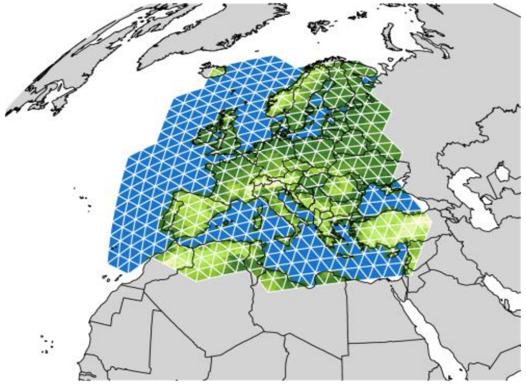
High-resolution experiments over the Alps and the Tibet-Himalaya region: Surprises and lessons learnt



Günther Zängl, and the ICON development team @ DWD

PHY-EPS hectometric Workshop, Offenbach, Feb 6, 2024

Motivation / Background

- ➔ First global convection-permitting experiments (conducted in 2021) indicated – among other things – substantial quality problems over the Tibetan Plateau
- ➔ This motivated more detailed investigations using multi-step nesting down to 1.6 km over the Tibet-Himalaya region
- ➔ For the Alpine region, there are multiple motivations to consider higher resolution (~ 500 m)
  - TEAMx – for which DWD plans to provide dedicated forecasts
  - GLORI-Alps – our Digital Twin project complementing DestinE
  - ICON-D05 – DWD's plan for higher-resolution operational forecasts for Germany

Bias FF 500 hPa vs. radiosondes, January 2021, 00-UTC
forecasts starting from interpolated IFS analyses
LT 12h-48h

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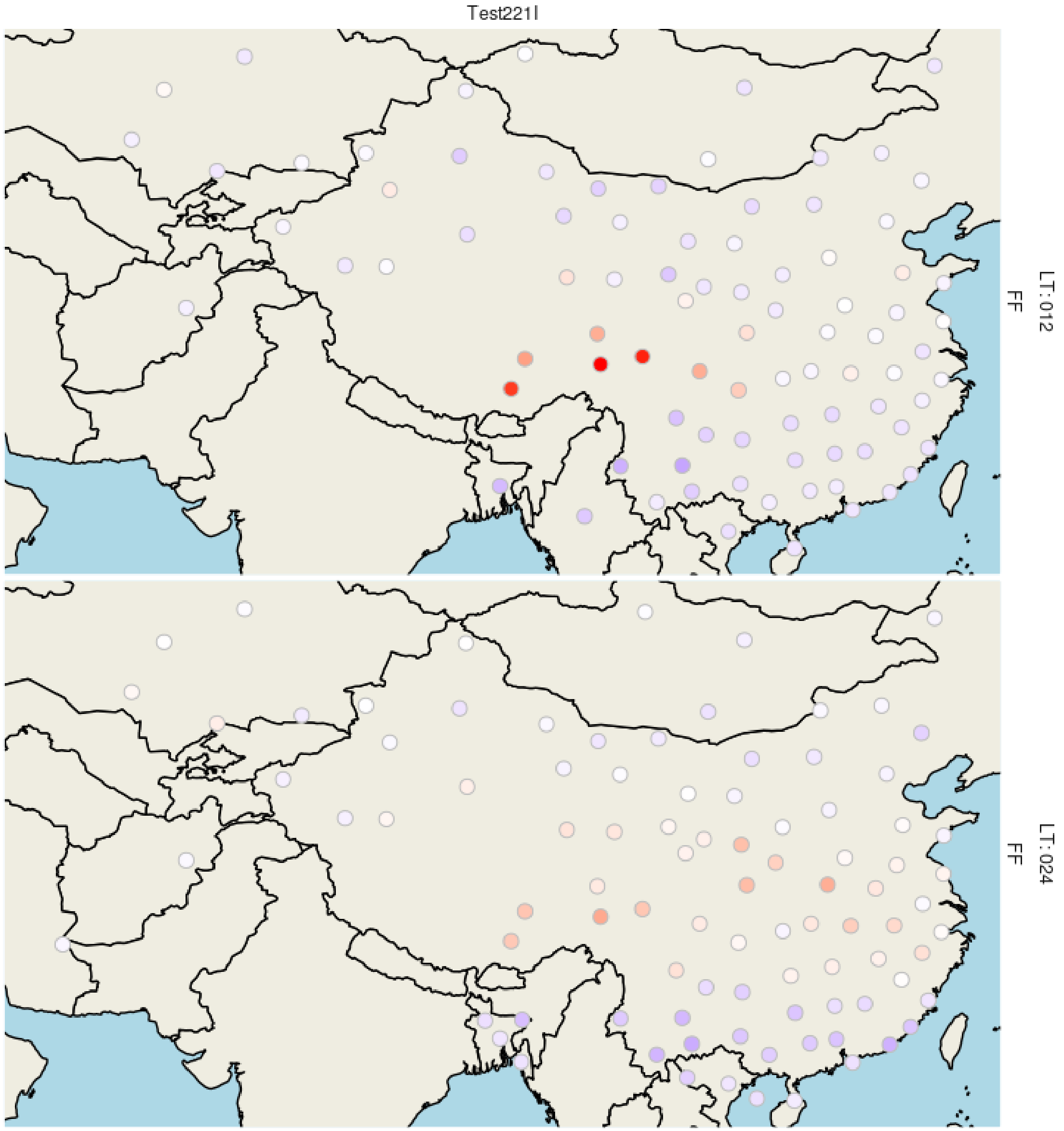
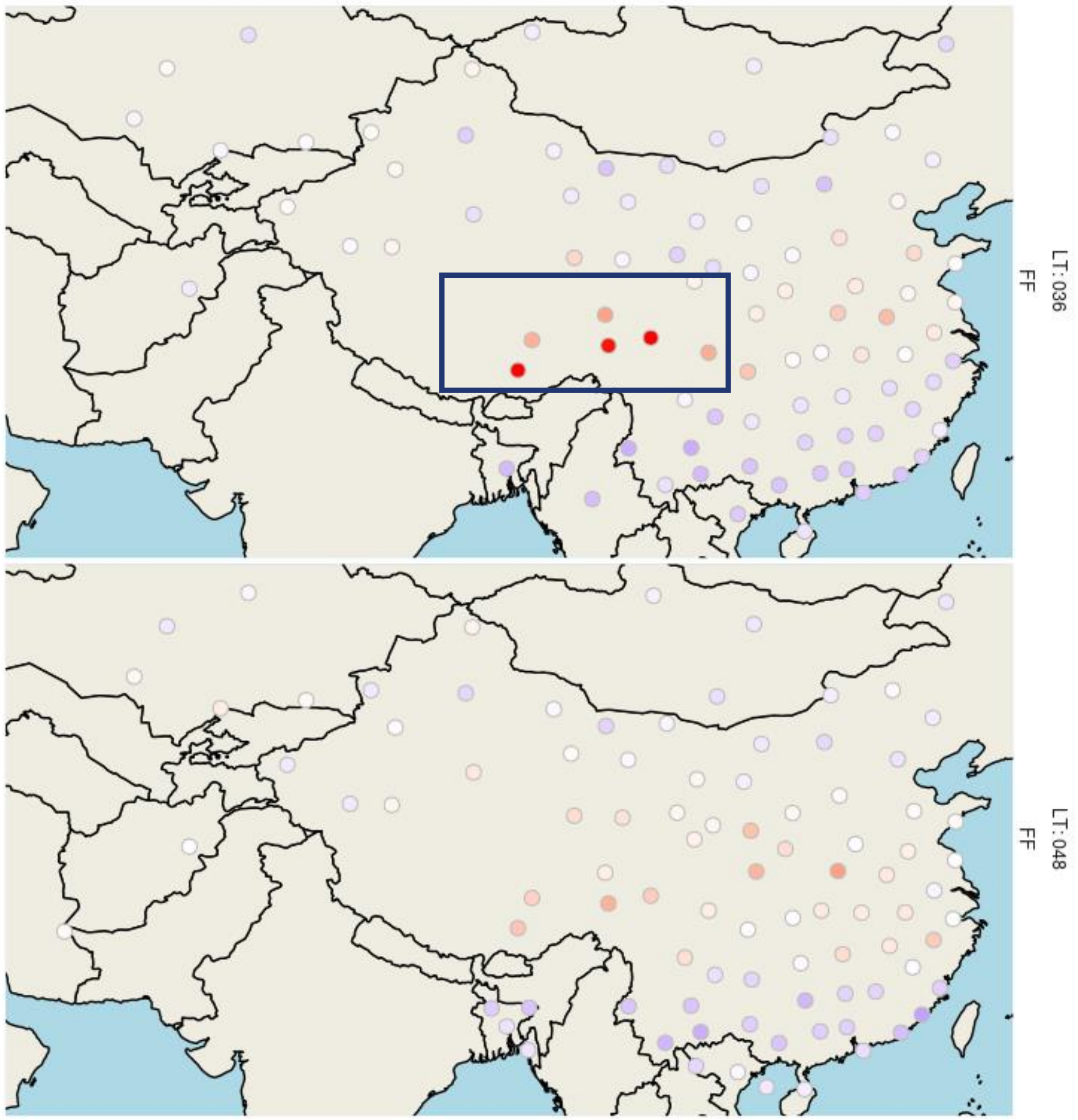
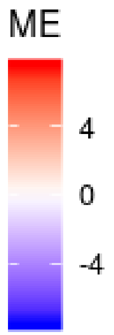
2021.01.01-00UTC - 2021.02.07-12UTC
INI: 00, LEVEL: 50000Pa



