The way towards global convection-permitting simulations: Challenges and opportunities

Günther Zängl

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with contributions from Nils Wedi, Peter Bechtold et al. (ECMWF) and Ariane Frassoni / Saulo Freitas (INPE)

Background / motivation

- **Global convection-permitting modelling is pursued in various upcoming Exascale projects**
- **Their focus is mostly on technical aspects (GPU port, DSL, parallel I/O), tacitly assuming that existing models will deliver higher forecast quality just by operating them at convection-permitting resolution and turning off the deep-convection scheme**
- **This investigation aims at demonstrating that major investments in parameterization development are needed as well**
- **As you will see, bias issues appearing in convection-permitting mode may have opposite sign in different models**

Overview

- **Comparison between parameterized and explicitly permitted deep convection for ICON, focusing on standard NWP scores, mesh sizes 6.5 and 3.25 km**
- **IFS results at 9 and 4 km, including an improved closure accounting for the advective moisture tendency**
- **GEOS/FV3 experiments ranging from 100 to 3 km, focusing on the performance of the scale-aware Grell-Freitas scheme**
- **Summary / conclusions**

ICON experiments

- ICON forecast runs for January 2021 (only the first 5 days for the time being) at R3B9 (3.25 km) with and without deep convection scheme; reference experiment at R3B8 (6.5 km)
- 120 vertical layers extending up to 75 km
- Initial conditions interpolated from IFS analyses for atmospheric fields, combined with interpolated surface fields from ICON analyses

Evaluation metrics:

- Standard verification against SYNOP and TEMP observations
- Analysis verification against IFS data

Some remarks on ICON expts

- **Orography data have a raw resolution of 30" (~1 km), which is insufficient for a proper calculation of SSO parameters for a 3 km grid (and barely sufficient for 6.5 km)**

- **On DWD's NEC SX Aurora, 45 nodes (with 64 cores each; 2880 cores in total) are needed for R3B9L120 to fit into the memory; a 7.5-day forecast takes about 5 hours in this case**
- **With 75 nodes (4800 cores), the 7.5-day forecast takes about 3 h 10 min**
- **After fixing an initial error in the external parameter generation, no numerical stability issues were encountered**

IFS and GEOS/FV3 experiments

- 9 km and 4 km L137 for a variety of test periods (1.4 km tests not discussed in this presentation)
- On the ECMWF slides, Q_{adv} denotes the improved convection closure

DYAMOND: FV3 NH Simulations of August 2016 (40-days)

GEOS Global Simulations

- 100km (c90) 72-levels
- 50km (c180) 72-levels
- 25km (c360) 72-levels
- 12km (c720) 72-levels
- 6km (c1440) 72-levels
- 3km (c2880) 72-levels [20,000 cores; 6.5 days/day … with chemistry coupling]

Scale-aware convective parameterization

- Grell-Freitas & UW ShallowCu
- Additional 3-km cases with DeepCu disabled (noDP) and Scale-Awareness disabled (noSA)

Cloud microphysics

- Single-moment GEOS microphysics

ICON results

- **Next two slides: comparison 3.25 km vs. 6.5 km, both with deep convection scheme**
- **Subsequent slides: 3.25 km without vs. with deep convection scheme**

Score card for verification against radiosondes, 6.5 km vs. 3.25 km (green: 3.25 km better)

