# Status of KENDA-O and Pre-operational Suite at DWD

*Christoph Schraff*

Contributions by:

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Lucio Torrisi, Francesca Marcucci, Valerio Cardinali (COMET)

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Mikhail Tsyrulnikov, Dmitri Gayfullin (HMC)

**PP KENDA-O : Km-Scale Ensemble-Based Data Assimilation for the use of High-Resolution Observations**

- Task 1: further development of LETKF scheme
  - mainly with conventional obs only
  - includes work towards operationalization
- Task 2: extended use of observations (high-resolution obs)
- Task 3: lower boundary: soil moisture analysis using satellite soil moisture data
- Task 4: adaptation to ICON-regional, hybrid methods (also particle filters)

**MeteoSwiss**

- **KENDA** provides the IC for **operational COSMO-E** since 19 May 2016
- further tests on SPPT and soil moisture perturbations

→ *talk by Daniel Leuenberger*

- next year: work on KENDA for COSMO-1 , screen-level obs

**ARPAE-SIM**

- start **pre-operational suite** with KENDA-IC for 2.2 km EPS soon (Oct.?)

**COMET**

- KENDA/DACE code: adapted to include required capabilities of COMET system and run in a **parallel suite**
- sensitivity tests on treatment of humidity and localisation
- soil moisture assimilation (Task 3)

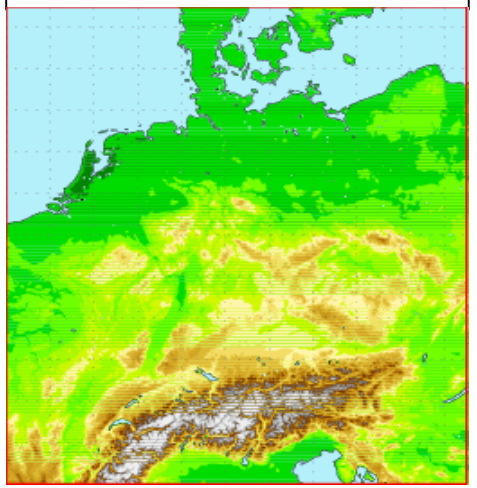
→ *talk by Francesca Marcucci*

**HMC** : stochastic pattern generator: refined, accelerated, cleaned

**DWD**

- reference paper on KENDA: Schraff et al. 2016, QJRMS (doi:10.1002/qj.2748)
- comparison to nudging in winter period: neutral
- some sensitivity tests (e.g. SPPT: mixed impact)
- **KENDA** run in **pre-operational suite** since May 2016
  for deterministic + EPS forecasts

COSMO-DE
($\Delta x$ = **2.8 km**)
deep convection
simulated explicitkly

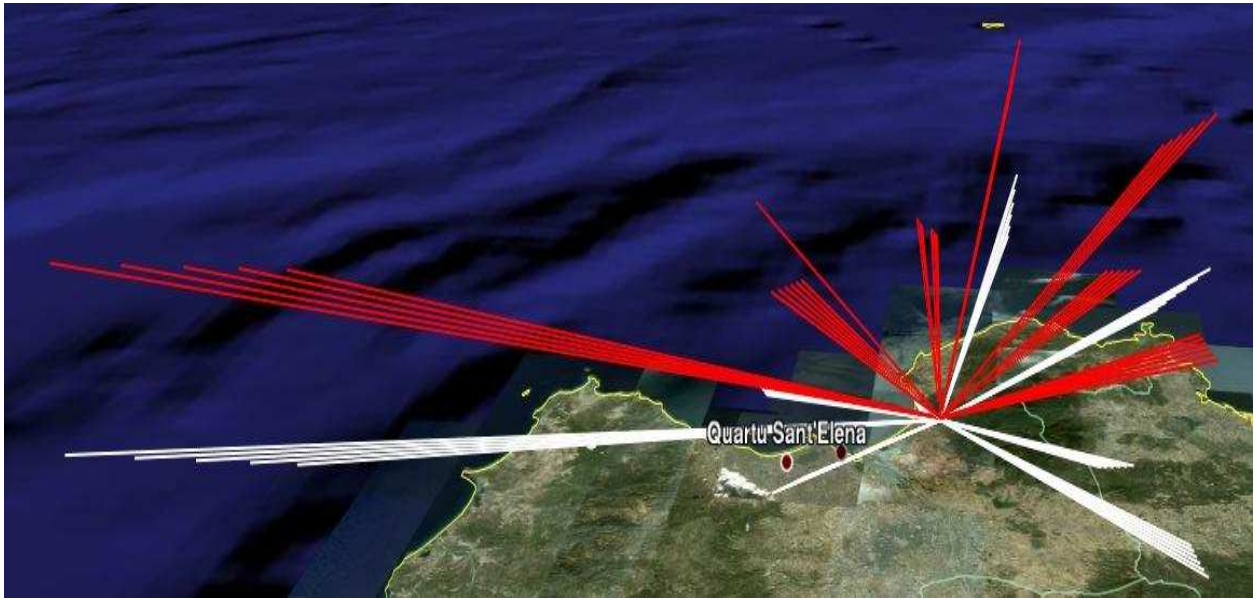


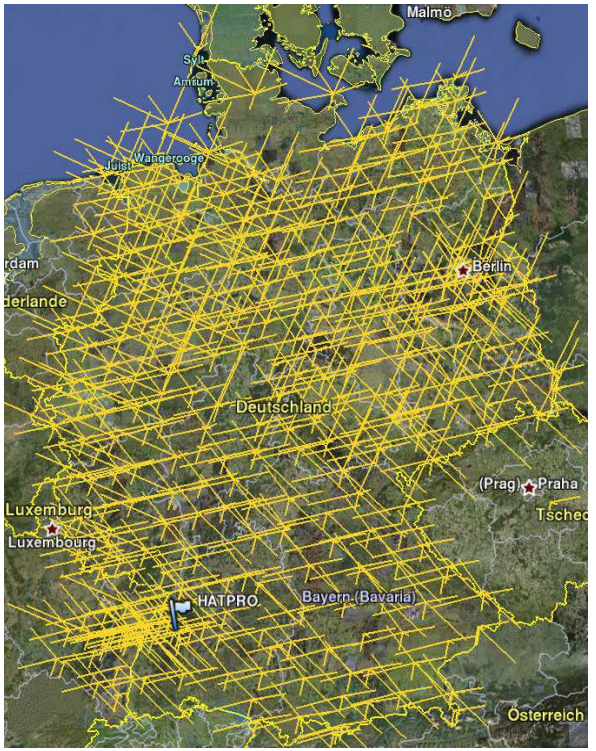
# KENDA-O overview, Task 2 (high-res. obs): GNSS Slant Total Delay (STD)

Deutscher Wetterdienst

→ 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.




→ 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)

→ 8-day data assimilation test

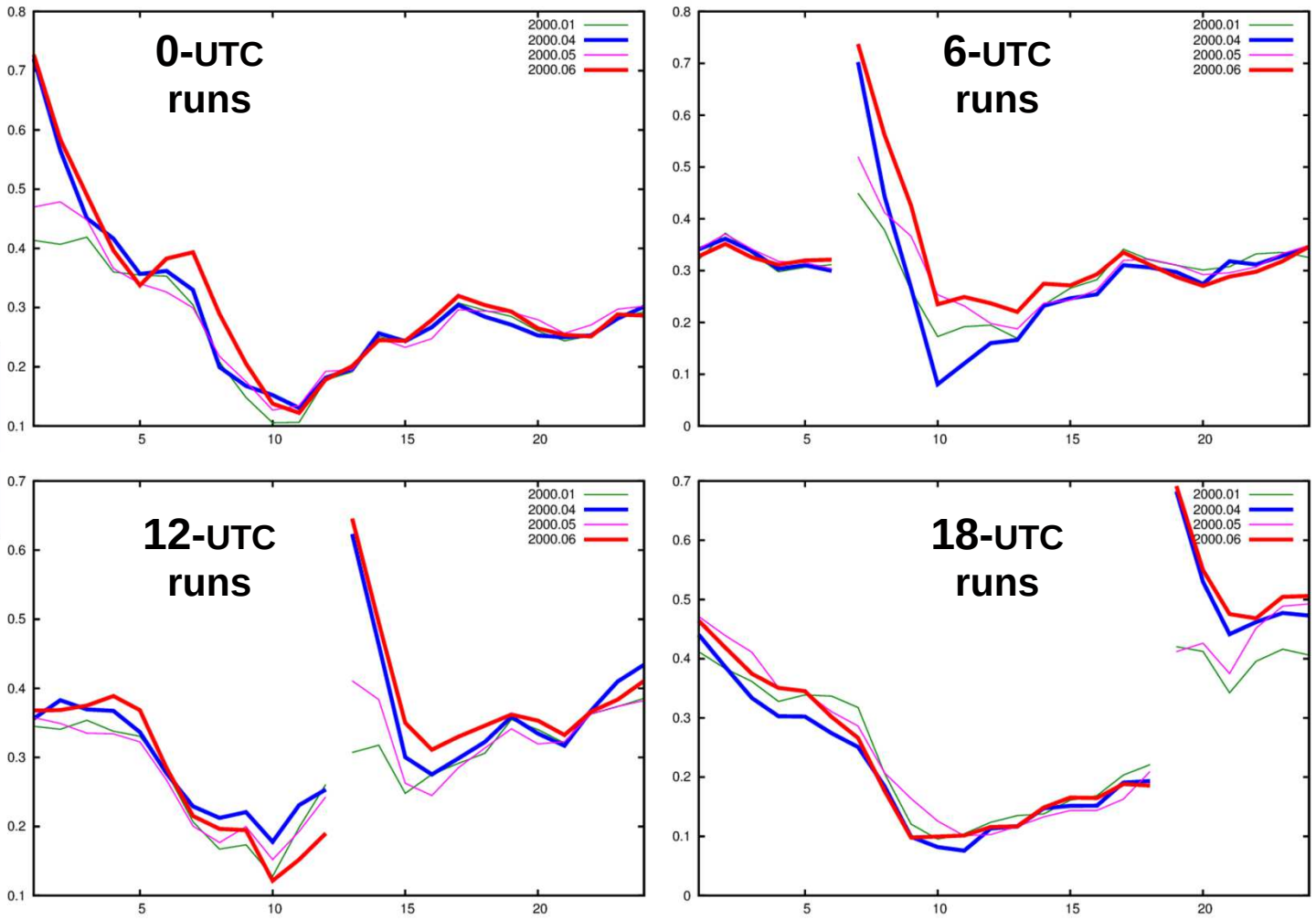
# KENDA-O overview, Task 2 (high-res. obs): GNSS-STD, first trial for use in KENDA

Deutscher Wetterdienst

**8 days**
17 – 24 May 2014

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

CONV only
CONV + GNSS
**CONV + LHN**
**CONV + LHN + GNSS**

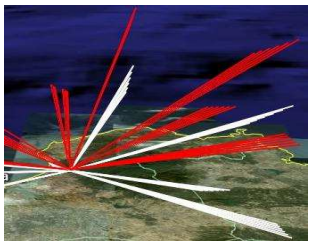



✓ 1 mm/h : slightly better for 0-, 6-, 18-UTC runs

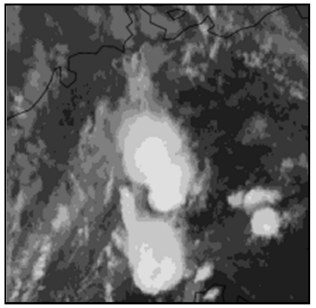
# KENDA-O overview, Task 2:
# High-res obs, in the context of convection

Deutscher Wetterdienst

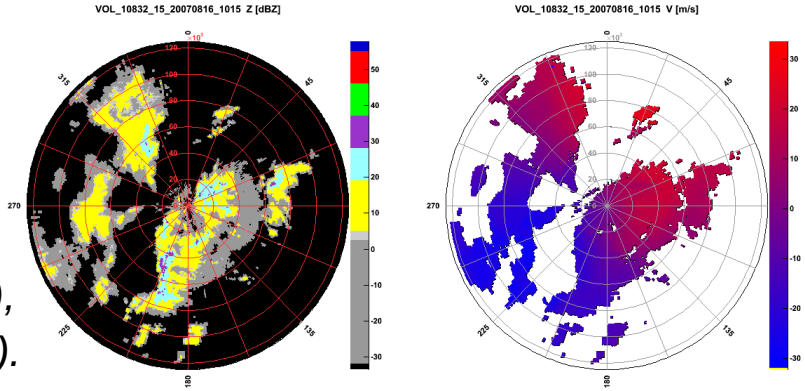
- pre-convective environment: no clouds
  → GNSS **Slant Total Delay** : *Michael Bender*



- developing convection: clouds
  → **cloudy SEVIRI** radiances (**IR** window + **WV** channels)
  all-sky approach for WV: *Axel Hutt* *(Florian Harnisch, HErZ)*
  work on cloud-dependent obs errors + bias correction
  very preliminary assimilation experiments with mixed impact



- mature convection: precipitation
  → **radar**: 3-dim. **reflectivity**
  3-dim. **radial velocity**
  → *Therea Bick left → Axel Seiffert*
  *Elisabeth Bauernschubert (DWD/IAFE),*
  *Virginia Poli (ARPAE): (1 week DA exp).*



# KENDA-O overview



Task 2

- GNSS slant total delay
- SEVIRI WV all-sky for cloud info
- radar reflectivity + radial velocity
- screen-level obs: sensitivity tests with 2-m humidity at MCH, to be continued
- Mode-S : tests at DWD & MeteoSwiss soon
  (motivated by positive results of H. Lange)

Task 4

- KENDA for ICON: start 2017, see later
- non-Gaussianity: Promising research ongoing with
  - hybrid LETK-PF applied to the COSMO model (Sylvain Robert, ETH)
  - hybrid VarEnKF-PF applied to ICON (Roland Potthast)

# pre-operational parallel suite at DWD, comparison to operational nudging setup

Deutscher Wetterdienst

- since mid-May 2016
- **KENDA-LETKF**: 1-hourly cycle, LETKF settings as in 2014 test (localis./inflation), using only same conventional obs, plus 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 (since 20 May also in KENDA forecast, as in operational nudgecast)
  - 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**
- verification based on FF by MEC + R (except for precip (radar) and wind gusts)

# pre-operational parallel suite at DWD, comparison to operational nudging setup

Deutscher Wetterdienst

results shown for:

- Period 1: May 26 (20) – June 12 (21): lots of local, often stationary, **heavy convection** over Germany: **high-impact weather** !

