Towards an operational use of the Kilometre-scale ENsemble Data Assimilation (KENDA) at DWD

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talk outline

- brief motivation and system setup
- towards operational use of KENDA: results
  - combination LETKF + latent heat nudging
  - test deterministic forecasts: KENDA vs. operational scheme
  - pre-operational suite: deterministic & EPS vs. operational
- outlook

Motivation : Why develop Ensemble Data Assimilation ?

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

→ deliver probabilistic (pdf) rather than deterministic forecast

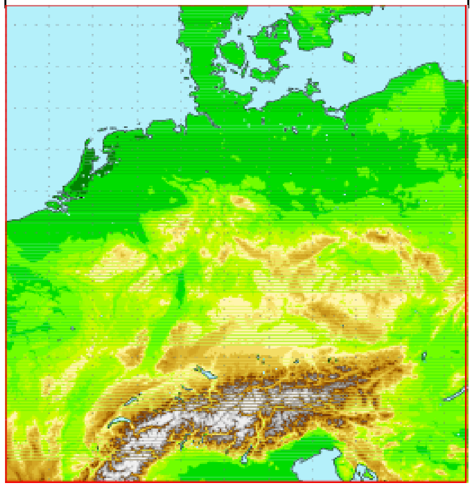
→ need ensemble prediction system (EPS)

COSMO-DE-EPS operational (20 members, +27h), but without data assimilation (DA) cycle:

- IC: operational deterministic analysis (nudging)
  + perturbations from 4 global model systems
  → "nudg./multi-model"
- LBC: perturbations from 4 global model systems
- perturbed physics parameters

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

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



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 ($\rightarrow$ simulated radiances)

$\rightarrow$ Local Ensemble Transform Kalman Filter (**LETKF**, Hunt et al. 2007) ,

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

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

KENDA-LETKF: setup, with deterministic analysis / forecast

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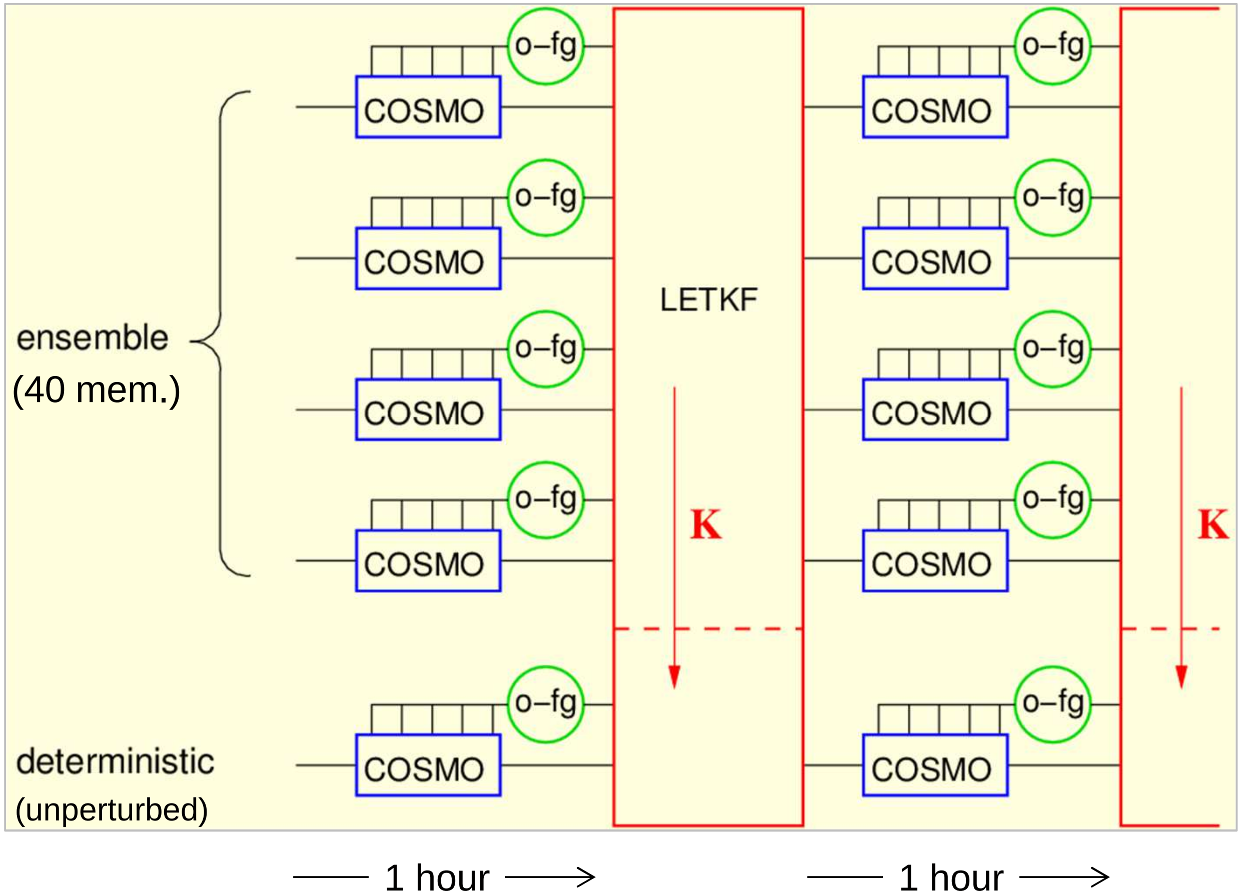
LETKF: **KENDA**



→ **4D** –LETKF

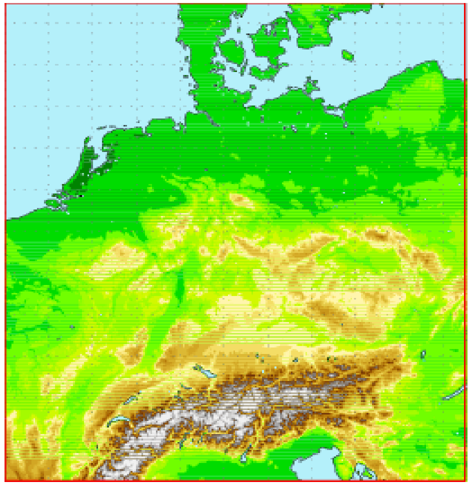
→ **K**: Kalman Gain for ensemble mean (to compute ana incr.)

→ benchmark: **Nudging**

LETKF: comparison to Nudging + LHN

- aim to replace current operational IC by KENDA both for deterministic and EPS forecasts with COSMO-DE (Δx = 2.8 km)

  $\rightarrow$ criterion: at least same forecast quality with KENDA IC



- focus first on deterministic:

  operational: nudging
  (using conventional obs: radiosonde, aircraft, wind profiler, surface)
  + latent heat nudging (LHN: for radar precip)
  (LHN: adds latent heat energy locally to increase precip, and vice versa)

