KENDA-O Overview

Deutscher Wetterdienst

PP KENDA-O : Km-Scale Ensemble-Based Data Assimilation for the use of High-Resolution Observations (Sept. 2015 – Aug. 2020)

- Work on KENDA @ DWD:
  Christoph Schraff, Hendrik Reich, Roland Potthast, Klaus Stephan, Harald Anlauf, Christian Welzbacher, Lilo Bach, Sven Ulbrich, Thorsten Steinert, Uli Blahak, Elisabeth Bauernschubert, Michael Bender, Axel Hutt, Christine Sgoff, Kobra Khosravian, Annika Schomburg, Martin Lange, Gernot Geppert, Walter Acevedo, Zoi Paschalidi, Leonhard Scheck, et al. (e.g. Günther Zängl)

- MeteoSwiss: *Daniel Leuenberger, Claire Merker, Alexander Haefele, Maxim Hervo, Marco Arpagaus*

- COMET: *Francesca Marcucci, Lucio Torrisi, (Paride Ferrante)*

- ARPAE-SIMC: *Virginia Poli, Thomas Gastaldo* (*Chiara Marsigli* → DWD)

- Roshydromet: *Mikhail Tsyrulnikov, Dmitrii Gayfulin,* (*Elena Astakhova)*

KENDA-O Overview

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- Task 1: further development of LETKF scheme (conventional obs, operationalisation)
- Task 2: extended use of observations
- Task 3: lower boundary:
  - soil moisture analysis using satellite soil moisture data (COMET)
    fellowship ended (no clear benefit yet, will continue tests in parallel suite, with little (!) FTE)
  - DWD: new fixed position (Gernot Geppert, since March 2019):
    - write *new* SST + snow analysis code in DACE (method: VAR)
    - possibly develop soil moisture analysis for ICON-LAM
- Task 4: – adaptation to ICON-LAM
  - particle filter (technically implemented for COSMO, test over 12 hrs)

MeteoSwiss → meteodrone, MW radiometer, etc. (Task 2)

- regional climatological B matrix: scientific problems (formulation did not work)
  now trying an alternative formulation (to compute velocity potential, streamfunct.)
  → task is important for future option of regional 3DVar
- statistical evaluation of LETKF analysis increments
- KENDA-1: KENDA at 1.1 km (same LETKF settings as at 2.2km, first test over 3 days promising)

ARPAE-SIMC → radar Z (Task 2)

COMET

- investigation of KENDA at 7 km and 2.2 km resolution; incl. use of AMV (sat winds)

Roshydromet (→ Stochastic Pattern Generator)

- technique to estimate (additive + mulitplicative) model errors
  by using COSMO-2.2km (as a model) vs. COSMO-0.22km
  (as the 'truth', tendencies started at the same point in phase space)
  shows problems (spin-up) → method might not work (not critical for KENDA project as a whole)

Task 4.1: KENDA for ICON-LAM
3-D MEC-LETKF

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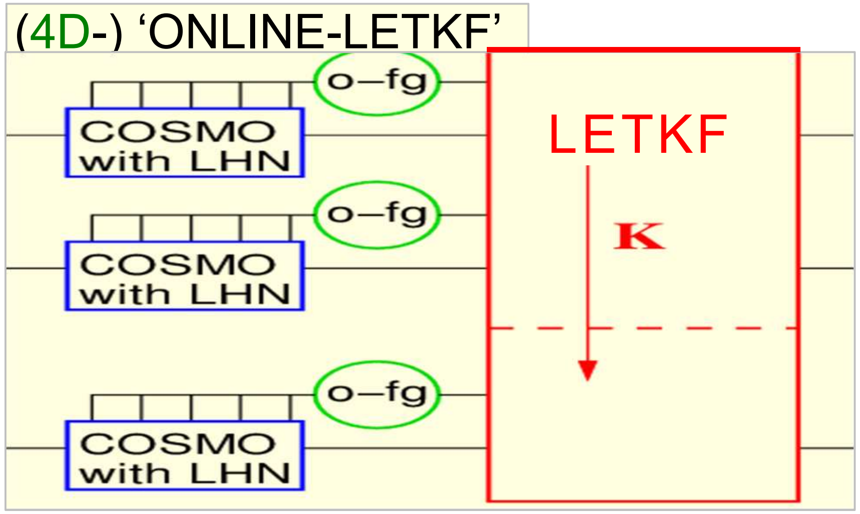
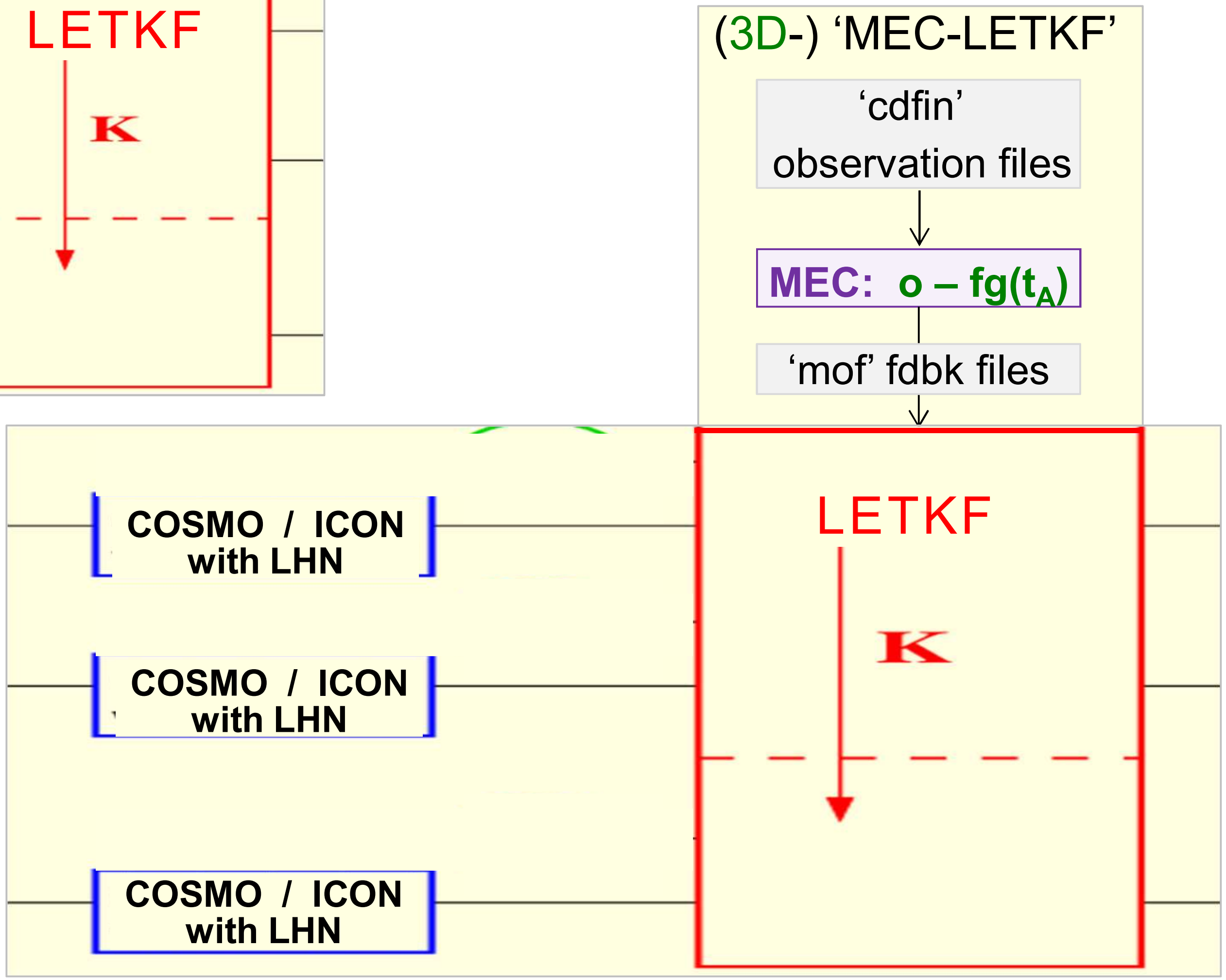




MEC-LETKF:

o – fg(t_A)

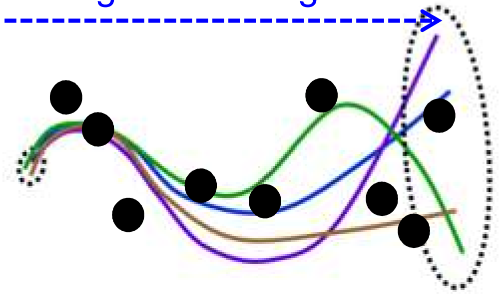
model equivalents at analysis time

→ 3-D LETKF

Task 1: 3-D / 4-D LETKF versions concepts

$H(\mathbf{x}) \rightarrow H(\mathbf{x}(t_{obs}))$
during model integration

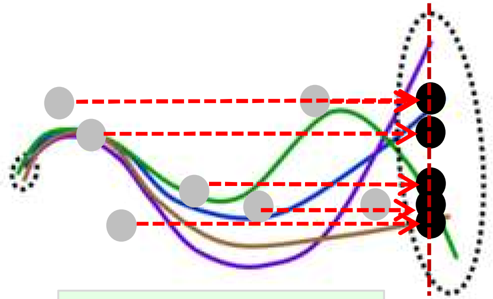
4D



→ **"4-D Online"**

$H(\mathbf{x}) \rightarrow H(\mathbf{x}_{FG}(t_a))$

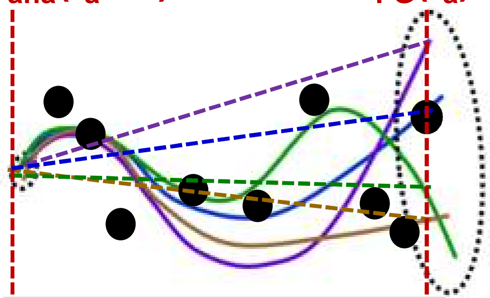
3D



→ **"3-D MEC"**

$H(\mathbf{x})$: $\mathbf{x}(t_{obs})$ by interpolation betw.
$\mathbf{x}_{ana}(t_a\text{-}1h)$ and $\mathbf{x}_{FG}(t_a)$

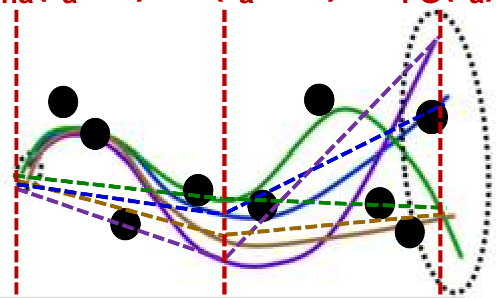
4D



→ **"4-D MEC-IPOL"**

$H(\mathbf{x})$: $\mathbf{x}(t_{obs})$ by interpolation betw.
$\mathbf{x}_{ana}(t_a\text{-}1h)$, $\mathbf{x}(t_a\text{-}½h)$, $\mathbf{x}_{FG}(t_a)$

4D



→ **"4-D MEC-IPOL2"**

Task 1: 3-D / 4-D LETKF versions results with COSMO

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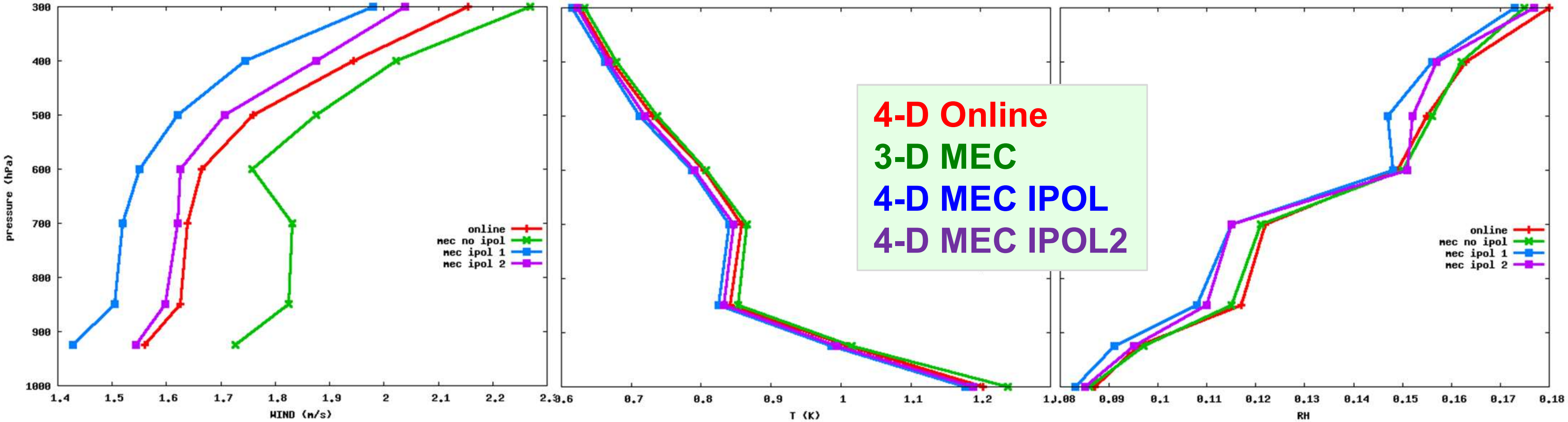
upper-air verification of first guess (1-h forecast)
25 / 06 – 10 / 06 / 2016