operational configuration (13 km)



Scale
7.5 m/s (!)



Wind speed profiles; 29-35N, 85-105E; January 2021, 00-UTC forecasts

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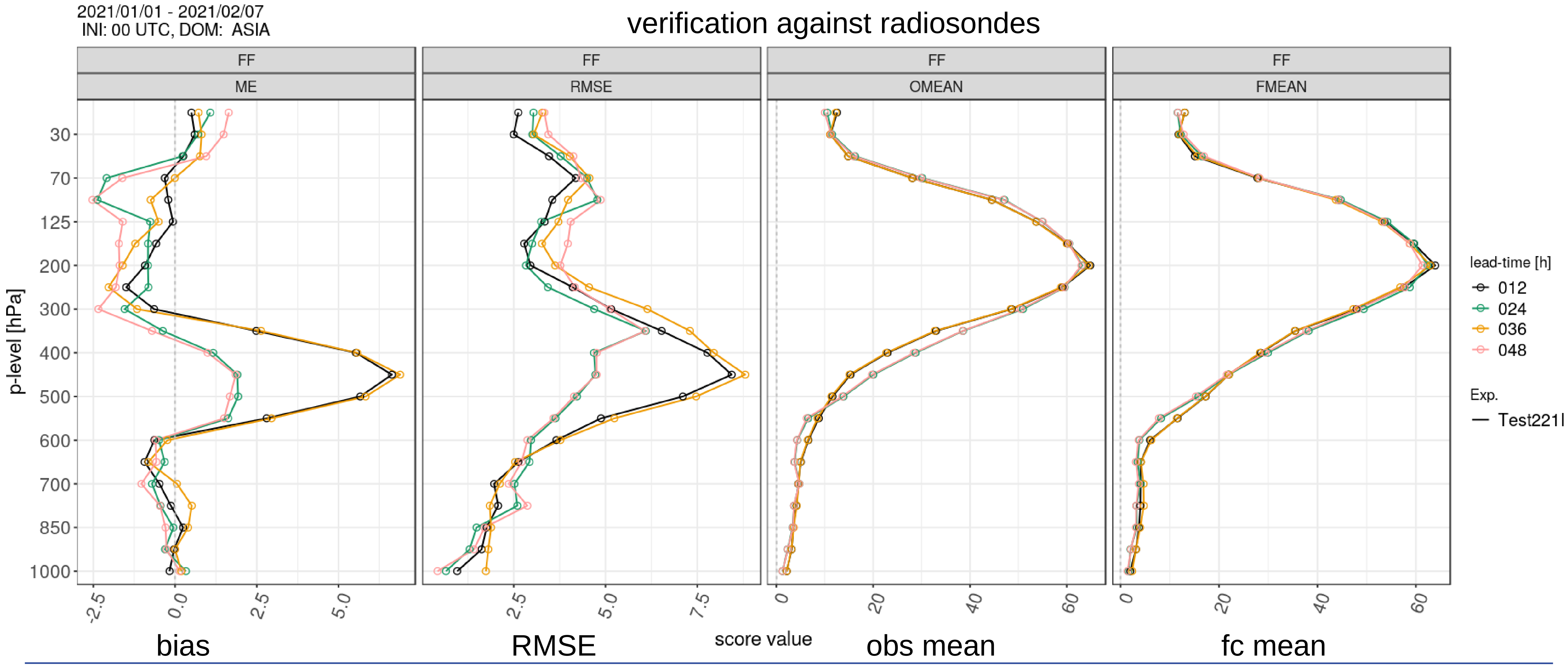

Temperature profiles; 29-35N, 85-105E; January 2021, 00-UTC forecasts

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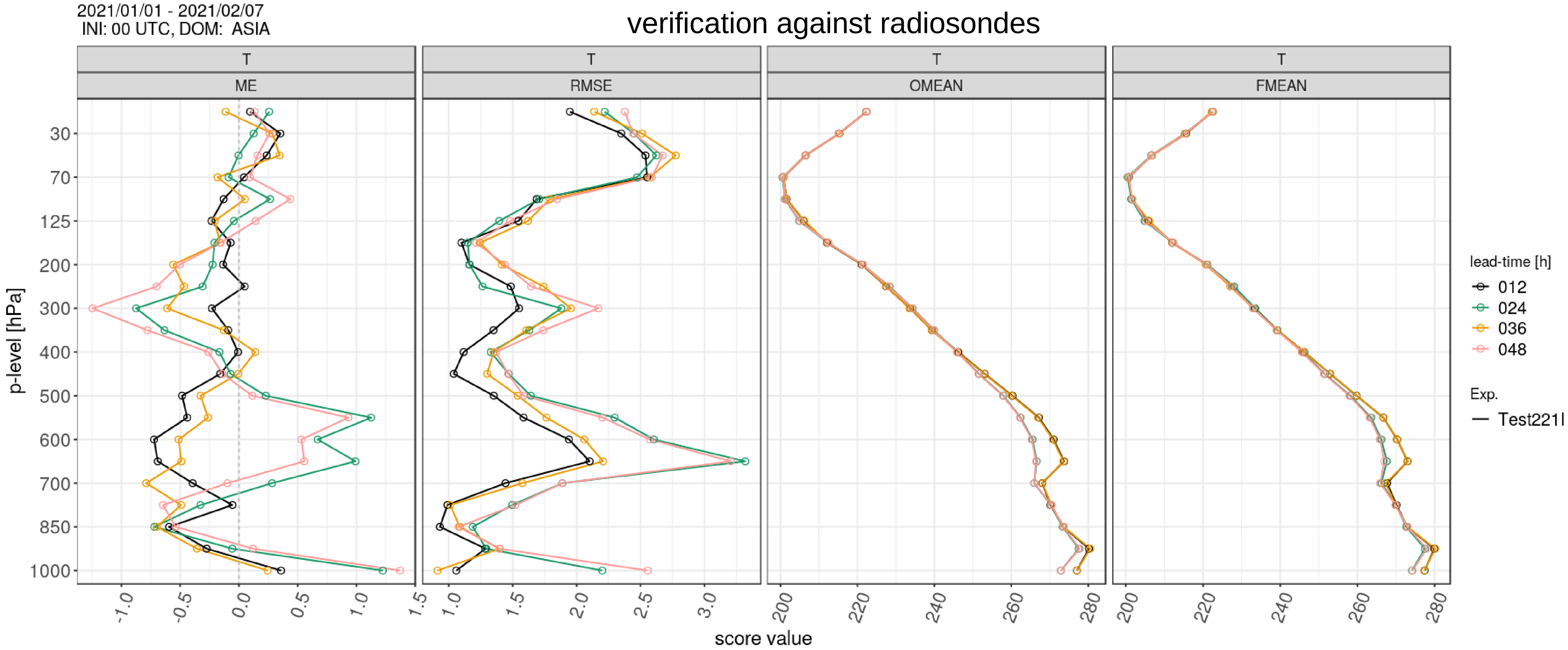


Note: the diurnal cycle bias of FF and T is in phase opposition!