LETKF: comparison to Nudging + LHN

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

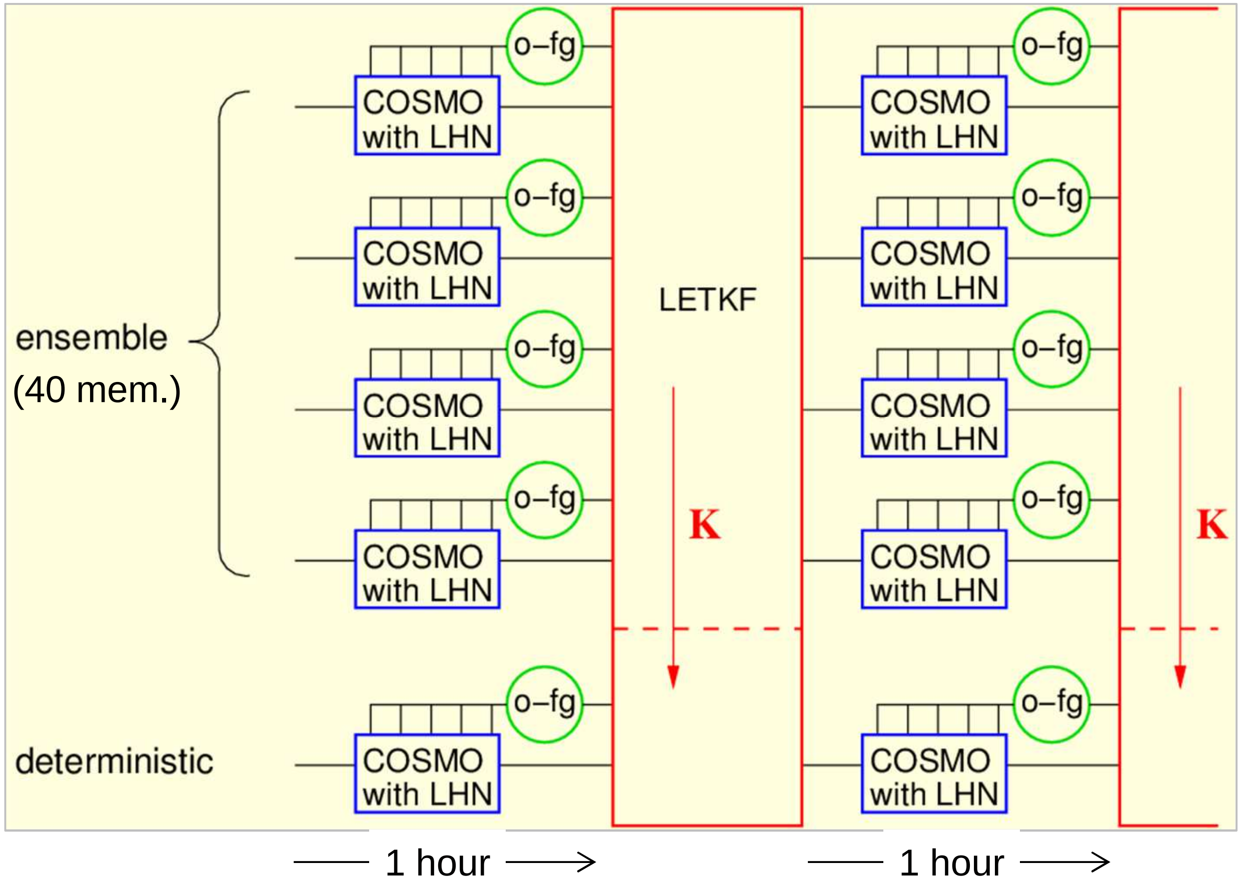
– conventional obs types only (same as in nudging for fair comparison, no RH2M)

– LETKF settings:
  - fixed vertical localisation with variable length scale (ln p) : 0.075 – 0.5
  - adaptive horizontal localisation (keep # obs constant, $50 \leq s \leq 100$ km)
  - adaptive mutliplicative covariance inflation (based on obs-f.g. statistics),
  - RTPP (relaxation to prior perturbations, $\alpha_p = 0.75$),
  - explicit soil moisture perturbations, …
  - 1-hrly LETKF cycle

– combine LETKF with LHN, to compare with nudging + LHN

KENDA-LETKF: setup, with LHN added to LETKF

KENDA-LHN



→ benchmark: Nudging + **LHN**

LETKF + LHN : new approach, does it work ?

KENDA-LETKF for deterministic forecasts: impact of LHN

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28 days
18.05. – 15.06. 2014

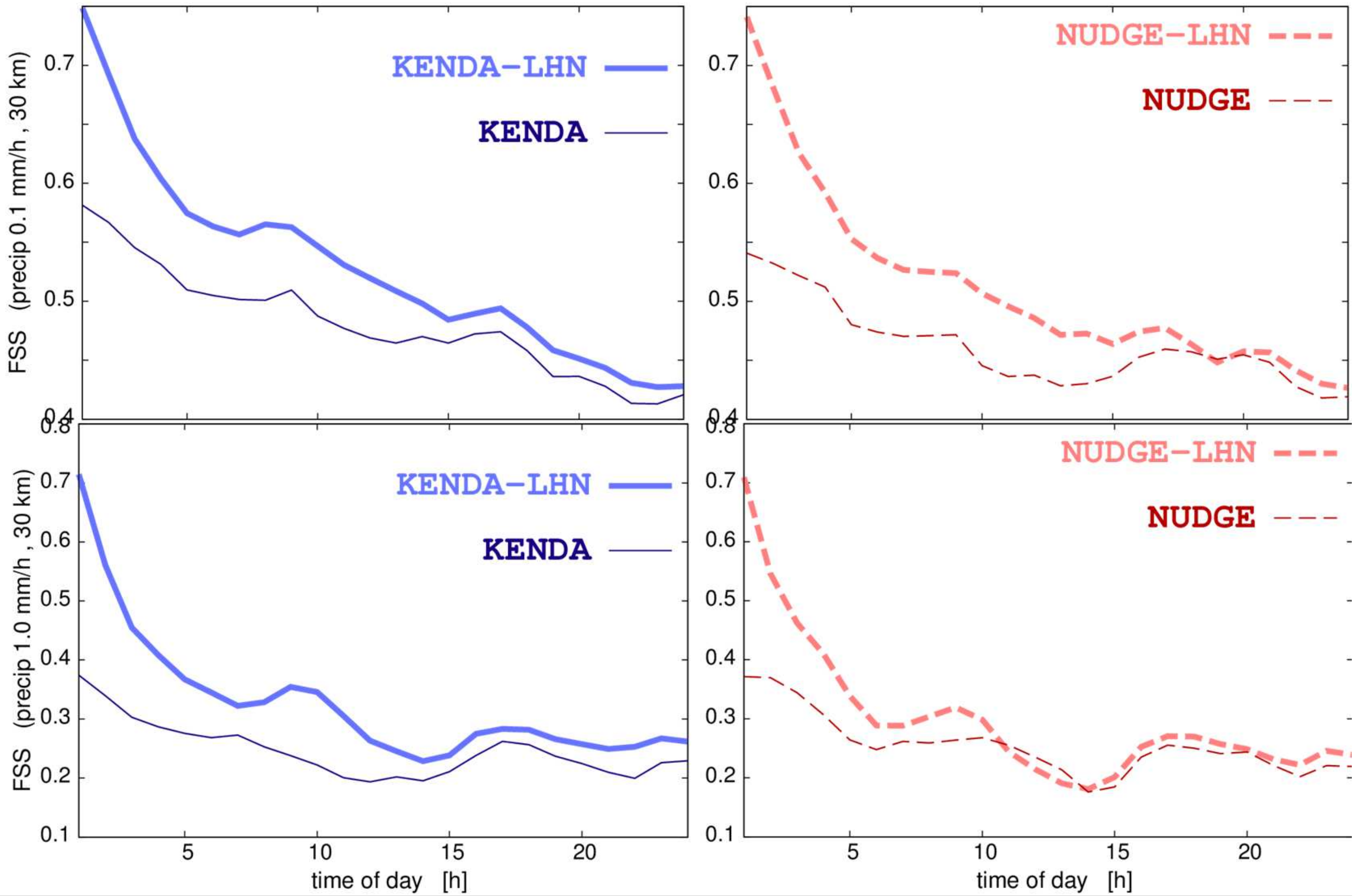
0.1 mm/h

0-UTC runs

1-hrly 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
- ✓ main difference: LHN influences B-matrix/(Kalman) gain in LETKF, not the nudging weights