wind profiler wind | radiosonde temperature | radiosonde rel. humidity



→ **ranking: 3-D MEC < 4-D Online < 4-D MEC IPOL2 < 4-D MEC IPOL !**

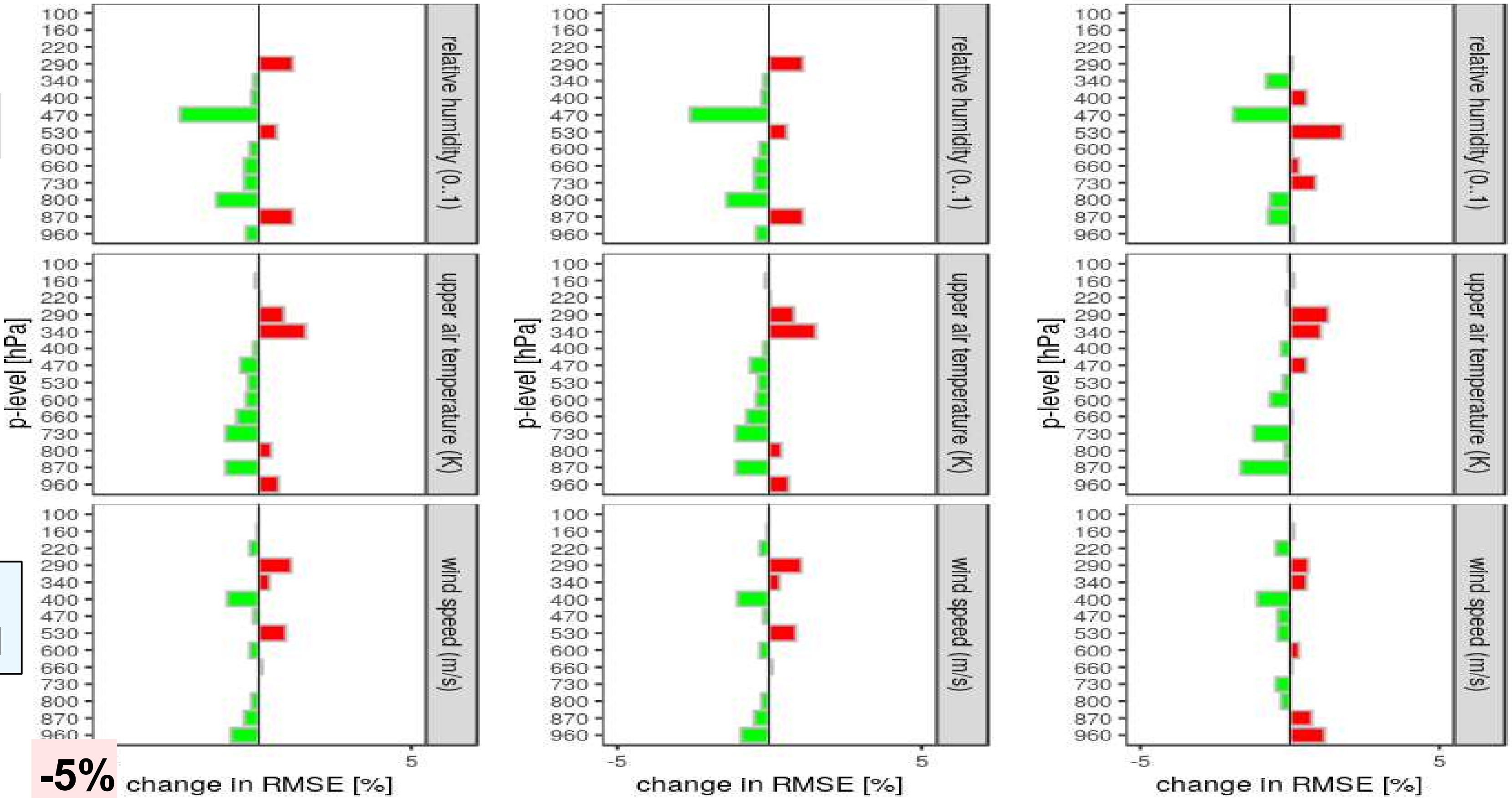
upper-air forecast verification 25 / 06 – 10 / 06 / 2016

4-D Online vs. 3-D MEC | **4-D MEC IPOL vs. 3-D MEC** | **4-D MEC IPOL2 vs. 3-D MEC**

RH

T

wind speed



-5%

→ **ranking: 3-D MEC slightly worse**

Task 1: 3-D / 4-D LETKF versions results with COSMO

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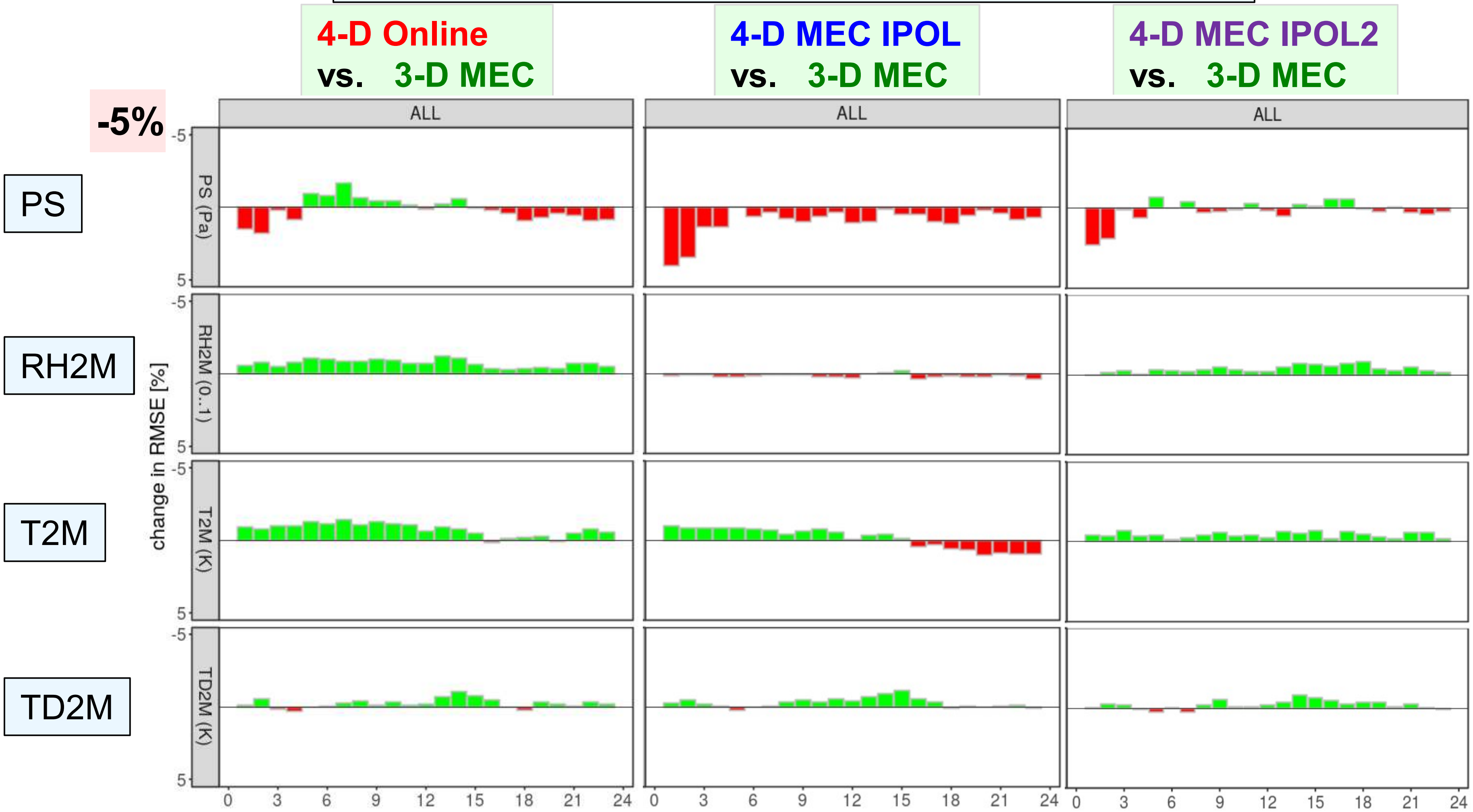
Synop forecast verification 25 / 06 – 10 / 06 / 2016



→ **ranking: 3-D MEC < 4-D MEC IPOL < 4-D MEC IPOL2 < 4-D Online !**

4-D (Online)-LETKF vs. 3-D MEC-LETKF (COSMO)

Type of verification	with LHN	without LHN
upper-air analysis	neutral – positive	neutral – positive
upper-air first guess (1-h)	neutral – positive	neutral – positive
upper-air forecast	neutral	neutral – positive
surface forecast	neutral – positive	neutral – positive
bias of precip yes/no	neutral	neutral
bias of strong precip	neutral	neutral
accuracy of precip yes/no	positive	positive
accuracy of strong precip	positive	positive

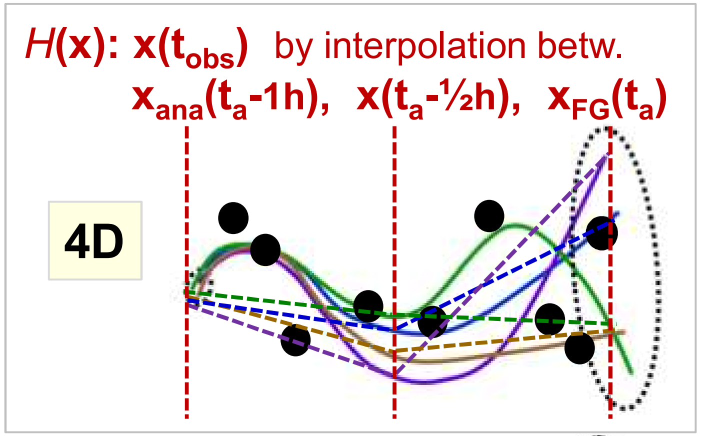
Task 1: 3-D / 4-D LETKF versions summary + implication for VAR

- 3-D LETKF *not much* worse than 4-D LETKF
- interpolated 4-D LETKF (→ ICON-LAM) ~ as good as online 4-D LETKF
  (due to reduced noise when computing $H(\mathbf{x})$ / observation increments?)
- results for high-res. obs (radar, satellite) up to now better with (1-hrly) 3-D approach

implication on **EnVar** (VAR approach expected to be advantageous (for det. ana/fcst)):

→ 3-D EnVar: not much degradation due to 3-D limitation expected

→ 4-D EnVar (requires time interpolation between model states used in control vector for minimization) : no degradation expected



⇒ additional motivation to develop EnVar for ICON-LAM

Task 2: use of additional observations overview

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- Task 2.1 (a): radar radial wind Vr → slides (DWD → COSMO)
- Task 2.1 (b): radar reflectivity Z → slides (ARPAE → COSMO) (DWD: → ILAM)
- Task 2.2: GPS slant total delay → (small) positive impact from combined ZTD + low-elevation STD (DWD)
- Task 2.3/2.4: SEVIRI IR (WV) : clear-sky data: small benefit on RH in upper troposph.
  good basis for extending work to all-sky data (→ ILAM)
- Task 2.5: screen-level obs (T2M, RH2M): resources since spring
  work on innovative parameterized non-lin. bias correct.
  → ILAM
- Task 2.6: Mode-S operational
- Task 2.7: ground-based remote sensing: wind lidar, Raman lidar, MW radiomdeter,
  meteodrone → slides (MCH)
- WG1 (DWD): SEVIRI VIS (cloud), lightning, land surface temperature, cars, ….

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Task 2.1: radar radial velocity (Vr)
conclusions at GM 09/18

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- **obs errors** depend on elevation and height / range
- **superobbing** (10 km), **vertical** (elevat. 0.5°, 1.5°, 3.5°) **+ temporal thinning** (1 h) beneficial
- **positive impact on precipitation** only **small** (in summer),
  larger without simultaneous use of Mode-S (in Exp. & Ref.)

  → operational use of radar Vr could increase obs redundancy in the DA system,
  might mitigate outage of Mode-S (pot. larger impact in areas w/o Mode-S)
- positive impact on wind, especially in first forecast hours → useful towards nowcasting
- neutral (or very small positive) impact in **winter**
- still challenge: radial wind **data quality (control)**
  increase of computational **cost**: COSMO 5 – 10%, LETKF up to 50%

- all experiments with COSMO-DE (2.8 km) so far,
  experiment with COSMO-D2 (2.2 km) for convective period being set up
- **radar Vr in parallel suite for COSMO-D2 since 12 June 2018,**
  with neutral impact in the dry summer so far

Task 2.1: radar radial wind in parallel suite (COSMO-**D2**!): Impact (Synop verification)

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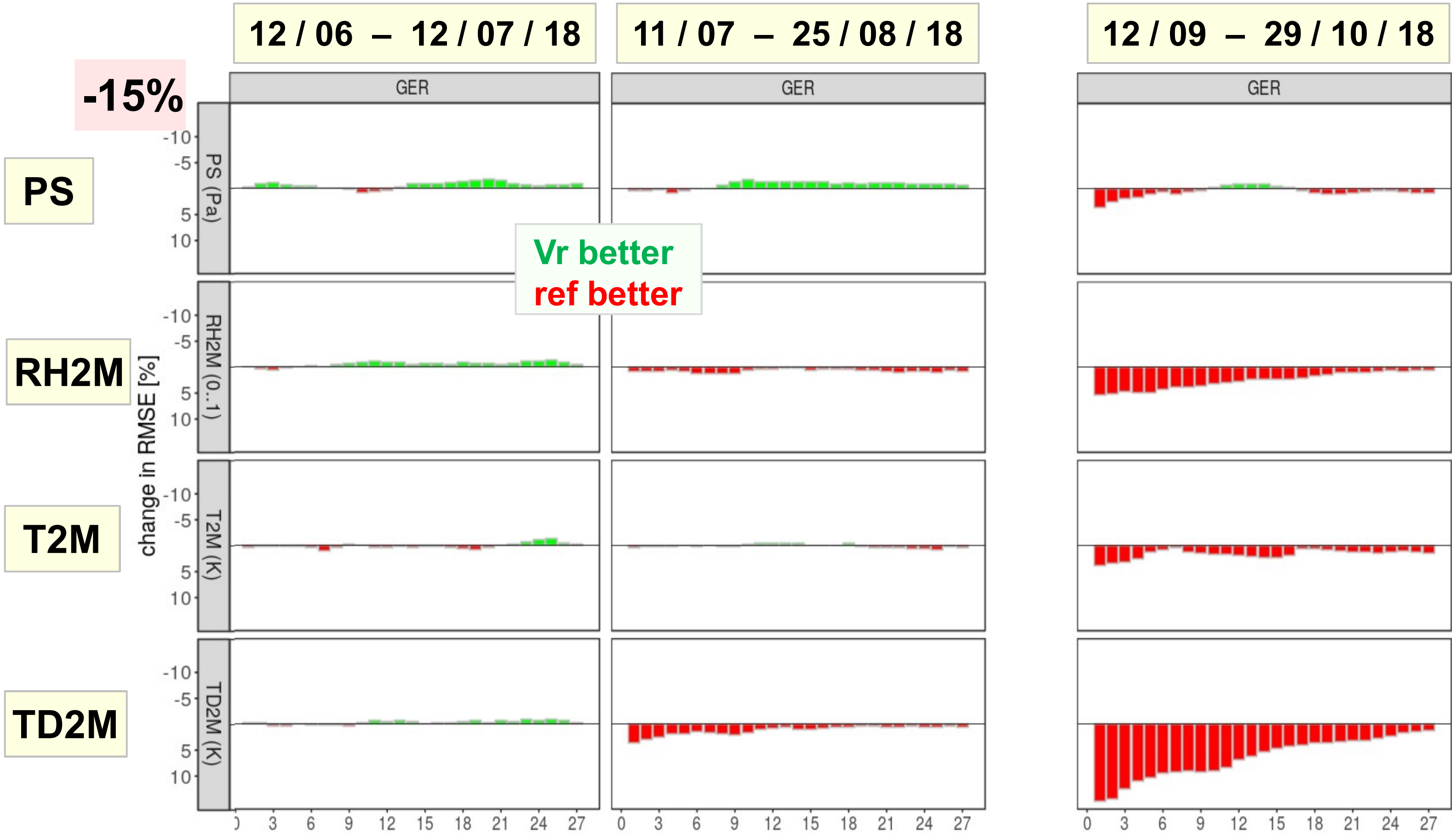

→ **impact** neutral in (dry) summer, becoming **negative in Sept.** (still dry)
(also slightly upper-air wind, T, RH, especially at lower levels)

→ Why !? (did not occur in various seasons in tests)

→ needs further investigation, radial winds not put into operations yet, removed from parallel suite !