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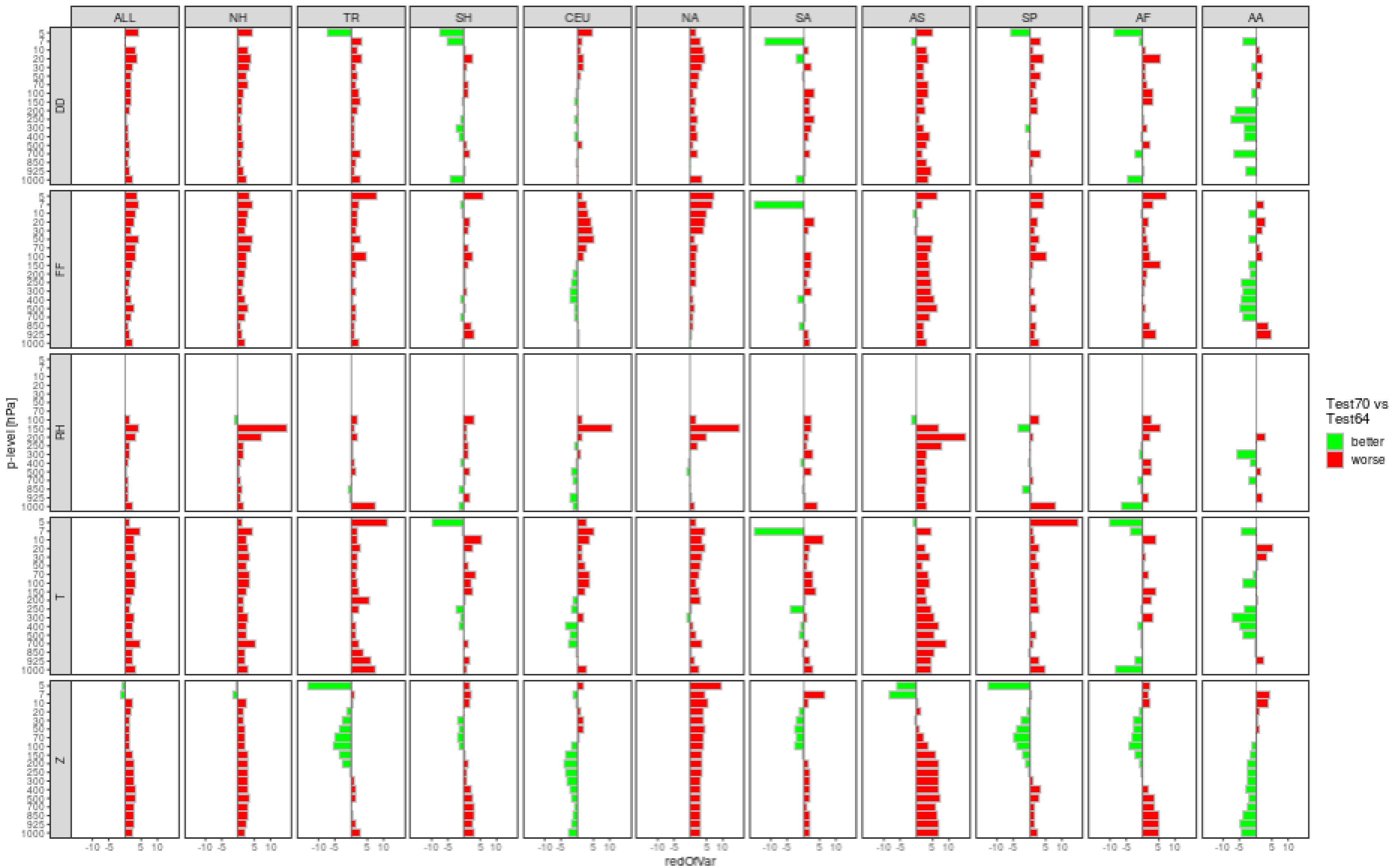
Verification period: 2021/01/01 - 2021/01/12
Data selection by initial-date
Reduction of RMSE [%]

degradation in NH may be due to poor quality of SSO data



Score card for verification against SYNOP data, 6.5 km vs. 3.25 km (green: 3.25 km better)

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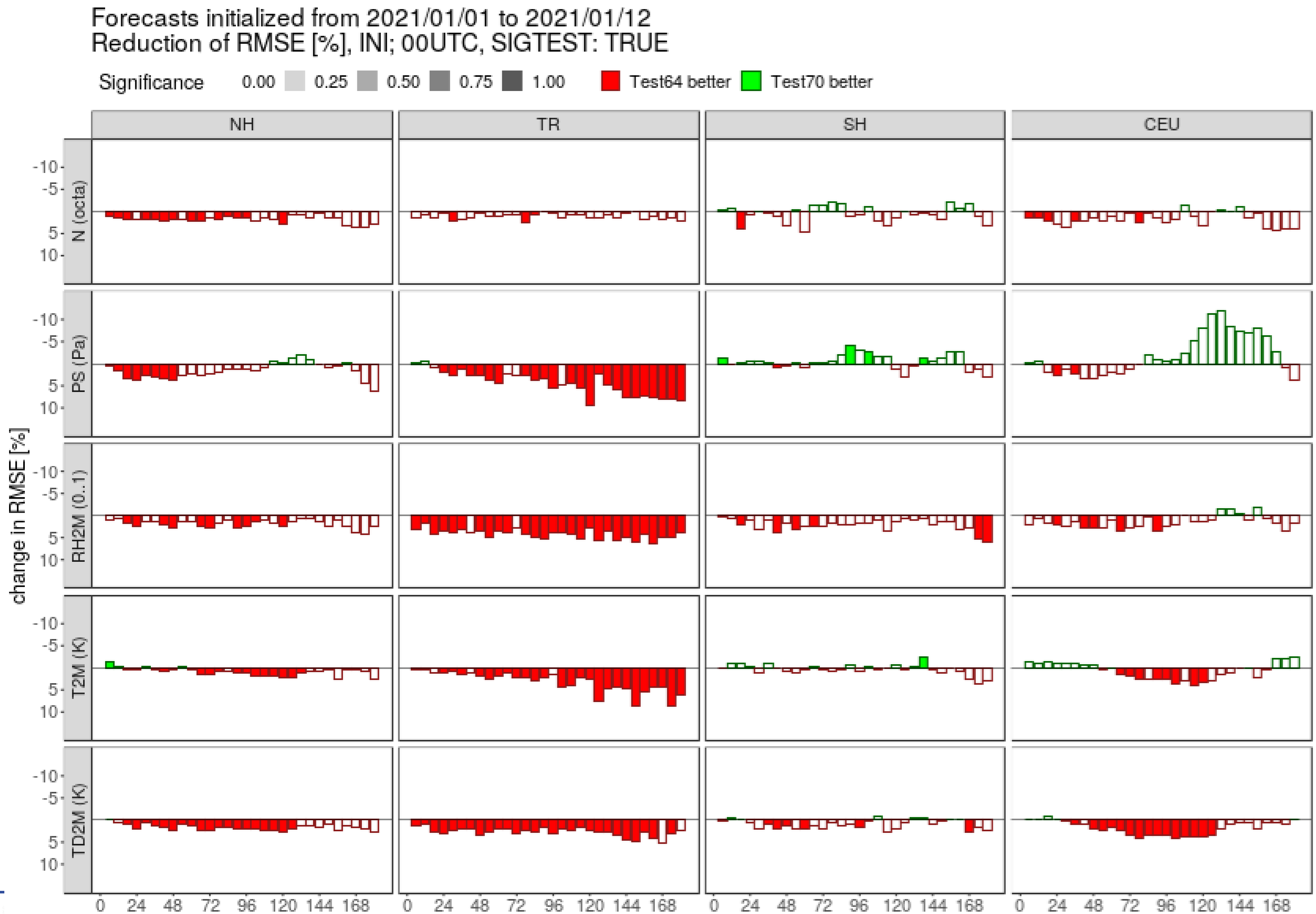

