WG1 / KENDA-O Overview

Deutscher Wetterdienst

DWD

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

- Task 1: further development of LETKF scheme (conventional obs, operationalisation)
  - → KENDA-1 (at 1.1 km) operational at MeteoSwiss (Aug. 20)
- Task 2: extended use of observations
  - → radar radial velocity + **reflectivity** operational at DWD (March / June 20) (1st direct assimilation of 3-D reflectivity in operational NWP worldwide ?)
  - → radiosonde descent profiles operational at DWD / COMET
  - → promising results for bias correction + assimilation of T2M + RH2M
  - → work on some other obs
- Task 3: soil moisture analysis using satellite soil moisture data (COMET)
- Task 4: – adaptation to ICON-LAM
  - → ICON-D2 in parallel suite at DWD (Nov. 19)
  - → ICON-IT in parallel suite at COMET (Feb. 20)
  - – particle filter (runs stably for ICON)

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Task 1: Further development of KENDA: KENDA-1

KENDA-1 *Daniel Leuenberger, Marco Arpagaus et al. (MeteoSwiss)*

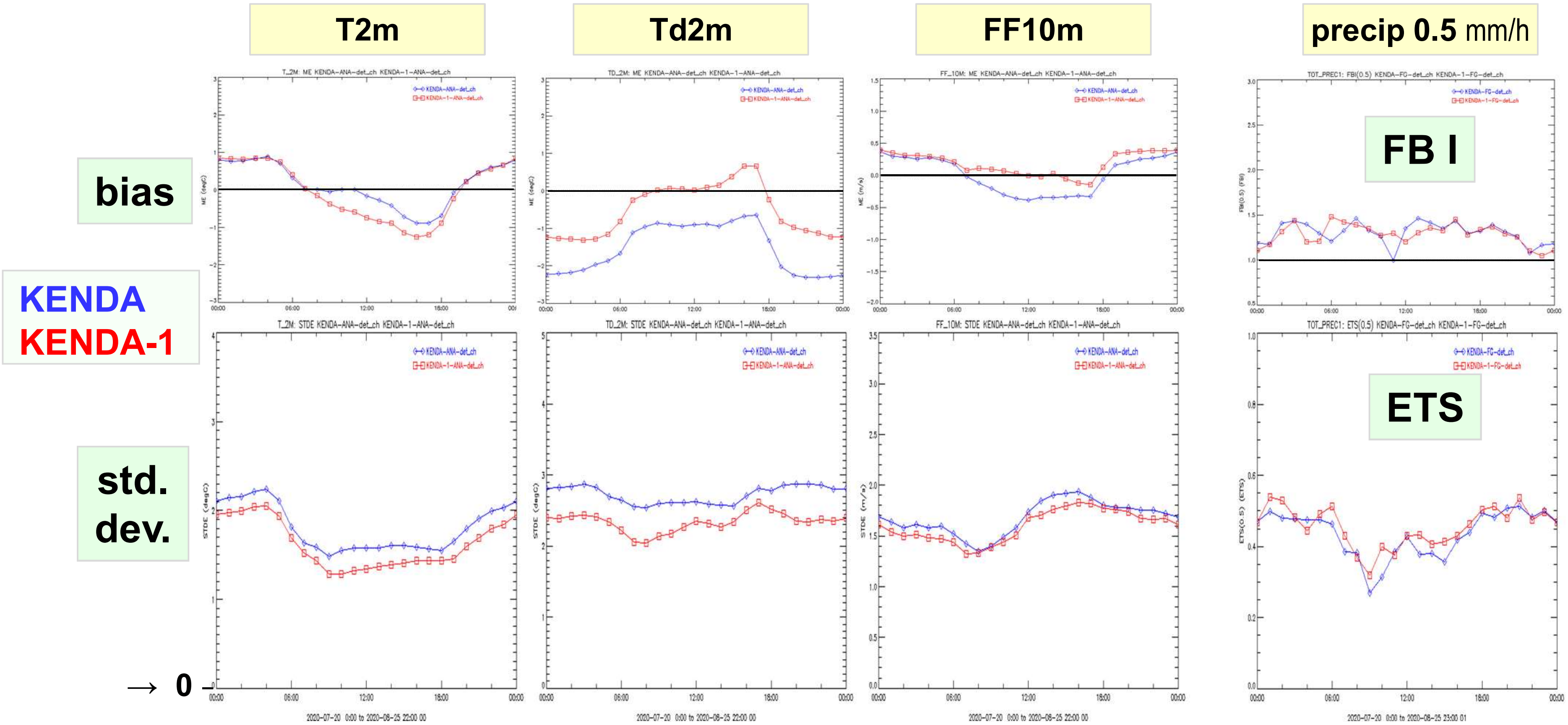
- 6 Aug. 2020: **KENDA-1 operational** : Δx = **1.1 km**
  - 1-h LETKF settings as at 2.2 km, 40 + 1 members, IFS BC (HRES + ENS pert. 30 – 36h)
  - new obs: **Mode-S** aircraft
  - snow analysis once a day (on deterministic analysis, applied to all members)
  - with SPPT + LHN (on all members, run in SP on GPU)
  - improved **bare soil evaporation** (Schulz and Vogel 2020)

- KENDA-1 analyses initialize
  - COSMO-1E fcsts. (first 10 mem.)
  - COSMO-2E fcsts. (first 20 mem.), **upscaled** to 2.2-km grid

- compare 1.1 vs. 2.2 km:
  - det. analyses (verif: indep. Synop)
  - in LETKF + EPS fcst (verif: Raob)
- compare LETKF vs. nudging:
  - det. forecasts (verif: indep. Synop)

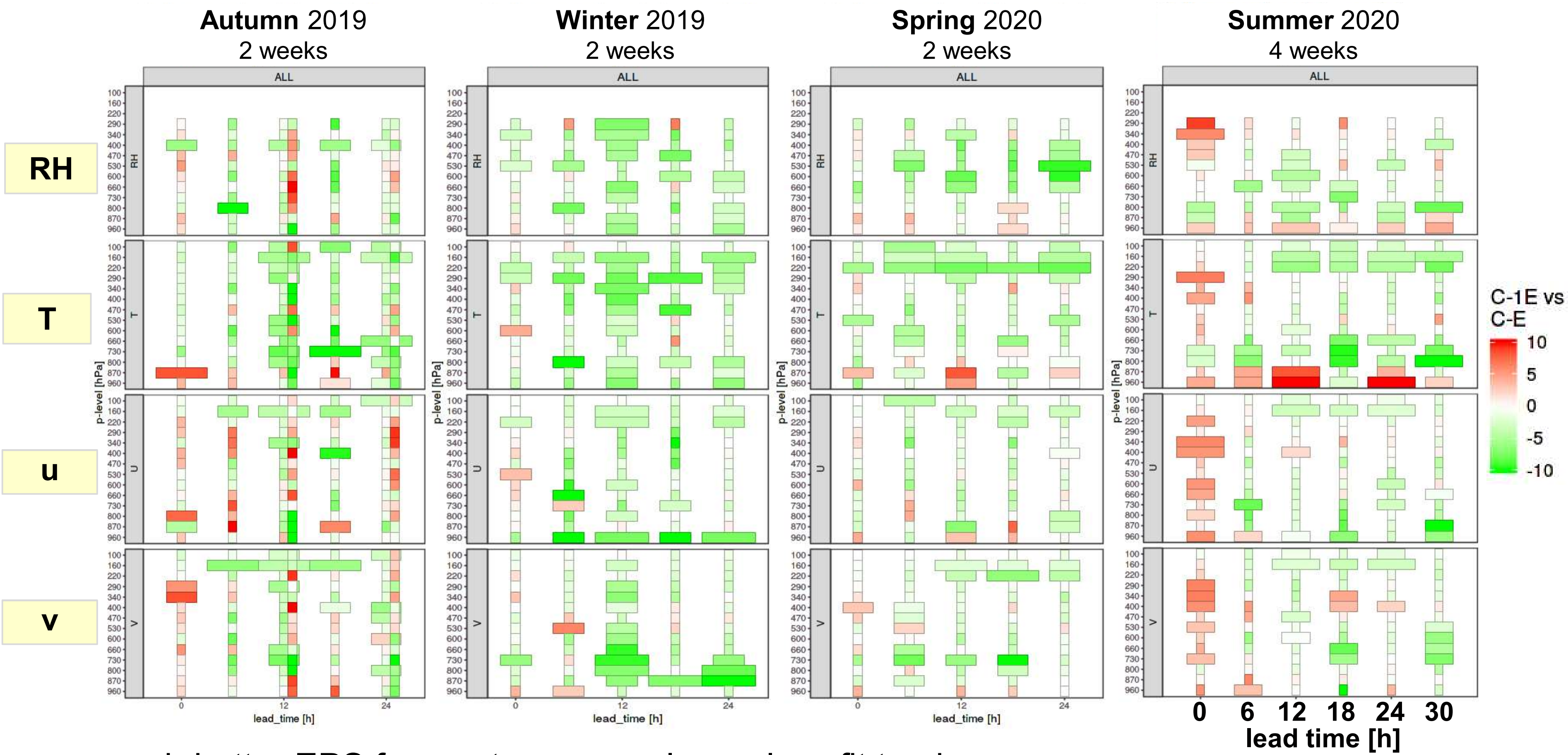
Task 1: Further development of KENDA: KENDA-1

compare 1.1 km ("KENDA-1") vs. 2.2 km ("KENDA") LETKF deterministic analyses :
verification against independent Synop (20 July – 25 Aug. 2020)



- much smaller errors (also due to bare soil evap.) – similar results for first guess compare 1.1 km EPS with LETKF vs. 2.2 km EPS based on LETKF:

CRPS reduction COSMO-1E (KENDA-1) vs. COSMO-E (KENDA) (radiosonde verif.)



- much better EPS forecasts ; analyses: less fit to obs

conclusions on KENDA-1 (IC for COSMO-1E, COSMO-2E)

- comparison deterministic forecasts COSMO-1E CTRL (KENDA-1) vs. COSMO-1 (Nudging), all on 1.1 km grid:
  - 1 – 6 h lead time: mixed results, overall similar quality
  - 7 – 12 h: temperature + global radiation better, especially in summer
  - generally: **2-m dewpoint worse**, as RH2m obs not yet assimilated in KENDA

- clear forecast gains by 1.1 km resolution + improved bare soil evaporation

- COSMO-1E , COSMO-2E with **KENDA-1 operational** since 6 Aug. 2020; COSMO-1E CTRL (IC: KENDA-1 CTRL) replaces COSMO-1 based on nudging

- observation **nudging** will **expire** this autumn at

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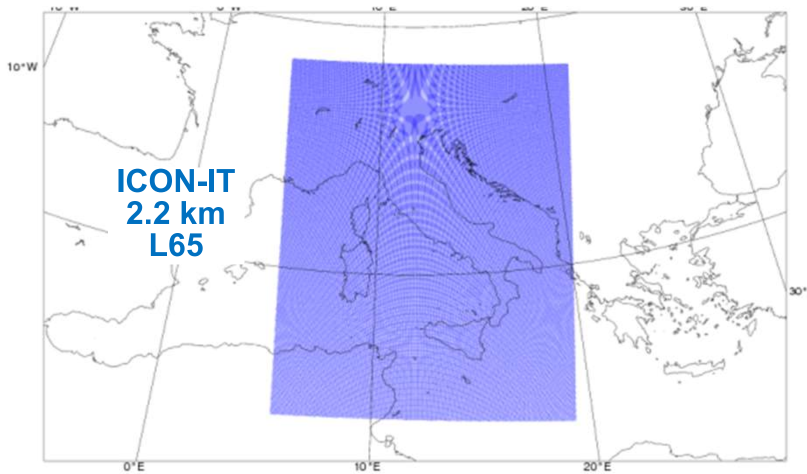
Task 4.1: KENDA for ICON-LAM: ICON-IT at COMET

<u>ICON-IT with KENDA</u> *Francesca Marcucci, Lucio Torrisi, Valerio Cardinali (COMET)*

- 14 Feb. 2020: 1-h **KENDA** cycle for **ICON-IT pre-operational**
  - 40 + 1 members, IFS BC, 2.2 km
  - LETKF settings as for COSMO
  - obs: RAOB (also descents), Synop, local surface stations, ship, buoy, wind profiler, AMDAR, Mode-S, Meteosat AMV, scatterometer winds, clear-sky satellite radiances (AMSU-A, MHS, ATMS)

- + 48 h deterministic ICON-IT fcst.

- ICON-IT-EPS forecast
  to be implemented with GPU version



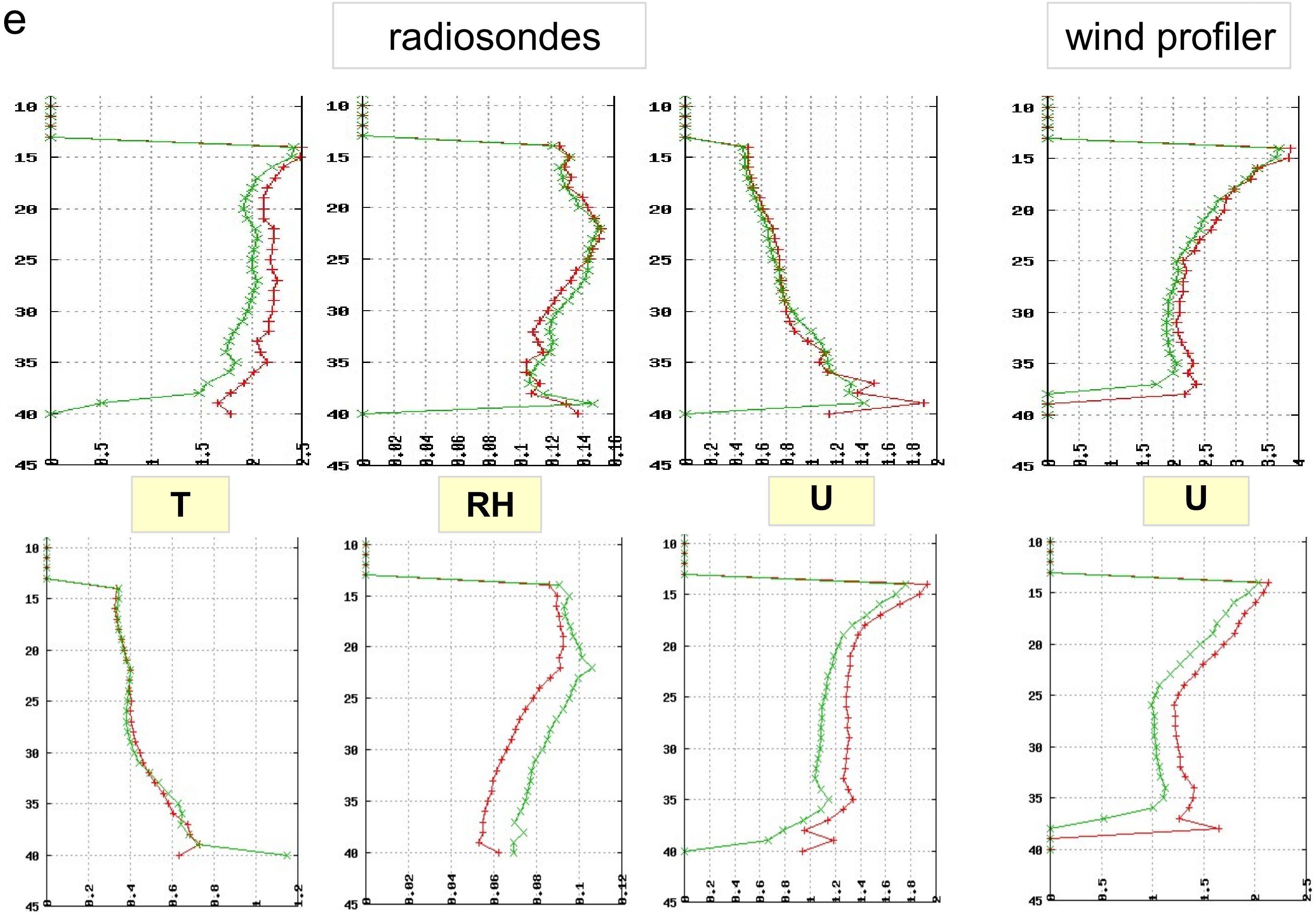
Task 4.1: KENDA for ICON-LAM: ICON-IT at COMET

assimilation cycle
1 May – 25 Aug. 2020

first guess
std. dev.

ICON-IT
COSMO-IT

first guess
spread



- ICON-IT: smaller error & spread, except humidity (to be investigated)

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Task 4.1: KENDA for ICON-LAM: ICON-IT at COMET