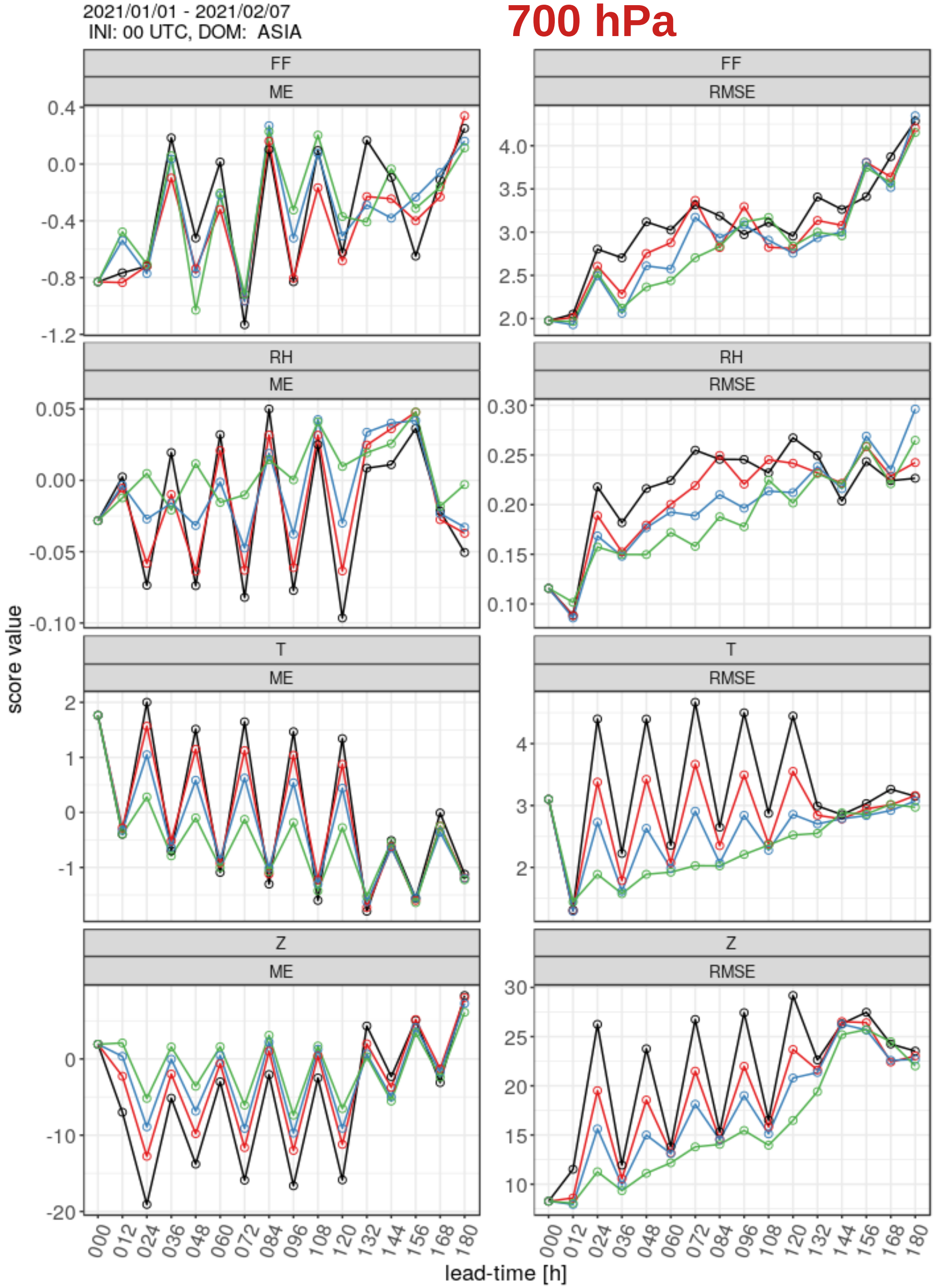
First findings

- There is an apparent lack of (parameterized) wave drag in the middle troposphere, which motivated a retuning of the SSO scheme in the operational configuration (not discussed here)
- The wind profile at the lower edge of the jet exhibits a remarkably large diurnal cycle that is largely missed by the model
- The reason for this error is unclear – also because the temperature bias is in anti-phase with the wind profile bias

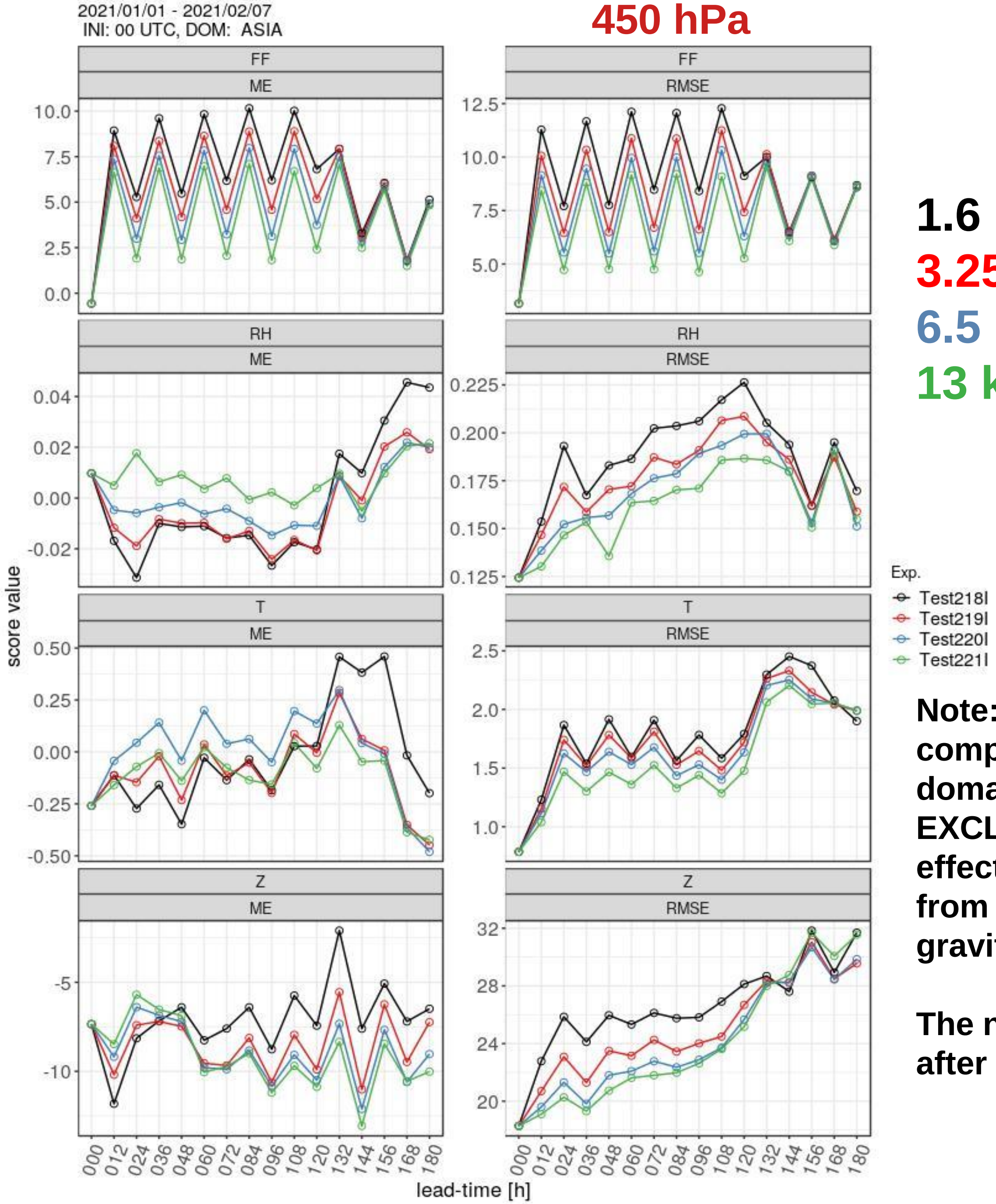
- As will be shown on the subsequent slide, both biases get further aggravated with increasing model resolution

