PP KENDA final report

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PP KENDA: overview

- Task 1: General issues in the convective scale , to decide on LETKF
  (e.g. occurrence and effects of non-Gaussianity in COSMO-DE-EPS)

- Task 2: Implementation of LETKF system
  → MEC (Model Equivalent Calculator) for feedback files (verification)

- Task 3: Main development (tuning, refinement, testing) of LETKF, comparison with nudging (using conventional obs)
  - Stochastic Perturbation of Physics Tendencies (*Torrisi, CNMCA*)
  - Stochastic Pattern Generator (*Tsyrulnikov, Gayfullin, HMC*)

- Task 4: Use of additional (high-resolution) observations

MEC (Model Equivalent Calculator)

- first version disseminated for testing + use
  - with documentation, test cases for deterministic and ensemble forecasts
  - for verification of conventional obs
- some pending issues
  - verification of time-accumulated quantities
  - some technical issues
    (e.g. need to use same model domain / resolution for first creation of feedback file and for forecasts for which model equivalents are computed)
- future : extend to non-conventional obs

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3-D radar radial velocity and reflectivity

- obs operator implemented, superobbing, thinning,
- tuning, sensitivity tests with LETKF , impact studies

GPS slant path delay *(Bender, DWD)*

- obs operator implemented, technically ready for DA experiments

Use of cloud top height (CTH) derived from satellite (SEVIRI) data

- obs operator implemented, LETKF single-obs experiments
- sensitivity tests and impact studies for low-stratus periods

Use of direct satellite radiances for assimilation of cloud information

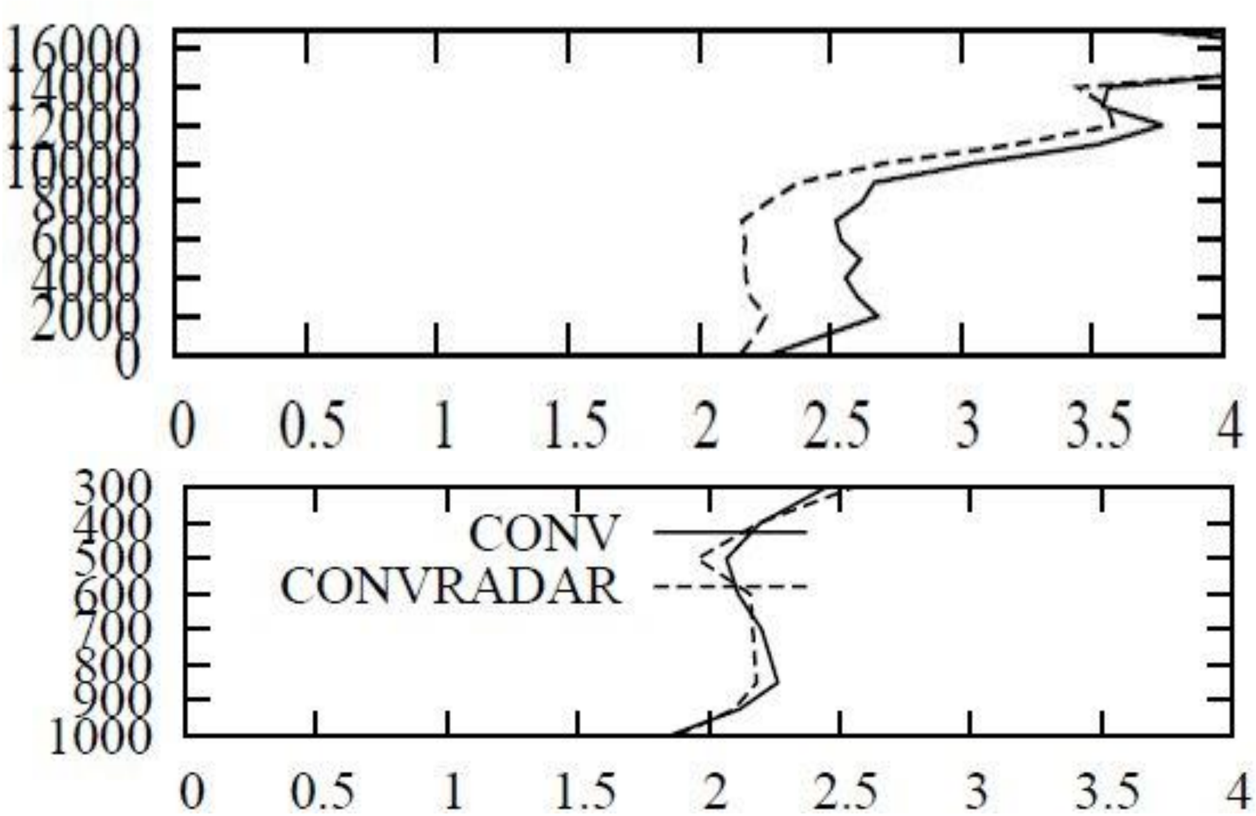
- first DA exp. over several days : benefit for f.g. simulated radiances

Raman lidar (qv-profile) & microwave radiometer (T-profile) delay *(Haefele, MCH)*

- innovation statistics of obs at Payerne with COSMO-2 forecasts

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

LETKF: use of radar reflectivity → *Theresa Bick et al* impact study (7 day period)

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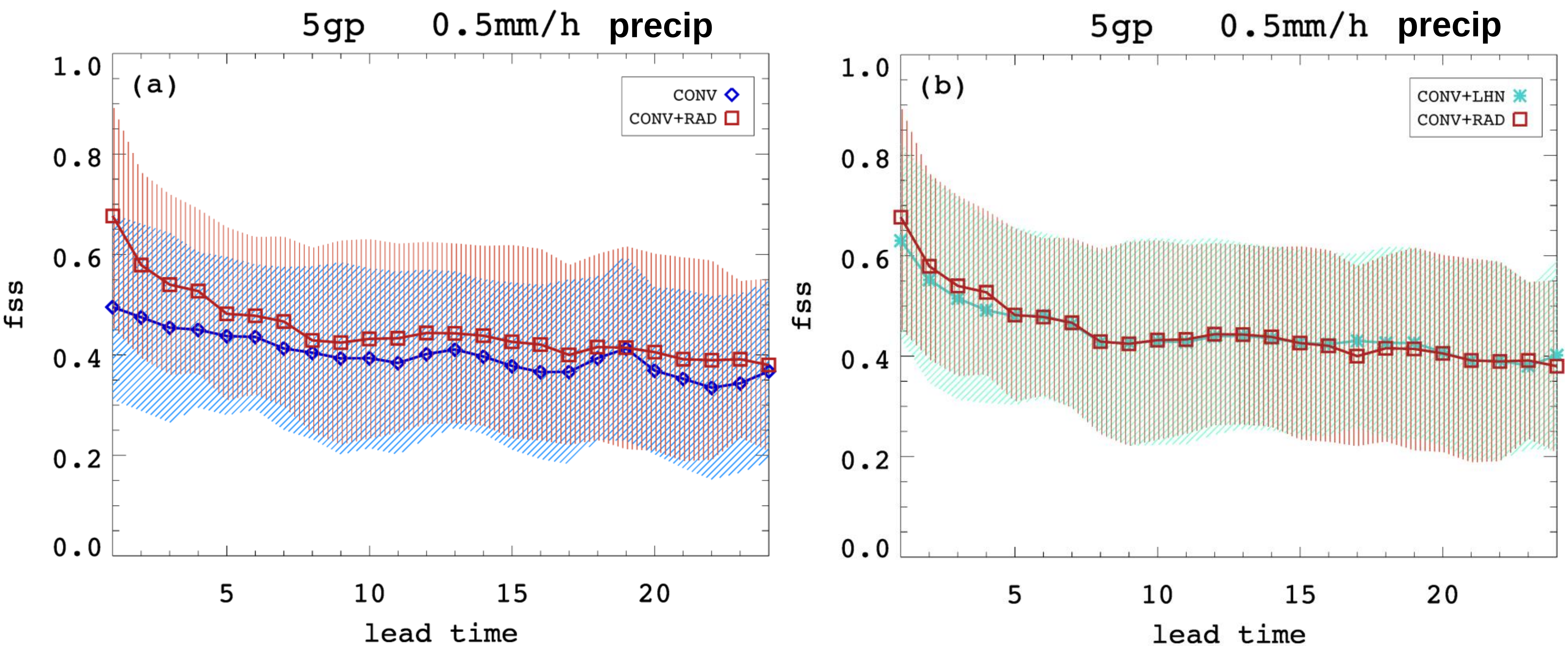
7 days: 22 – 29 May 2014

CONV
CONV + RAD

– mean FSS (precip) over **19** forecasts
– 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

radar radial velocity (5-day period)

- (small) positive impact on 1-hr forecast of upper-air wind

radar reflectivity (7-day period)

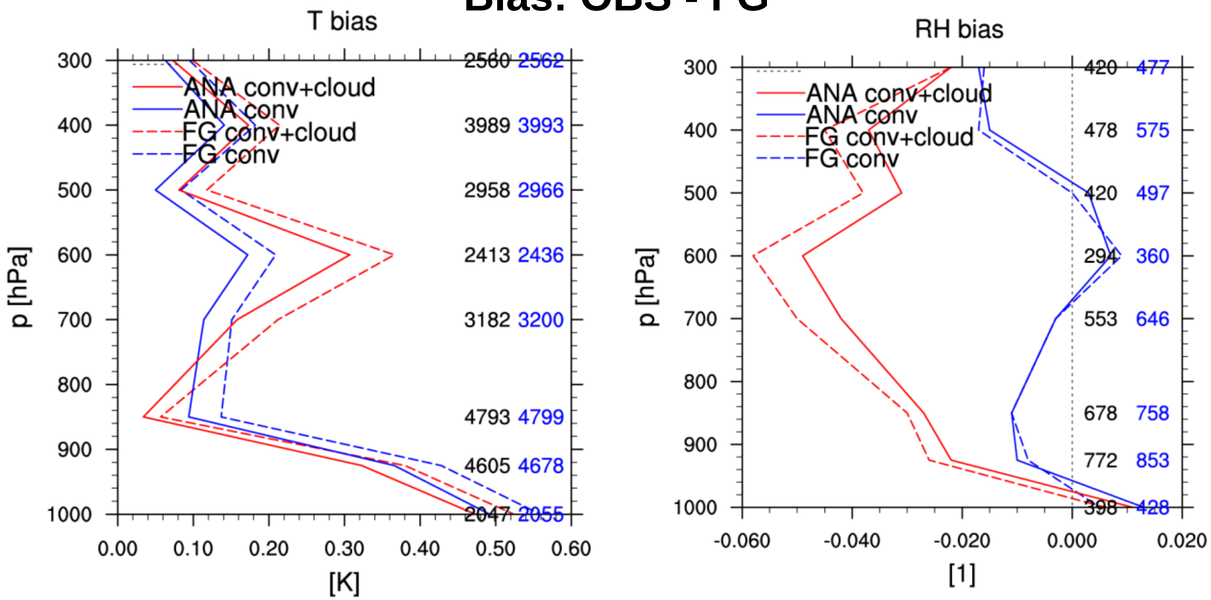
- long-lasting positive impact on precip, slightly better than LHN
- (small) positive impact on 1-hr forecast of upper-air wind, better than LHN
- small positive impact in surface verification, not as good as LHN

further steps

- quality control
- balance impact of precip vs. non-precip obs / (4-D) radar vs. conventional obs
- thinning / superobbing, obs errors, localization, Gaussianity (variable transform?)
- more test periods

upper-air verification for 83 hours cycled assimilation starting 12 Nov. 2011, 12 UTC