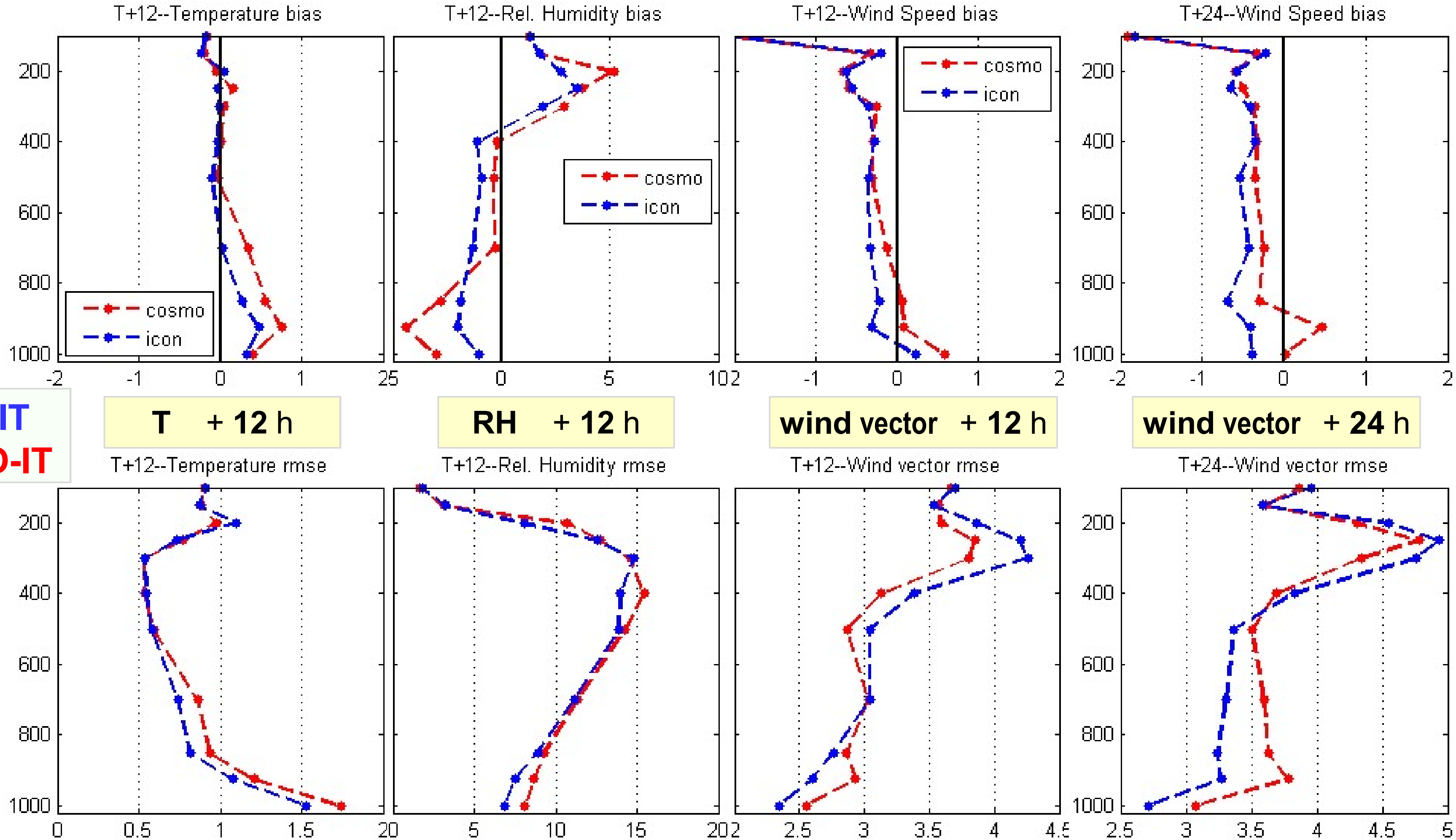
upper-air verification, **deterministic** forecasts 1 May – 25 Aug. 2020

bias

ICON-IT
COSMO-IT

T + 12 h **RH + 12 h** **wind vector + 12 h** **wind vector + 24 h**

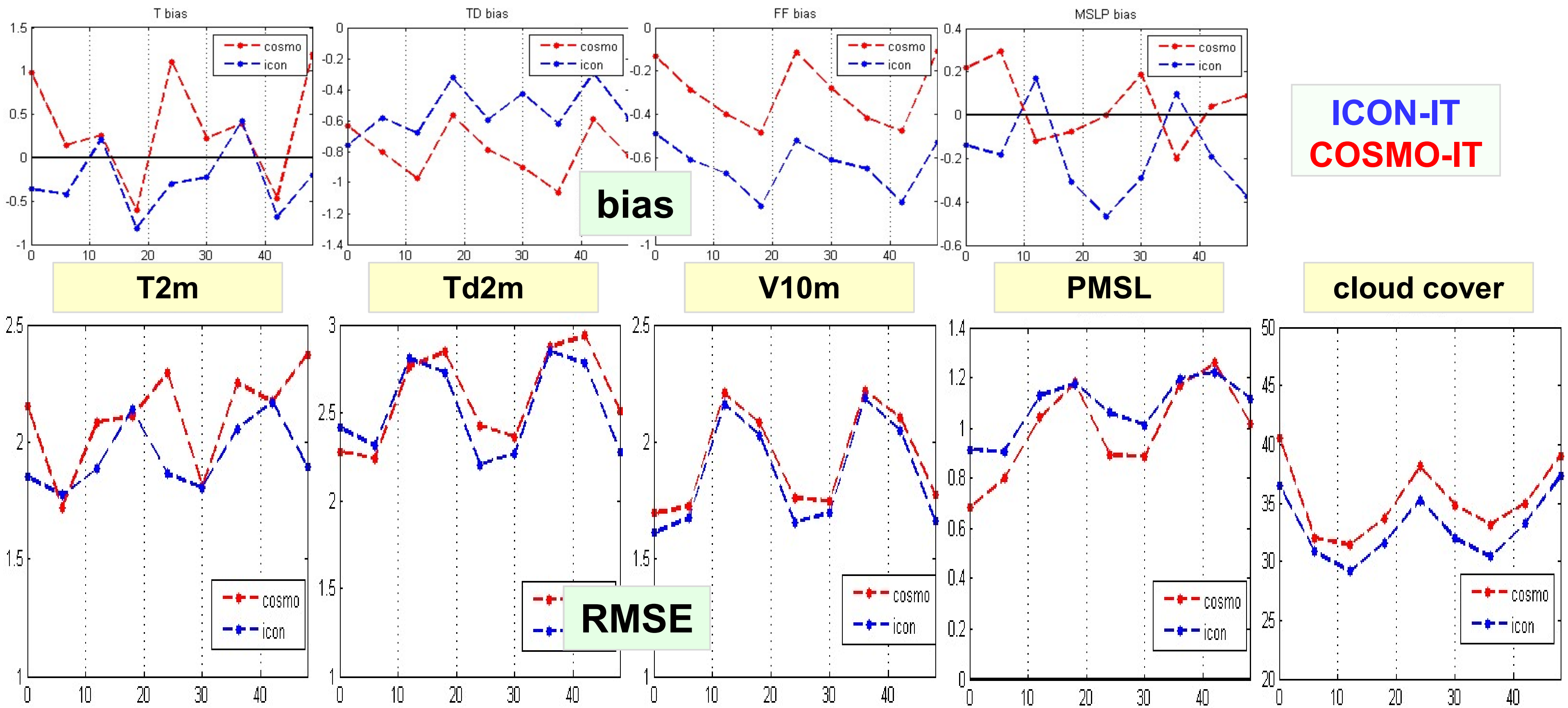
RMSE



- wind at upper levels ?

Task 4.1: KENDA for ICON-LAM: ICON-IT at COMET

surface verification, **deterministic** forecasts 1 May – 25 Aug. 2020



- better skill, except surface pressure (+ 10 m wind speed bias)

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Task 4.1: KENDA for ICON-LAM: ICON-IT at COMET

conclusions on ICON-IT

- **ICON-IT pre-operational** @2.2 km since Feb. 2020
- forecast products provided daily (00,12 UTC) to operational forecast room
- forecasters quite satisfied with ICON-IT performances

  but collected many cases of failure (**summer convection** not well forecasted) and correctly predicted by COSMO-IT – vice versa too
- **good** verification **scores** except surface pressure → to be investigated

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highlights

- 19 Nov. 2019: **ICON-D2** (based on KENDA) **in parallel suite**
- 5 March 2020: **Radar radial velocity operational** (in COSMO-D2)
- 17 June 2020: **Radar reflectivity** + **radiosonde descent profiles operational**

… and a **huge** amount of **work** into adaptation of KENDA to ICON-LAM, incl. testing **!**

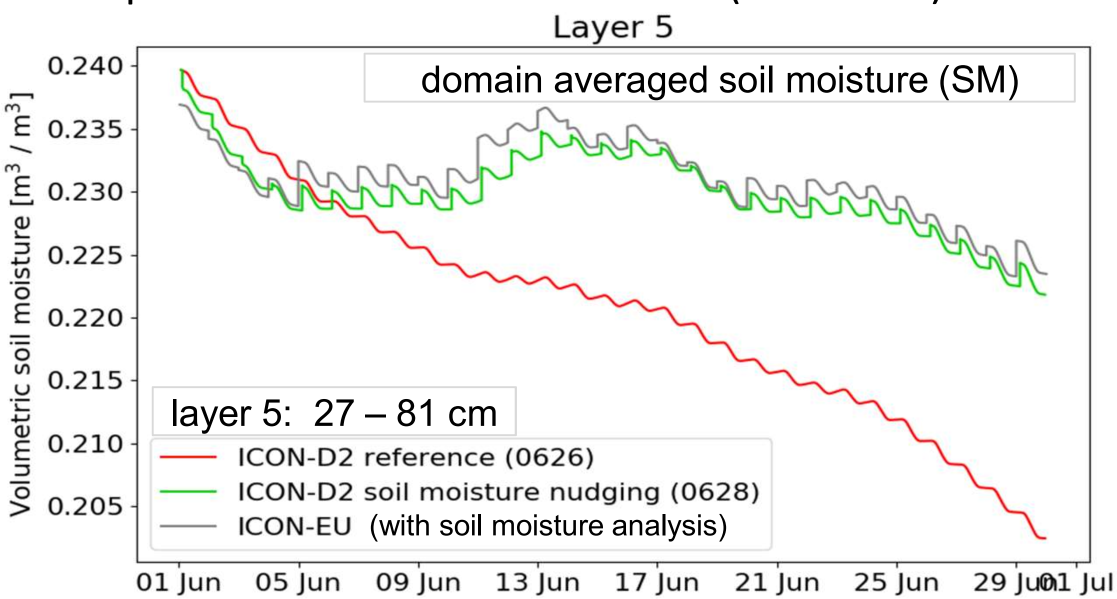
… and into port to NEC (→ a lot of compiler bugs, etc.)

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

important steps:

- LETKF: same settings as for COSMO (e.g. for localization, covariance inflation incl. soil moisture perturbations, …)
- LHN: reading of blacklist info and processing of radar beam height map for **bright band detection** implemented in ICON-LAM; further **tuning**
  → solves previous problems in winter
- **soil moisture nudging** towards interpolated ICON-EU soil moisture (with SMA)

  → to prevent excessive drying in dry summers

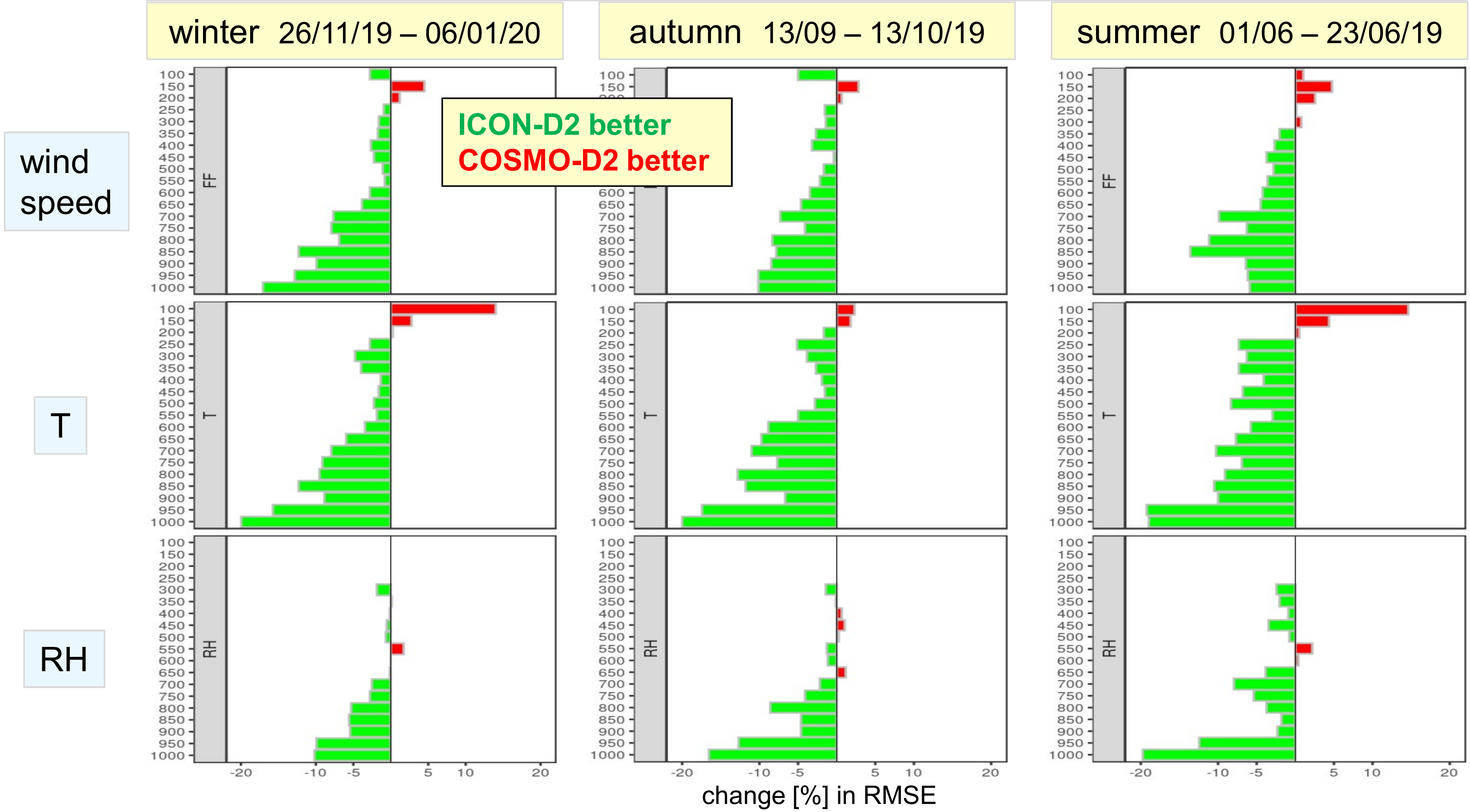


- comparison **ICON-D2** with KENDA (complete LETKF + LHN, except for soil moisture nudging)
  (and w/o use of 3-D radar obs)
  - for 3 periods:
    winter: 26 Nov. 19 – 6 Jan. 2020
    autumn: 13 Sept. – 13 Oct. 2019
    summer: 1 June – 23 June 2019
  - vs. **COSMO-D2**
  - vs. **downscaler**: ICON-D2 with interpolated ICON-EU as IC (“ID2-EU-IC”)
    autumn: different external param (orography) → surf. pressure, 10-m wind not comparable
    summer: & difference in cloud scheme → cloud cover, surface radiation not comparable

Task 4.1: KENDA for ICON-LAM comparison to COSMO

Deutscher Wetterdienst

change [%] of RMSE, averaged over 12-h & 24-h forecasts, against radiosondes



→ **ICON-D2 much better than COSMO in troposphere**, all seasons, all variables

Task 4.1: KENDA for ICON-LAM comparison to downscaler

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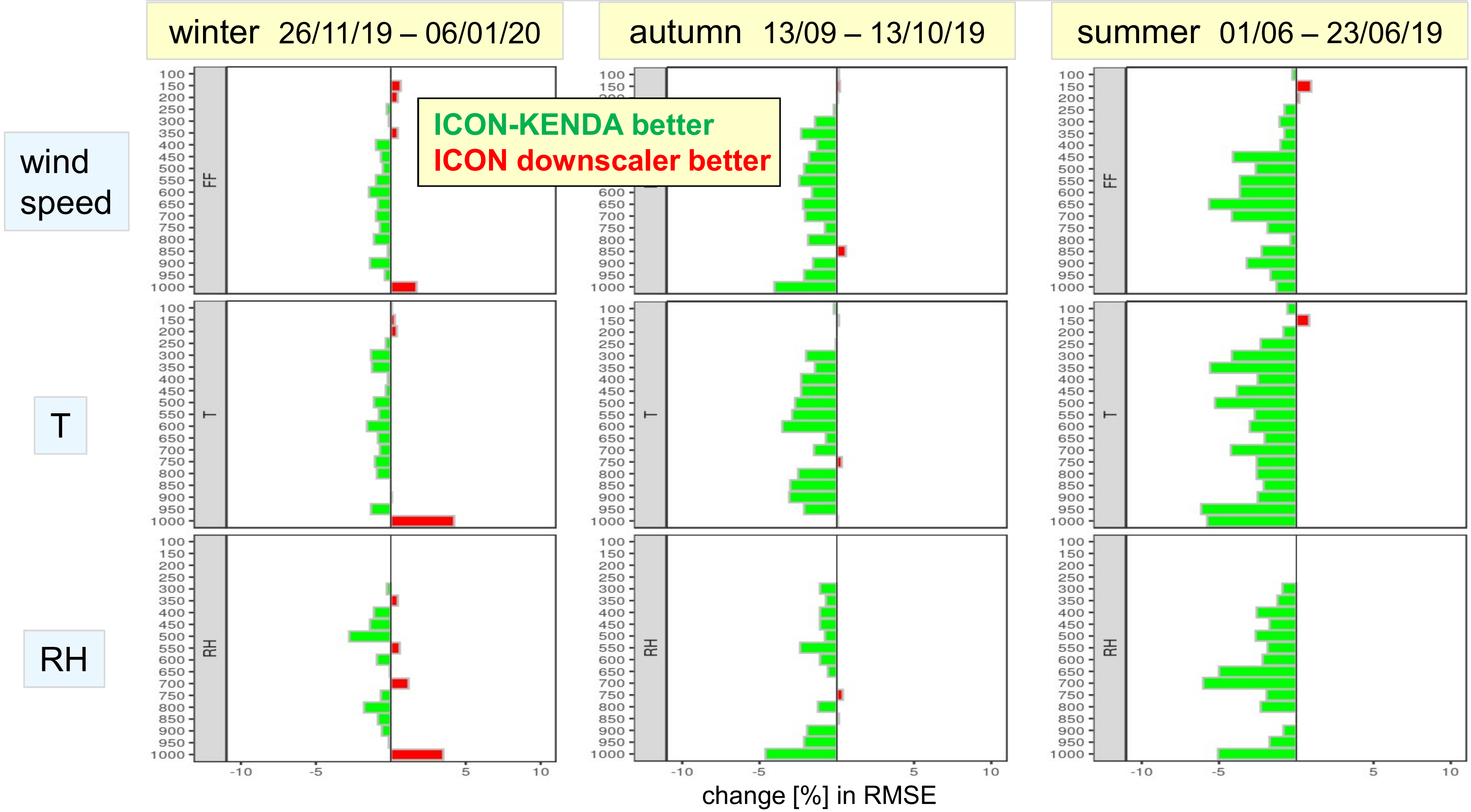
DWD

change [%] of RMSE, averaged over 12-h & 24-h forecasts, against radiosondes

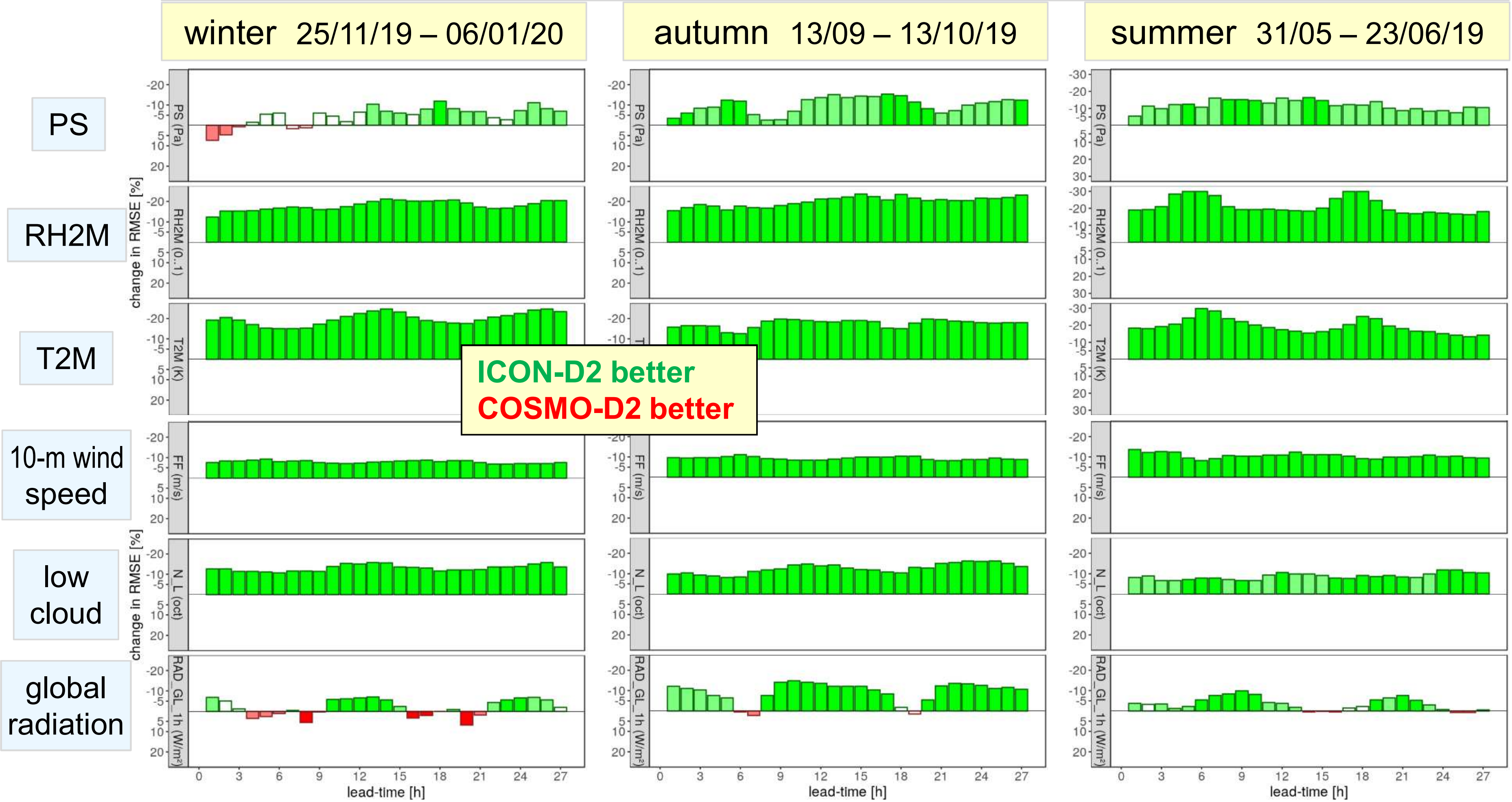


→ **KENDA better than downscaler** (mainly summer, autumn), except lowest level in winter

