# KENDA developments at DWD

*Christoph Schraff*

Deutscher Wetterdienst

***KENDAscope***: KENDA from Surface to Cloud Observations Progressive Extension
(Sept. 2020 – Aug. 2025)

- Task 1: algorithmic developments
  - 1.1 refinements of reference KENDA (currently LETKF)
  - 1.2 Variational DA (EnVar , CEnVar, 4D-EnVar)
  - 1.3 Particle Filter
- Task 2: observations (from surface to clouds)
  - 2.1 Radar (Z + Vr)
  - 2.2 ground-based GNSS ZTD + STD
  - 2.3 all-sky IR + VIS radiances
  - 2.4 MTG IRS
  - 2.5 screen-level obs (T2M, RH2M)
  - 2.6 PBL profiling obs (wind lidar, MW radiometer, Raman lidar, drones, towers)
- Task 3: soil / surface (satellite soil moisture, SST, …)

## ARPAE-EMR *(Thomas Gastaldo, Virginia Poli)*

- implementation of DA suite for ICON-I2 (to replace COSMO-2I in 2023)
  (ongoing due to some issue with the radar operator)

- (further) evaluation of correlated R estimated from Desroziers stats for radar radial wind

## COMET *(Francesca Marcucci, 0.01 FTE)*

- maintenance of operational suite, migration to new ECMWF ATOS system

# Task 1.1: Refinements on reference KENDA

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**DWD** *(Hendrik Reich, Stefanie Hollborn, et al.)*

Ongoing technical work on

- processing of 'rof' (raw feedback) files in DACE:
  - contains only obs w/o model info, for easier testing of use of new obs or obs from external providers (e.g. field campaigns):

- non-diagonal R (obs error covariance matrix) with inter-channel or vertical correlations in LETKF

  → hyperspectral satellite data (IASI, IRS), ground-based MWR, lidar (?), GNSS STD (?)

  - a.o. requires (MPI-) parallel processing of obs in LETKF
    (due to memory problems, at least for satellite obs, e.g. IASI)

## EnVar for ILAM

*(Mareike Burba, Stefanie Hollborn, Hendrik Reich, Sven Ulbrich, Christoph Schraff et al.)*

- **EnVar**: runs technically in a preliminary version (for conventional obs with DACE obs operators that are used operationally in global DA)
  - 'unified DACE operators' := DACE operators adapted for convective scale (based on contents of COSMO operators)
    - → little / no effort to derive TL + adjoint
    - → implemented + applied for aircraft obs
    - → 1st step for Synop: revised + unified processing of cloud-related obs, cloud ceiling + visibility added (for verification)
  - careful EnVar tests / comparison to LETKF done
    (to be continued (with unified operators), less resources in next future

# Task 1.2: Variational DA (EnVar, CEnVar)

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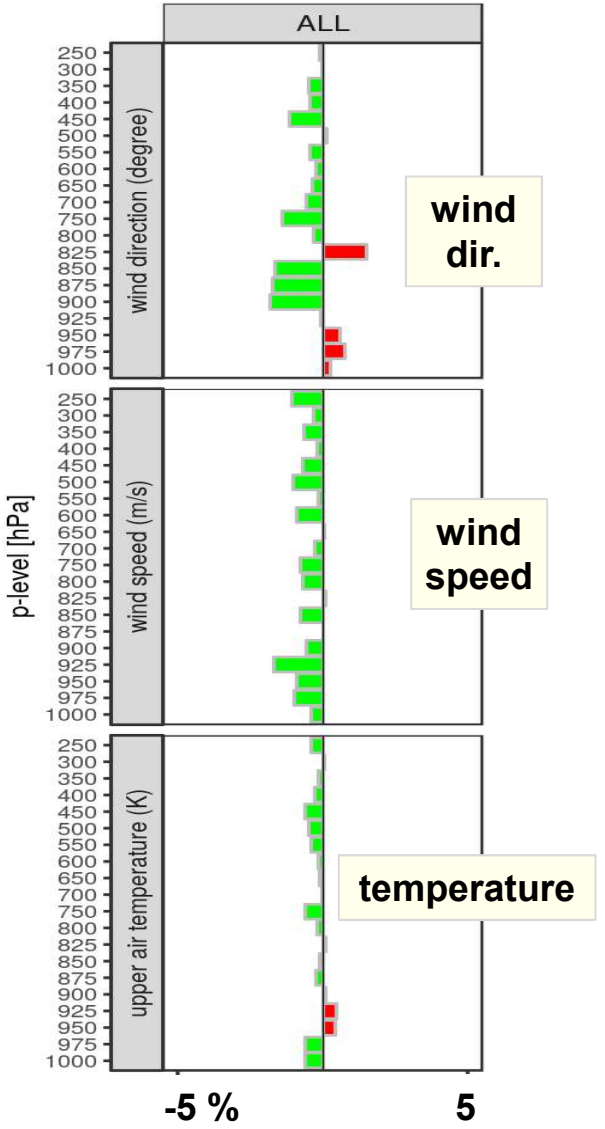
comparison of methods EnVar vs. LETKF:
use of obs as similar as possible
(far from operational setup)

- assimilation of aircraft T + wind only
- almost no thinning
- „3D-LETKF“
- 01 – 15 June 2021
- deterministic forecast

**aircraft**
verification

EnVar vs.
3D-LETKF

change [%]
of **RMSE**



# Task 1.2: Variational DA (EnVar, CEnVar)

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towards comparison of systems EnVar vs. LETKF:

(closer to operational KENDA settings, no EnVar tuning (VarQC…)

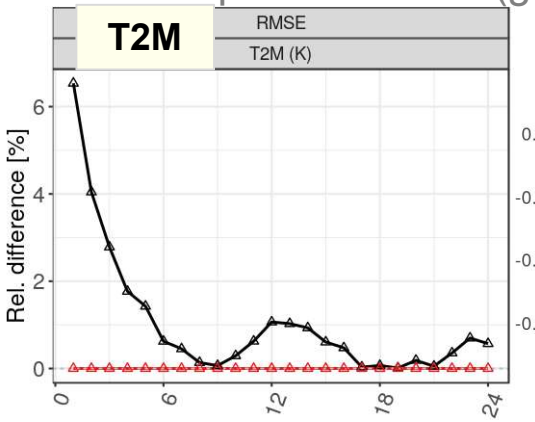
- assimilated obs: – aircraft T + wind, with thinning
  – (only high-res) radiosondes
  – Synop: T2M, RH2M, 10-m wind, ps
- „4D-LETKF“, with adaptive localisation
- 1 – 15 June 2021