Verification against radiosondes, 3.25 km (green: better without deep convection)

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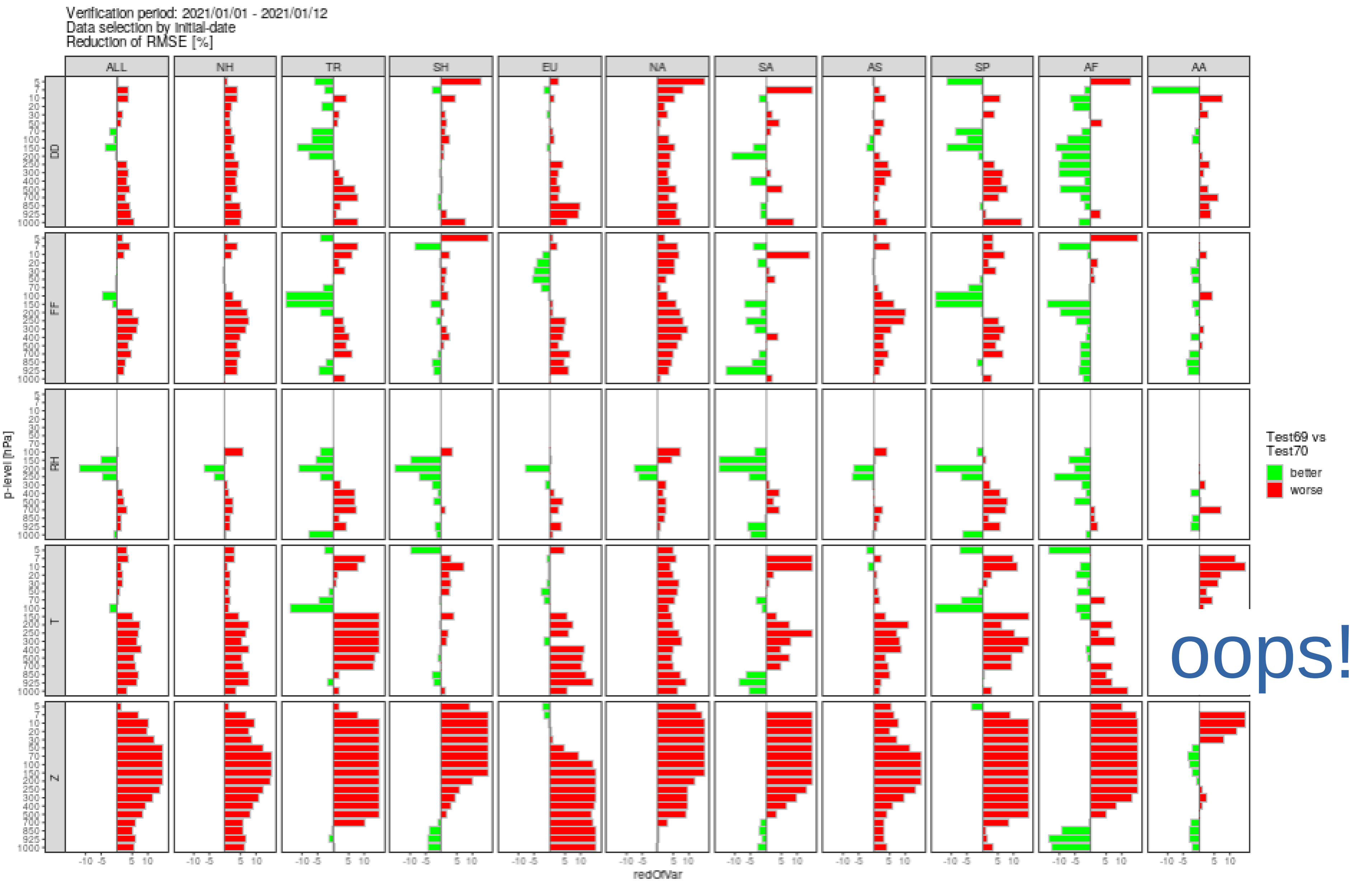