Task 4.1: KENDA for ICON-LAM comparison to COSMO

Deutscher Wetterdienst

change [%] of RMSE against synop



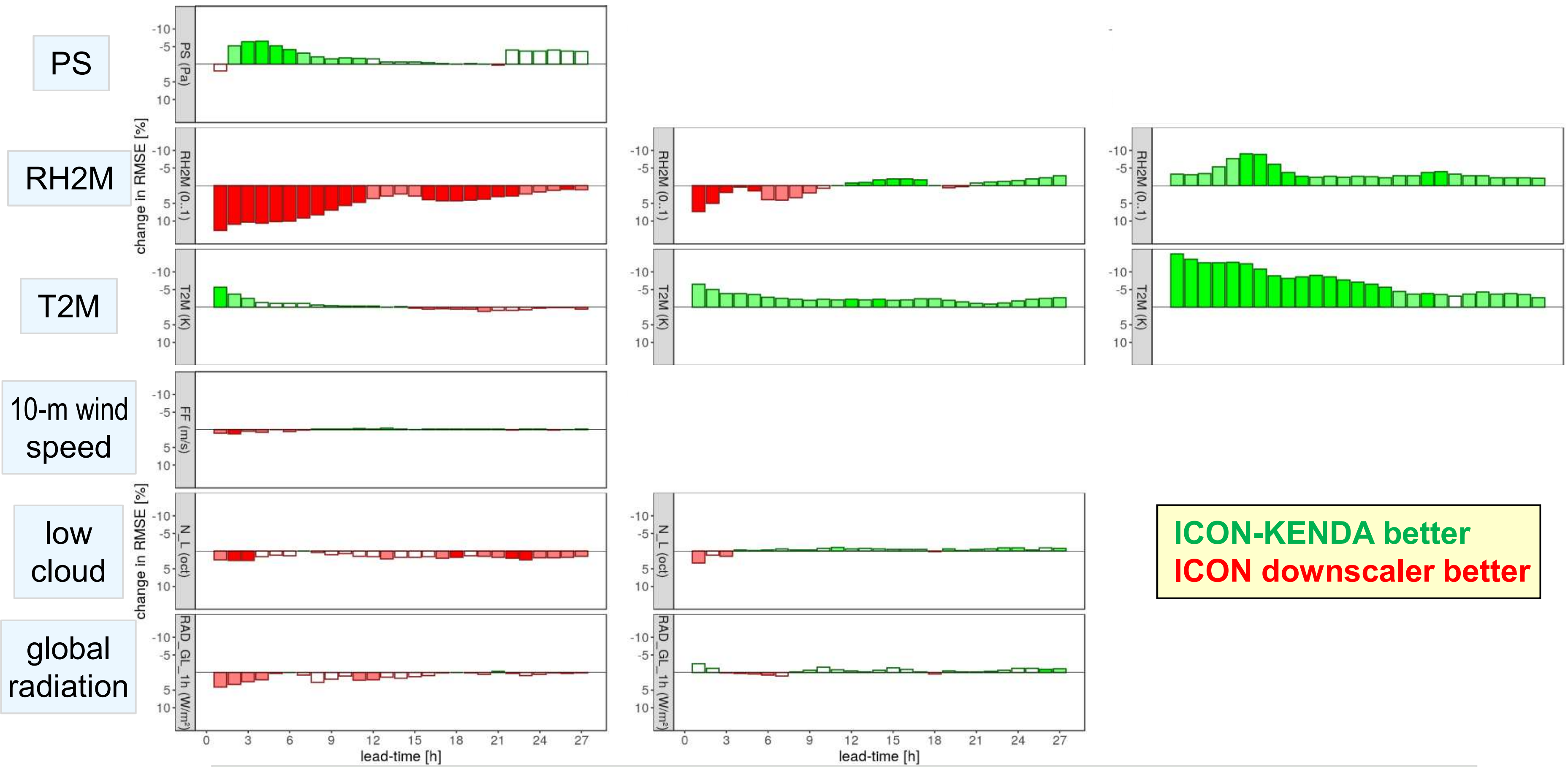
→ **ICON-D2 much better than COSMO**

Task 4.1: KENDA for ICON-LAM comparison to downscaler

Deutscher Wetterdienst

change [%] of RMSE against synop

winter 25/11/19 – 06/01/20	autumn 13/09 – 13/10/19	summer 31/05 – 23/06/19



→ **KENDA better than downscaler** (particularly in summer)
except for low cloud and **RH2M** (LETKF w/o RH2M vs. EnVar with use of RH2M)

Task 4.1: KENDA for ICON-LAM comparison to COSMO

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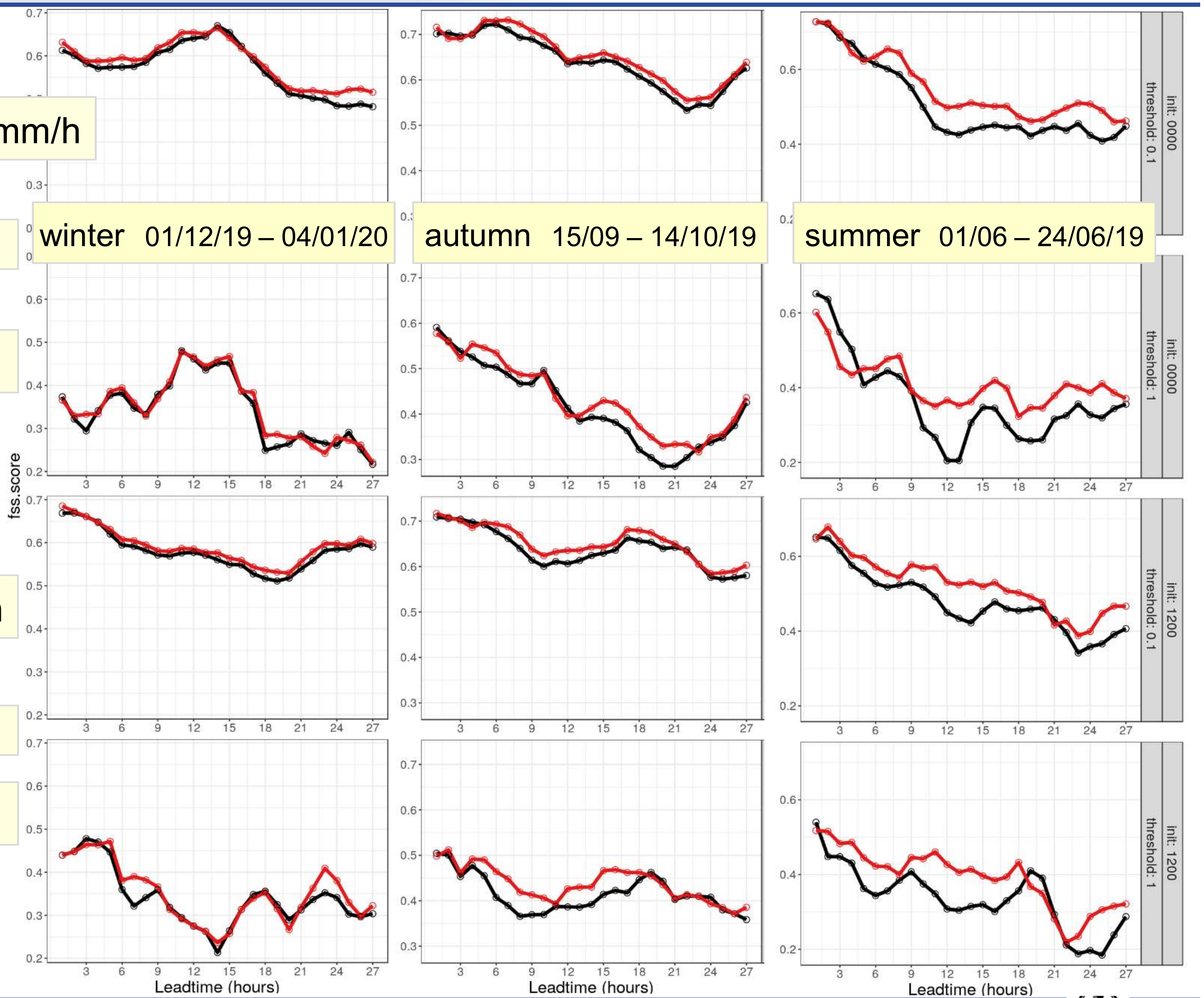
1-h precip vs. radar

FSS
(15 g.pt. ≅ 30 km)

0-UTC runs: 0.1 mm/h, 1 mm/h

12-UTC runs: 0.1 mm/h, 1 mm/h

ICON-D2
COSMO-D2



→ **after first 3 hrs, ICON better than COSMO** (particularly summer)

Task 4.1: KENDA for ICON-LAM comparison to downscaler

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1-h precip vs. radar

FSS
(15 g.pt. ≅ 30 km)

0.1 mm/h

0-UTC runs

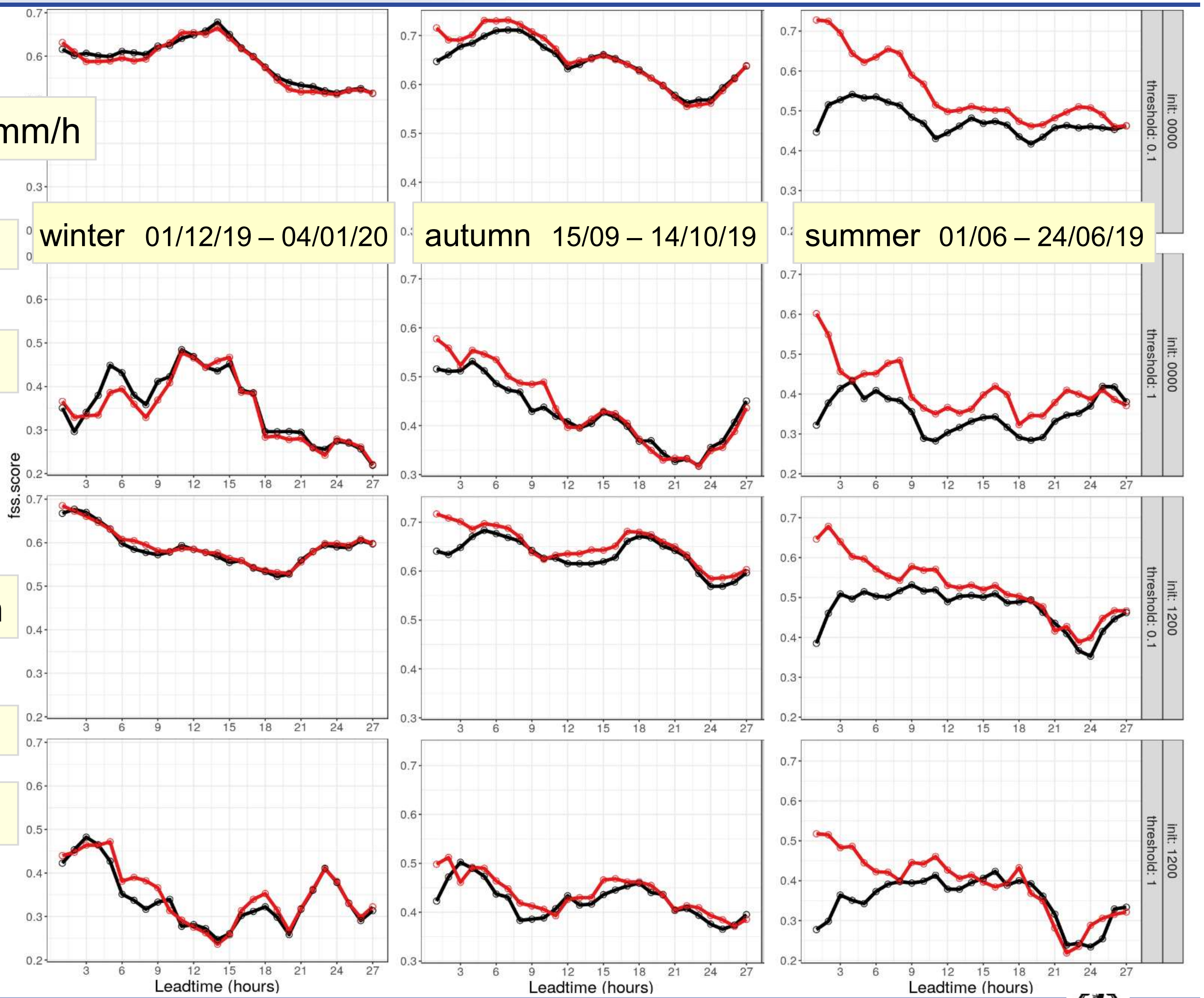
1 mm/h

ICON-KENDA
ICON downscaler

0.1 mm/h

12-UTC runs

1 mm/h



→ **KENDA improves precip for ~ 12 – 24 h** in autumn & **summer**

Task 4.1: KENDA for ICON-LAM comparison to COSMO

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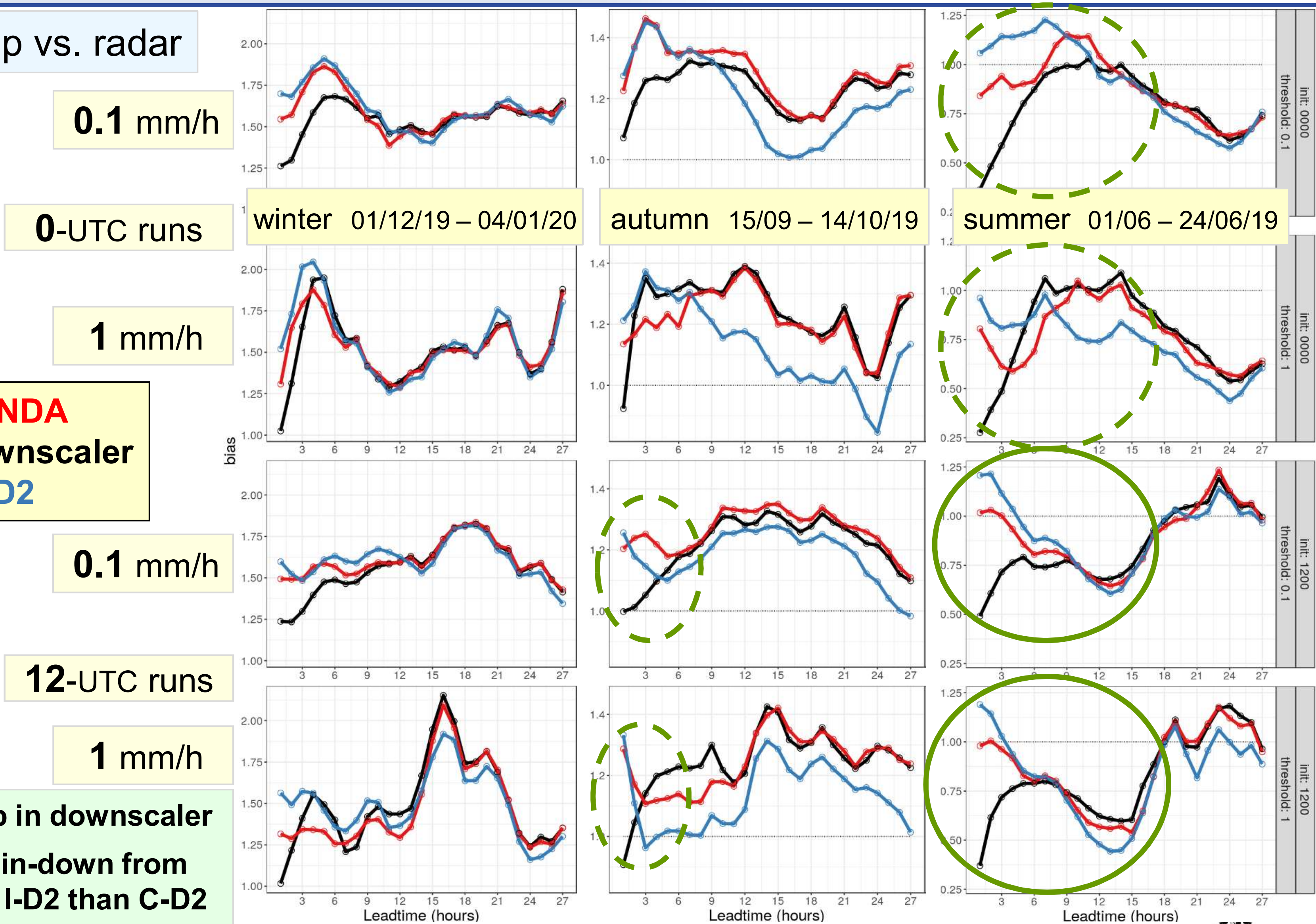
1-h precip vs. radar

bias



ICON-KENDA
ICON downscaler
COSMO-D2

→ **spin-up in downscaler**

→ **less spin-down from LHN in I-D2 than C-D2**

Bias correction and assimilation of 2-m temperature and humidity observations

Christine Sgoff, Elisabeth Bauernschubert, Roland Potthast, Christoph Schraff (DWD)

- whenever you compare the model with observations (DA, verif., spread/skill, …) :