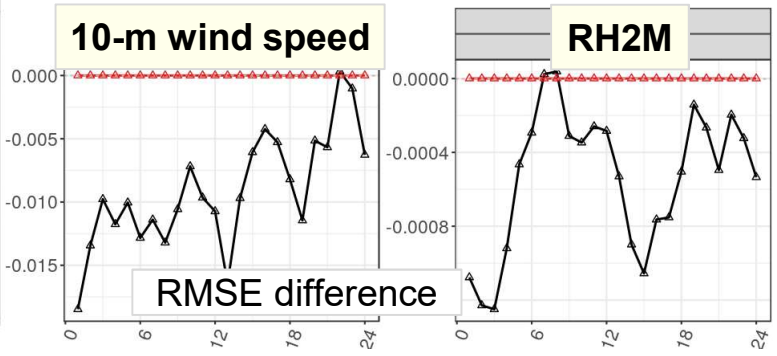
- T2M (T in PBL): mainly bias problem → BC?
- T2M obs error differs
- obs operator differs (grid pt. assign. → Δz)

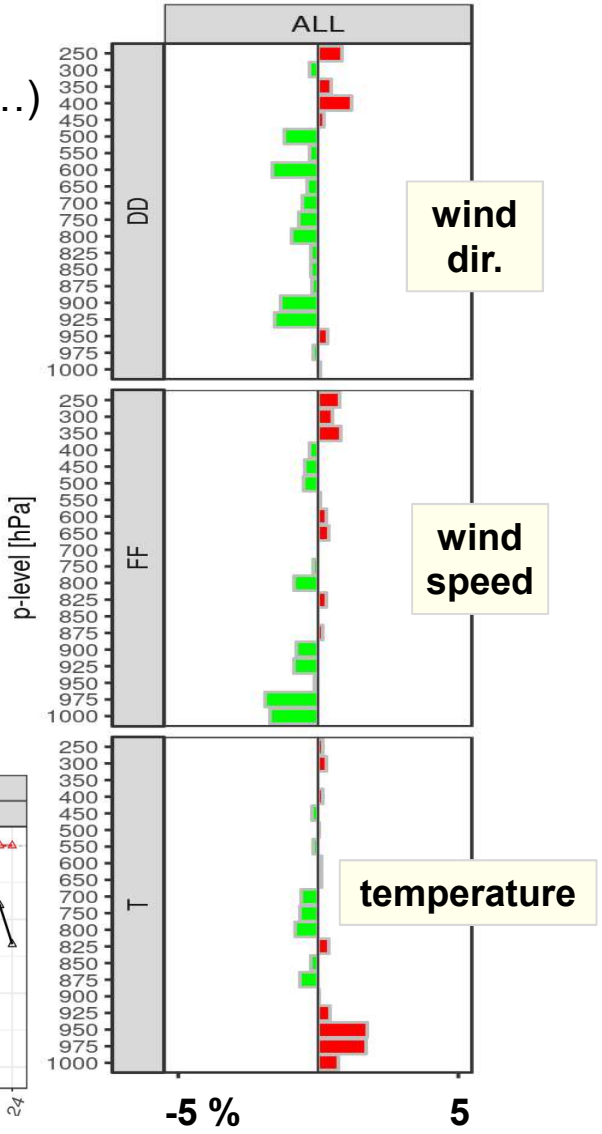
**aircraft** verification

EnVar vs. 4D-LETKF

change [%] of **RMSE**

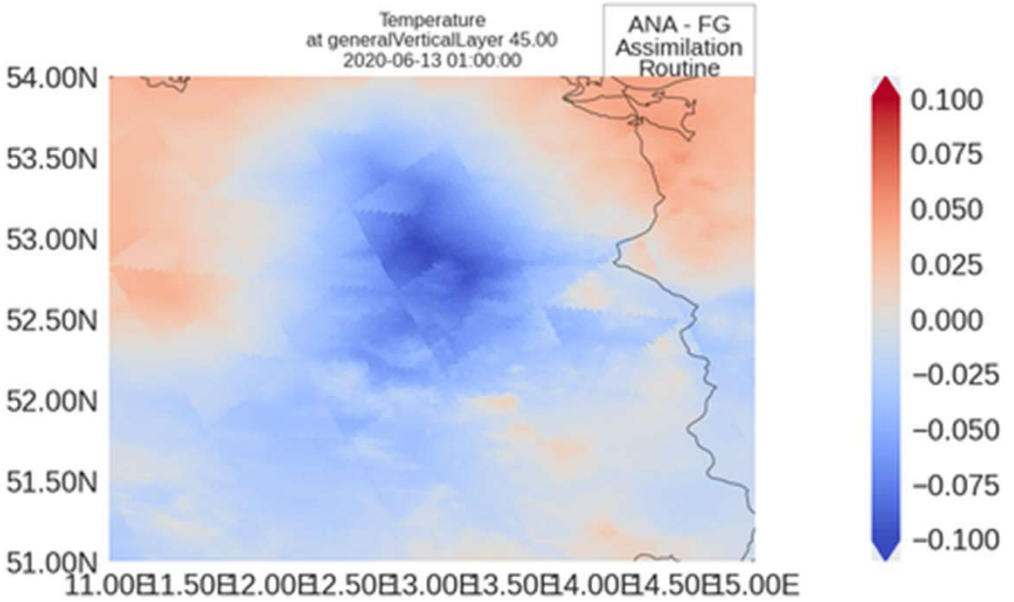


- **CEnVar** *(Sven Ulbrich, Mareike Burba, et al.)*
  - runs technically with ensemble-B from ICON-EU or ICON-global
    (complete model fields, or from fields cropped around target domain by ICONremap
    (can be afforded if certain fields precomputed))
  - interpolation of analysis increments from 40 km grid (resolution of global B-matrix)
    to 2 km LAM grid has shown artefacts (due to 'jumps' in selected 3 source grid points
    still visible in initialized analyses after IAU)

CEnVar analysis increments with B-matrix from global ICON EPS



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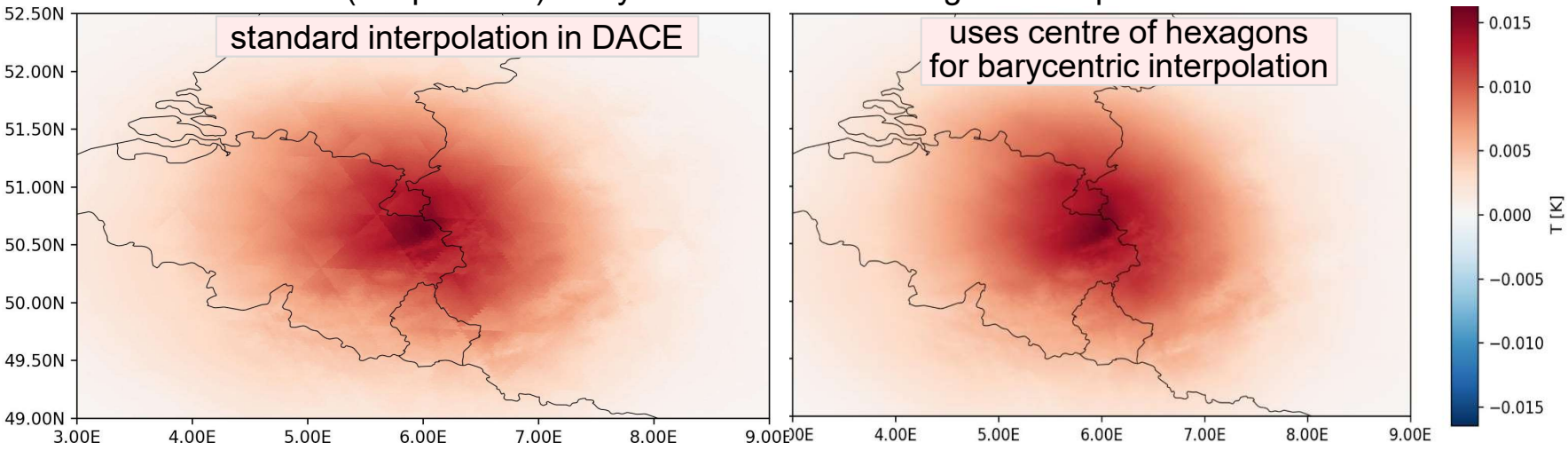
  - runs technically with ensemble-B from ICON-EU or ICON-global
    (complete model fields, or from fields cropped around target domain by ICONremap
    (can be afforded if certain fields precomputed))
  - interpolation of analysis increments from 40 km grid (resolution of global B-matrix) to 2 km LAM grid has shown artefacts …
    … avoided by an alternative scheme at negligible cost (uses virtual centre of hexagon as one interpolation source points for barycentric interpolation of resulting triangle)