Task 2.1: radar radial wind
tackling the problem

- at night: more obs in total, much more obs with large FG departures (> 5 m/s)
  many of which are related to low reflectivity (< 5 dBz)

  reason: Vr obs are produced in stable PBL (where reflectivtiy is low)

→ decrease influence of obs in analysis by increaseing specified obs error
where observed reflectivity is low (linear function betw. 0 – 10 dBz)

Task 2.1: radar radial wind: impact (Synop verification)

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DWD

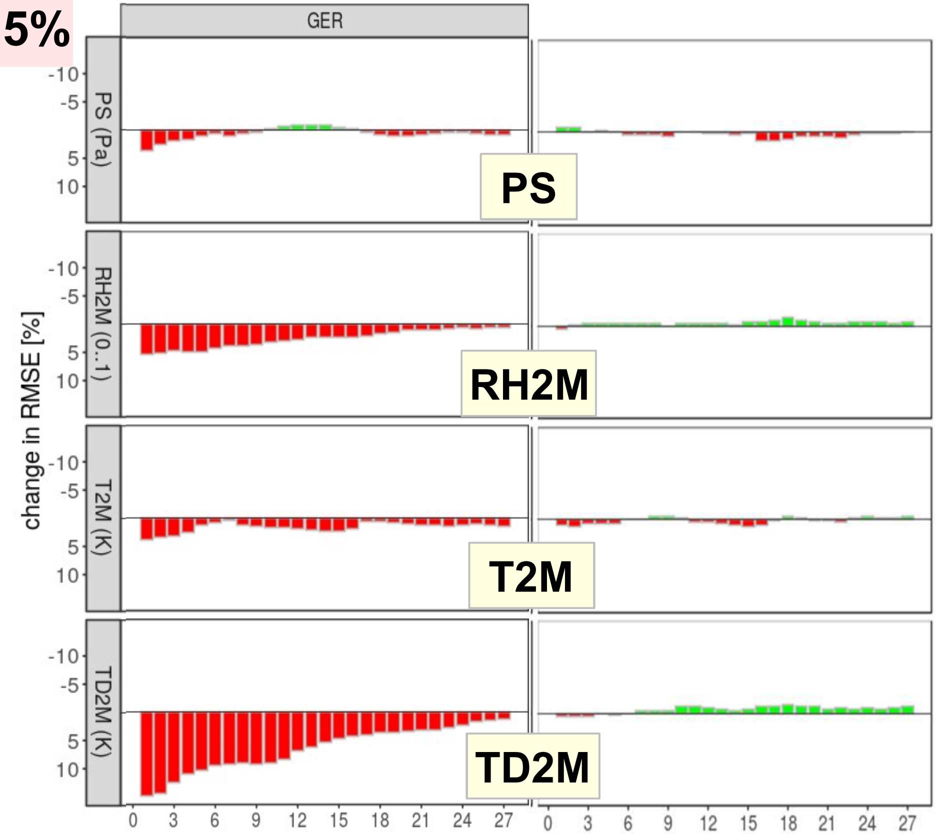
12 / 09 – 29 / 10 / 18	12 / 09 – 20 / 10 / 18	15 / 04 – 10 / 05 / 19	02 / 06 – 25 / 06 / 19 convective

Vr better
ref better

parallel suite

modified version

-15%



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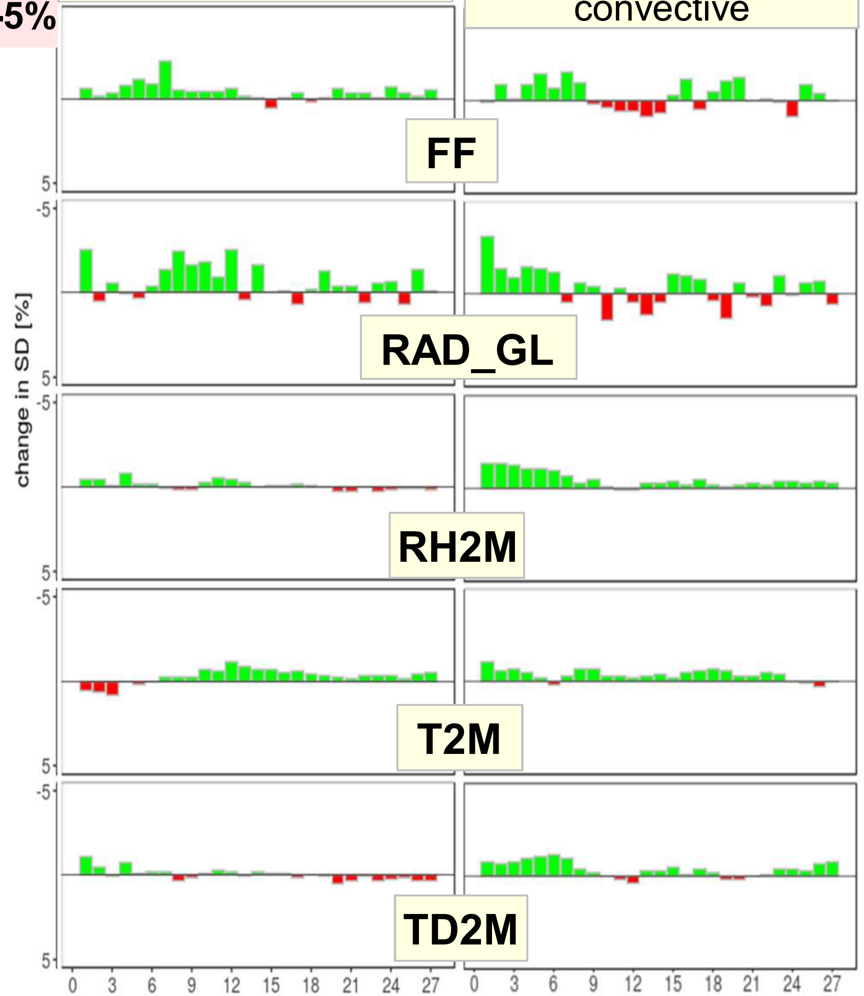

→ **negative impact removed, now small positive impact**

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Task 2.1: radar radial wind: impact (radiosonde verification)

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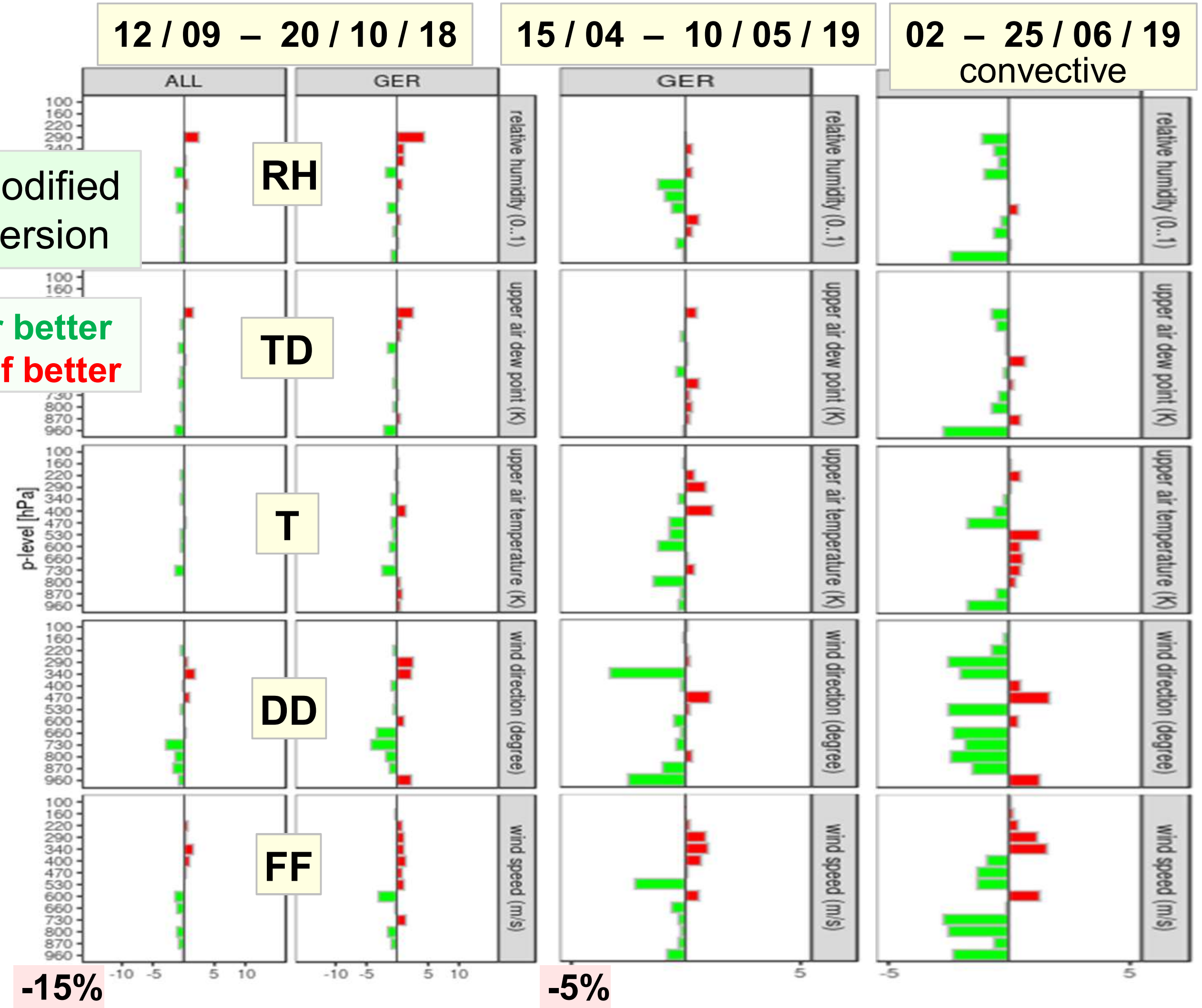
DWD

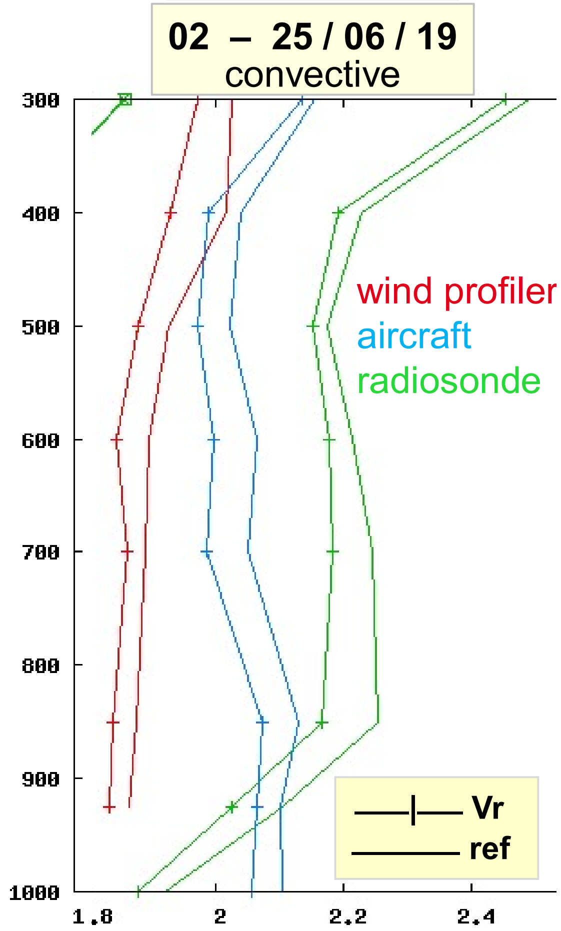
% change of **rmse** (+6, 12, 18, 24h)

modified version

Vr better
ref better



rmse FG (+1h)



→ small positive impact
more pronounced at +1h

Task 2.1: radar radial wind: impact (precip verification)

