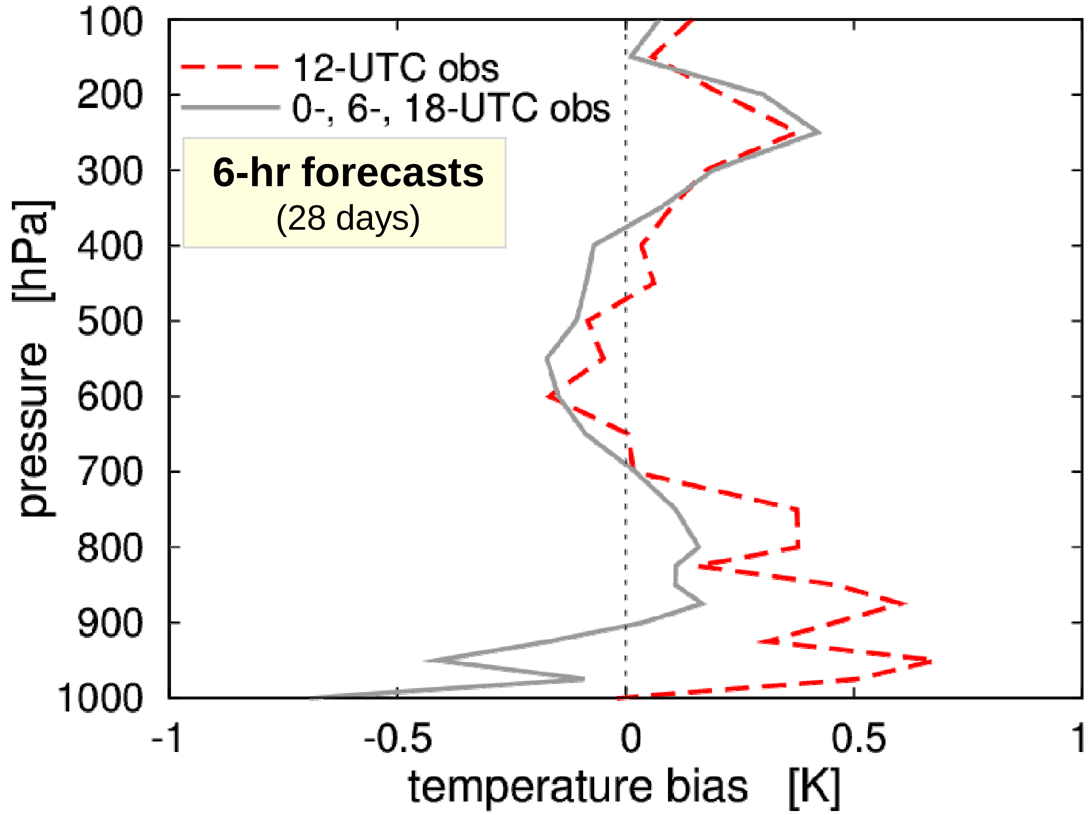
1-hrly precip FSS (30 km , 0.1 mm/h)



- ✓ large, long-lived positive impact from LHN (except 12 UTC run)
- ✓ slightly better to apply LHN to all ens. members than only to deterministic run

LETKF: main development + testing
impact of LHN added to LETKF

Why is impact different in 12-UTC runs ?



→ COSMO-DE has warm bias in PBL around noon
(requires excessive instability to produce realistic convection - limited resolution!)

→ assimilating unbiased temperature profile obs tends to suppress convection

→ LHN able to generate precip, but without destabilising the convective environment

→ model tends to dissolve convection in free forecast, impact of LHN more short-lived

