Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Adaptive parameter tuning

Improving uncertain model parameters by indirect usage of data assimilation

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Idea

- **Data assimilation (DA) usually pertains to the prognostic variables of a model and tries to provide an optimal synthesis between the first guess (previous forecast) and the assimilated observations**
- **The idea behind adaptive parameter tuning (APT) is to make – in addition – indirect use of DA in order to optimize uncertain parameters of a model, in particular physical property fields that need to be derived from external parameter data**
- **Reference:** https://doi.org/10.1002/qj.4535
- **The most important components were introduced into operational NWP at DWD during 2022; gradual improvements / extensions afterwards**

Special acknowledgements to my colleagues Harald Anlauf and Hendrik Reich for their related work in data assimilation

Motivation

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- ➔ Near-surface model biases are strongly affected by uncertain physical properties of vegetation and soil (e.g. stomata resistance, heat conductivity) as well as model tuning parameters
- ➔ Physical properties are usually derived from external parameter data (land-cover and soil-type classification, ...), which may not cover the full heterogeneity that exists in nature
- ➔ This typically leads to ambivalent results when trying to tune parameters (better in some regions, worse in others)
- ➔ To some extent, this kind of systematic errors can be reduced by APT, provided that there is a strong relationship between a model bias and an uncertain parameter

Methodology

- ➔ Forecast variables targeted for adaptive optimization: T2M, RH2M, FF10M
- ➔ Time-filtered data assimilation increments for temperature, humidity and wind speed at the lowest model level are used as proxies for the model bias / predictors for adaptive optimization (default filtering time scale 2.5 days)
- ➔ This obviously requires assimilation of T2M, RH2M and FF10M data
- ➔ In principle, using offline analyses for T2M etc. would be possible as well, but taking the existing assimilation increments is preferred for the sake of simplicity

Methodology

Model parameters selected for adaptive optimization

- ➔ **T2M/RH2M: stomata resistance of plants, minimum evaporation resistance of bare soil, hydraulic diffusivity of (near-surface) soil, soil moisture in dry regimes for which our soil-moisture analysis has deficits**

  Implemented but not used operationally: full soil-moisture adjustment
- ➔ **T2M diurnal amplitude: soil heat capacity, heat conductivities of soil and skin layer, near-surface profiles of minimum vertical diffusion coefficient**
- ➔ **T2M in the presence of snow cover: snow and sea-ice albedo, tuning factor in diagnosis of snow-cover fraction**
- ➔ **FF10M: vegetation roughness length, SSO blocking tendency at lowest model level**

A-priori knowledge about the relationship between uncertain parameters and related model biases is essential.

Implementation details

Basic formula for filtered increments:
simple Newtonian relaxation approach

$$\psi_{\mathrm{fi}}(t) = \psi_{\mathrm{fi}}(t - dt_{\mathrm{ana}}) + \frac{dt_{\mathrm{ana}}}{dt_{\mathrm{filt}}}[\psi_{\mathrm{i}}(t) - \psi_{\mathrm{fi}}(t - dt_{\mathrm{ana}})], \quad (1)$$

where ψ represents T, wind speed FF, or relative humidity RH, and subscripts i and fi signify analysis increments and filtered increments respectively; t is the validity time, $dt_{\mathrm{ana}} = 3\,\mathrm{hr}$ is the analysis interval (1 hr for ICON-D2), and $dt_{\mathrm{filt}} = 2.5\,\mathrm{days}$ is the filtering time-scale.

Cosine-weighted temperature increments:
proxy for diurnal cycle bias of T2M

$$T_{\mathrm{wfi}}(t) = T_{\mathrm{wfi}}(t - dt_{\mathrm{ana}}) + \frac{dt_{\mathrm{ana}}}{dt_{\mathrm{filt}}} \times \left[T_{\mathrm{i}}(t)\cos\left(\frac{2\pi}{86{,}400}t_{\mathrm{loc}}\right) - T_{\mathrm{wfi}}(t - dt_{\mathrm{ana}})\right], \quad (2)$$

where t_{loc} denotes local time (in seconds) at a given model grid point. The sign convention is such that negative values of T_{wfi} correspond to an underestimated diurnal temperature amplitude.

The time-filtered assimilation increments are assumed to be proportional (with opposite sign) to the model bias in a free forecast. To the extent that this assumption is valid, they can be taken as a predictor for APT.

Implementation details

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For surface friction, the formulation that was found to provide the best results is given by

$$f_{sf} = \frac{1}{1 + 2.5 f_{ai} FF_{fi}} \quad (3)$$

for negative FF_{fi} and

$$f_{sf} = 1 - 2.5 f_{ai} FF_{fi} \quad (4)$$

for positive FF_{fi}

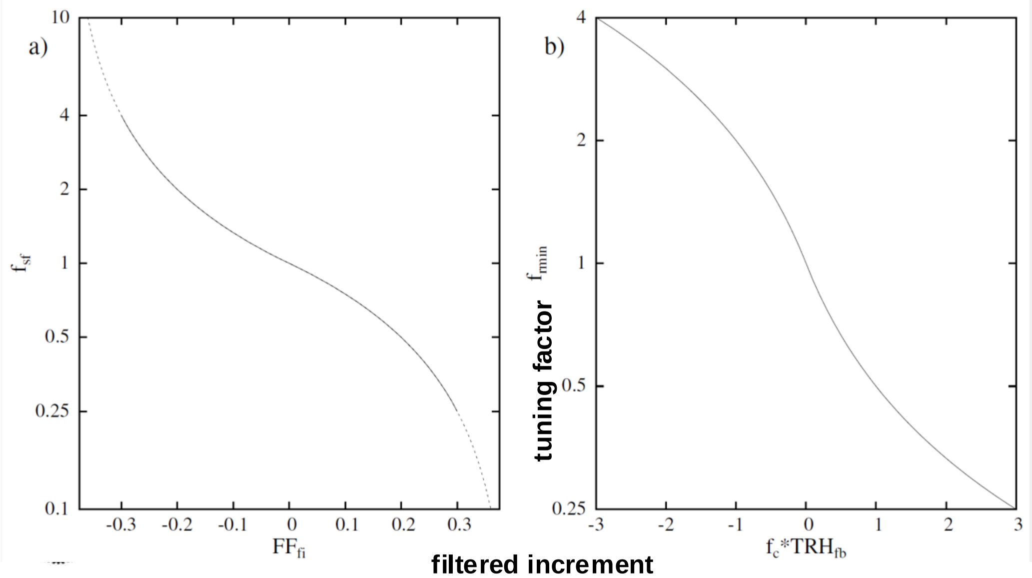
Based upon TRH_{fb}, the minimum evaporation resistances of bare soil and plant stomata, $rmin_{bs}$ and $rmin_{pl}$ are modified with the multiplicative factor