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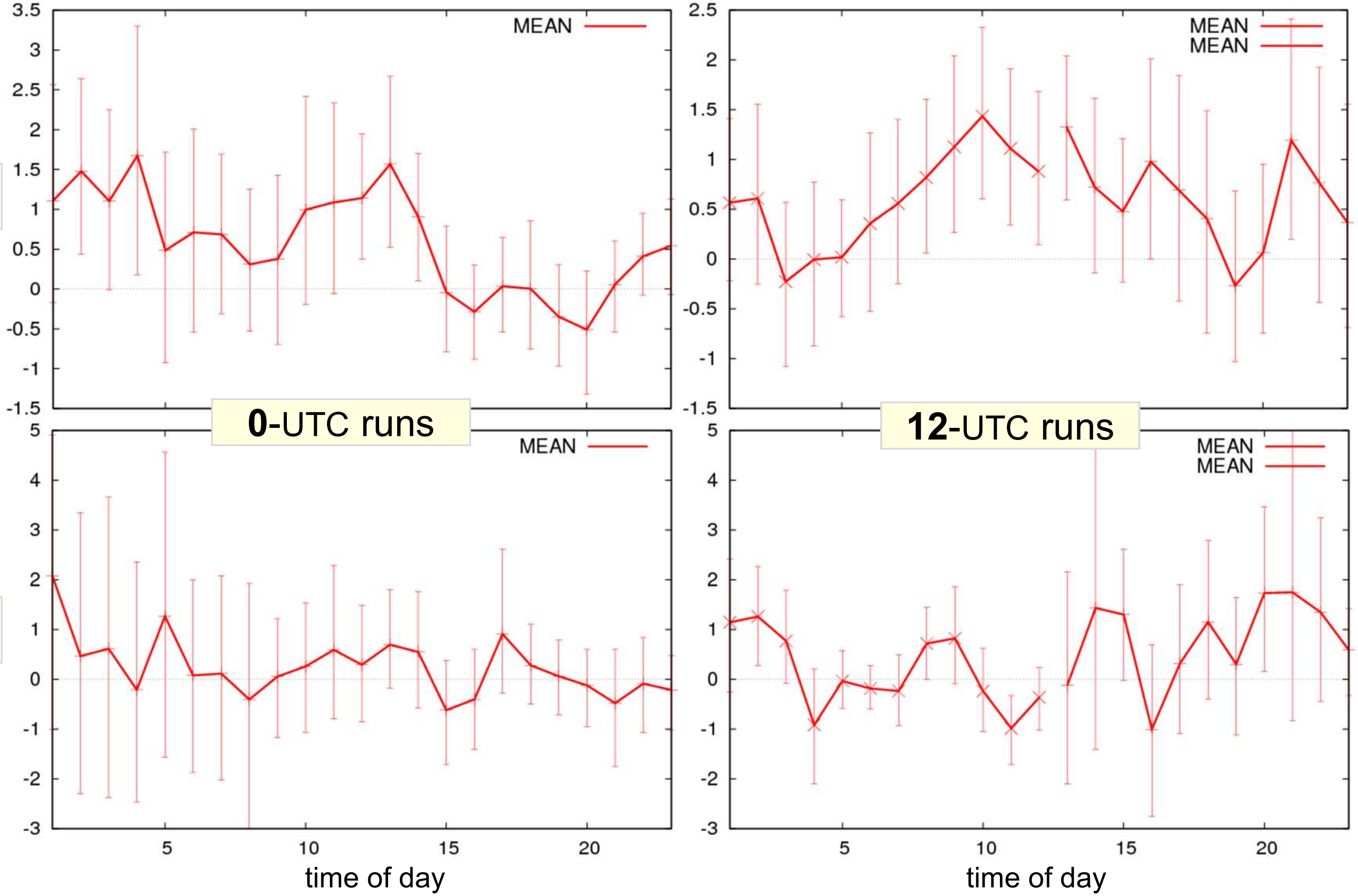
1-h precip vs. radar
15 April – 10 May 2019

FSS % improvement (30 km)
radar Vr vs. ref (conv. only)

0.1 mm/h

1 mm/h



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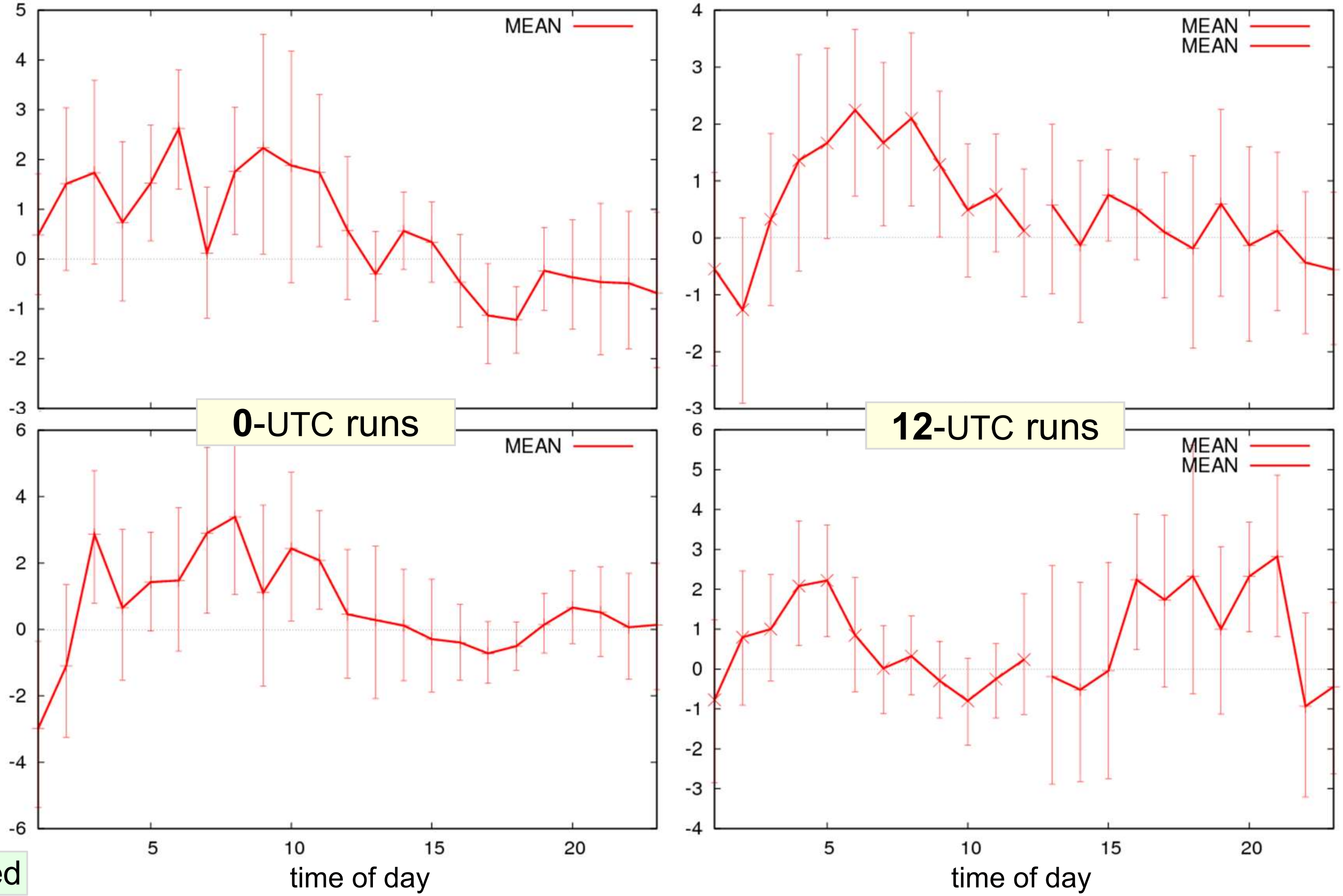
Task 2.1: radar radial wind: impact (precip verification)

1-h precip vs. radar
2 – 25 June 2019

FSS % improvement (30 km)
radar Vr vs. ref (conv. only)

0.1 mm/h

1 mm/h

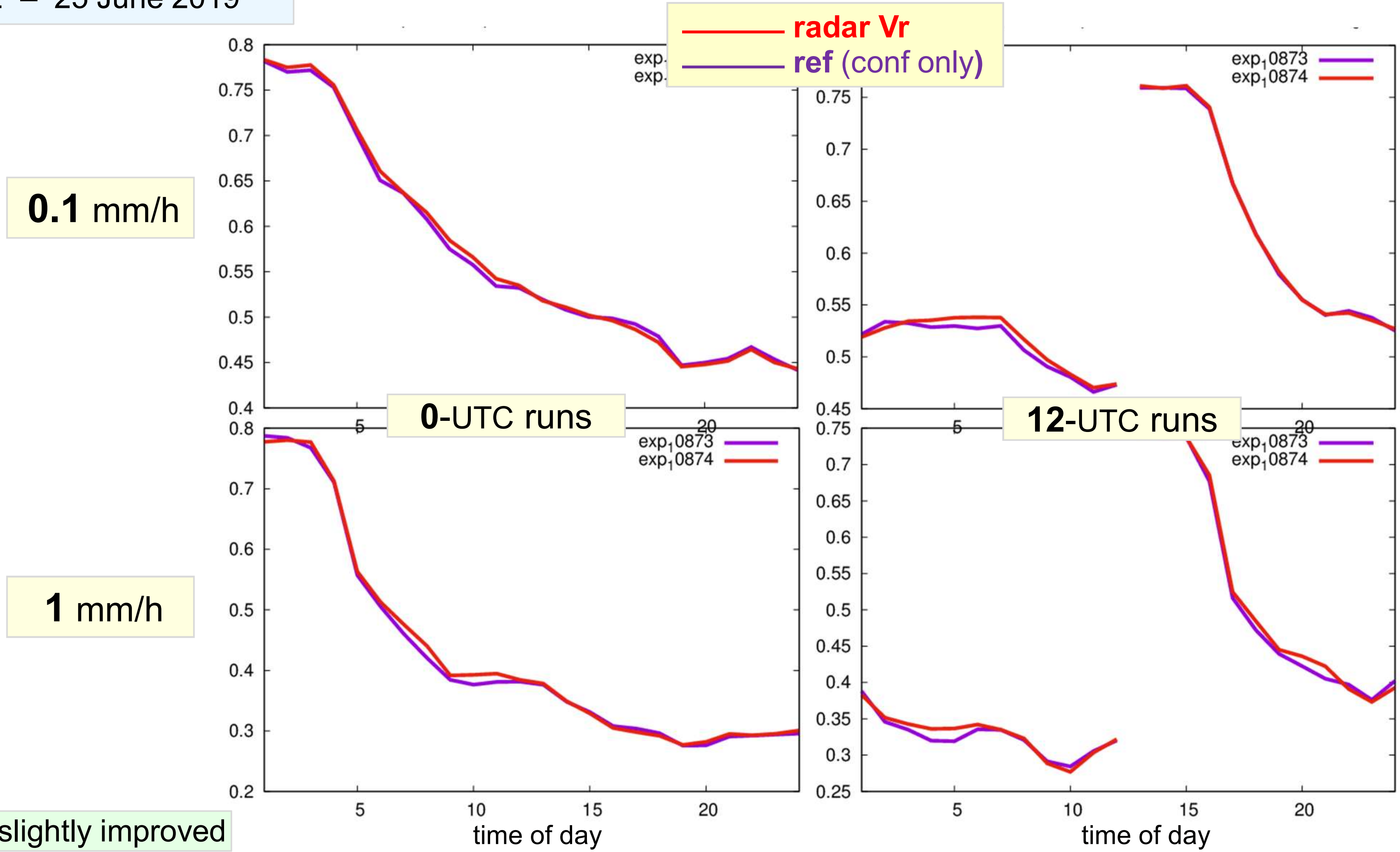


→ slightly improved

Task 2.1: radar radial wind: impact (precip verification)

1-h precip vs. radar
2 – 25 June 2019

FSS (30 km)



→ slightly improved

Task 2.1: radar radial wind summary

- modification applied: reduced influence of radial winds by increasing specified obs error where observed reflectivity is low (more often at night)

- negative impact seen in parallel suite removed
  now small, but consistent positive impact from radar radial winds

- planning to re-introduce Vr into parallel suite (for COSMO !)

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Task 2.5: screen-level observations bias correction of 2-m temperature

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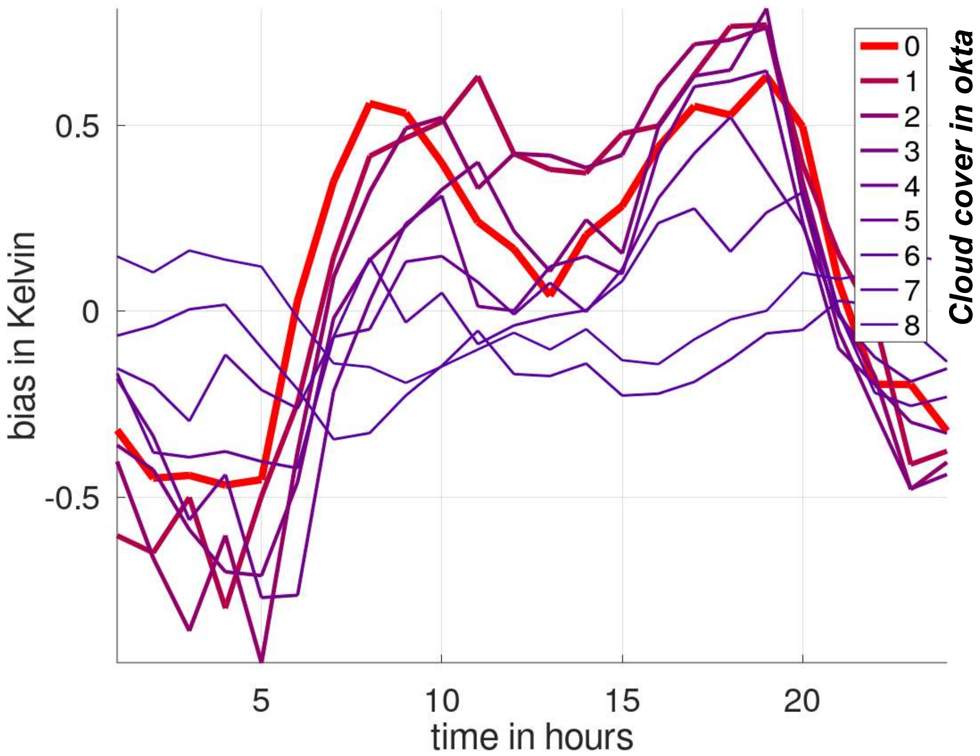
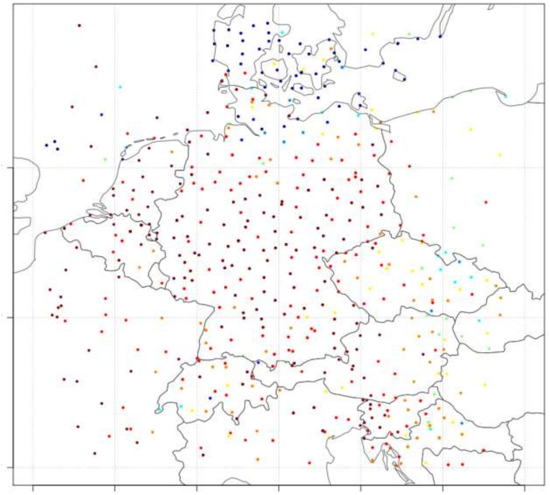
***Christine Sgoff**, Elisabeth Bauernschubert*
(Roland Potthast, …)