KENDA-LETKF for deterministic forecasts: comparison to Nudging

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28 days
18.05. – 15.06. 2014

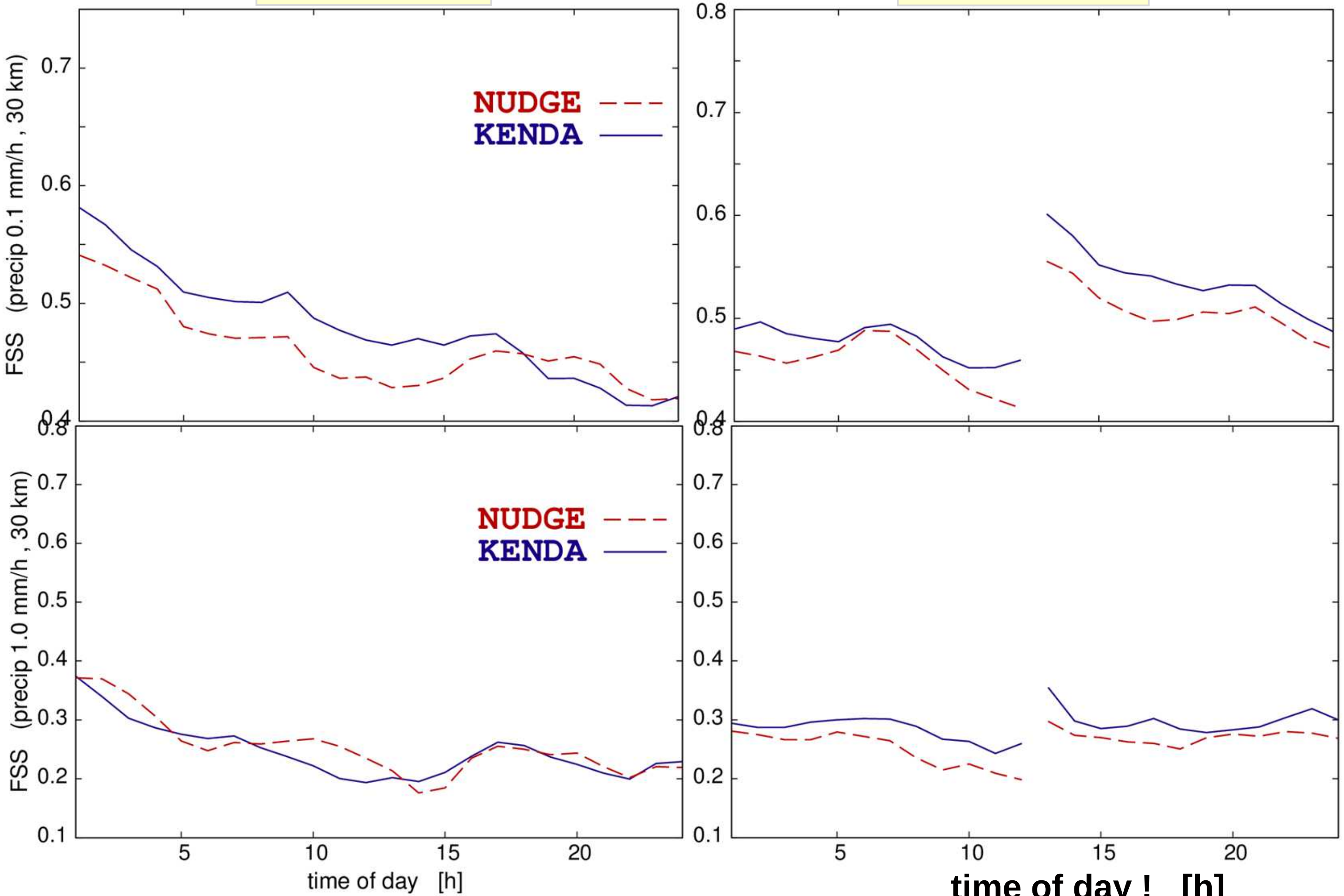
0-UTC runs

12-UTC runs

0.1 mm/h

1-hrly precip FSS (30 km)

1 mm/h



time of day ! [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

1-hrly precip FSS (30 km)

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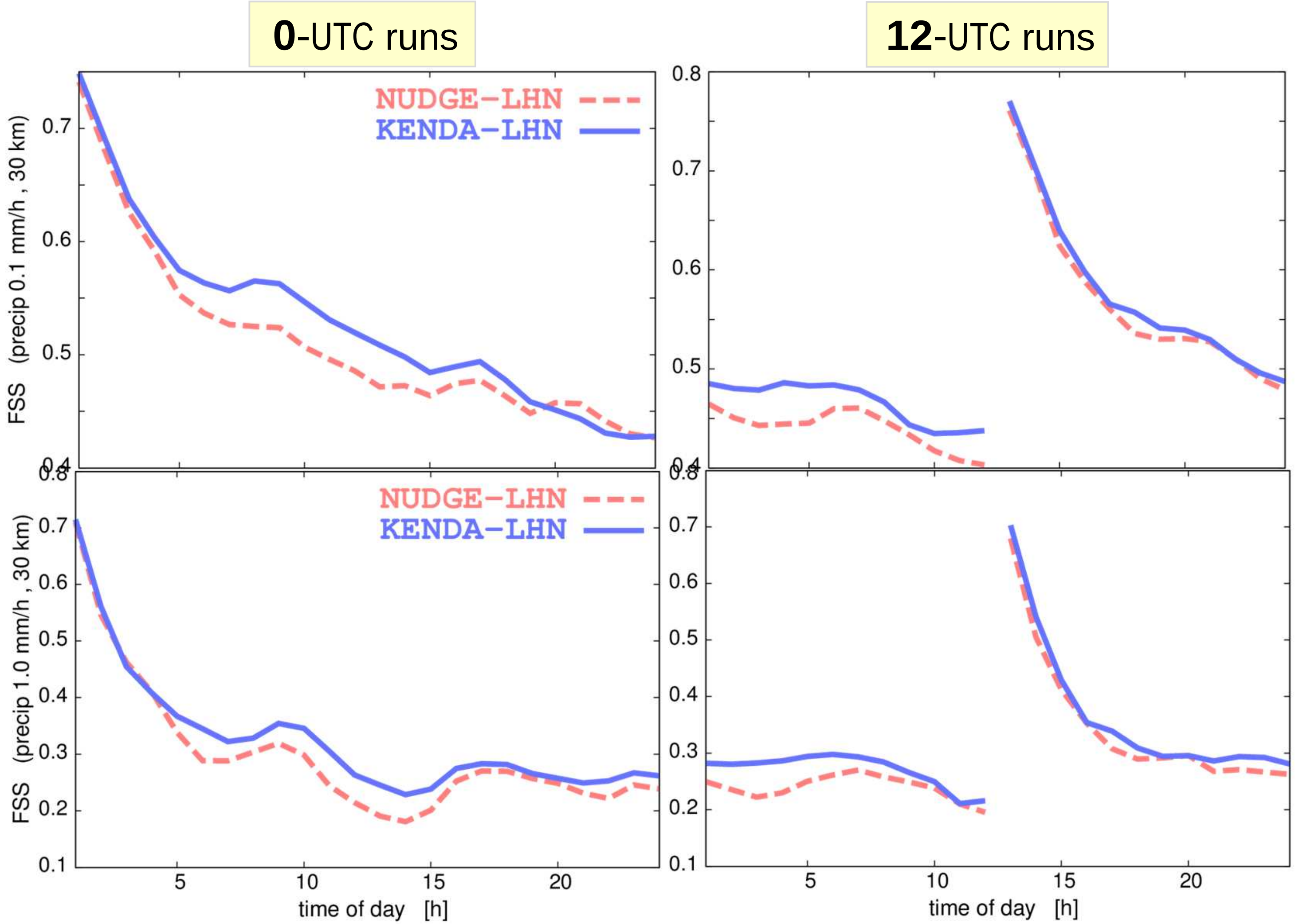

