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)*

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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, but will soon be able to continue work)
  - 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.)
- 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
  and build a model-error model

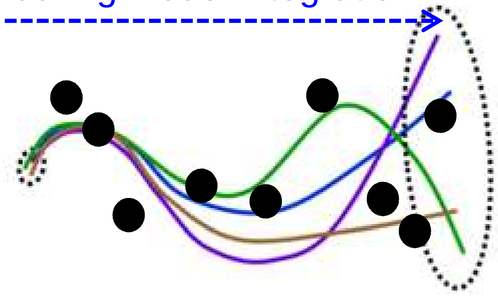
  by comparing tendencies of COSMO-2.2km vs. COSMO-0.22km
  (as the 'truth', tendencies started at the same point in phase space)

  problems (spin-up) → new idea, indication this might work

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

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

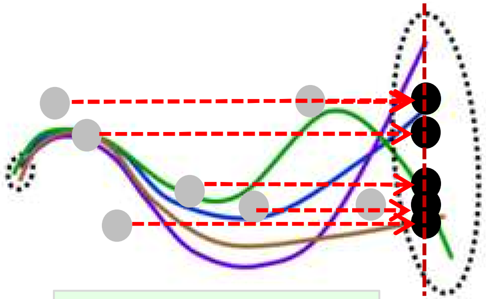
4D



→ **"4-D Online"**

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

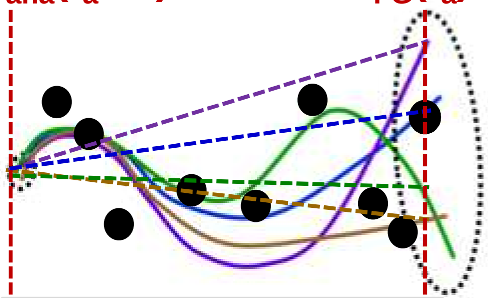
3D



→ **"3-D MEC"**

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

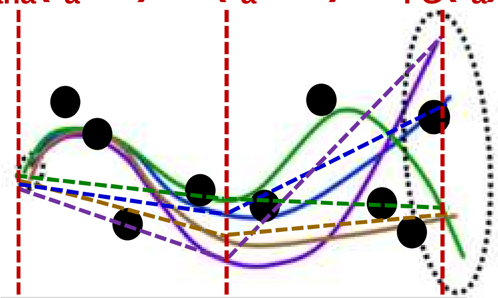
4D



→ **"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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DWD

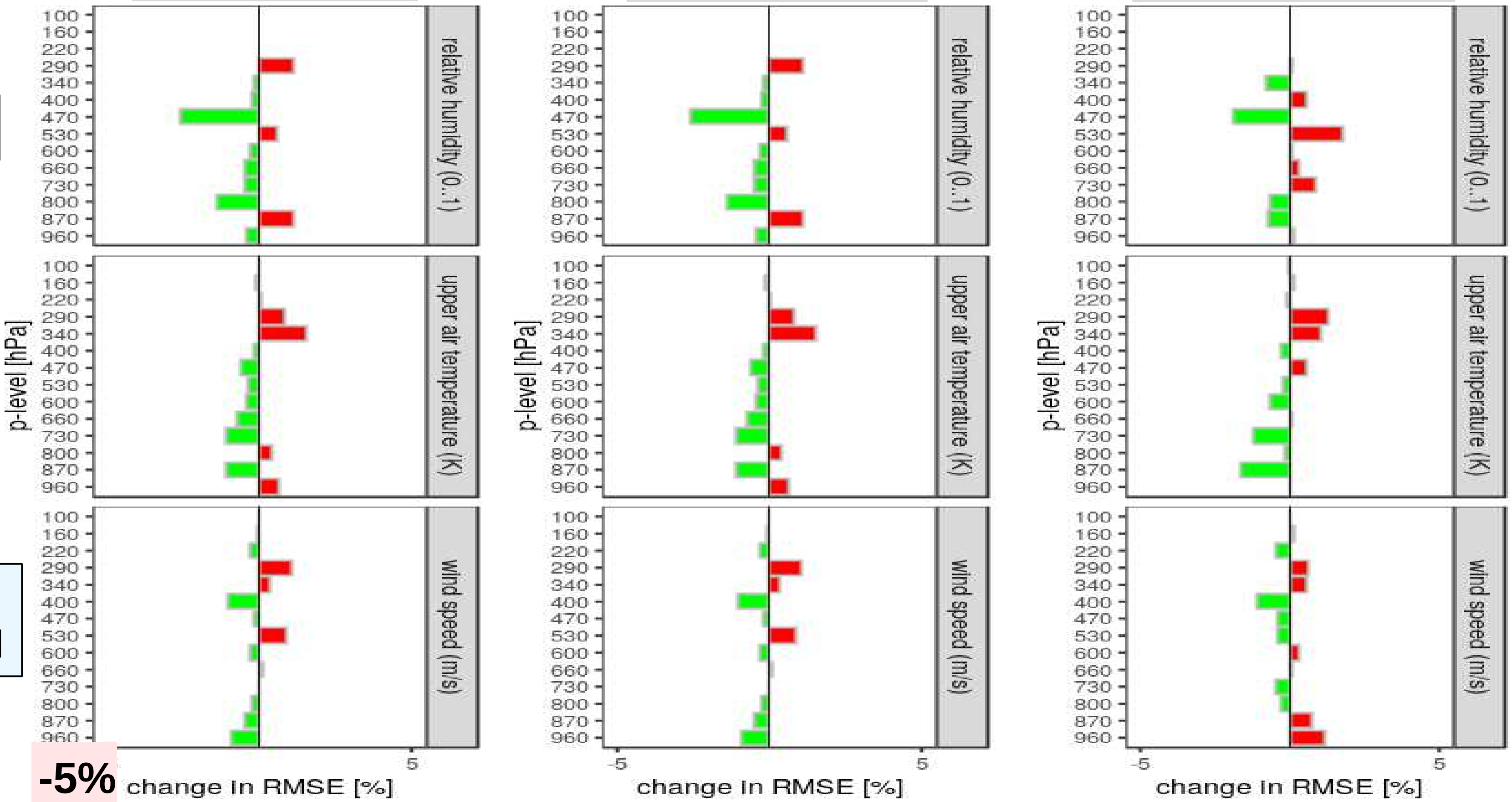
upper-air forecast verification 25 / 06 – 10 / 06 / 2016

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



→ **ranking: 3-D MEC slightly worse**

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

- 3-D LETKF *not much* worse than 4-D LETKF

  → potential future 3-D EnVar alternative for deterministic analysis: not much degradation due to 3-D limitation expected

- interpolated 4-D LETKF (→ ICON-LAM) ~ as good as online 4-D LETKF

- results for high-res. obs (radar, satellite) up to now better with (1-hrly) 3-D approach

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discrepancies between MeteoSwiss and DWD verification results, when comparing KENDA analysis with nudging analysis

experiment at DWD: comparison KENDA vs. Nudging
for Dec. 2016 (winter, extended low stratus periods)

- DWD setup (KENDA, ICON-LBC, obs (no Mode-S)), but on **COSMO-E domain**

- perform verification (applying MEC for verification) in 2 ways,
  i.e. as done at

  – DWD 'ekf-MEC' verification : use QC info from DA — COSMO FG check + LETKF FG check → stricter QC

  – MCH 'cdfin-MEC' verification : do QC independent from DA — COSMO FG check only : → less strict QC

In Task 1: Investigation of discrepancies between MeteoSwiss & DWD KENDA

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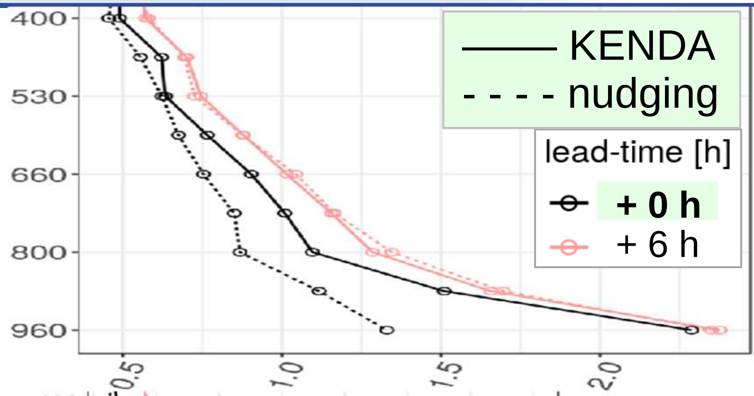
DWD

temperature RMSE

1 – 31 Dec 2016

‘cdfin-MEC’
w. COSMO FG check
no LETKF FG check



→

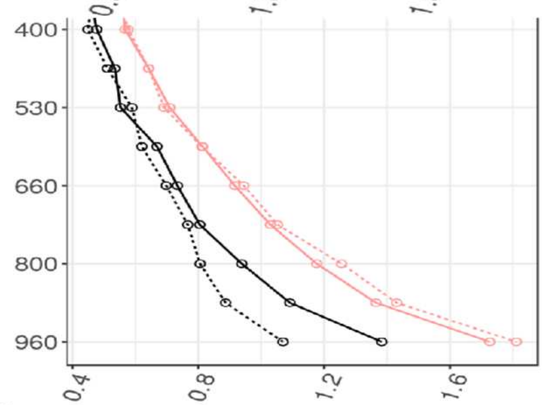
this verif. uses (many) obs which nudging analysis has been drawn towards, but not KENDA analysis

→ unfair for verification of analyses !

“does not tell you anything about analysis quality!”

stricter quality control in verification

‘ekf-MEC’
w. COSMO FG check
+ LETKF FG check
active + passive obs



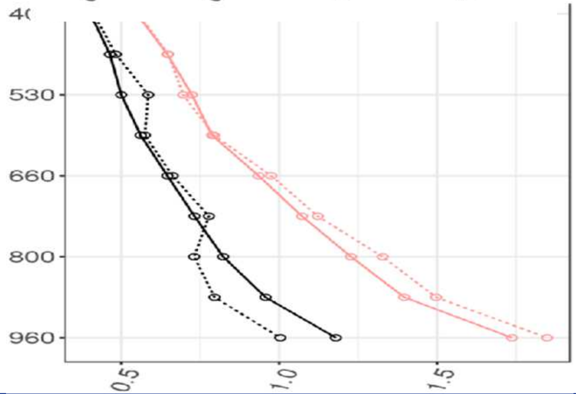
→

fewer of these obs

→ less, but still unfair for verif of analyses !

obs near lateral BC (75 km): assimilated in nudging, not used in KENDA; now neglected in verif

‘ekf-MEC’
w. COSMO FG check
+ LETKF FG check
only active obs



→

analyses verified only against obs which were assimilated in both experiments

→ verification is ‘**fair**’ in 1st order but (even if QC were perfect) still does not tell about analysis quality, but only how close the analysis is drawn towards the assimilated obs !