(temperature) analysis increments for single-obs experiment



# Task 1.2: Variational DA (EnVar, CEnVar)

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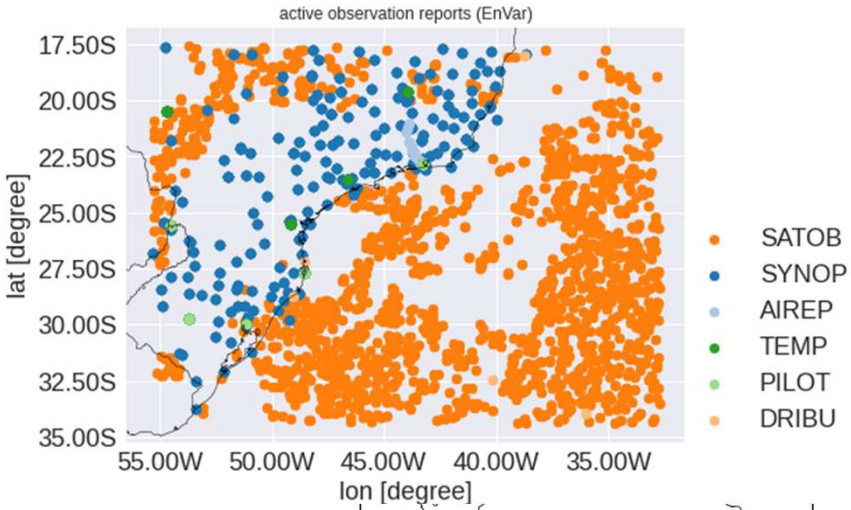
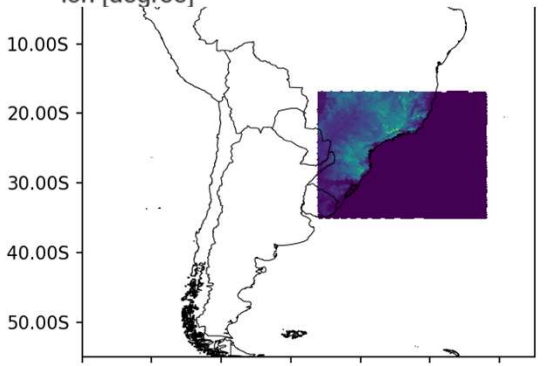
- **CEnVar**:
  - 6-day test South. Brazil (only few obs!)
    - CEnVar vs. 3DVar (global clim. B) far better
    - CEnVar vs. downscaler neutral




  - Romanian NMA domain / model fields:
    - testing at DWD:
      works with obs from DWD data base,
      and also with (hourly Synop) obs from NMA
    - ready for testing at NMA




  - full performance tests should be done by institutes that want to apply CEnVar on their own model domain

# Task 1.2: Variational DA (EnVar, CEnVar)

Deutscher Wetterdienst

- EnVar for operational KENDA
  - requires TL / AD of EMVORADO (in DACE!) (some work by Uli Blahak), SEVIRI VIS, …
  - cloud variables / hydrometeors currently not included in control vector of VAR
    → (e.g. CONTRAILS project): extend VAR to allow for use of cloud-related info
    (e.g. work on relation sub-grid var. qc_dia, qi_dia, clc to grid-scale var e.g. by ML, or ens. pert. X)

- Hybrid EnVar: aim to develop **regional** climatological B-matrix (no resources): really?
  → 3D-EnVar at Meteo-France pre-operational with pure ensemble B
  (info from radar meeting)

- DWD *(Stefanie Hollborn, Roland Potthast et al.)*
  4D-EnVar: EnVar, but with several time slices within assimilation window:
  - technical implementation ~ done
    - read ensemble at different time slices
    - first guess at appropriate time
    - ensemble B-matrix interpolated in time
    - post-multiplication with temporal weights
  - to be done: testing (incl. bug fixing), tuning, evaluation

## Particle Filter for ICON-LAM *(Nora Schenk, Anne Walter, Roland Potthast)*

- very little human resources for time being (Nora now on another project)
- presented at EWGLAM 2022, summary:
  - LMCPF able to show better results than LETKF for Lorenz 1996 model
  - LMCPF runs stably for ICON-D2 (8 days),
    but rmse of FG ensemble mean ~ 5 % larger than LETKF
  - LMCPF runs stably for ICON-global (months),
    skill (of ensemble mean) as good as LETKF (troposphere)
  - LMCPF ensemble spread smaller than with LETKF

## Task 2.1: 3-D radar

*(Kobra Khosravian, Klaus Vobig, Lisa Neef, Klaus Stephan, Uli Blahak et al.)*

- reflectivity: testing / adjustment to 2-moment microphysics (also model tuning!)
  investigating spin-up (mostly due to LHN)
- reflectivity: testing targeted covariance inflation:
  in areas with missing (insufficient) precip / spread → only new cells
- use of foreign radars :

  technically, 47 foreign radars (NL, BE, FR, CH, POL, CZ, DK) ready for operational use
  (reflectivity: all radars, radial velocity only partly (DK good, F, NL not so good))
  but need to specify / tune selection of elevation from each country (very heterogeous)

- WG1: assimilation of radar-derived objects / lightning / nowcast cell features / FSS (ongoing)
- WG1: use of dual-polarization moments (direct / hydrometeor mixing ratio retrieval)