  → meteorologically highly interesting, but affected by bugs (mainly ENS):

  – no use of any aircraft obs in 30 % of the hourly analyses (until 21 June)

  – no updating of climatological fields in ensemble part since 2 May
  → activity of vegetation underestimated (evapotranspiration !)

  → only scores on precipitation shown

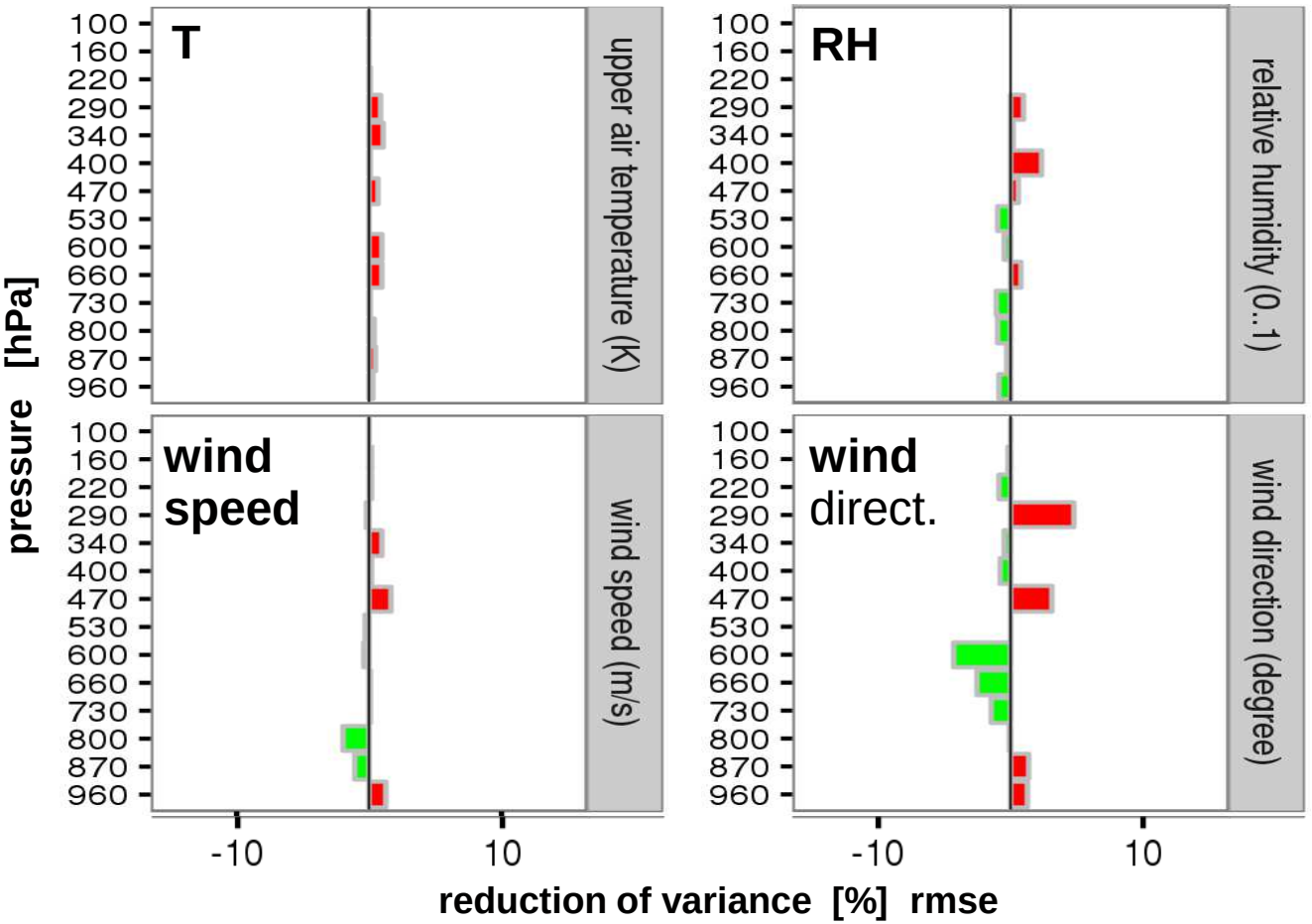
- Period 2: July 26 – August 31: mainly **frontal** precip, some days with showers in (N)W flow
  → less interesting, but not affected by known bugs

- precip: May 26 – August 29: full summer season (> 3 months)

# pre-operational parallel suite, **deterministic**: radiosonde verification (26 July – 31 August 2016)

Deutscher Wetterdienst

**KENDA-LETKF** vs. nudging




**rmse**
(averaged over lead times & initial times)

better
worse

✓ KENDA: neutral (similar results for convective period)

# pre-operational parallel suite, deterministic: radiosonde verification

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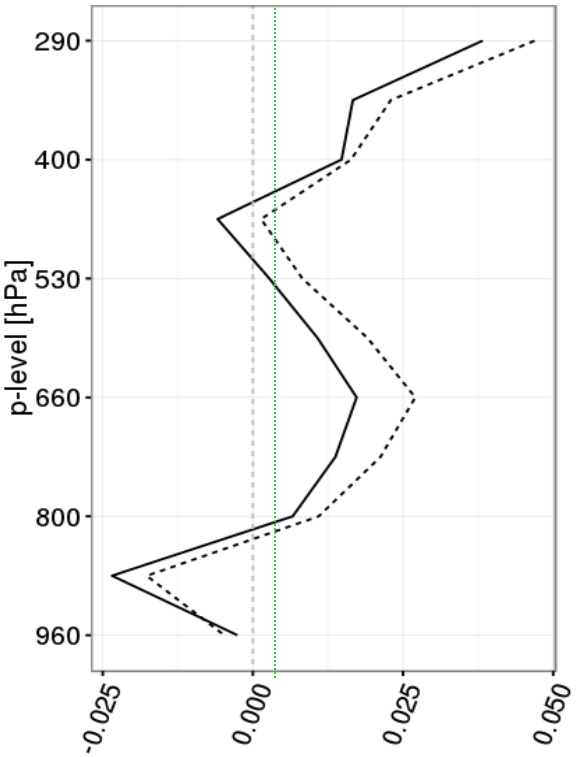
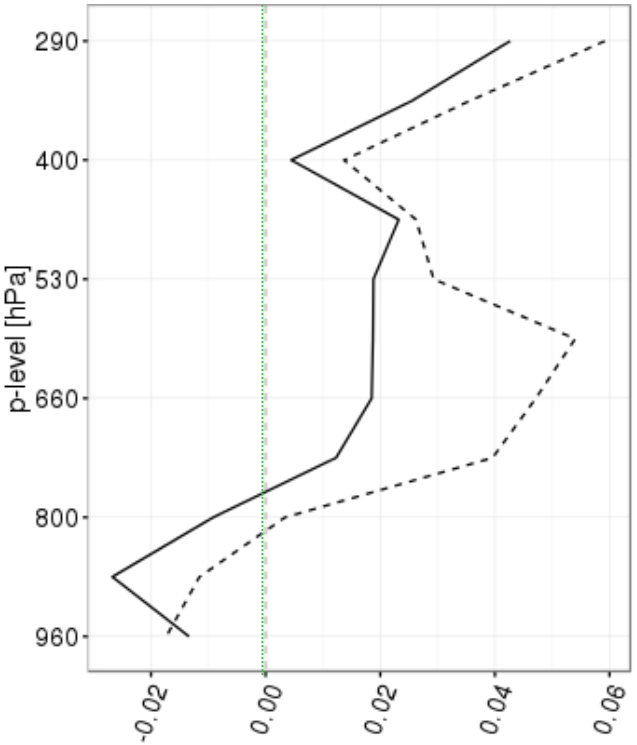
**RH bias**

- - - - **KENDA**
——— n**udging**

26 July – 31 August
mostly frontal precip,
+ 12 h




26 May - 12 June
convection: high-impact weather
+ 6 h

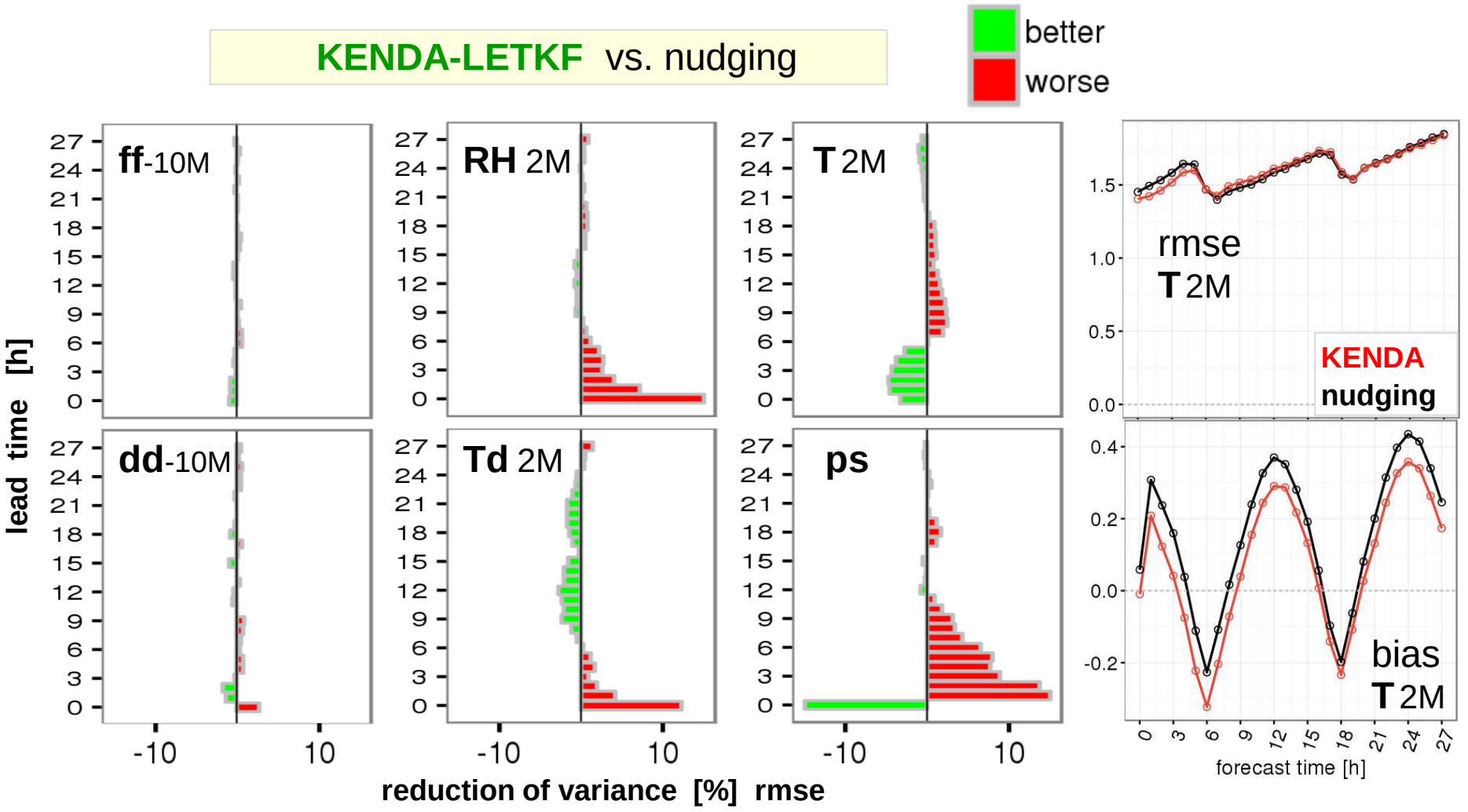



✓ KENDA: model humidity (moist) bias less corrected

# pre-operational parallel suite, deterministic: surface verification (26 July – 31 August 2016)

Deutscher Wetterdienst

**KENDA-LETKF** vs. nudging




✓ KENDA: worse for 2-m humidity in first 6 hours and for surface pressure, otherwise neutral