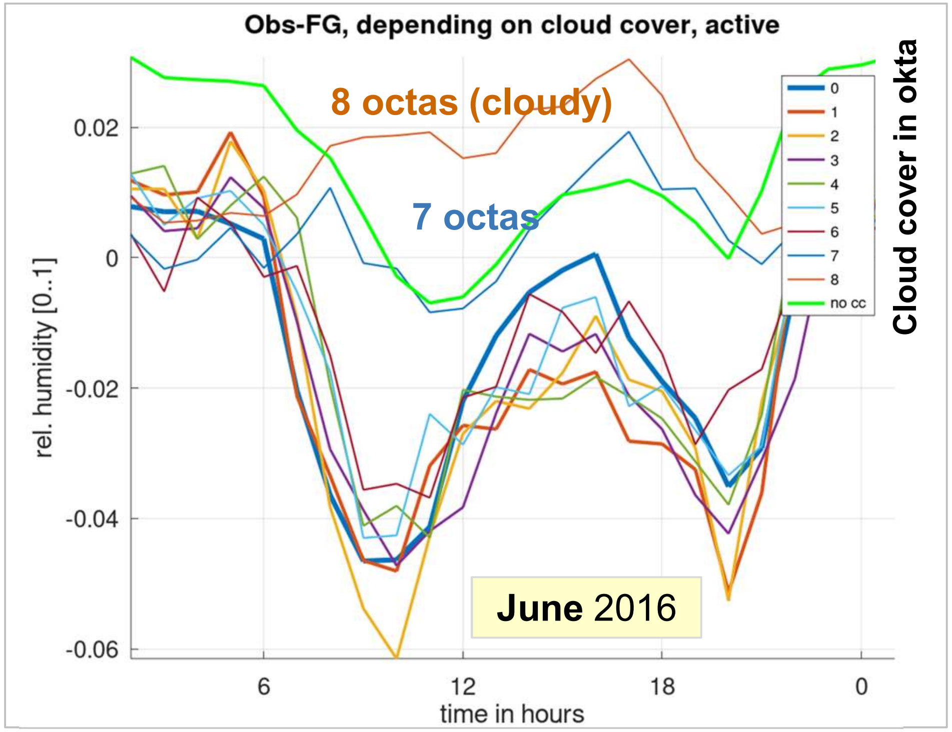
  "**observation error**" = instrument error (incl. calibration error)
  \+ representation error
  \+ error of observation operator to compute model equivalent (e.g. interpolation error)

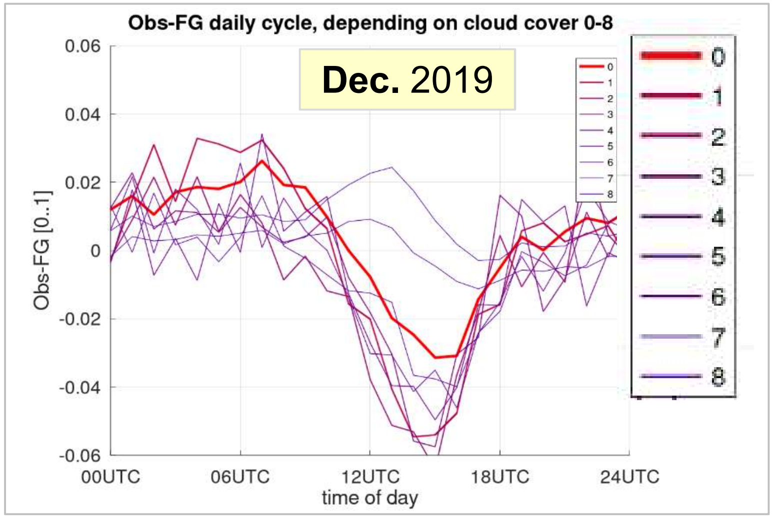
- **representation error** (often a large part of the obs error)
  - point measurements (depend. on local environment) vs. grid box averages of model equivalents
  - differences station height vs. model orography

→ Synop T2M, RH2M: obs error (random error & bias) depends on station, time of day, meteorological situation (cloud cover, season),…

bias = mean error (obs – first guess)
= **relative** difference betw. observed and model "climate'

bias of RH2M, averaged over stations





- small diurnal cycle of bias if very cloudy
- diurnal cycle otherwise

→ bias correction for LETKF assimilation
- – station-dependent
- – dependent on time of day
- – dependent on (observed) cloud cover
- – online (dynamic)
- – (parameterized non-linear)

bias correction concept

- bias: described (approx.) by scalar product of vector A of basis functions and vector c of coefficients : $\text{bias} = A \cdot c$

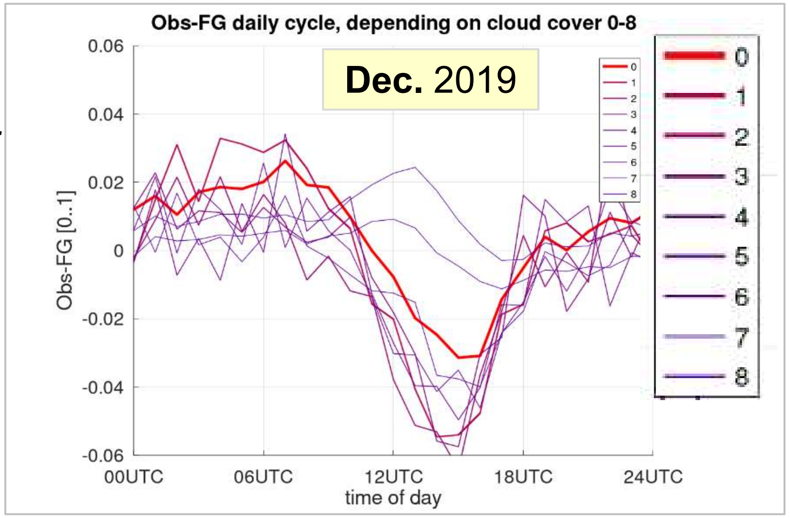
- each element of A is the product of
  - 1 of 5 (7) trigonometric fn. of time of day t

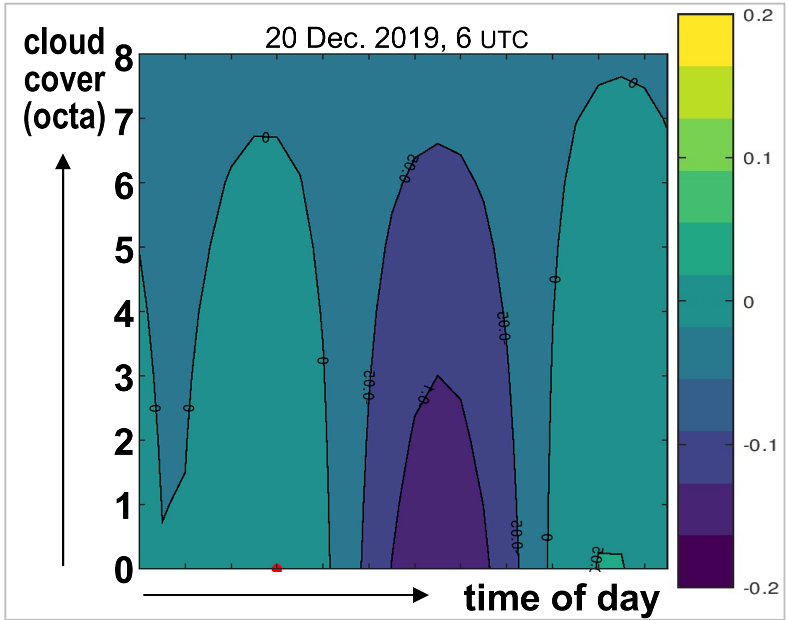
    $1\ , \sin nt\ , \cos nt\ , \sin 2nt\ , \cos 2nt\ \ldots$

    $n = 2\pi/24$
  - 1 of 2 (3) polynomial fn. of cloud cover N

    $\boxed{1\ , 9 - N}\ , (9-N)^2$

- need to specify / estimate coefficients c





bias correction concept

$$bias = A \cdot c$$

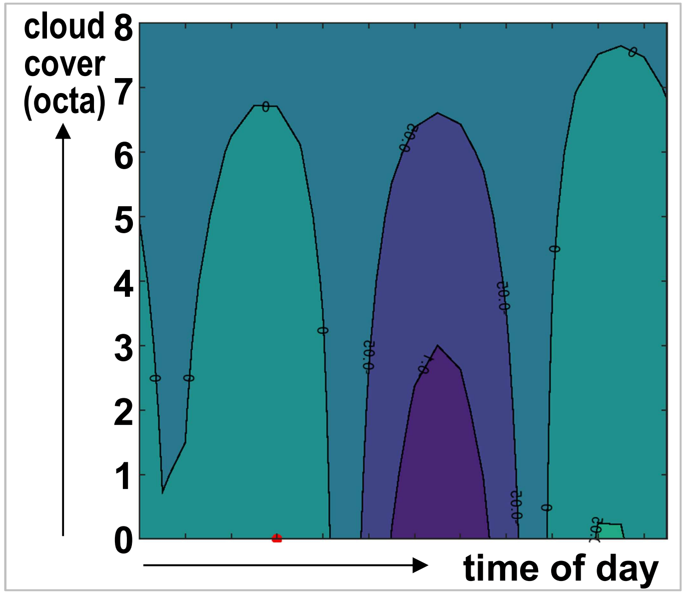
- need to specify / estimate coefficients c

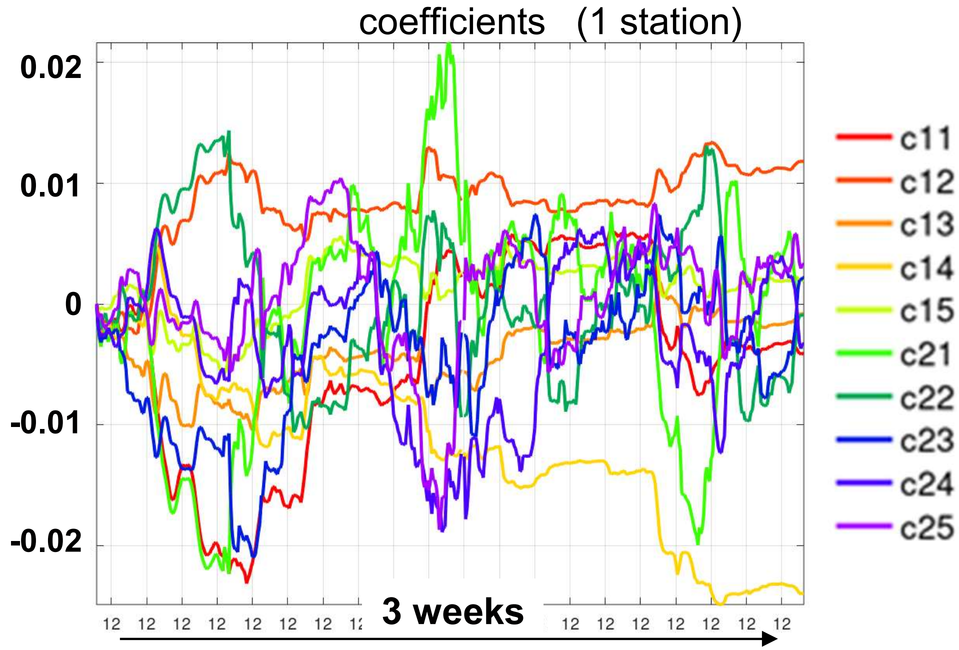
- how to compute vector c and apply bias correction ? $\rightarrow$ at analysis step k:
  - bias correction : $bcor = -bias^{estimated} = -A \cdot c^{k-1}$
  - bias-corrected obs: $obs_{bc} = obs + bcor$

  … used in LETKF: $\mathbf{x}^{\mathrm{a}} = \mathbf{x}^{\mathrm{b}} + K\big(obs_{bc} - H(\mathbf{x}^{\mathrm{b}})\big)$

  … and to update c: $c^{k} = c^{k-1} + K_c\big(obs_{bc} - H(\mathbf{x}^{\mathrm{b}})\big)$ $\quad K_c = BA^t(R + ABA^t)^{-1}$

  example: 3D-Var with $B = I$ and $R = \alpha I$, α = damping/ regularization parameter bias correction concept





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  … and to update c: $c^k = c^{k-1} + K_c\left(obs_{bc} - H(\mathbf{x}^{\mathrm{b}})\right)$ $K_c = BA^t(R + ABA^t)^{-1}$

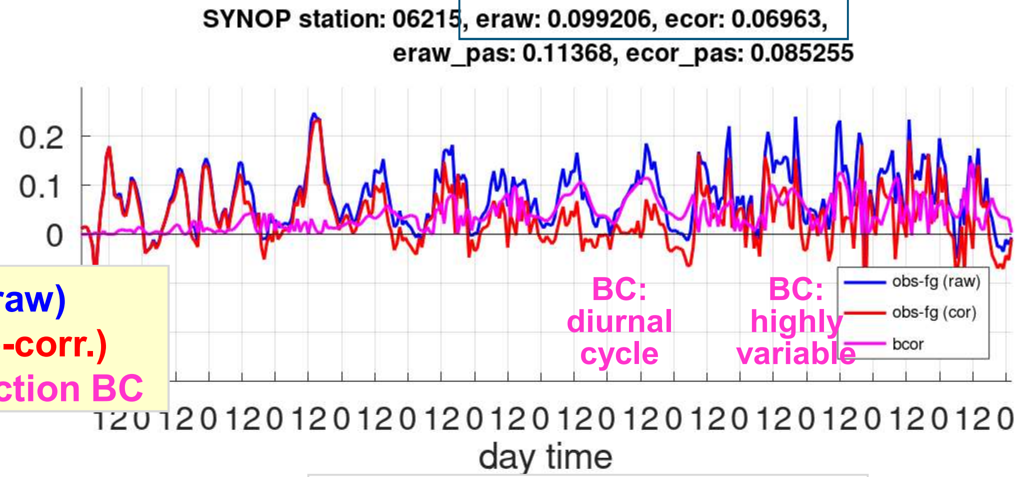
example: 3D-Var with $B = I$ and $R = \alpha I$, α = damping/ regularization parameter

obs minus first guess RH2M

time series over 2 weeks
at 1 station

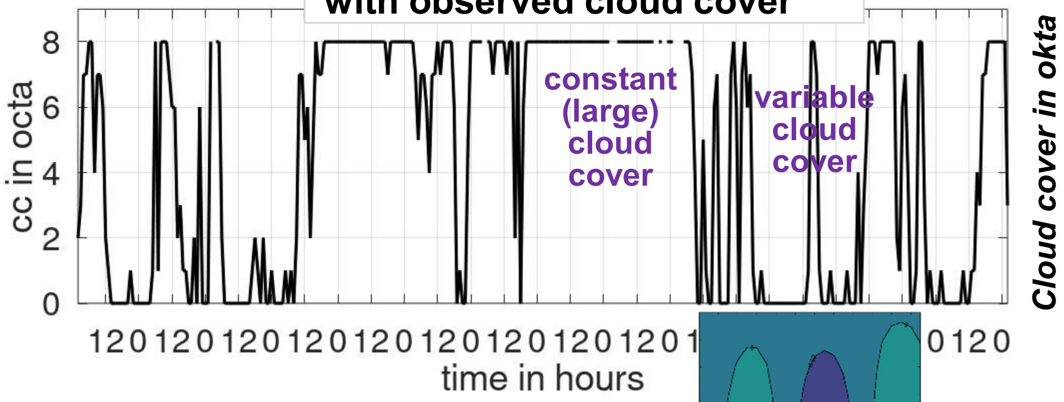
(with a slightly different (old) version of the bias correction scheme)

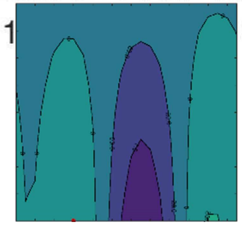
rmse reduced by 30 %



obs – fg (raw)
obs – fg (b-corr.)
bias correction BC

with observed cloud cover



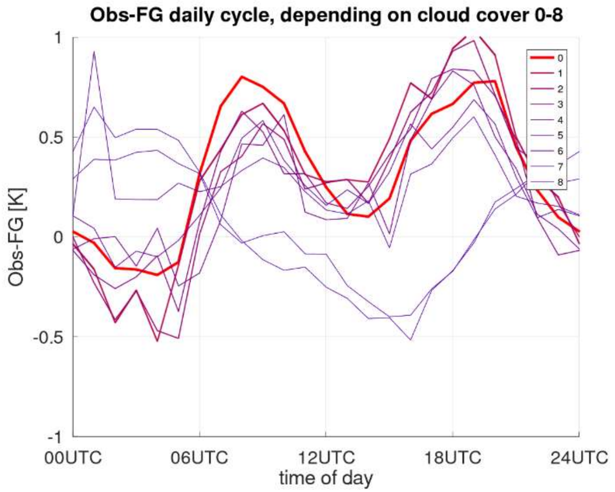


on average over all stations, rmse reduced by 20 %

Task 2.5: 2-m temperature + humidity obs: **bias correction** and assimilation

Deutscher Wetterdienst DWD

<table>
<tr><td>bias
(mean difference)
averaged over stations
in Dec. 2019</td><td>2-m temperature</td><td>2-m relative humidity</td></tr>
<tr><td>obs - FG</td><td>



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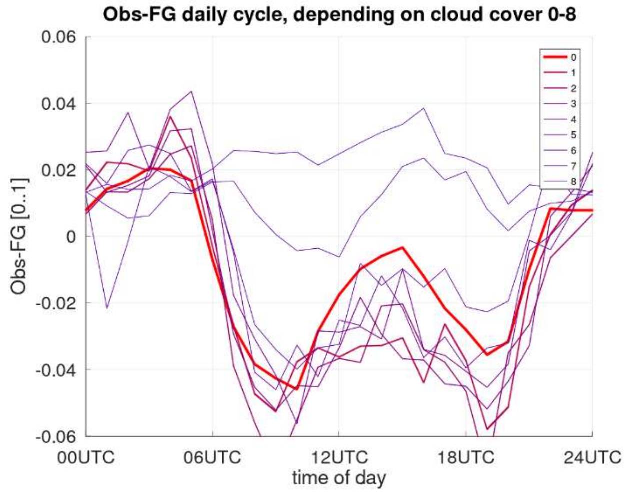
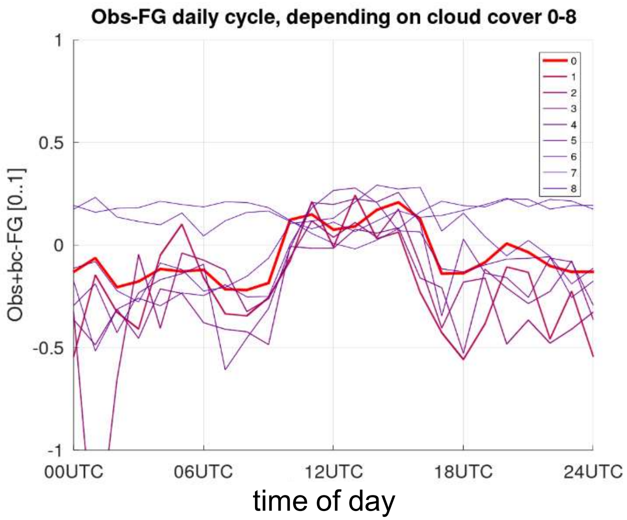


</td></tr>
<tr><td>obs_{bc} - FG</td><td>



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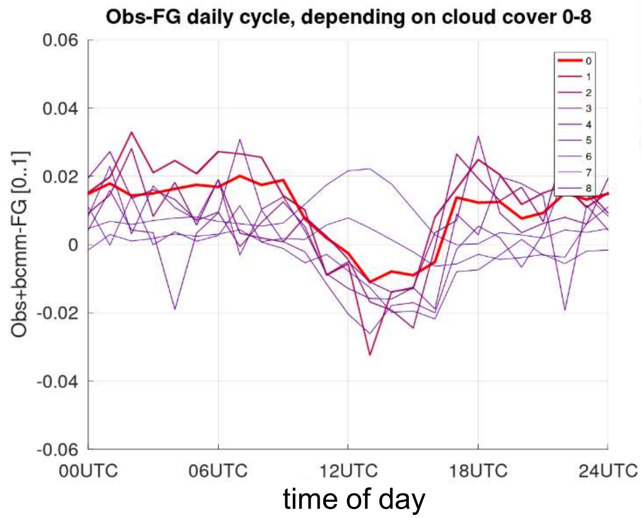