Bias: OBS - FG

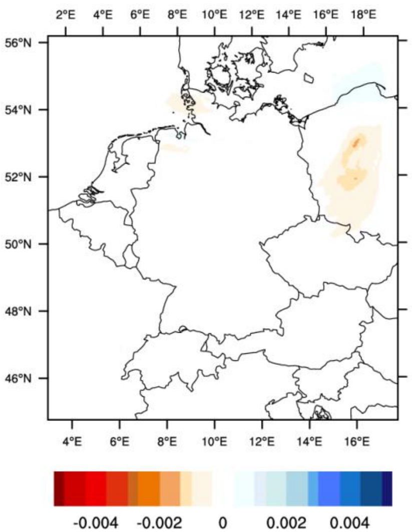


assimilation of conventional obs only
assimilation of conventional + cloud obs

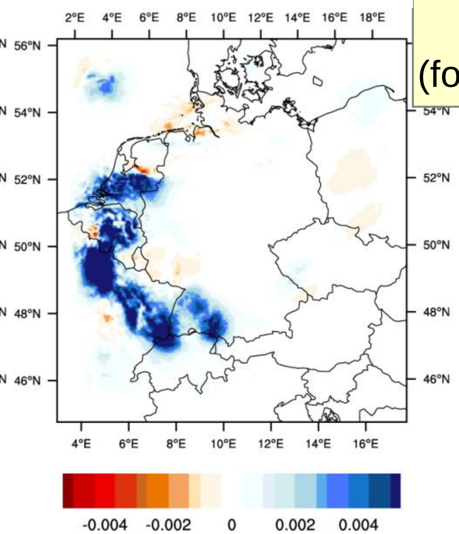
→ cold and strong moist bias in mid-levels ! Why ?

LETKF: use of **satellite cloud top height data** application to low stratus period

conventional only

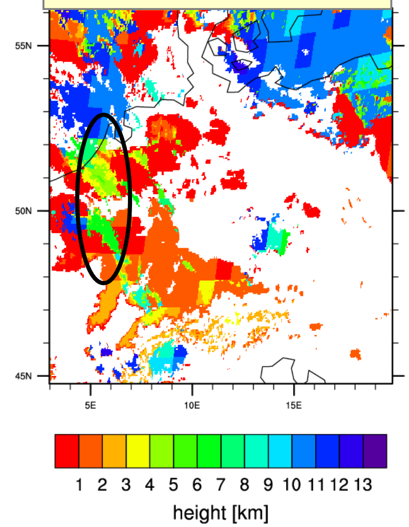


conv + cloud

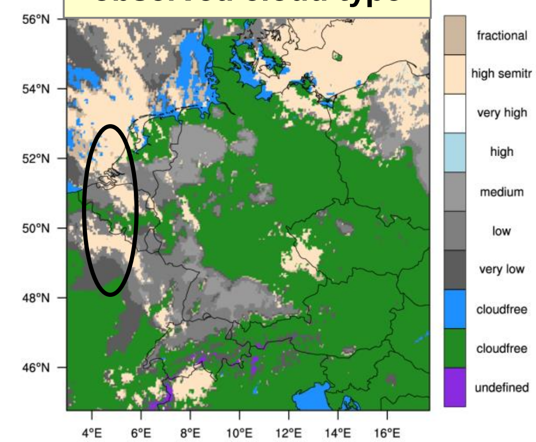


mid-level moisture analysis increment
(for 13 Nov. 2011, 12 UTC)

'observed' cloud top height



observed cloud type



→ mid-level moisture increment in low-stratus situation ! Why ?

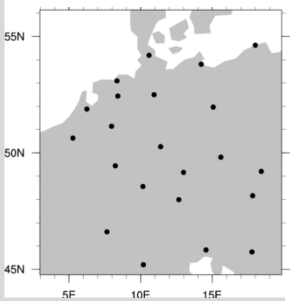
→ problems caused by incorrect cloud top height in NWCSAF cloud top height product

LETKF: use of **satellite cloud top height data** application to low stratus period

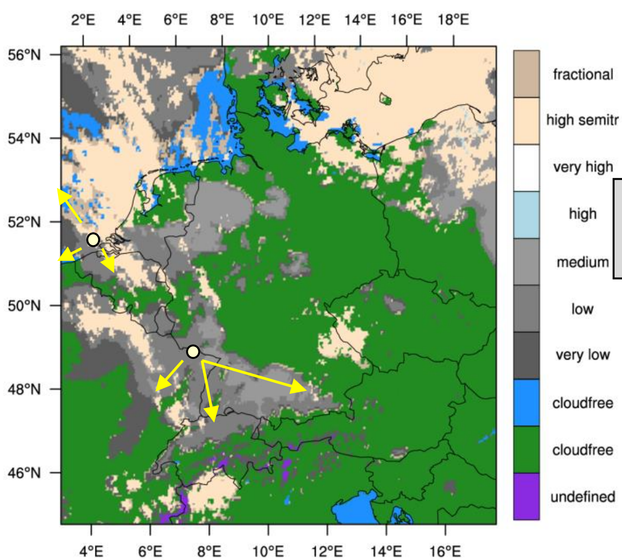
pre-processing to merge satellite and radiosonde cloud top height information (cloud analysis):

use nearby radiosondes within the same cloud type to determine quality flag

Radiosondes: coverage

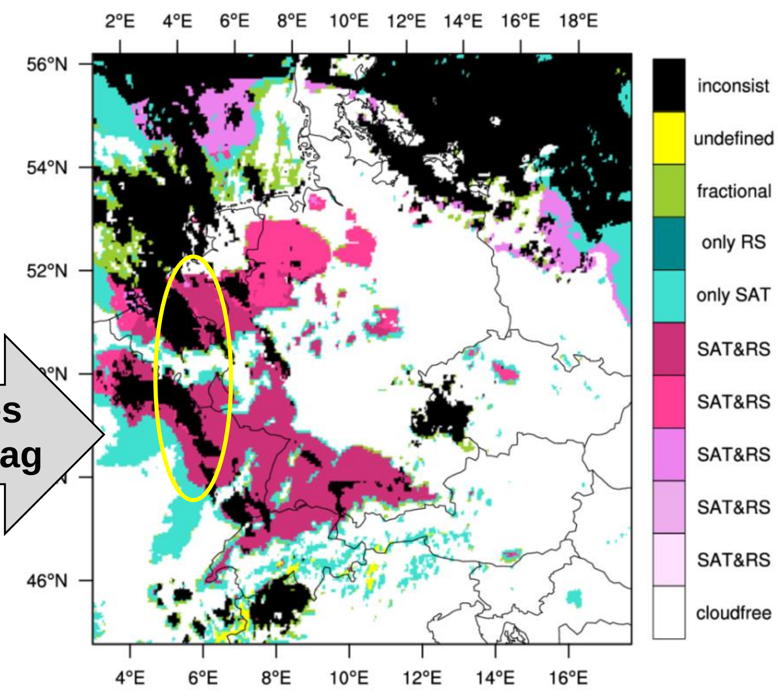


Satellite cloud type



provides quality flag

Flag

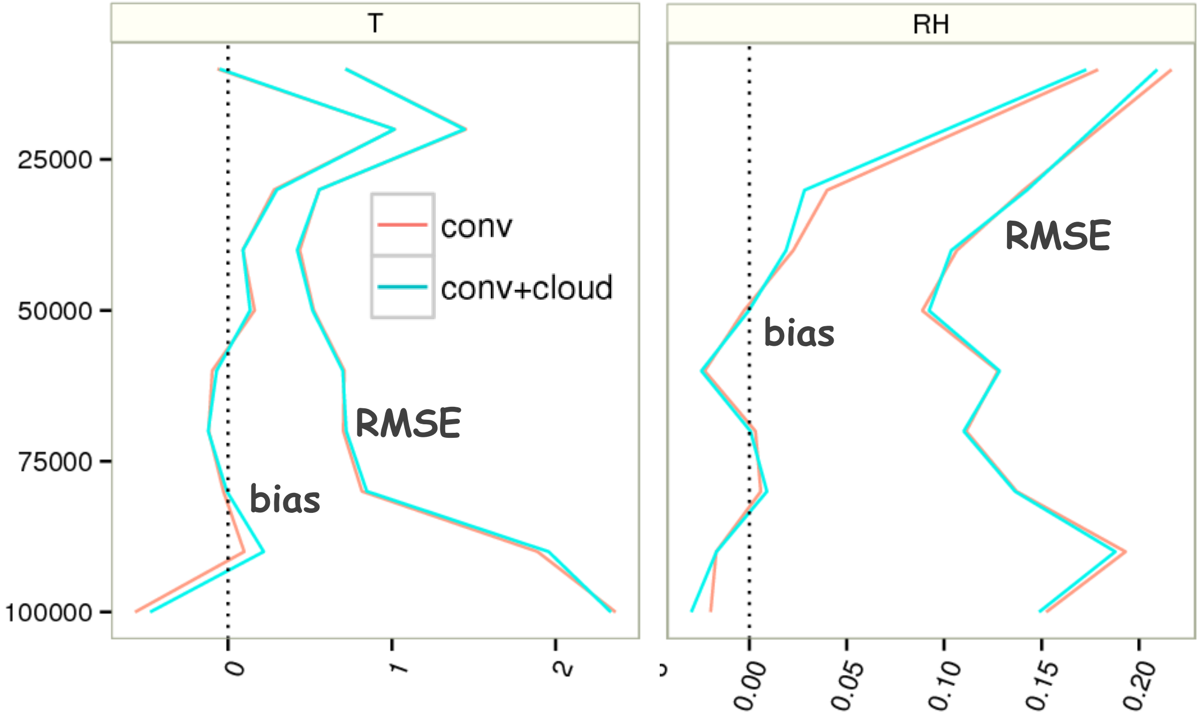


→ discard data flagged as ‘inconsistent’

→ applied to new experiment

LETKF: use of **satellite cloud top height data** application to low stratus period