# pre-operational parallel suite, deterministic: surface verification (26 July – 31 August 2016)

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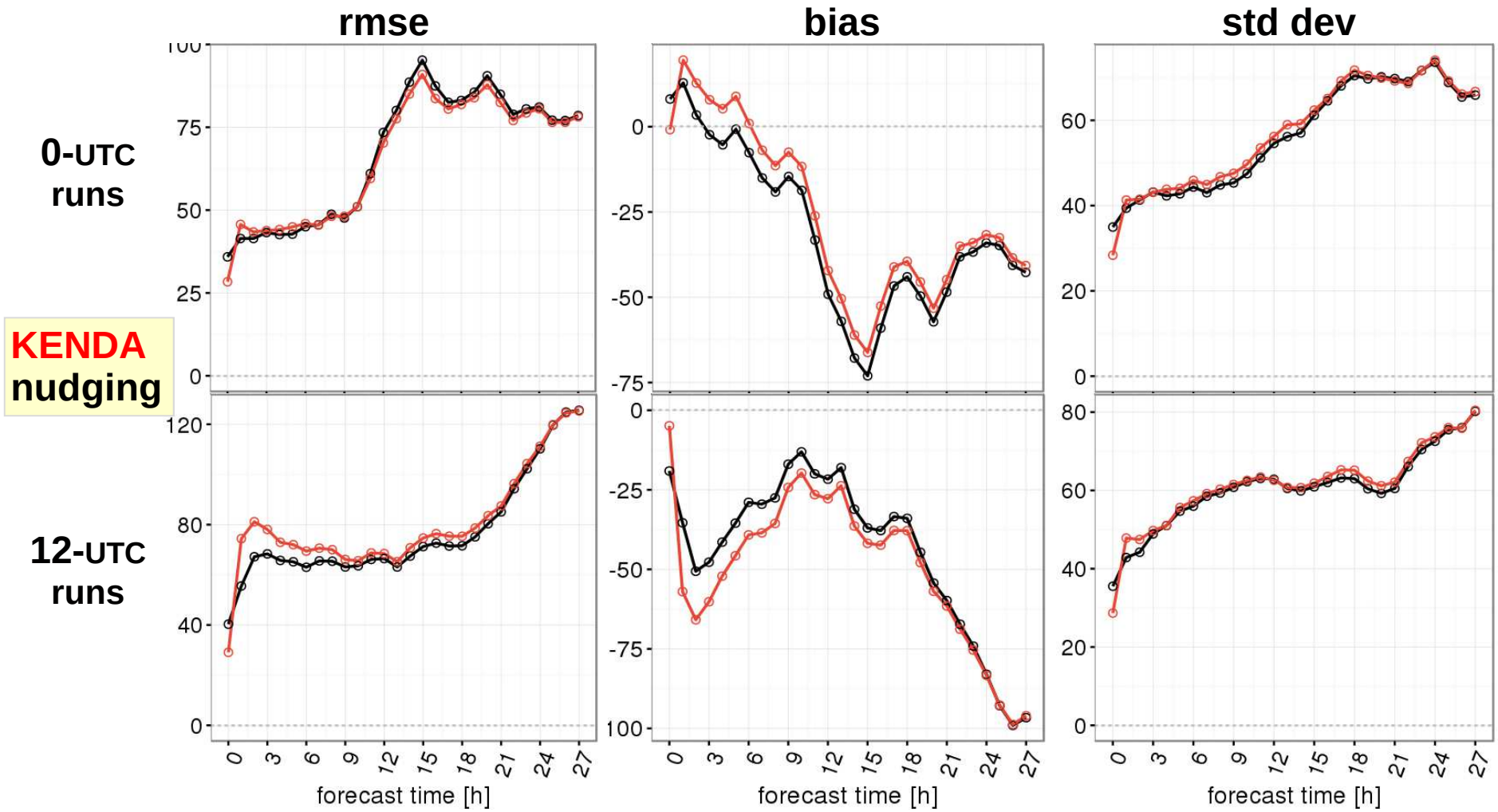



- surface pressure: (~ geostrophic) balance issue, under investigation
  (lateral BC with bias)

# pre-operational parallel suite, deterministic: radar verification (26 July – 29 August 2016)

Deutscher Wetterdienst

mostly frontal precip, some post-frontal showers

**0.1** mm/h

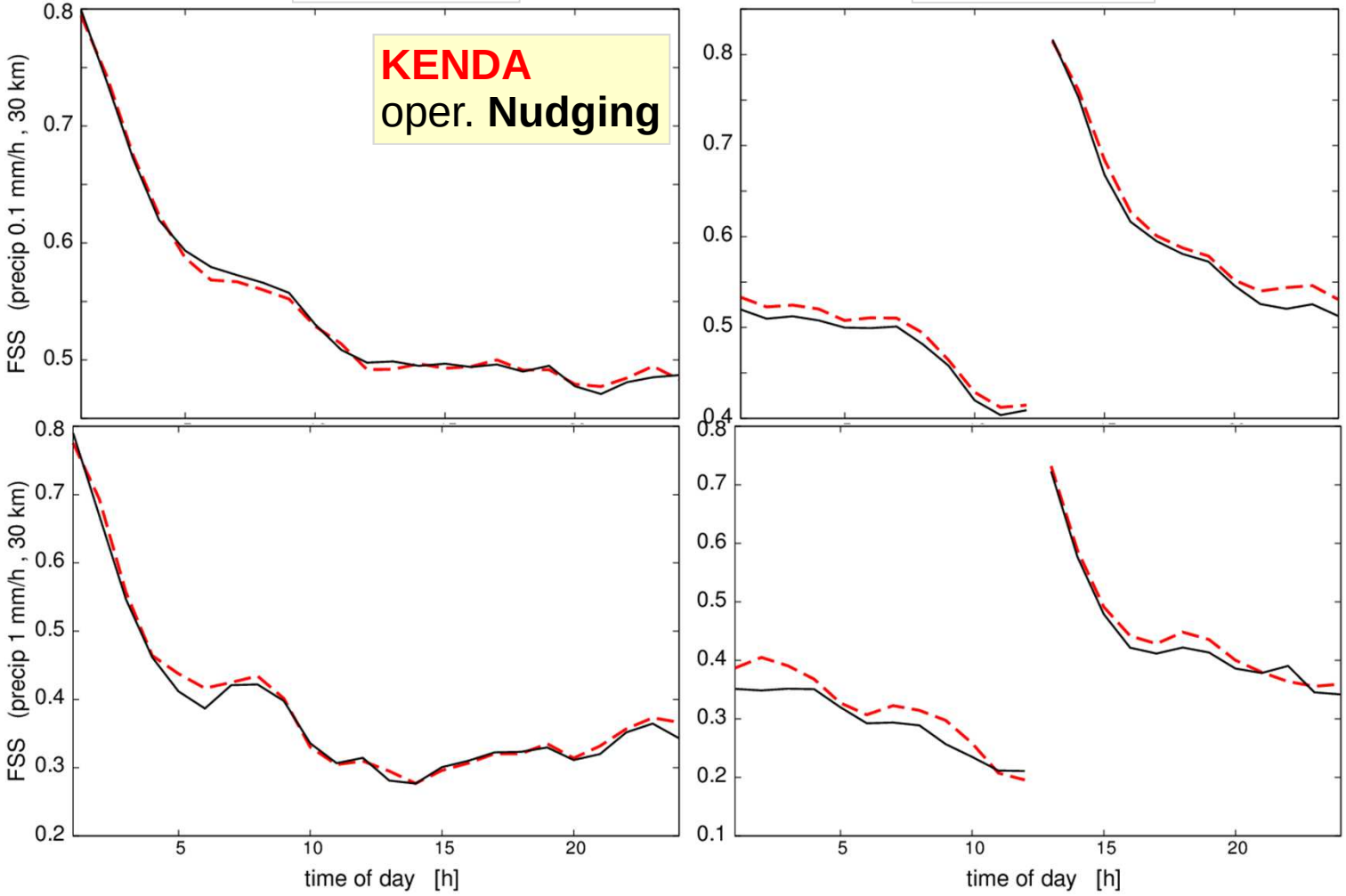
**1-hrly precip FSS ( 30 km )**

**1** mm/h

**0**-UTC runs

**12**-UTC runs

**KENDA**
oper. **Nudging**




✓ KENDA: only small, but long-lasting improvements in 12-UTC runs

# compare with last year's results: (deterministic KENDA vs. Nudging)

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**28 days**
18.05. – 15.06. 2014

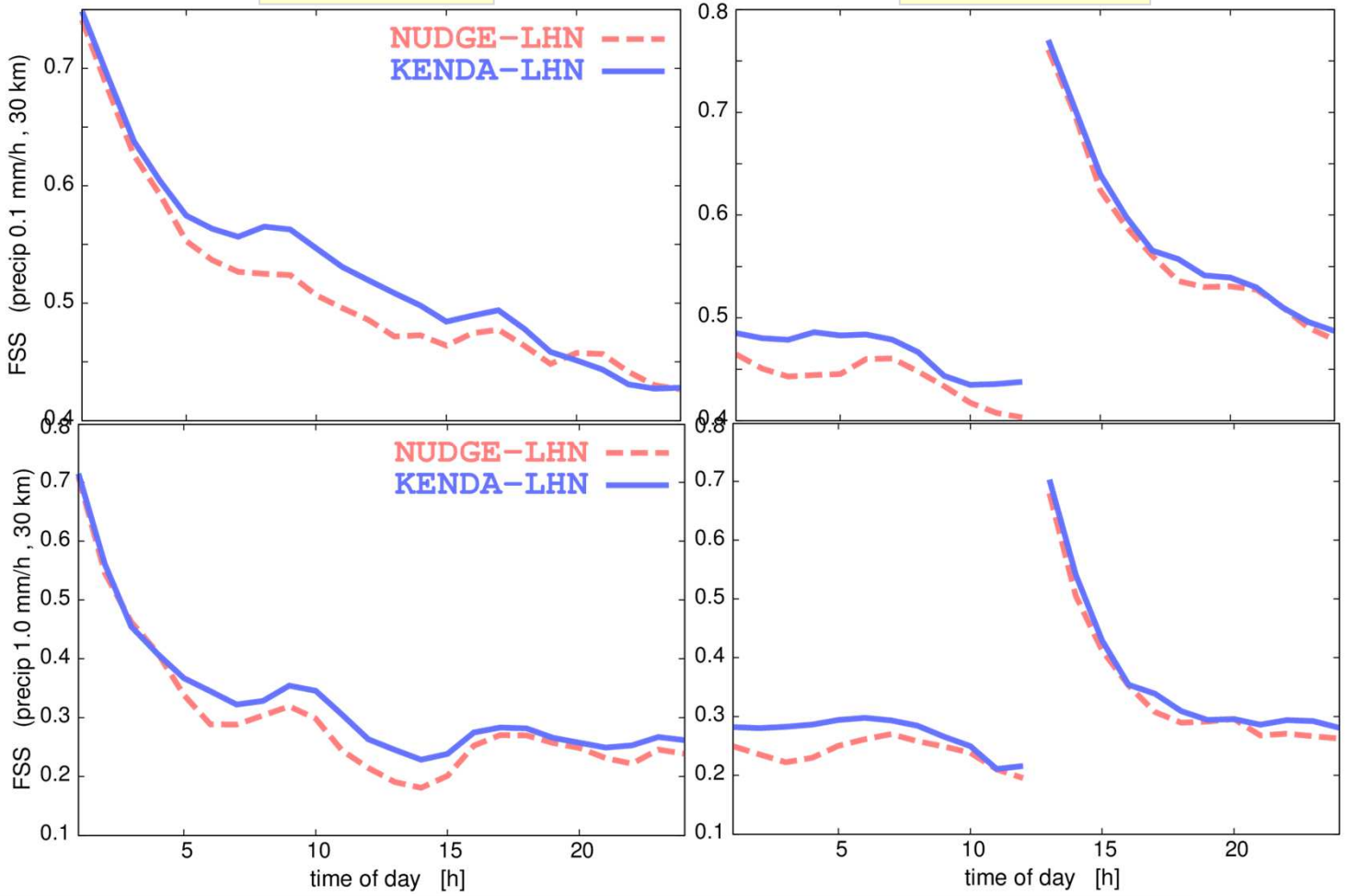
**0**-UTC runs

**12**-UTC runs

**0.1** mm/h

**1-hrly precip FSS ( 30 km )**

**1** mm/h




✓ 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

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

Deutscher Wetterdienst

lots of local, often stationary, heavy convection (high-impact wea.)