</td></tr>
</table>

cloud cover [okta]

Task 2.5: 2-m temperature + humidity obs: bias correction and **assimilation**

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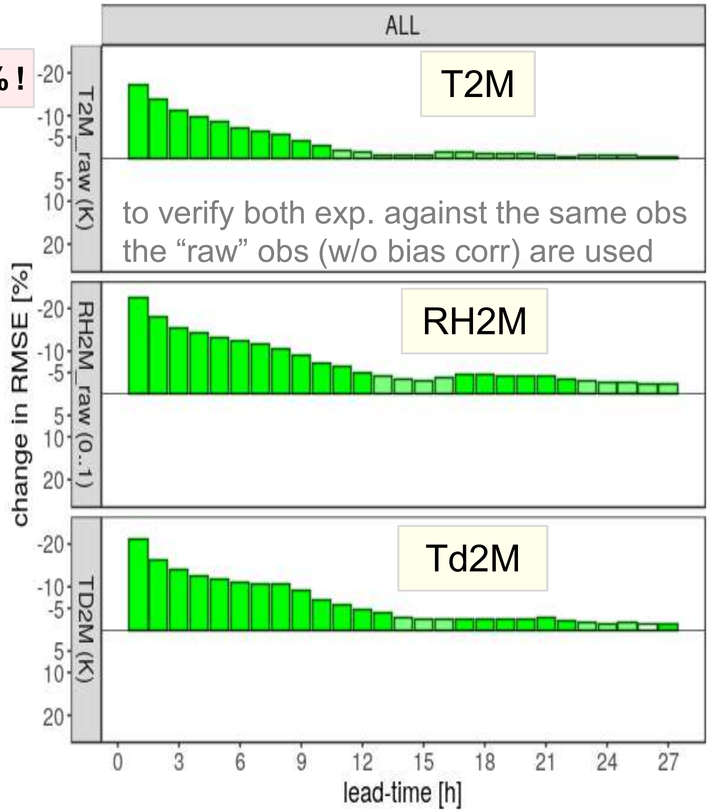
winter 21/12/19 – 08/01/20

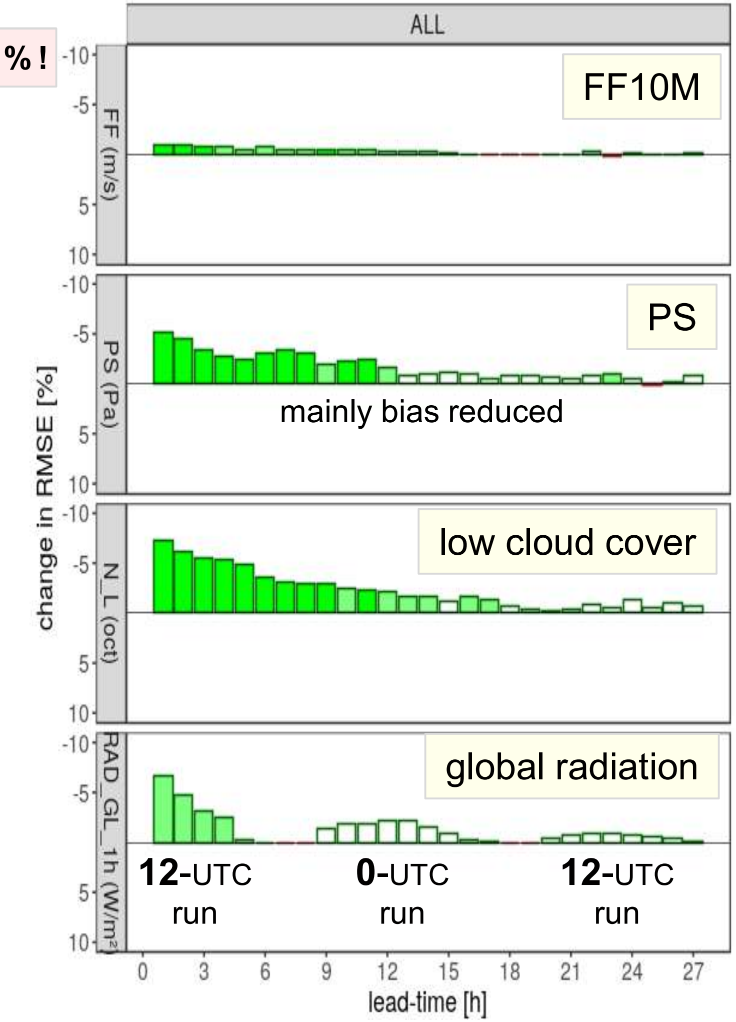
change [%] of RMSE against synop

ICON-D2
with RH2M + T2M better
w/o RH2M + T2M better

20 % !



10 % !



Task 2.5: 2-m temperature + humidity obs: bias correction and **assimilation**

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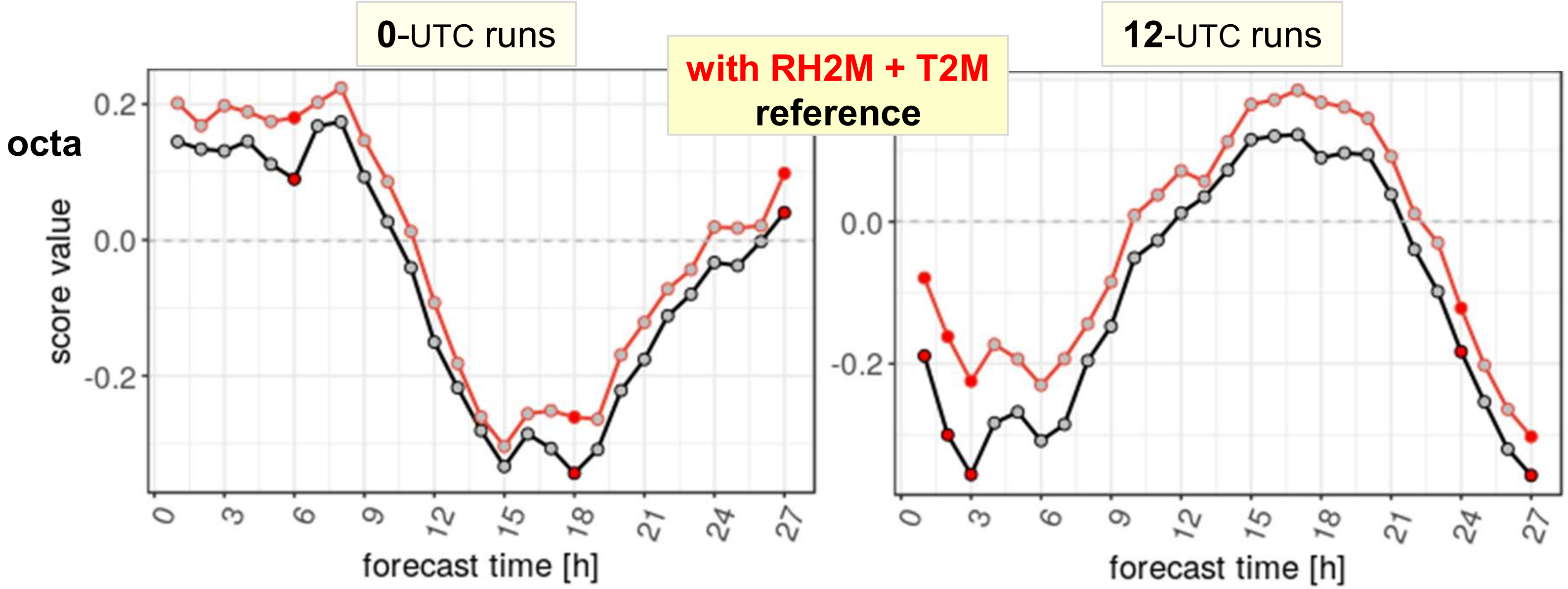
winter 21/12/19 – 05/01/20

bias
low cloud cover

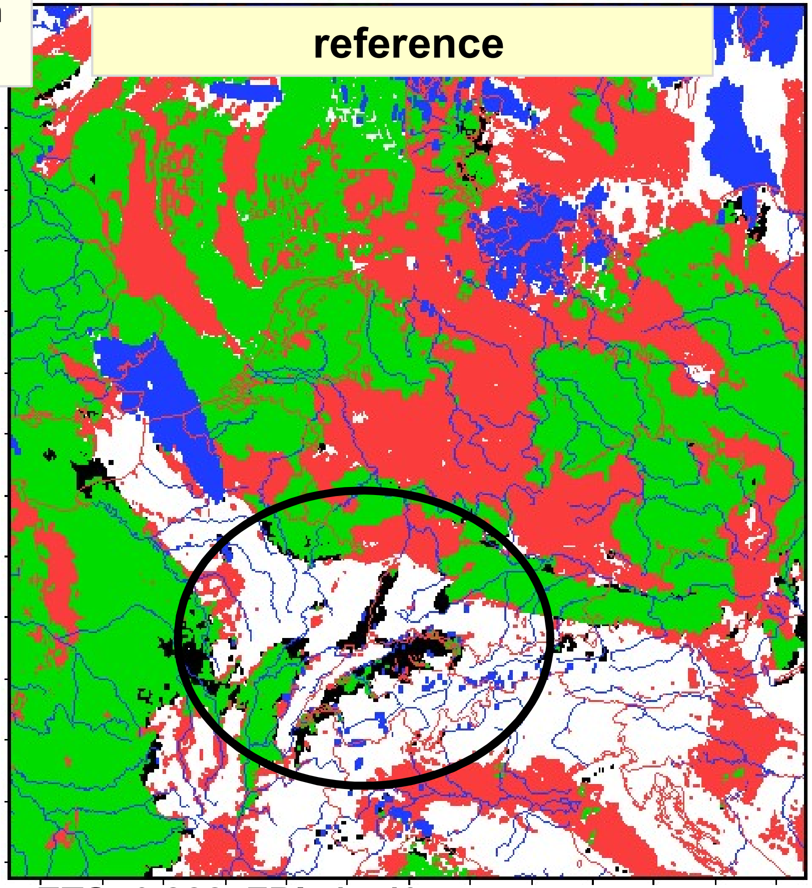


- low cloud too extended at night, too sparse at daytime (by 0.2 – 0.3 octas)
- **low cloud** cover **increased** (by 0.05 - 0.1 octa) after assimilation of RH2M, T2M

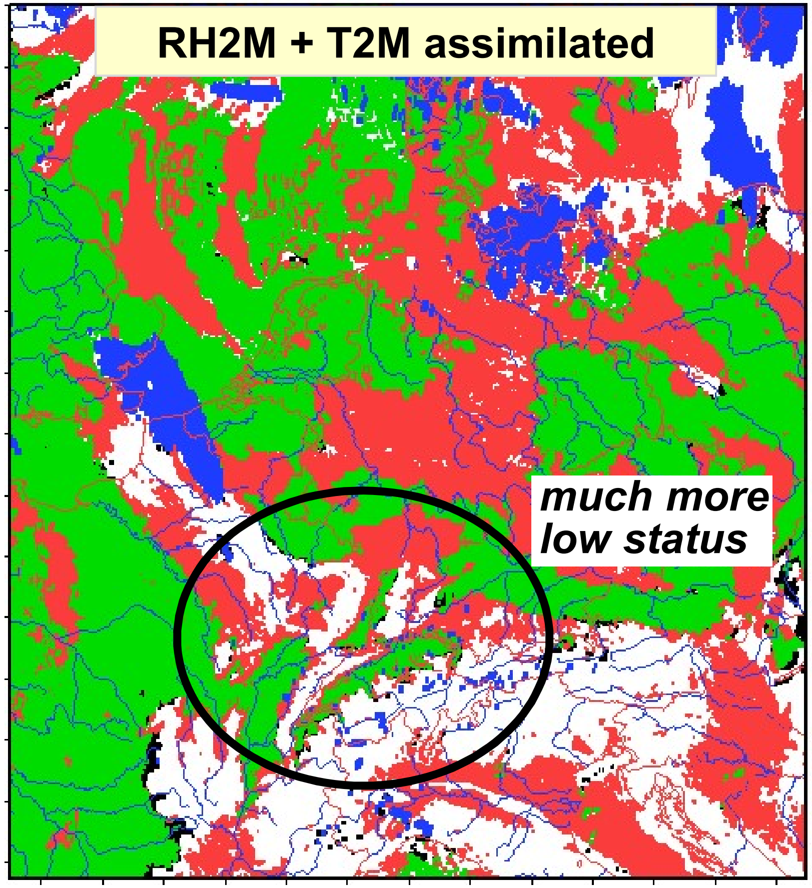
Task 2.5: 2-m temperature + humidity obs: bias correction and assimilation

low stratus case study: **1 Jan. 2020** , comparison to **NWCSAF cloud type**

0-UTC run
+ 1 h



ETS: 0.228 FBI: 1.749



ETS: 0.218 FBI: 1.868

correct cloudy / correct cloud-free / missed events / false alarms / undefined (observed higher cloud)

Task 2.5: 2-m temperature + humidity obs: bias correction and **assimilation**

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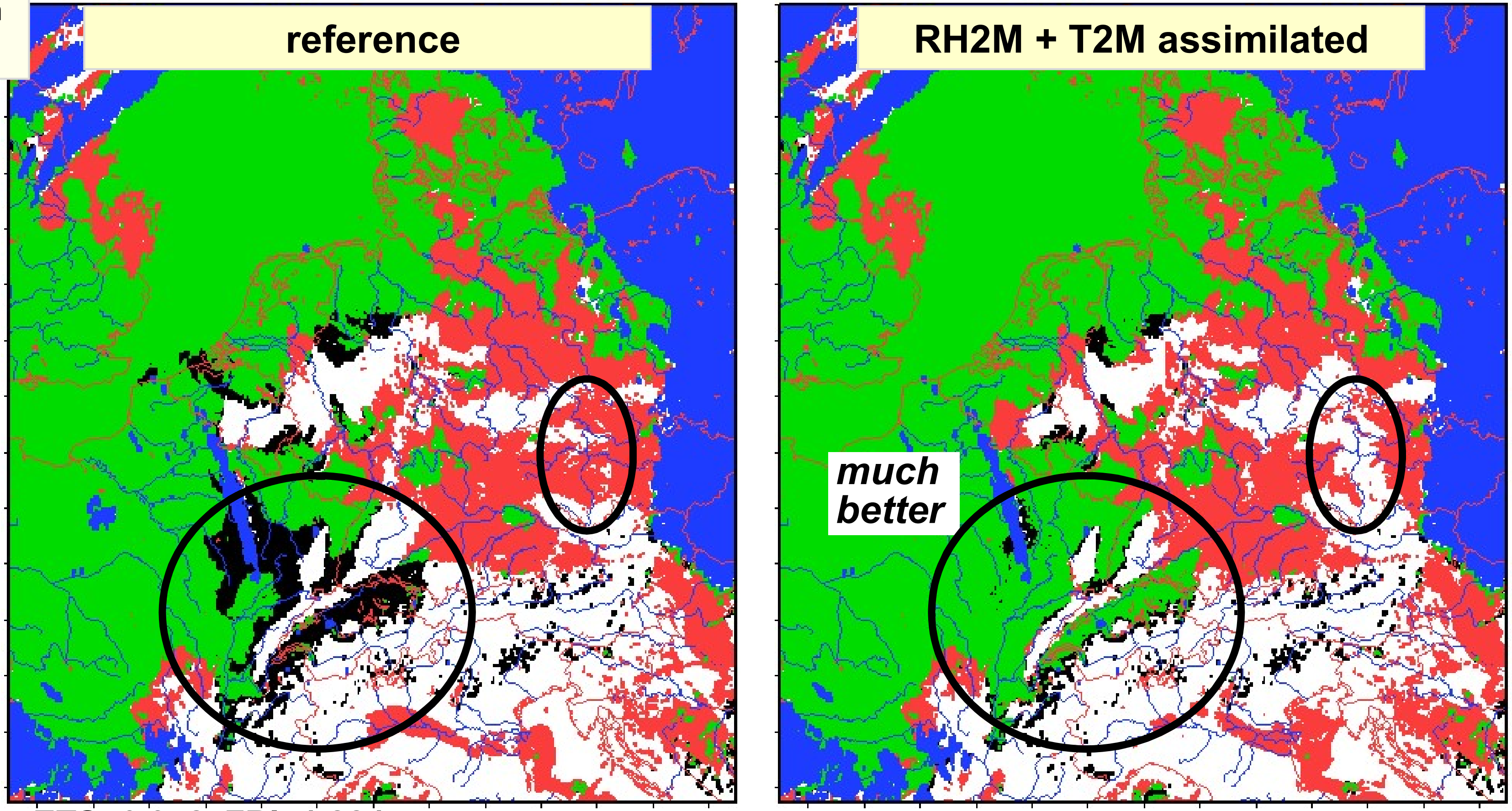
low stratus case study: **1 Jan. 2020** , comparison to **NWCSAF cloud type**

0-UTC run
+ 13 h



ETS: 0.352 FBI: 1.224

ETS: 0.408 FBI: 1.302

correct cloudy / correct cloud-free / missed events / false alarms / undefined (observed higher cloud)

Task 2.5: 2-m temperature + humidity obs: bias correction and **assimilation**

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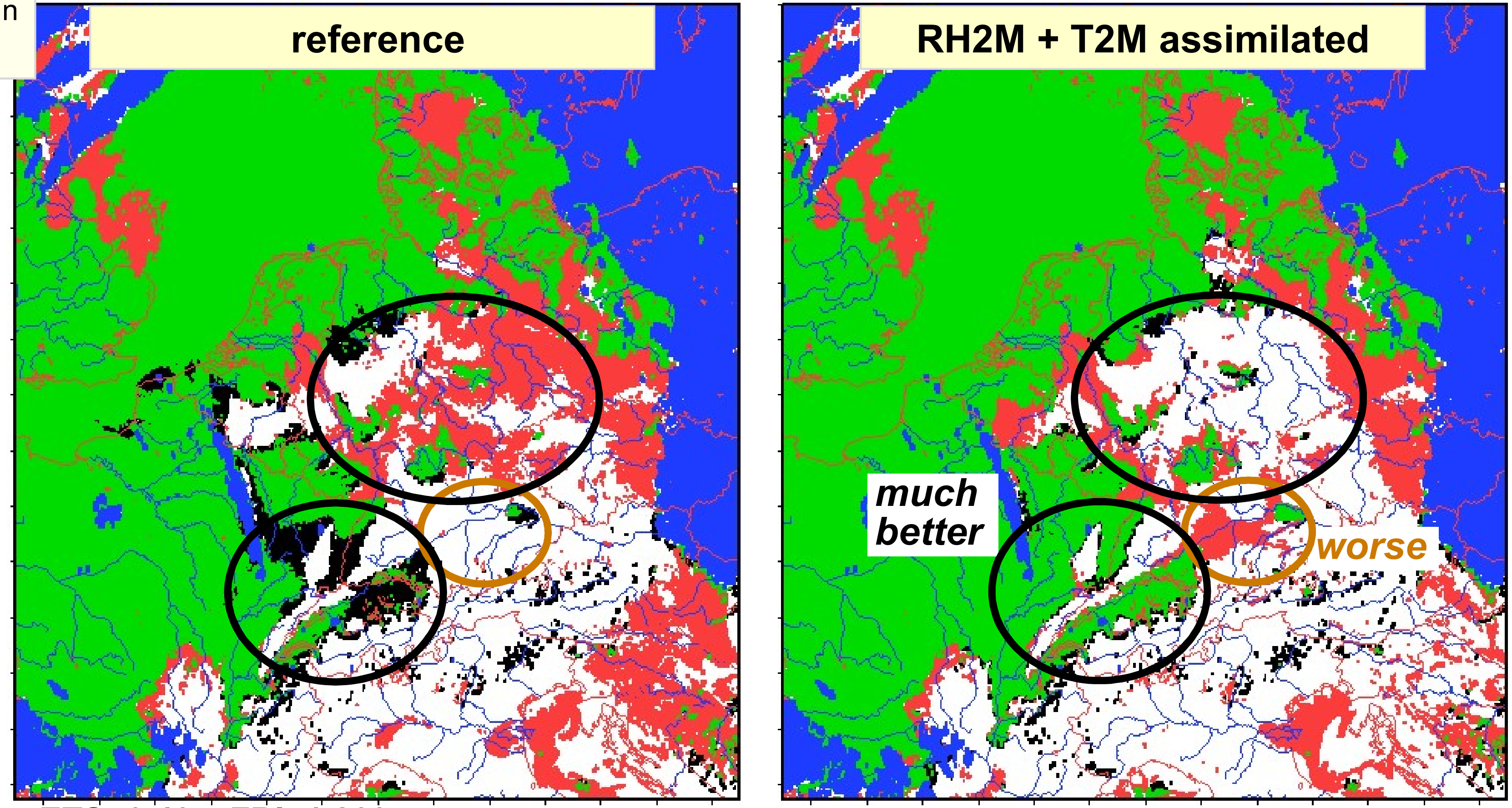
low stratus case study: **1 Jan. 2020** , comparison to **NWCSAF cloud type**