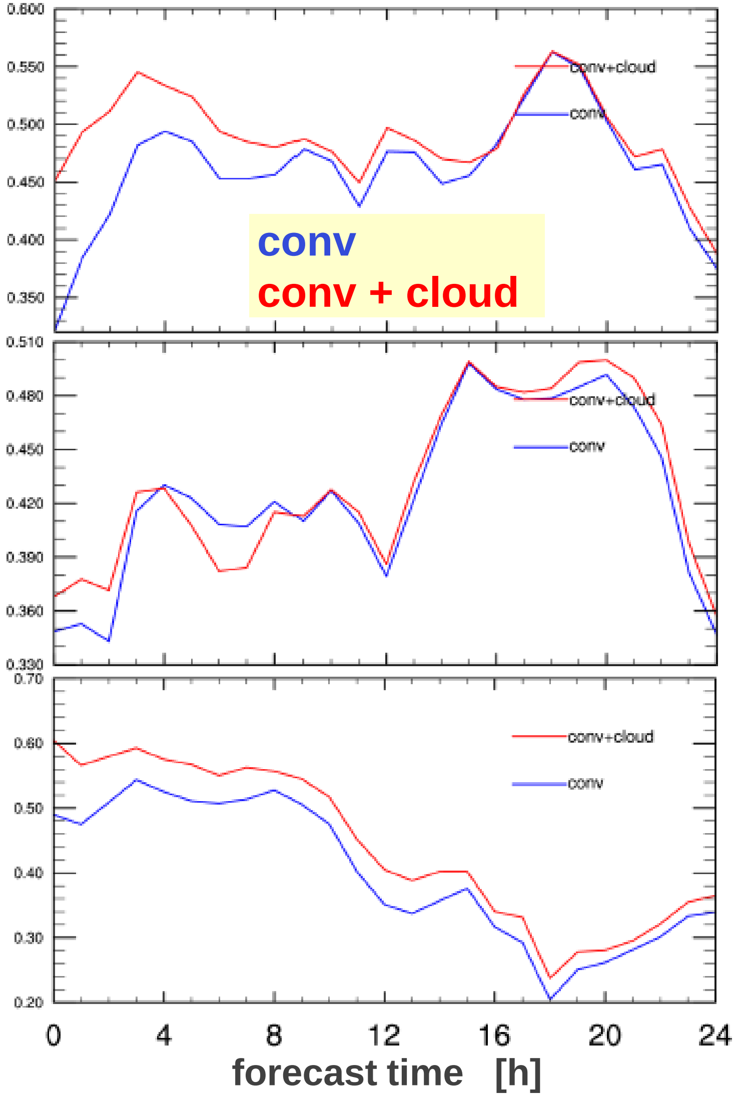
results of new experiment with rigid quality control:
upper-air verification for several 6-h forecasts from 13 – 15 Nov. 2011



- → no detrimental effect of cloud assimilation any more
- → but sometimes a lot of cloud data are discarded by new QC

LETKF: use of **satellite cloud top height data** application to low stratus period

correlation between forecast and observed total cloud cover



13 Nov. 2011 6 UTC

14 Nov. 2011 12 UTC

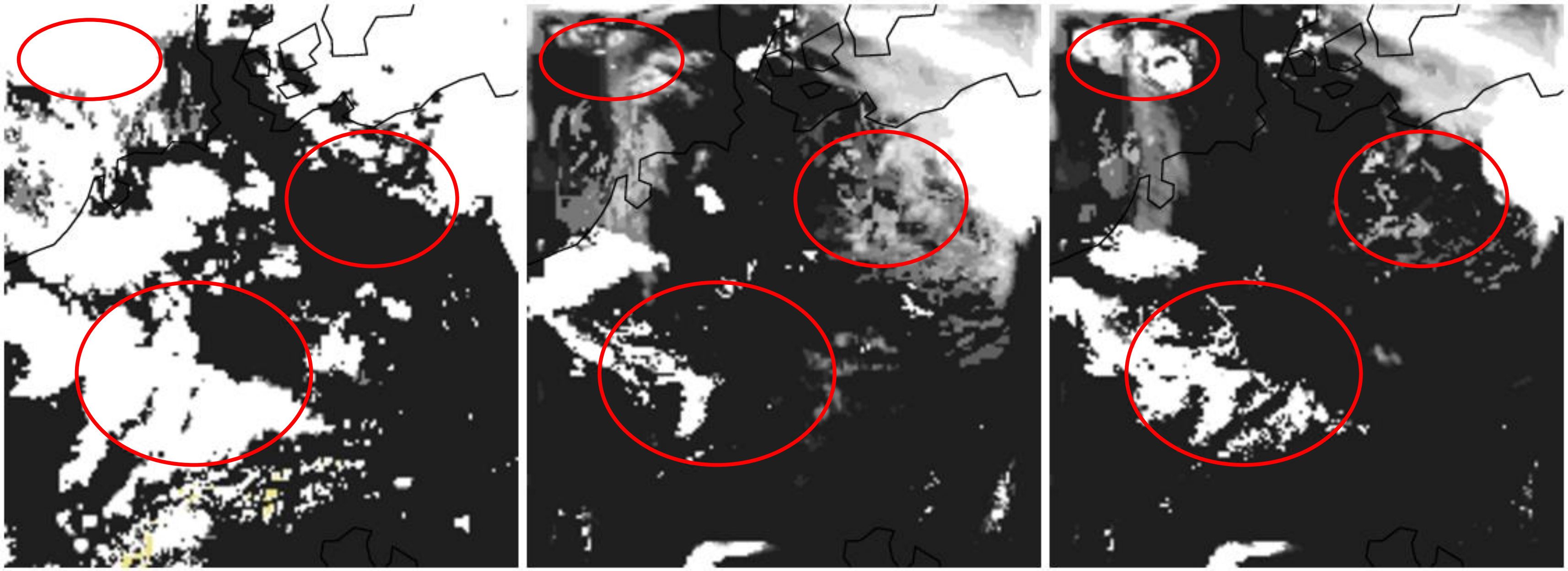
15 Nov. 2011 0 UTC

new experiment with rigid quality control

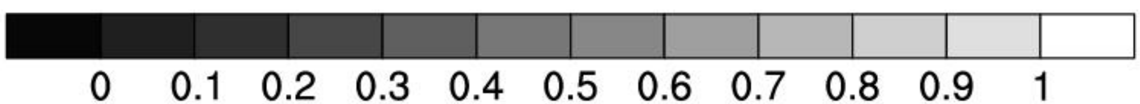
→ some long-lasting benefit in some cases

results of (new experiment with rigid quality control:
total cloud cover of first guess fields (1-h forecast) after 24 hours of cycling

satellite obs	conventional only	conventional + cloud



13 Nov 2011,
12:00 UTC



→ better match with observed cloud cover

LETKF: use of **satellite cloud top height data** status summary, further steps

status

- problem with mid-tropospheric cold / moist bias solved;
  with new QC, less data are used in LETKF
- some positive impact on cloud cover remains

further steps

- quality control
- balance impact of cloudy (which may be flagged by QC)
  vs. cloud-free obs (which are never flagged)
- localization (dep. on observed cloud ?), thinning / superobbing, obs errors
- alternative use of Optimal Cloud Analysis (Watts et al., 2011) ,
  which can detect multi-layer clouds ?
- more test periods, other weather types

LETKF: main development + testing
comparison to Nudging + LHN

DWD

- sensitivity tests, impact studies

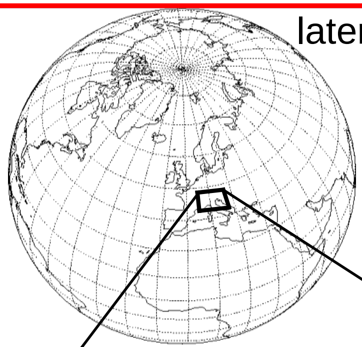
MeteoSwiss

- sensitivity tests (10-day summer 2014 period: RTPP + soil perturbations, LHN, use of RH2m, new FG-check, ENS-LBC perturbations w. lead time 15-24h)
- real-time KENDA suite at CSCS since 11 Jan. 2015 !
- impact studies

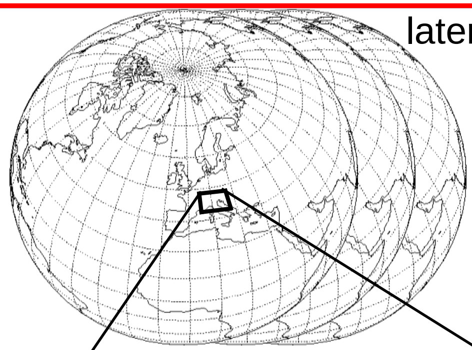
ARPA-SIM

- sensitivity tests for 2 autumn cases (LHN, SPPT, etc.)

Next Generation MCH NWP System

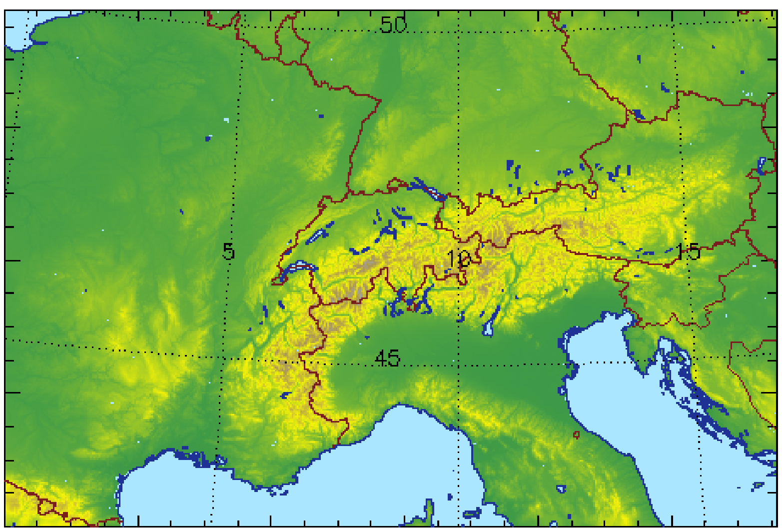


lateral boundary conditions:
IFS-HRES
8-10km
4x per day

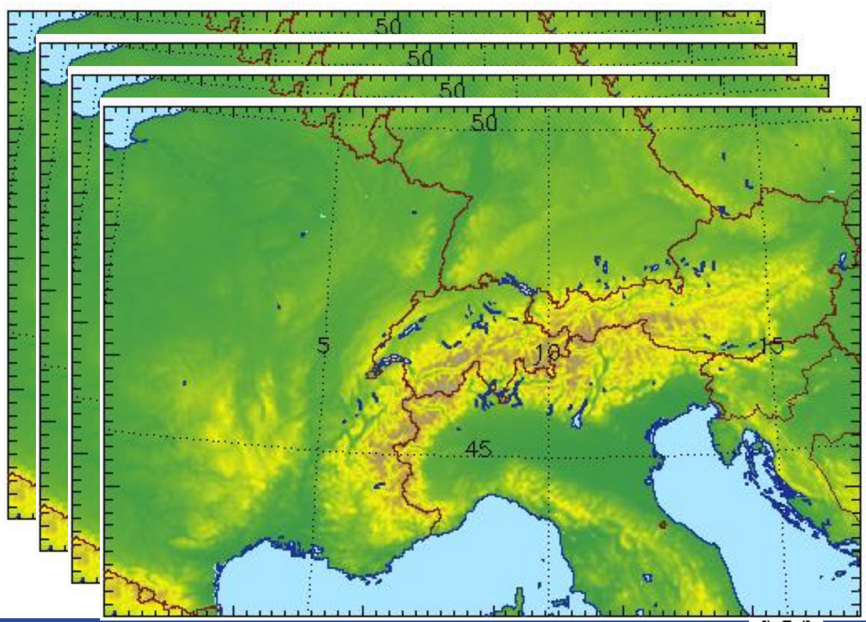


lateral boundary conditions:
IFS-ENS
20km
4x per day

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

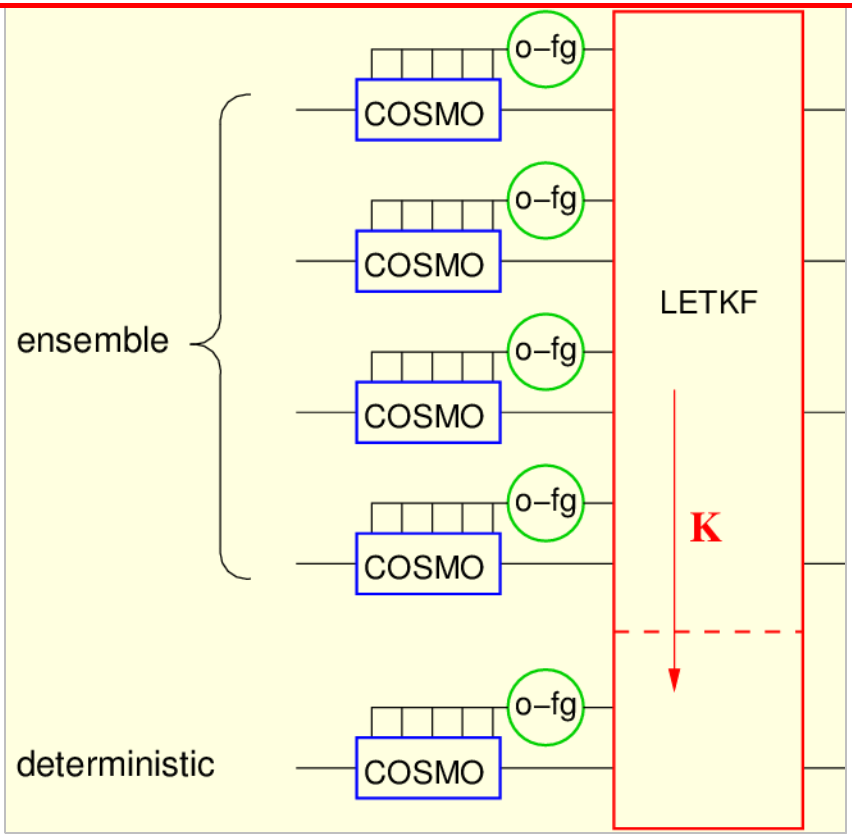


COSMO-E: 5 day forecasts, 2x per day
2.2km grid size (convection permitting)
21 ensemble members