**0.1** mm/h

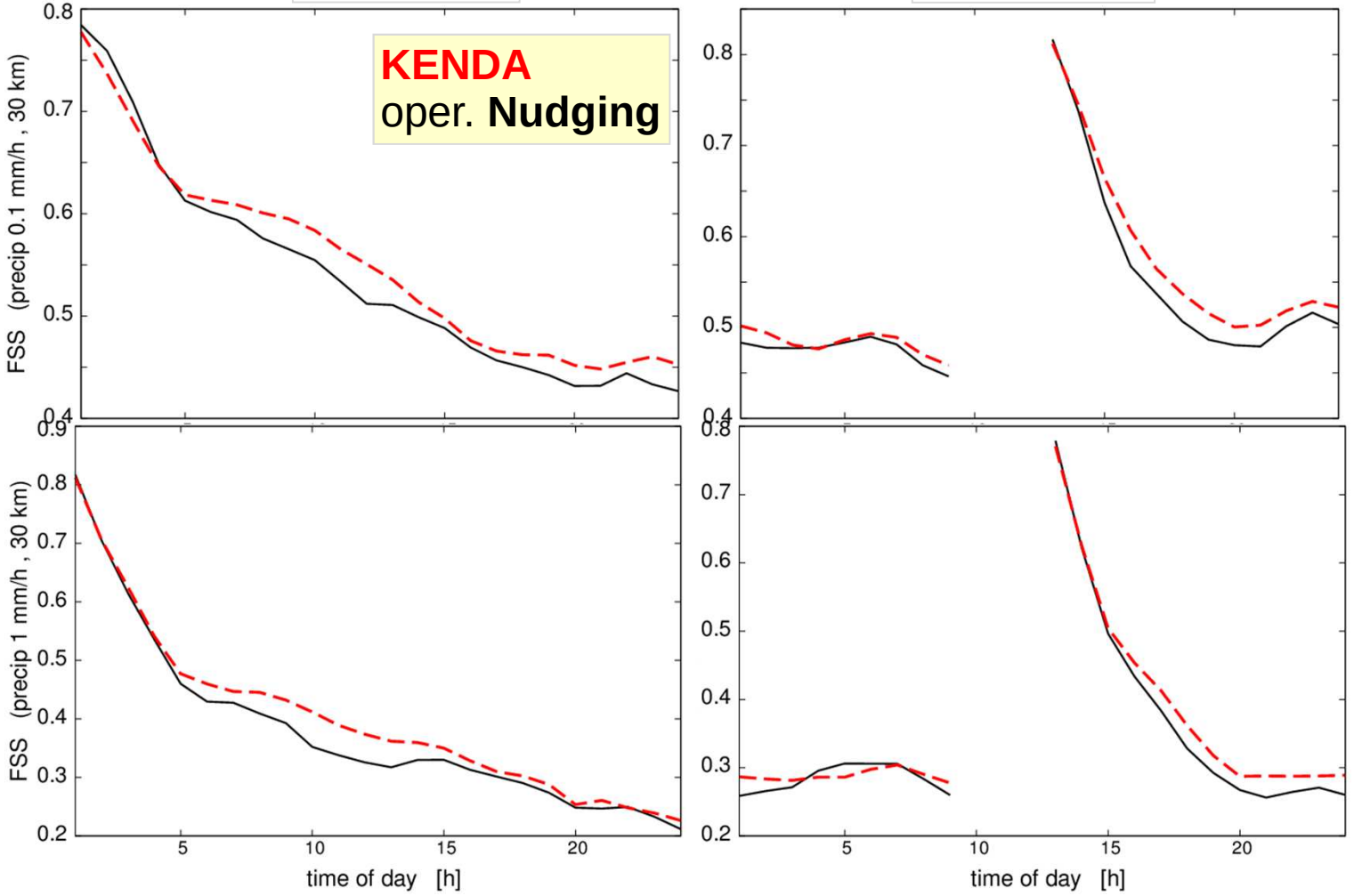
**1-hrly precip FSS ( 30 km )**

**1** mm/h

**0**-UTC runs

**12**-UTC runs

**KENDA**
oper. **Nudging**




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

# pre-operational parallel suite, deterministic: radar verification (26 May – 29 August 2016)

Deutscher Wetterdienst

complete summer (3 months)

**0**-UTC runs

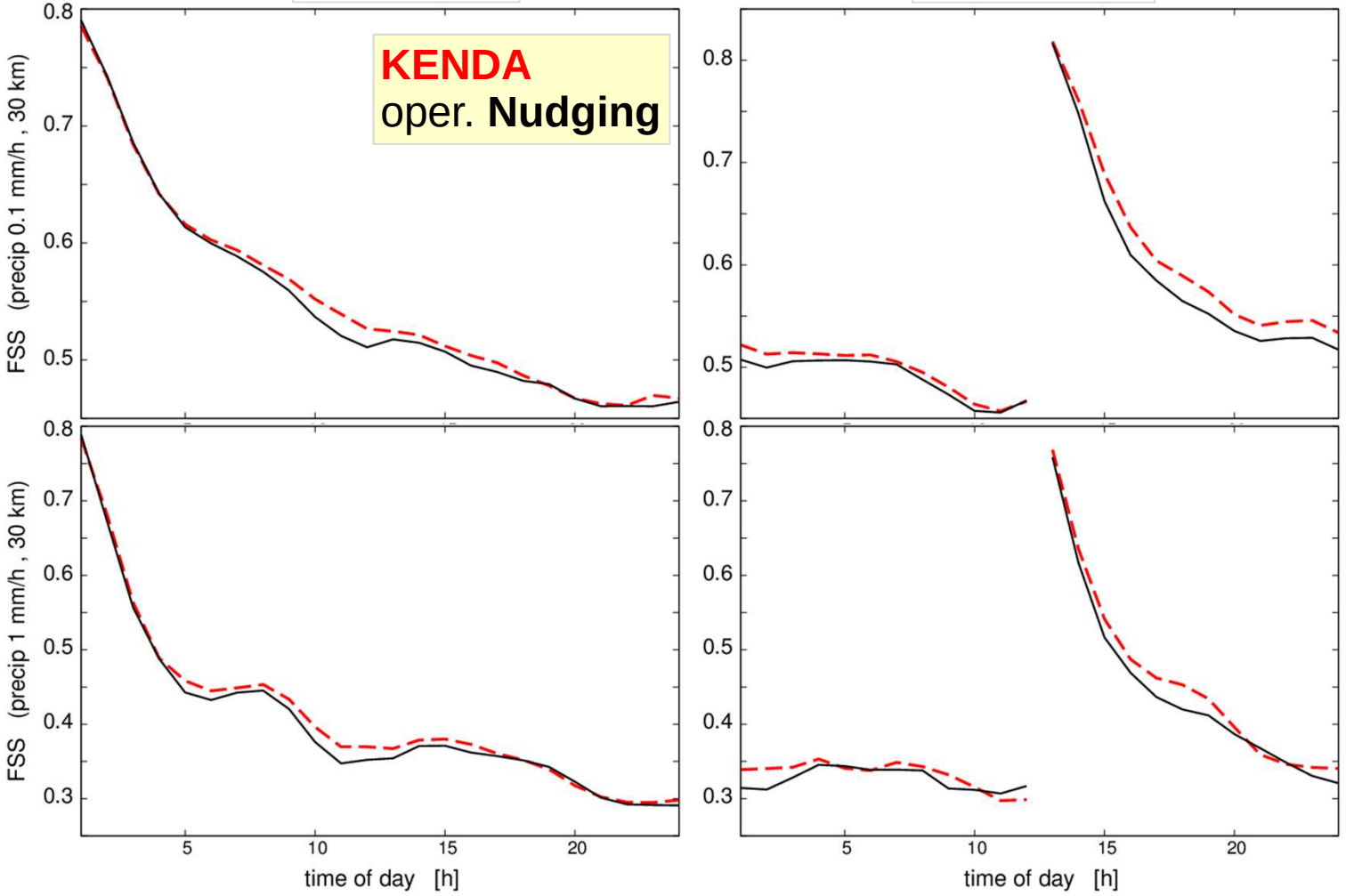
**12**-UTC runs

**KENDA**
oper. **Nudging**

**0.1** mm/h

**1-hrly precip FSS ( 30 km )**

**1** mm/h




✓ KENDA: on average rather small, but long-lasting improvements in summer

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

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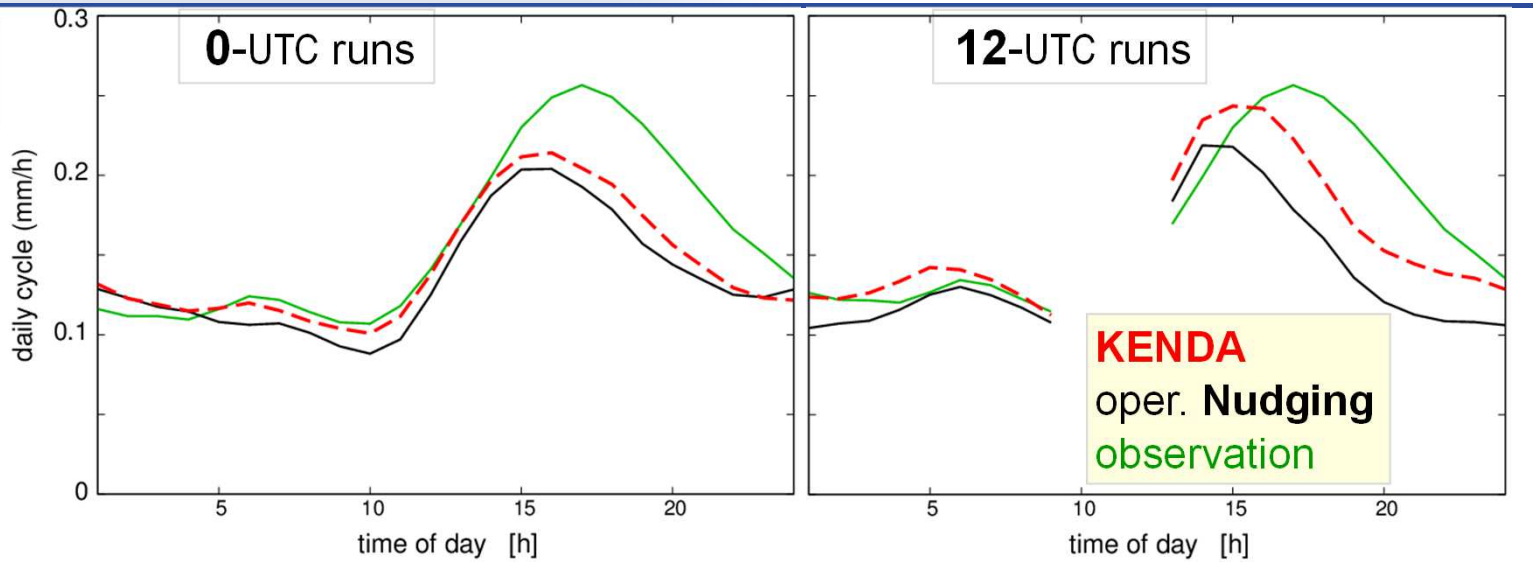
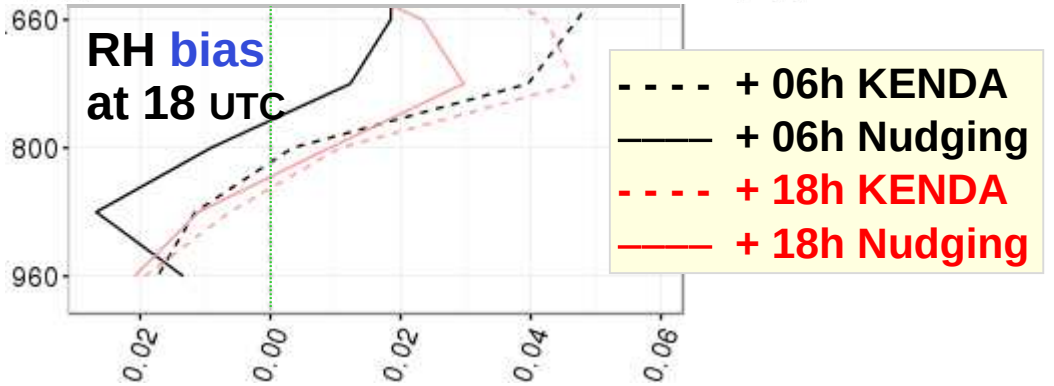
**daily cycle of precip amount**

lots of local, often stationary, heavy convection (high-impact weather)




✓ 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 !

# pre-operational parallel suite, EPS

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- EPS with KENDA IC vs. EPS with nudg./multi-model (operational “COSMO-DE-EPS”)
  - nudg./multi-model: operational deterministic analysis (nudging) + perturbations from 4 global model systems
  - LBC: perturbations from 4 global model systems (“BCEPS”)
  - perturbed physics parameters

*thanks to Christoph Gebhardt + Felix Fundel for plots*

# pre-operational parallel suite, EPS (probabilistic): radiosonde verification (26 July – 31 August 2016)

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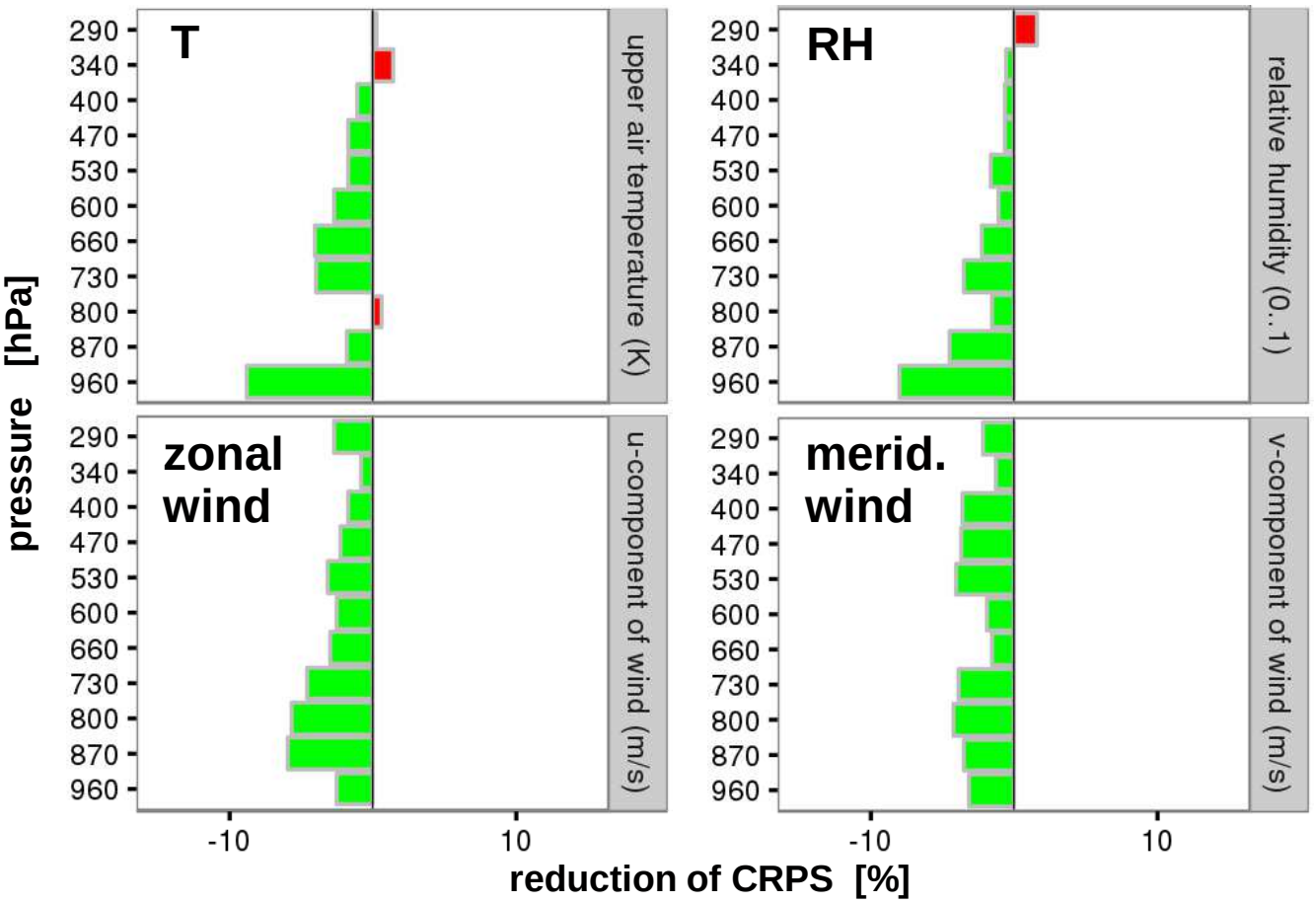
**KENDA-LETKF** vs. nudg./multi-model