## Task 2.2: ground-based GNSS Zenith / Slant Total Delay *(Michael Bender)*

- 'final' bug fixed to allow for **online** BACY DA experiments with ICON-D2
- first ICON-D2 experiments (June + July 2021 : old Mode-S, no SEVIRI VIS):
  - **no-GPS**: reference (no GNSS)
  - **ZTD**: (GPS-derived) ZTD only
  - **STD+ZTD**: ZTD + GPS-derived STD (low elevations < 25 deg only)
  - ZTD + GNSS-derived STD (2.5 * more STD's, incl. Galilei, Glonass)

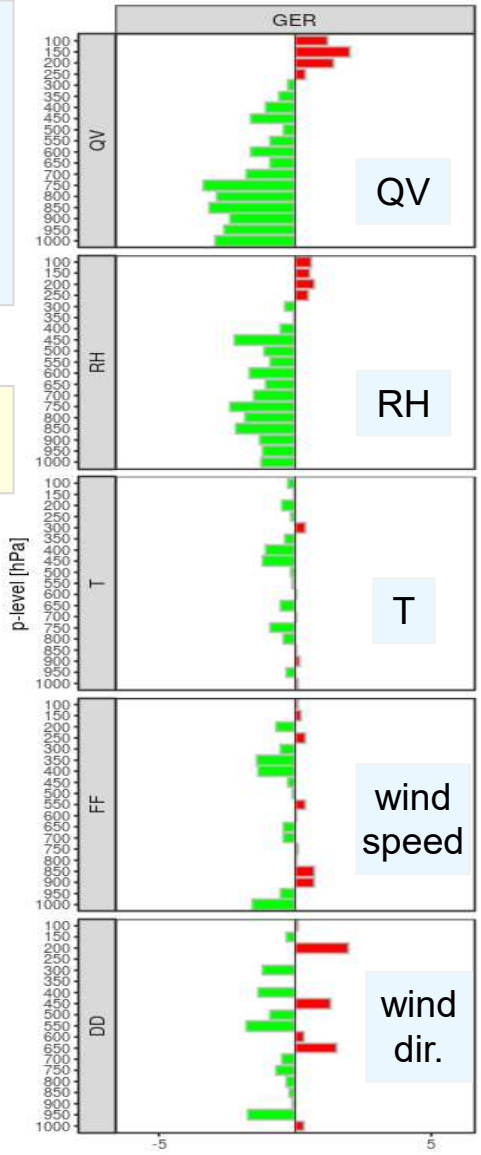
# Task 2: Observations (surface to clouds)

Deutscher Wetterdienst

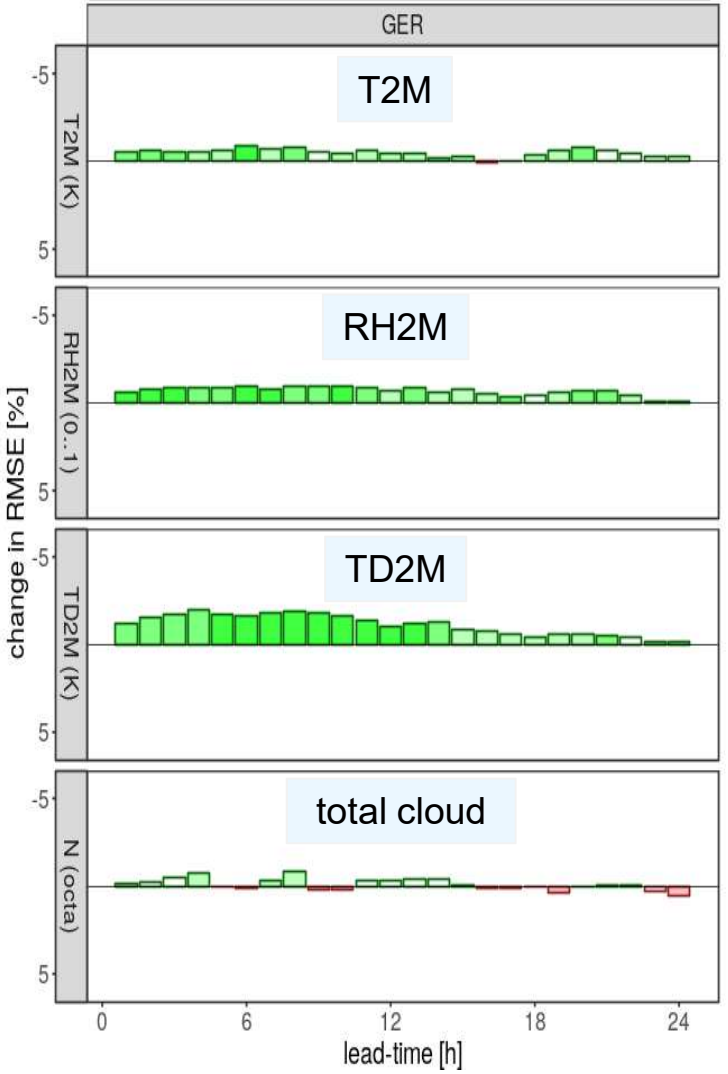
**ZTD vs. no-GPS**: change [%] of RMSE vs. radiosondes (Germany) averaged over 1 – **12 h**, 0, 6, 12, 18 UTC runs

07.06. – 31.07.2021

**ZTD better**
**no-GPS better**




RMSE vs. Synop (Germany)



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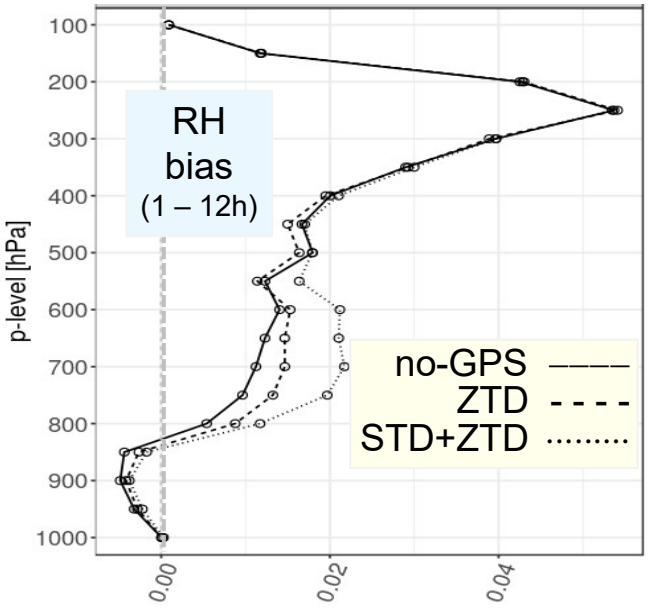
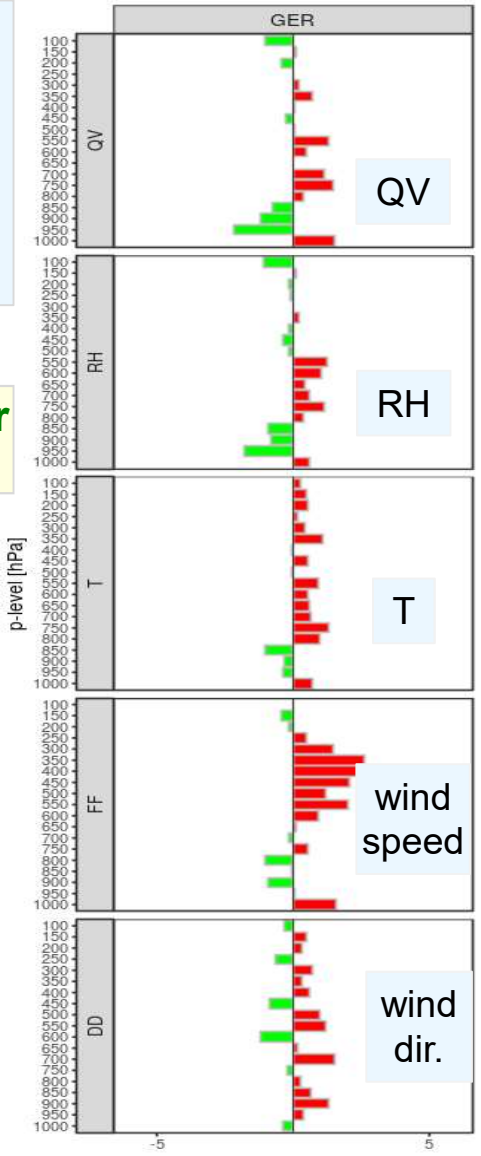
Deutscher Wetterdienst