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In Task 1: Investigation of discrepancies between MeteoSwiss & DWD KENDA

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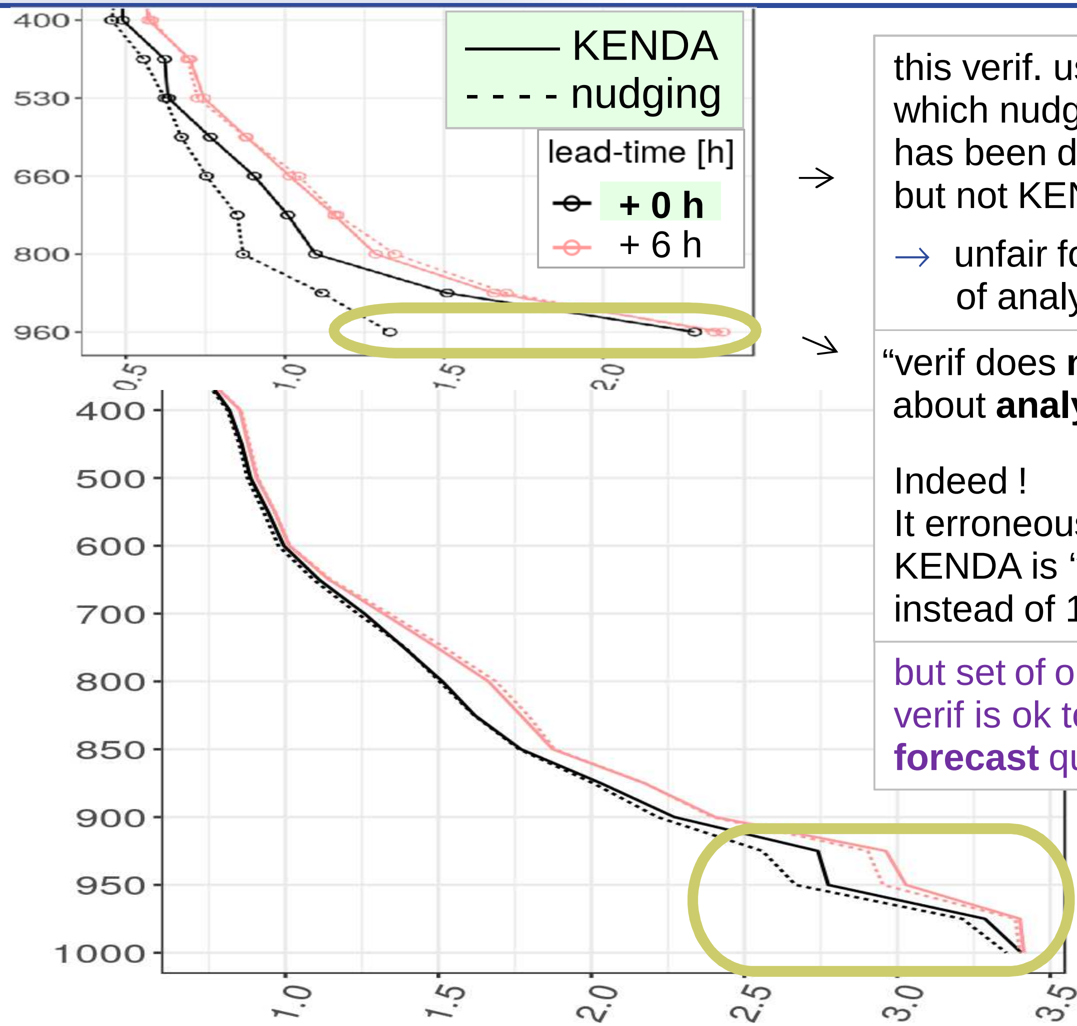
temperature RMSE

1 – 31 Dec 2016

‘cdfin-MEC’

w. COSMO FG check
no LETKF FG check



how to assess analysis quality?

1. verify against independent obs (e.g. for re-analyses) → Mode-S aircraft !
2. for NWP: verify subsequent forecasts !

this verif. uses (many) obs which nudging analysis has been drawn towards, but not KENDA analysis

→ unfair for verification of analyses !

“verif does **not** tell anything about **analysis** quality”?

Indeed !
It erroneously claims that KENDA is ‘worse’ by 75 %, instead of 1 – 5 % !

but set of obs in cdfin-MEC verif is ok to judge **forecast** quality !

Conclusions on use of observations in verification to compare 2 (several) 'experiments'

basic (trivial) requirement: use same set of obs to verify both experiments

usage of obs in **verification of analyses**:

- independent obs (not assimilated in either exp.): suitable to assess quality of analyses
- obs assimilated in both exp. ('ekf-MEC'): indicates only how close the analysis is drawn towards the obs, but does *not* indicate analysis quality
- including obs which are assimilated only in 1 exp. e.g. due to QC independ. from DA ('cdfin-MEC'): can be completely misleading, hence almost *impossible to interpret*

usage of obs in **verification of forecasts**:

- obs assimilated in both exp. ('ekf-MEC'): (i.e. obs passing QC of DA) suitable, except if quality control (QC) of DA has serious shortcomings (e.g. verif. is blind where good obs were rejected)
- obs w. QC different from DA ('cdfin-MEC'): better (only) if QC used is better than QC of DA

→ optimal: 'ekf-MEC' as standard verification;
also do 'cdfin-MEC' verif., differences in verif. results indicate need to check QC

Task 2: use of additional observations overview

- Task 2.1 (a): **radar** radial wind Vr → slides (DWD → COSMO)
- Task 2.1 (b): **radar** reflectivity Z → slides (ARPAE → COSMO) (DWD: → ICON-LAM)
- 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 extension to all-sky data (→ ICON-LAM)
- Task 2.5: screen-level obs: (**T2M**, RH2M) resources since spring work on parameterized non-linear bias correction → ICON-LAM
- Task 2.6: Mode-S operational
- Task 2.7: ground-based remote sensing : wind lidar, Raman lidar, MW radiometer, meteodrones → 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 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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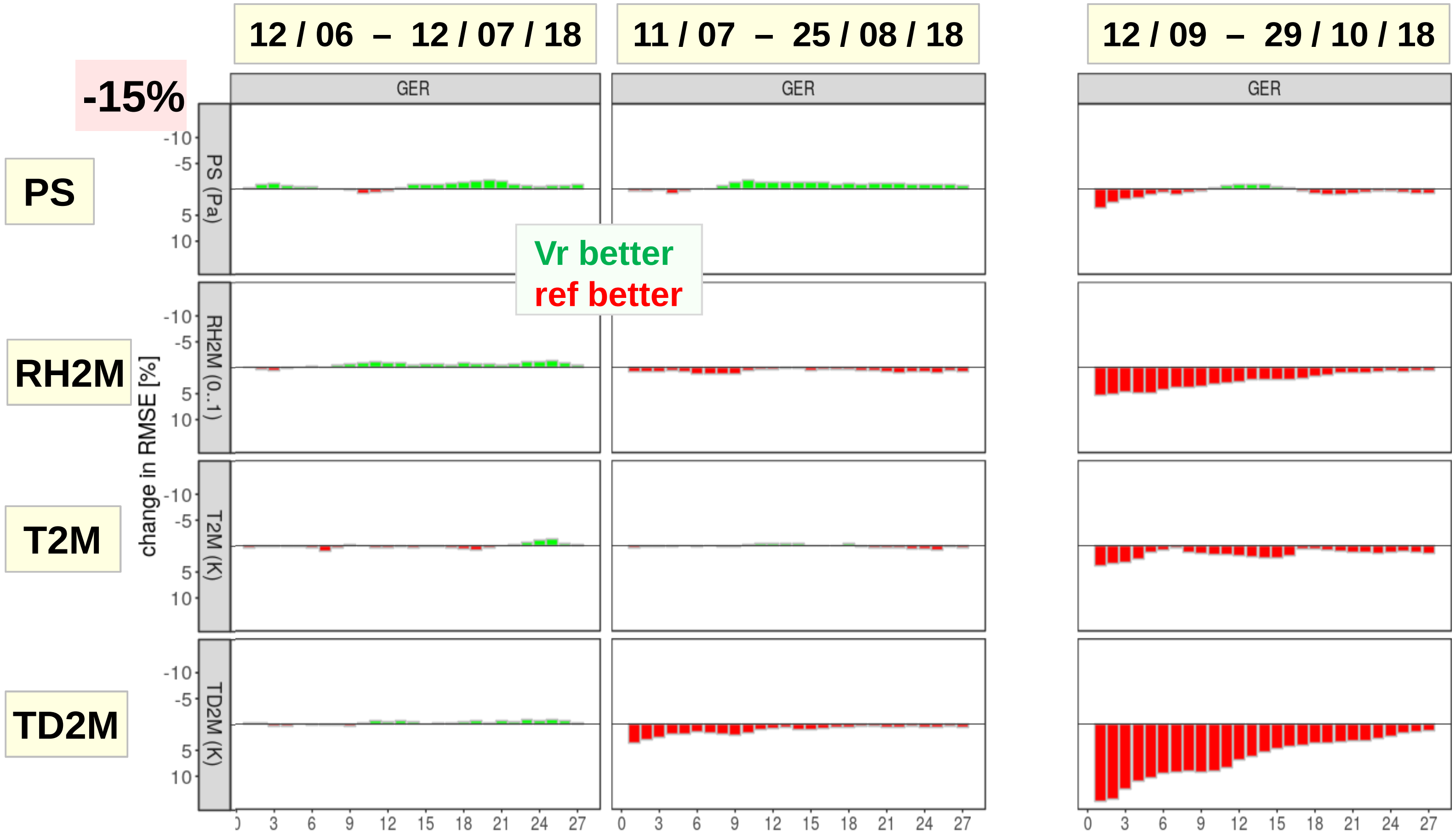

→ **impact** neutral in (dry) summer, becoming **negative in Sept.** (still dry)
(also slightly upper-air wind, T, RH, especially at lower levels)

→ 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 reflectivty is low)