LETKF: main development + testing comparison to Nudging + LHN

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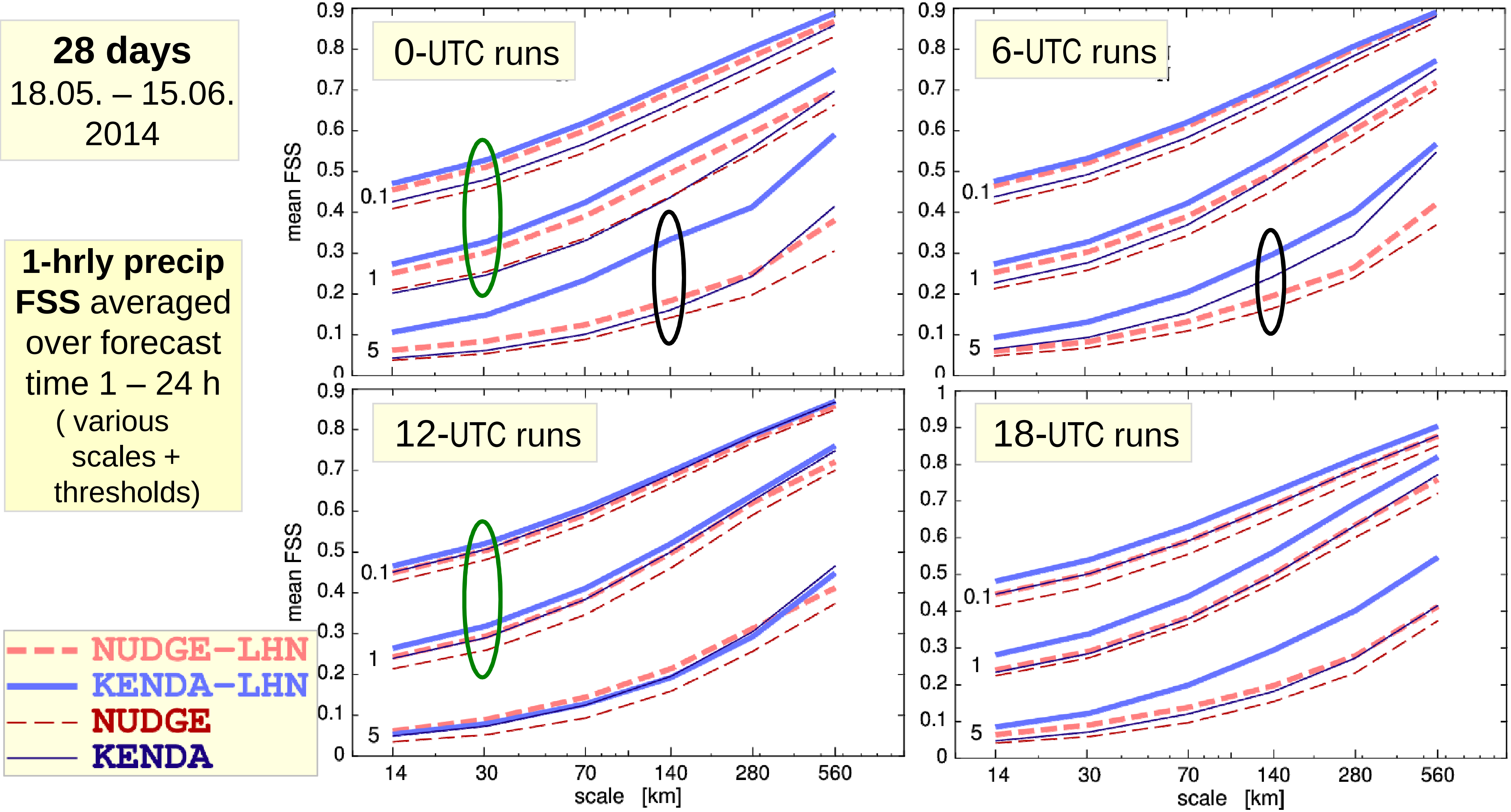
28 days
18.05. – 15.06. 2014

1-hrly precip FSS averaged over forecast time 1 – 24 h (various scales + thresholds)



- ✓ previous findings confirmed for all scales
- ✓ KENDA + LHN is best particularly for high thresholds (except 12 UTC run)

LETKF: use of **radar radial velocity** → *Yuefei Zeng et al.*
impact study (5 day period)