12-UTC run
+ 1 h



ETS: 0.407 FBI: 1.209

ETS: 0.537 FBI: 1.194

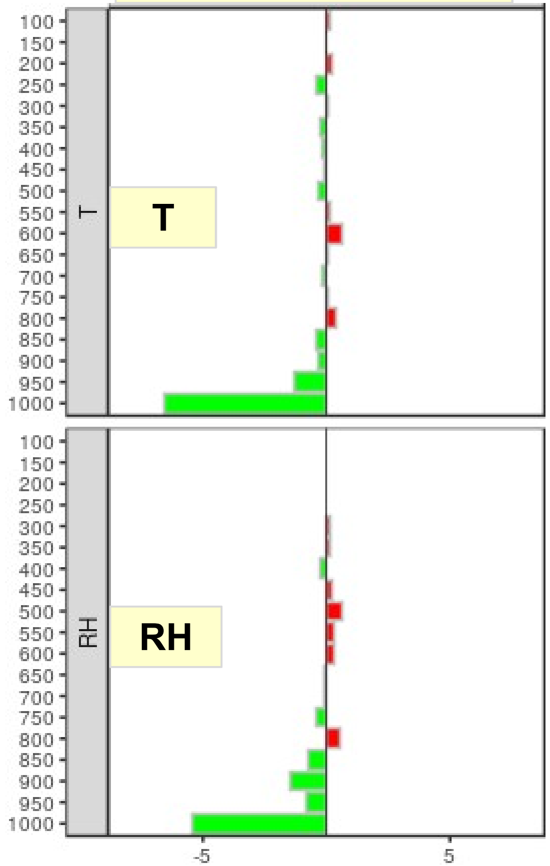
correct cloudy / **correct cloud-free** / **missed events** / **false alarms** / **undefined** (observed higher cloud)

Task 2.5: 2-m temperature + humidity obs: bias correction and assimilation

- station-dependent, conditional, non-linear online bias correction developed

- **assimilation** of **RH2M + T2M with bias correction**
  (without having adjusted obs errors, QC, vertical localization …!)
  - **improves** clearly T2M, RH2M (mainly first 9 hrs),
    T + RH in PBL (up to 24 hrs, only winter),
    radiative **low stratus** (in winter, esp. in the prone valleys),
  - increases low cloud (sometimes too much)
  - (assimilating only RH2M w/o bias correction degraded T2M)

TEMP verif
averaged +12h, +24h
21/12/19 – 08/01/20



next steps

- further investigation of the low clouds
- longer experiment periods, investigate impact on precip
- estimate station-dependent observation errors

Task 2.1: 3-D radar radial velocity + reflectivity: in ICON-D2

Deutscher Wetterdienst

DWD

common use of **radial velocity + reflectivity** tested for **ICON-D2**: 2 – 23 June 2019
(by accident)

Christian Welzbacher, Klaus Stephan et al. (DWD)

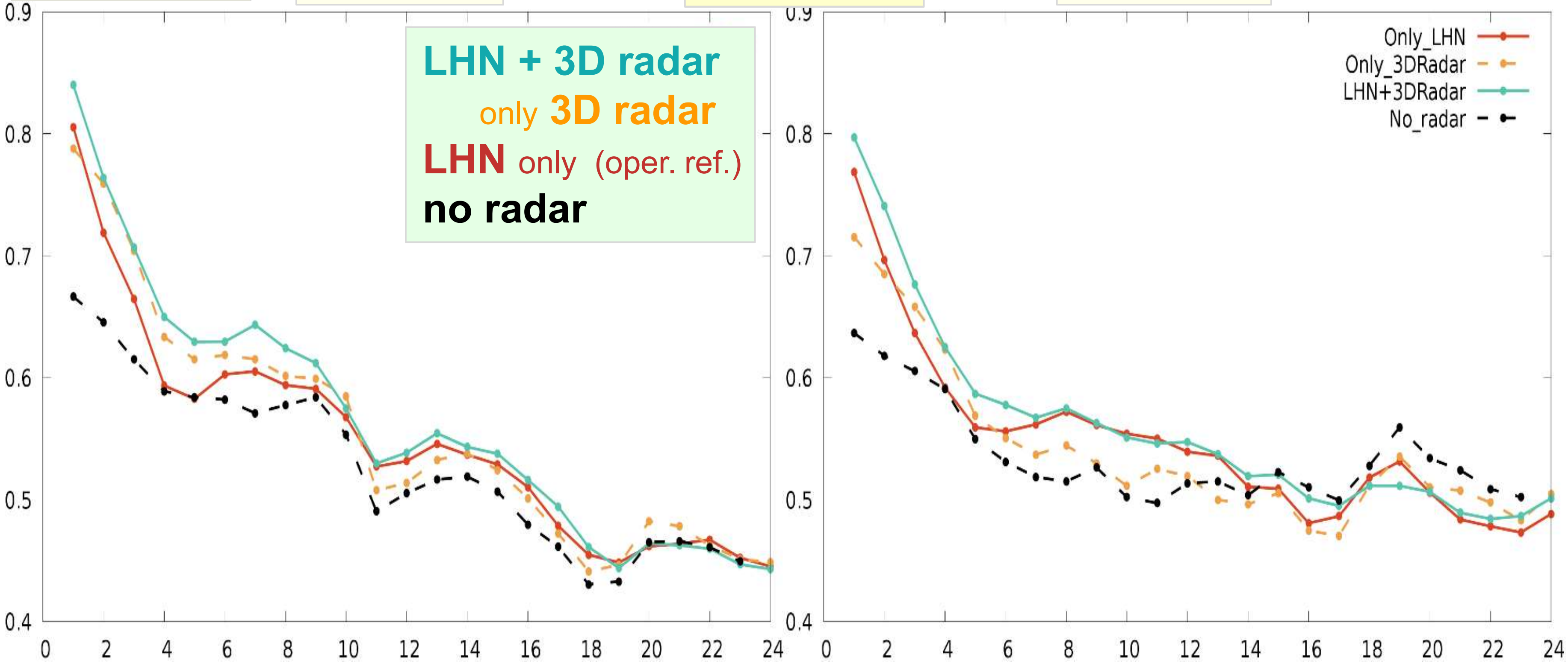
FSS precip
25 km (GER)

0-UTC runs

0.1 mm/h

12-UTC runs

LHN + 3D radar
only **3D radar**
LHN only (oper. ref.)
no radar



→ **LHN + 3D radar** > **LHN** only ~ **3D radar** only > **no radar**

Task 2.1: 3-D radar radial velocity + reflectivity: in ICON-D2

Deutscher Wetterdienst

DWD

common use of **radial velocity + reflectivity** tested for **ICON-D2**: 2 – 23 June 2019

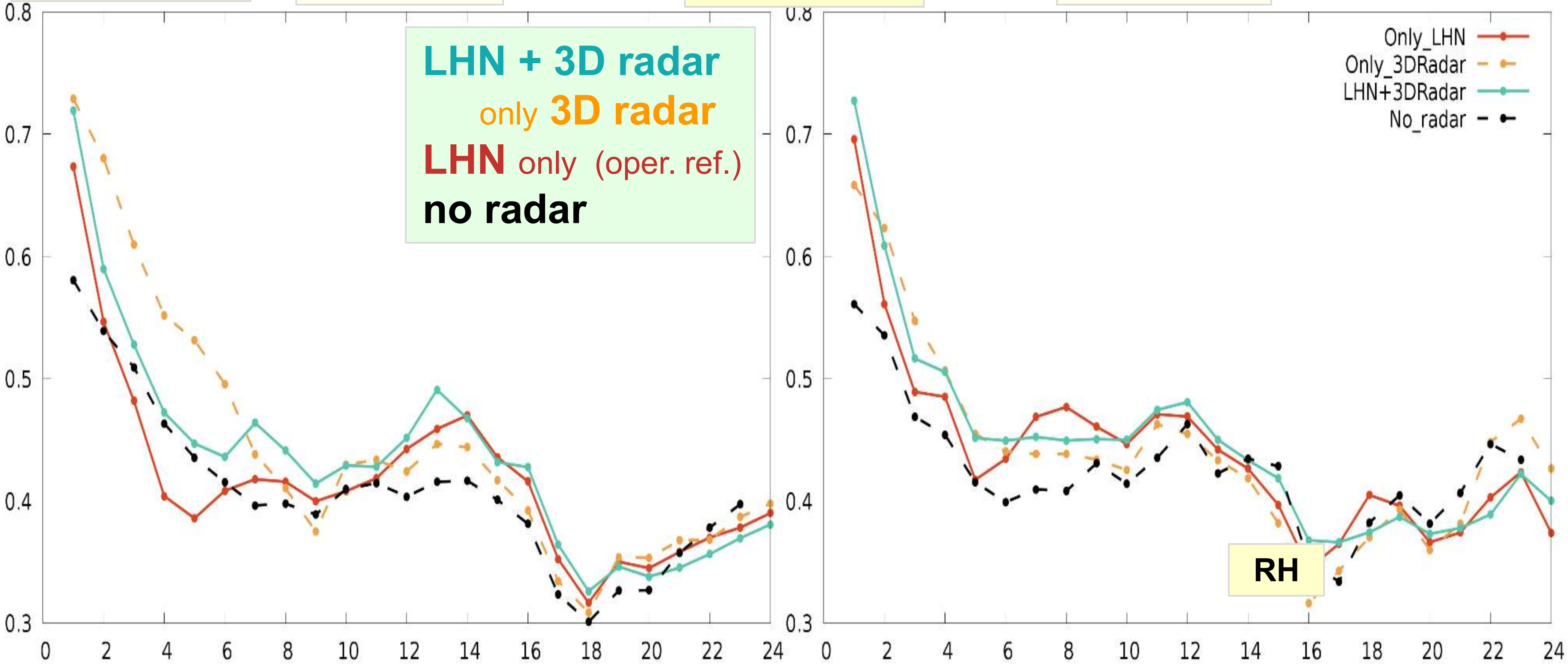
FSS precip

25 km (GER)

0-UTC runs

1 mm/h

12-UTC runs



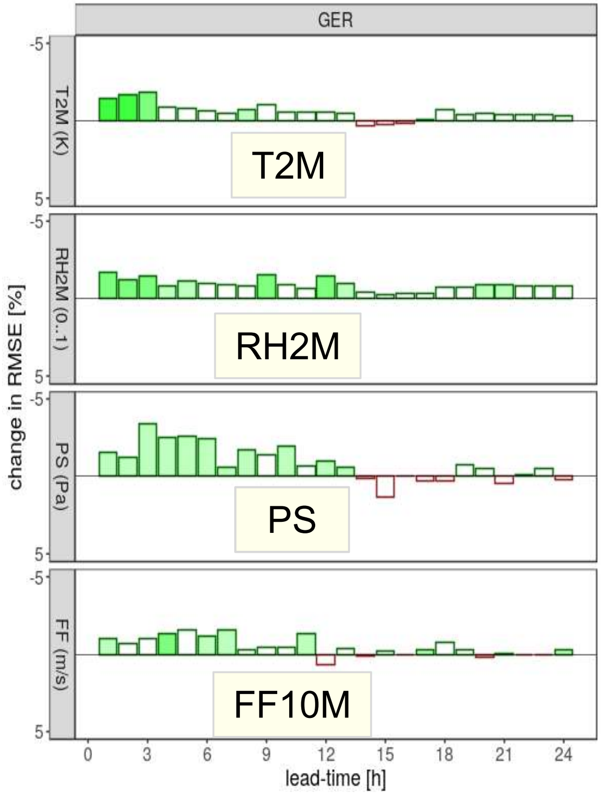
→ **LHN + 3D radar** **>~** **3D radar** only **>** **LHN** only **>** **no radar**

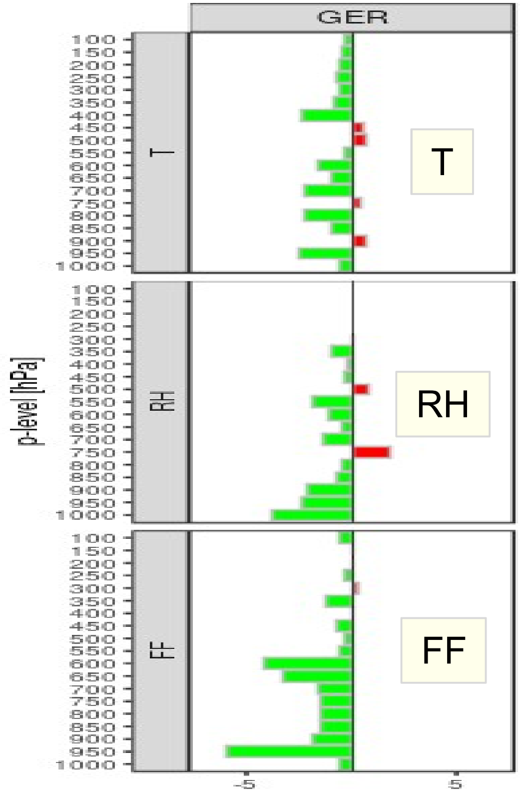
Task 2.1: 3-D radar radial velocity + reflectivity: in ICON-D2

Deutscher Wetterdienst

common use of **radial velocity + reflectivity** tested for **ICON-D2**: 2 – 23 June 2019

LHN + 3D radar better
Ref (LHN) better





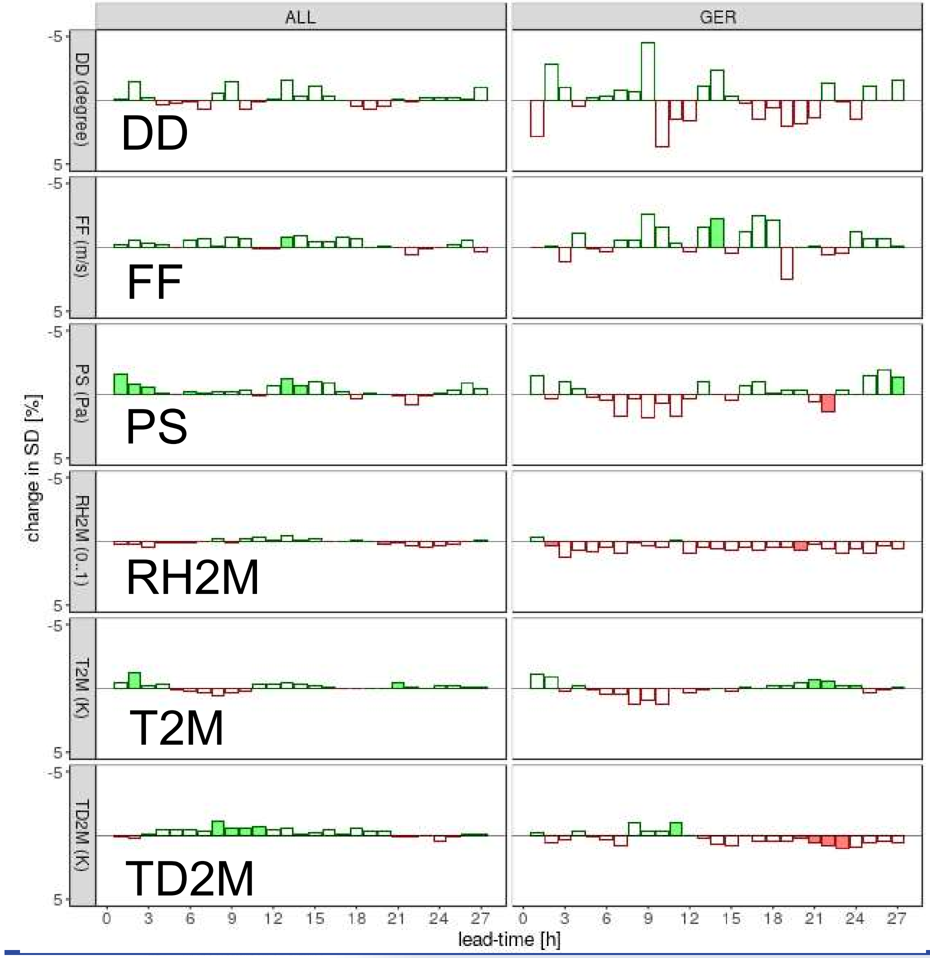
- introduced **ICON-D2 parallel suite** 22 June 2020
  (after becoming operational with COSMO-D2)

Task 2.1: 3-D radar radial velocity + reflectivity: in COSMO-D2

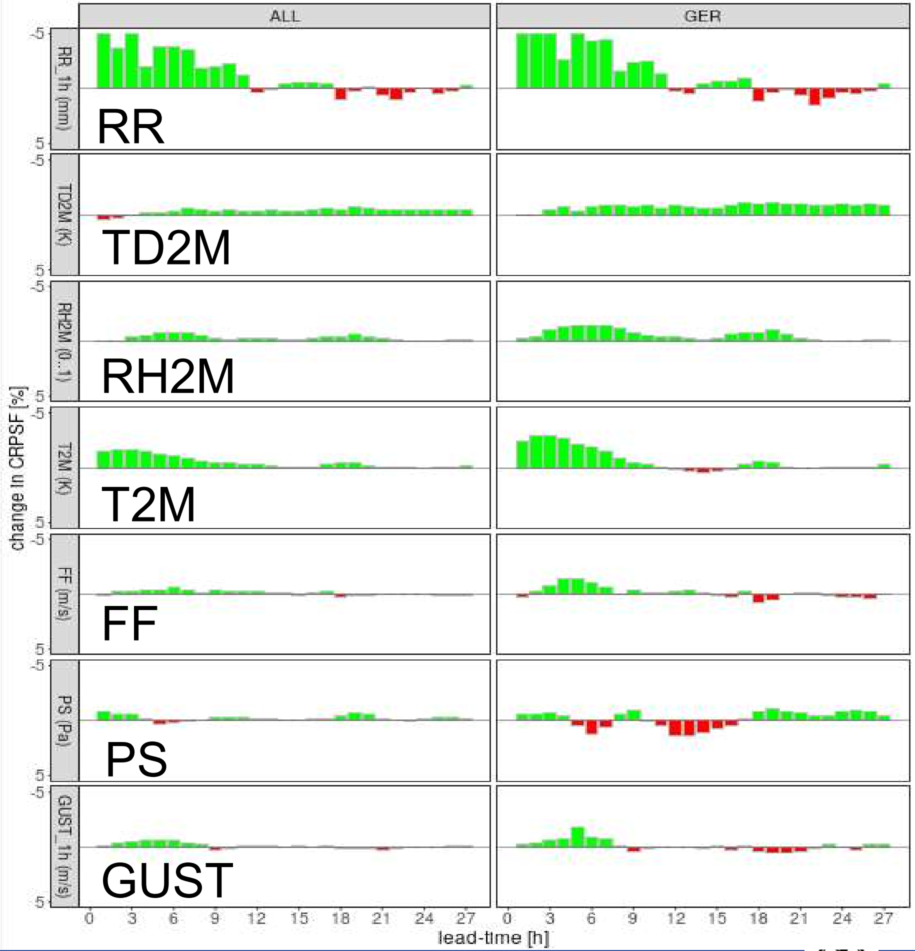
Deutscher Wetterdienst

after positive test in ICON-D2, and due to loss of aircraft obs due to pandemic:
why not test additional use of **reflectivity** for COSMO-D2? → test 1 – 12 June 2020

deterministic: std. dev.