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

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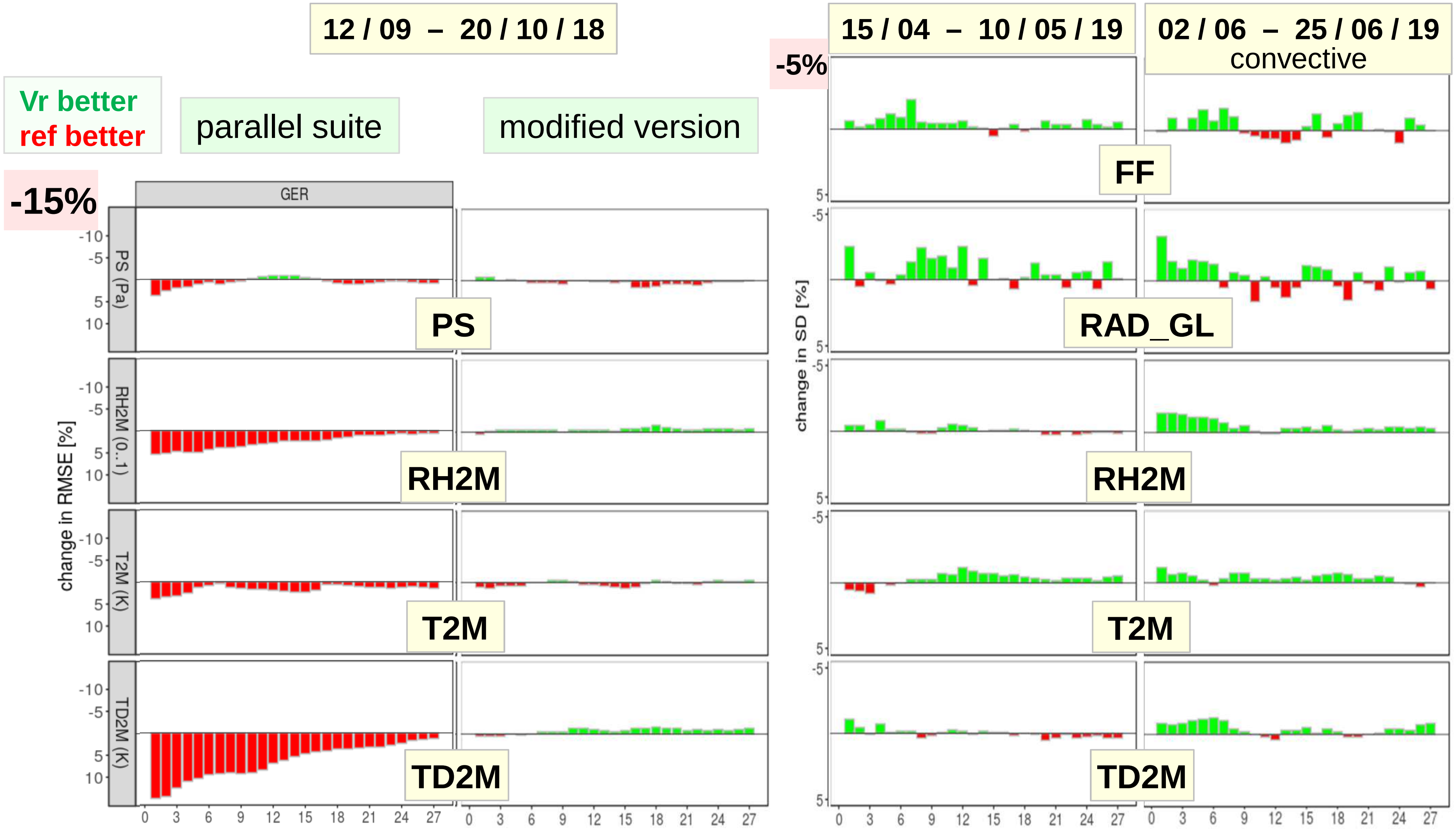

→ **negative impact removed, now small positive impact**

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

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DWD

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

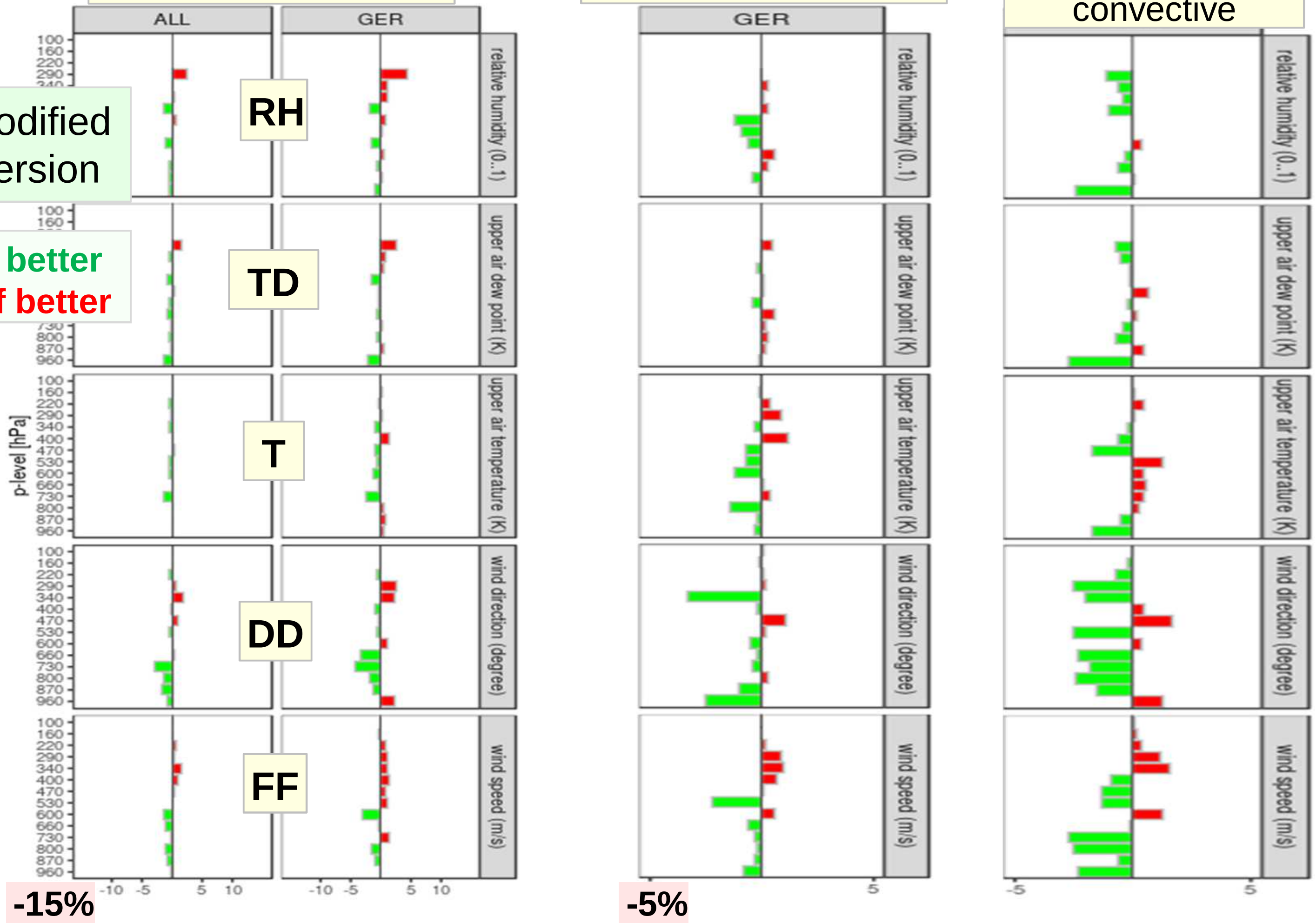
12 / 09 – 20 / 10 / 18

15 / 04 – 10 / 05 / 19

02 – 25 / 06 / 19 convective

modified version

Vr better
ref better



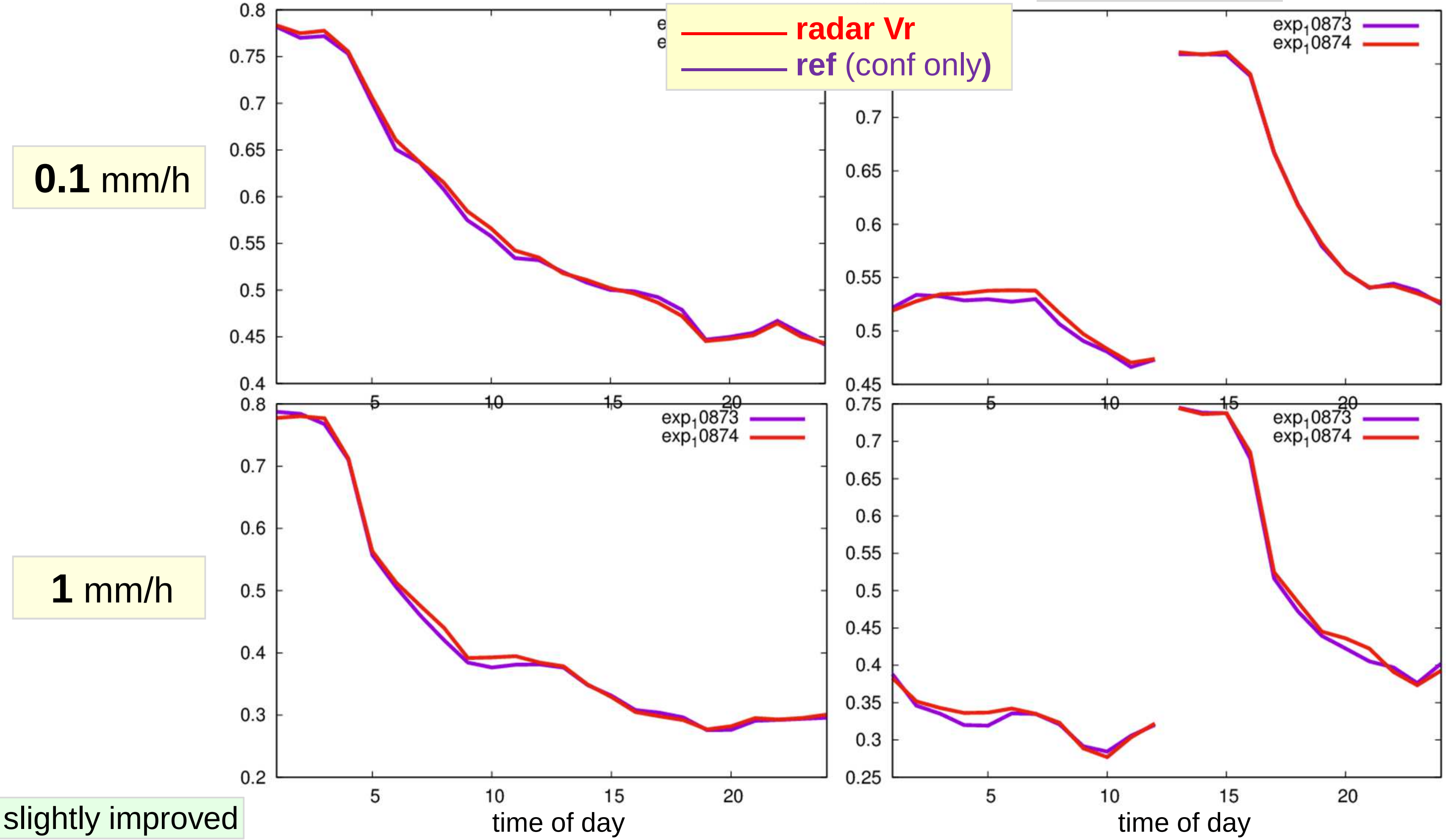
Task 2.1: radar radial wind: impact (precip verification)

1-h precip vs. radar
2 – 25 June 2019

FSS (30 km)

0-UTC runs

12-UTC runs



→ 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 2.1: radar reflectivity Z
impact experiments at ARPAE