$$f_{rmin} = \frac{1}{1 + f_c TRH_{fb}} \quad (6)$$

for positive TRH_{fb} and

$$f_{rmin} = 1 - f_c TRH_{fb} \quad (7)$$

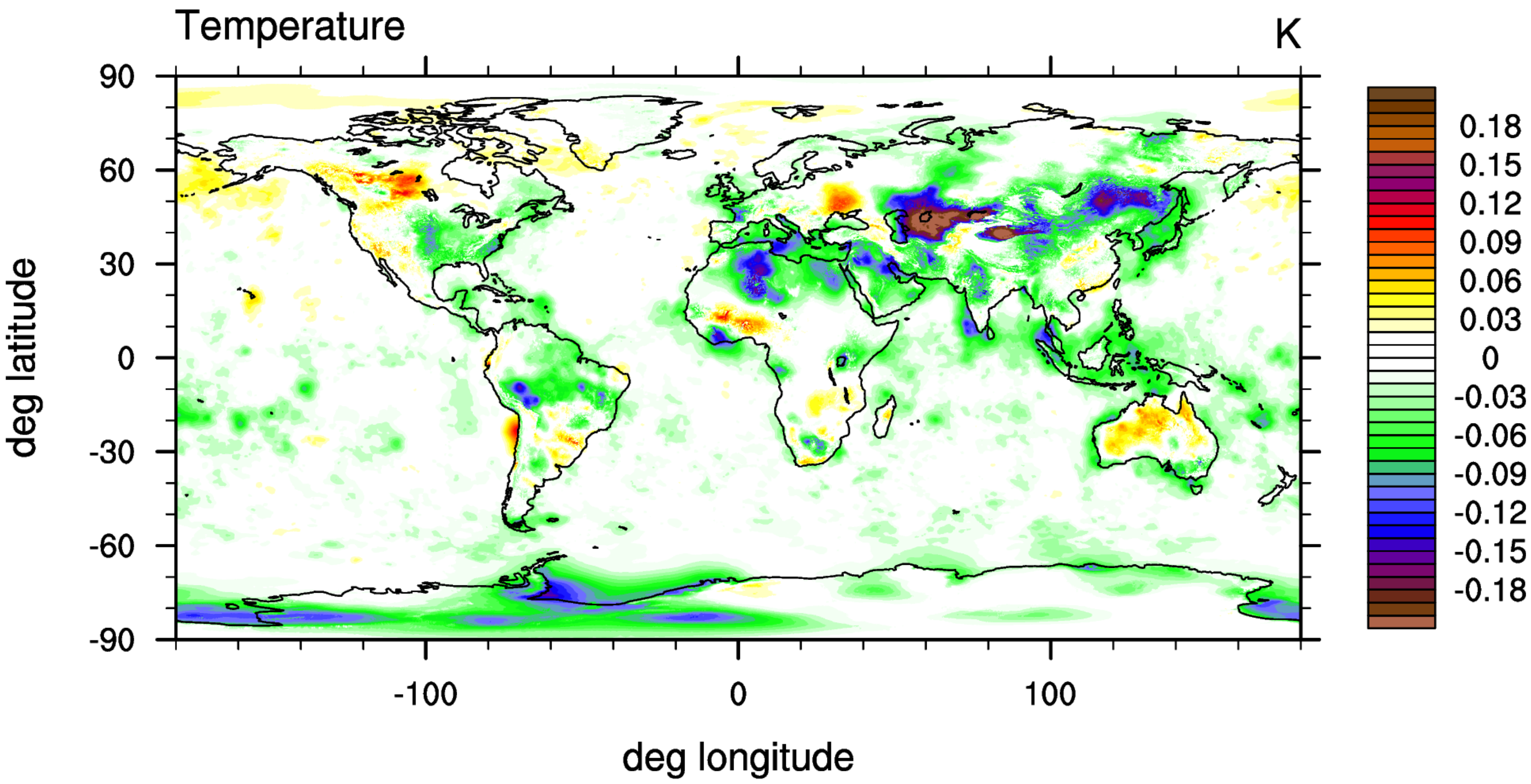
for negative TRH_{fb}



Based upon the time-filtered assimilation increments, the selected uncertain model parameters are varied around their default value (derived from external data) using a force-restore approach with multiplicative factors.

A filtered increment of zero implies that the parameter attains its original value. There is no permanent modification as in LETKF-based approaches tested in other studies.

For illustration: time-filtered COS-weighted assimilation increment for temperature



Average over November 2020

negative values correspond to an underestimated diurnal temperature amplitude;

the filtered 3-hourly assimilation increment typically has about 1/4 the amplitude of the model bias (with model-DA coupling)

The same without APT ...