Radiosonde verification

700 hPa



450 hPa



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DWD

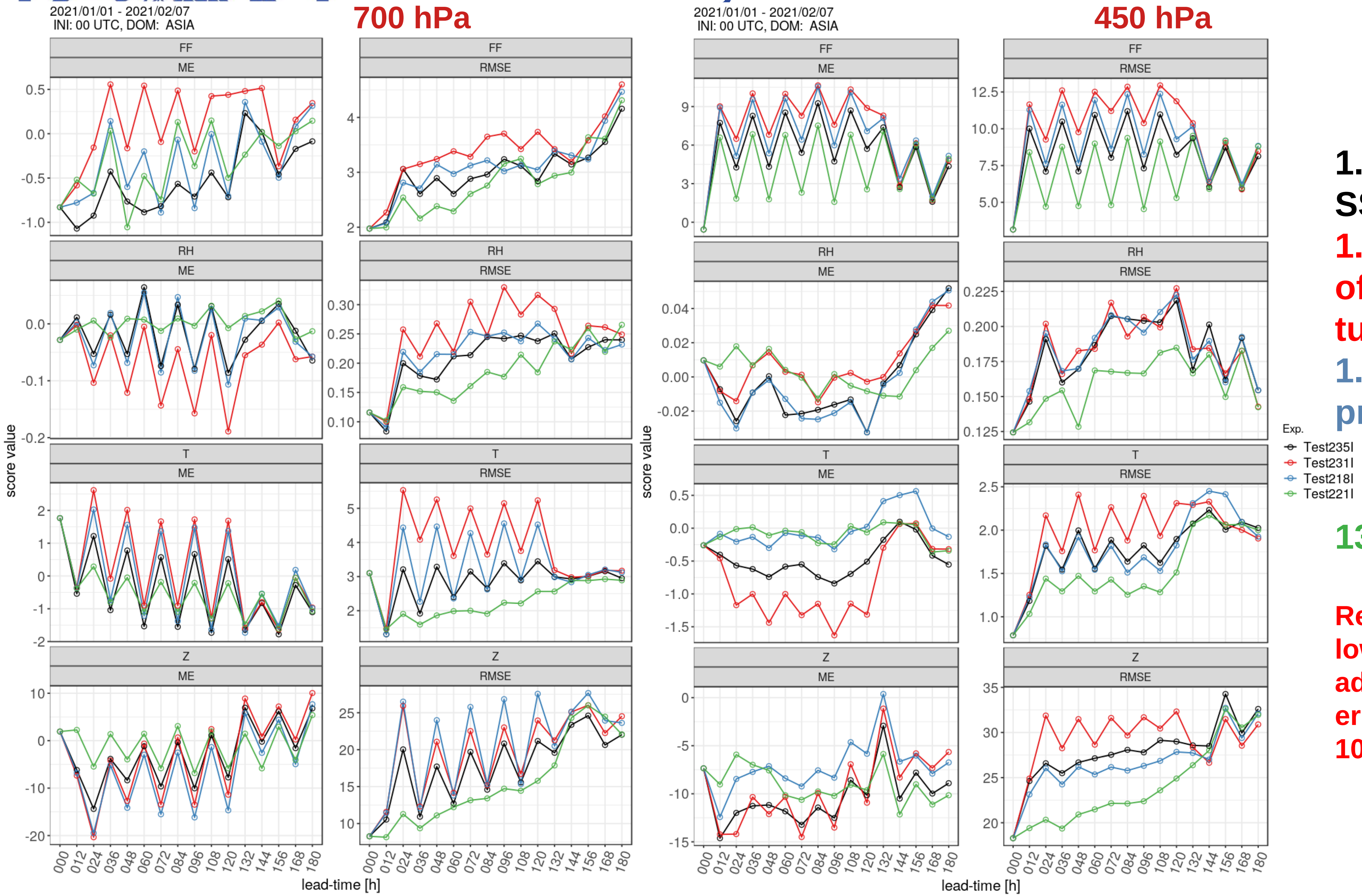
1.6 km
3.25 km
6.5 km
13 km

Note: the verification is computed from the 13-km domain in all cases; it EXCLUDES double-penalty effects that might arise from resolving more gravity waves!

The nests are turned off after 120 h

Sensitivity tests

700 hPa **450 hPa**



1.6 km, increased SSO tuning

1.6 km, GWD part of SSO scheme turned off

1.6 km, result from previous slide

13 km

Remark: turning off low-level blocking in addition increases the errors by another 10-30%

Further findings

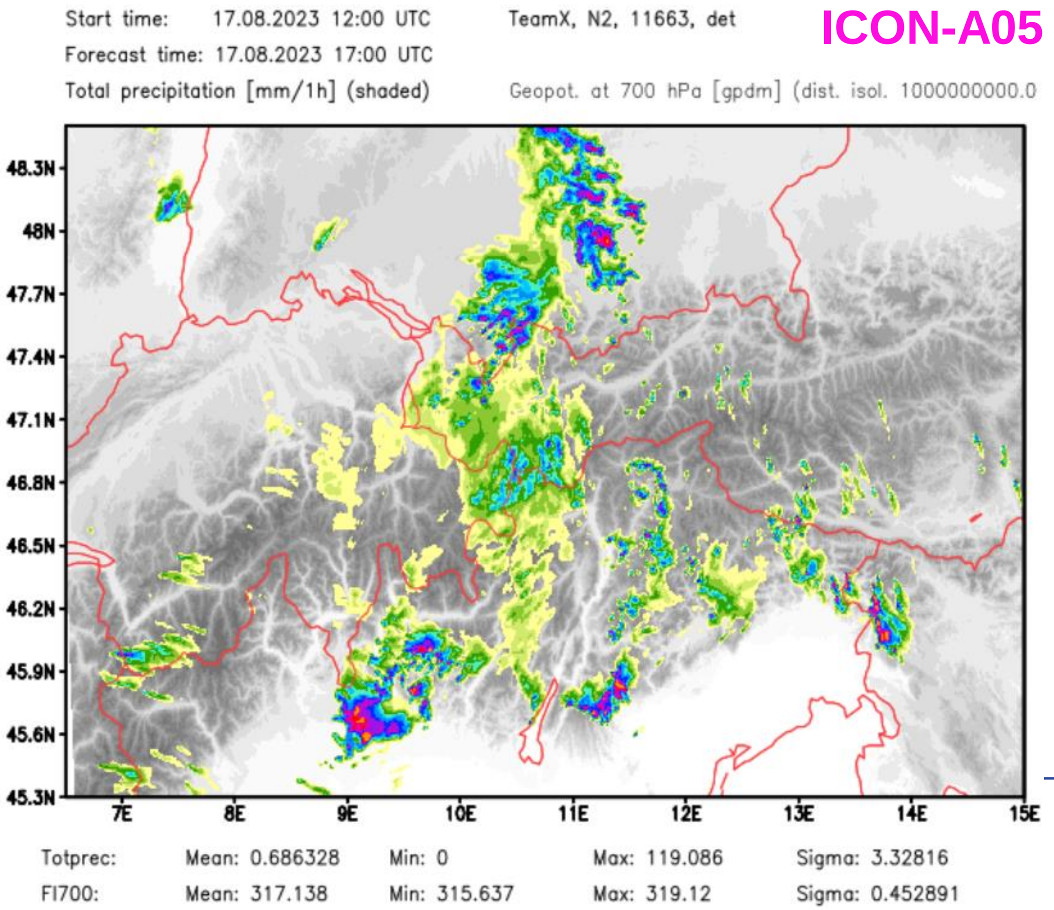
- ➔ The growth of the forecast errors with increasing model resolution can be reduced by (strongly) increasing the SSO tuning parameters, and an additional experiment with interpolated SSO parameter fields (from 13 to 6.5 km) showed almost no degradation over Tibet (with unchanged tuning parameters)
- ➔ This leads us to the hypotheses that
  - increasing the SSO tuning parameters partly compensates the implicit resolution-dependence of the SSO parameter fields (subgrid slopes, standard dev. etc.)
  - Resolving the vertically propagating part of the GW spectrum (which is the case at 1.6 km) is not sufficient to get the wave – mean-flow interaction right
  - Rotors that may form beneath the crests of trapped waves are still unresolved in km-scale models, and the related turbulence acts similar to breaking GWs
  - Moreover, low-level wave breaking is also possible for initially vertically propagating GWs that afterwards get trapped by the tropopause jet
  - Both features still need to be parameterized in some way, maybe until reaching LES scales
  - We hope to get further insight into this issue from the TEAMx campaign