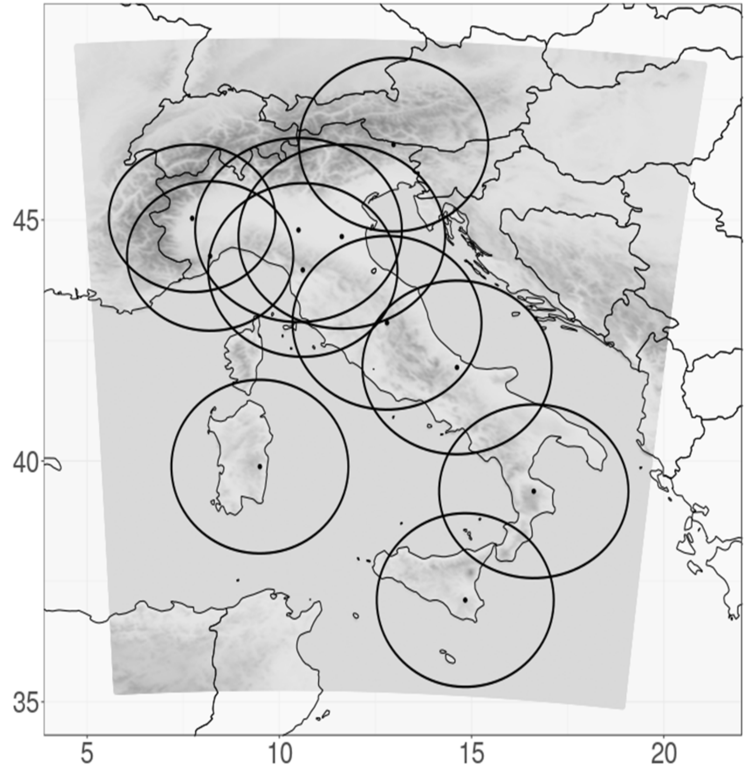
arpae emilia-romagna

Setup

- 1-hrly LETKF 2.2 km, **20** (!) ensemble members

  reference: conv. obs only **+ LHN** (!)

- Radar Z: obs error 10 dBz
  superobbing 10 km
  threshold on Z: 5 dBz
  1 scan per hour (closest to analysis time)



- evaluated: deterministic forecast every 3 hrs

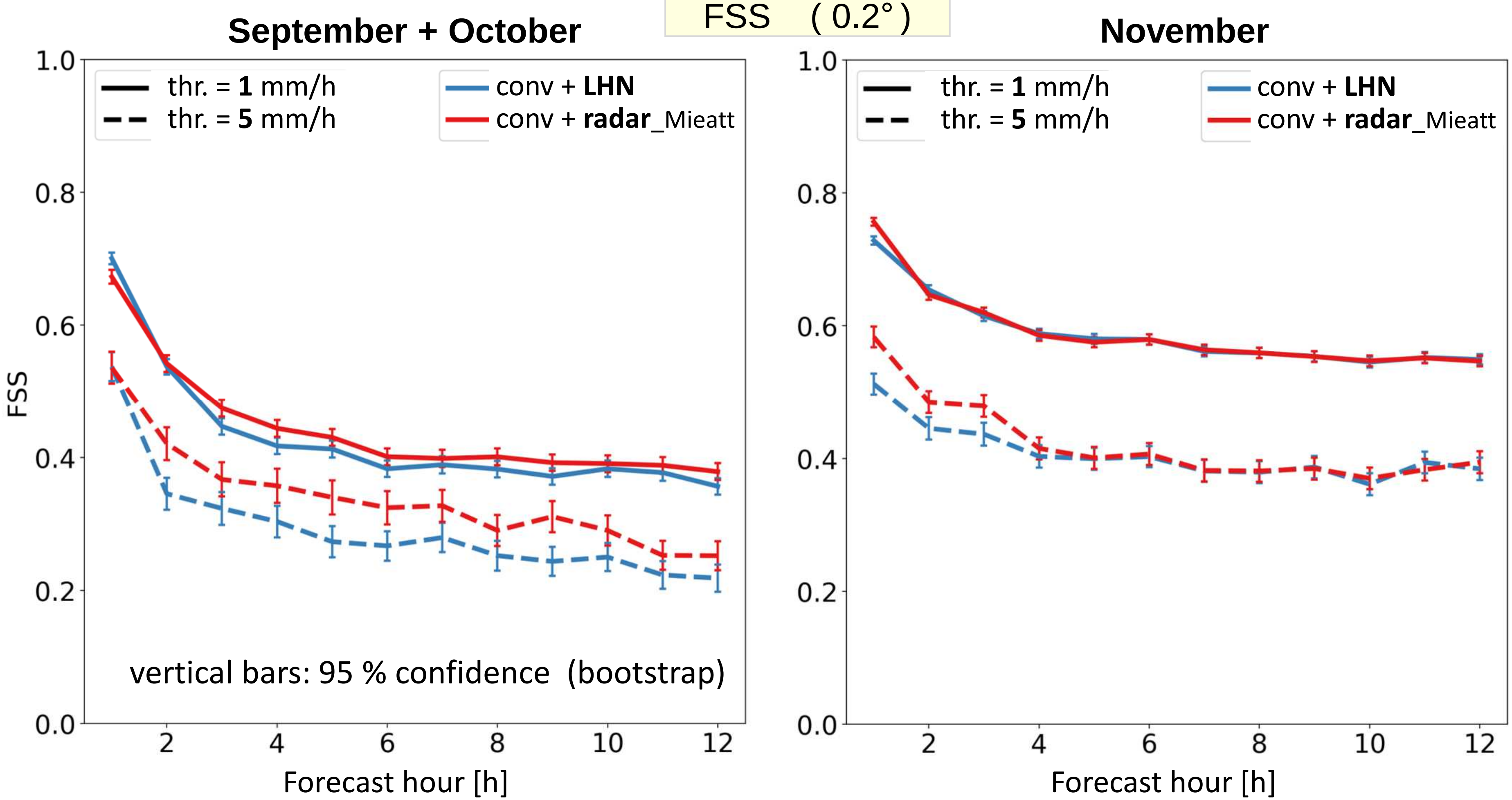
  3 periods (72 – 123 forecasts)

Event	**Start**	**End**	**Type of event**
Sept. 2018	31/08 - 00UTC	09/09 - 00UTC	thunderstorms
Oct. 2018	30/09 - 15UTC	14/10 - 00UTC	organized thunderstorms
Nov. 2018	26/10 - 12UTC	11/11 - 00UTC	stratiform precipitation

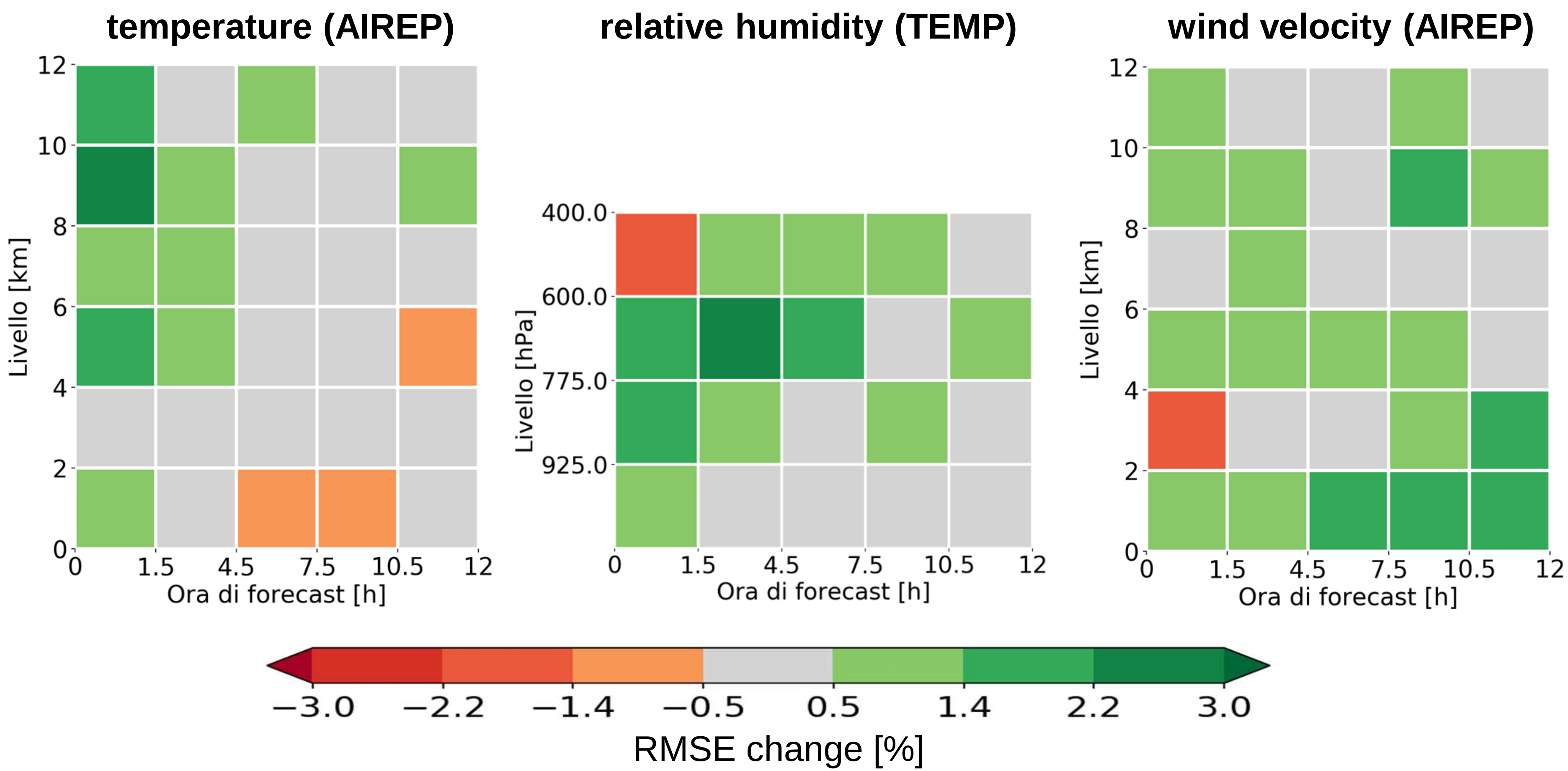
Task 2.1: radar reflectivity Z
impact experiments at ARPAE

Verification of 1-h precip vs. radar composite adjusted by rain-gauges

FSS (0.2°)



upper-air verification for all 3 periods together



Task 2.1: radar reflectivity Z
conclusions at ARPAE

Results: assimilation 3-D reflectivity by LETKF compared to LHN

- **precip**: **statistically significant positive** impact, especially for heavy and non-organized precip;

  upper-air: positive impact on RMSE (T, RH, mainly wind),

  surface: T2M slightly improved, RH2M + ps slightly degraded, 10-m wind neutral
- slight further improvement by doubling ensemble size from 20 to **40 members** (not shown)

Plans:

- tests on a spring case
- tests to better understand how the assimilation of reflectivity volumes may be improved
- introduction of reflectivity volumes in operational KENDA set-up (in 2020)
- possibly, first tests on use of radial winds over the Italian domain

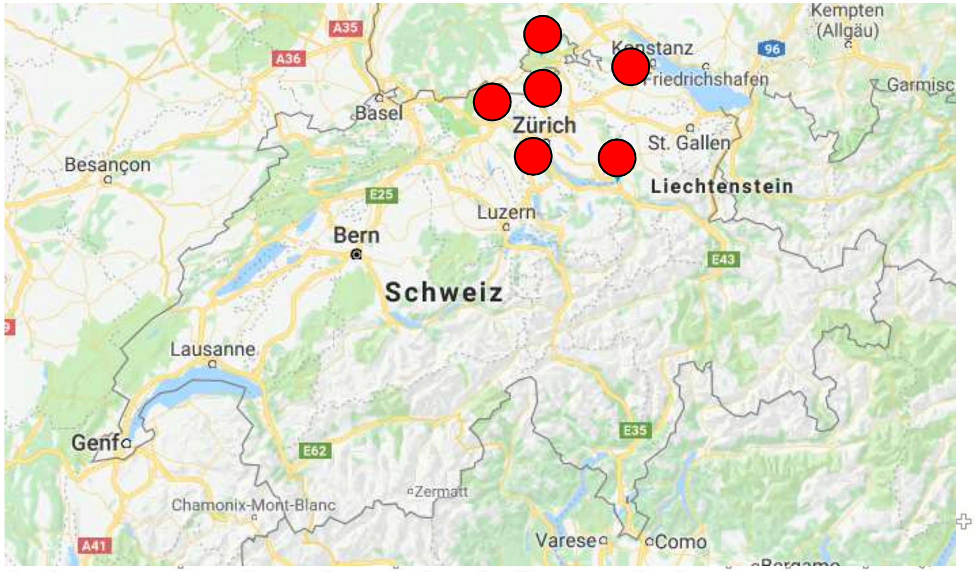
Assimilation of Meteodrone Obs

- operated by Meteomatics GmbH (Switzerland)
- observations for **T, RH, wind** and pressure
- **several profiles per hour up to 3100 m** above msl
- currently only **night** obs, due to restrictions with aviation traffic

→ assimilation in LETKF: positive impact on fog and low stratus forecasts in 3 (of 7) case studies