**CRPS**
(averaged over lead times & initial times)

better
worse

✓ KENDA: much better CRPS

# pre-operational parallel suite, EPS (probabilistic): radiosonde verification (26 July – 31 August 2016)

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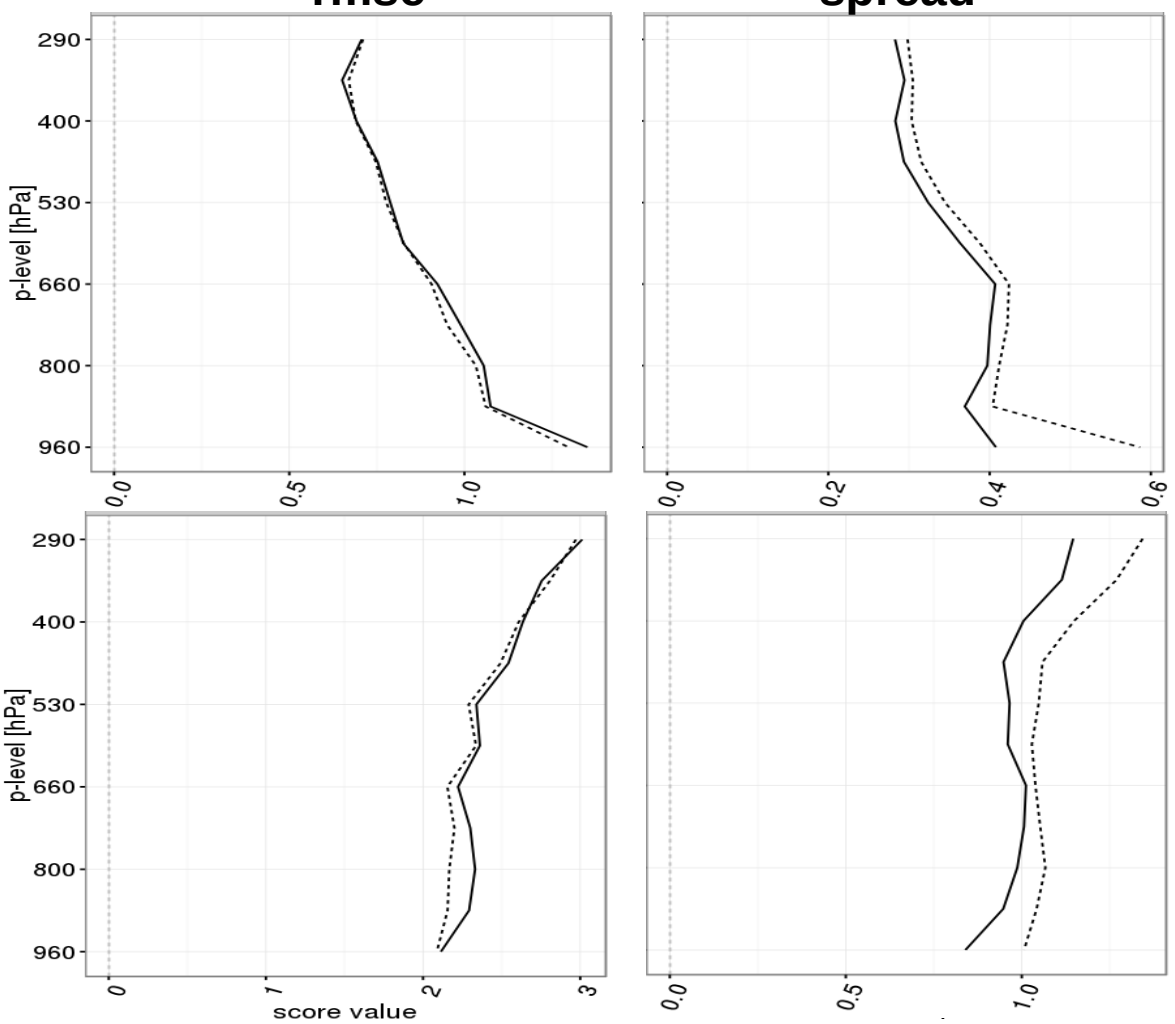
**rmse** **spread**

**temperature**

**wind speed**




**- - - - KENDA**
——— nudg./multi-model

**12-h forecasts**

✓ KENDA: much better (larger) spread, also slightly smaller errors (rmse)

# pre-operational parallel suite, EPS (probabilistic): surface verification (26 July – 31 August 2016)

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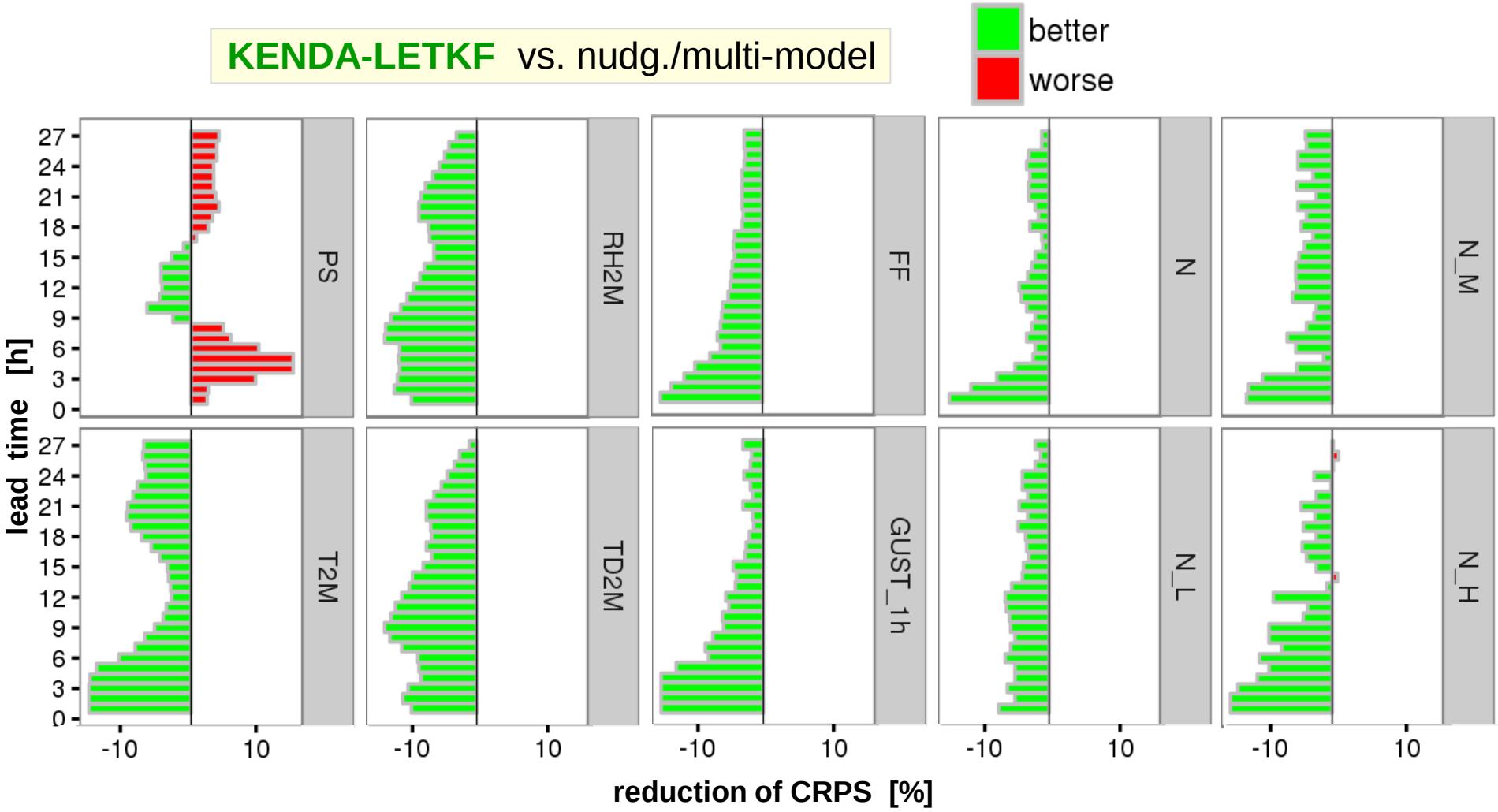
**KENDA-LETKF** vs. nudg./multi-model




✓ KENDA: much better CRPS in all variables except surface pressure

# pre-operational parallel suite, EPS (probabilistic): surface verification (26 July – 31 August 2016)

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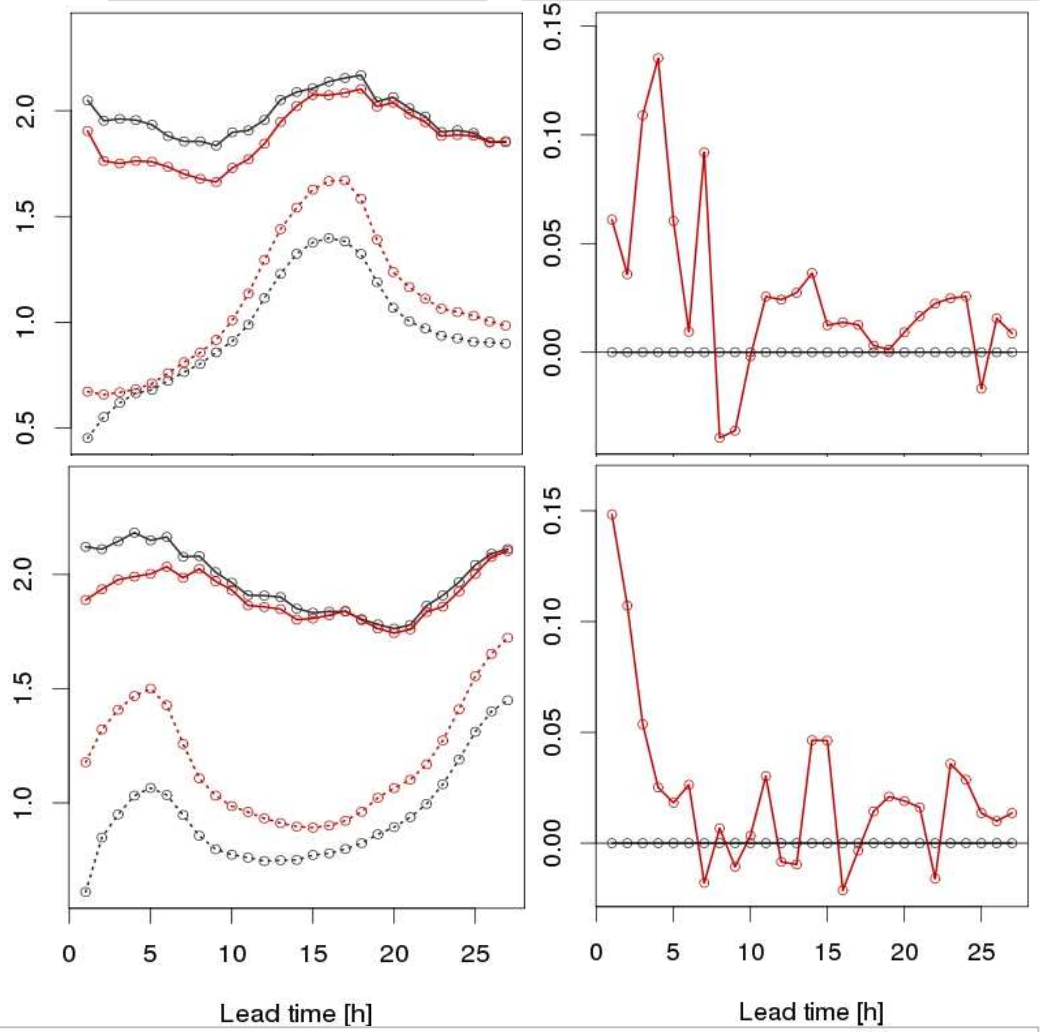
**10-m wind gusts**