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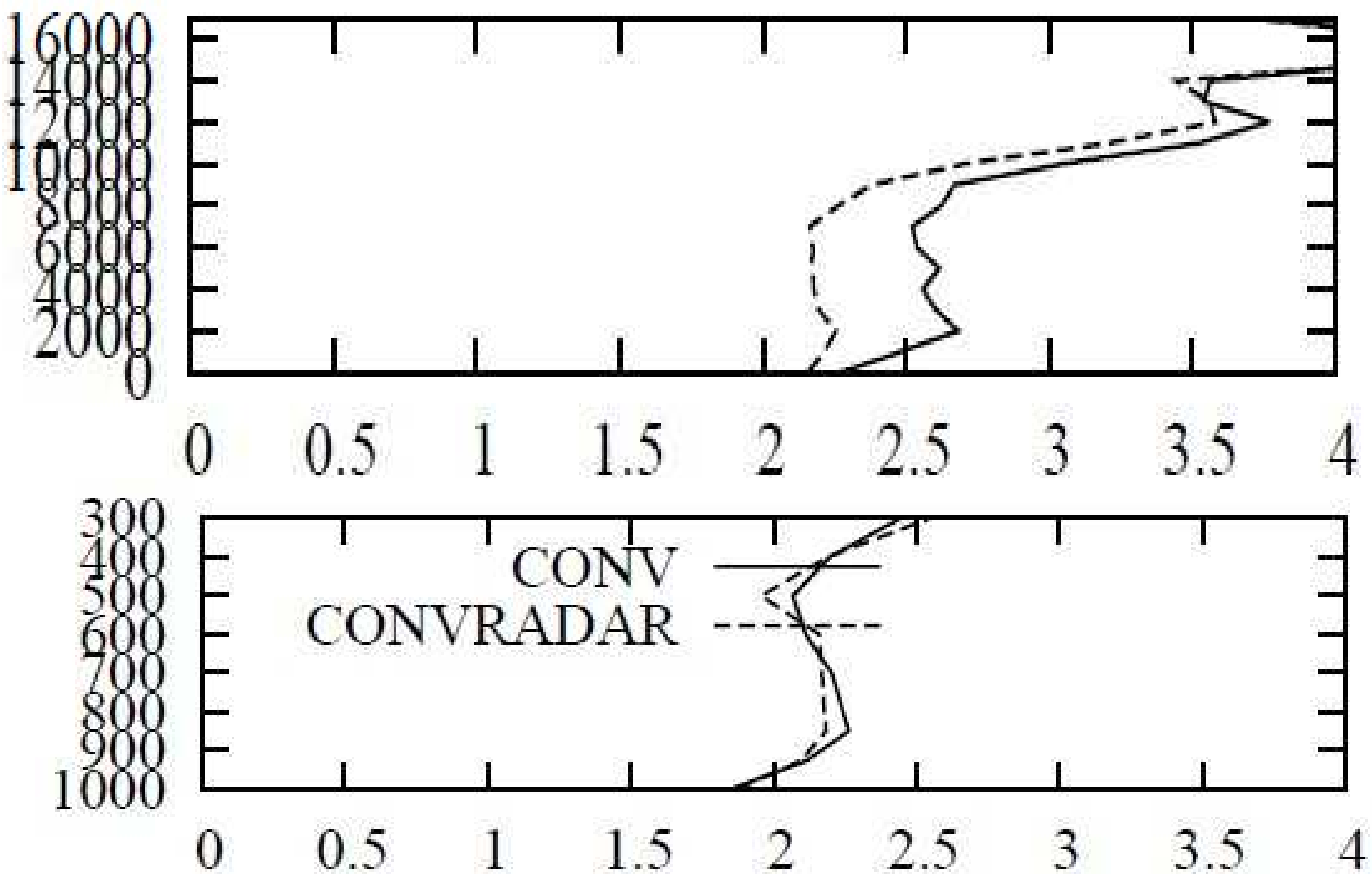
1-hrly LETKF cycling over 5 days (1 – 6 June 2011)

RMSE of first guess (1-hr forecast)



against Radar radial velocity

against radiosonde + aircraft wind speed