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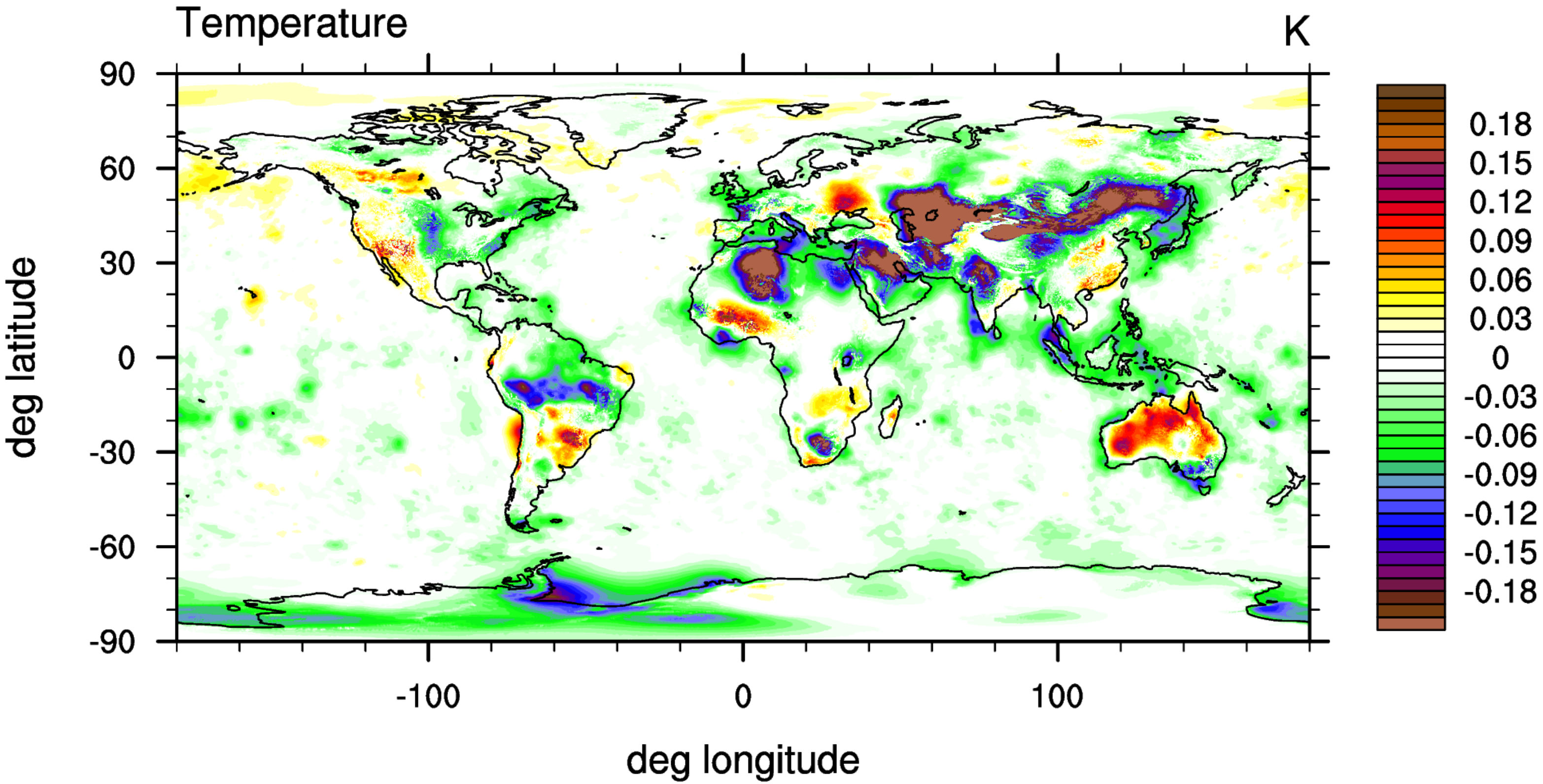