Verification against radiosondes, 3.25 km (green: better without deep convection)

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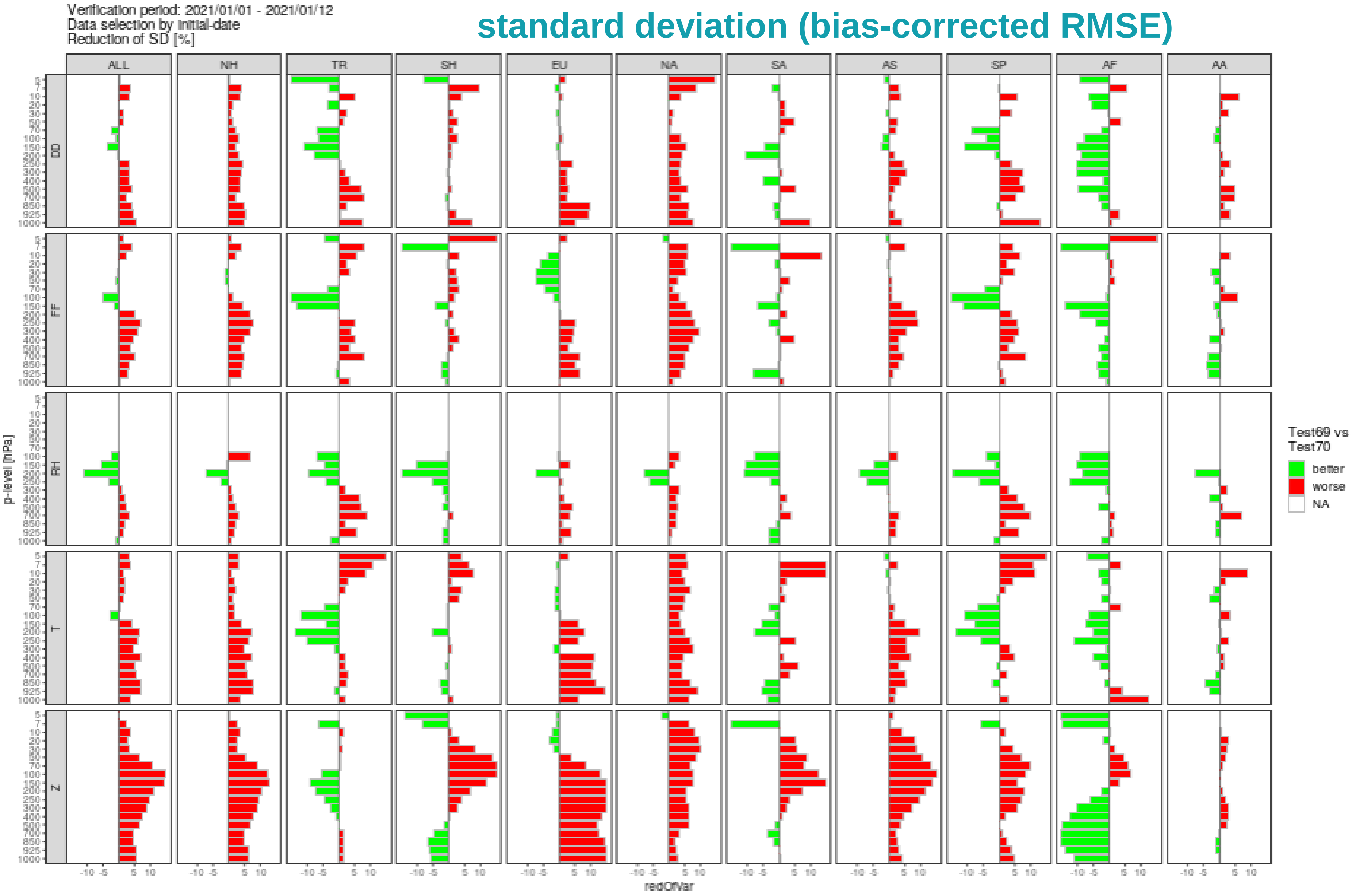
standard deviation (bias-corrected RMSE)