ICON-LAM with 500 m

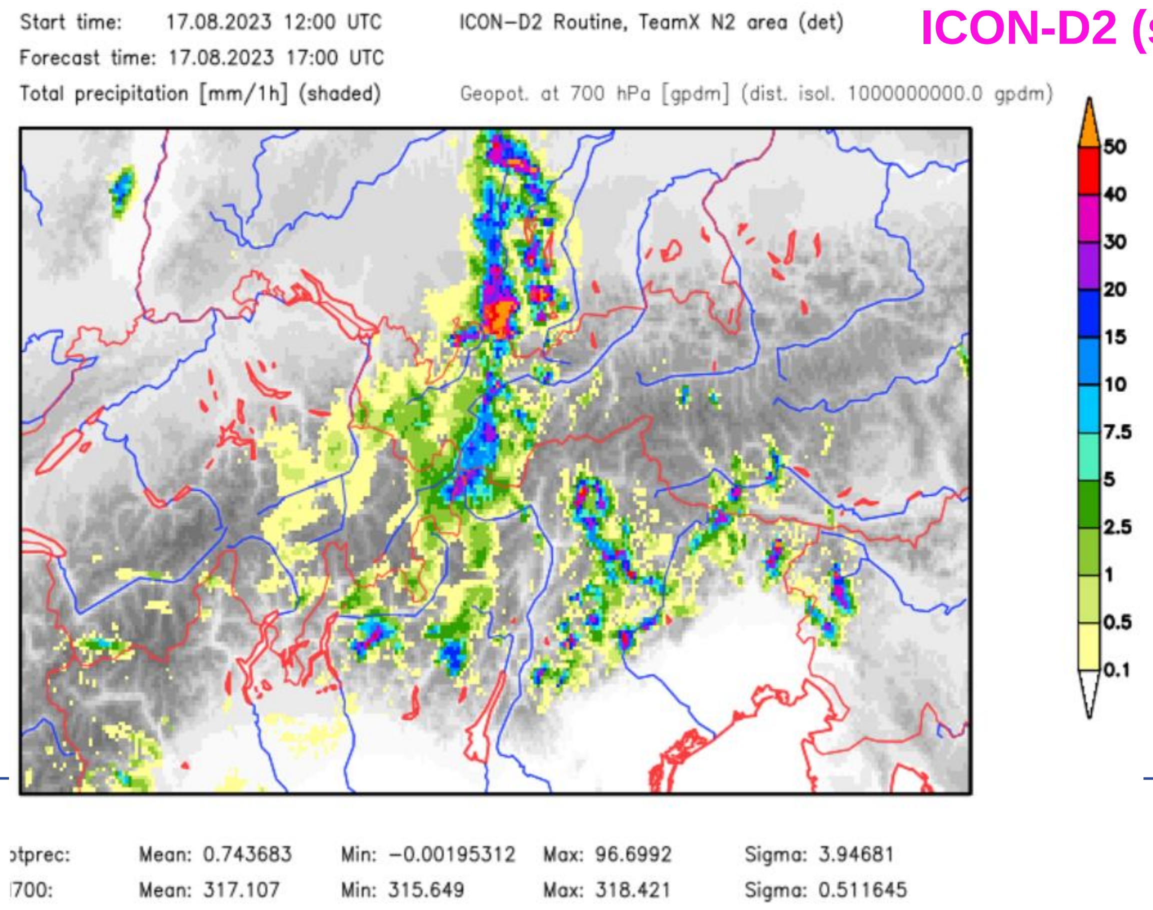
➔ **Refining the mesh size from 2 km to 500 m tends to improve the model skill in various aspects**

- **Reduced overestimation of high precipitation intensities (> 10 mm/h)**
- **However, local intensity peaks get even higher**

ICON-A05



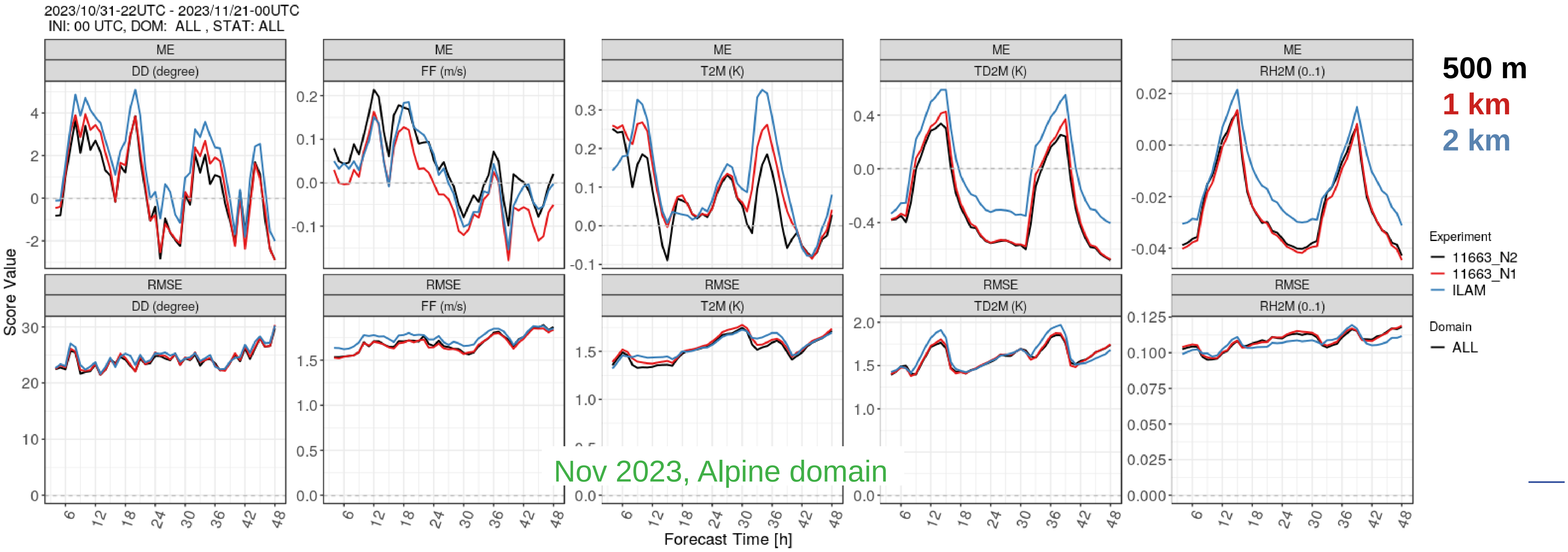
ICON-D2 (subd.)



ICON-LAM with 500 m

➔ Refining the mesh size from 2 km to 500 m tends to improve the model skill in various aspects

- **Improved 10-m winds in mountainous regions under stable conditions, for T2M this depends on the time period, and results for TD2M (dew point) and RH2M are contradicting**