✓ with LHN: small difference in first 4 hours due to dominating influence of LHN, thereafter, advantage of KENDA over nudging tends to be larger than without LHN

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

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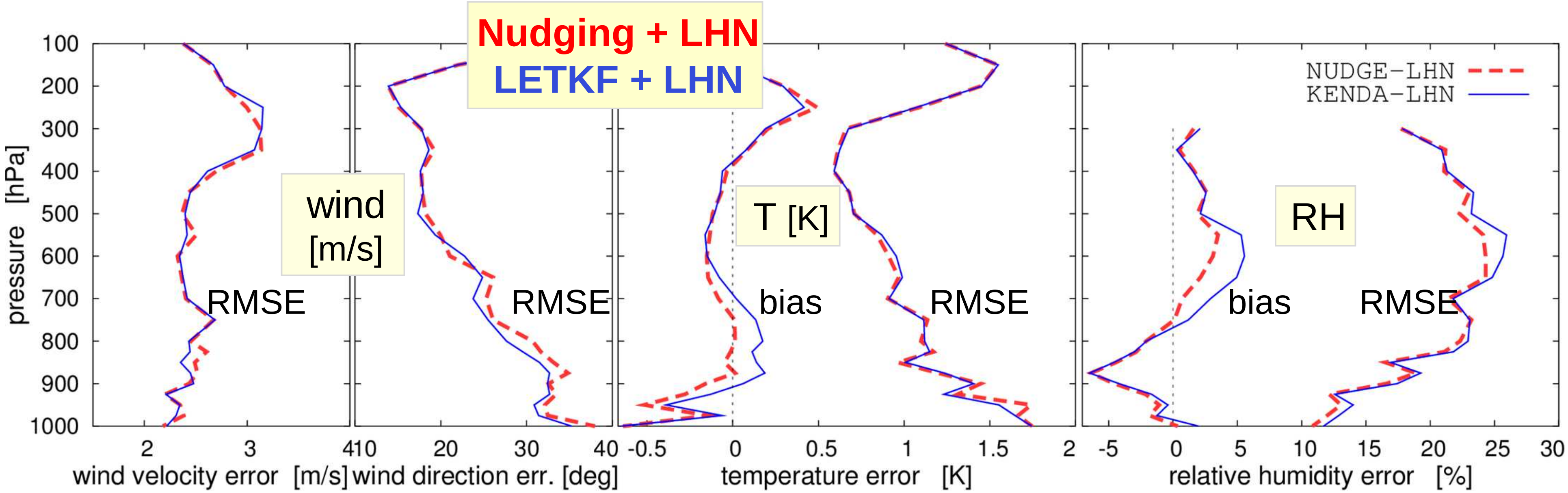
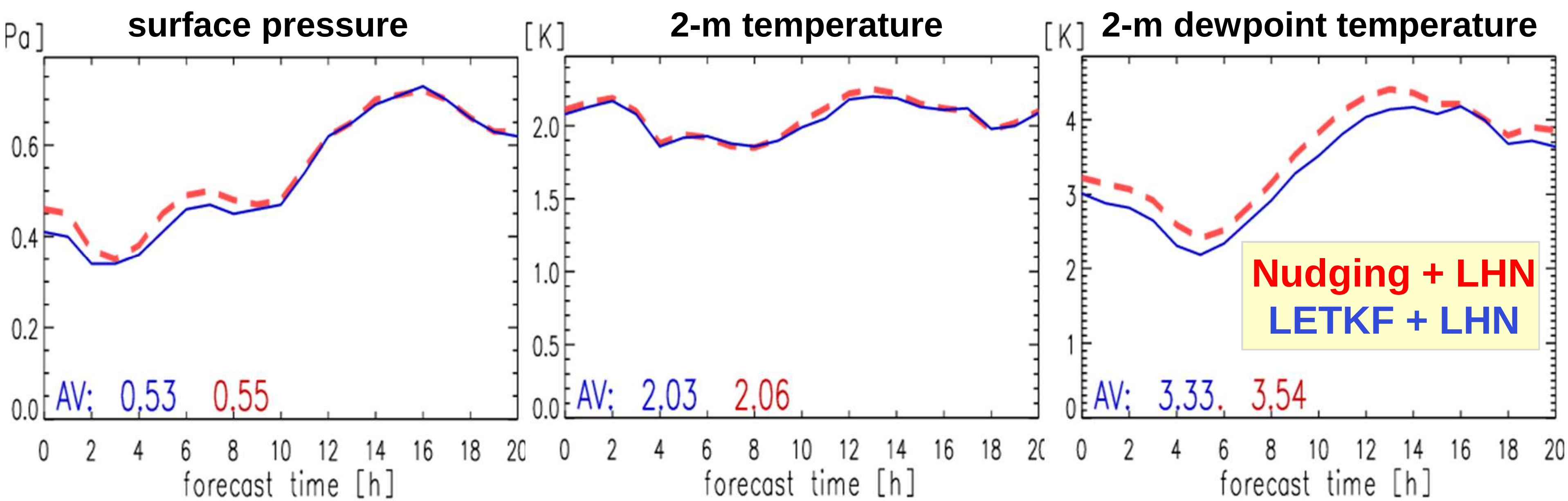
verification of **6-h** forecasts against radiosondes , 28 days (18.05. – 15.06. 2014)



- ✓ 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

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

- **LETKF outperforms nudging** , in particular if both combined with LHN
  for precipitation, surface pressure, 2-m humidity, upper-air wind, etc.
  in summer test period (→ Schraff et al., QJRMS 2016)

- upper-air humidity slightly worse, mainly in PBL
  (→ sampling noise in LETKF cross-covariances ?)

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

- winter period (with more advection): neutral

- since mid-May 2016
- **KENDA-LETKF** used humidity data from 9 aircrafts,
  but by error did not use any aircraft data in 20 – 30 % of the hourly analyses
- benchmark: operational **nudging** uses 2-m humidity data (with limited weight),
  continues to nudge new obs in first 30 minutes of forecast
- both systems apply
  - latent heat nudging (LHN) for assimilation of radar precipitation
  - lateral BC from operational global ICON EnVar system,
    with resolution: deterministic global 13 km / **EU 6.5 km** ,
    ensemble global 40 km / **EU 20 km**
    (→ global EnVar: talk A. Fernandez del Rio, poster A. Rhodin)
- different lengths of verif. periods (18 days – 1.5 months, betw. 14 May – 28 June),
  but all include 2 weeks with lots of local, often stationary, heavy convection
  over Germany (high-impact weather)

pre-operational parallel suite, deterministic: surface verification (14 May – 28 June 2016)