**STD+ZTD vs. ZTD**: change [%] of RMSE vs. radiosondes (Germany) averaged over 1 – **12 h**, 0, 6, 12, 18 UTC runs

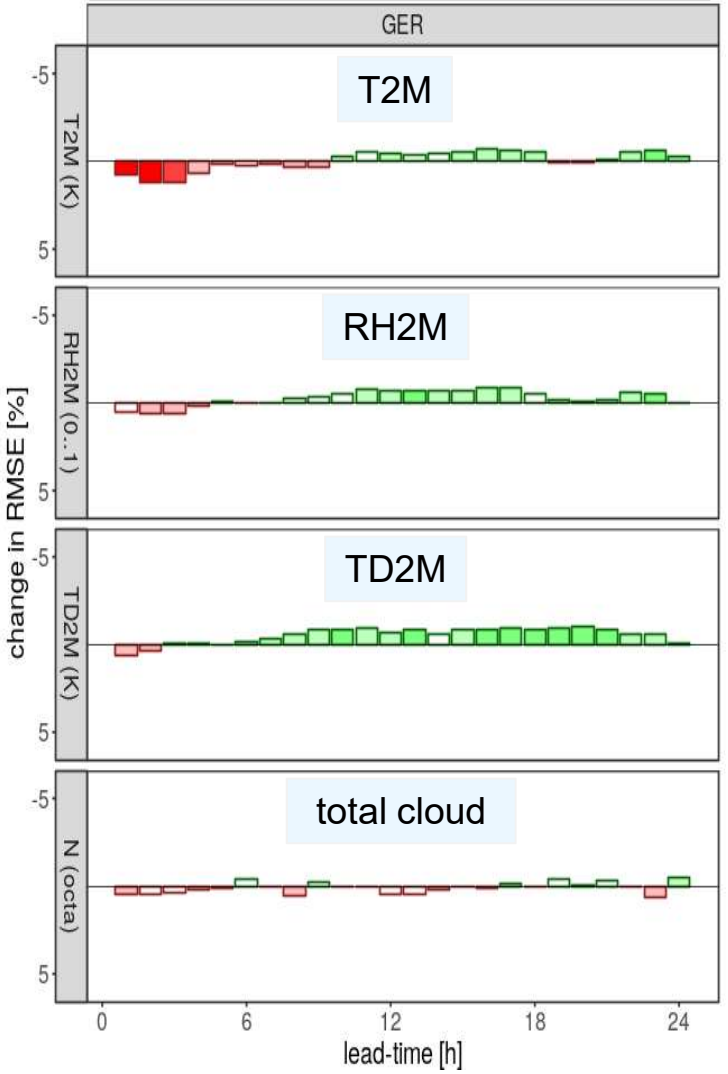
07.06. – 31.07.2021

**STD+ZTD better**
**ZTD better**




RMSE vs. Synop (Germany)



# Task 2: Observations (surface to clouds)

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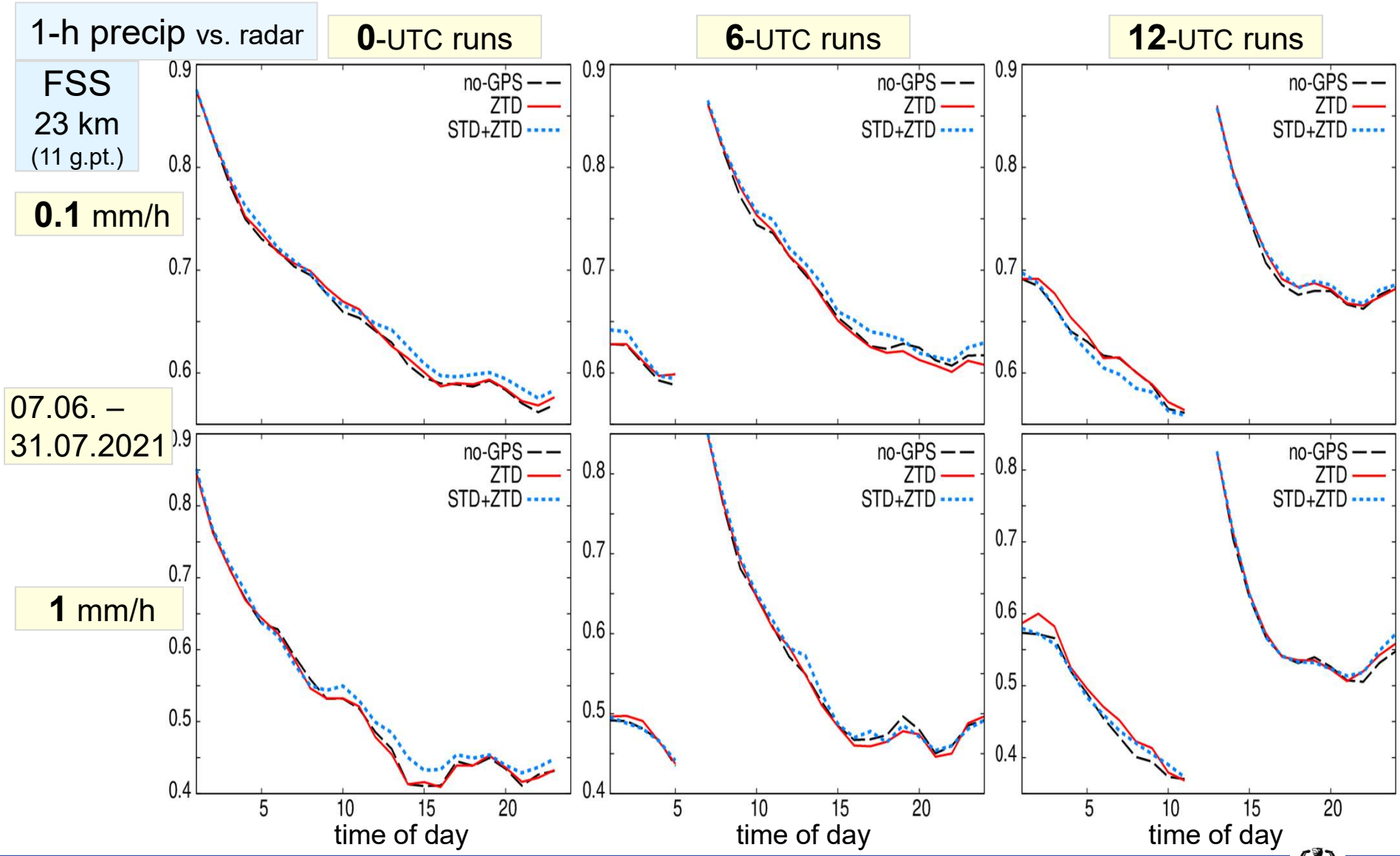