2m Temperature – Bias Behavior





Observation stations with 2m temperature and cloud cover measurements

- ➔ Diurnal cycle of T2M bias, depending on cloud cover (average over all stations)
- ➔ More clouds → less pronounced diurnal cycle

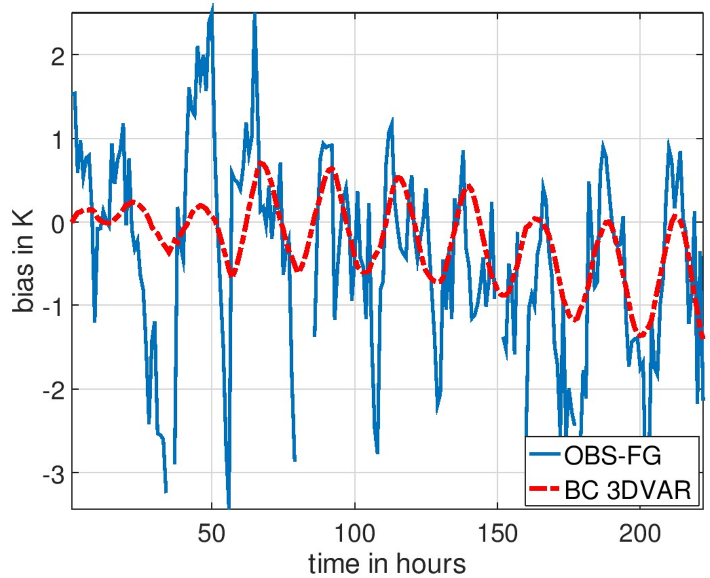
Approach: dynamic parameterized non-linear bias correction

- ➔ approximate diurnal cycle of bias ***b*** with basis functions $\boldsymbol{A_i}$ with a dynamic coefficients $\boldsymbol{a_{ik}}$ update depending on the measured cloud ***k*** cover

$$b_k = \Sigma_i A_i \cdot aik \quad 1 \; \sin(nt) \; \cos(nt) \; \sin(2nt) \; \cos(2nt) \; \sin(3nt) \; \cos(3nt)$$

- ➔ 3Dvar update of a_{ik} each time step with new observation
- ➔ Assimilation including bias correction only with reliable statistics (~ 50 updates)
- ➔ Each station has its own set of coefficients a_{ik}

bias and bias estimates of one SYNOP station



Task 4.1: KENDA for ICON-LAM: implementation

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- **Fortran codes:**
  - **LETKF/KENDA** adjusted to ILAM (model grid structure ($\rightarrow$ obs operators, exclusion of obs near lateral BC, …), parallelisation, writing increments instead of analyses, SST perturbations (derived in LETKF instead of separate program 'adjust_sst_snow'), nudging of soil moisture (towards ICON-EU), …);
  - **ICON:** DACE obs operators (plus RADVOROP) included for **4-D online LETKF**;
  - **SST- / Snow Analysis** adjusted to ILAM;

- **DA suite:** MEC-based + online **ILAM-LETKF** implemented **in BACY-1,** with **options for IAU, LHN, SST-/Snow-Analysis** etc.; **bug corrections, adjustments**, and refinements in the
  - **model** (e.g. shallow convection, SSO parameters, reduced divergence damping, extended upper and lateral boundary relaxation, IAU)
  - **data assimilation** (hydrostatic balancing, analysis increments for qc, qi, w, MEC-QC against deterministic run, bug fixes and adjustments in LHN, …)
  - **BACY-1** (experimentation script environment developed in DA Section of DWD)

- whole ICON-LAM **DA + forecast system** (chain) developed and tested in **BACY-1** so that:
  - all **components** available + compatible with each other
  - implementation in NUMEX / parallel suite / **operational** suite made much **easier**

→ a **huge** amount of **work** into adaptation of KENDA to ICON-LAM, incl. testing **!**
(also for porting forward operators for additional obs, e.g. radar, SEVIRI, etc.)

→ thanks to:

Hendrik Reich, Christian Welzbacher, *Harald Anlauf, Klaus Stephan, Thomas Rösch, Martin Lange, Thorsten Steinert, Sven Ulbrich, Gernot Geppert, Lilo Bach, Uli Blahak, Christoph Schraff, Roland Potthast, … , Günther Zängl*

- results from a few major tests, with 3-D MEC-based LETKF:
  - impact of **LHN** (latent heat nudging) in summer
  - **comparison of ICON-DE vs. COSMO-DE**
    - in summer (convection) with (and w/o) LHN
    - in winter without LHN

Optimization of ICON-LAM model setup in LETKF cycle: Relaxation at **upper boundary**

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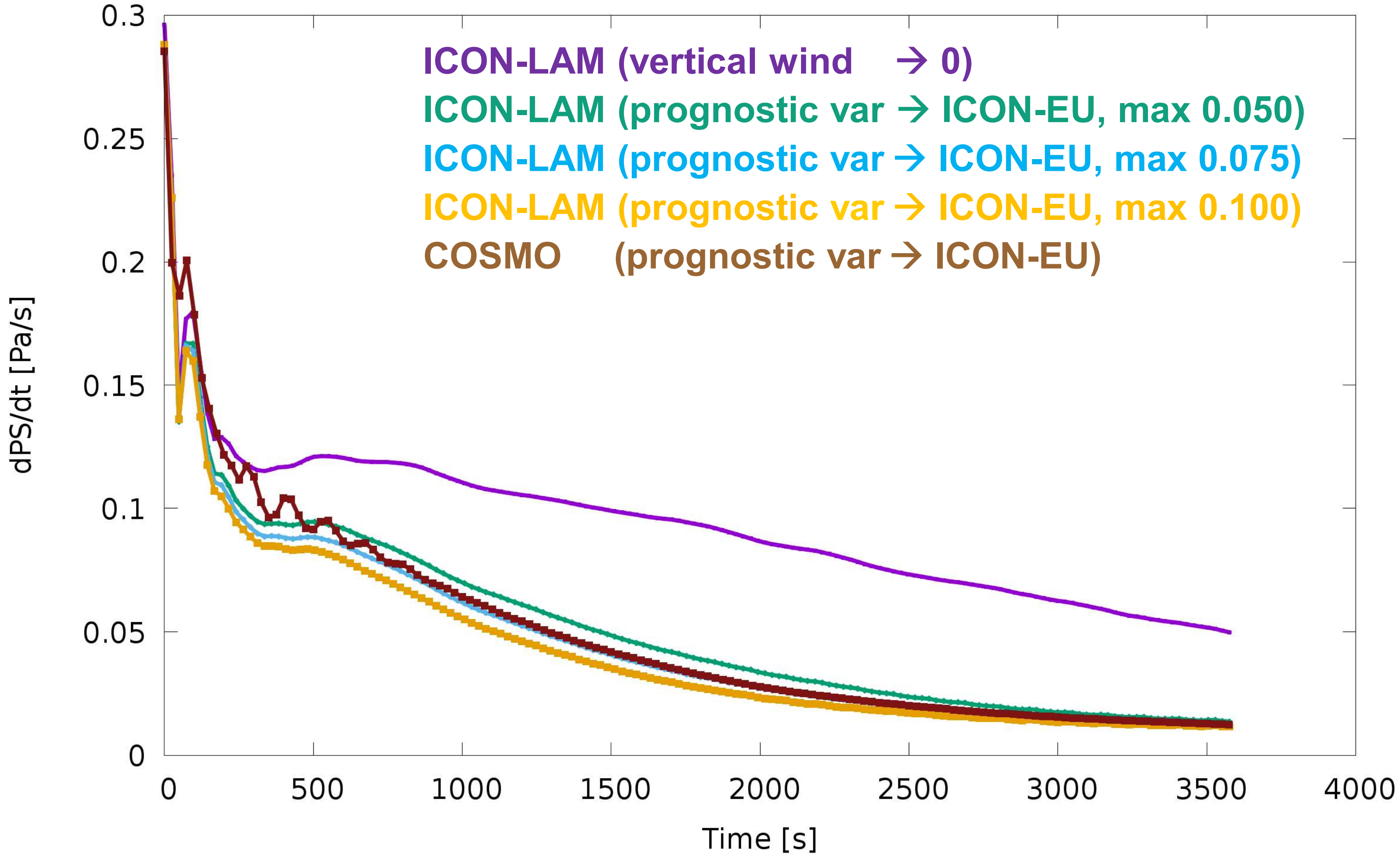
DWD

balance: evolution of mean abs. **surface pressure tendency**



Optimization of ICON-LAM model setup in LETKF cycle: Incremental Analysis Update (IAU)

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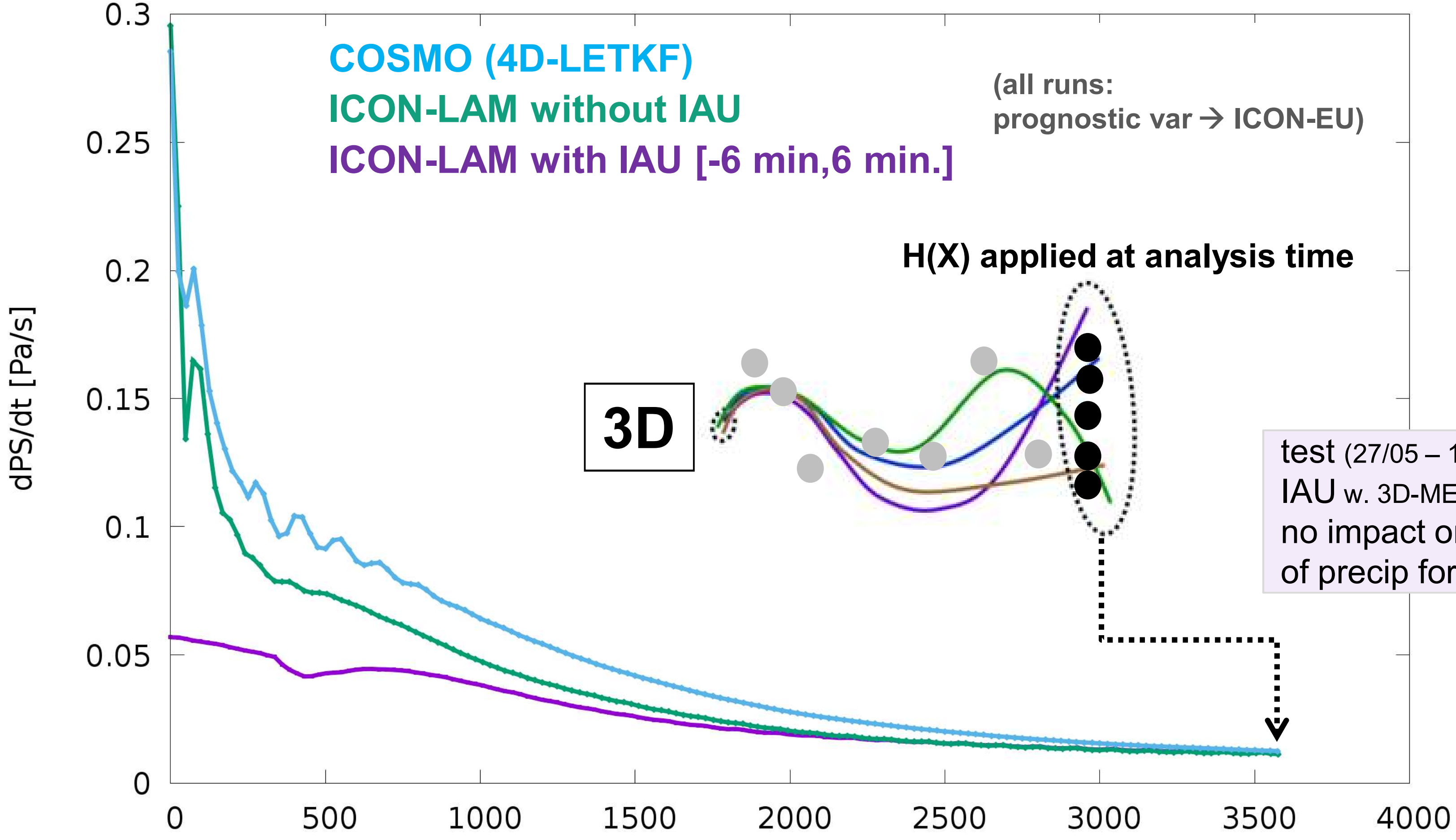
balance: evolution of mean abs. **surface pressure tendency**



test (27/05 – 10/06/16)
IAU w. 3D-MEC-LETKF:
no impact on quality of precip forecast

IAU: do not add analysis increments to model state once at analysis time, but incrementally over a certain period (to reduce gravity/sound waves)

ICON-LAM responds to LHN quite differently than COSMO

→ tuning done (climatological profile where rain is missing in model; no log-scaling)