**0**-UTC runs

**KENDA-LETKF**
nudg./multi-model

**12**-UTC runs




✓ KENDA: better spread + skill + BSS (for 14 m/s + 18 m/s, due to improved reliability)

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

Deutscher Wetterdienst

1-hrly **precipitation**

**Brier skill score** (averaged over lead times 1 – 27 h)

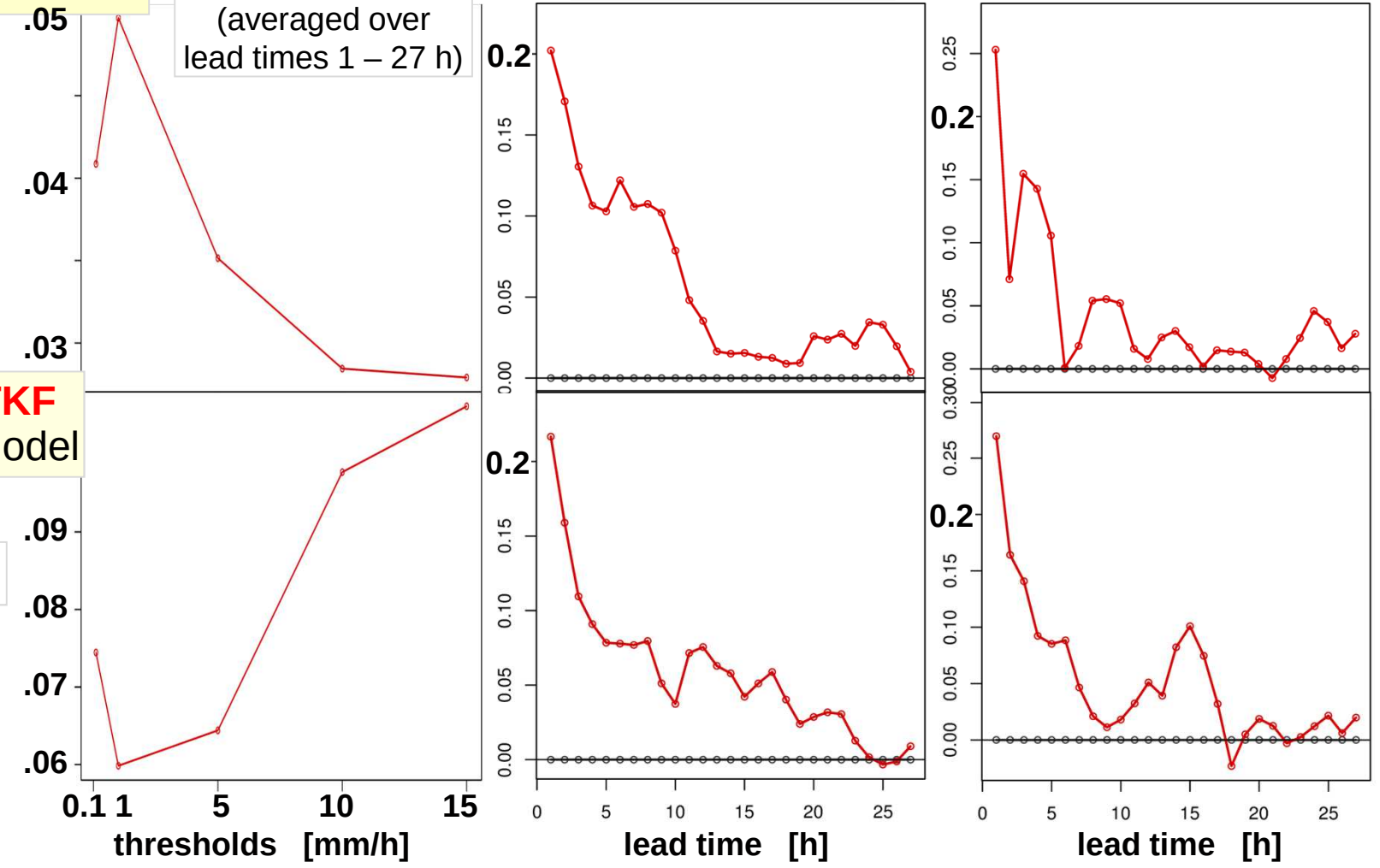
**BSS 1** mm/h

**BSS 5** mm/h

**0**-UTC runs

**KENDA-LETKF** nudg./multi-model

**12**-UTC runs




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

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

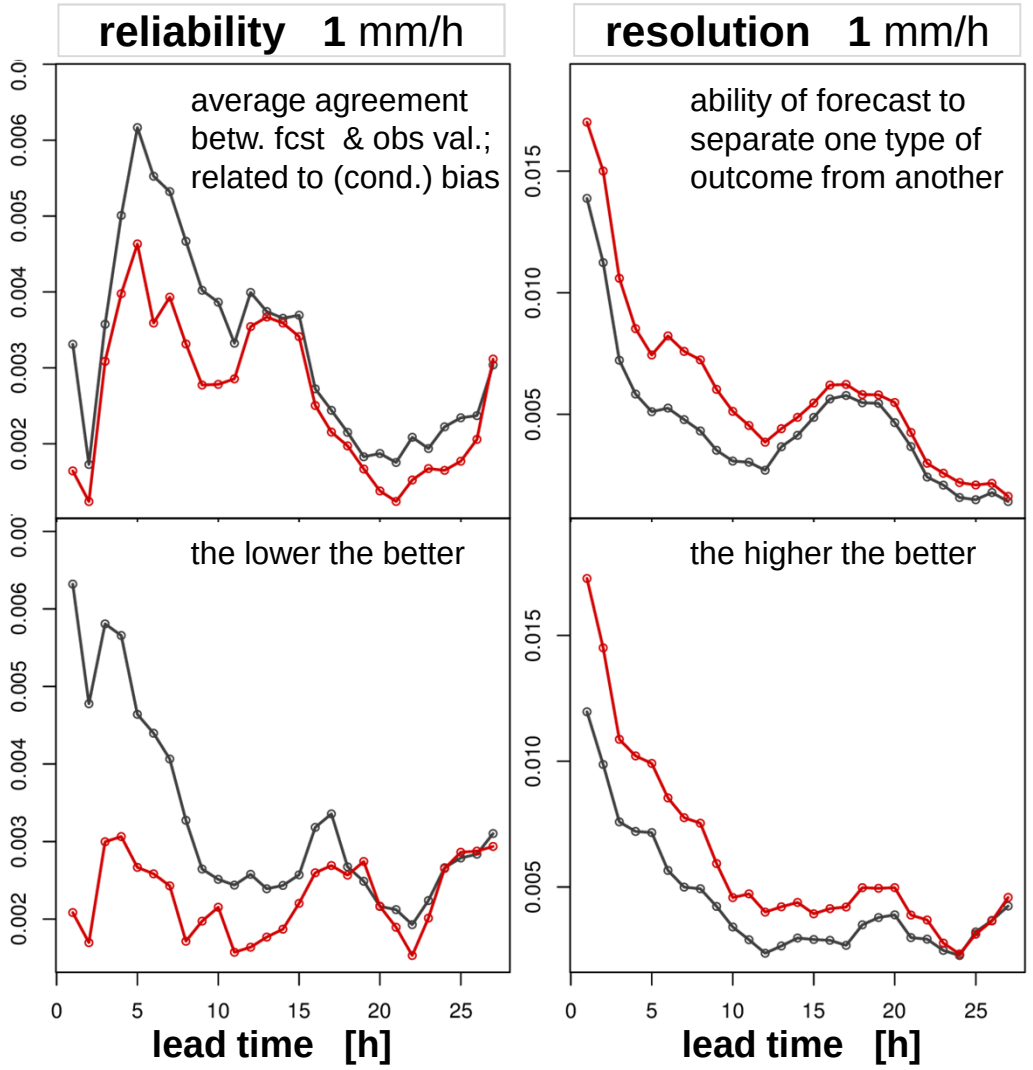
Deutscher Wetterdienst

**precipitation**

**0**-UTC runs

**KENDA-LETKF**
nudg./multi-model

**12**-UTC runs




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

# pre-operational parallel suite, EPS (probabilistic): radar verification (26 July – 31 August 2016)

Deutscher Wetterdienst

1-hrly **precipitation**

**Brier skill score** (averaged over lead times 1 – 27 h)

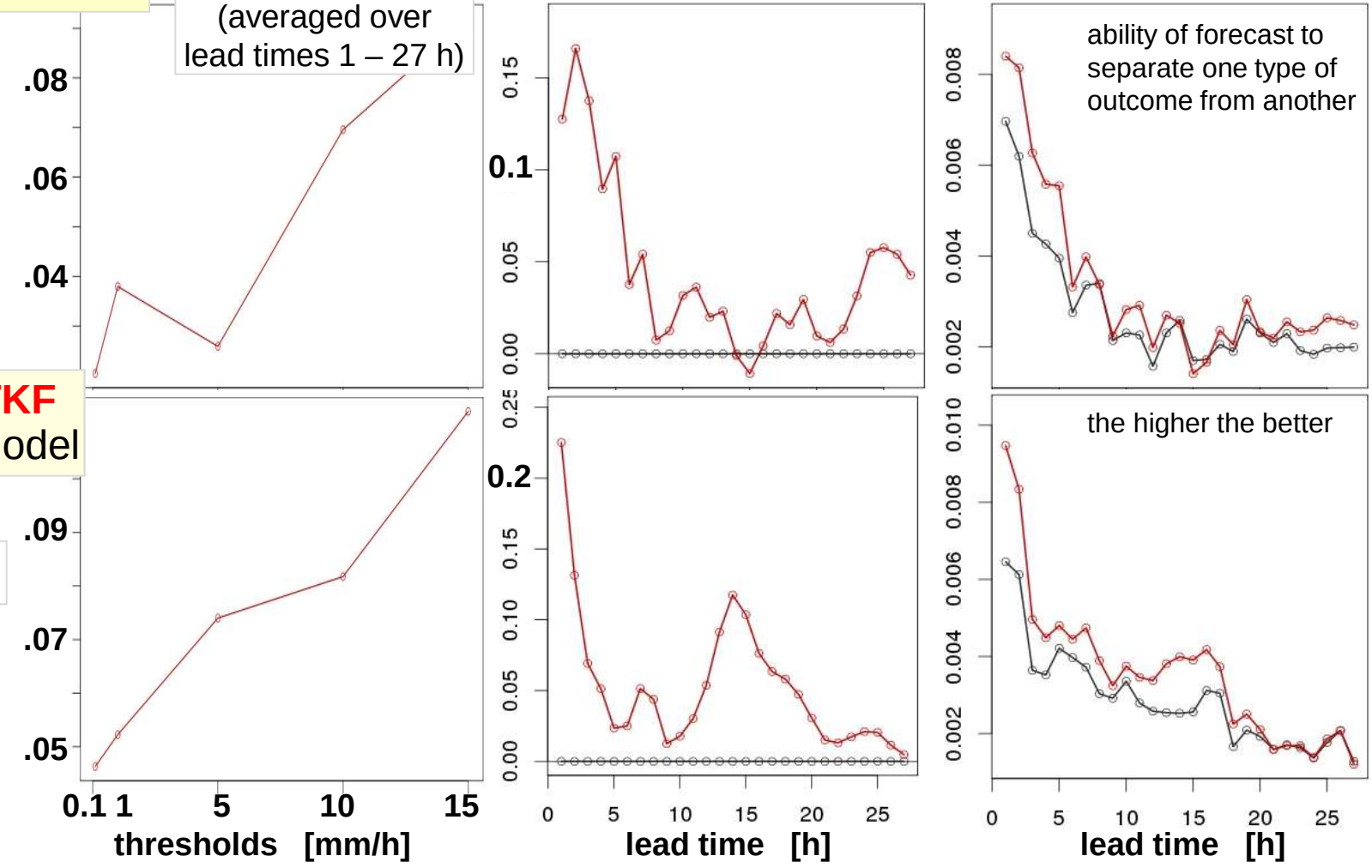
**BSS** **1** mm/h

**resolution** **1** mm/h

**0**-UTC runs

**KENDA-LETKF** nudg./multi-model

**12**-UTC runs




✓ KENDA: BSS (resolution (neutral for 0.1mm/h) + reliability) better for all thresholds, long-lasting

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)
  - all variables, in particular (convective) precipitation, except surface pressure clearly improved (errors and in particular spread, ensemble scores)

→ KENDA operational in late 2016 or 1st half 2017, depends on
  - data base
  - winter period with pre-operational configuration (LBC!), keep an eye on wind gusts

# outlook: KENDA for ICON

- Task, starting 2017: port KENDA from COSMO to **ICON-regional**

  → implement also hybrid (4-D) EnVar and compare with pure 4-D LETKF

  motivated by some advantages:

  – very positive experience with (3-D) EnVar for global ICON;
  KENDA 4-D LETKF: large improvement for EPS, not for deterministic

  – certain advantages of VAR (localisation, variational bias correction & QC,…) and hybrid approach (hybrid B)

  – further code unification with global DA at DWD

  – nudging not available any more for ICON-regional:
  → capability to use KENDA analysis code without need to run ensemble:
  3DVar, or use global ensemble for ensemble perturbations in EnVar

  some disadvantages:

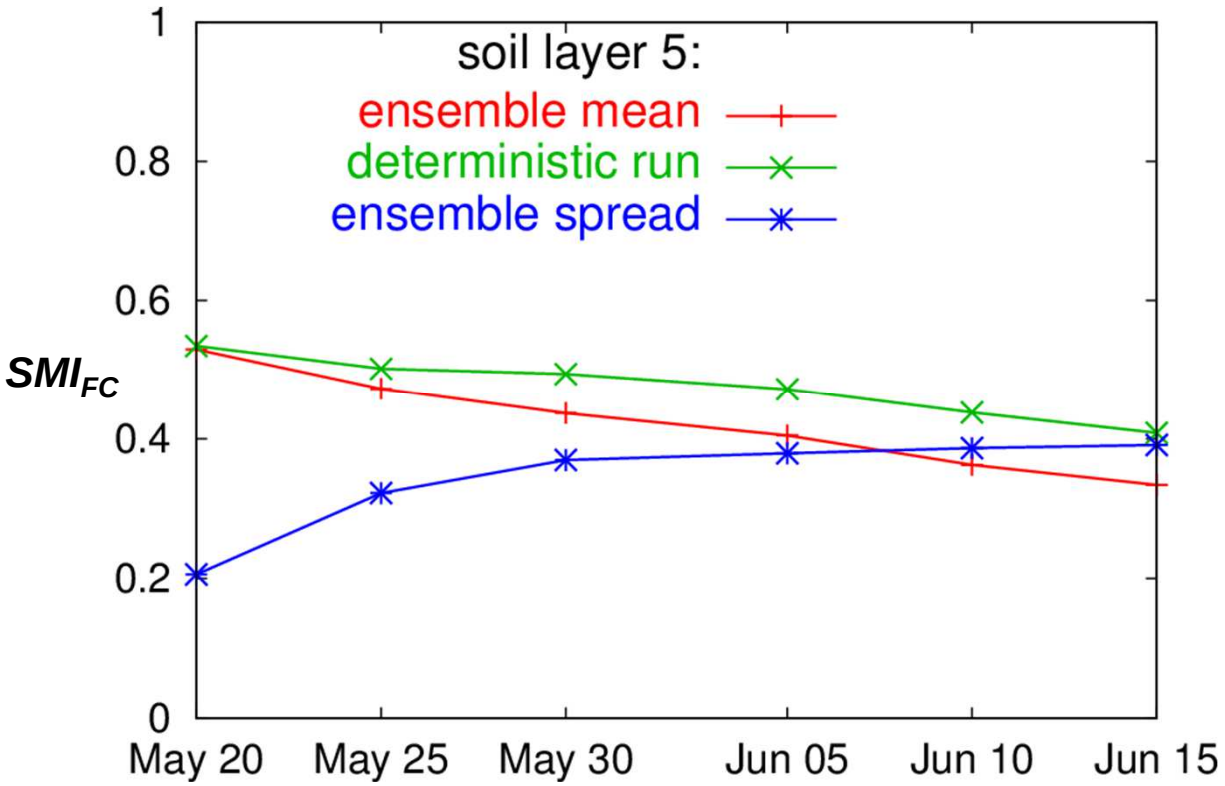
  – limited 4-D capability , need to interpolate, lot of I/O

  – increased complexity, need of tangent linear / adjoint obs operators

# KENDA system: outlook

# 2015: "remaining problem": explicit soil moisture perturbations






**soil layer 5 (27 – 81 cm)** (and 4):

- **drift** (**bias**) of mean of perturbed ensemble vs. unperturbed det.
- **spread** becomes (too) large

(no problems for soil layers 1 - 3)

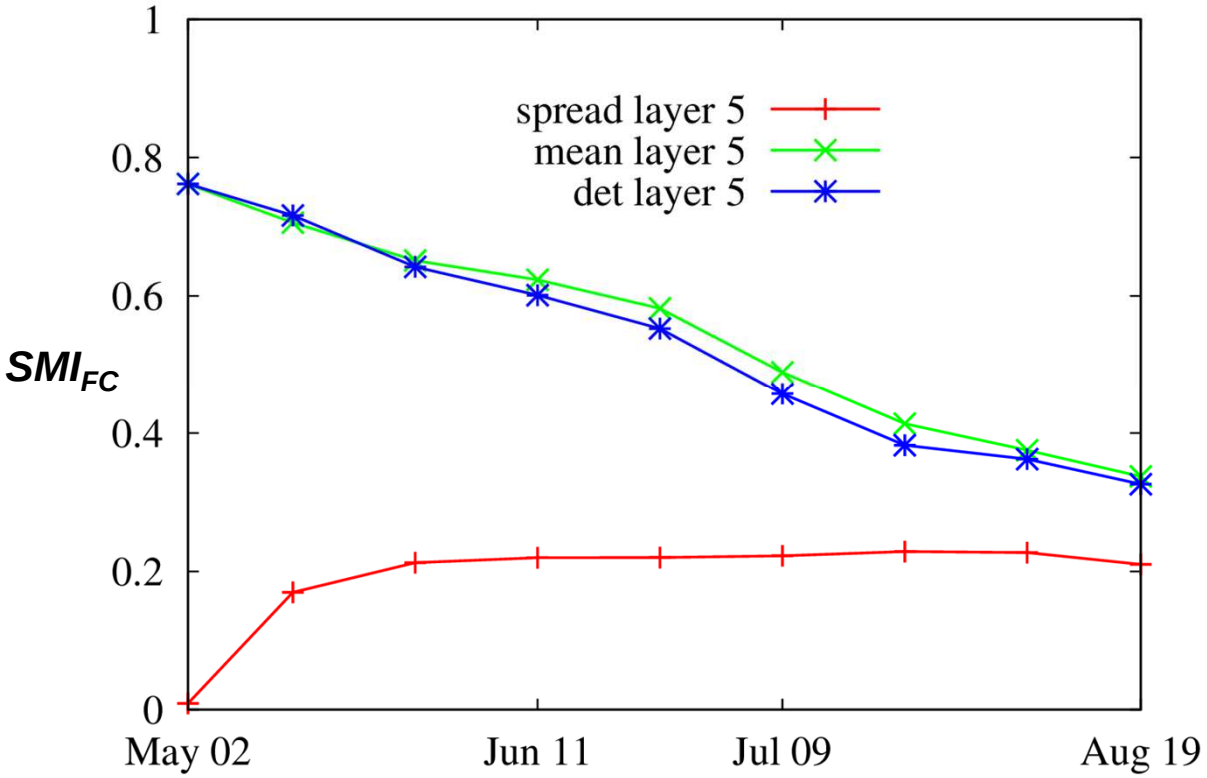
→ implemented in pre-operational suite:

✓ drift: relaxation of ensemble mean to deterministic soil moisture

✓ spread: amplitude of explicit soil moisture perturbations decreased at lower layers, in particular layer 5

# pre-operational parallel suite: explicit soil moisture perturbations





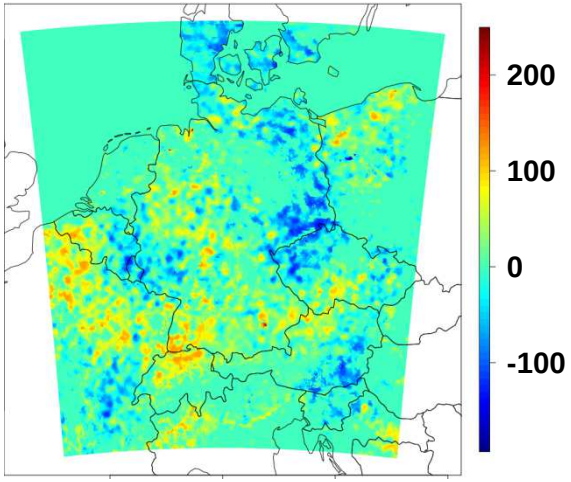

**soil layer 5 (27 – 81 cm)** (and 4):

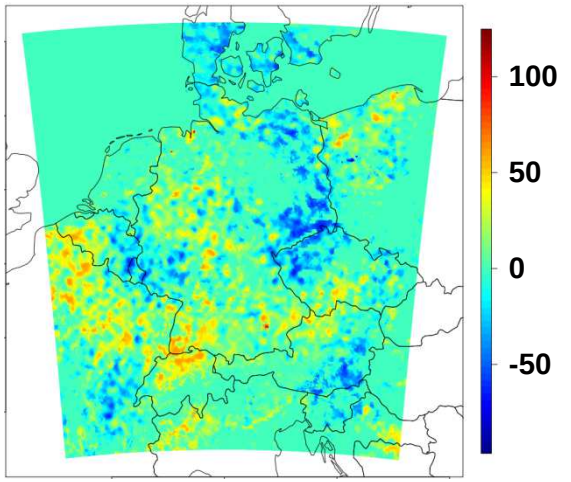
- ✓ **drift** (**bias**) of mean of perturbed ensemble vs. unperturbed det. strongly reduced
- ✓ **spread** ≤ 22 % , no further increase

# pre-operational parallel suite: soil moisture perturbations (24 August 2016)

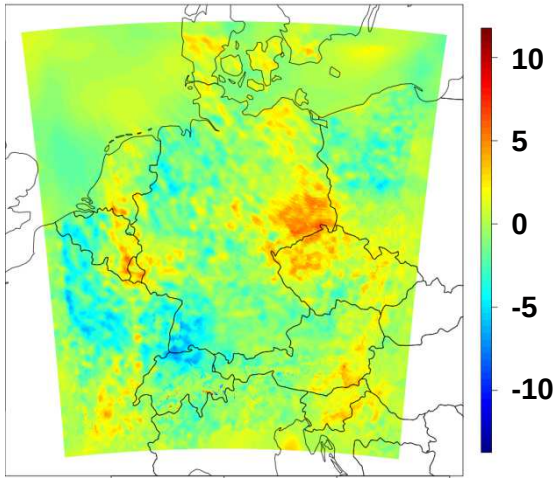
Deutscher Wetterdienst

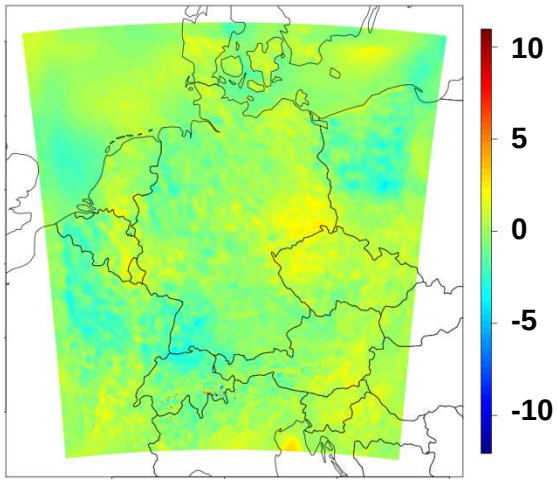
**soil moisture layer 5, diff. betw. 2 mem.** (1,8)




**T2m at noon, diff. betw. 2 mem.** (1,8)




standard soil moisture perturb.:

→ T2m deviations of individual ensemble members unrealistically large in some situations

test: soil moisture perturbations reduced by 50 % :

→ T2m deviations realistic

→ will implement limiter to spread of soil moisture index and assess impact on LETKF (spread)

some further work

- adaptive multiplicative inflation with obs errors estimated by Desroziers statistics
- additive inflation, e.g. stochastic pattern generator
- noise control:  incremental analysis update,  use of IC as initial LBC
- Kalman smoother
- 80 ensemble members
- ICON :  see later