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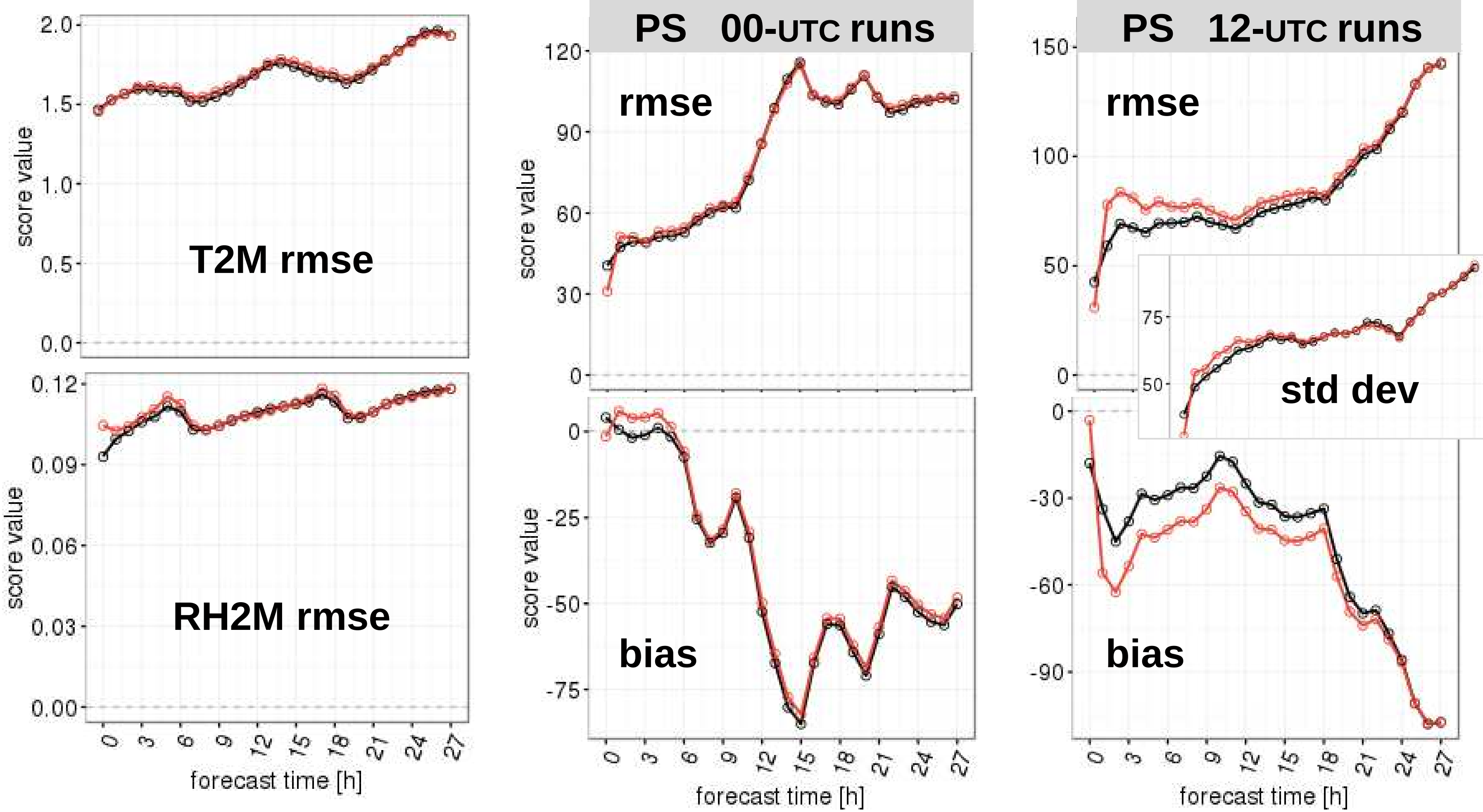

KENDA
oper. **Nudging**

- ✓ 2-m temperature + humidity ok
- ✓ surface pressure: balance issue, under investigation
  (lateral BC from 3-h old forecast, has time to develop negative pressure bias)

pre-operational parallel suite, deterministic: radiosonde verification (15 May – 26 June 2016)

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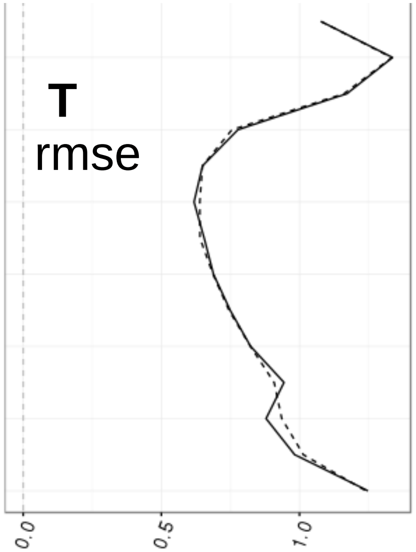
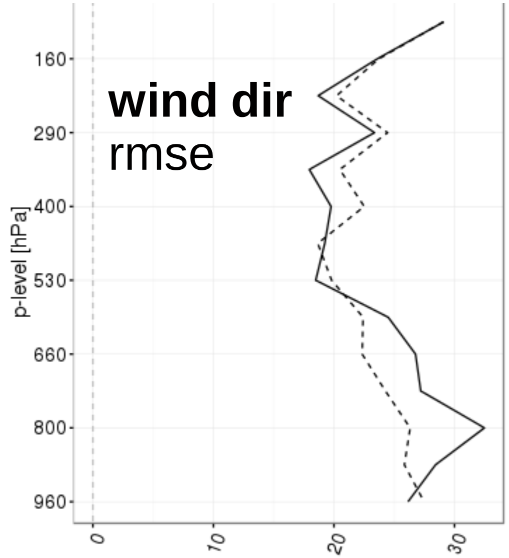
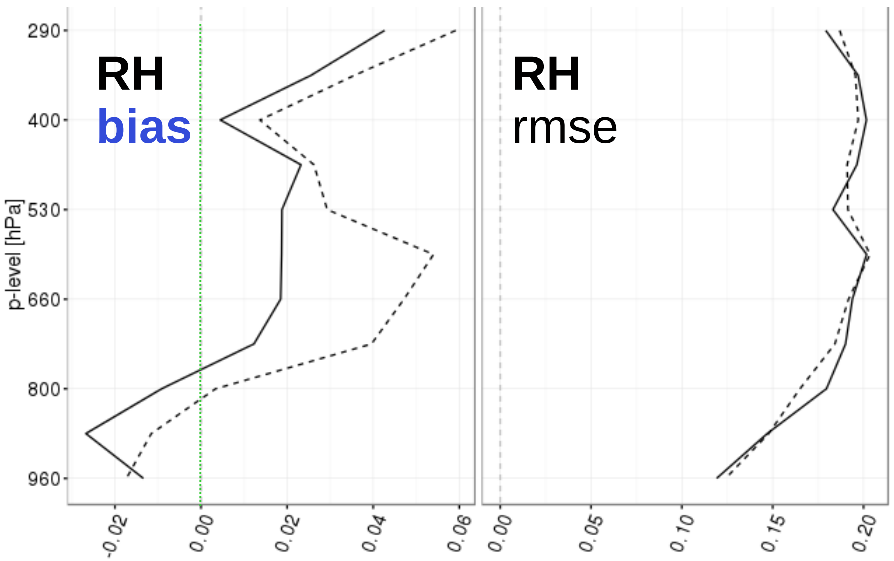
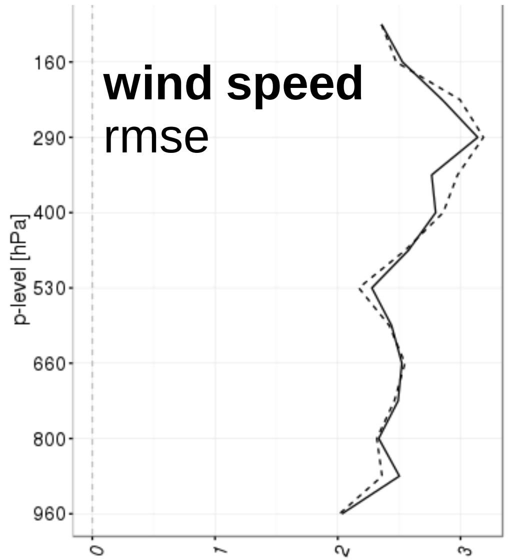
- - - - **KENDA**
——— oper. **Nudging**