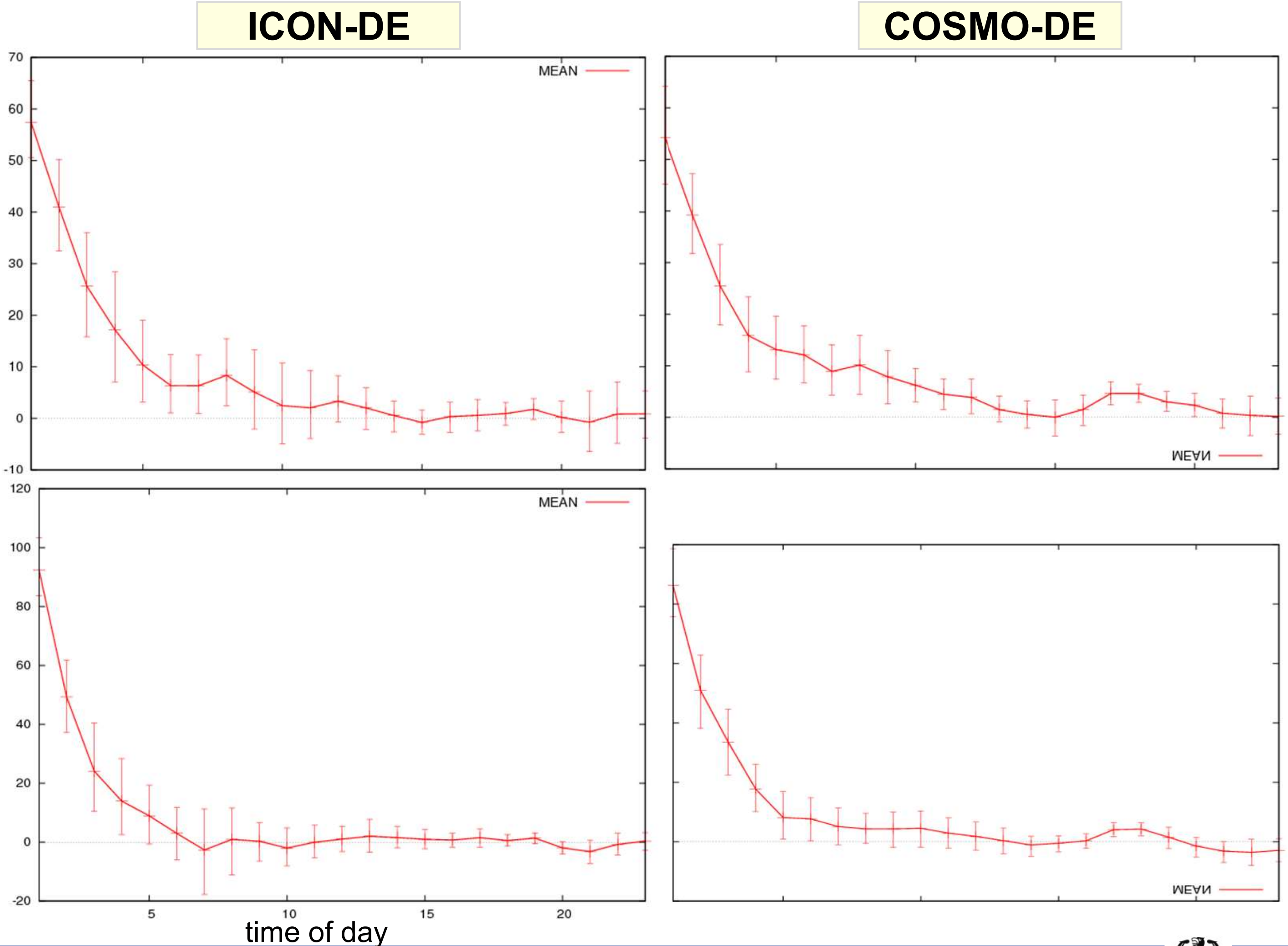
1-h precip vs. radar
27 May – 10 June 2016

0.1 mm/h

FSS % improvement
(30 km)
0-UTC runs

1 mm/h

→ typical benefits by LHN, in ICON-DE slightly less than in C-DE



ICON-DE vs. COSMO-DE **with LHN** (MEC-based 3-D LETKF)

(27 May – 10 June 2016)

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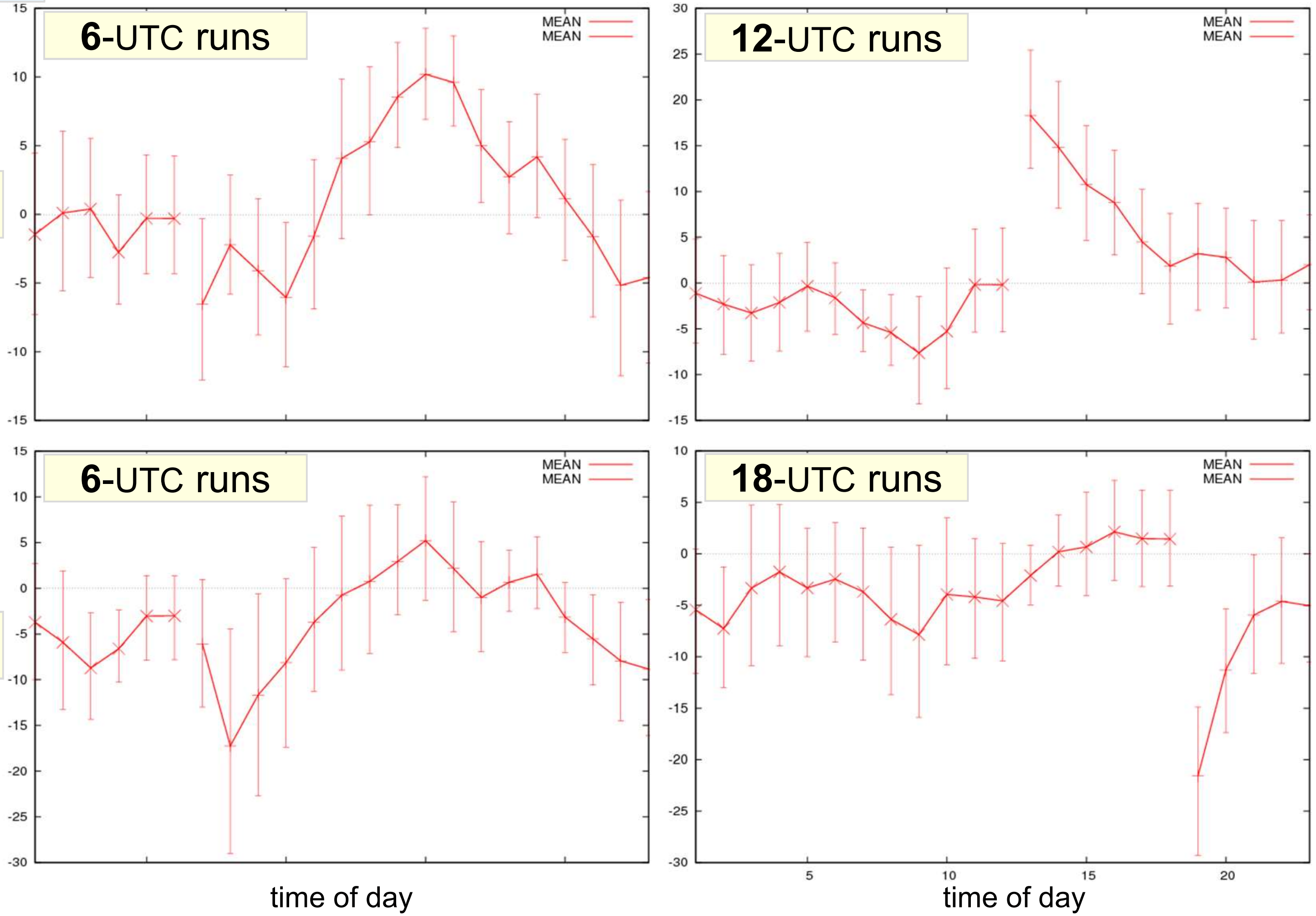
1-h precip vs. radar
27 May – 10 June 2016

FSS % improvement (30 km , **1** mm/h)
COSMO-DE vs. ICON-DE

0.1 mm/h

1 mm/h



→ overall neutral

ICON-DE vs. COSMO-DE (MEC-based 3-D LETKF)

(27 May – 10 June 2016)

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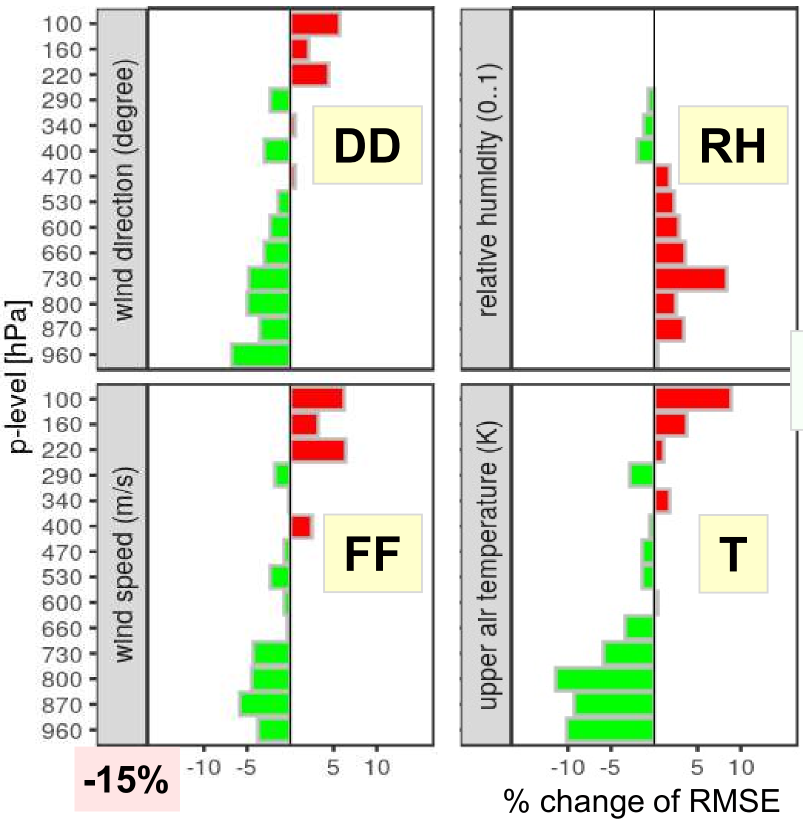
radiosonde verification

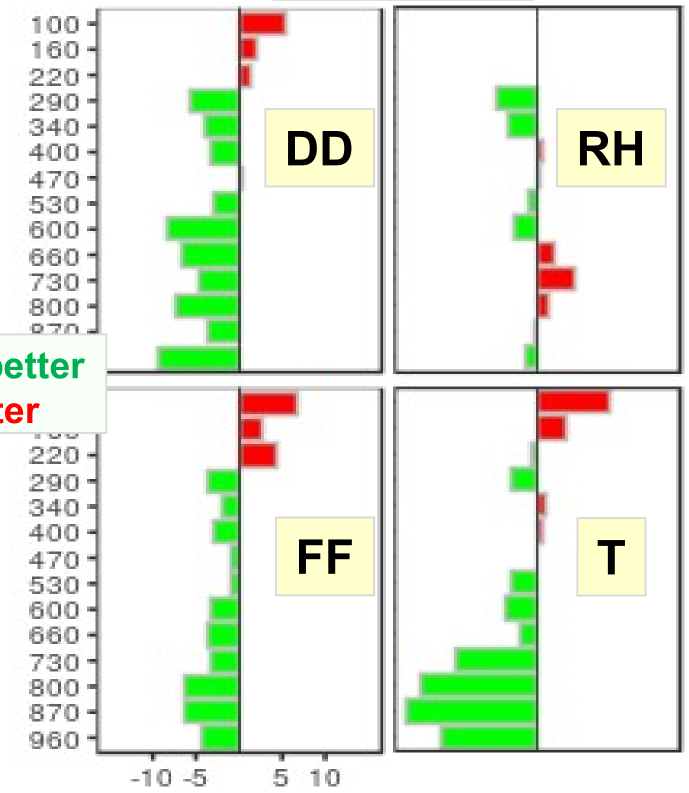
% change of **rmse** (+6, 12, 18, 24h)

with LHN



ICON-LAM better
COSMO better

without LHN



→ troposphere , ICON: T, wind better, humidity worse
→ stratosphere, ICON: worse (no relax to driving model)
→ with LHN, the overall advantage of I-DE over C-DE is a bit reduced

ICON-DE vs. COSMO-DE **with LHN** (MEC-based 3-D LETKF)

(27 May – 10 June 2016) 

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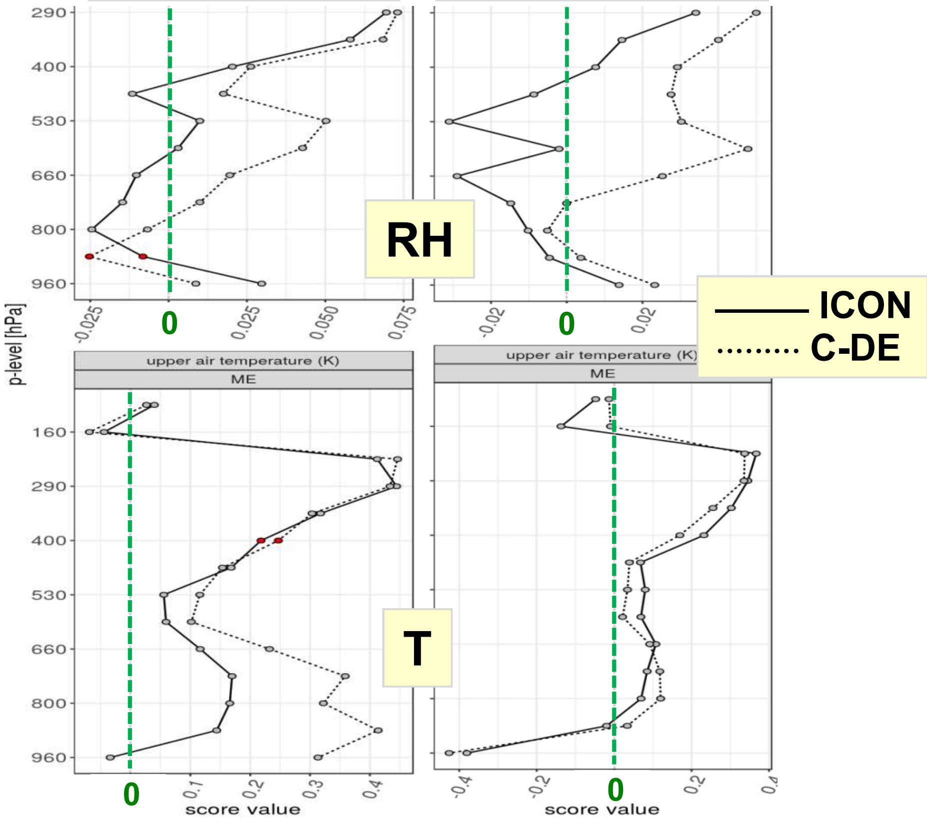
radiosonde verification