Analysis verification, tropics, 250 hPa
without / with deep convection scheme

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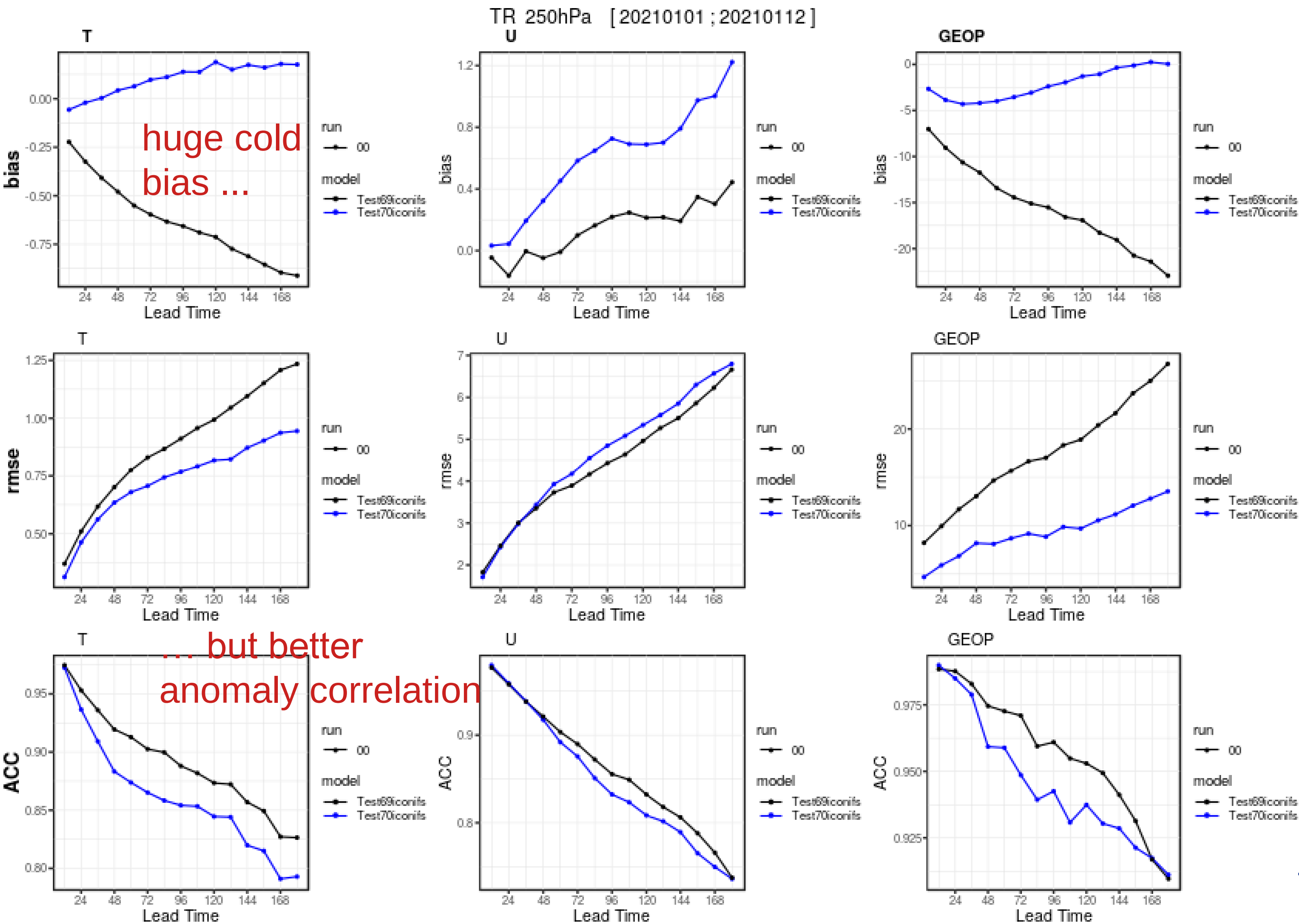

