Reducing systematic forecast errors by coupling uncertain model parameters to data assimilation

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WGNE Systematic Error Workshop

02/11/2022

Overview

- Motivation
- Methodology
- Results
- Summary and concluding remarks

Motivation

- **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)**
- **At DWD, we developed a methodology to use information from data assimilation (DA) to adaptively optimize uncertain parameters (internally referred to as model-DA coupling)**

Special acknowledgements to Harald Anlauf and Christine Sgoff for related work in data assimilation

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 (filtering time scale 2.5 days)
- This obviously requires assimilation of T2M, RH2M and FF10M data

Remarks

- The adaptive optimization of T2M was put into operations together with the assimilation of T2M (previous attempts of T2M assimilation were not successful)
- In regions where FF10M observations are blacklisted for assimilation, the adaptive tuning of surface friction needs to be turned off as well

Methodology

Model parameters selected for adaptive optimization

- **T2M/RH2M: stomata resistance of plants, minimum evaporation resistance of bare soil, LAI and root depth (transitional seasons only)**
- **T2M diurnal amplitude: soil heat capacity, heat conductivities of soil and skin layer, (under testing) near-surface profiles of minimum vertical diffusion coefficient**
- **T2M in the presence of snow cover: snow albedo**
- **FF10M: vegetation roughness length, SSO blocking tendency at lowest model level**

Implementation details

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exemplarily for diurnal amplitude of T2M

weighted analysis increment: $$T_{wif} = T_{wif} + \frac{dt_{ana}}{dt_{filt}}\left(T_i \cos\left(\frac{2\pi}{86400}t_{loc}\right) - T_{wif}\right) ,$$

with $dt_{filt} = 2.5$ days as for T_{if} and RH_{if}, T_i being the assimilation increment at the lowest model level and t_{loc} being local time.

Based upon $\check{T}_{wif}$, multiplicative factors for skin conductivity, soil heat conductivity and soil heat capacity are defined, all having the same functional structure:

$$f_x = 1/(1 - f_s f_{ai} T_{wif})$$

for positive T_{wif} and

$$f_x = 1 + f_s f_{ai} T_{wif}$$

for negative T_{wif}. Here, the scaling factor f_{ai} is taken to be

$$f_{ai} = (10800/dt_{ana})^{(2/3)}$$

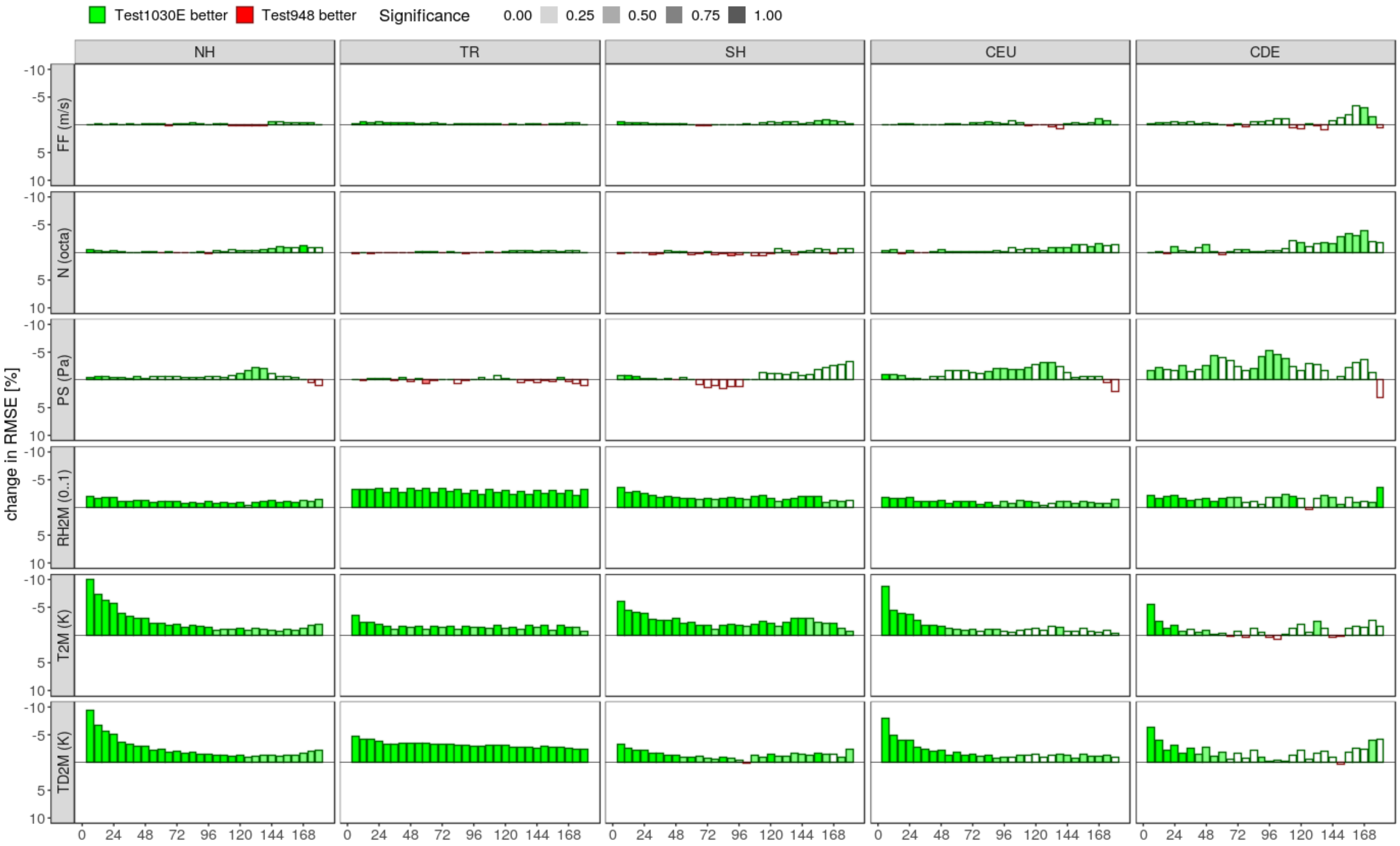
Results

- **T2M assimilation and the related elements of model-DA coupling were operationalized in May 2022**
- **Adaptive surface friction will follow in late November 2022 in combination with new (higher resolution) raw data for orography and a resolution upgrade (40 → 26 km for EPS, 90 → 120 levels for DET and EPS)**

- **To demonstrate the isolated effect of model-DA coupling on forecast skill, an experiment for autumn 2020 was repeated without coupling**