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

- use of KENDA for
  - IC perturbations for COSMO-E
  - IC for deterministic COSMO-1



- real-time assimilation cycle running since 11. 01. 2015
  - 40 ensemble members + deterministic analysis
  - Control: nudging / 'NO-OBS'
  - **2.2 km** grid length
  - since 28. 08. 2015: deterministic analysis with 1.1 km

- test forecasts (March + April 2015)
  - deterministic **2.2 km** forecasts, comparison with nudging
  - COSMO-E ensemble forecasts, comparison with IC perturbations downscaled from ECMWF-EPS

MeteoSwiss: deterministic forecast verification

- March + April 2015 , benchmark: nudging analysis

SYNOP

Parameter	ME	STDE
Surf. Pres.	✓	✓
T 2m	✓	✓
Td 2m	↑	✗
DD 10m	✓	✓
FF 10m	✓	✓

radiosondes (PBL)

Parameter	ME	STDE
T	↓	✓
RH	↑	✗
DD	✓	✓
FF	✓	✓

(combi-) precip

better Frequency Bias

very similar FSS

- cooler and moister than nudging (too cool and too moist) especially during night
- generally better than nudging at daytime, slightly worse during night

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MeteoSwiss: ensemble forecast verification

- March + April 2015
- focus on first 6 forecast hours
- comparison against COSMO-E started from downscaled IFS-ENS analysis

median verification

Parameter	ME	STDE
Surf. Pres.	✓	✓
T 2m	↓	✓
Td 2m	✓	✗
DD 10m	↑	✓
FF 10m	✓	✓

probabilistic verification

Parameter	RPS(S)	Outliers	Spread/ Error	Resolution Thrs1	Resolution Thrs2
T 2m	✓	✓	✓	✓	✓
Td 2m	✓	✓	✓	✗	✓
ff 10m	✓	✓	✓	✓	✓
Prec 12h	✓	✓	✗	✓	✓
Prec 1h	✓	✓	✓	✓	✓
Gusts	✓	✓	✓	✓	✓

- reduces spin-up, particularly Td 2m and FF 10m bias

MeteoSwiss: summary + outlook

- real-time KENDA assimilation cycle runs very stably since mid-January 2015
- verification results from first months are encouraging
- deterministic 2.2km analysis performance similar to nudging
- COSMO-E forecasts started from KENDA compare mostly favourably to those downscaled from IFS-ENS (reduced spin-up effect)
- approaching to meet benchmark, but some problems in PBL humidity and temperature, still lack of spread there (soil moisture perturbations not applied !)
- COSMO-1 deterministic analysis under development
- COSMO-E plans to use KENDA IC when going operational in Spring 2016, (COSMO-1 will first use nudging IC)

DWD

- 1st goal: replace nudging + LHN with deterministic LETKF analysis
  for COSMO-DE (2.8 km, 10.5 x 11.5 deg.)
  / COSMO-D2 (2.2 km, 13.0 x 14.3 deg.)
  (in summer/autumn 2016)

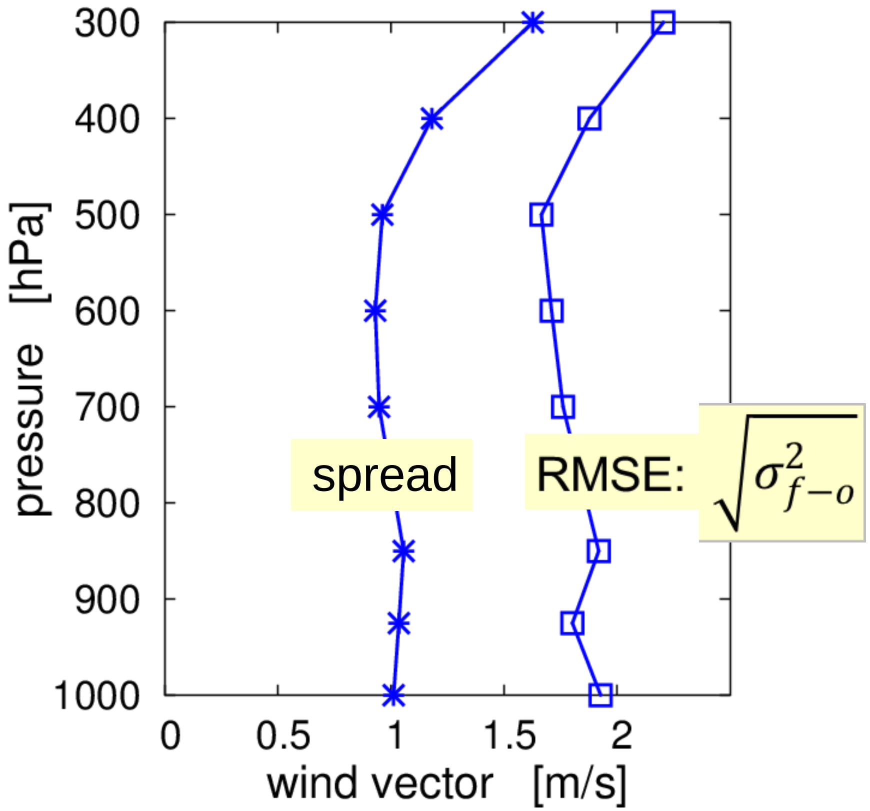
→ main task for operation-ability:
quality of deterministic forecast from KENDA as good as nudging + LHN

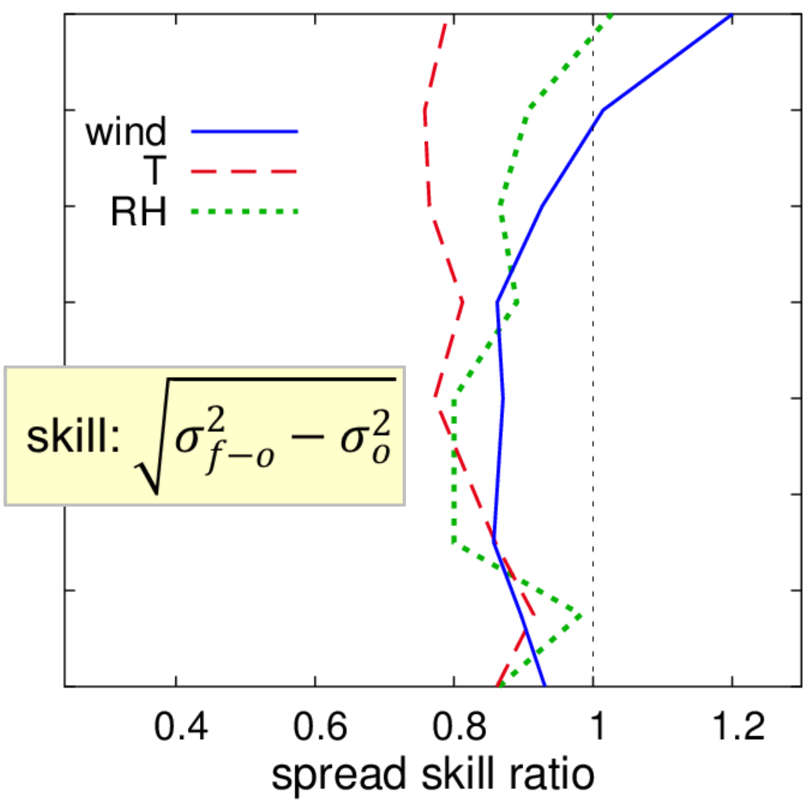
→ test period 28 days (18 May – 15 June 2015 : convection, little advection)
- LBC from 80-km ICON-LETKF / 40-km 3DVar
- RTPP (relaxation to prior perturbations), soil moisture perturbations
- combine LETKF with LHN, compare with nudging (+ LHN)

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

→ WG7 / DWD-FE15 : encouraging results

LETKF with adaptive multiplicative cov. inflation + RTPP + soil moisture perturb.
(6-day period July 2012)

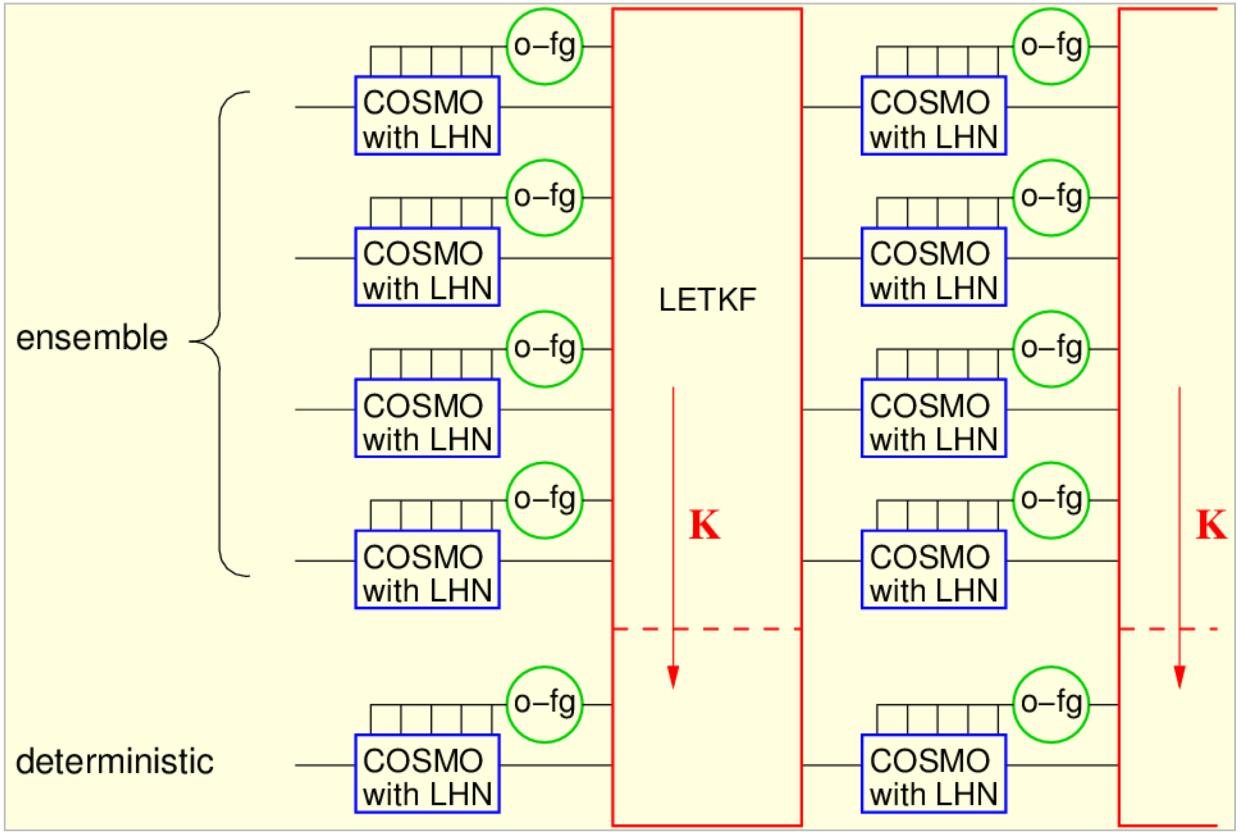




✓ spread-skill ratio of LETKF first guess mostly within 0.8 – 1.0
if (diagnosed) observation errors taken into account

LETKF: main development + testing
LHN added to LETKF

KENDA-LHN



→ benchmark: Nudging + LHN

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

→ adverse influence of LHN on LETKF ?