Average over November 2020

negative values correspond to an underestimated diurnal temperature amplitude

Corresponding Bias/RMSE, Central Asia

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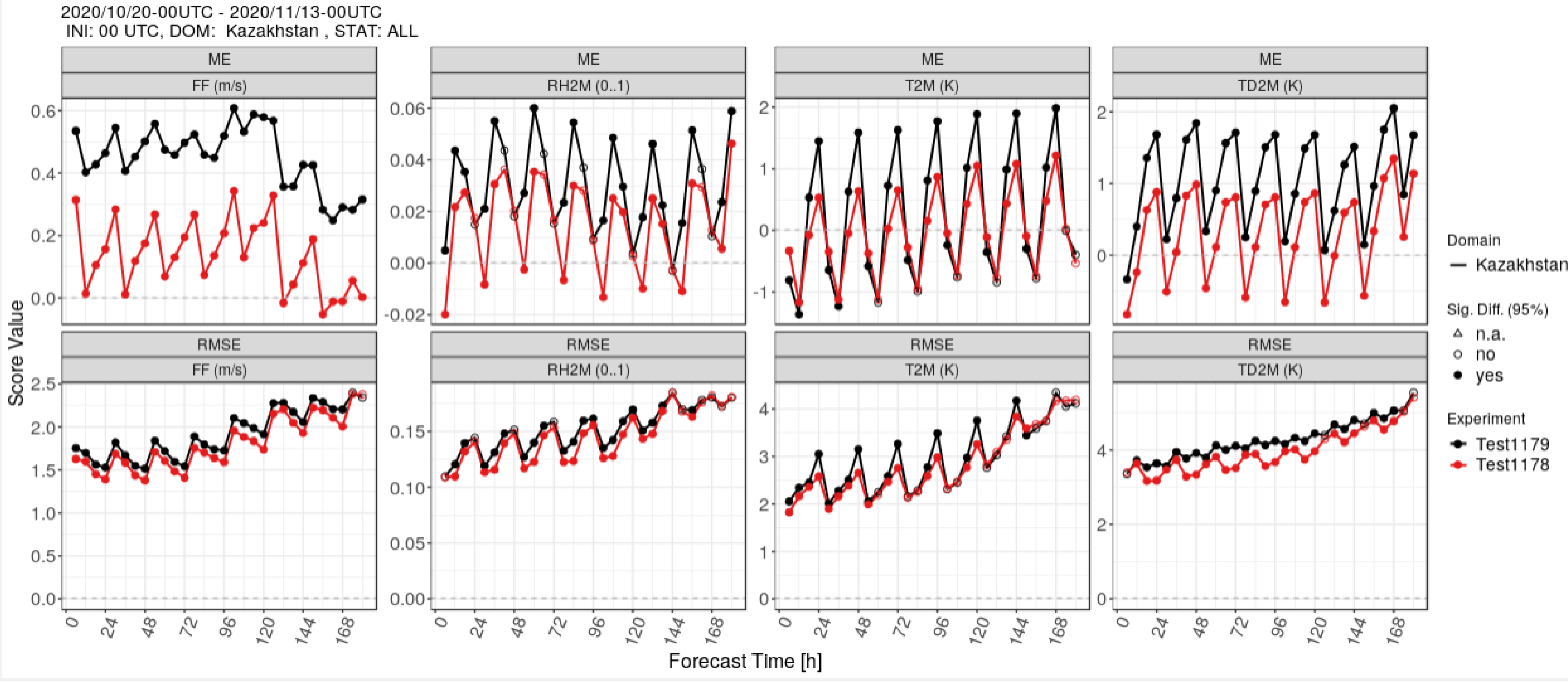
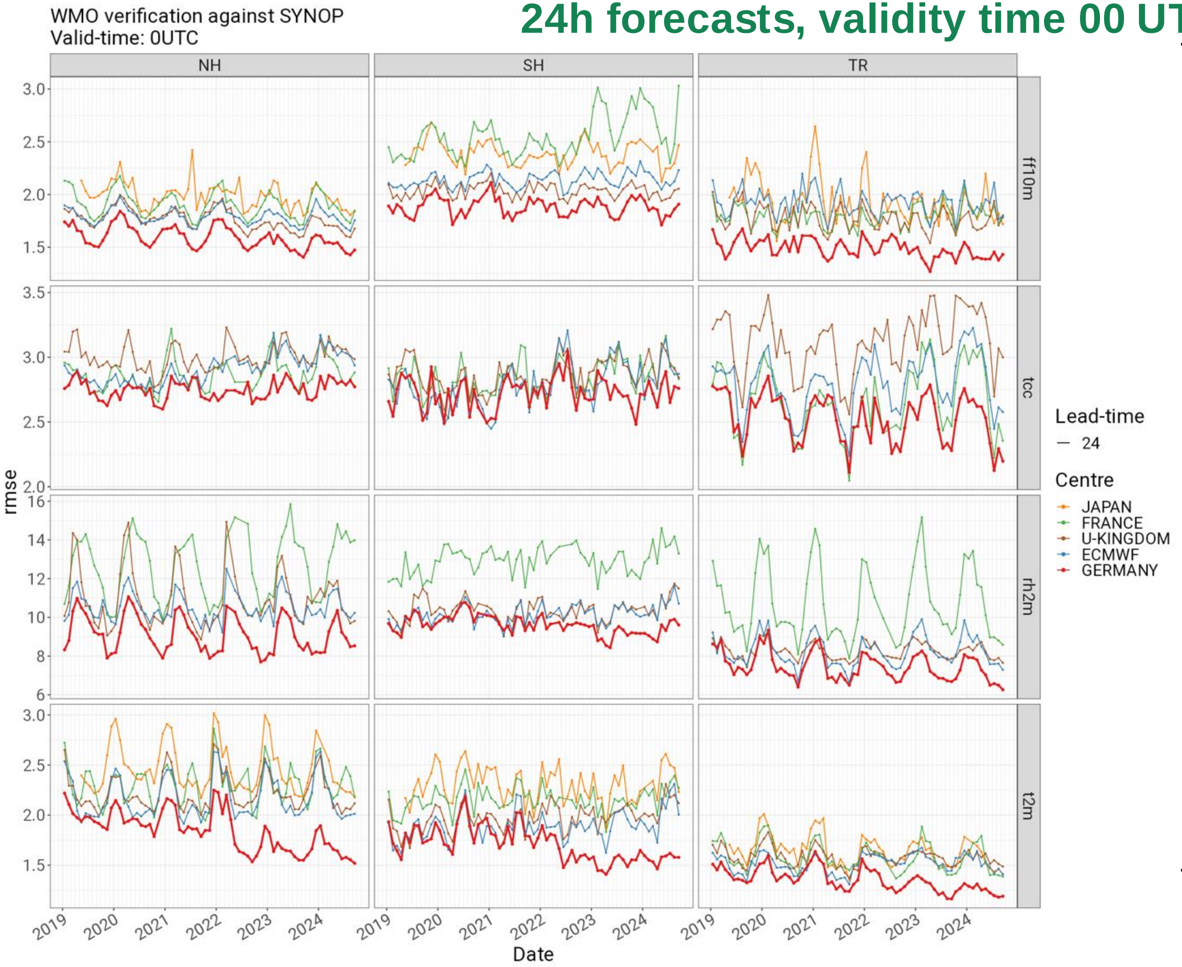
no APT APT for T2M, RH2M, FF



WMO (WGNE) intercomparison for SYNOP scores

24h forecasts, validity time 00 UTC



10m wind speed

cloud cover

2m humidity

2m temperature

DWD

ECMWF

UKMO

JMA

Météo France

Summary

- → **The APT approach developed for DWD's ICON modeling system allows reducing systematic forecast errors related to poorly known external parameter data / physical properties derived therefrom**
- → **Particularly at short lead times, APT led to a marked improvement of DWD's SYNOP verification scores**
- → **ICON-D2 (central-European LAM) exhibits similar benefits as the global system, and for FF10M, they are even larger than in the global system over the same region**
- → **Caveat: our approach requires a local relationship between a given model bias and the responsible uncertain parameter(s)**
- → **For instance, it does not work for tuning the SSO scheme**

Additional slides

Results

- As just mentioned, APT was introduced into our operational system in several steps, and adaptive surface friction was combined with new orography data and a resolution upgrade
- To demonstrate the isolated effect of APT on forecast skill, an experiment for autumn 2020 was repeated without APT
- In addition, results for the preparatory (parallel routine) phases for the main upgrade steps will be shown