- **In addition, results for the preparatory (parallel routine) phases for the above-mentioned upgrade steps will be shown**

Scorecard for SYNOP verification, T2M assimilation and related coupling

Forecasts initialized from 2020/10/20 to 2020/12/31
Reduction of RMSE [%], INI; 00, 12UTC, SIGTEST: TRUE



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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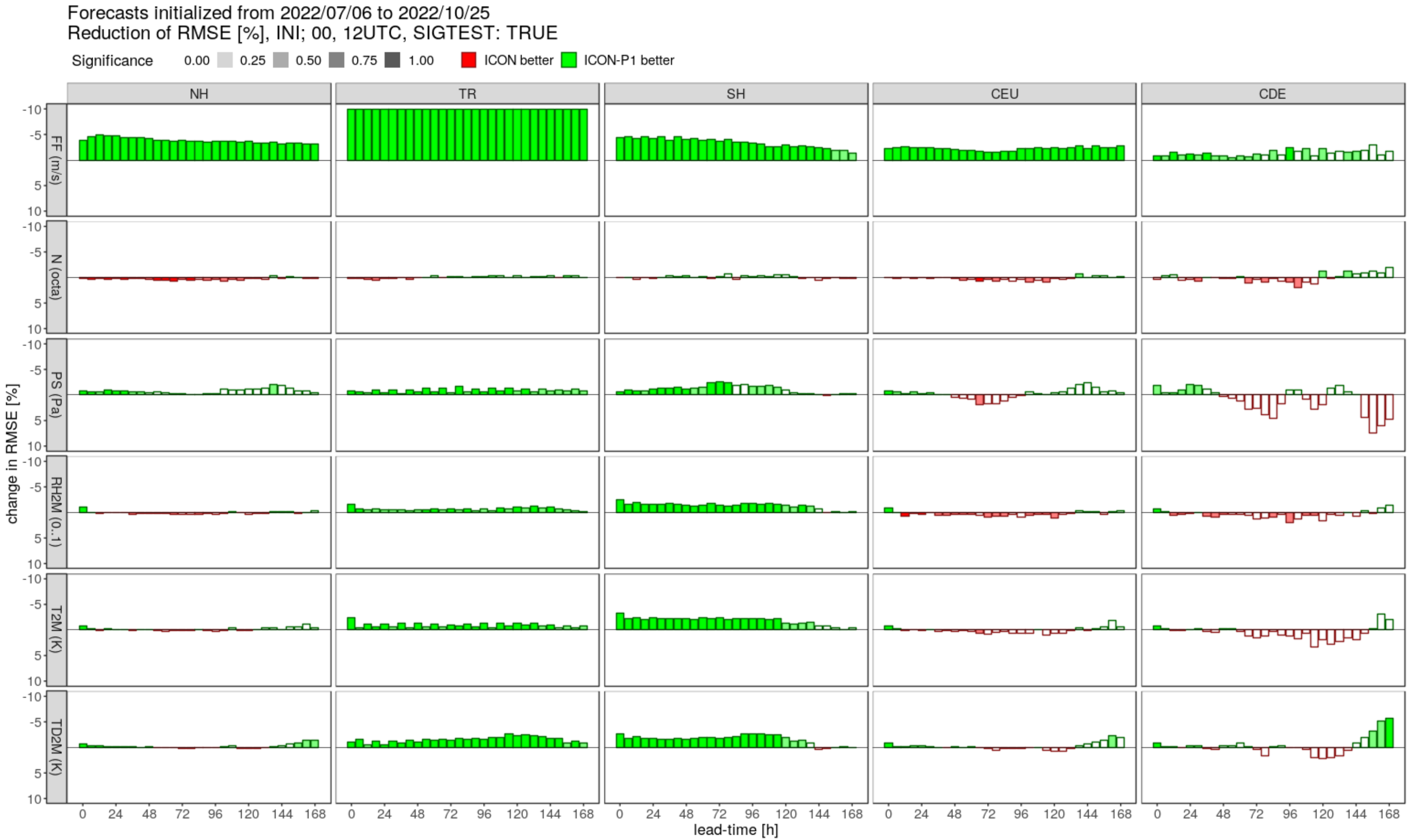

wind speed

cloud cover

surface pressure

2m humidity

2m temperature

2m dewpoint

Scorecard for SYNOP verification, benefit from full model-DA coupling when starting from same analyses