6-h forecasts









- ✓ rmse: neutral
- ✓ model humidity bias less corrected

pre-operational parallel suite, deterministic:
radar verification (26 May – 12 June 2016)

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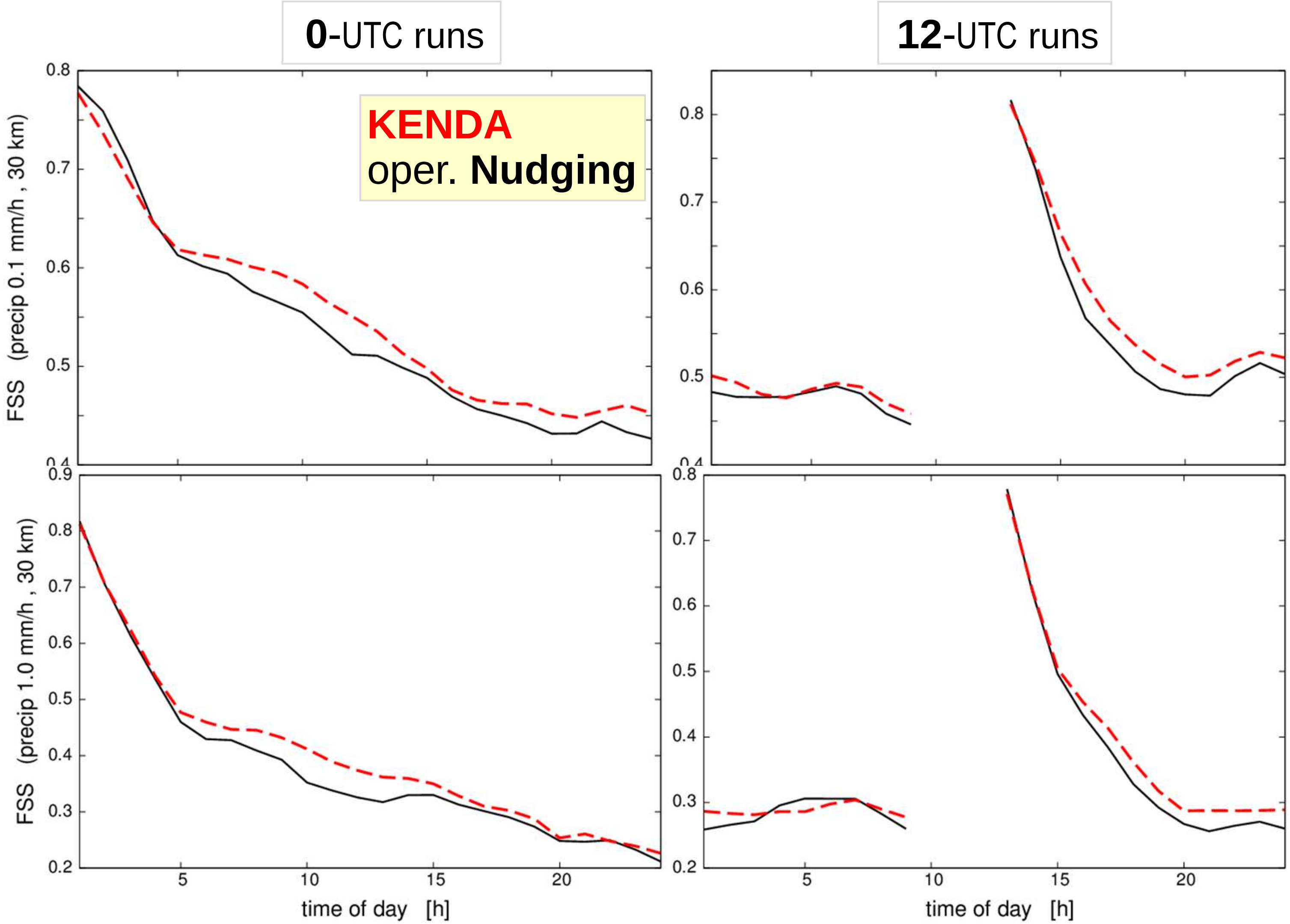
1-hrly precip FSS (30 km)

0.1 mm/h

1 mm/h



✓ KENDA: long-lasting improvements after first 2 – 4 hours in summer convective period

pre-operational parallel suite, deterministic: radar verification (26 May – 12 June 2016)

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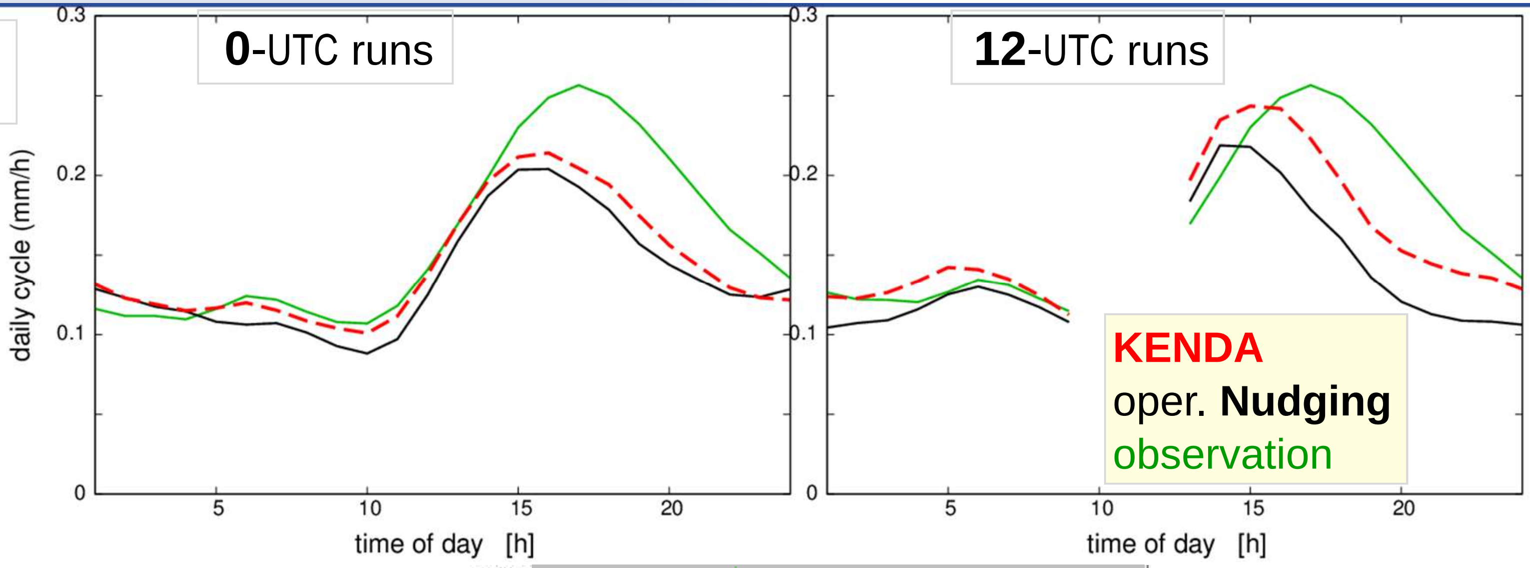
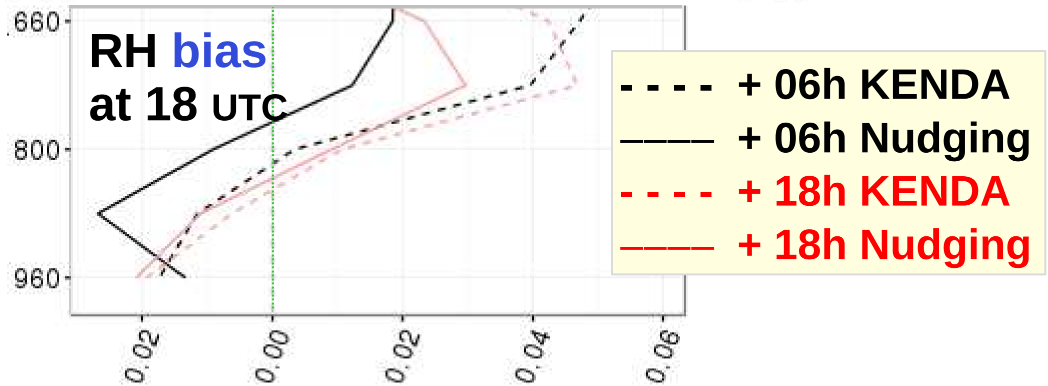
precip amount daily cycle