Scorecard for SYNOP verification, T2M assimilation and related APT components

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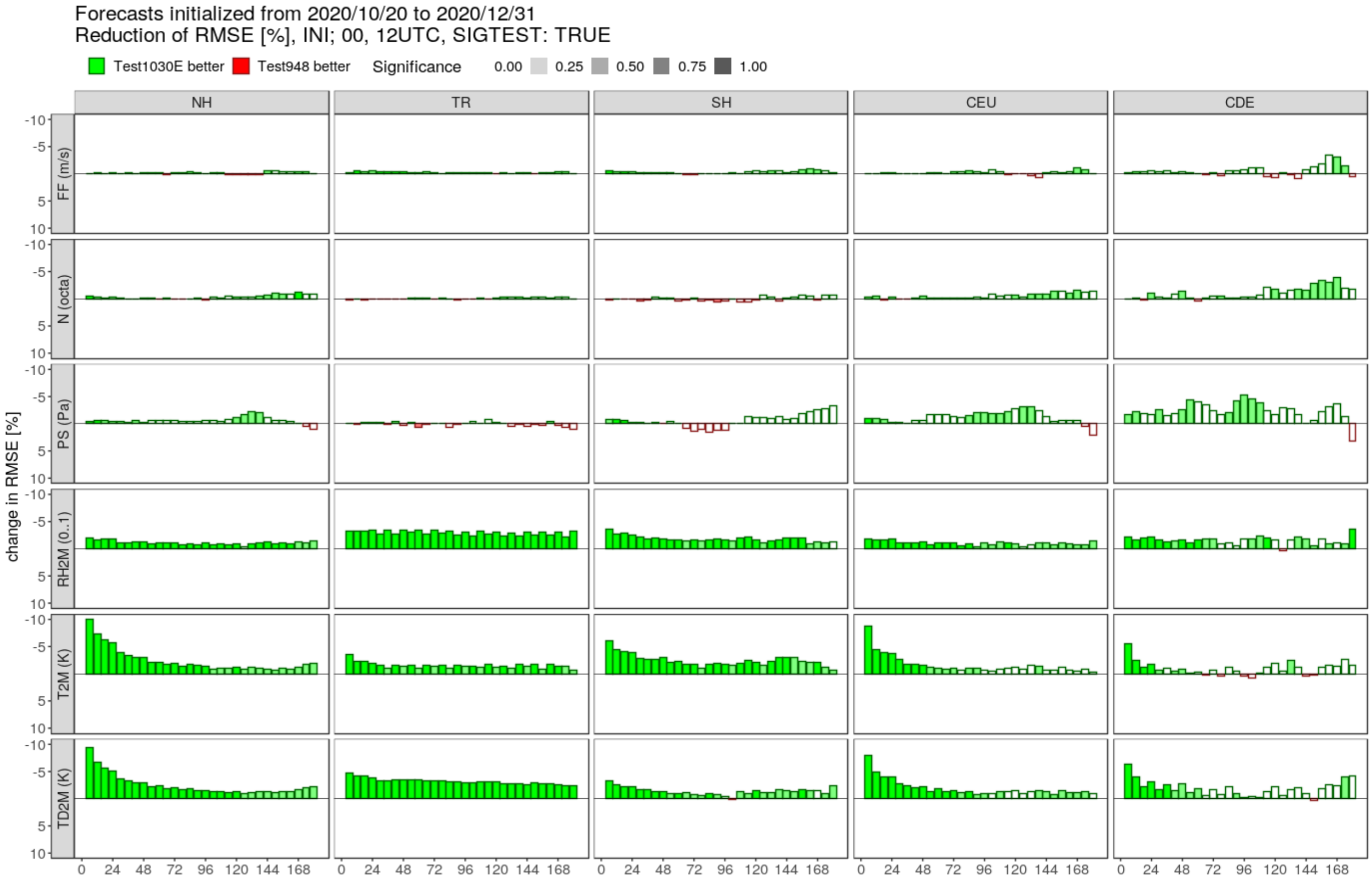

wind speed

cloud cover

surface pressure

2m humidity

2m temperature

2m dewpoint

Scorecard for SYNOP verification, adaptive surface friction and orography+resolution upgrade

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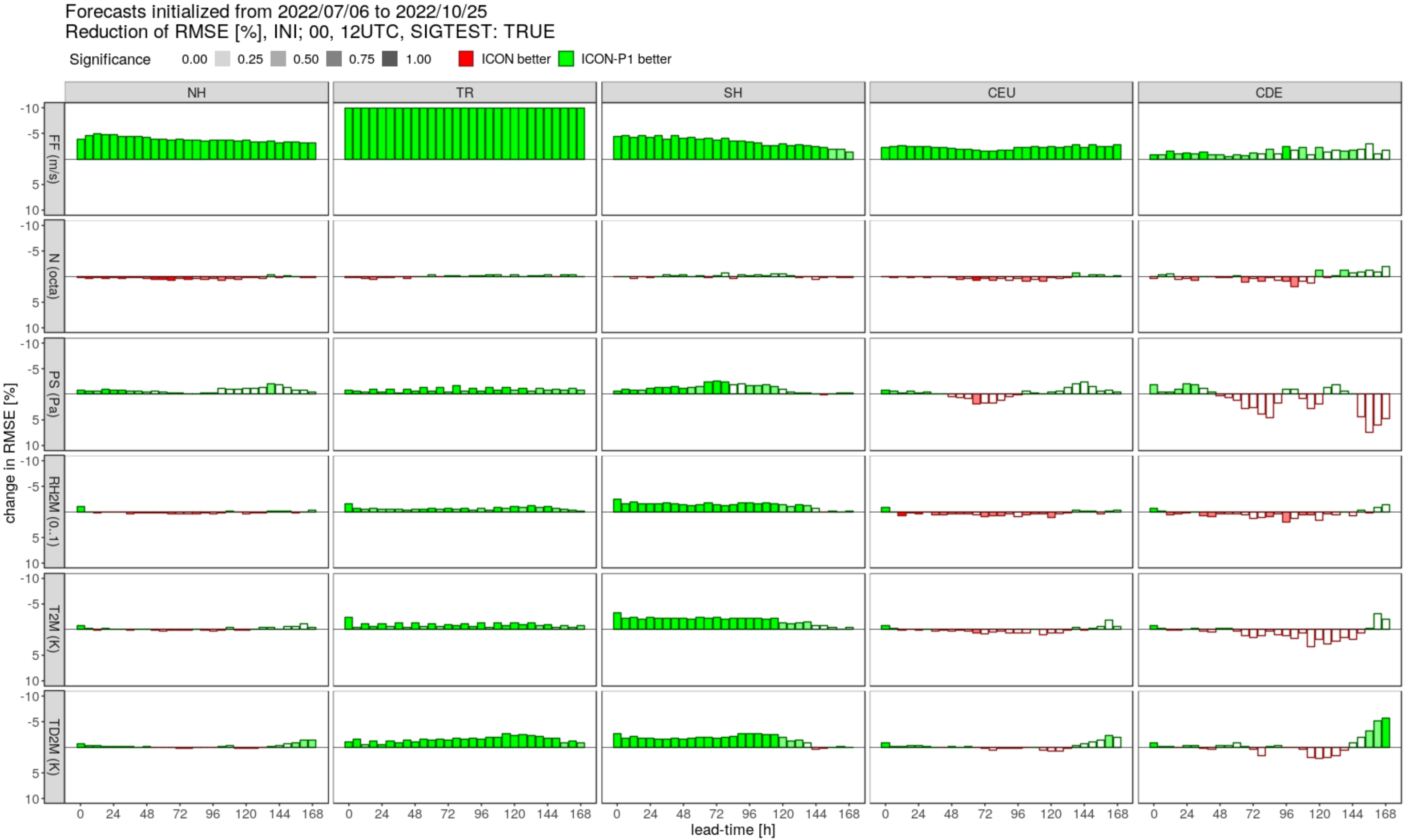