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

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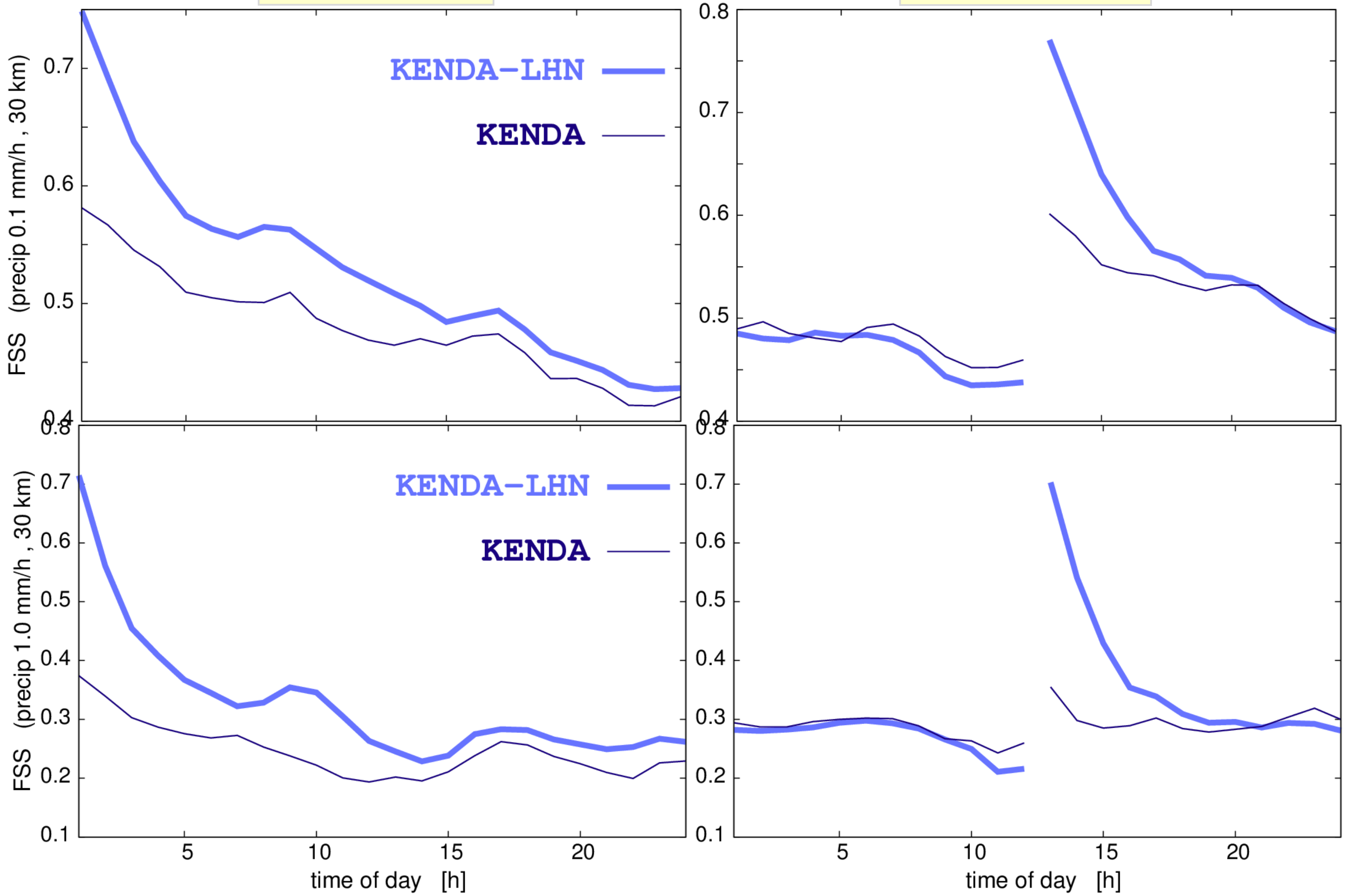
28 days
18.05. – 15.06. 2014

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

0.1 mm/h

precip FSS (30 km)

1 mm/h



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

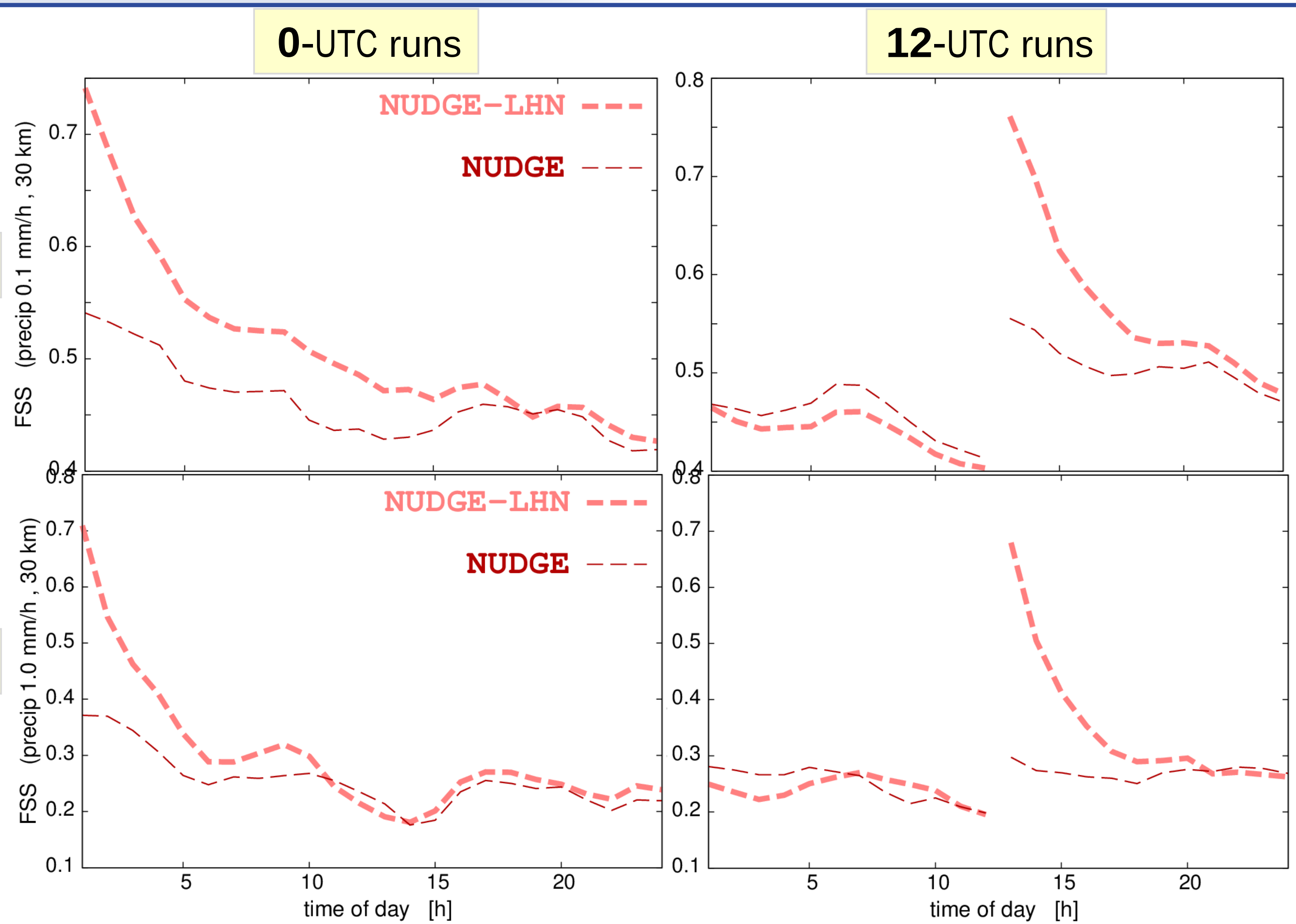
LETKF: main development + testing
impact of LHN added to Nudging

28 days
18.05. – 15.06.
2014

0.1 mm/h

precip
FSS
(30 km)