- ✓ KENDA: better daily cycle of (convective) precip, particularly in afternoon of 12-UTC runs
  → KENDA makes less correction to the moist bias of the model (climatology)
- ✓ not always good to correct model biases in the analysis

- EPS with KENDA IC vs. EPS with nudg./multi-model

  - nudg./multi-model: operational deterministic analysis (nudging)
    \+ perturbations from 4 global model systems

  - LBC: perturbations from 4 global model systems
  - perturbed physics parameters

thanks to C. Gebhardt for plots

pre-operational parallel suite, EPS (probabilistic): surface verification (20 May – 21 June 2016)

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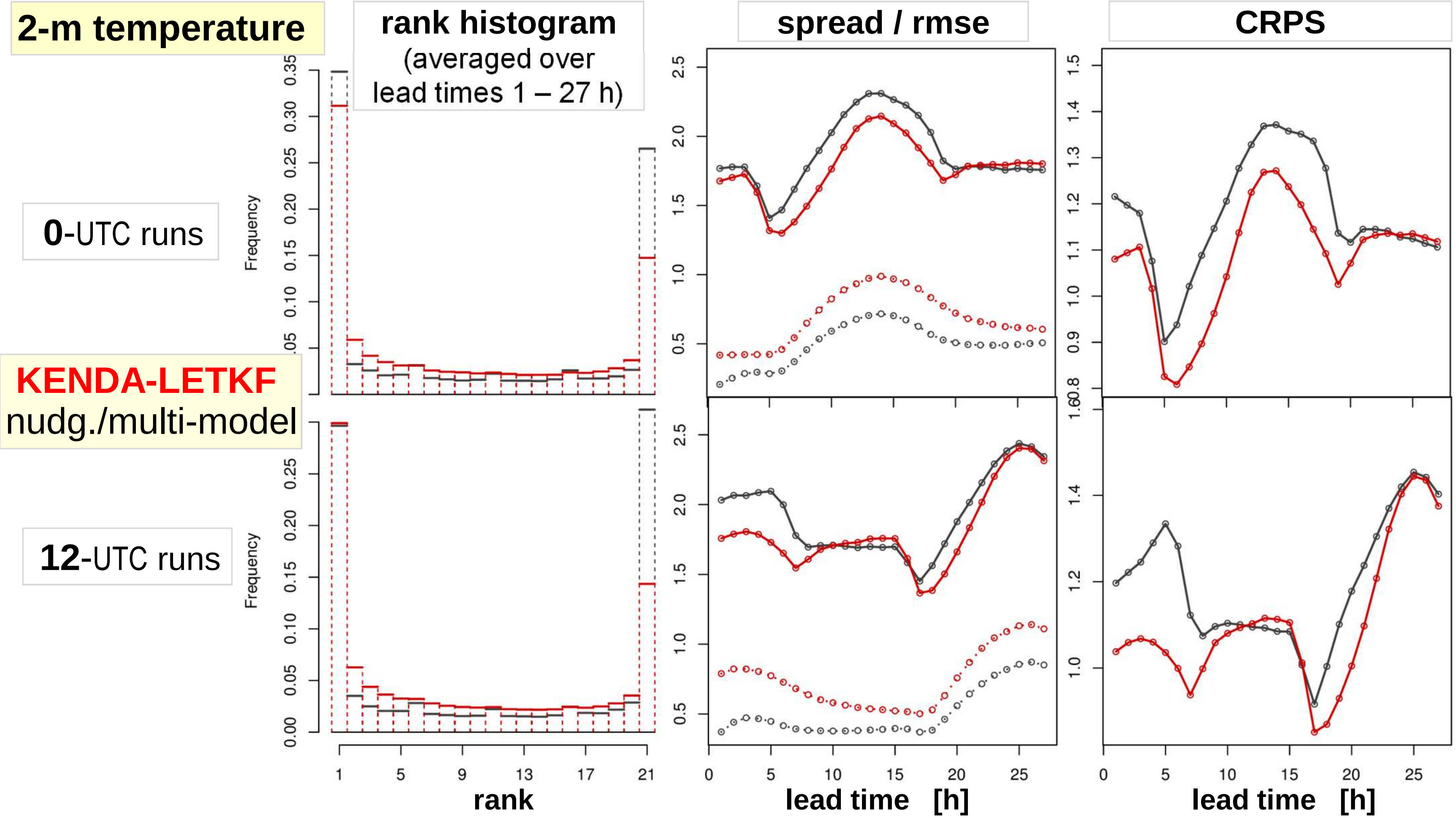
2-m temperature



✓ KENDA: spread & errors clearly improved over multi-model approach, still underdispersive

pre-operational parallel suite, EPS (probabilistic): radar verification (20 May – 21 June 2016)

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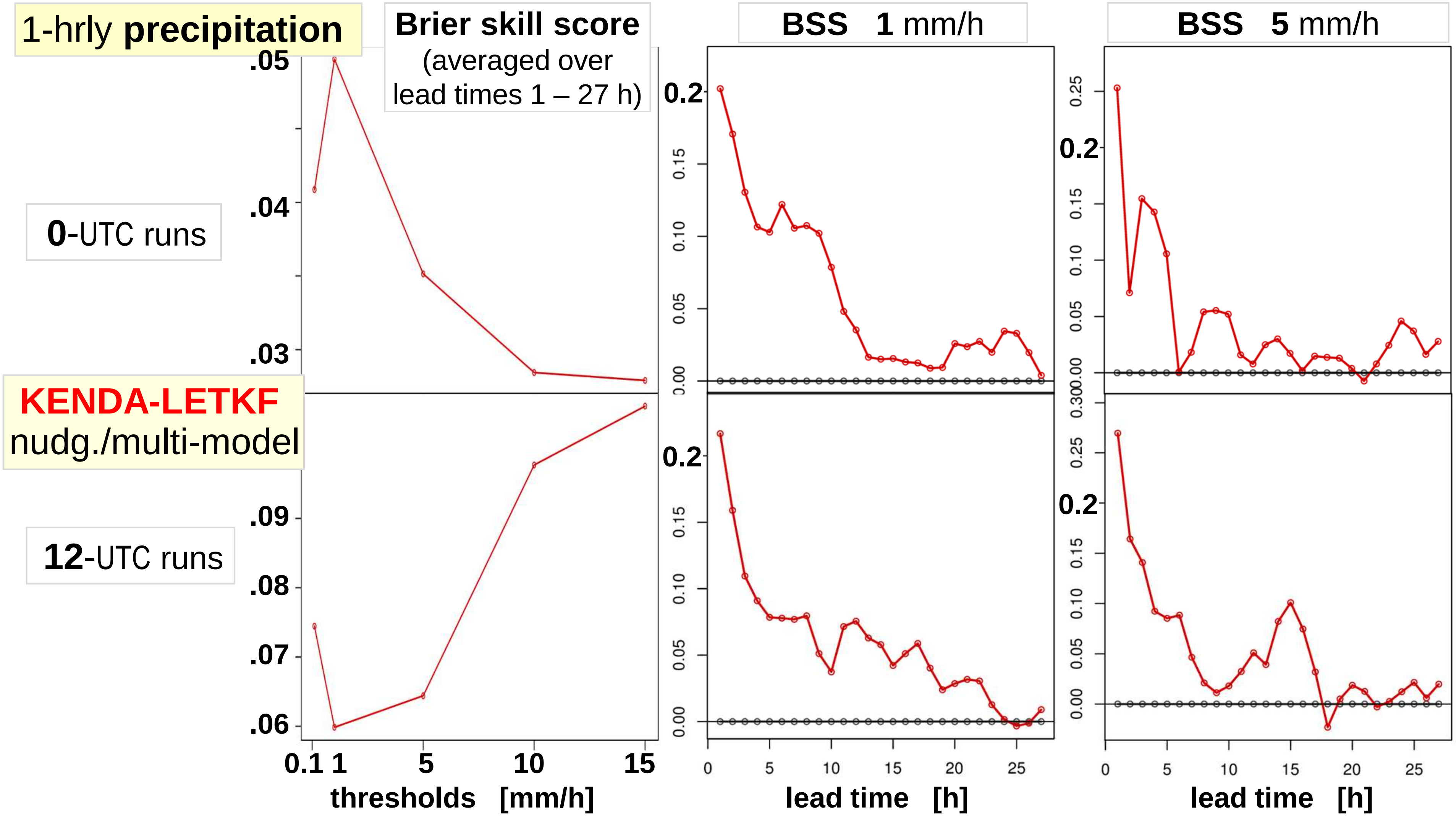
DWD