bias

init 6 UTC, + 6h noon	**init 18 UTC, + 6h night**



→ COSMO too warm at noon at low levels, too moist
→ ICON better

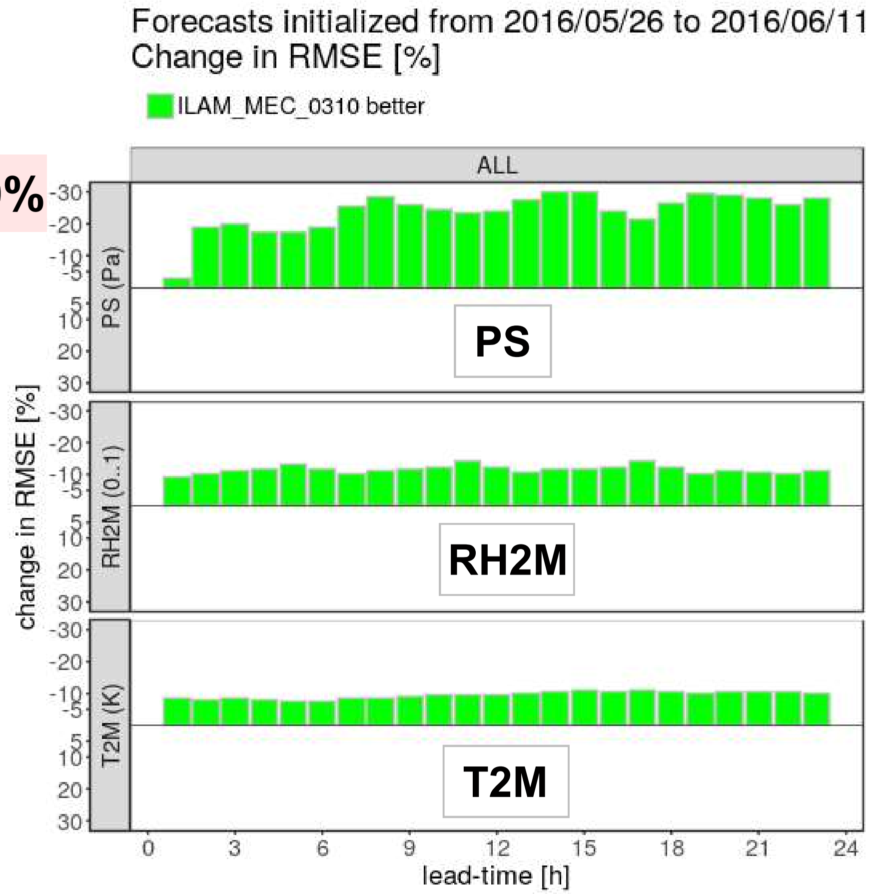
ICON-DE vs. COSMO-DE (MEC-based **3-D LETKF, without LHN**)

(26 May – 11 June 2016)

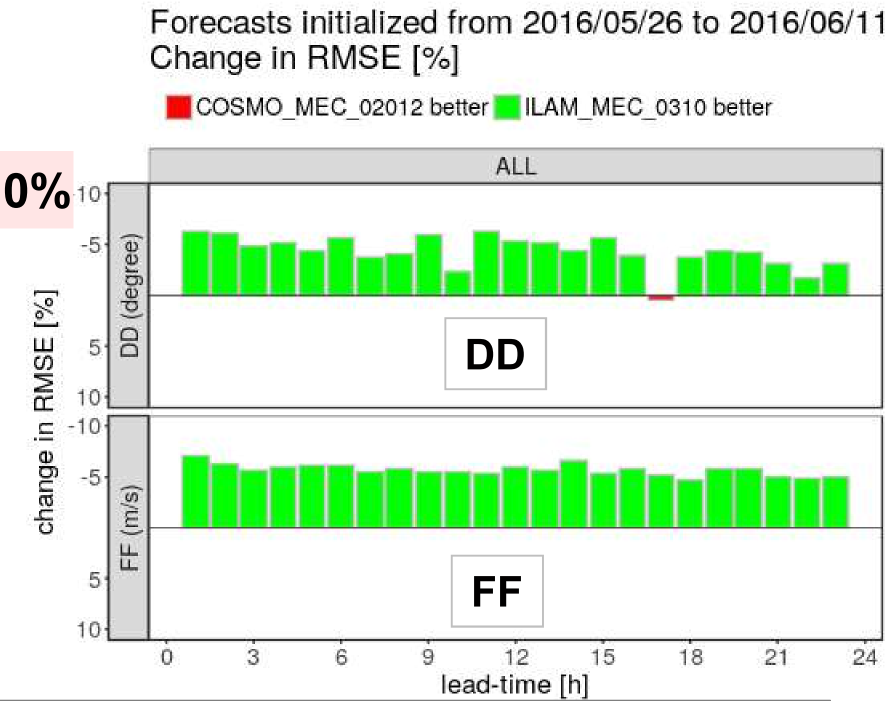
SYNOP verification

ICON-DE better
COSMO better

-30%



-10%



→ all variables clearly improved

→ surface pressure strongly improved (possibly due to more consistent lateral BC (from ICON-EU); surface pressure in summer has been known as an issue in COSMO-KENDA)

ICON-DE vs. COSMO-DE **with LHN** (MEC-based 3-D LETKF)

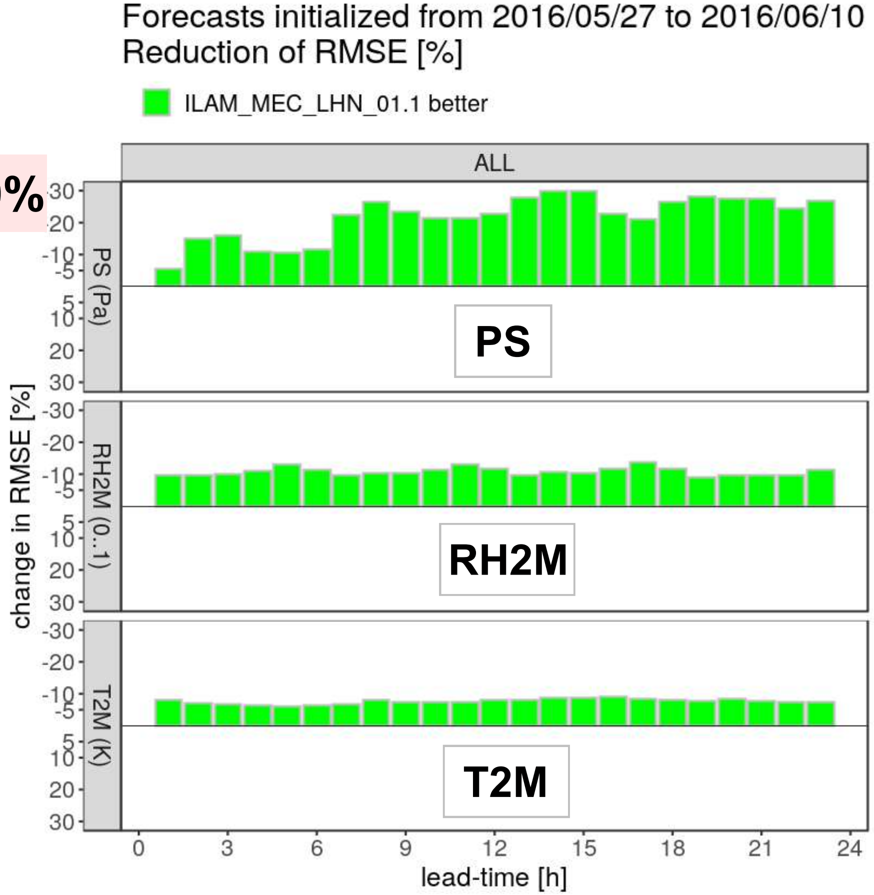
(27 May – 10 June 2016)

Deutscher Wetterdienst

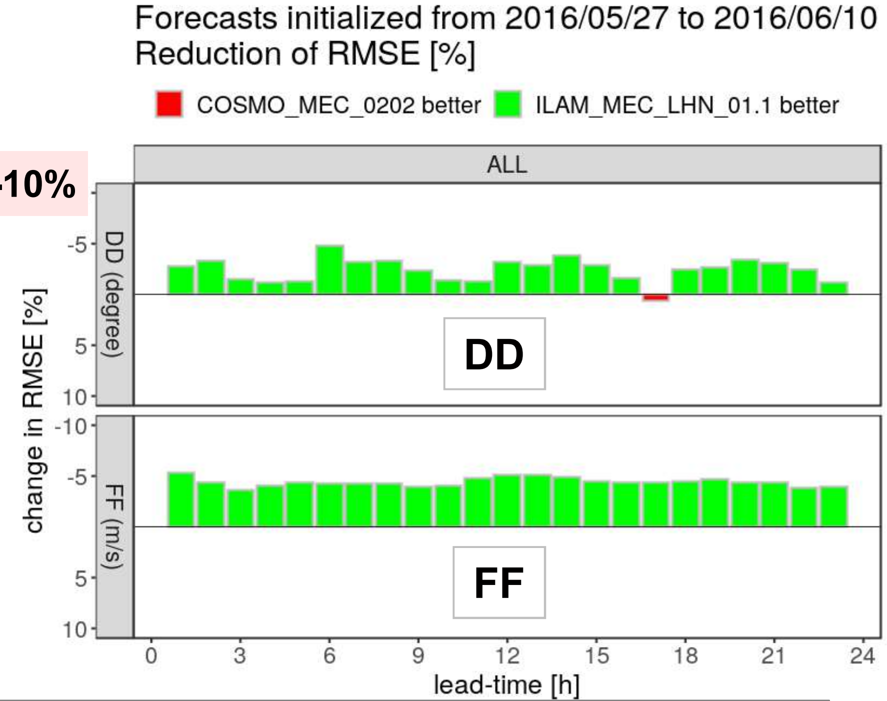
SYNOP verification

ICON-DE better
COSMO better

-30%



-10%



→ all variables clearly improved

→ surface pressure strongly improved (possibly due to more consistent lateral BC (from ICON-EU); surface pressure in summer has been known as an issue in COSMO-KENDA)

ICON-DE vs. COSMO-DE **with LHN**

(27 May – 10 June 2016) 

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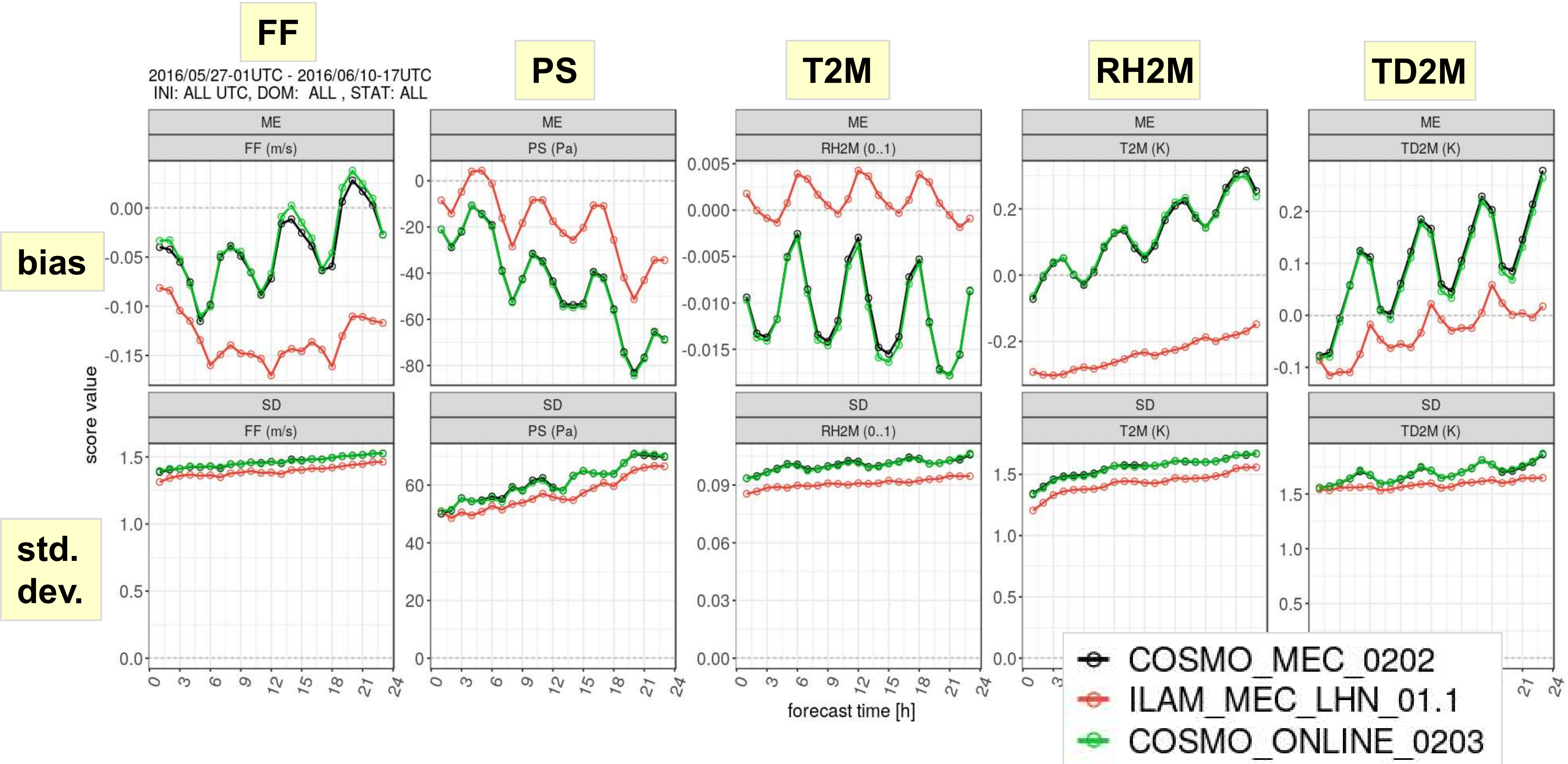
SYNOP verification



→ both **bias + std. dev. improved**

ICON-DE vs. COSMO-DE without LHN (MEC-based 3-D LETKF)