1 mm/h



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

LETKF: main development + testing
comparison to Nudging

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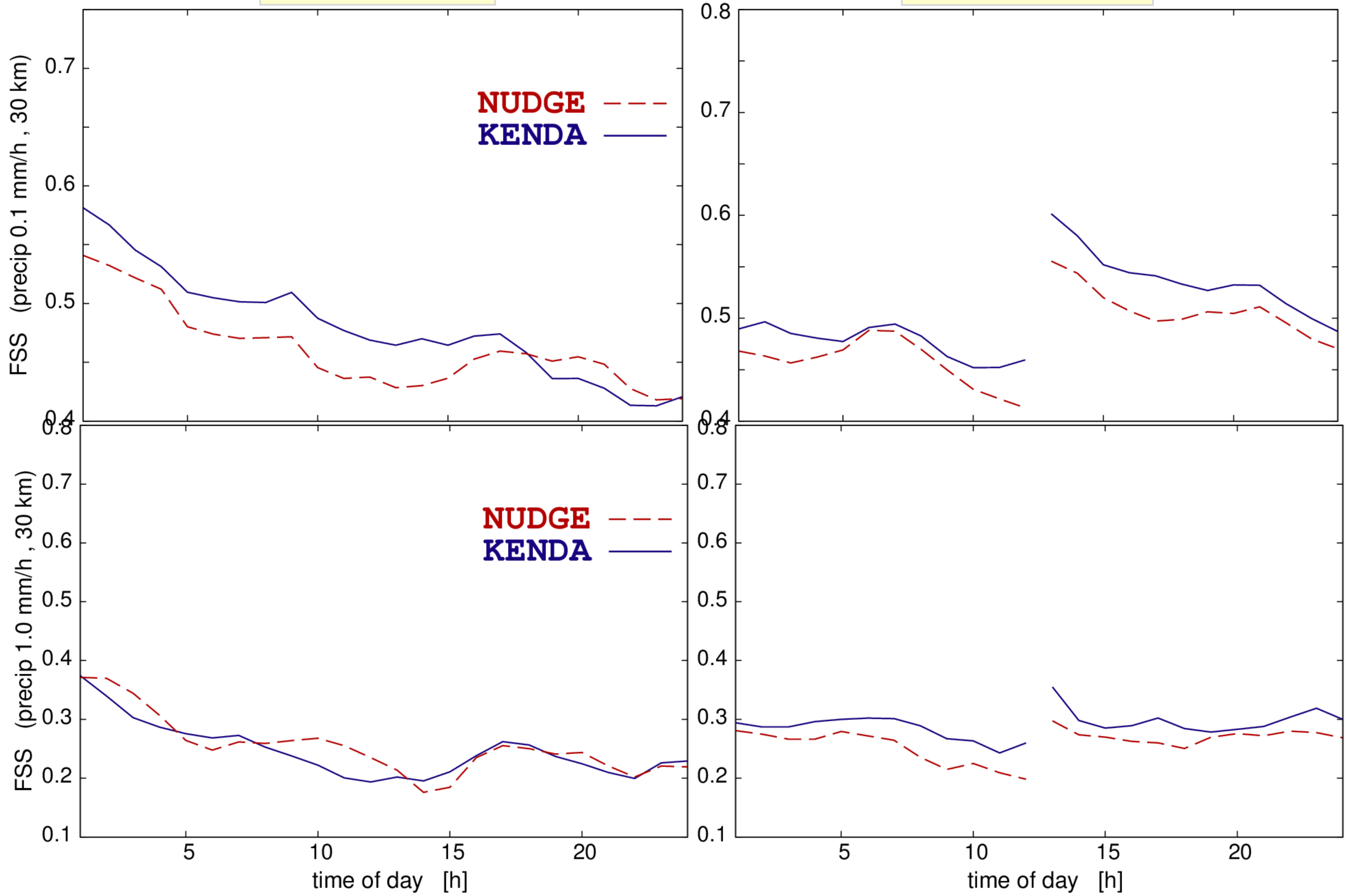
28 days
18.05. – 15.06. 2014

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

0.1 mm/h

precip FSS (30 km)

1 mm/h



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

LETKF: main development + testing
comparison to Nudging + LHN

28 days
18.05. – 15.06.
2014

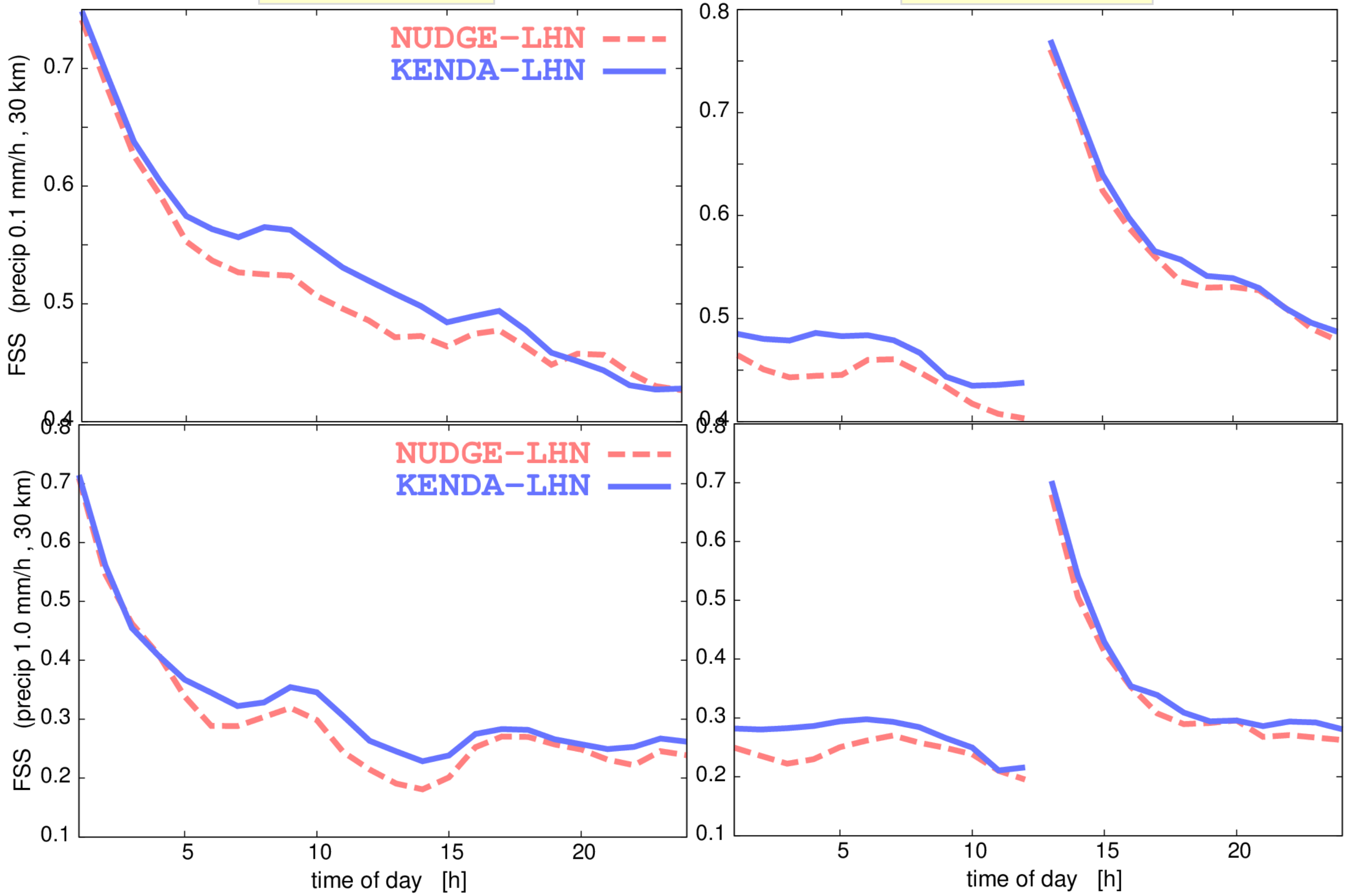
0.1 mm/h

precip
FSS
(30 km)

1 mm/h

0-UTC runs

12-UTC runs



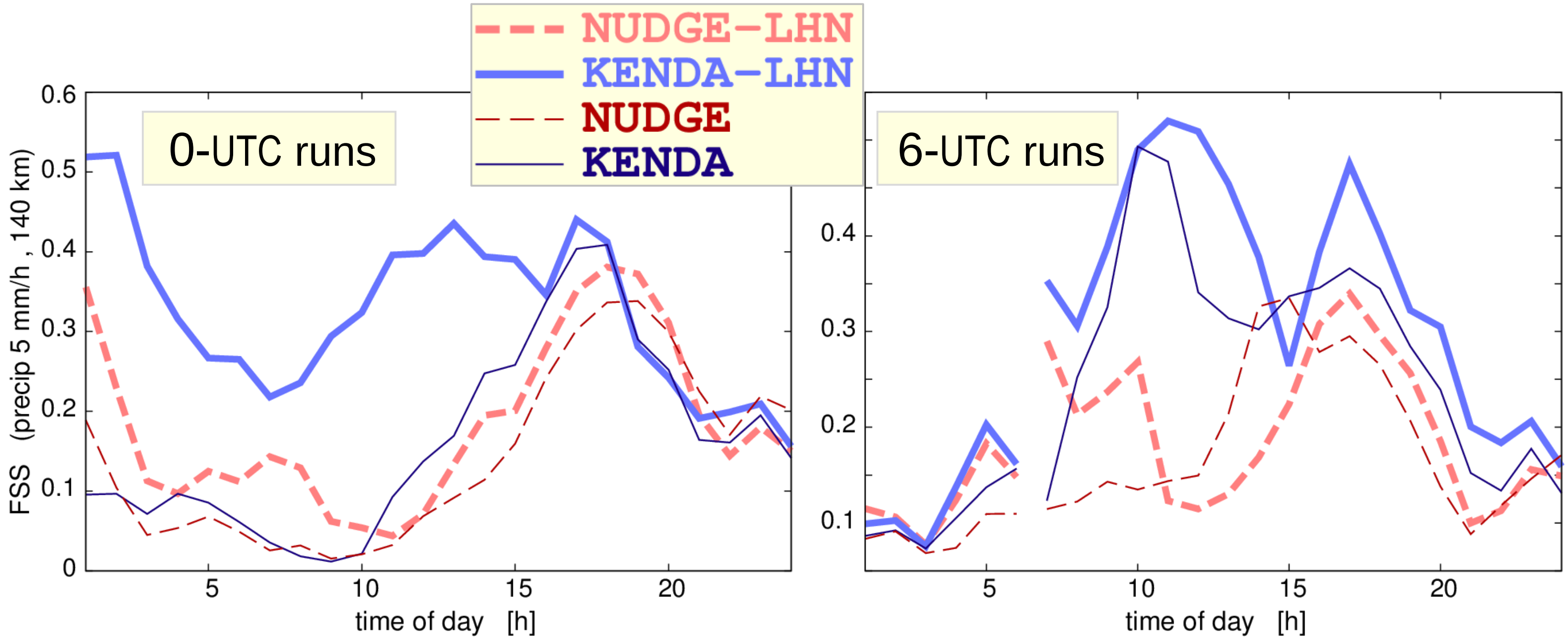
✓ with LHN: small difference in first 4 hours due to dominating influence of LHN, thereafter, advantage of KENDA over nudging tends to be larger than without LHN

LETKF: main development + testing
comparison to Nudging + 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)



- KENDA-LHN better than KENDA-LDET

  → 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)

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LETKF: main development + testing
comparison to Nudging + LHN

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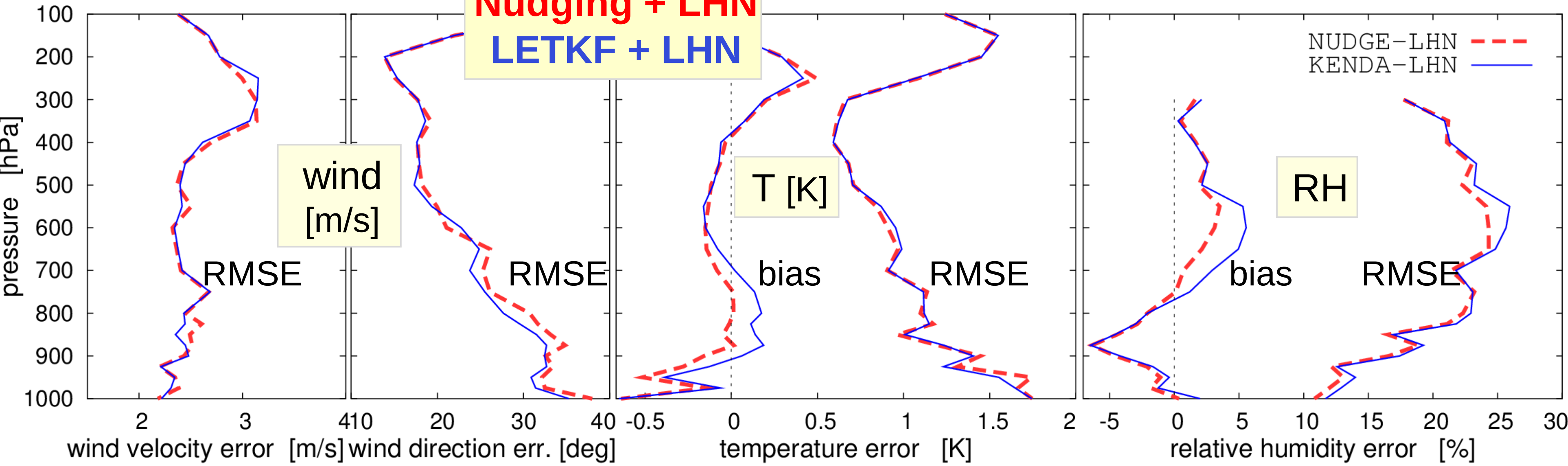
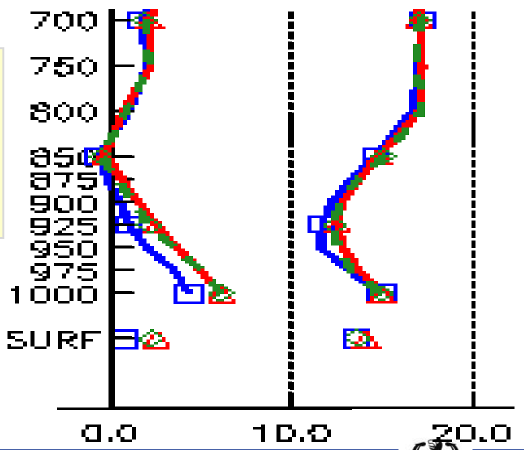
DWD