Precipitation verification, tropics
without / with deep convection scheme

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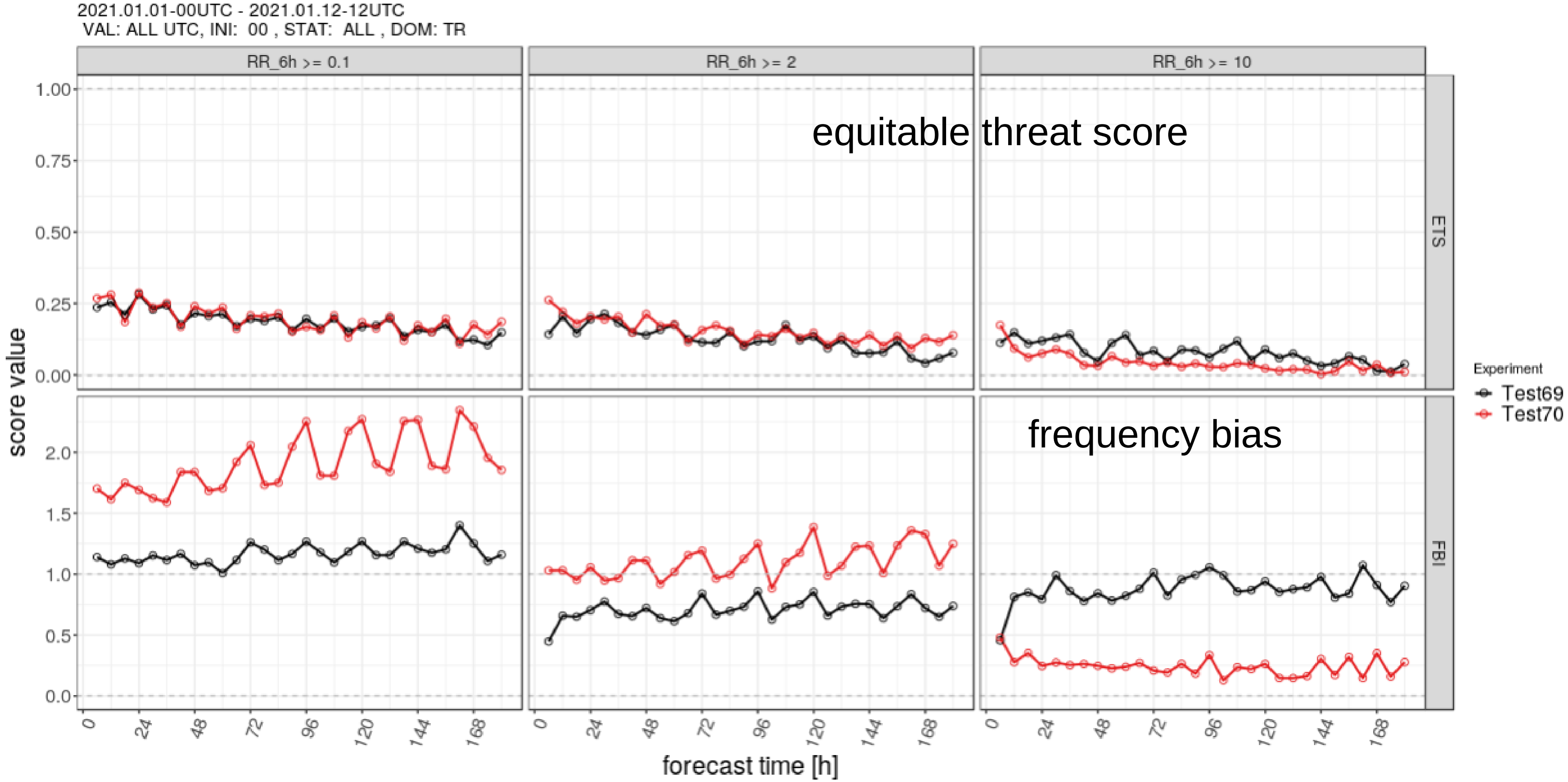


Much better representation of intensity spectrum

Summary of ICON results

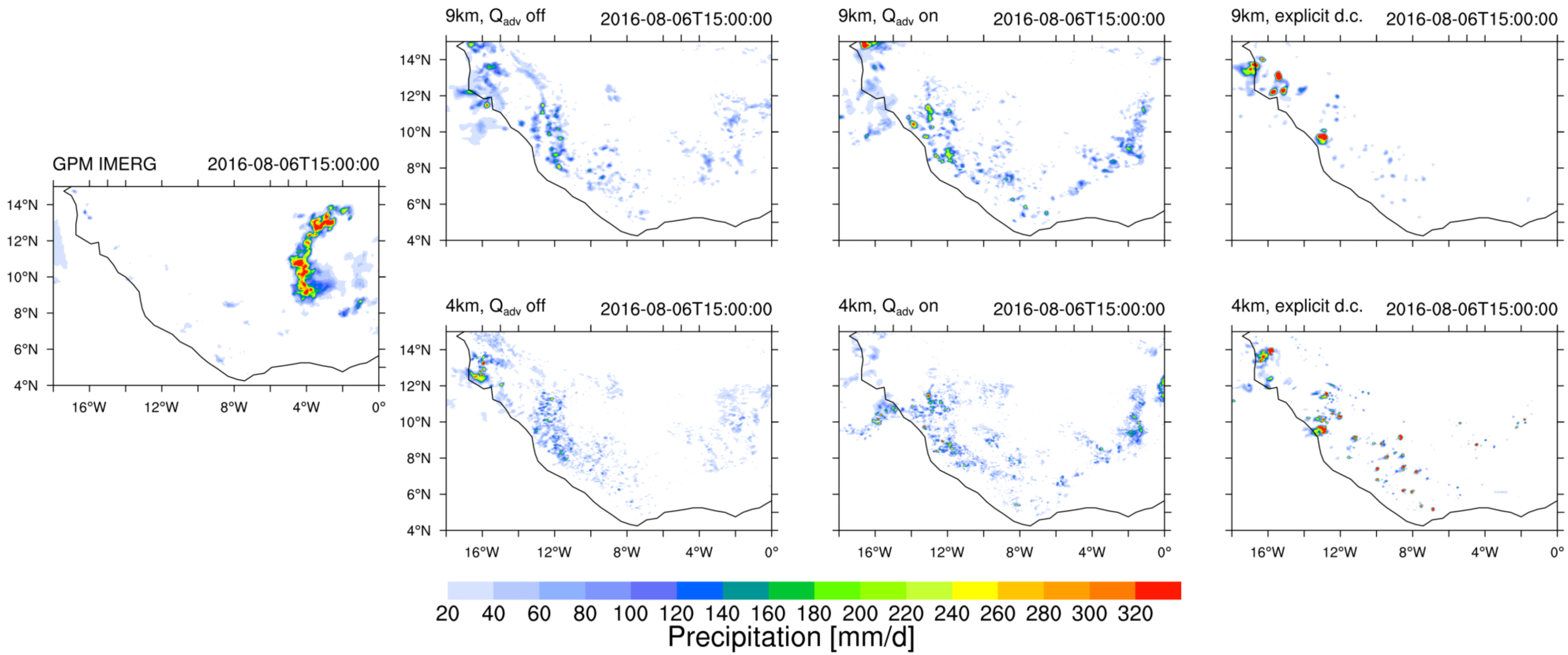
- With deep convection active, atmospheric scores degrade when moving from 6.5 km to 3.25 km particularly in North America and Asia. Insufficient resolution of orography data for calculating SSO parameters might play a role here