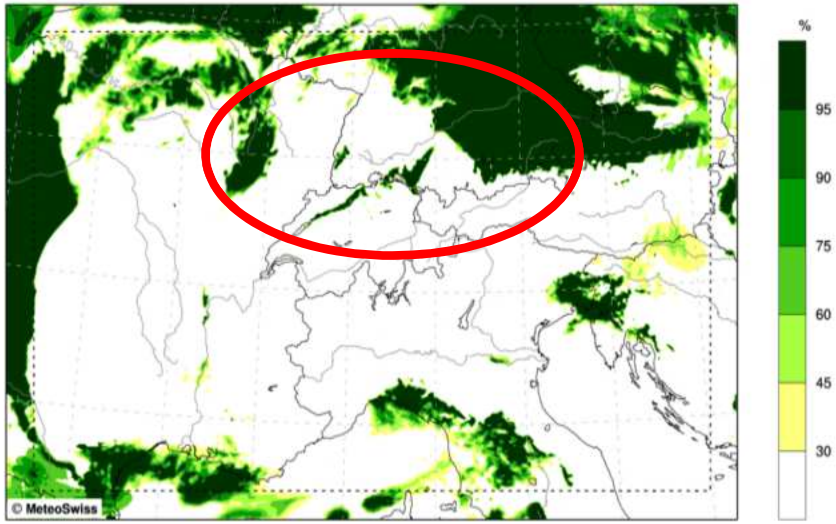
www.meteomatics.com

Profile locations during measurement campaign

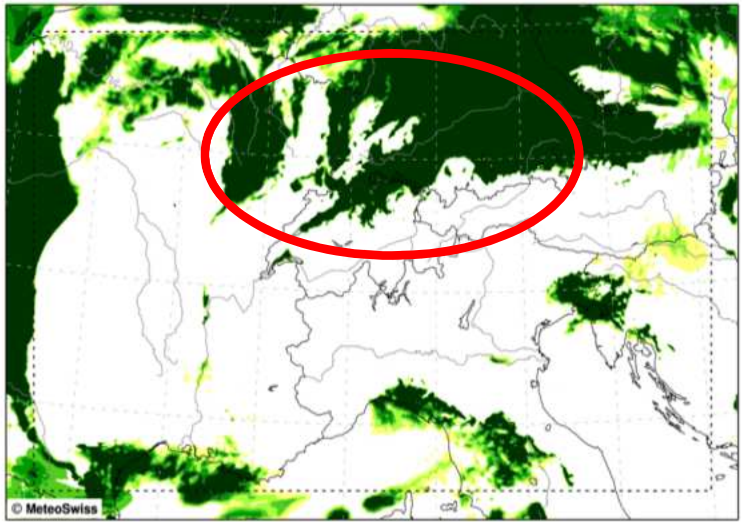


Case Study of Fog and Low Stratus

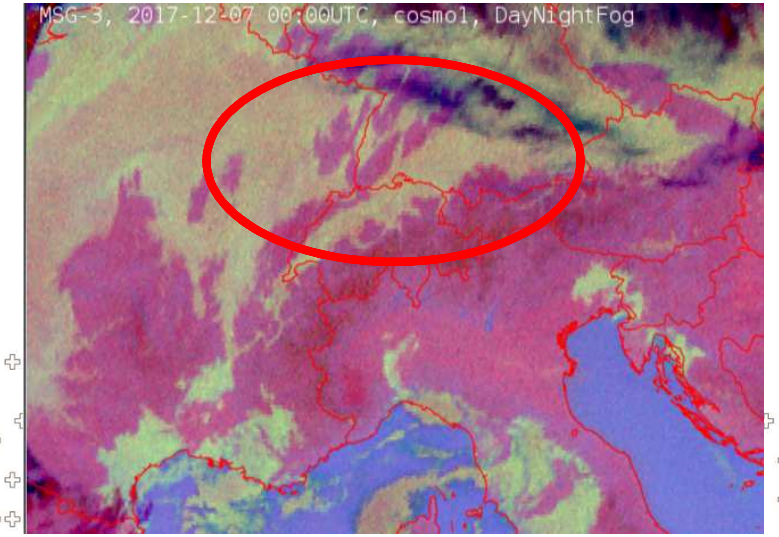
Without Meteodrones



With Meteodrones



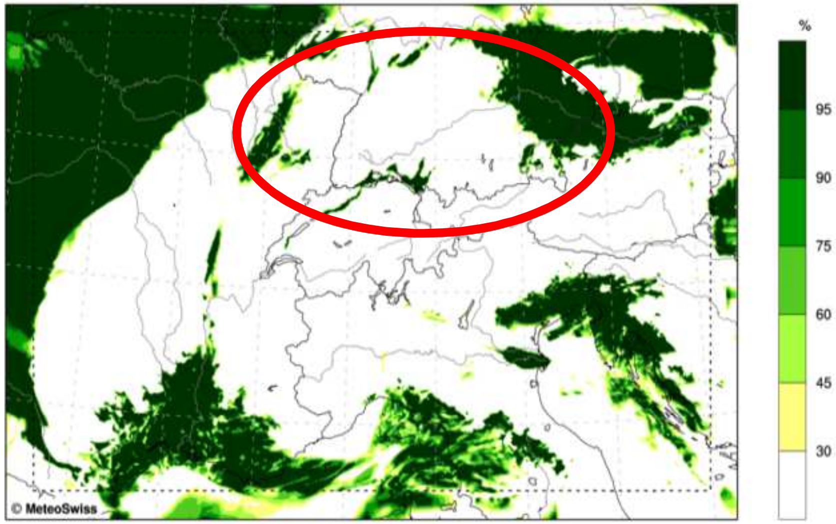
Satellite Observation



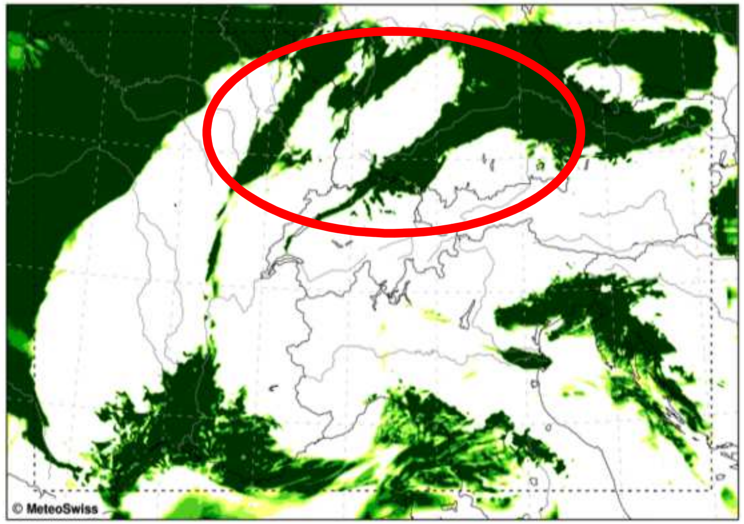
2017-12-07 00UTC **+0 h**

Case Study of Fog and Low Stratus

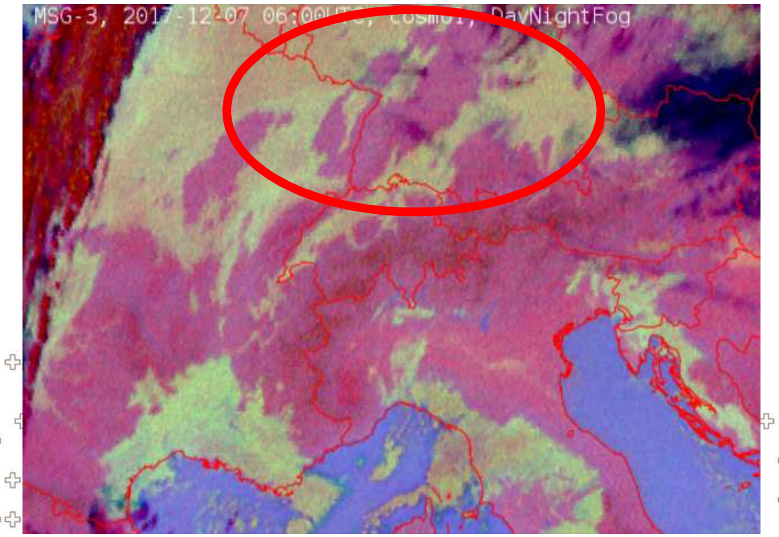
Without Meteodrones



With Meteodrones



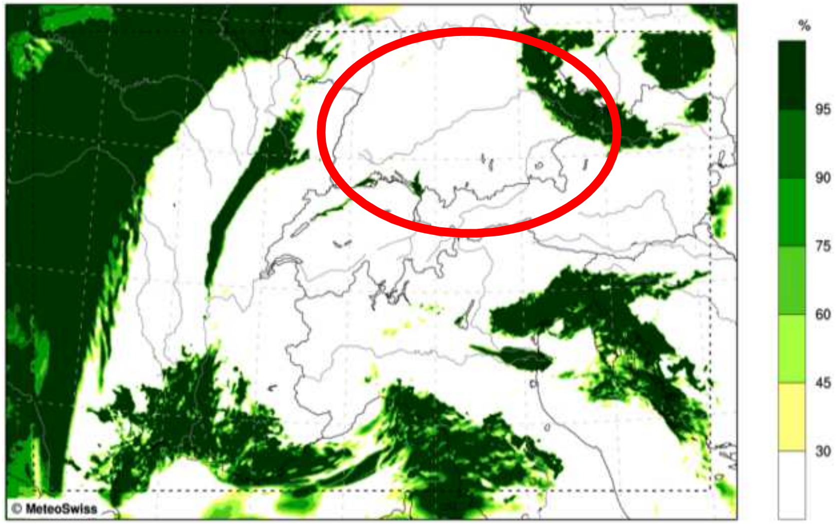
Satellite Observation



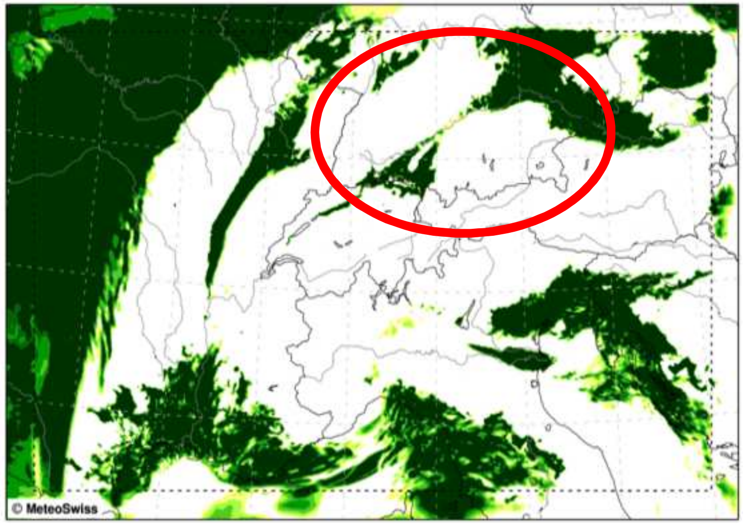
2017-12-07 00UTC **+6 h**

Case Study of Fog and Low Stratus

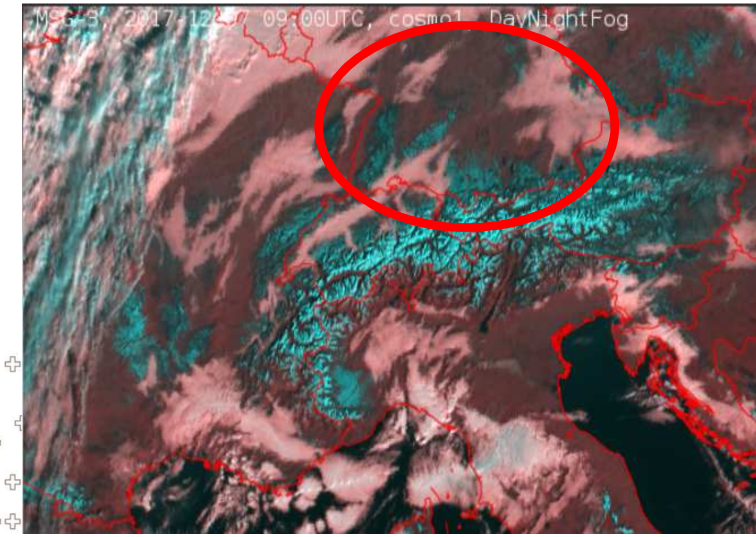
Without Meteodrones



With Meteodrones



Satellite Observation



2017-12-07 00UTC **+9 h**

Task 4.1: KENDA for ICON-LAM: implementation

- **Fortran codes:**
  - **LETKF/KENDA** adjusted to ILAM (model grid structure (→ 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)

Task 4.1: KENDA for ICON-LAM: implementation

- 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

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

ICON-LAM responds to LHN quite differently than COSMO
→ tuning done (climatological profile where rain is missing in model; no log-scaling)

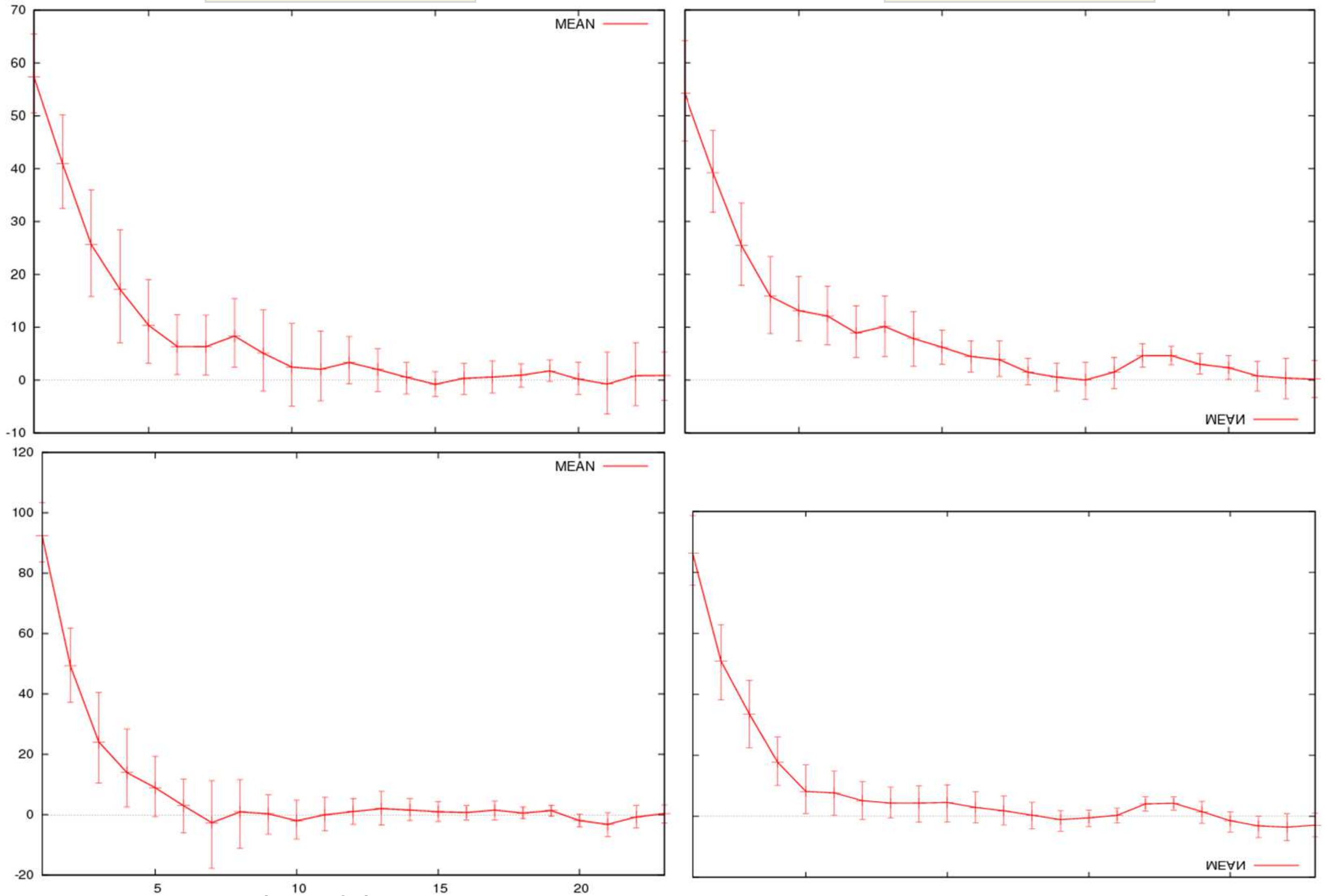
1-h precip vs. radar
27 May – 10 June 2016

ICON-DE | **COSMO-DE**

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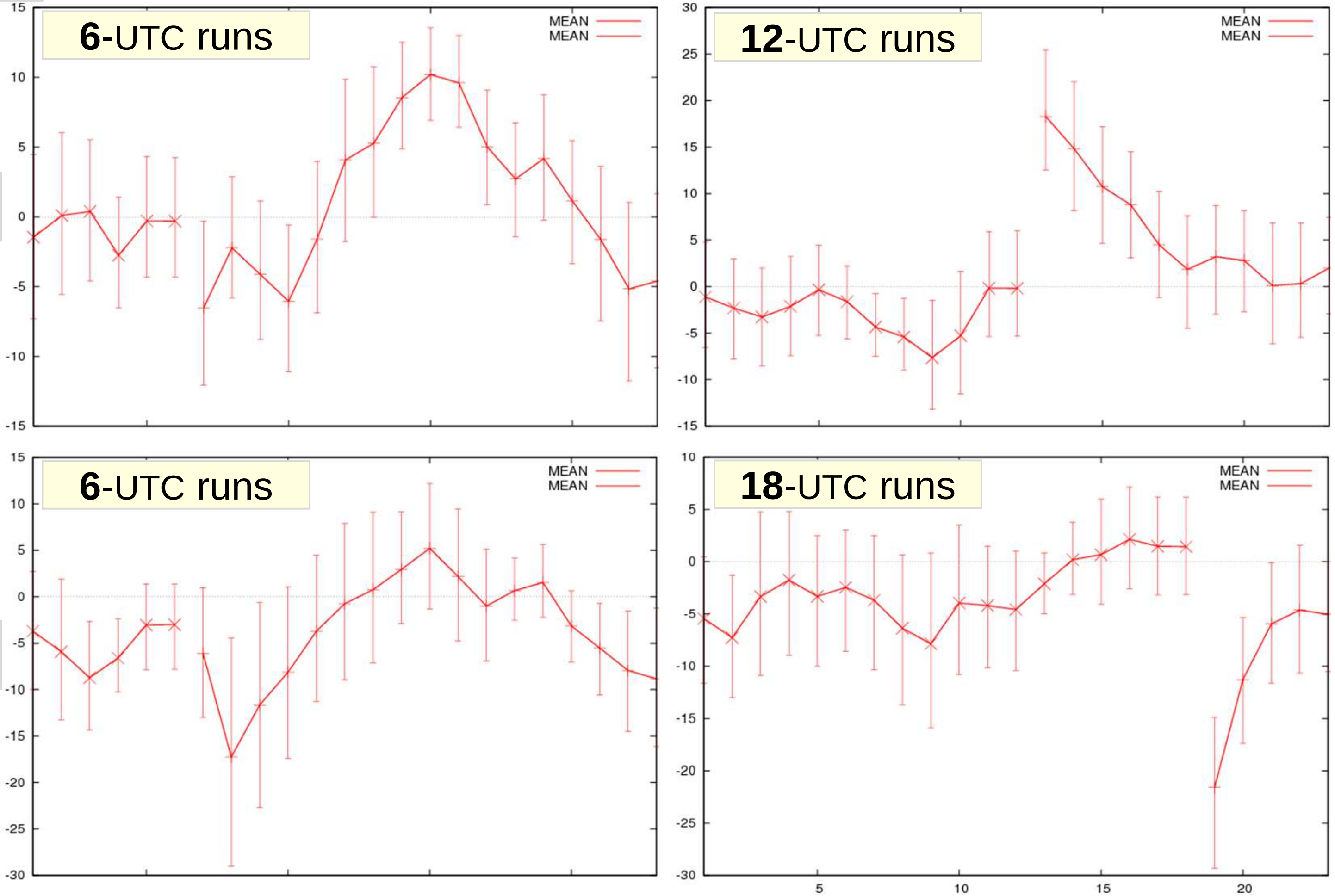
1-h precip vs. radar
27 May – 10 June 2016