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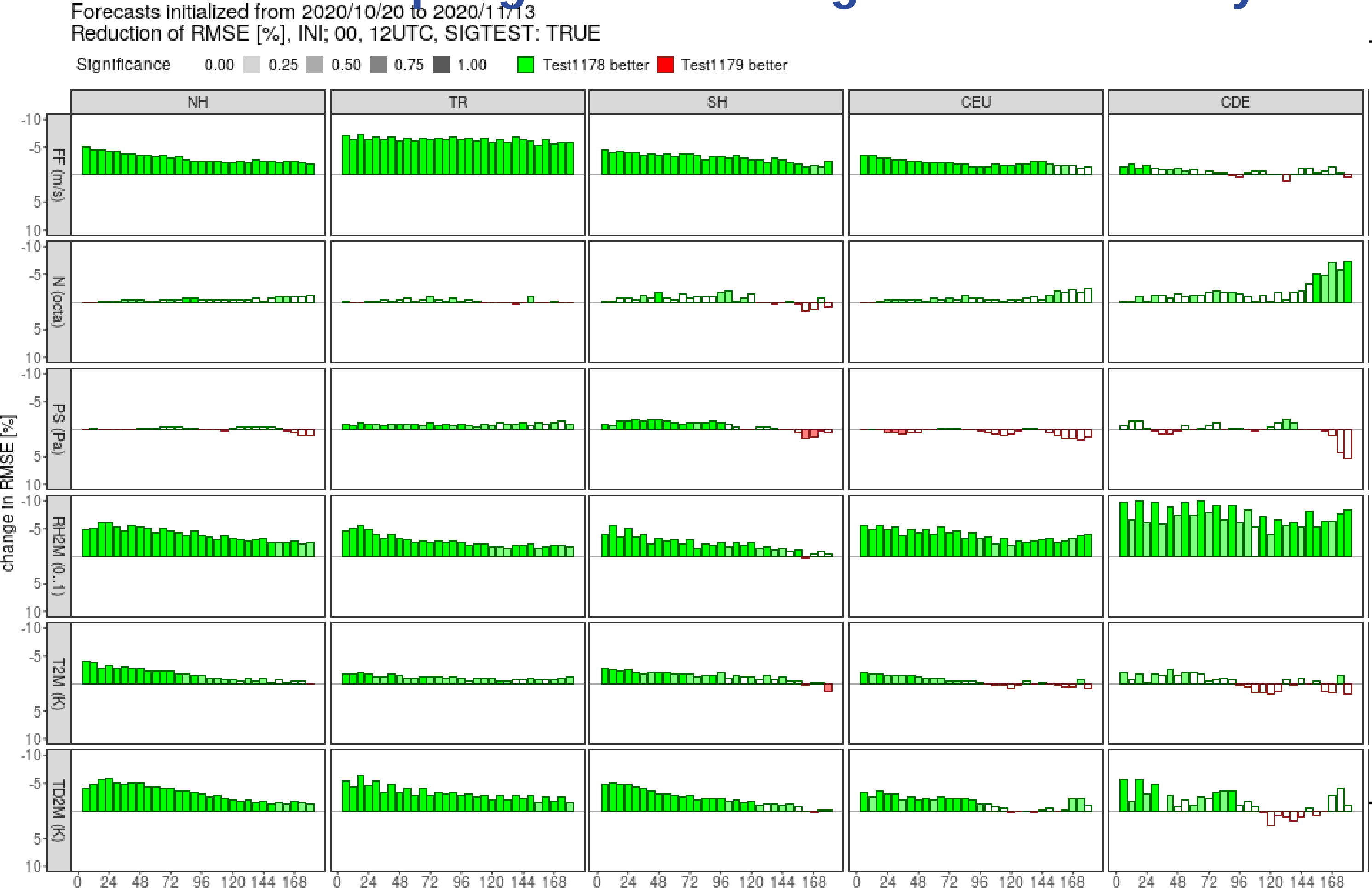