wind speed

cloud cover

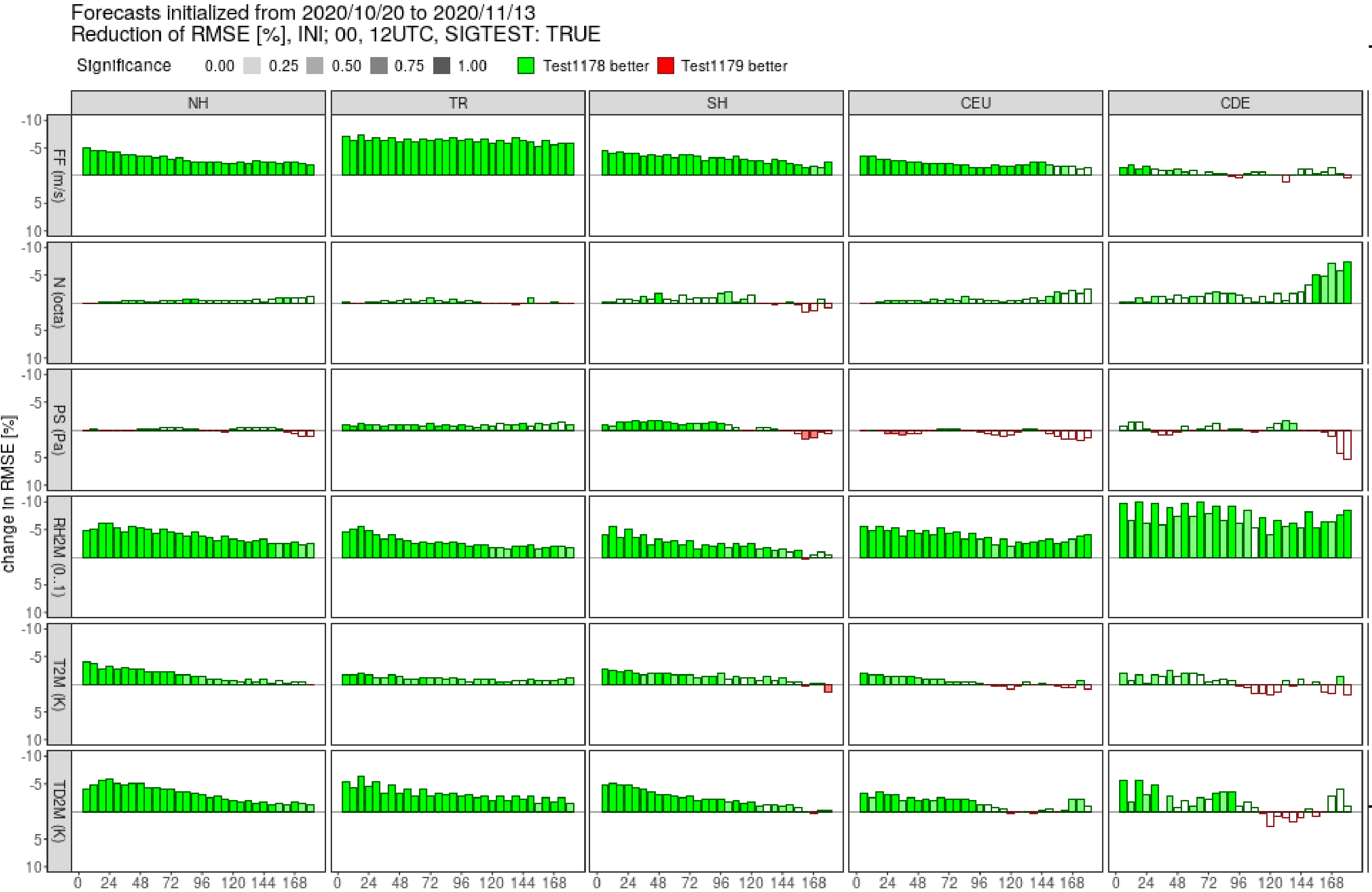
surface pressure

2m humidity

2m temperature

2m dewpoint

Scorecard for SYNOP verification, benefit from full APT when starting from same analyses