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

0.1 mm/h

1 mm/h



→ overall neutral

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

(27 May – 10 June 2016)

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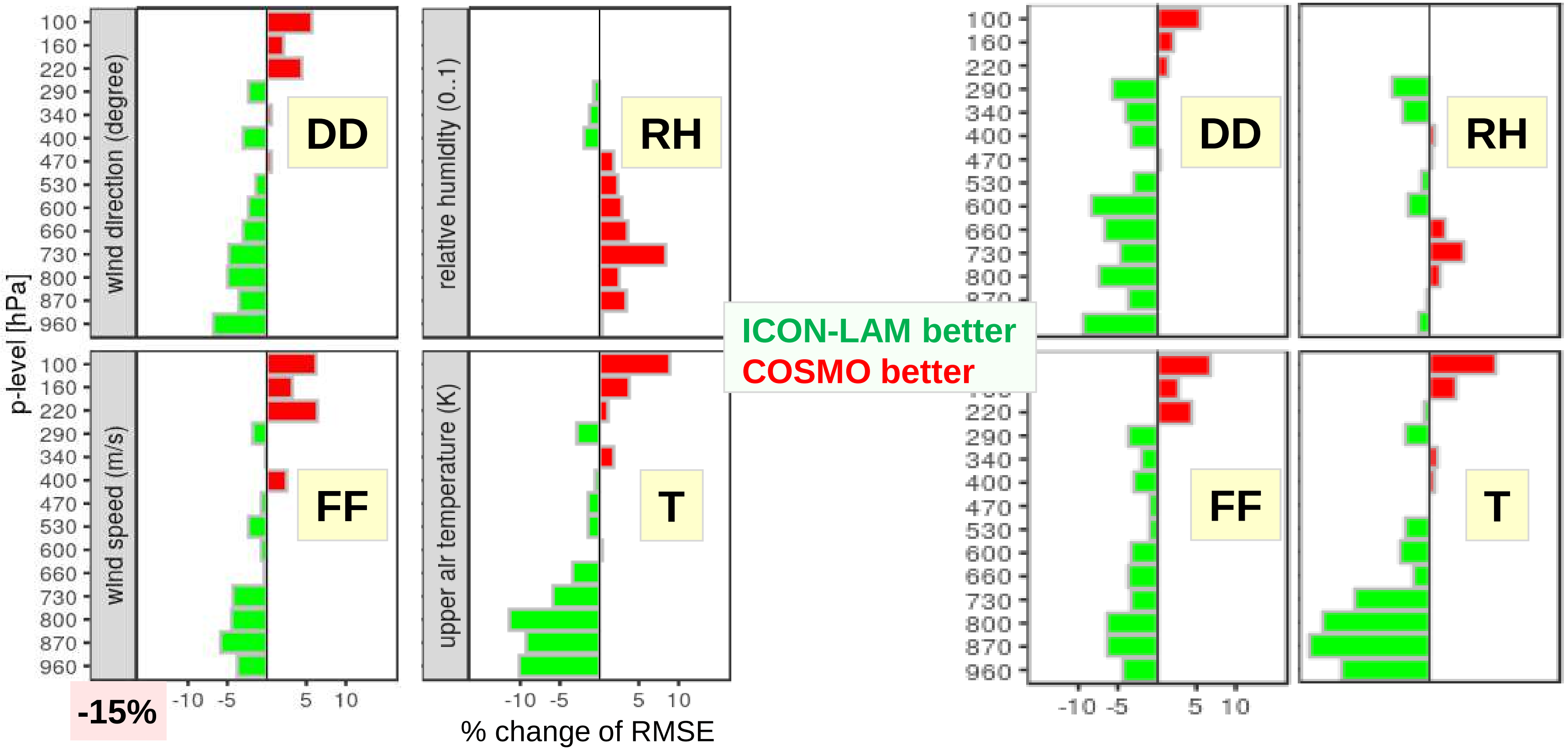
radiosonde verification

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

with LHN **without LHN**



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

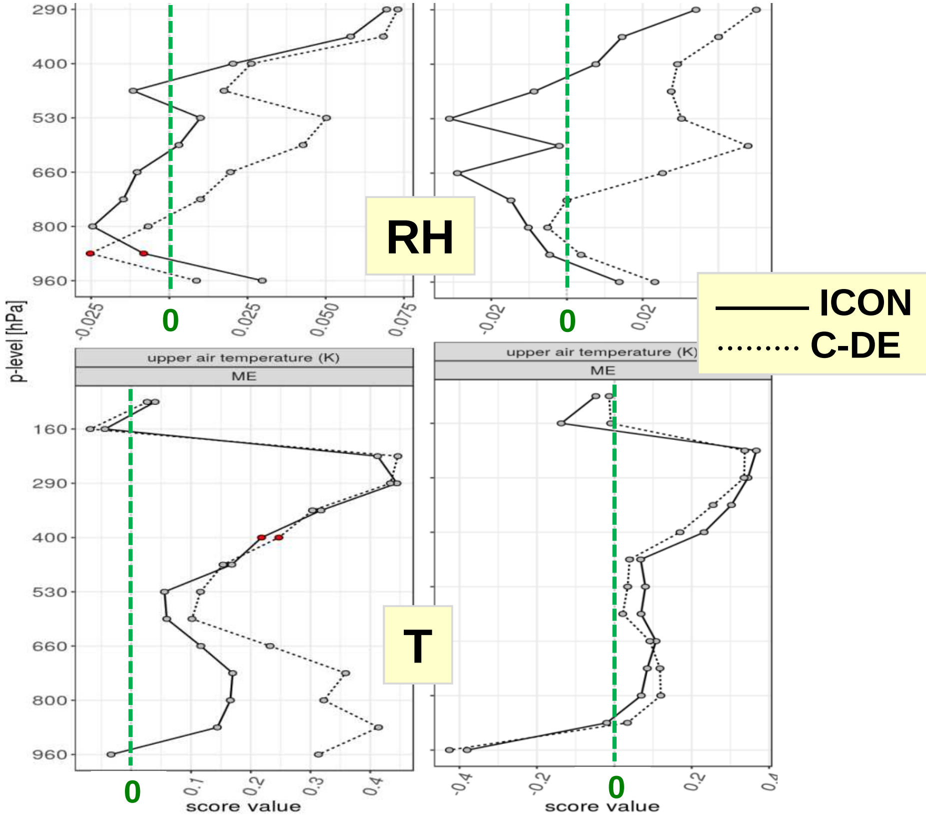
ICON-DE vs. COSMO-DE **with LHN** (MEC-based 3-D LETKF)

(27 May – 10 June 2016)

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

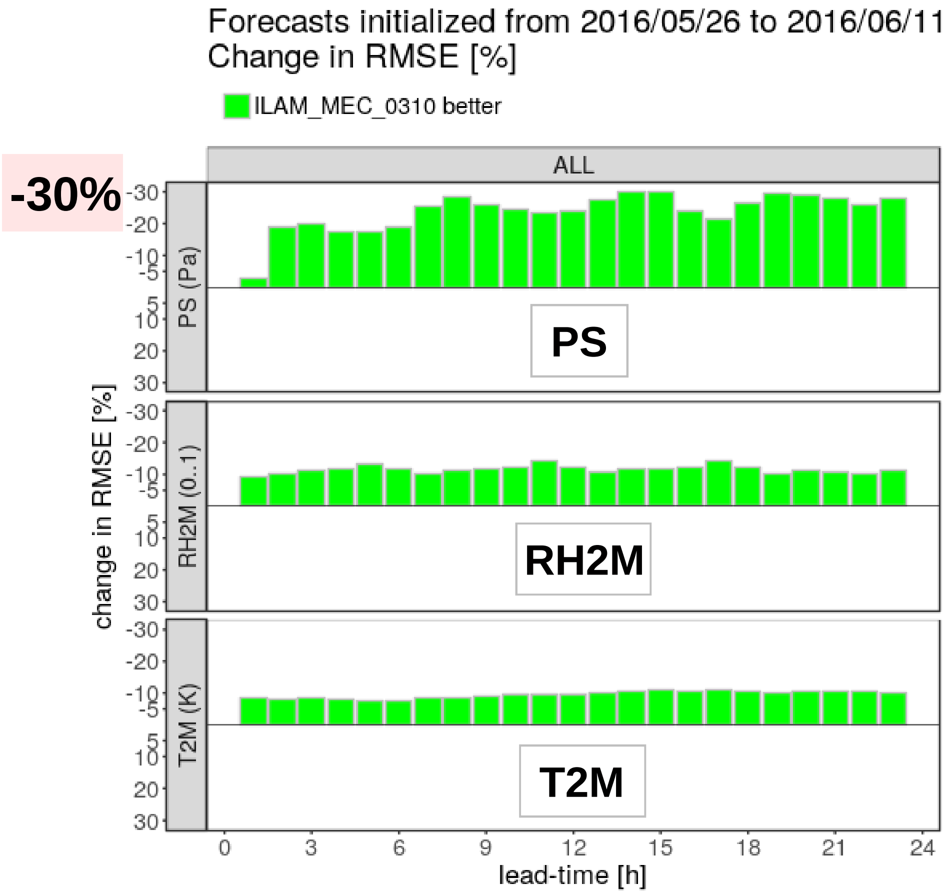
ICON-DE vs. COSMO-DE (MEC-based **3-D LETKF, without LHN**)