wind speed

cloud cover

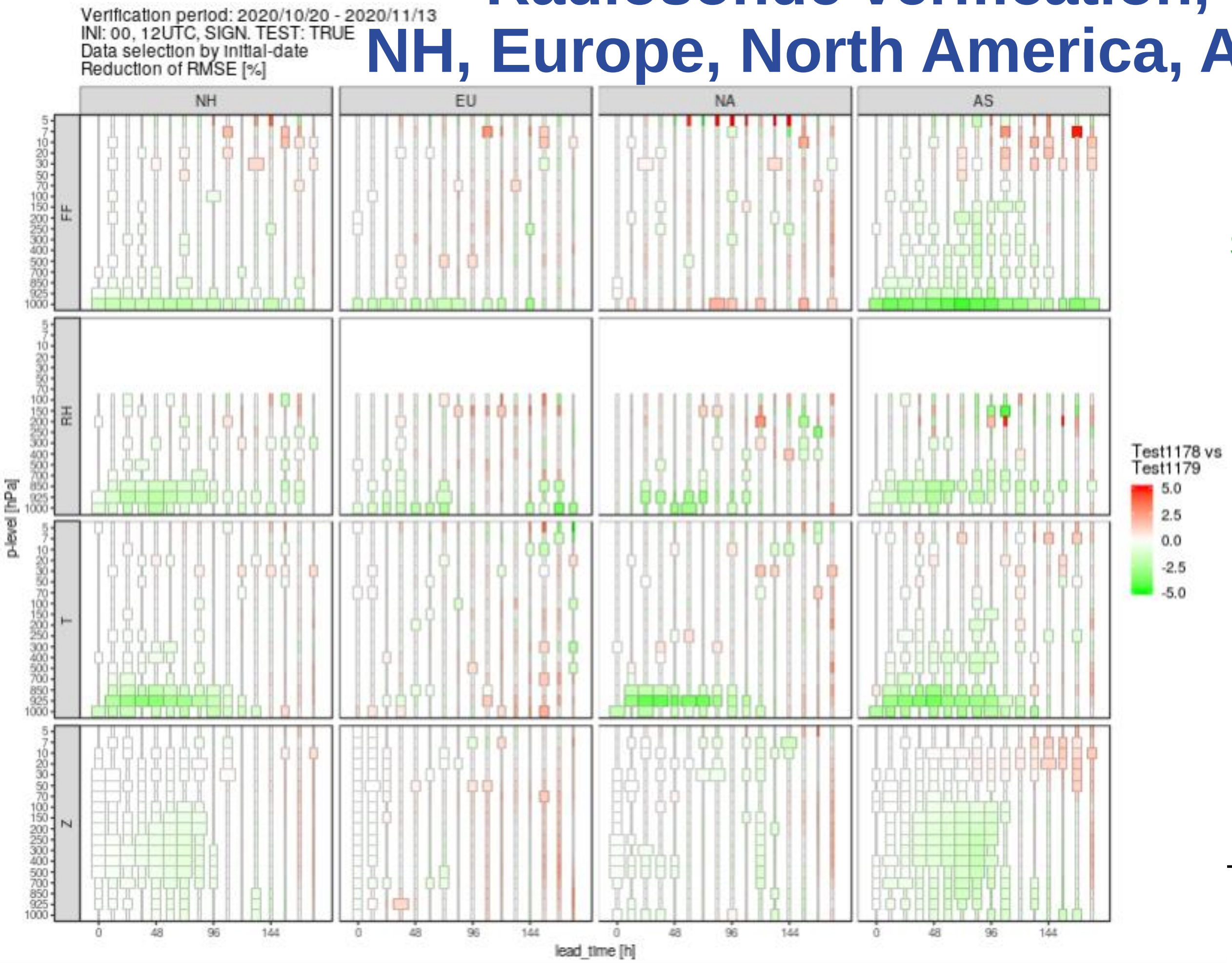
surface pressure

2m humidity

2m temperature

2m dewpoint

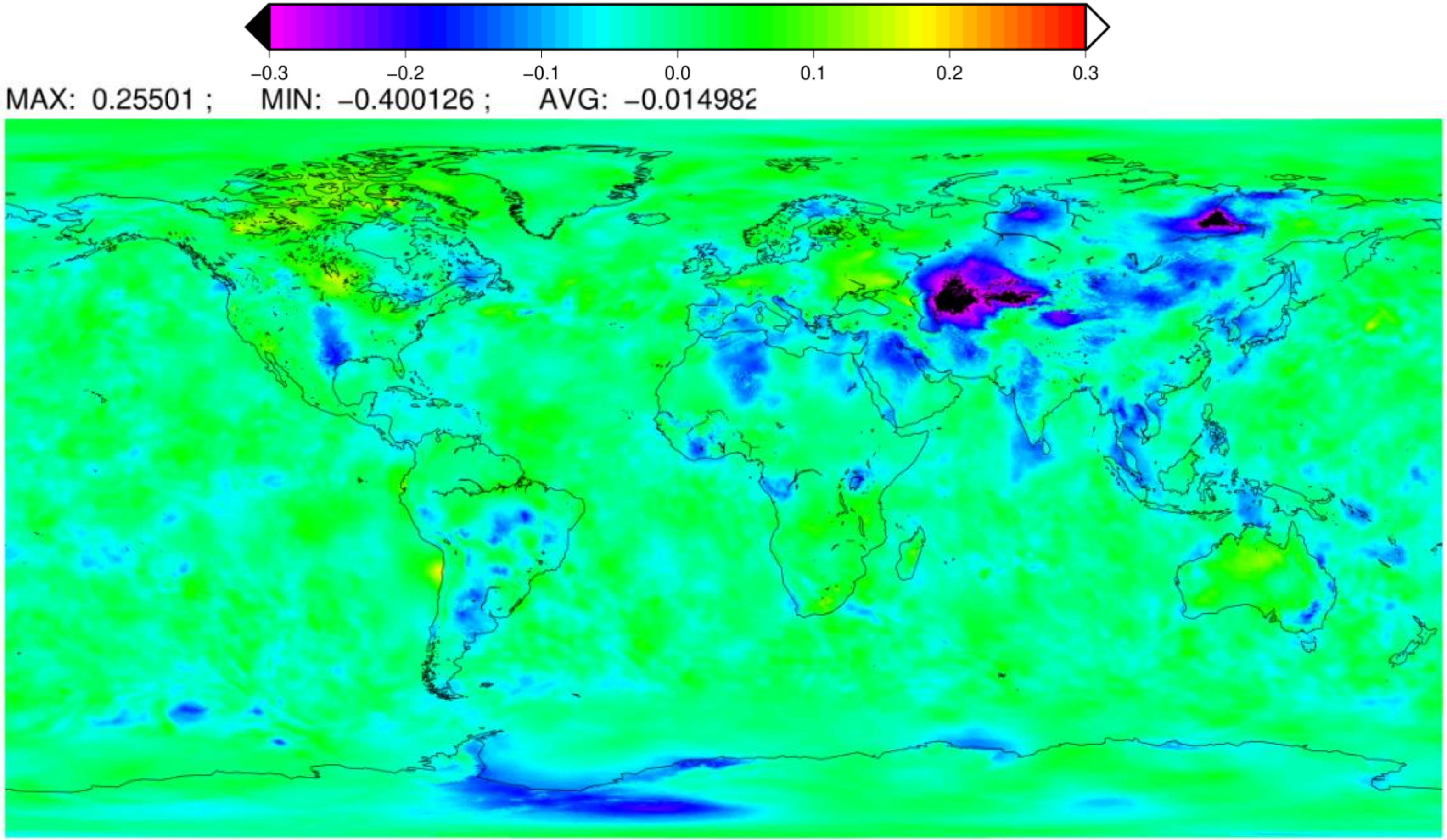
Radiosonde verification, NH, Europe, North America, Asia