# pre-operational parallel suite, EPS (probabilistic): surface verification (26 July – 31 August 2016)

Deutscher Wetterdienst

**2-m temperature**

**0**-UTC runs

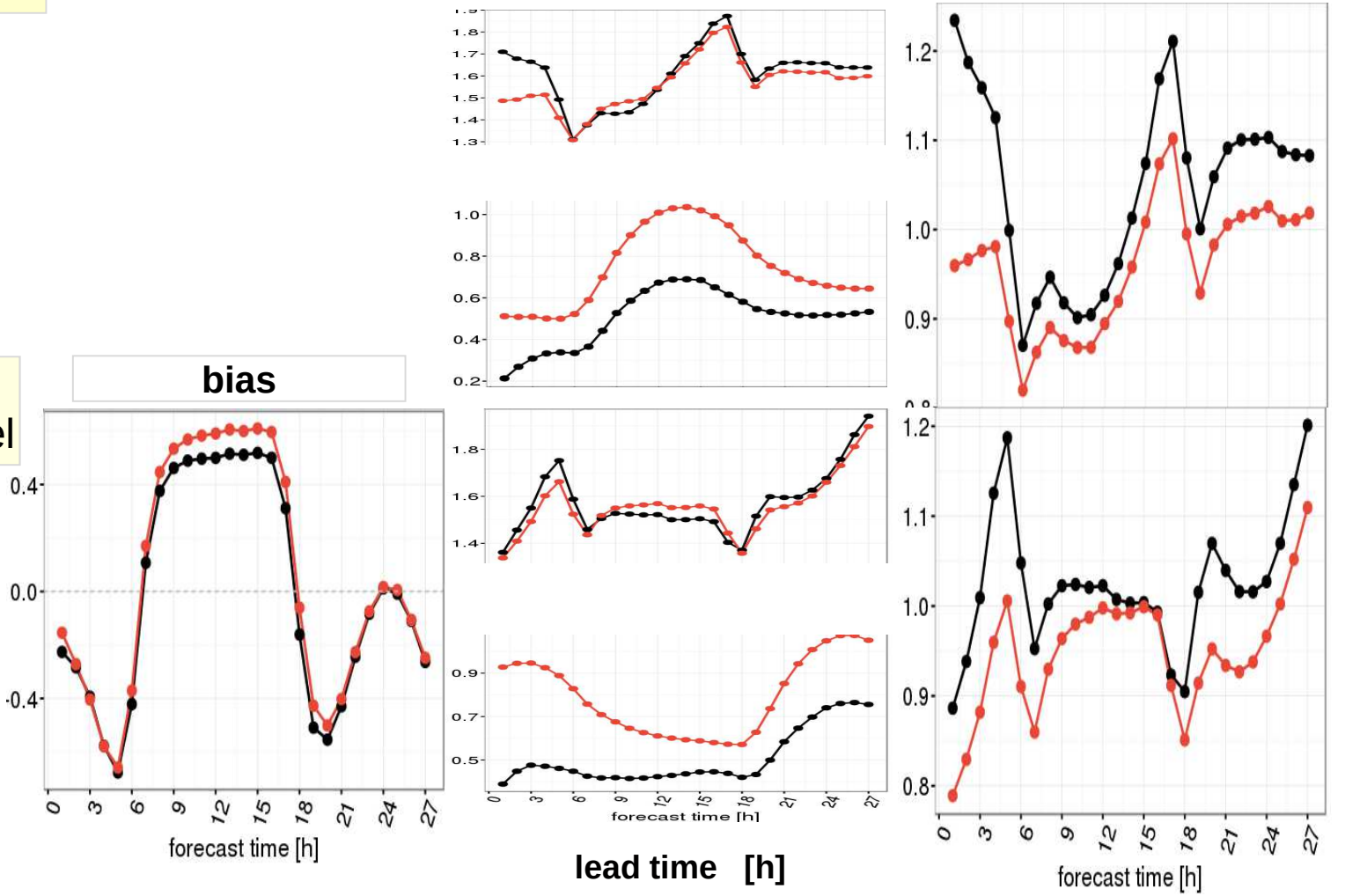
**KENDA-LETKF**
nudg./multi-model

**12**-UTC runs

**spread / rmse**

**CRPS**

**bias**




**lead time [h]**

✓ KENDA: spread + CRPS clearly improved, errors improved except for bias issue

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

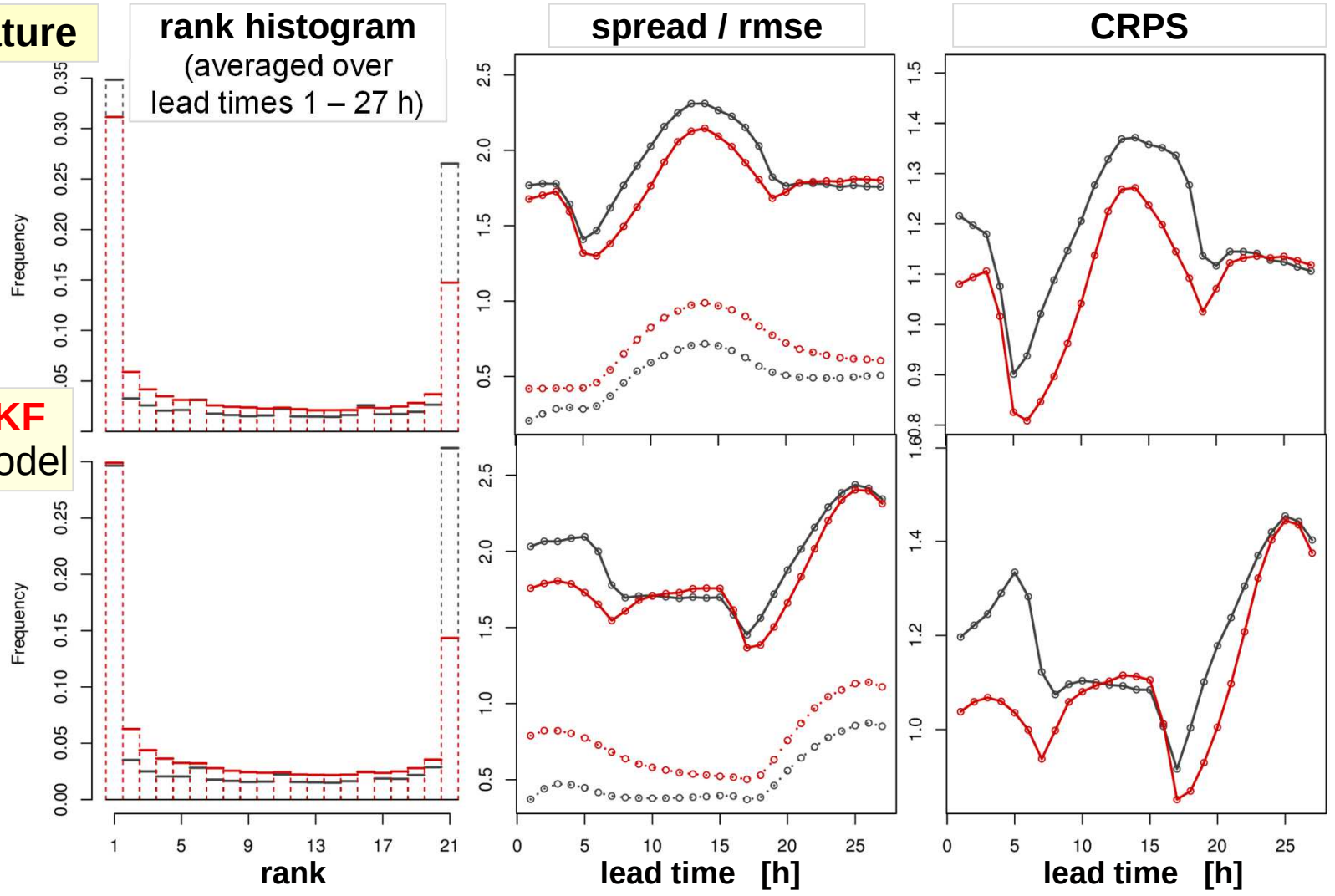
Deutscher Wetterdienst

**2-m temperature**

**KENDA-LETKF**
nudg./multi-model

**0**-UTC runs

**12**-UTC runs




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

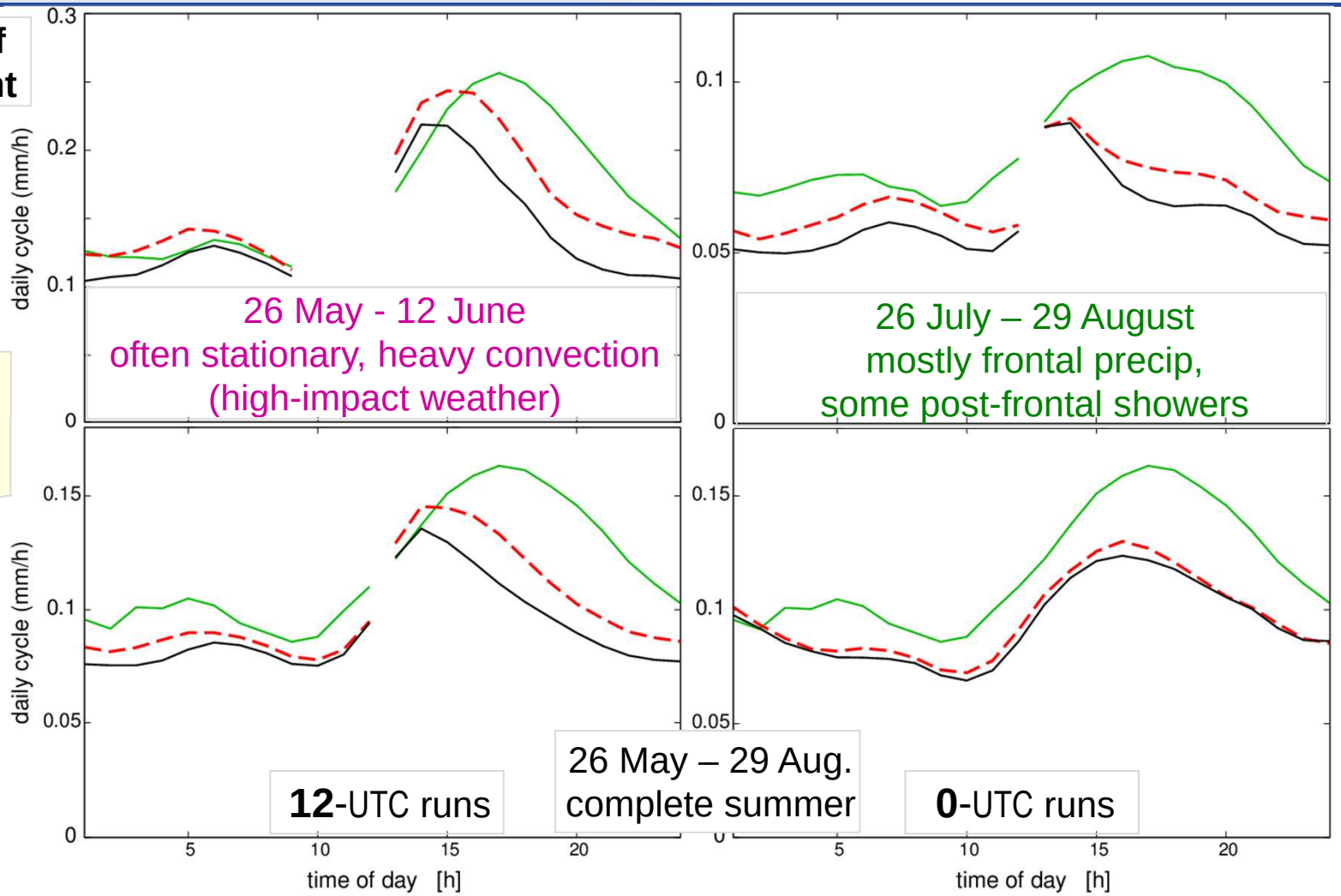
# pre-operational parallel suite, deterministic: radar verification

Deutscher Wetterdienst

**daily cycle of precip amount**

**12**-UTC runs

**KENDA**
oper. **Nudging**
observation

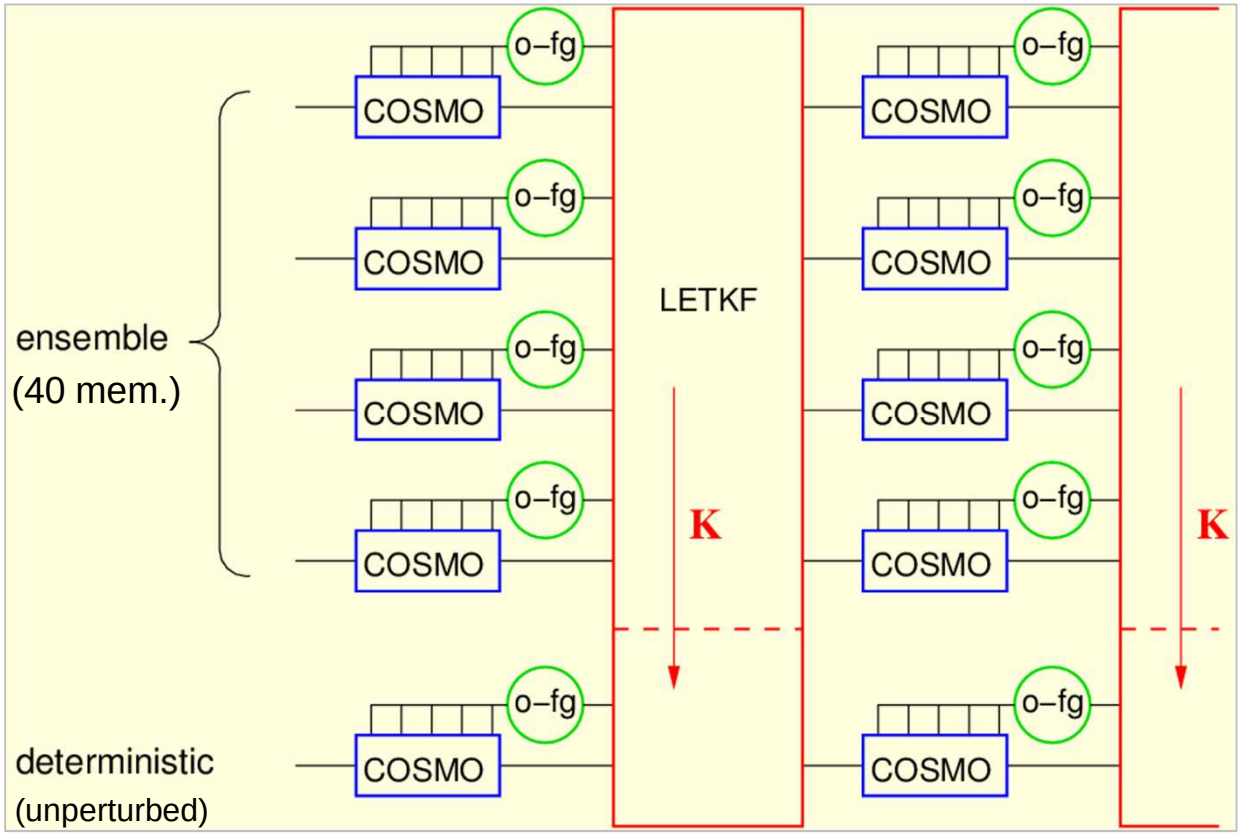



✓ better daily cycle of precip mainly for 12-UTC runs in convective situations

# KENDA-LETKF:
# setup, with deterministic analysis / forecast

Deutscher Wetterdienst

LETKF: **KENDA**




→ **4D** –LETKF

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

→ benchmark: **Nudging**