wind speed

cloud cover

surface pressure

2m humidity

2m temperature

2m dewpoint

Radiosonde verification, NH, Europe, North America, Asia

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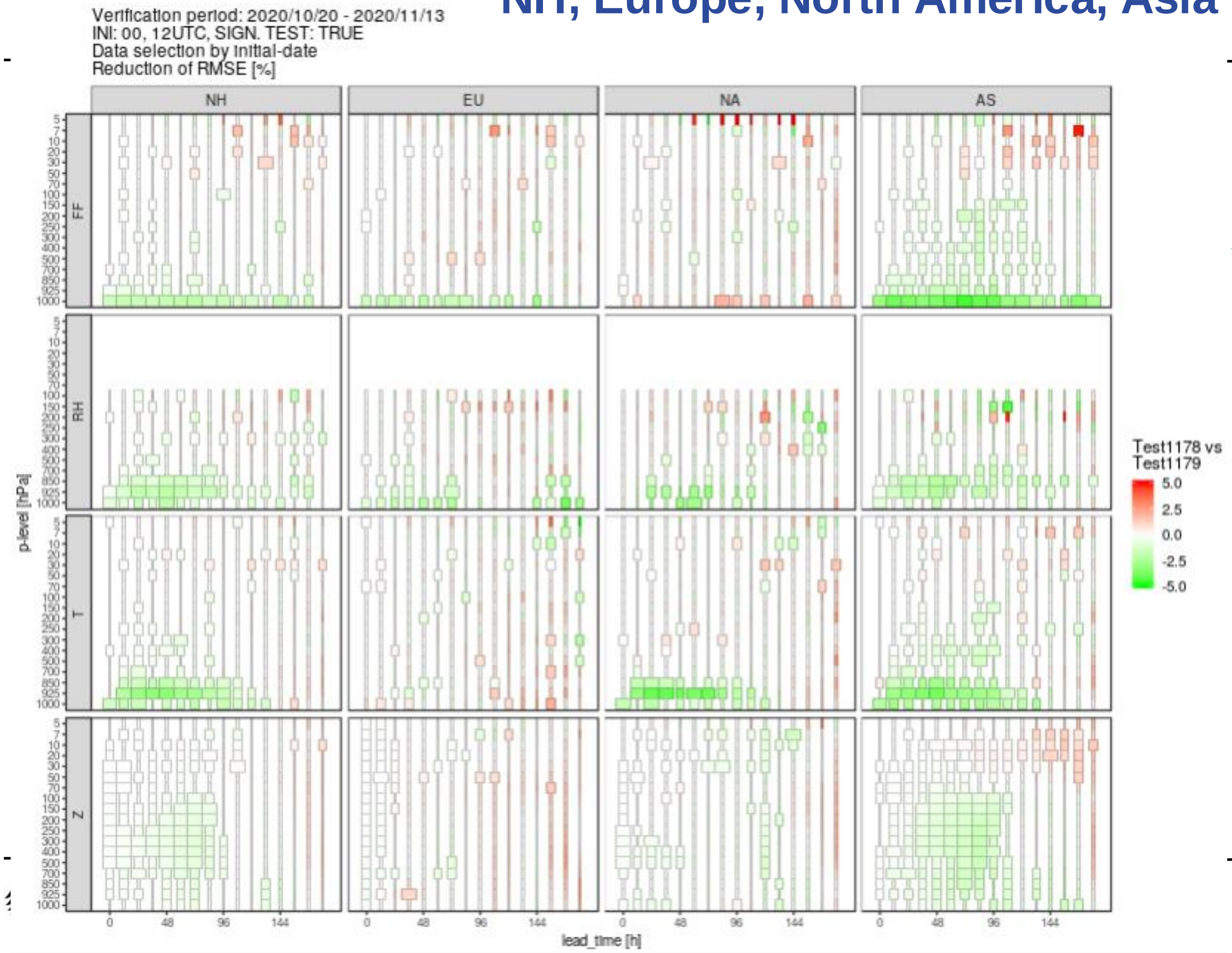

filled boxes: significant at 95% level

The score improvements in the lower troposphere give confidence that the model-DA coupling corrects true biases, not representativity errors of surface stations

ICON-D2 (LAM configuration for central Europe), March 2022

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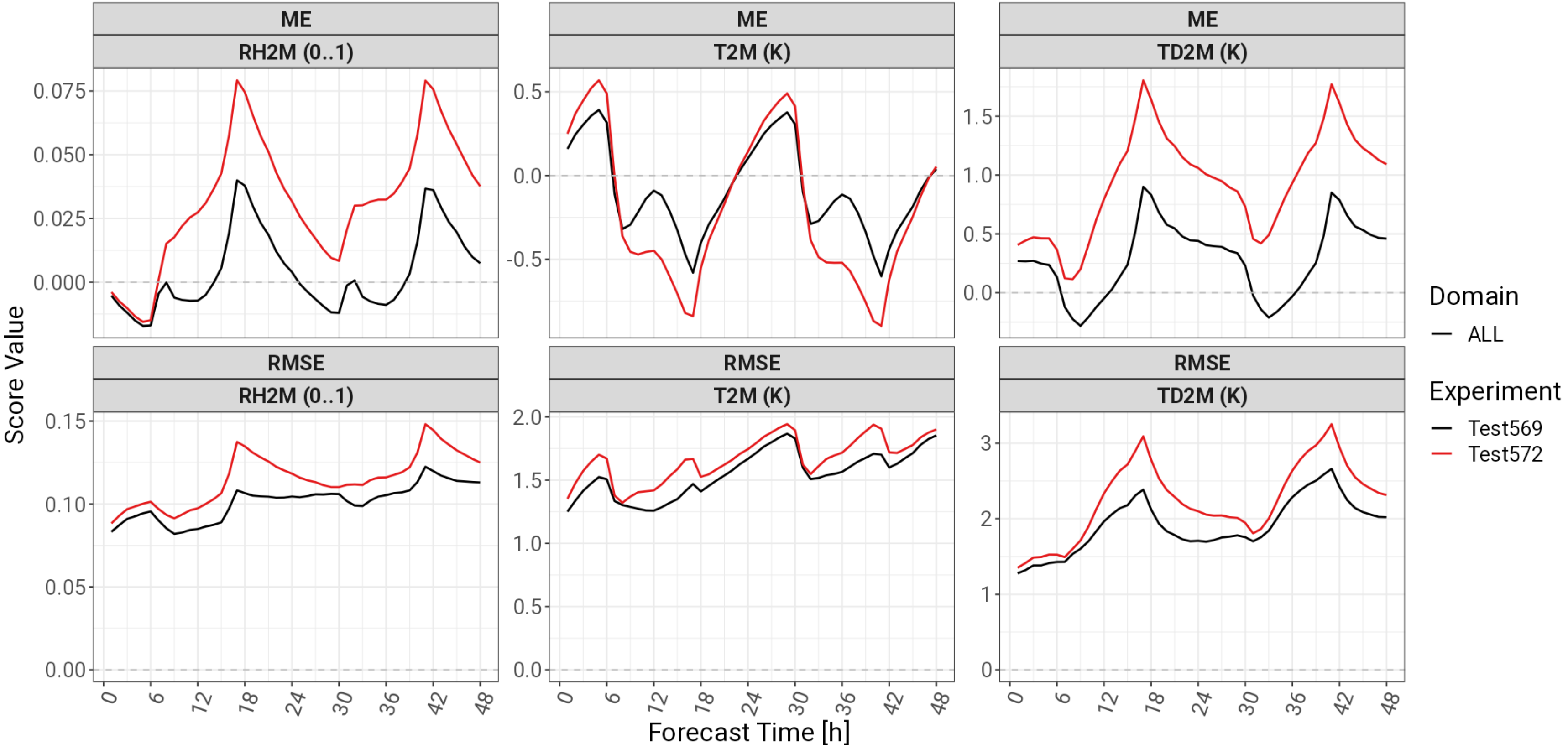
2022/03/01-00UTC - 2022/04/02-15UTC
INI: 00 UTC, DOM: ALL , STAT: ALL