- With explicitly simulated convection, some aspects that are well known to be notoriously misrepresented by parameterizations improve: intensity spectrum and diurnal cycle of convection, probably also organization and propagation of mesoscale convective systems

- However, a huge cold bias arises that has its maximum in the upper tropical troposphere. It entails a planetary-scale redistribution of mass that compromises the pressure forecast over the whole globe

IFS results

The impact of Q_adv on convective organisation



Becker, T., P. Bechtold, and I. Sandu 2021: Characteristics of convective precipitation over tropical Africa in storm-resolving global simulations. *Q. J. Roy. Meteorol. Soc. 2021*

IFS results

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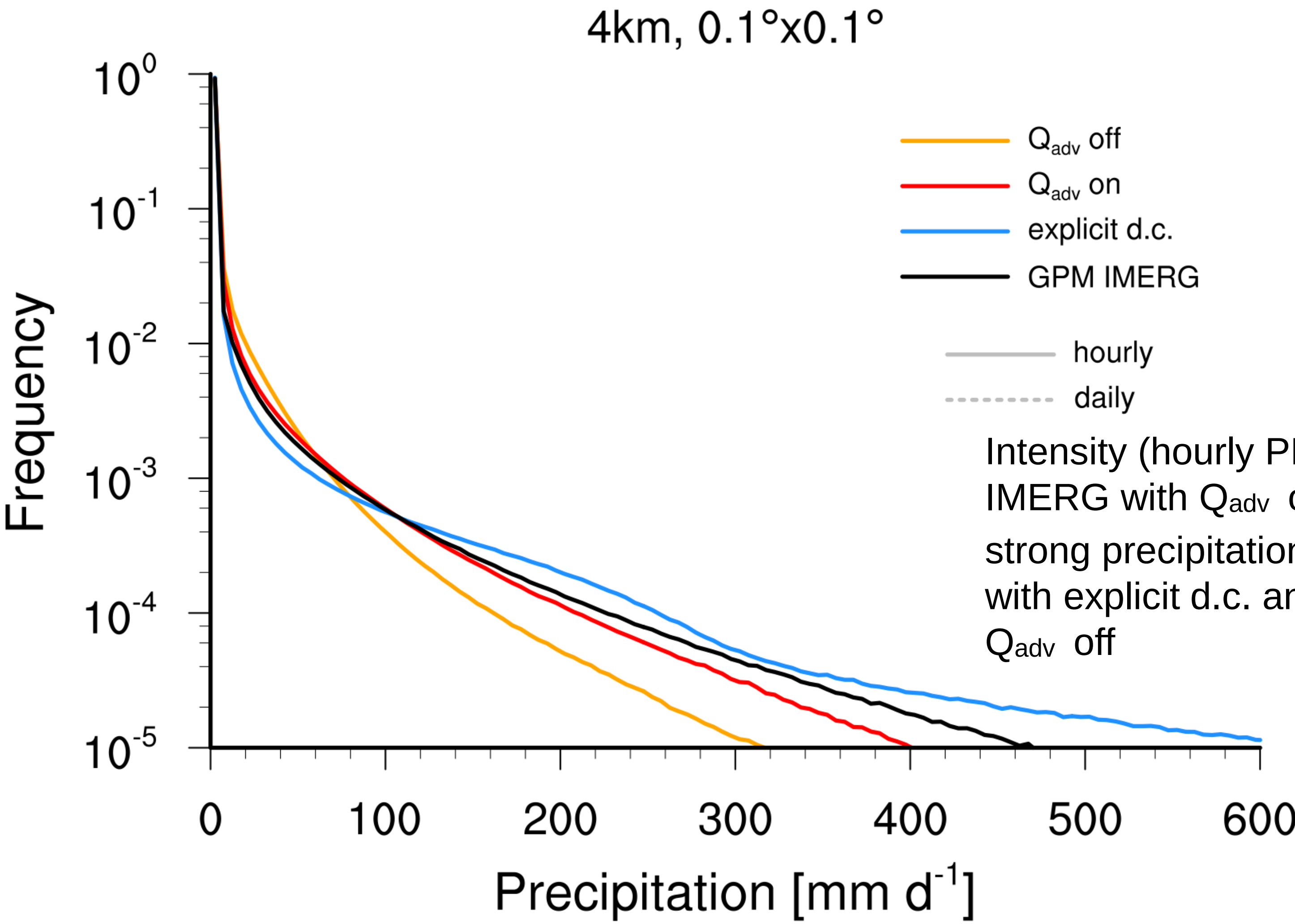
The impact of Q_adv on precipitation rates: Intensity, Size and Duration