ICON-LAM with 500 m

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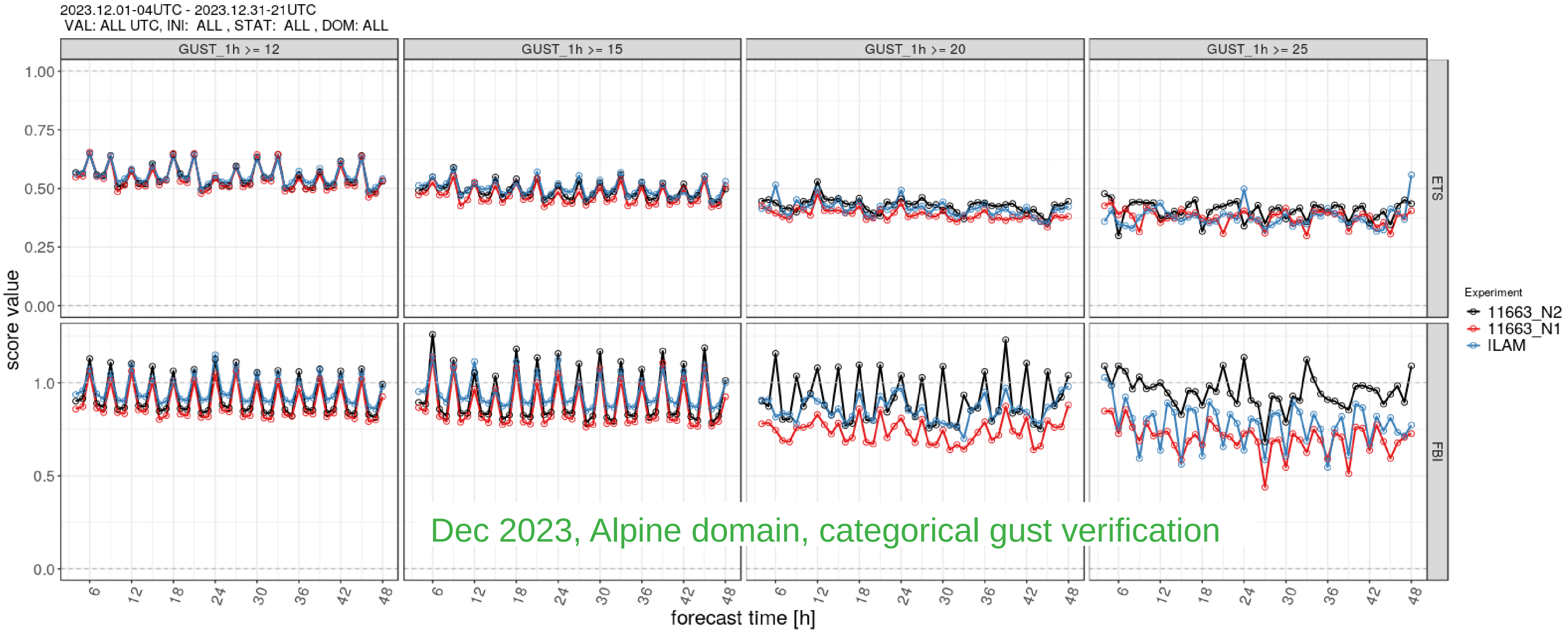
➔ **Refining the mesh size from 2 km to 500 m tends to improve the model skill in various aspects**

- ➢ **Better representation of wind maxima / gust at mountain crests**



Dec 2023, Alpine domain, categorical gust verification

ICON-LAM with 500 m

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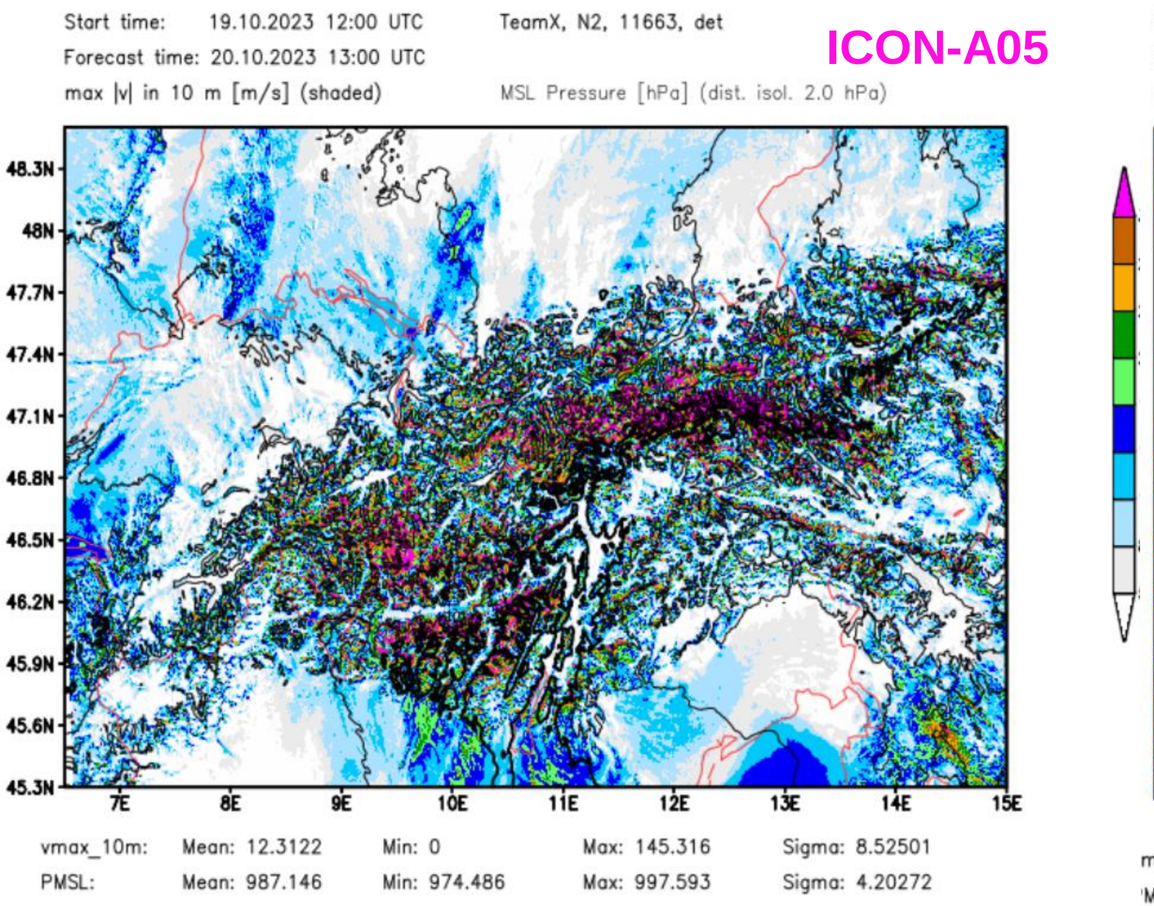
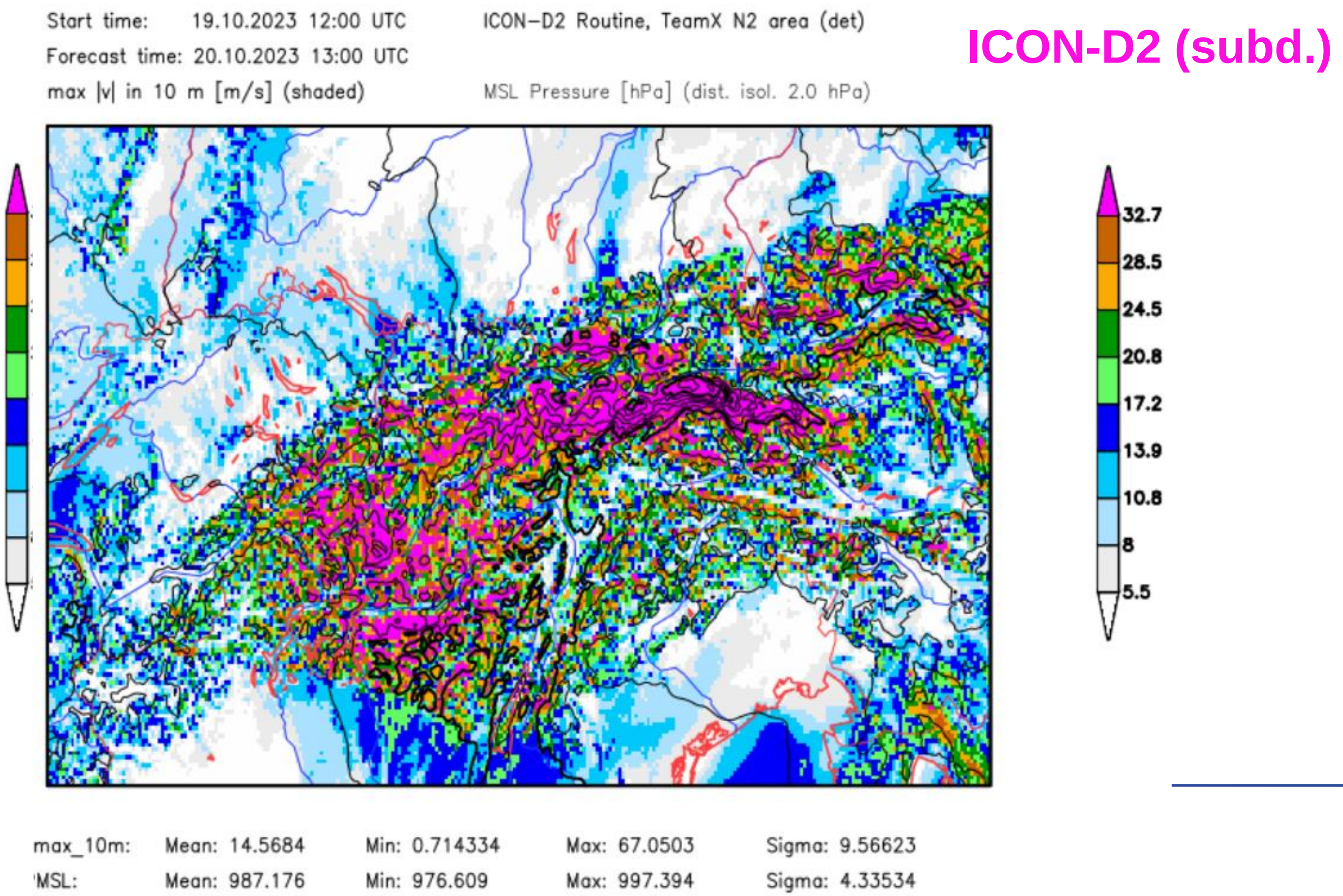
- **However, there are also several issues needing further consideration**
  - **Although the restriction of strong wind gusts to mountain peaks / crests is much better at 500 m than at 2 km, local extrema are way too high (145 m/s in the south foehn case displayed below)**