APT for T2M and RH2M **no APT**



Adaptive surface friction in ICON-D2, Jan/Feb 2023

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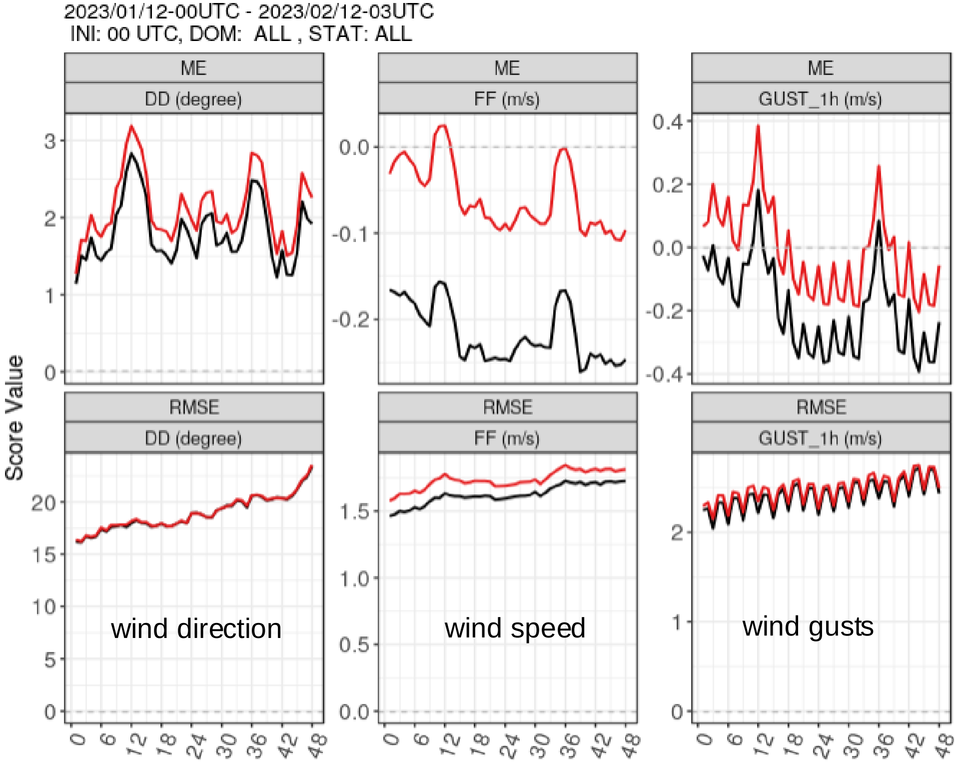
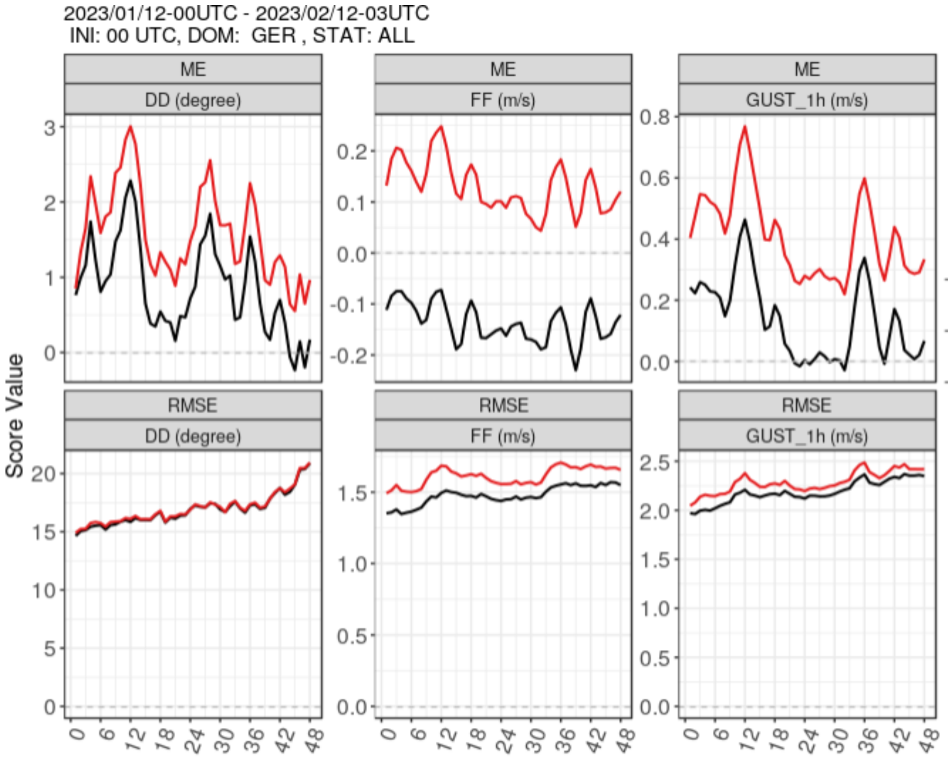
Full APT **no adaptive surface friction**

Full domain



German stations only



Remarks

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- In the global system, the adaptive optimization of T2M was put into operations in May 2022 together with the assimilation of T2M (previous attempts of T2M assimilation were not successful)
- Adaptive surface friction followed in late November 2022 in combination with new (higher resolution) raw data for orography, which includes using SSO information down to standard deviations of 1 m (previously 10 m)
- In ICON-D2 (LAM configuration for Central Europe), T2M assimilation and the related adaptive parameter tuning were active from the beginning (Feb. 2021)
- However, ICON-D2 assimilated FF10M only for stations below 100 m ASL until Feb. 2024; then, adaptive surface friction was introduced together with extending the FF10M assimilation to the full domain