# Task 2: Observations (surface to clouds)

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- **ZTD** impact: positive on humidity (2 % up to 700 hPa, 1 % RM2M + up to 400 hPa)
  very slightly positive on temperature ( < 1 % T2M, upper-air T)
  ~ neutral on wind, precip, cloud, etc.

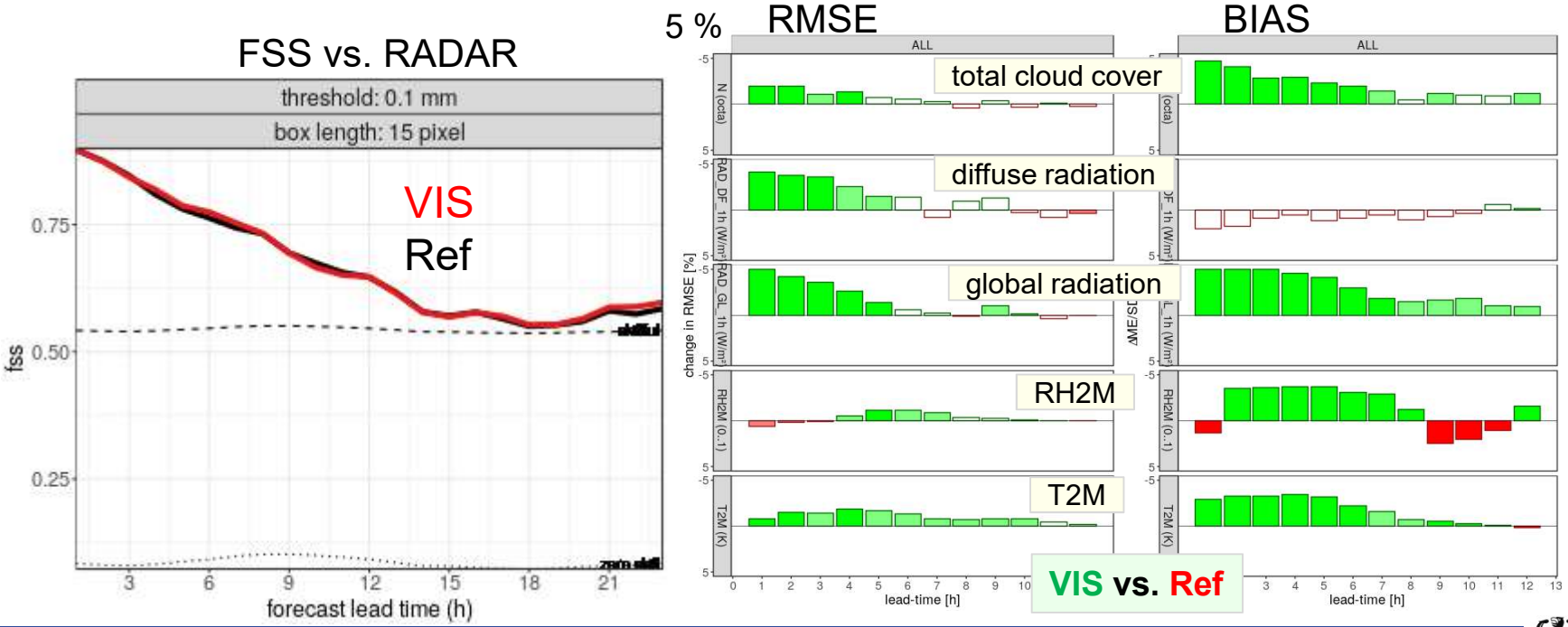
- additional low-elevation **STD**: small impact,
  slightly negative for upper-air wind + temperature,
  T2M, RH2M: slightly negative in first 6 hrs, slightly positive later on
  precipitation: slightly positive (0-, 6-UTC runs)

- technical: consolidate BACY adjustments, introduce into NUMEX

- further experiments (with VIS + WV rad., new Mode-S; also winter …?) +
  work on: obs error variances (online, using O–FG stats + GPS processing info),
  obs error correlations
  bias correction (elevation + azimuth bins)
  localization (info from FSOI tool)

## Task 2.3: all-sky (cloudy) IR + VIS SEVIRI radiances

- **VIS** channels: info on all clouds, incl. low clouds (but not on cloud top height) at daytime
  *(Lilo Bach et al.)*
  - latest experiment, ICON with LH of sub-grid cloud condensation, 12.05 – 11.06.2022
  - positive impact on cloud, radiation, 2-m temperature + humidity; upper-air neutral
  - precip neutral, no increase of negative bias



# Task 2: Observations (surface to clouds)

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- **VIS** channels: info on all clouds, incl. low clouds (but not on cloud top height) at daytime
  *(Lilo Bach et al.)*
  - **in Sinfony-RUC** since Oct. 2022
  - in ICON-D2 parallel suite since 9 Dec. 2022 (extra cost ok)
  - monitoring of SEVIRI VIS set up in global DA system (in NUMEX exp. for time being)
  - **operational** since 15 March 2023:
    - ✓ **first time in KENDA**: use of **satellite** data (except clear-sky rad. at COMET)
    - ✓ first time at **DWD**: use of **cloudy** satellite data
    - ✓ first time **internationally**: use of **visible** channel data
  - future steps
    - combination with (SEVIRI) WV channels
    - preparation for VIS of FCI @MTG
    - further visible + near IR channels

- **IR WV** (water vapour) channels: info on WV + clouds in mid- to upper troposphere