✓ KENDA: BSS better for all thresholds, long-lasting

pre-operational parallel suite, EPS (probabilistic): radar verification (20 May – 21 June 2016)

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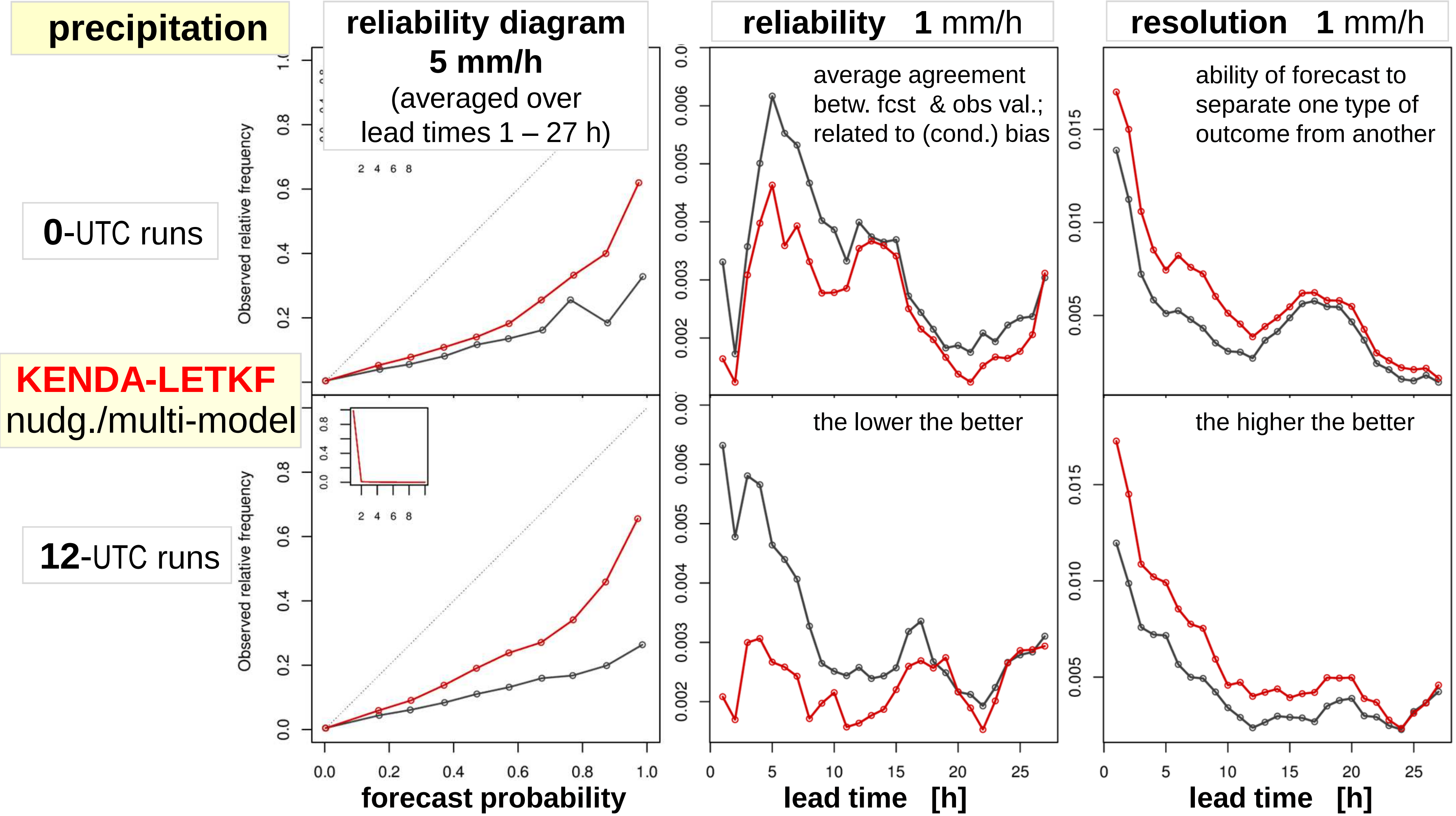
DWD



✓ KENDA: better reliability and (not susceptible to calibration:) resolution

summary of results

- **deterministic** (vs. nudging)
  - convective precipitation improved
  - surface pressure degraded, balance issue, partly due to bias in lateral BC
  - otherwise neutral; biases less corrected

- **EPS** (vs. nudging + multi-model perturbations)
  - convective precipitation + T2m clearly improved

- increase of computational **costs** for the whole system:

  (40-member EnDA + det forecast + 20-member EPS) :   ~ 40 – 50 %

  only half of it time critical

KENDA system: outlook

- **operational** in late 2016 or spring 2017 (data base issue)

  → KENDA operational at MeteoSwiss for EPS (→ poster D. Leuenberger)

- further refinement of 4D-LETKF: additive covariance inflation, balance (IAU?), test Kalman smoother, 80 members, …

- starting 2017: porting from COSMO to **ICON-regional**
  - consider testing hybrid EnVar
    (→ EnVar for global ICON: talk A. Fernandez del Rio, poster A. Rhodin)
  - research: particle filter (PF), LETKPF (→ talk S. Robert (ETH Zurich)),
    hybrid EnVar-PF (→ talk R. Potthast)

- ongoing: work on additional **observations** (high-res. → towards nowcasting)
  - GPS (GNSS) Slant Total Delay (M. Bender)
    → first test (no tuning, 13 days, summer convection, no LHN):
    improved precip forecast in first 8 – 16 hours
  - cloud info: SEVIRI WV all-sky approach (A. Hutt; Harnisch et al., QJRMS 2016;
    → poster M. Weissmann, LMU)
  - 3-D radar radial velocity (→ Poster E. Bauernschubert)
    & radar reflectivity (Bick et al., QJRMS 2016)
    → 7-day test: even slightly better precip for LETKF conv+Z vs. LETKF-conv + LHN
  - aircraft Mode-S (Lange and Janjic, MWR 2016; → poster H. Lange (LMU))
  - VIS + NIR SEVIRI radiances (→ talk L. Scheck, LMU Munich)
  - etc. (screen-level obs, ground-based remote sensing, ….)