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



MeteoSwiss: 2 months
(March + April 2015)

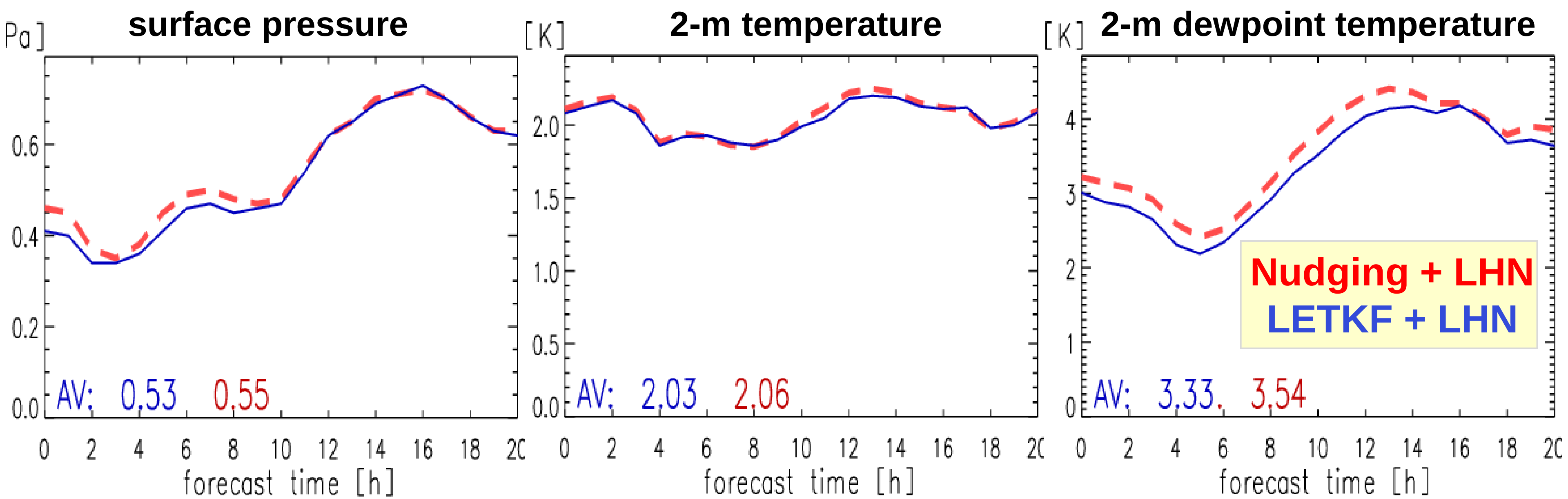
Nudging
LETKF
NO-OBS



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

LETKF: main development + testing
comparison to Nudging + LHN

surface 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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LETKF: main development + testing comparison to Nudging + LHN

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

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

MeteoSwiss : mostly only neutral results for deterministic forecast

$\rightarrow$ possible reasons for different performance:

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

LETKF: main development + testing
remaining problems

- explicit soil moisture perturbations: bias (drift), too large spread
  - → solutions: symmetric limiter, re-scaling & re-centering of soil perturbations
- 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

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The end of PP KENDA …

… but not end of the KENDA system !

Thanks to:

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

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

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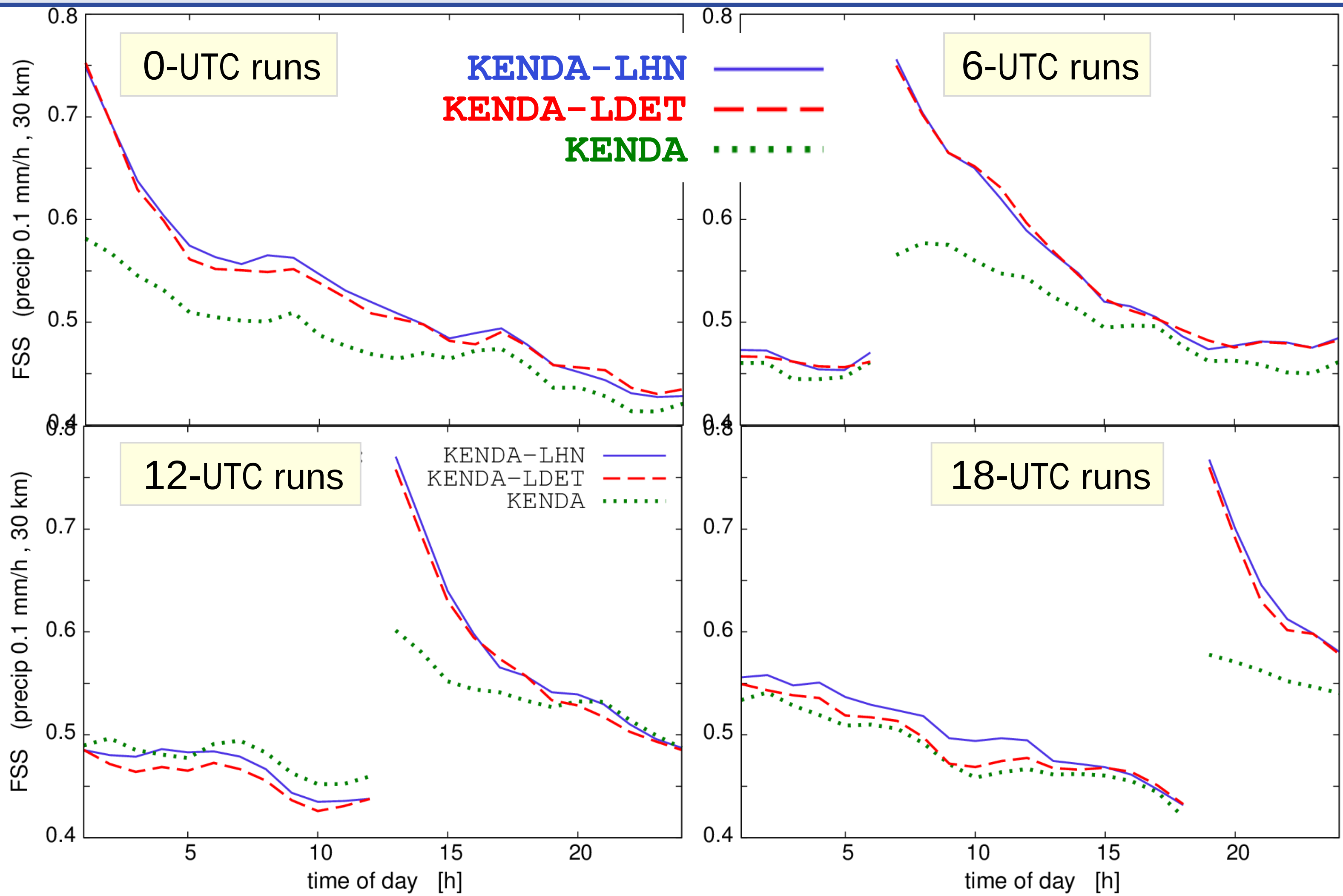
T2014:
28 days
18.05. – 15.06. 2014

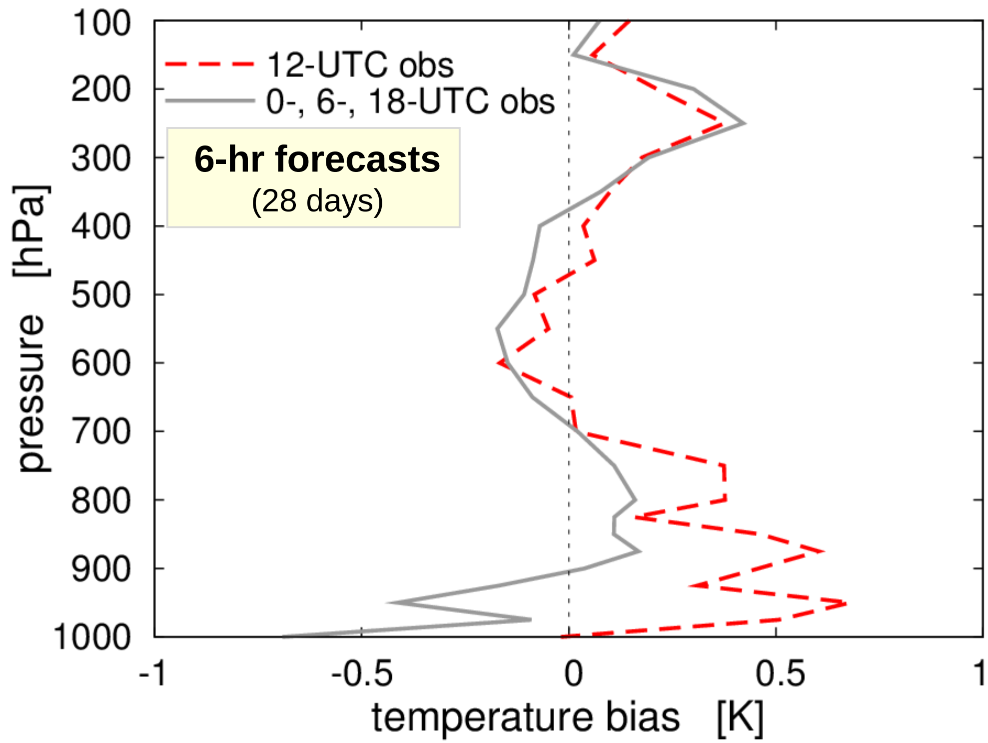
1-hrly precip FSS (30 km , 0.1 mm/h)



- ✓ 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 ?