  *(Annika Schomburg et al.)*

  – joint online processing of WV + VIS implemented in ICON-DACE coupling

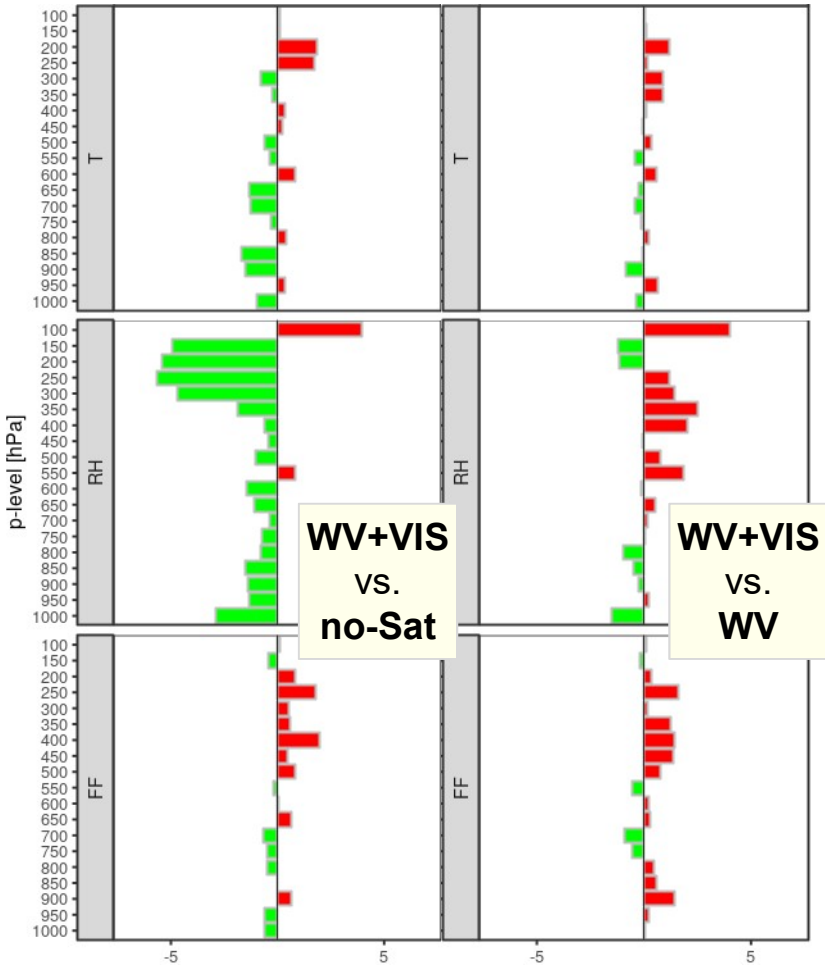
  – tuning experiments for combined use of WV + VIS:

  best results with thinning 4 x 2 grid pts, 25 km localisation for all channels
  (instead of superobbing 4 x 2 g.p, / 35 km for VIS)

  – 1 – 22 June 2021:
  WV + VIS still worse than
  WV above 500 hPa

  (VIS (w/o vertical localisation) appear to negatively affect impact of WV at high levels)

change [%] of RMSE, averaged over
**1 – 24 h**, 0-, 6-, 12-, 18- UTC runs



- **IR WV** (water vapour) channels: info on WV + clouds in mid- to upper troposphere

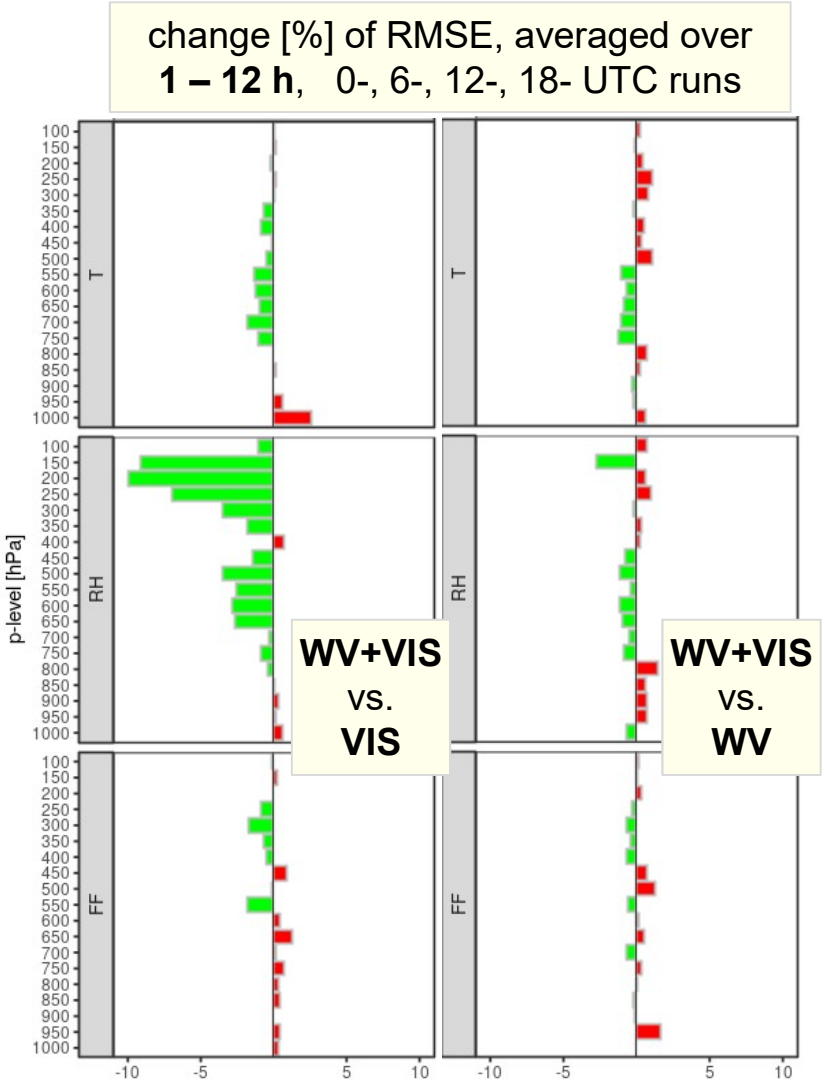
  *(Annika Schomburg et al.)*

  – tuning experiments for combined use of WV + VIS: vertical localisation for VIS fixed at 800 hPa

  – 15 Aug. – 12 Sept. 2022

  (new Mode-S, ICON with latent heating from subgrid-scale condensation, operational VIS (superobbing …) = ref)