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

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



snapshot for October 31, 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)

Corresponding Bias/RMSE, Central Asia

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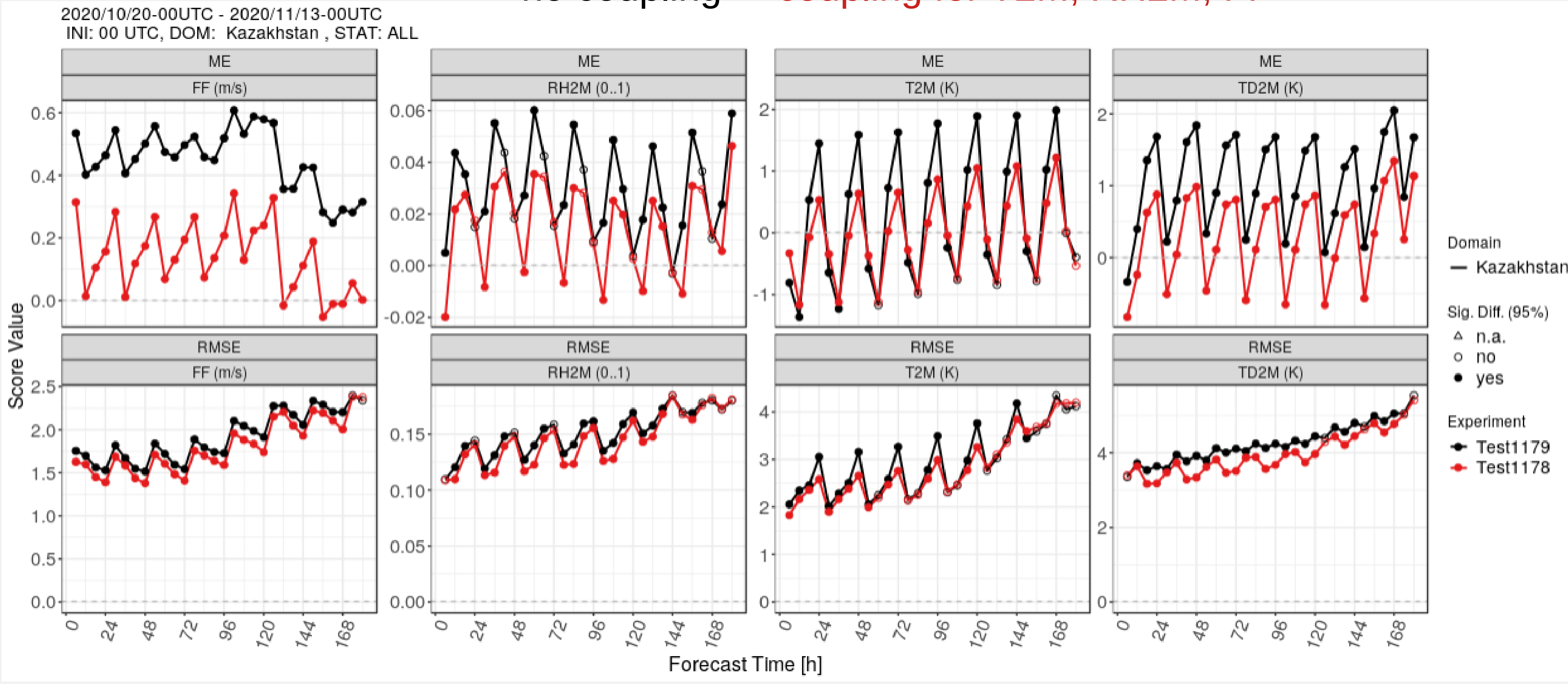
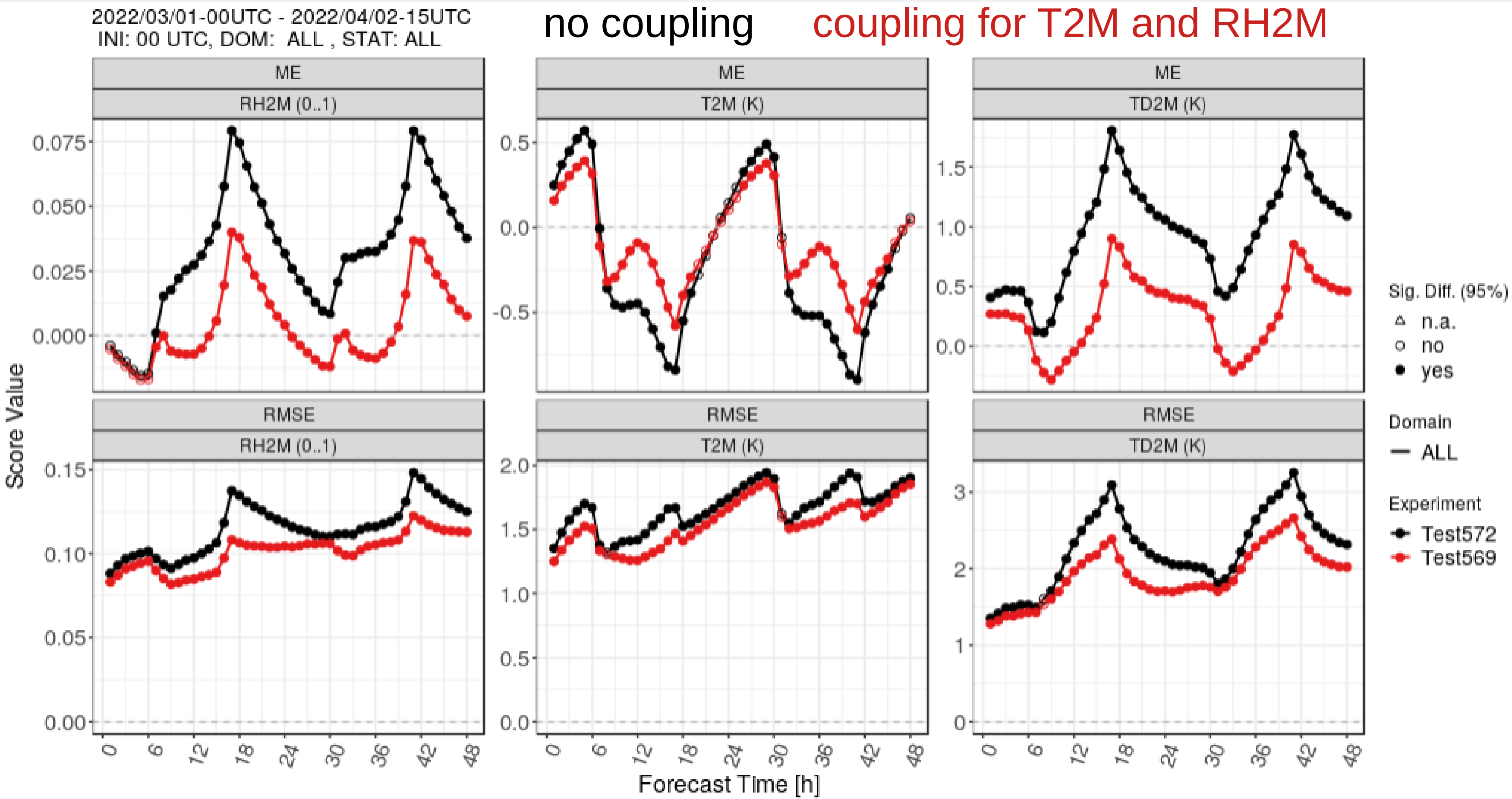
no coupling   coupling for T2M, RH2M, FF