EPS: CRPS

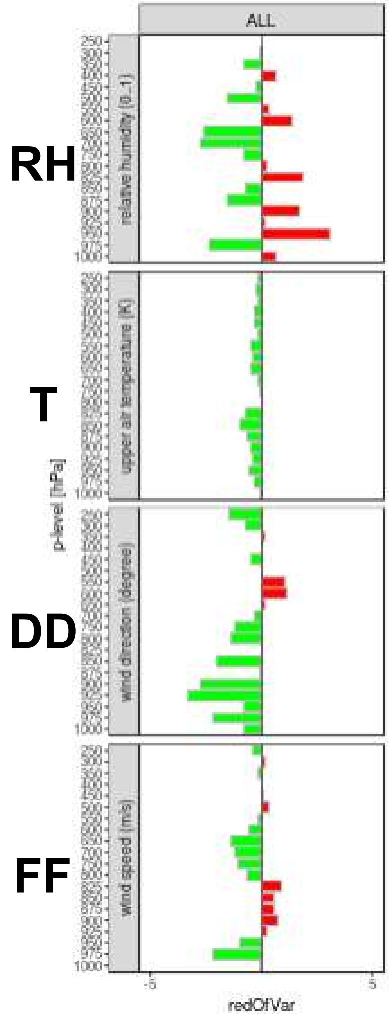


Task 2.1: 3-D radar radial velocity + reflectivity: in COSMO-D2

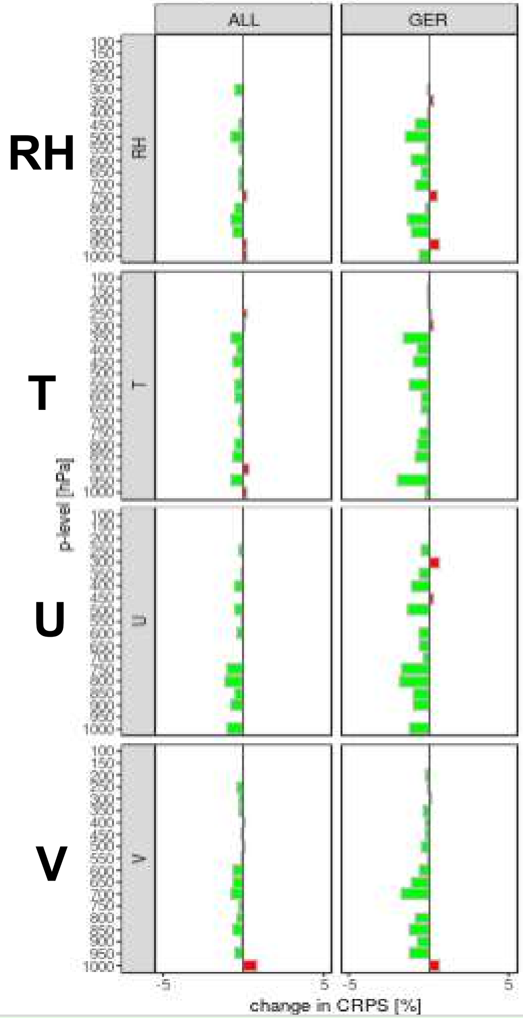
Deutscher Wetterdienst

DWD

deterministic: AIREP, std. dev.



EPS: TEMP, CRPS



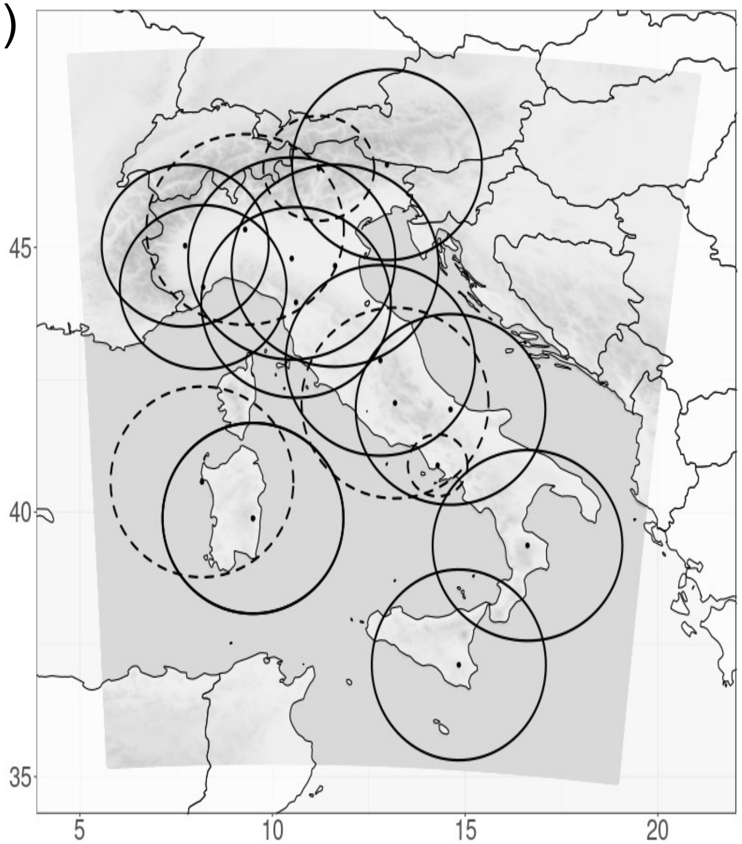
- introduced **COSMO-D2 operationally** 17 June 2020 due to moderate benefit

Task 2.1: Extended use of observations: 3-D radar reflectivity

<u>radar reflectivity at ARPAE</u> *Thomase Gastaldo, Virginia Poli, D. Cesari, P.P. Alberoni, T. Paccagnella*

- 27 Apr. – 29 June 2020: **parallel suite** with **radar reflectivity** assimilation
  - **1-h** LETKF cycle (36 + 1 members, 2.2 km)
  - 3-D radar approach: only 1 (latest) scan used per hour (solid cirlcles)

    (obs error = 10 dBz; superobbing 10 km; 5 dBz threshold on reflectivity)

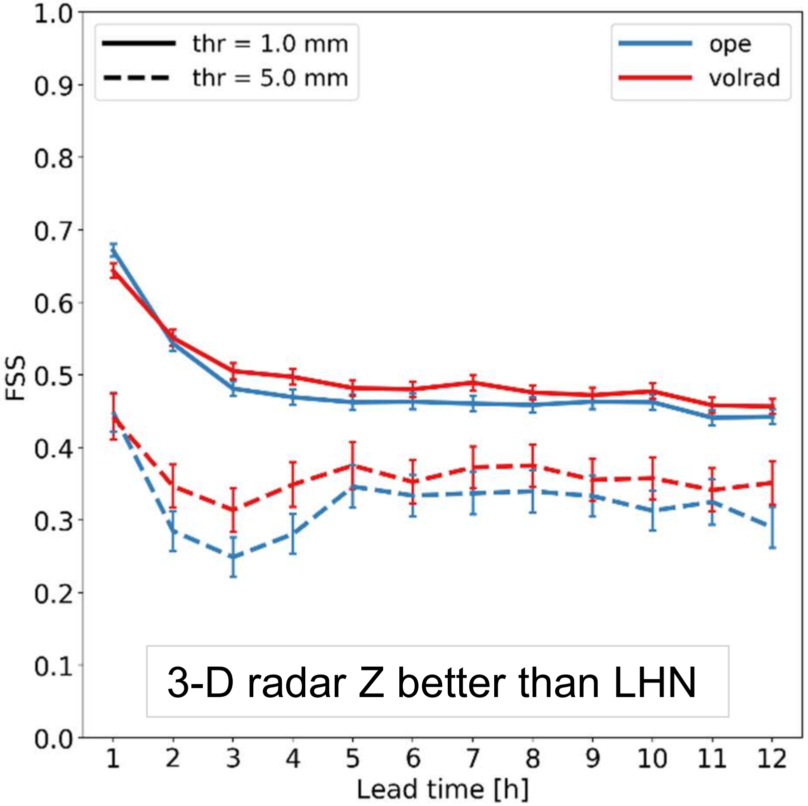


- reference: operational **3-h** LETKF cycle, with **LHN**
- 12-h forecasts every 3 hrs

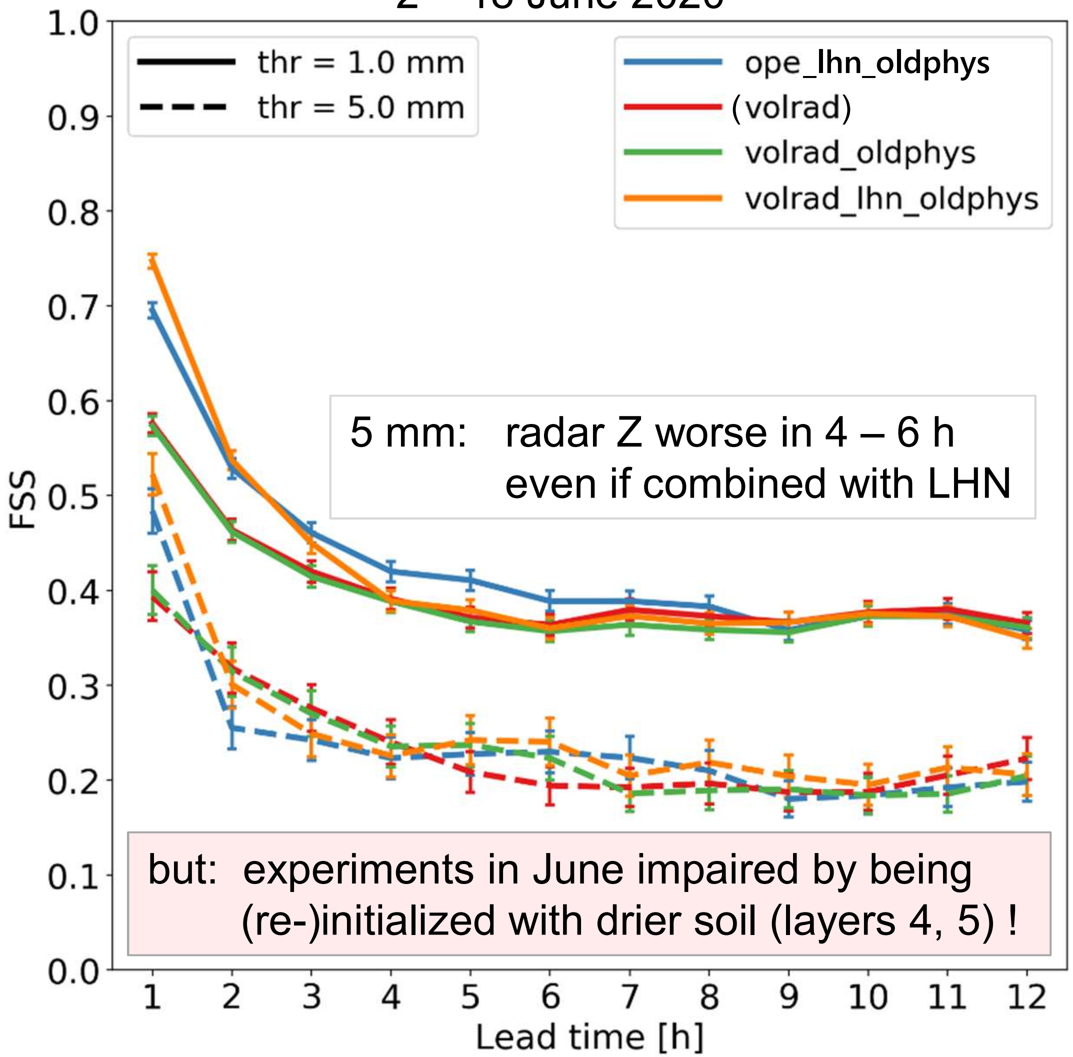
Task 2.1: Extended use of observations: 3-D radar reflectivity

precip verif: FSS 0.2°

May (27 April – 1 June) 2020



2 – 18 June 2020



Task 2.1: Extended use of observations: radar reflectivity

3-D radar reflectivity at ARPAE

- assimilation of 3-D reflectivity outperforms LHN in May, like in previous experiments (but has negative impact in June 2020)
- there might be a tendency to dry the soil
- parallel suite restarted 28 Aug. (with 'correct' soil moisture !)
- plans:
  - radar reflectivity hopefully **operational** in autumn 2020
  - investigate use of **radial winds** + more available radars

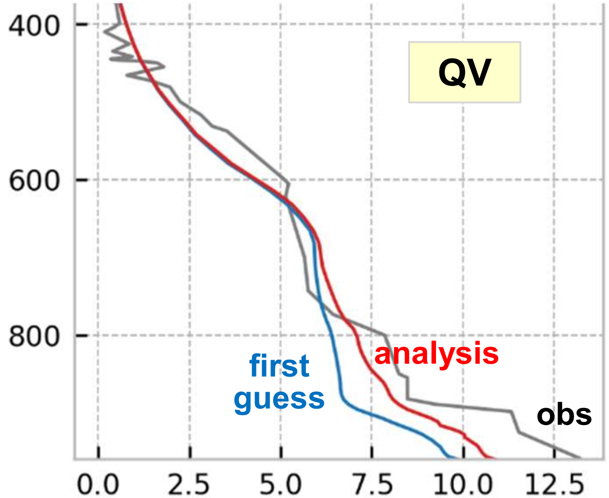
Microwave Radiometer (MWR)

Claire Merker, Daniel Leuenberger (MeteoSwiss);
Jasmin Vural, Roland Potthast, Annika Schomburg et al. (DWD)

HATPRO (RPG)

- measures atmospheric radiation (passive): brightness temperature
  (similar to MW radiances from polar-orbiting satellites, but from bottom of atmosphere)

- (e.g.) 14 channels sensitive mainly to T or humidity q
  → info on T, q at high temporal / low vertical resolution in PBL



- active assimilation of MWR data in COSMO & ICON works technically,

  first single-obs experiments

Task 2.7: Ground-based remote sensing: Microwave Radiometer (MWR)

Doppler Wind Lidar *Samuel Monhart, D. Leuenberger, C. Merker, M. Hervo, A. Haefele (MeteoSwiss)*

- wind components (u, v) derived from Doppler info in backscattered laser beams
- profile of horiz. wind in PBL (0 - 2km) with high temporal resolution
- wind components directly assimilated in KENDA-1

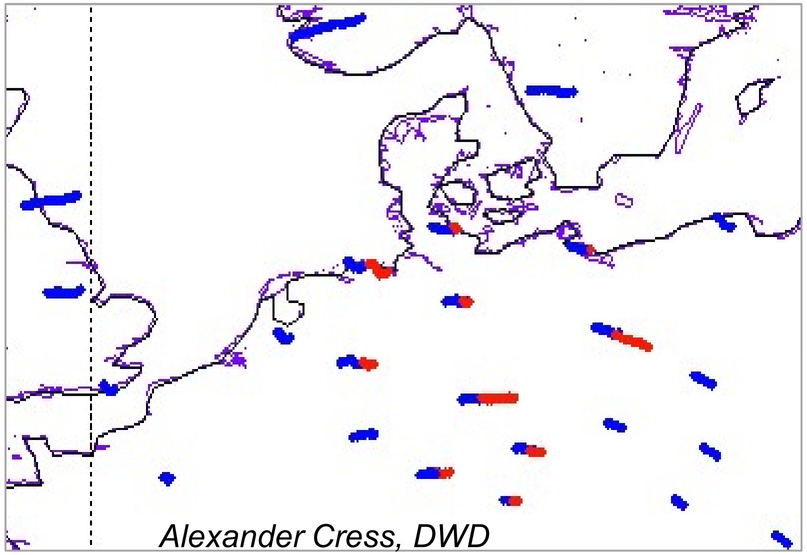
- 1 – 2 week assimilation experiments, 2 lidars: short-lived positive impact on wind in PBL

- plan:
  - Q1 2021: operationalization of Wind Lidar assimilation
  - Q3 2021 to Q3/2022: analysis for a 3rd station (Basel)

Task 1: Refinement of KENDA
Radiosonde descent profiles

Deutscher Wetterdienst

DWD



ascents
descents

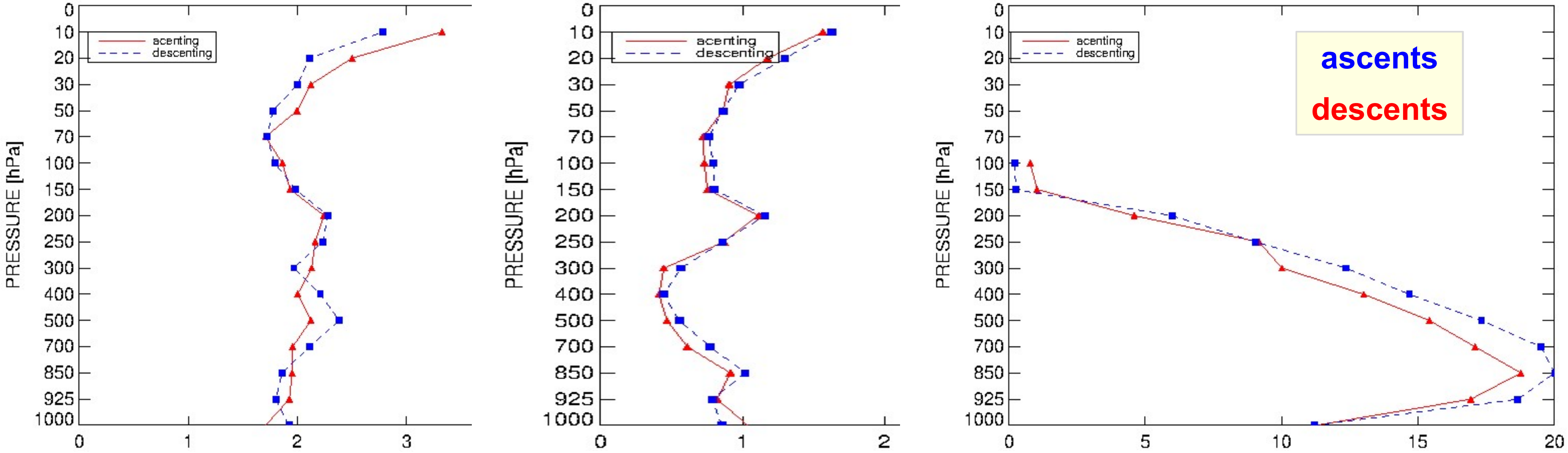
- ascents: ~ 2 hrs : (still old 'TEMP' used in KENDA at DWD)
  descents: 0.5 – 2 hrs : high-resolution profiles with drift info