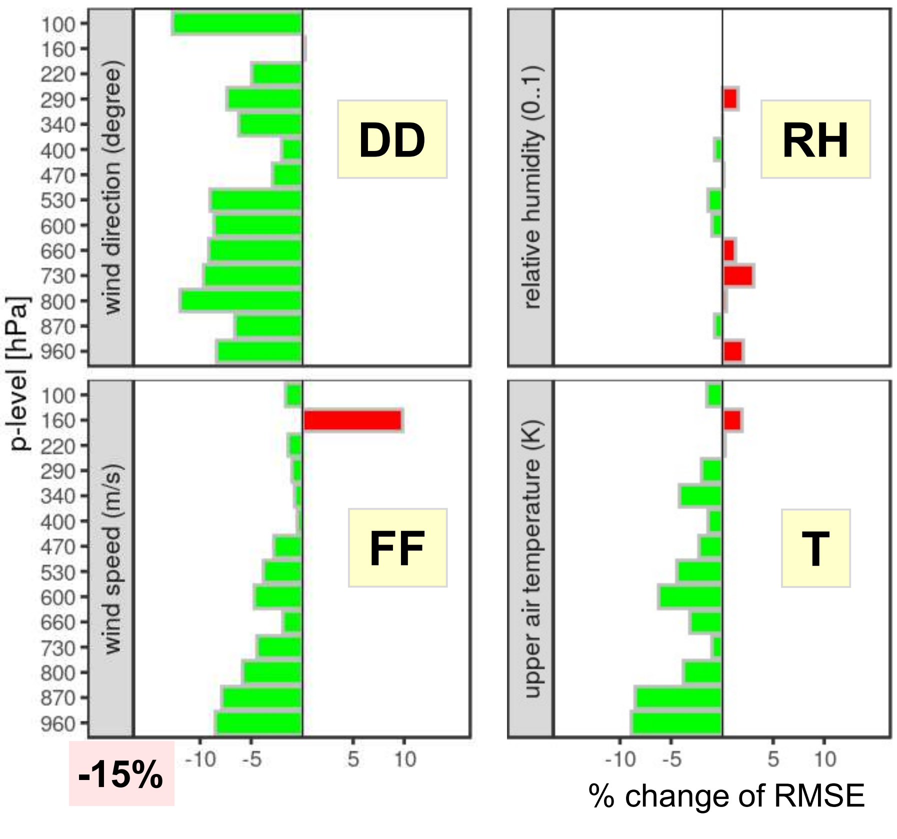
winter (18 – 31 Jan. 2018)

Deutscher Wetterdienst

radiosonde verification

% change of **rmse** (+6, 12, 18, 24h)

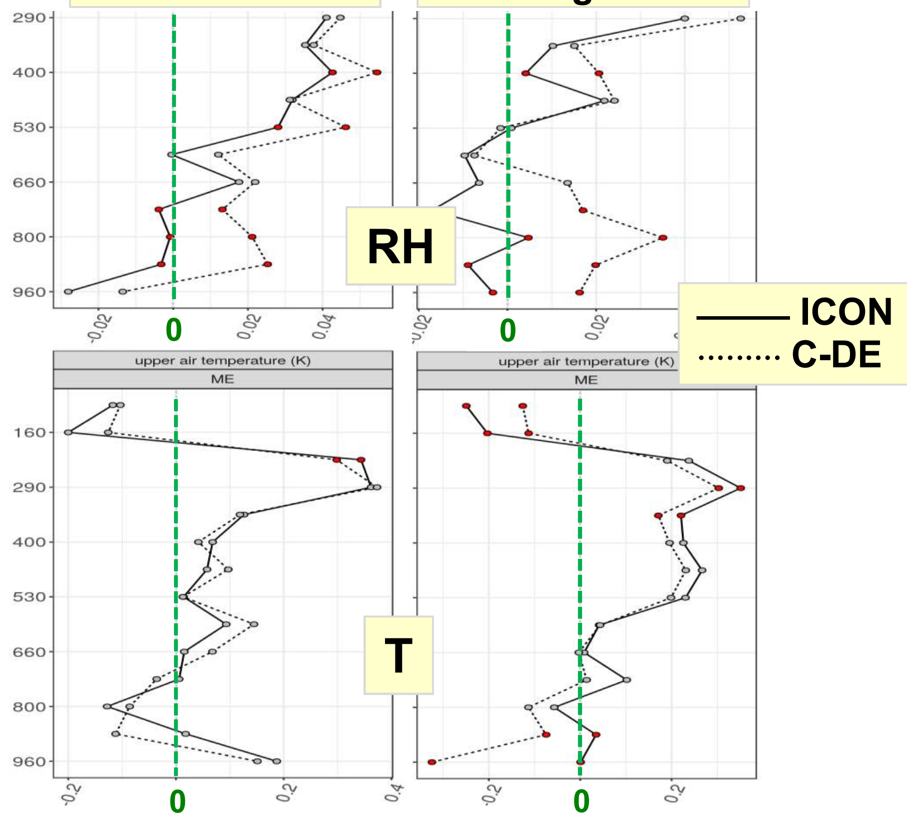
ICON-LAM better
COSMO better



bias

init 6 UTC, + 6h
noon

init 18 UTC, + 6h
night



→ ICON: T, wind better, humidity neutral

→ COSMO too moist, ICON better

ICON-DE vs. COSMO-DE without LHN (MEC-based 3-D LETKF)

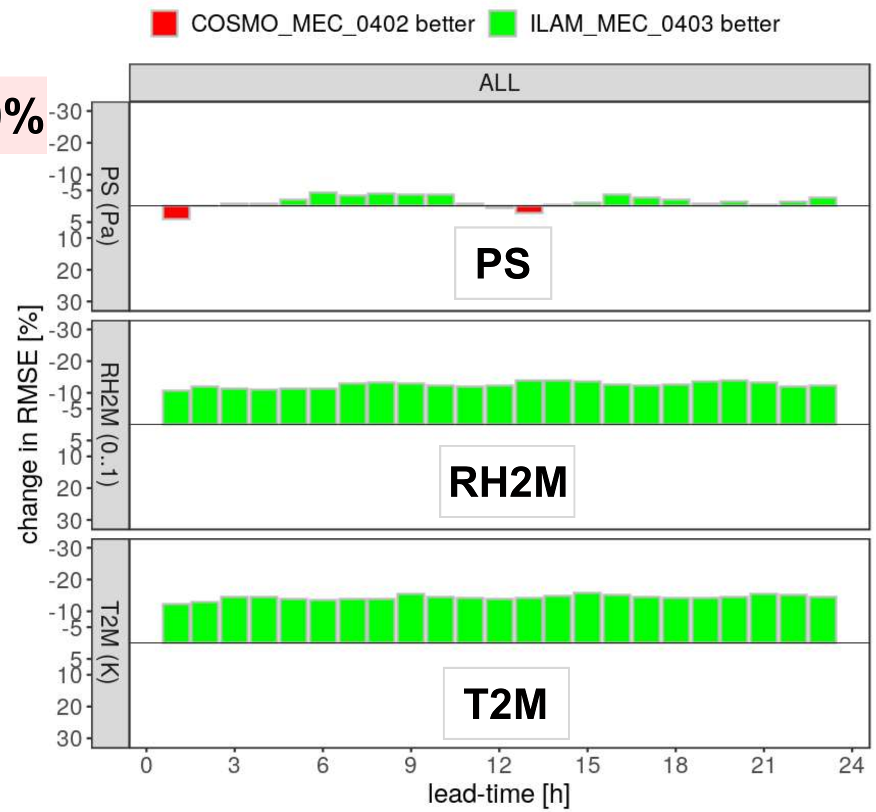
winter (18 – 31 Jan. 2018)

Deutscher Wetterdienst

SYNOP verification

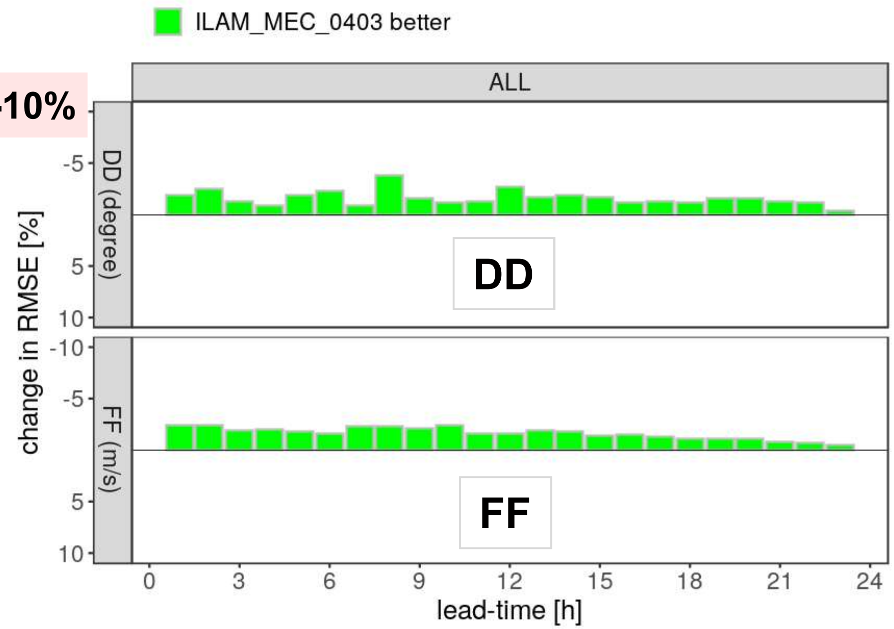
ICON-DE better
COSMO better

-30%



Forecasts initialized from 2018/01/18 to 2018/01/31
Reduction of RMSE [%]

-10%

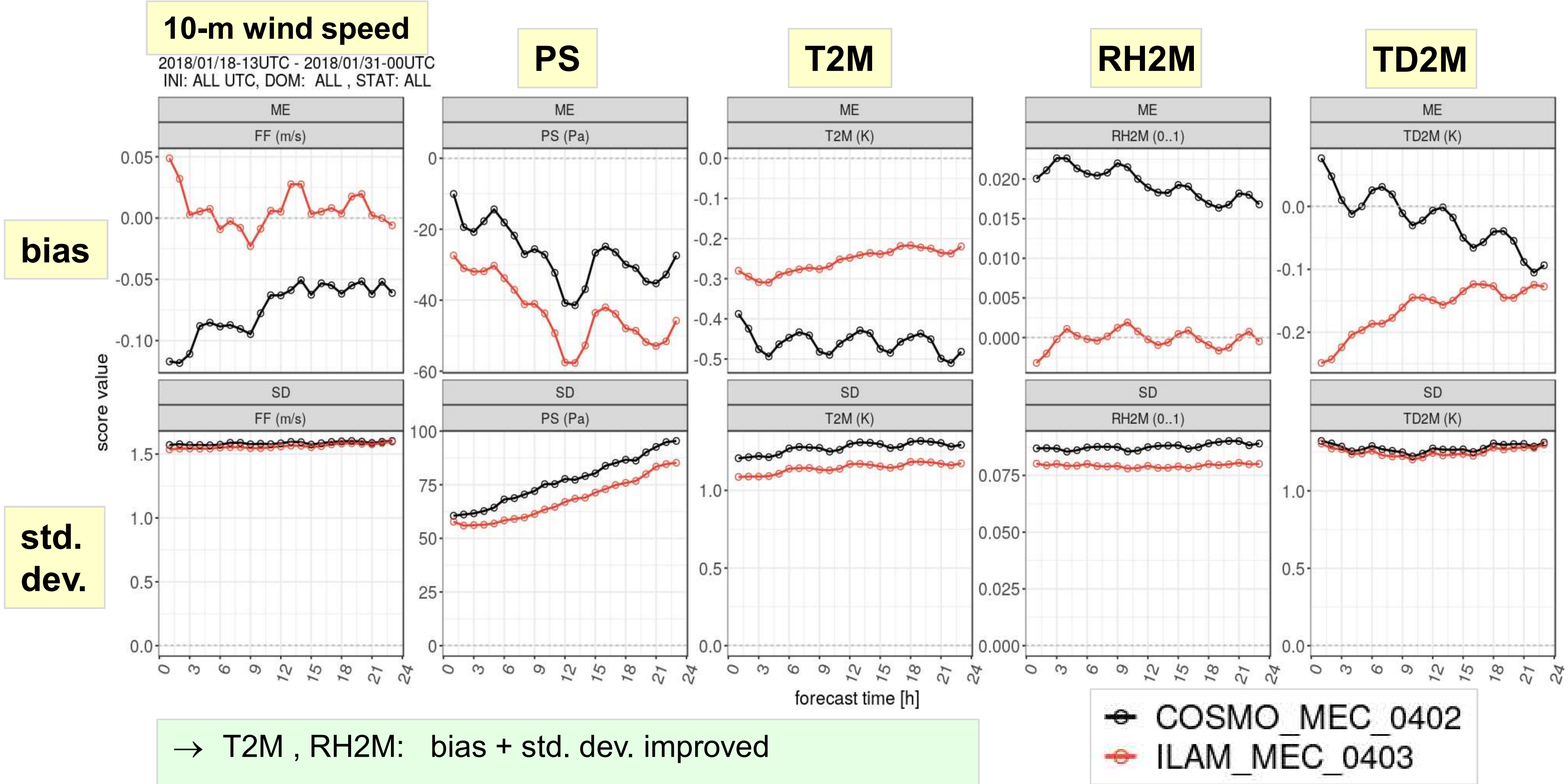


→ surface pressure neutral, **all other variables clearly improved**

ICON-DE vs. COSMO-DE without LHN (MEC-based 3-D LETKF)
winter (18 – 31 Jan. 2018)

Deutscher Wetterdienst

SYNOP verification



→ T2M , RH2M: bias + std. dev. improved

→ surface pressure: std. dev. improved, bias degraded

→ precipitation (vs. radar, not shown): neutral

Task 4.1: Adaptation to ICON-LAM: **status**

Deutscher Wetterdienst

- LHN (latent heat nudging) adapted to ICON-LAM
  - summer (convection): positive impact in ICON-DE almost as large as in COSMO-DE
  - winter: almost no benefit, LHN needs further evaluation / tuning
    (ICON-DE has 100 % more precip than radar, LHN may have problems to reduce it)
- impact experiments (MEC-based 3-D LETKF): ICON-DE verifies better than COSMO-DE

  (convective summer with & w/o LHN (14d); winter w/o LHN (14d):
  upper-air T + wind better, T2M, RH2M, 10-m wind much better; precip similar)
- first extended impact experiments with 4-D online LETKF for ICON-D2 ongoing

  (also testing nudging of soil moisture towards ICON-EU ← SMA)
- pre-operational suite ICON-D2 with KENDA starting Oct. 2019 (after NUMEX implement.)

- in parallel: development for use of additional observations

- towards 3DVar / EnVar option (for deterministic run):
  - preliminary MEC-based 3DVAR + EnVar exists (for COSMO / ILAM in BACY-1)
  - to do: COSMO obs operators (conventional, + radar etc.!) in DACE + TL/Adjoint;
    regional B-matrix ; tuning, testing, etc.