ICON-LAM with 500 m

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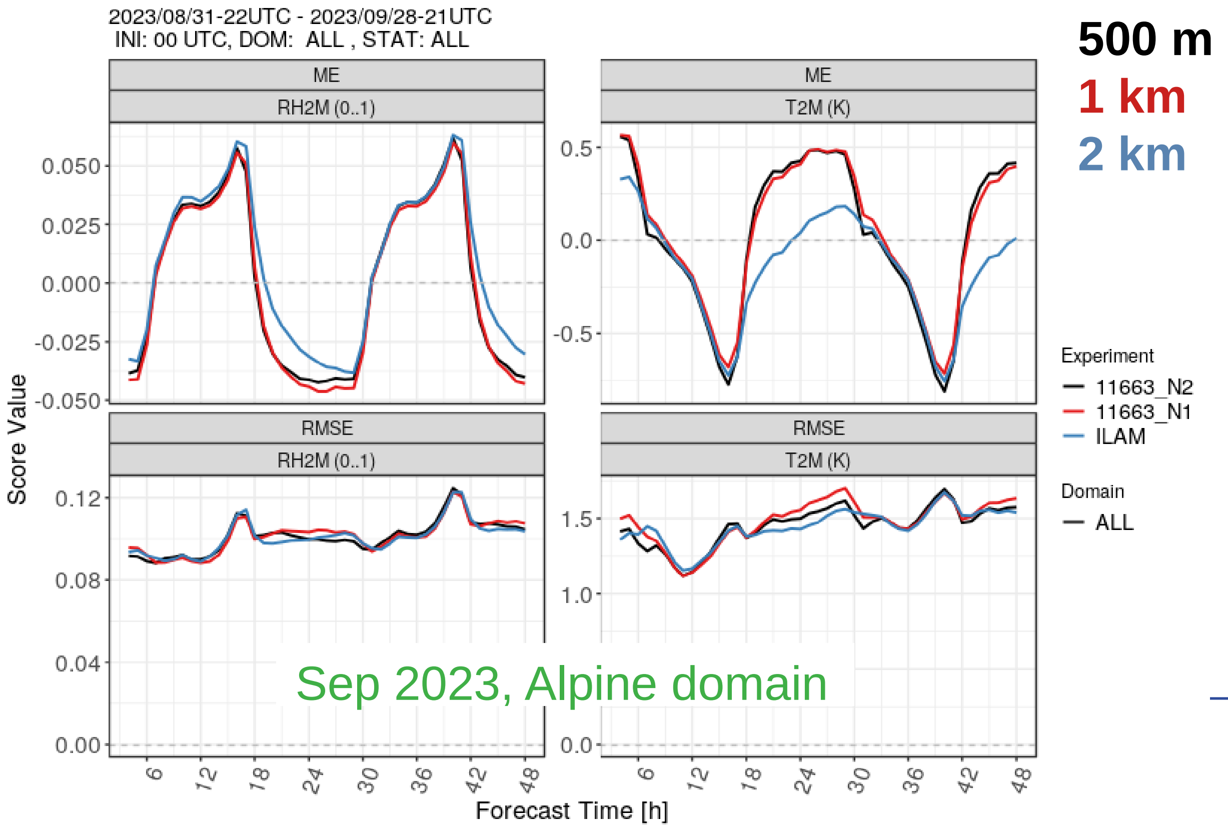
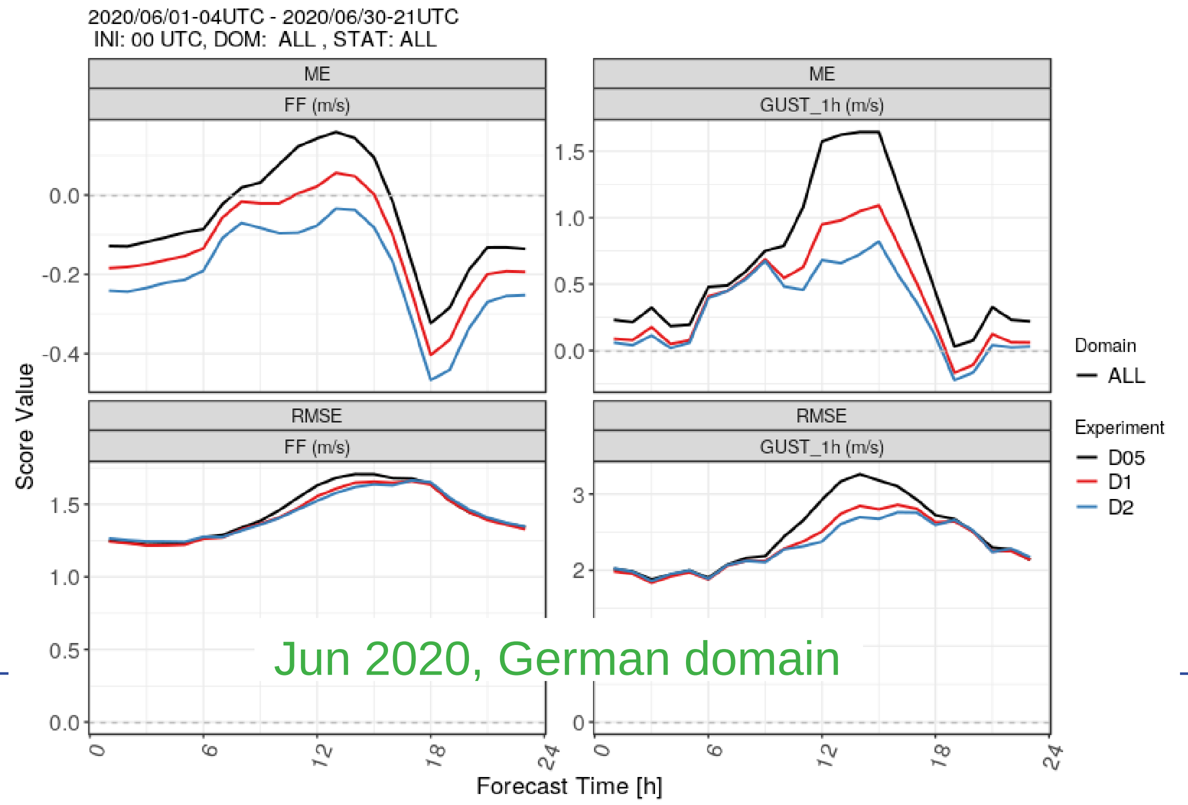
➔ However, there are also several issues needing further consideration

- Increased nocturnal warm bias in valleys during the summer months
- Large overestimation of diagnosed wind gusts in summertime conditions with a deep daytime PBL due to double-counting issues with 'permitted large eddies'