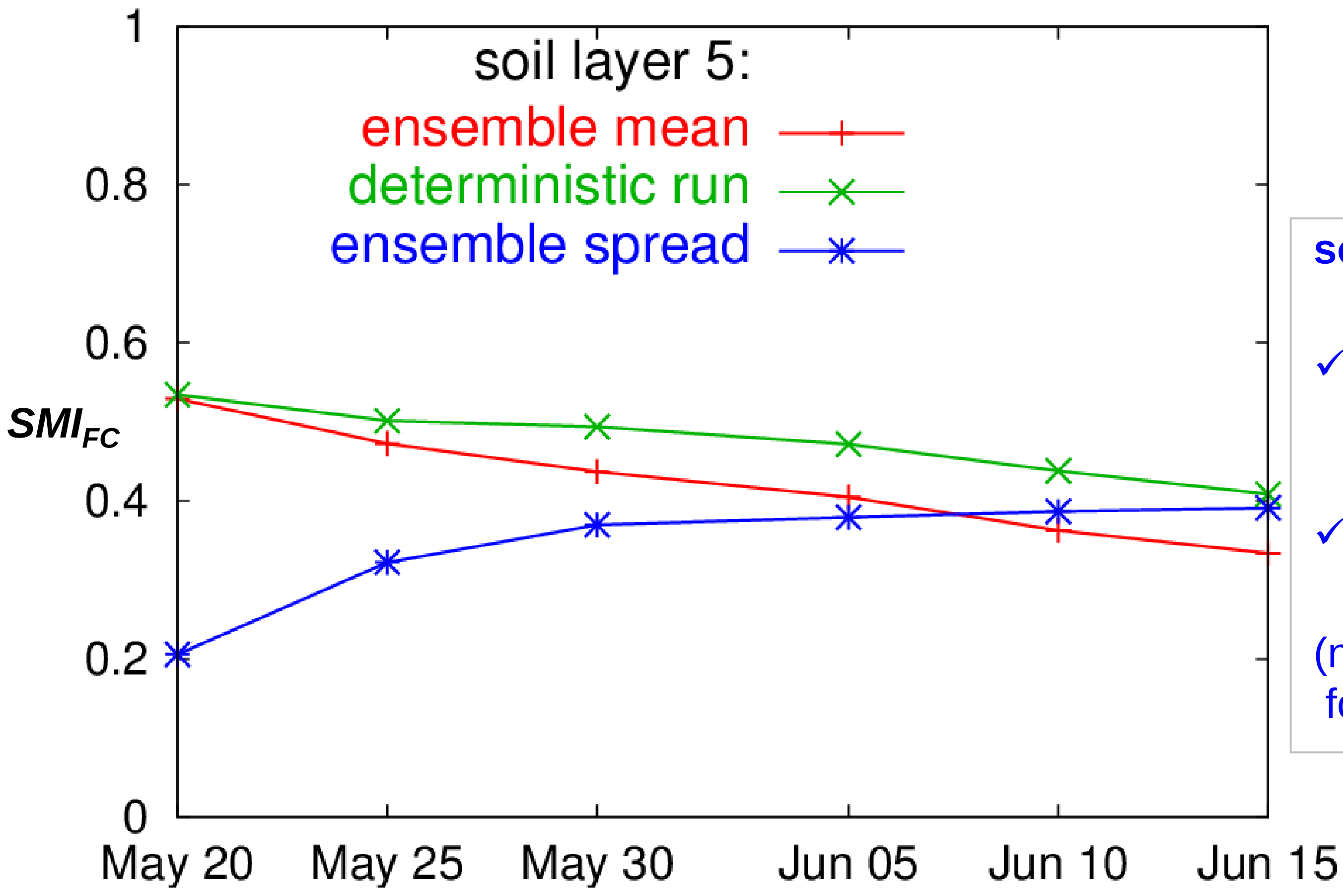
→ COSMO-DE has warm bias in PBL around noon
(requires excessive instability to produce realistic convection - limited resolution!)

→ 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

- 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)

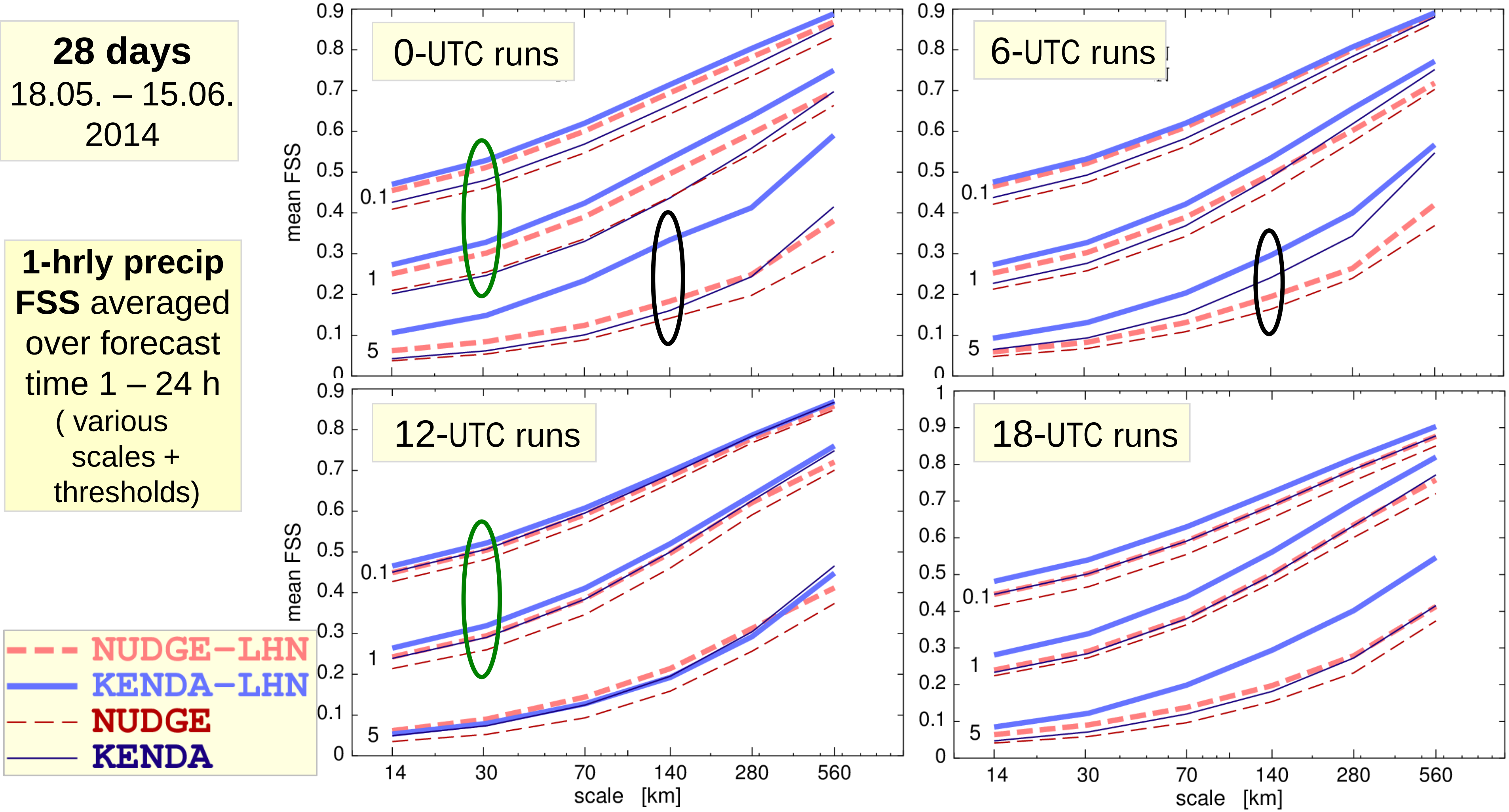
LETKF: main development + testing comparison to Nudging + LHN

Deutscher Wetterdienst

DWD

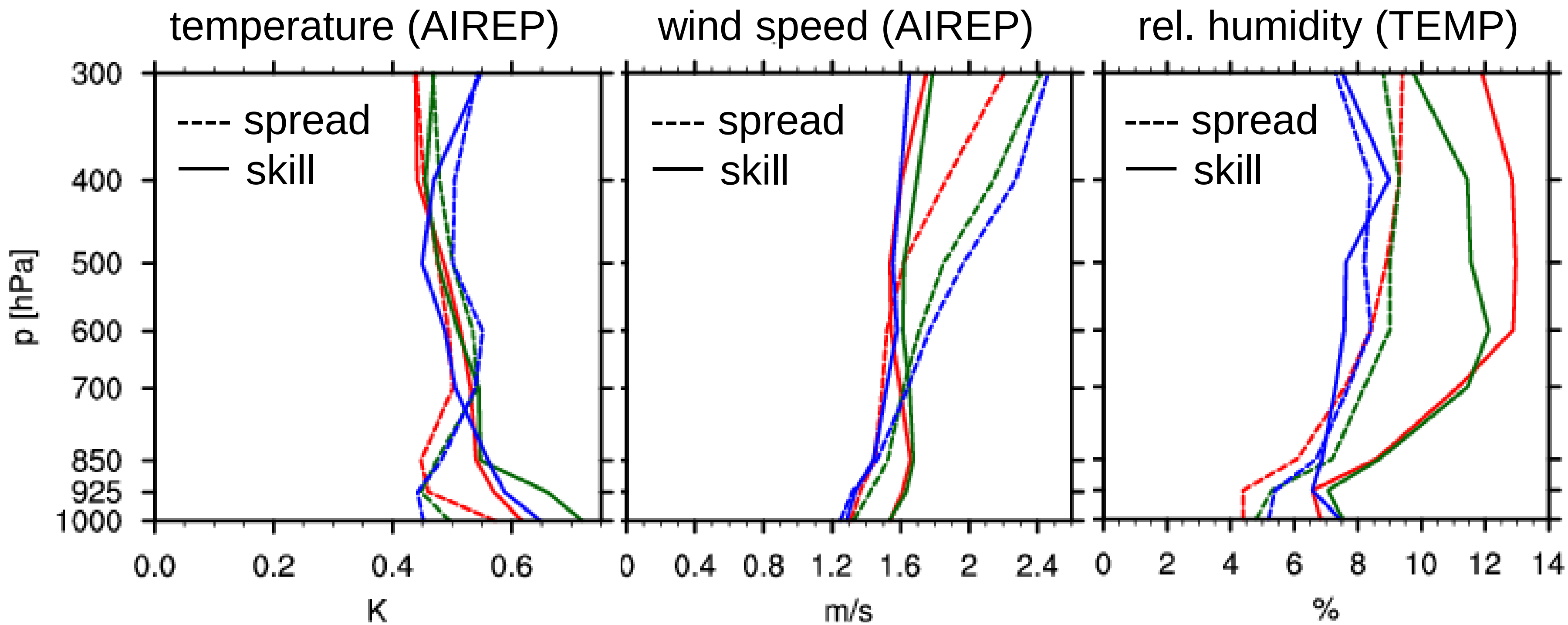
28 days
18.05. – 15.06. 2014

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

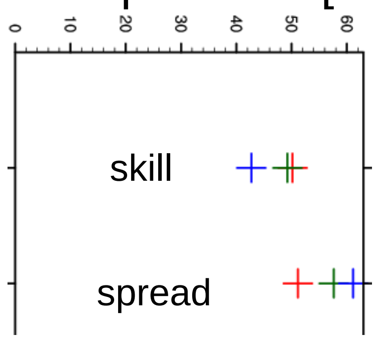


- ✓ previous findings confirmed for all scales
- ✓ KENDA + LHN is best particularly for high thresholds (except 12 UTC run)

MeteoSwiss: seasonal LETKF spread-skill relation



surface pressure [Pa]



Winter (JF)
Spring (MAM)
Summer (JJA)

observation error taken into account in skill !

✓ spread-skill ratio of LETKF mostly ok, more underdispersive near surface (no explicit soil moisture perturbations !)