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

no coupling   coupling for T2M and RH2M



Station-based RMSE difference for FF10M due to adaptive surface friction + new orography data

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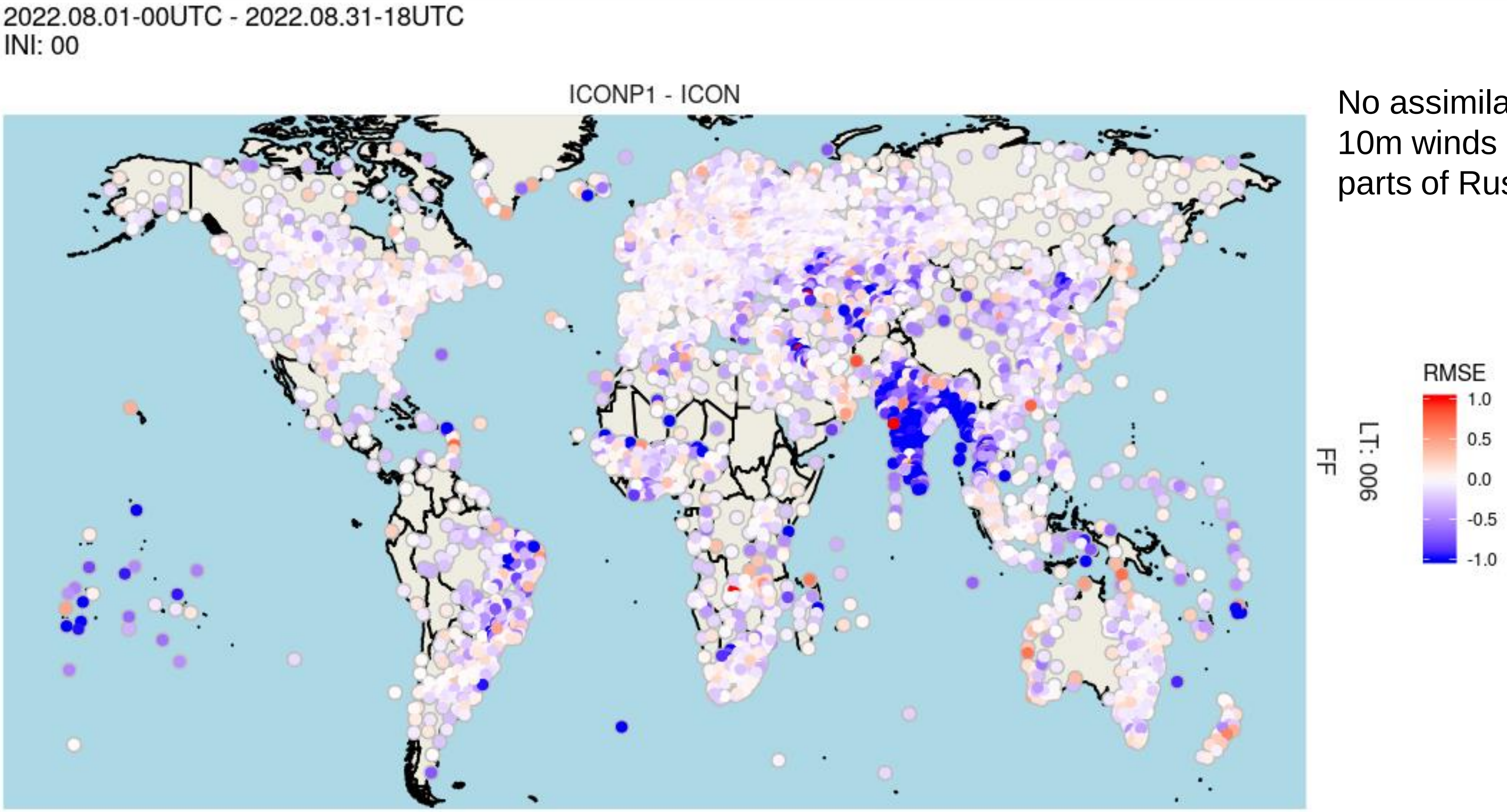
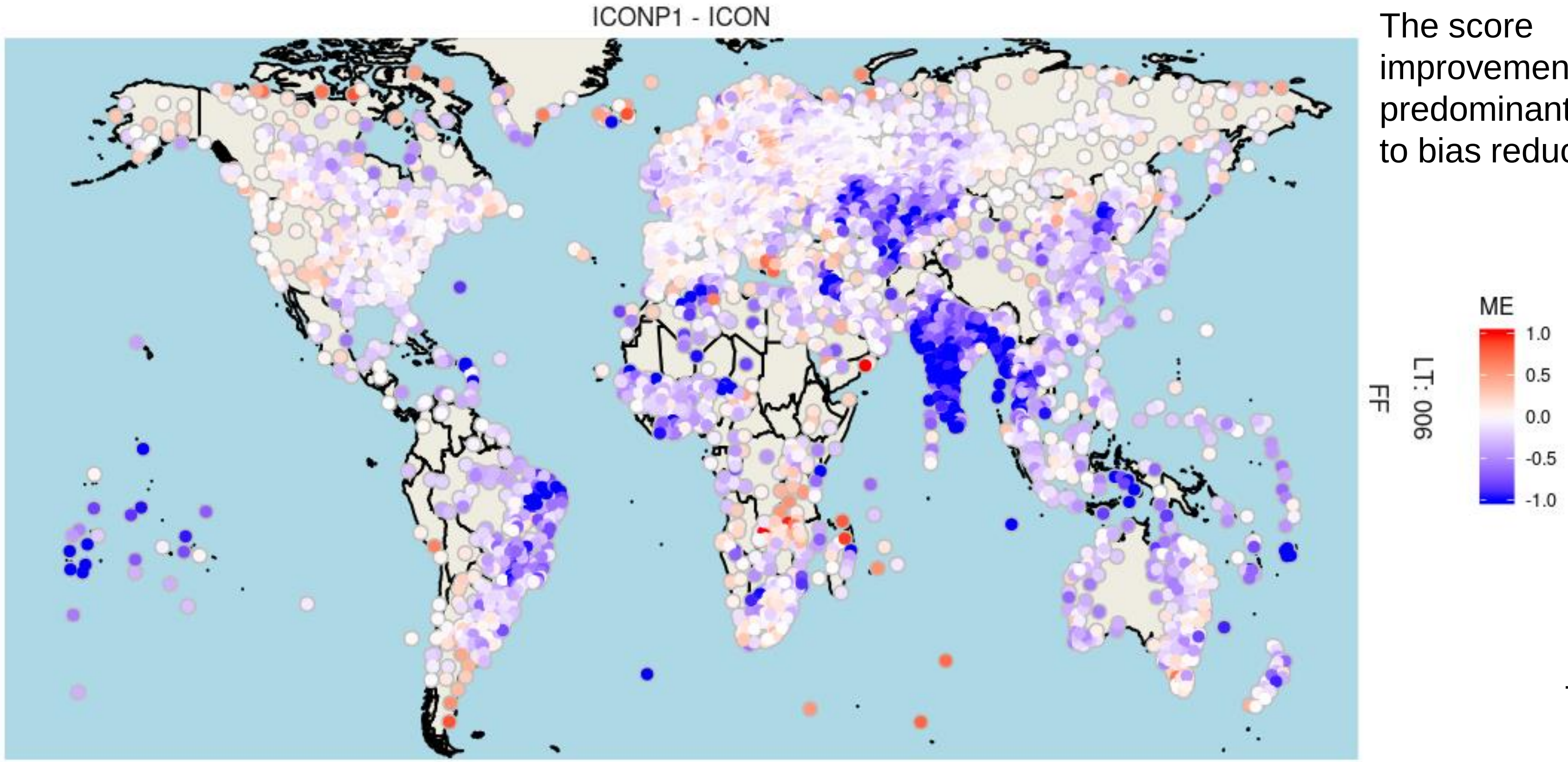


No assimilation of 10m winds in most parts of Russia

Related bias difference

2022.08.01-00UTC - 2022.08.31-18UTC
INI: 00



The score improvements are predominantly related to bias reduction

What happens when activating the 10m wind assimilation over Russia?