Sep 2023, Alpine domain



Jun 2020, German domain

ICON-LAM with 500 m

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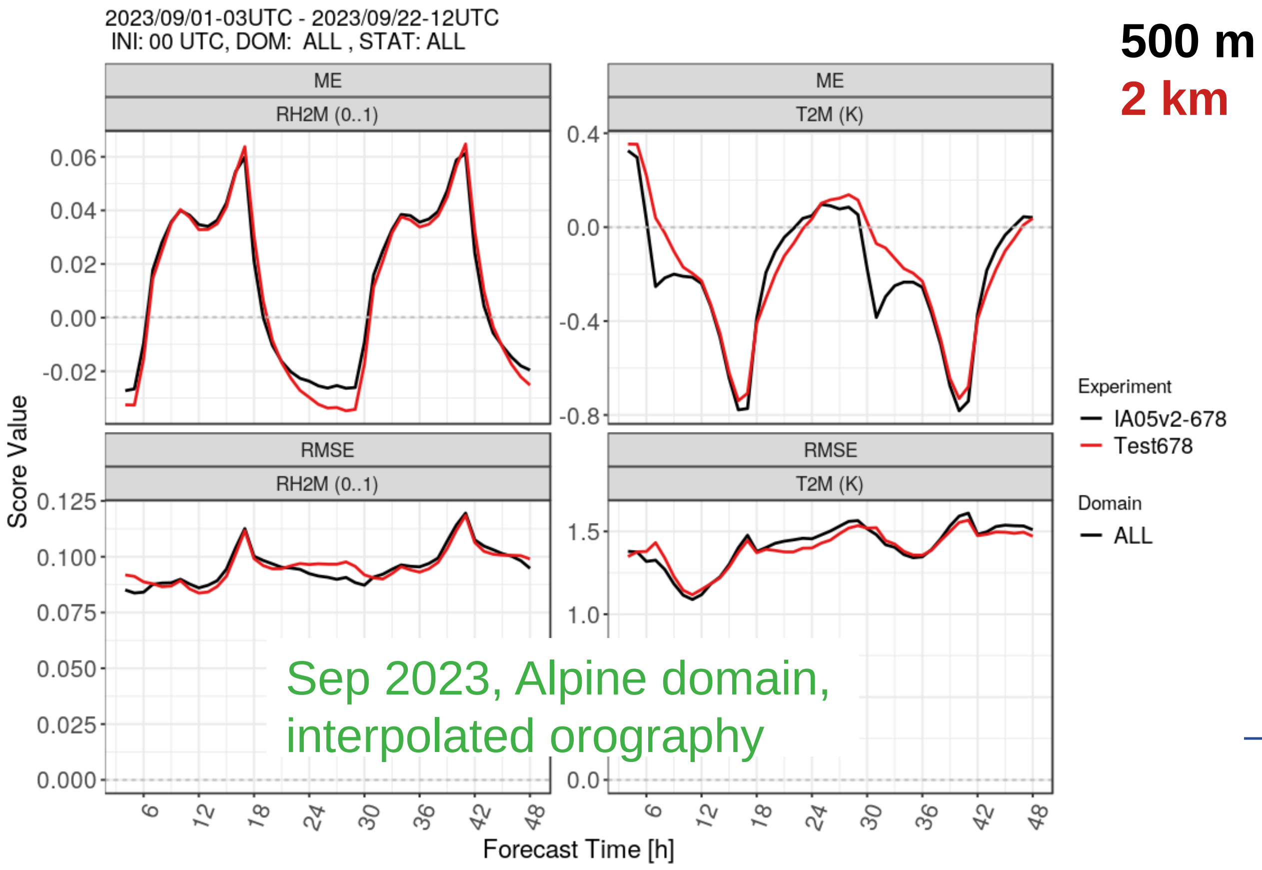
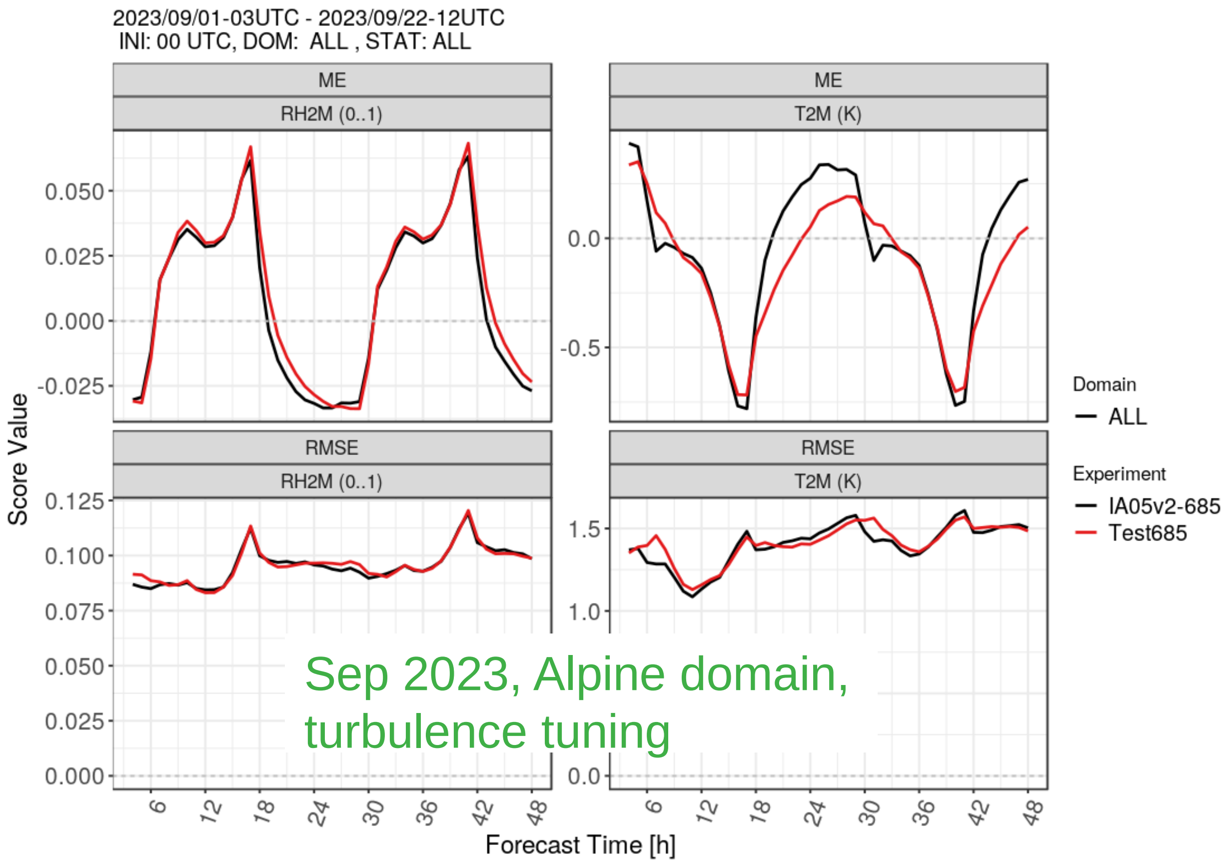
➔ **Further findings related to the nocturnal temperature bias difference**

- **Interpolating the model orography from 2 km to 500 m removes the bias difference (left)**
- **Reducing parameterized turbulent mixing over sloping terrain reduces the bias difference (right)**



500 m
2 km

Sep 2023, Alpine domain, interpolated orography



Sep 2023, Alpine domain, turbulence tuning

ICON-LAM with 500 m

➔ **Tuning changes / model improvements developed and implemented so far**

- **Slightly increased orography filtering**
- **Reduced parameterized turbulent mixing over sloping terrain, combined with reduced transfer resistance for surface fluxes**
- **Reduced SSO source term for TKE**
- **Turn off sub-grid-scale condensation heating at 500 m**
- **Reduced distribution width in subgrid-scale cloud cover near the surface (to avoid excessive fog formation)**
- **Revision of resolution-dependence of tuning parameters in convection scheme (shallow convection is still active at 500 m)**

Under investigation

- **Reduced snow albedo over steep slopes**
- **Time-filtered 10-m winds as input for gust diagnosis**

Summary

- ➔ Resolving the vertically propagating part of the GW spectrum by no means guarantees that the vertical profile of momentum exchange with the mean flow is correct
- ➔ In particular, the SSO/GWD parameterization continues to be needed at much finer resolutions than one would intuitively expect
- ➔ Further investigations – and observational data – are needed to see which mesh size we need to fully resolve orographic GWD

- ➔ Going down to 500 m has obvious benefits in mountainous regions because the orography is better resolved
- ➔ However, permitting / partly resolving slope flows and large turbulent eddies leads us into the next gray zones