- potentially available from Vaisala sondes, type 41, with parachutes:
  11 – 12 German, 1 Swiss, (additional ones since recently)

Monitoring of data quality:

standard deviation (vs. ICON-global FG, 1 – 15 March 2020)

wind speed **temperature** **relative humidity**



Alexander Cress, DWD

- bias (very small, not shown) + random errors
  similar to radiosonde ascents (below 70 hPa)

implementation

- high-resolution profiles, **superobbing** (10 hPa > 750 hPa, 20 hPa < 700 hPa)
- assimilated as **instantaneous vertical** profile at location / time of **lowest** obs level
  - → location + time are well accounted for in **low** troposphere (PBL)
  - → 00- / 12-UTC sondes assimilated in 1 – 3 UTC / 13 – 15 UTC analyses
  - → largest impact expected in **03-, 15-UTC** forecast runs (… over Germany)
- (requires COSMO V5_7a, better V5_7d after bug fixes)

quick and short experiment for **COSMO**

- 22 – 29 March 2020: deterministic every 3 h, EPS at 03-, 15-UTC
- meteorological situation: quiet, little precip

deterministic, change of **RMSE**, **8 runs / day** **EPS**, change of **CRPS**, **03 + 15 UTC runs**

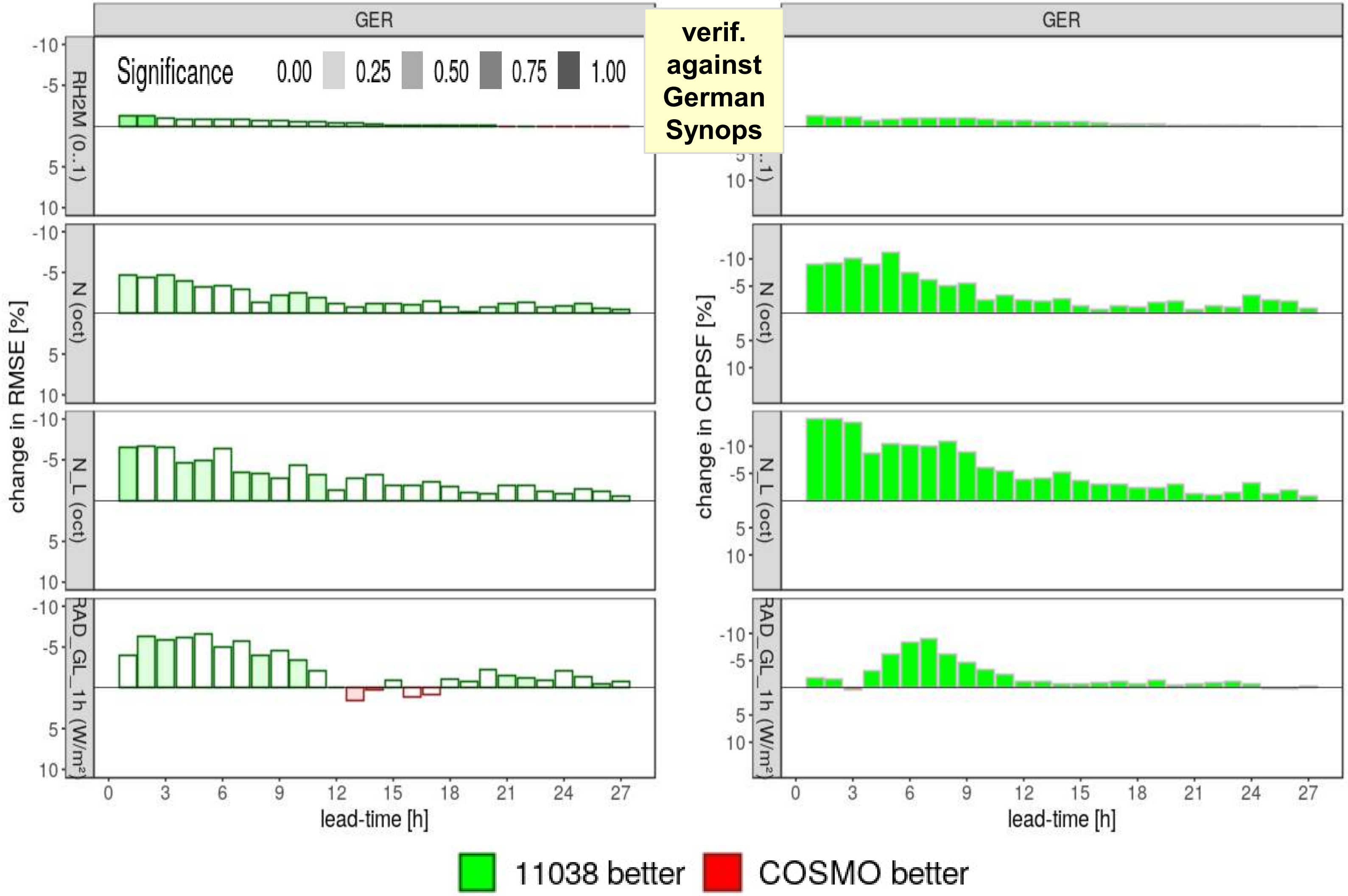
2-m rel. humidity

total cloud

low cloud

global surface radiation

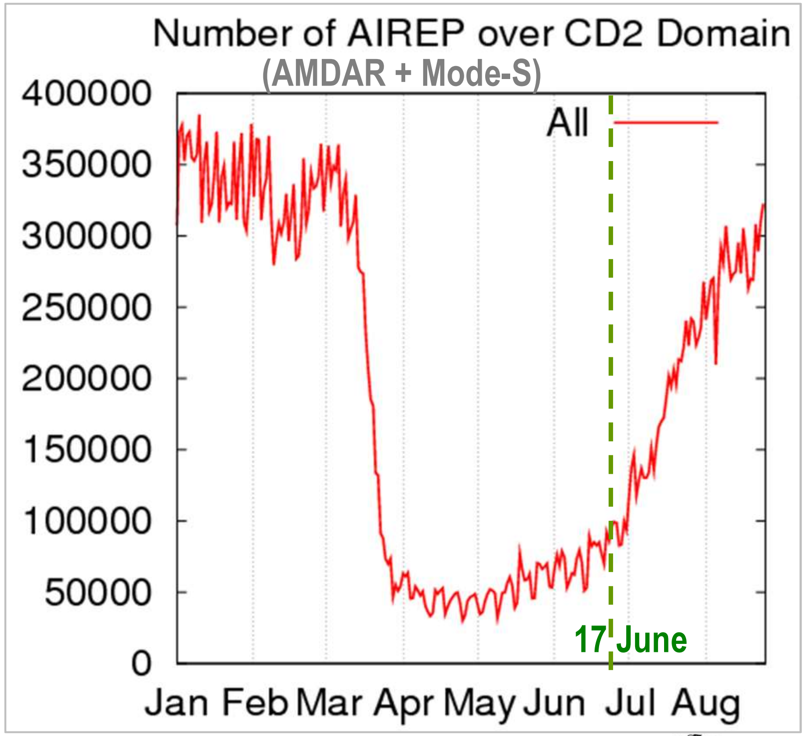
verif. against German Synops



COSMO-D2

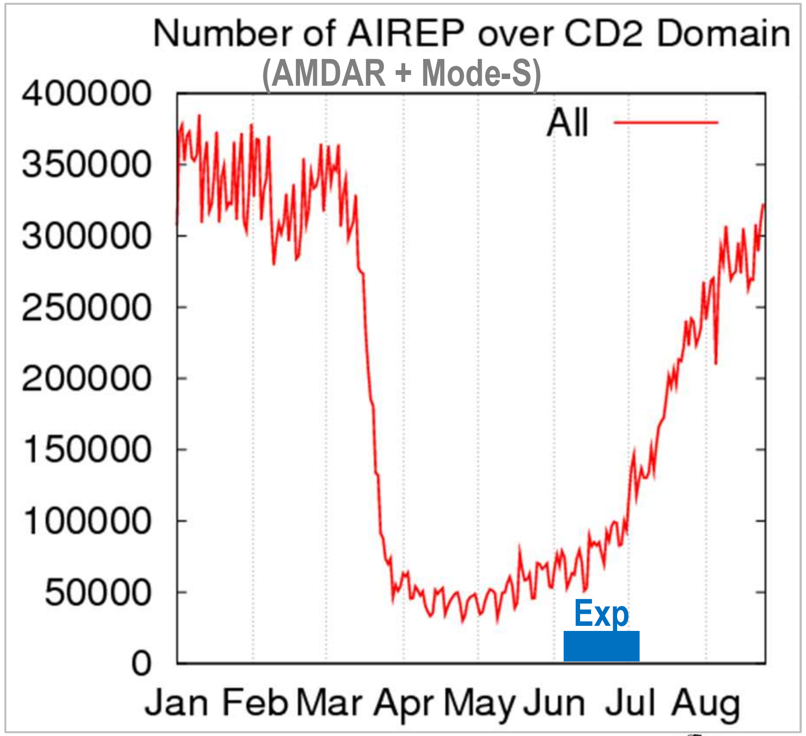
- **positive impact** on 2-m temperature + humidity, **cloud**, global radiation …
- small positive impact in radiosonde verification; no precip verif (too few events)
- introduced **operationally** on **17 June 2020**

  (also to mitigate impact of loss of aircraft obs)



ICON-D2 experiments

- 4 June – 3 July 2020: (with 3-D radar data in Exp. + Ref.) (fairly wet, convective)
  determ. runs 00, 12 + 03, 15 UTC ; EPS runs 03, 15 UTC



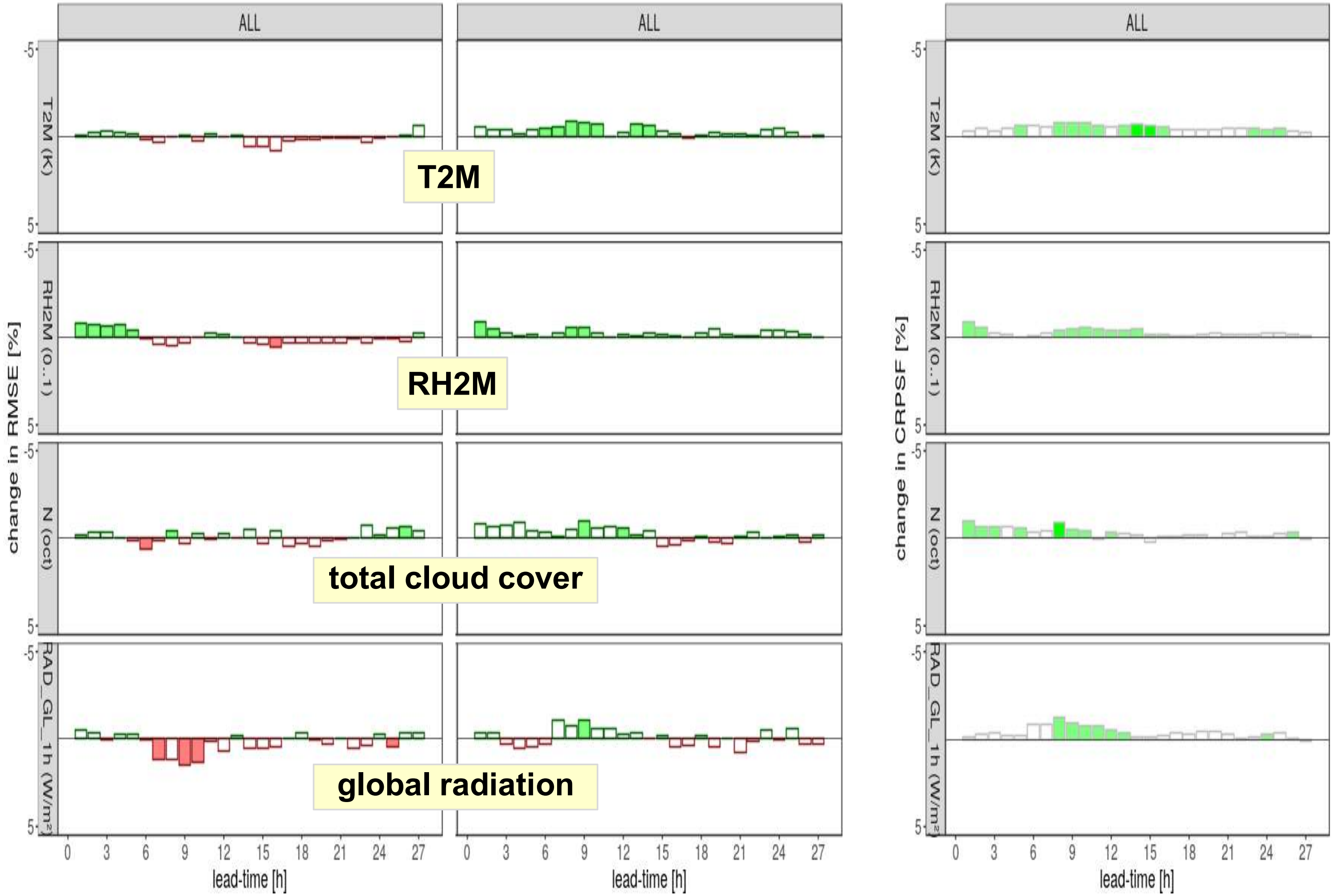
Impact of radiosonde descent data on ICON-D2

4 June – 3 July 2020

Deutscher Wetterdienst

Synop verification

00-, **12**-UTC **det.** runs | **03-**, **15**-UTC **det.** runs | **03-**, **15**-UTC **EPS** runs



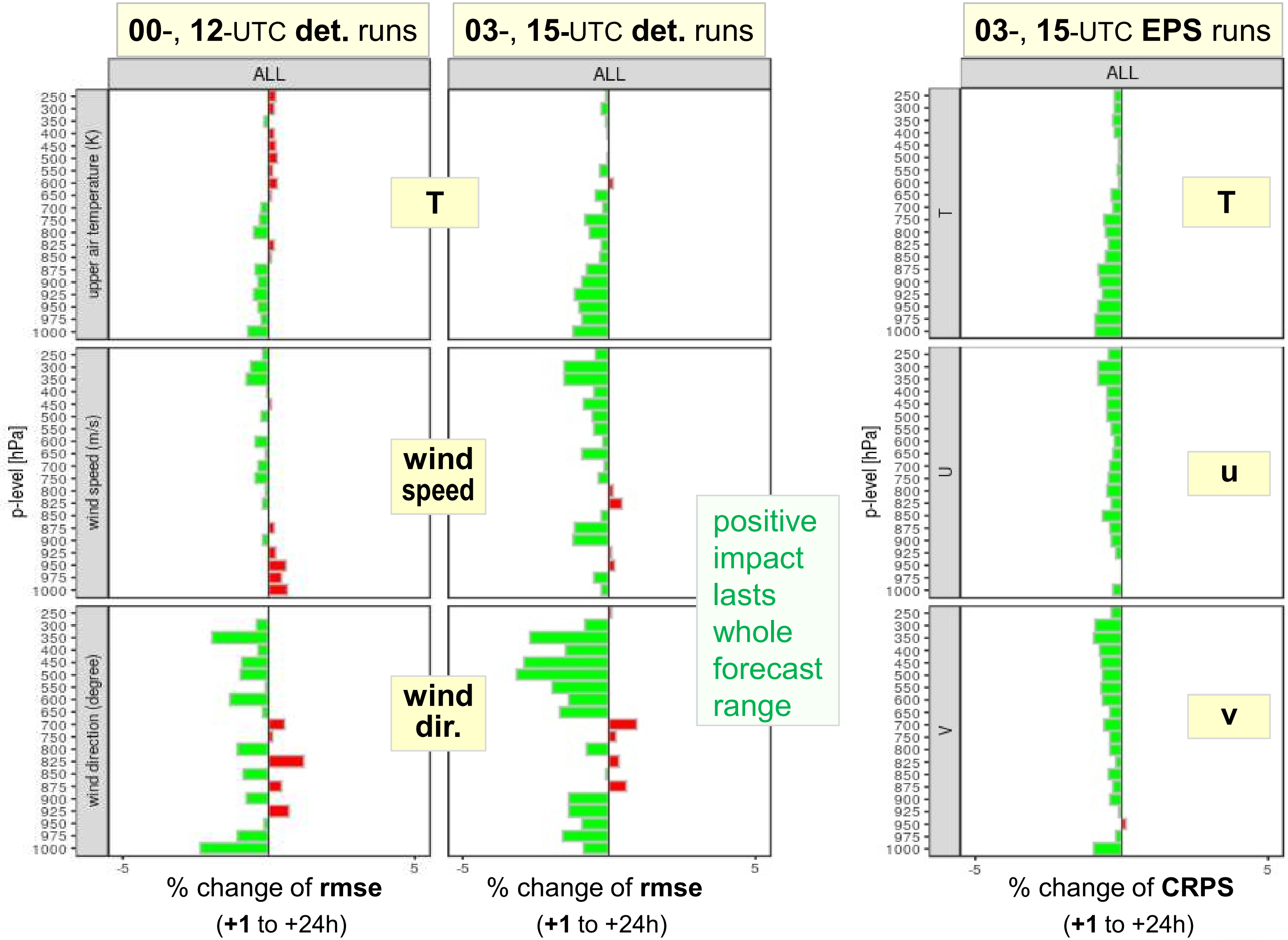
better
worse

Impact of radiosonde descent data on ICON-D2

4 June – 3 July 2020

verification against **aircraft** data

better
worse



ICON-D2

- small, but rather consistent **positive** impact (mainly) in **03-, 15-UTC runs** …
  in deterministic (RMSE) and EPS fc. (also precip)
  (neutral impact in 00-, 12-UTC runs (slightly positive in aircraft verif.))

- introduced in ICON-D2 parallel suite on **22 June 2020**

christoph.schraff@dwd.de

Final Status of KENDA-O / Status of WG1

- Task 1: further development / operationalization of LETKF scheme (conventional obs)

KENDA-scope → algorithmic developments
  - 3DVar / 3D-EnVar, 4D-EnVar, exploring Particle Filter
  - bias correction, obs errors, QC, etc.

- Task 2: extended use of observations : ongoing, but project goals mostly met
  - operational: aircraft Mode-S, radar radial velocity, radar reflectivity
  - close to operational: GPS STD / ZTD; screen-level obs (T2M, RH2M)
  - ground-based remote sensing: some implementation and first tests as intended
  - except for: SEVIRI IR WV: clear-sky data ok, but delay for all-sky (cloudy) data; porting to ICON-LAM, continued (resources available)

KENDA-scope → SEVIRI VIS ; MTG IRS

- Task 3: soil moisture analysis using satellite SM data (no clear benefit yet)

- Task 4: adaptation to ICON-LAM (successful pre-operat. applic.) → done