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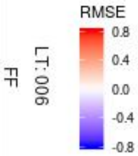
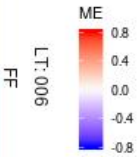
2020.10.20-00UTC - 2020.11.28-00UTC
INI: 00

Test1178 - Test1072

RMSE difference



Bias difference



Our 10m wind speeds currently have a large positive bias over parts of Russia, the origin of which is not entirely clear

10m wind data over Russia and some adjacent countries are reported only in full m/s, which raises questions about their quality

Assimilating them used to degrade the surface pressure analyses over Europe without DA coupling

Work in progress...

WMO (WGNE) intercomparison for SYNOP scores

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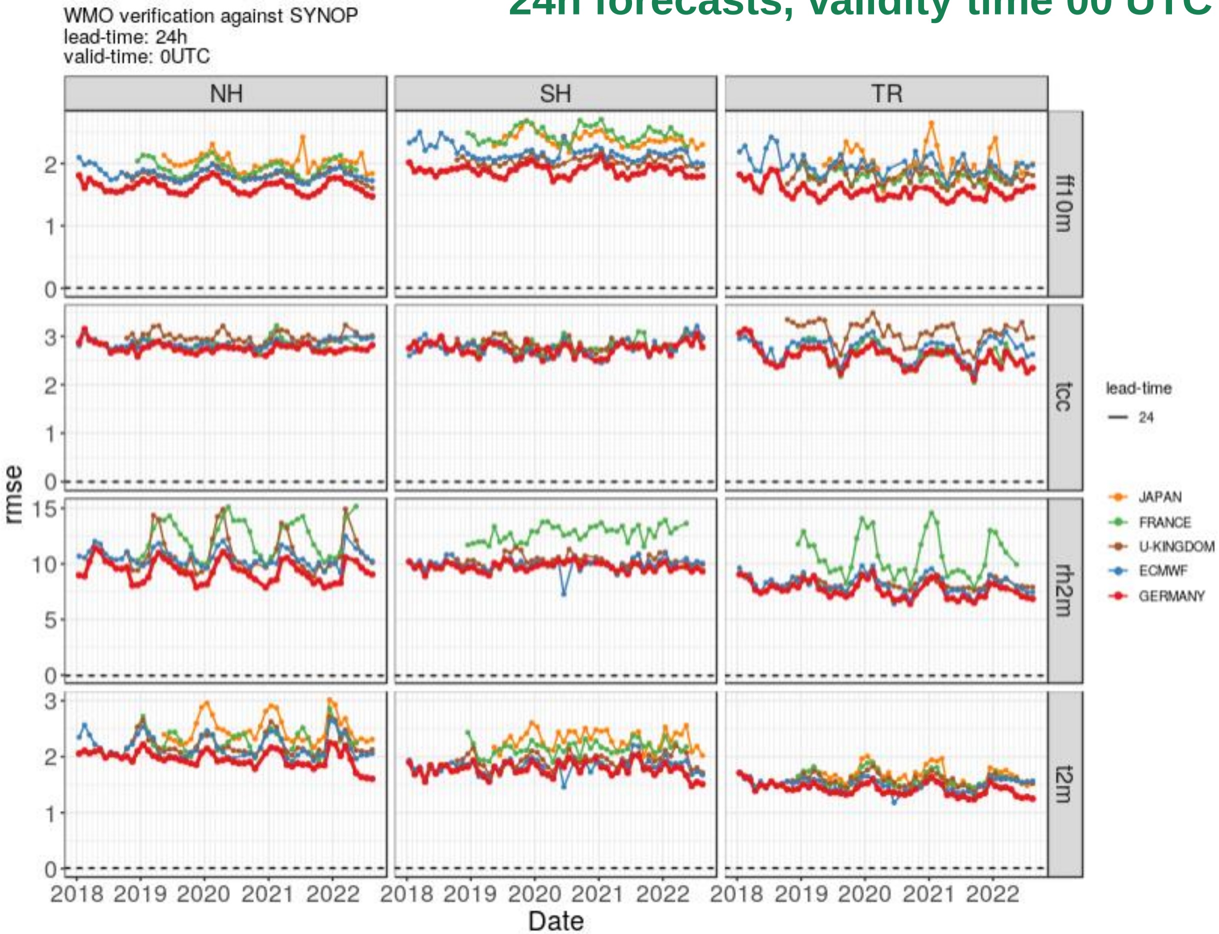
24h forecasts, validity time 00 UTC



10m wind speed

cloud cover

2m humidity

2m temperature

DWD

ECMWF

UKMO

JMA

Météo France

Summary

- The model-DA coupling approach developed for DWD's ICON modeling system allows reducing systematic forecast errors related to poorly known external parameter data / physical properties derived therefrom
- To some extent, it may also correct deficiencies in the physical process description; this is hard to separate in practice, but our experience gained so far is that improvements at process level are not hidden by the model-DA coupling (they still lead to better forecast quality)

- For 2m temperature, 2m humidity and 10m wind speed, RMSE reductions of about 5% are achieved
- To a weaker extent, the improvements also show up in the lower-tropospheric levels of the radiosonde verification

Concluding remarks

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- Our methodology differs from common ML algorithms by not relying upon training data
- It adapts to changes in physics parameterizations within a couple of days
- In case of fundamental changes (e.g. new schemes), adapting the coupling variables might be necessary

- Using time-filtered assimilation increments is the most convenient way for us because we use an incremental assimilation scheme anyway, but alternatives involving offline analyses of T2M etc. would be possible
- As most of the biases are annually recurring, developing a related ML approach for climate applications could be possible