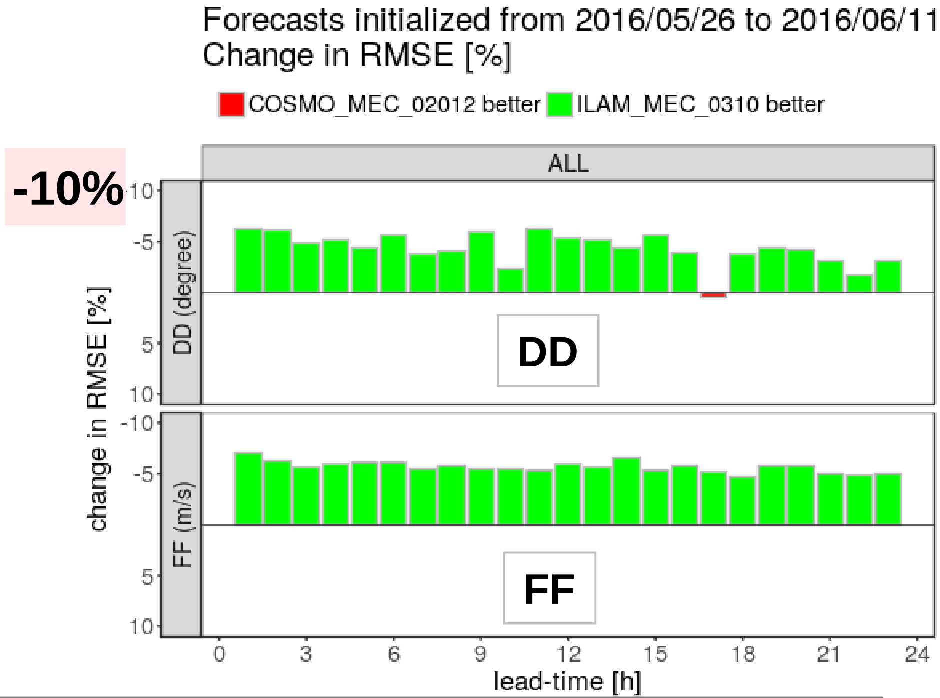
(26 May – 11 June 2016)

Deutscher Wetterdienst

SYNOP verification

ICON-DE better
COSMO better





- → 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)

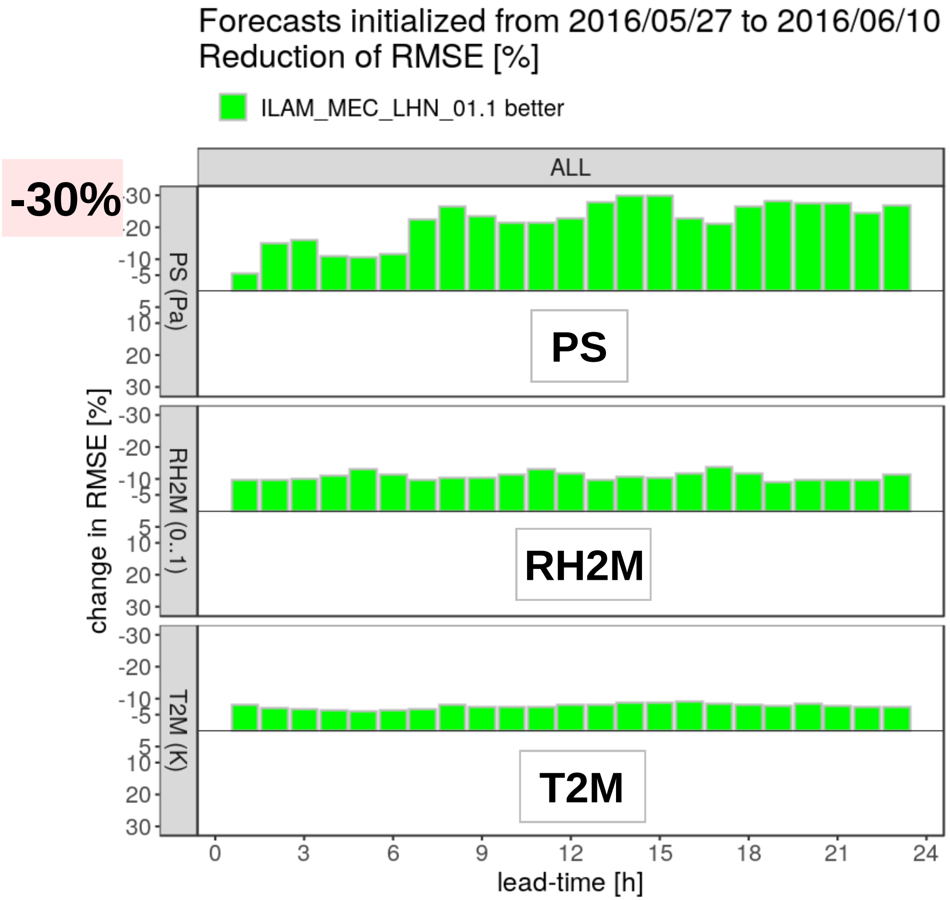
(27 May – 10 June 2016)

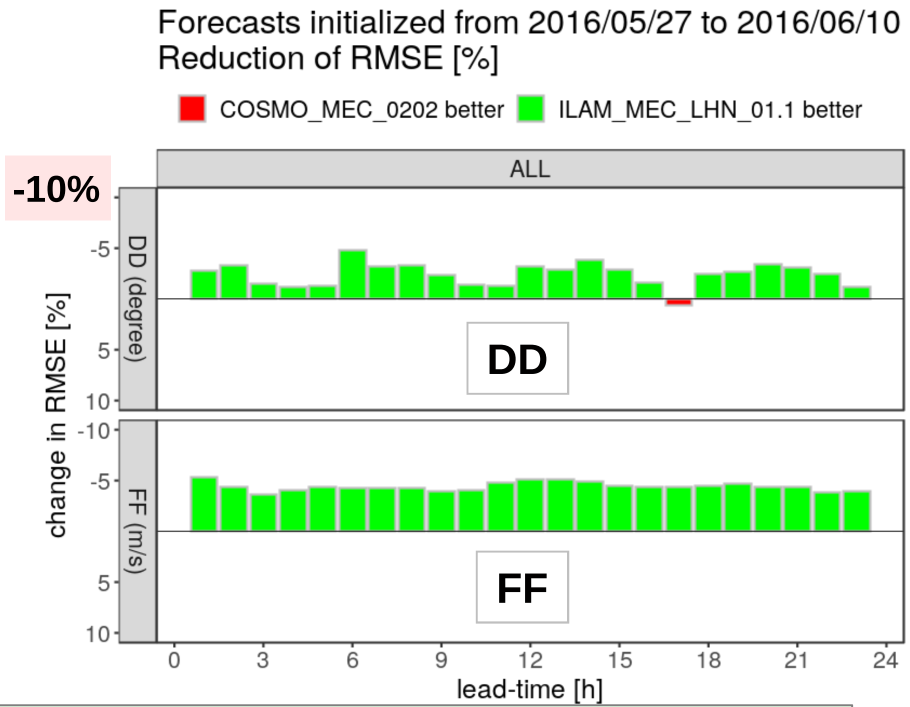
Deutscher Wetterdienst

DWD

SYNOP verification

ICON-DE better
COSMO better





→ all variables clearly improved

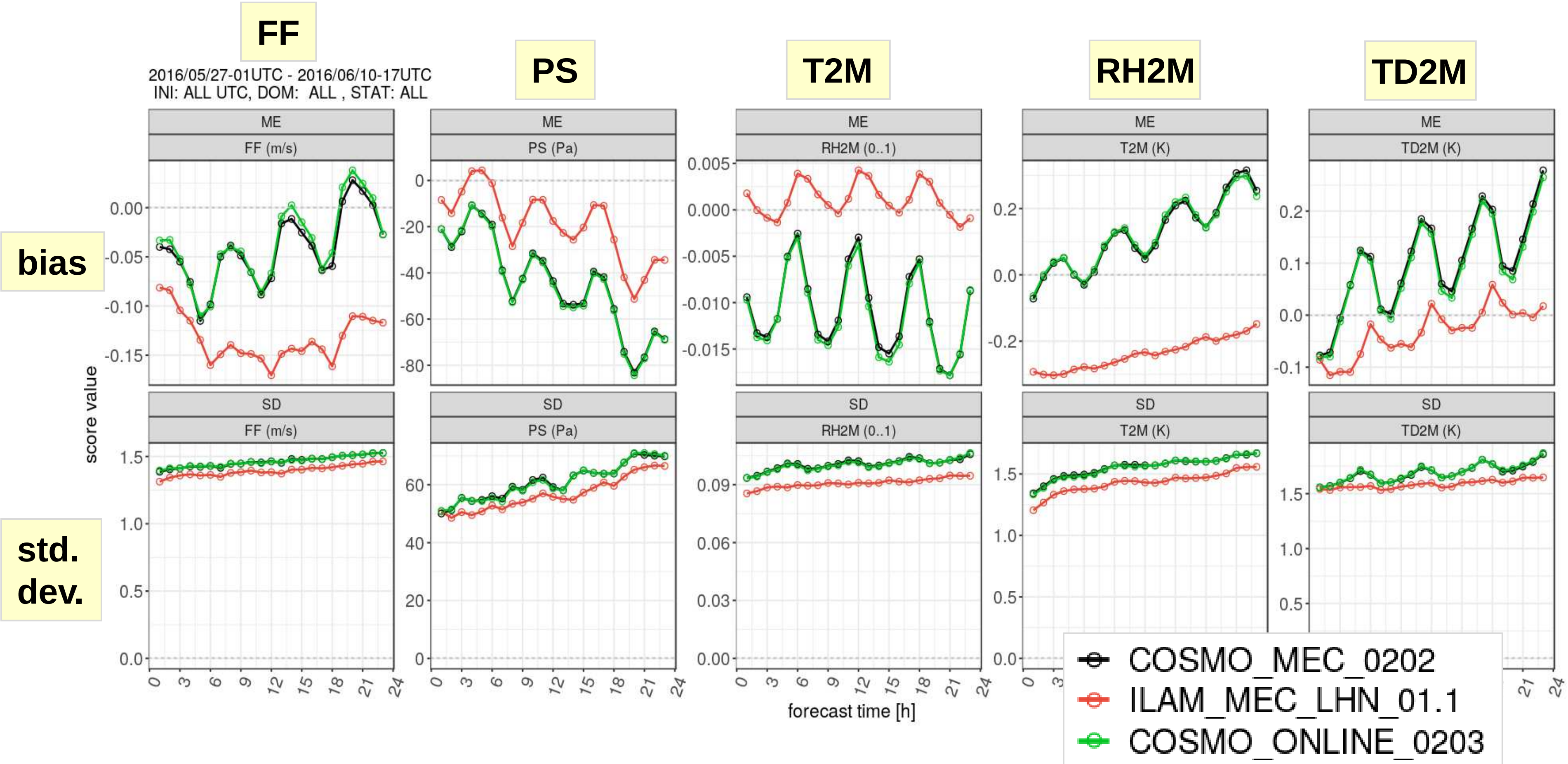
→ surface pressure strongly improved (possibly due to more consistent lateral BC (from ICON-EU); surface pressure in summer has been known as an issue in COSMO-KENDA)

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

(27 May – 10 June 2016)

Deutscher Wetterdienst

SYNOP verification



→ both **bias + std. dev. improved**

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

- 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.

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