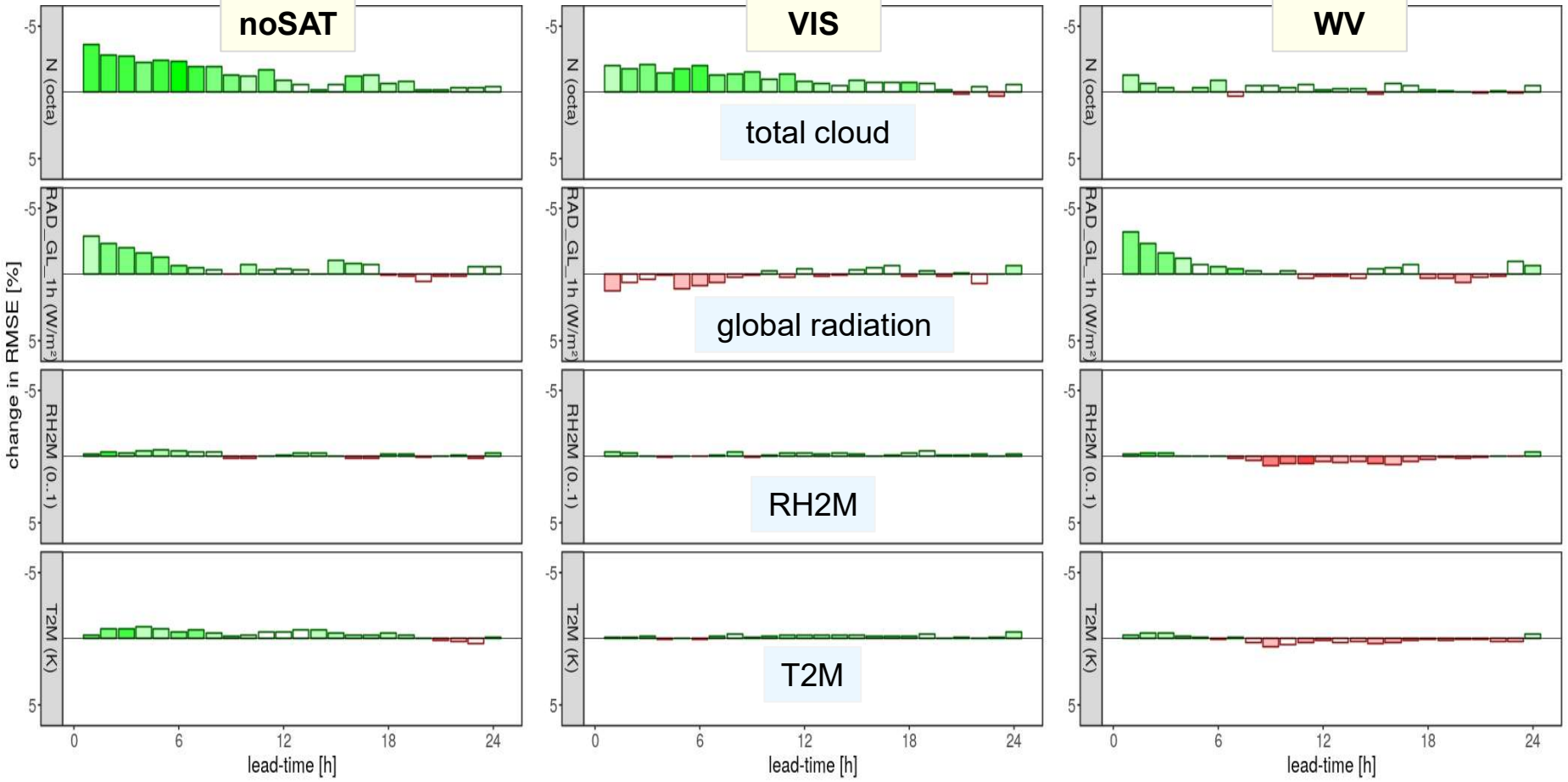
  WV + VIS as good as WV !



# Task 2: Observations (surface to clouds)

Deutscher Wetterdienst

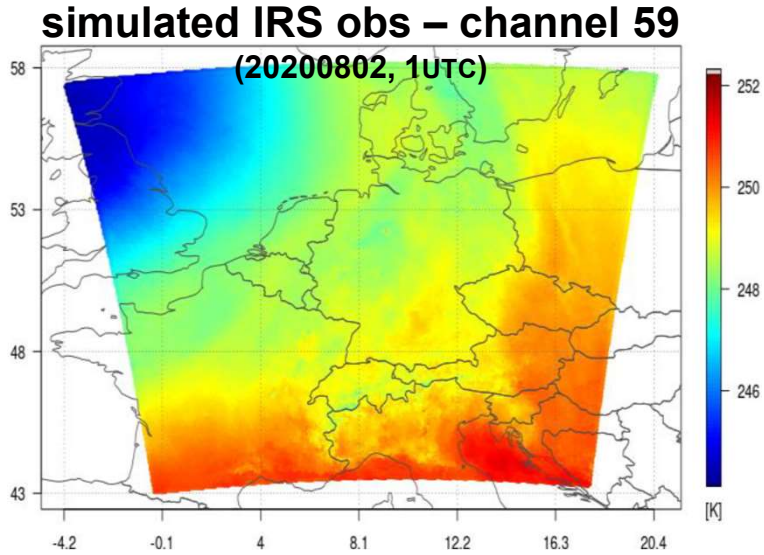
**WV+VIS** vs. **noSAT** | 0-, 6-, 12-, 18- UTC runs | **WV+VIS** vs. **VIS** | **WV+VIS** vs. **WV**




- extra benefit VIS: surface radiation
- extra benefit WV: upper-level QV + total cloud cover (high cloud slightly worse in new exp.)

## Task 2.4: MTG IRS (Meteosat Third Gen. hyperspectral IR Sounder)

*(Mahdiyeh Mousavi, Christina Köpken-Watts, DWD)*




- simulated IRS ‚obs' (with RadSim) into fdbk file
- EnVar-global tecnhical end-to-end test:
  DA of simulated obs ok, + applying monitoring tools
- working on skin temperature retrieval
  from very low peaking channels
  (similar to emissivity retrieval for MW channels), to be
  applied then for assimilated channels (in LETKF)
- implementing **land** IR-emissivity Atlas & using IASI obs over land (as IRS proxy for DA exp.)
- LETKF being extended for use of non-diagonal obs error covariance R
  with inter-channel correlations
- soon: prerequisites available to start meaningful DA experiments (with simulated obs)
- important aspects: slant radiative transfer, 4D-EnVar (for indirect wind info),
  horiz. obs error correlations (for use of obs at high resolution)

## Task 2.5: 2-m Temperature + Humidity

- operational for ICON (DWD, COMET) and COSMO (MeteoSwiss) without bias correction due to strong positive impact
- no further work on bias correction (at least) until Elisabeth is back to work (~2023)

## Task 2.6: ground-based PBL profile obs

- MW Radiometer, wind lidar: talk by Jasmin Vural
- generally: if only 1 station (MWR, wind lidar) available for DA:
  - verification results (e.g. vs. Lindenberg radiosonde) often not statistically significant even in 3-month experiment
  - experience: difficult to discriminate betw. signal and noise in verification

## Task 3.1: Soil moisture analysis using **satellite soil moisture data**

*(Valerio Cardinali, Francesca Marcucci, COMET)*

- no further work (no impact so far)

## Task 3.3: **Sea Surface Temperature** (SST) analysis

*(Gernot Geppert, Martin Lange, Thomas Hüther, DWD)*

- "**omniVAR**": flexible (at present 2-D)-variational analysis in DACE:
  - core of code developed, for plain 2D-Var
  - to be adapted to SST analysis (needs to account for land/sea mask)

  → April 2023: SST analysis technically ready and tested with full set of obs