Intensity (hourly PDF): close to GPM IMERG with Q_{adv} on ;

strong precipitation events overestimated with explicit d.c. and underestimated with Q_{adv} off

IFS results

Summary - Towards realistic mesoscale convective systems

Precipitation / MCS	Q_{adv} off	Q_{adv} on	**explicit d. c.**
Mean	good fit	best spatial fit	wet regions too wet
Intensity	underestimated	best fit	overestimated
Size	overestimated	best fit	underestimated
Duration	underestimated	underestimated	best fit
Diurnal Cycle	rain peaks too early	nocturnal improved	best fit
Propagation	eastward	westward	westward, though systems too small

Overall, best agreement with satellite observations with Q_{adv} on
➔ a form of deep convection parameterization is still needed, even at 4 km resolution

Characteristics of mesoscale convective systems are mostly independent of resolution
➔ to get full benefit of 4 km resolution, more work is needed

IFS results

47r3 deep off 4km-47r1

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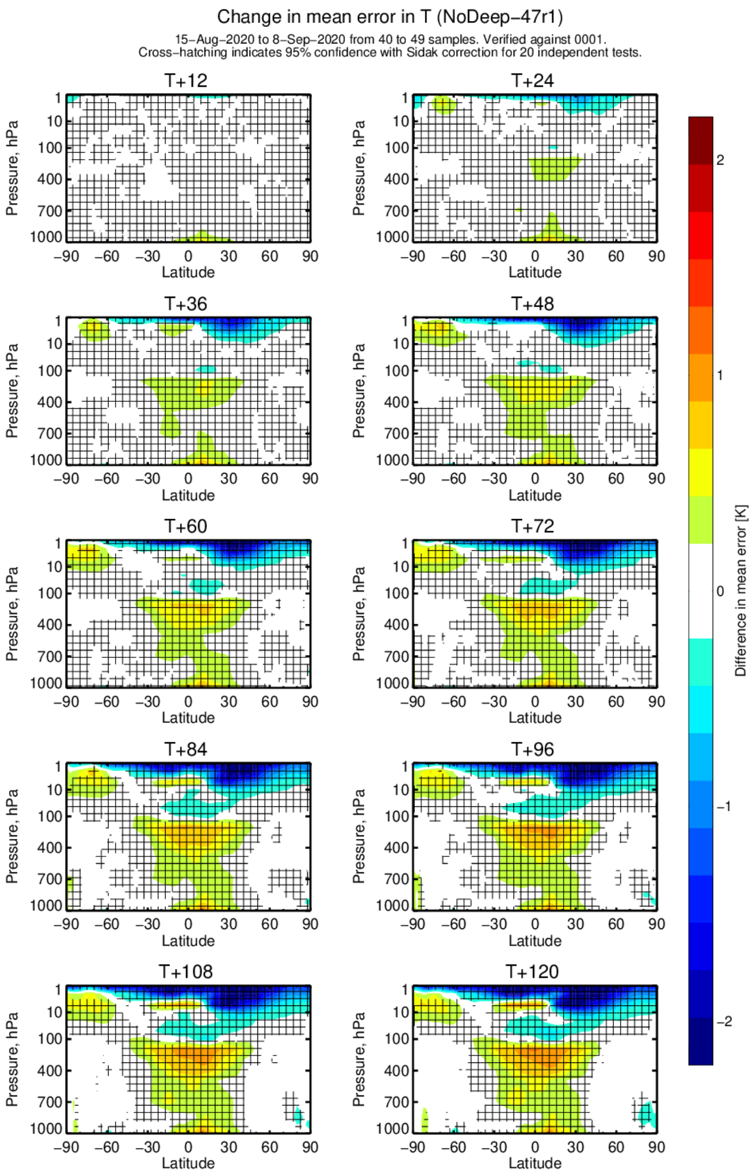
bias T



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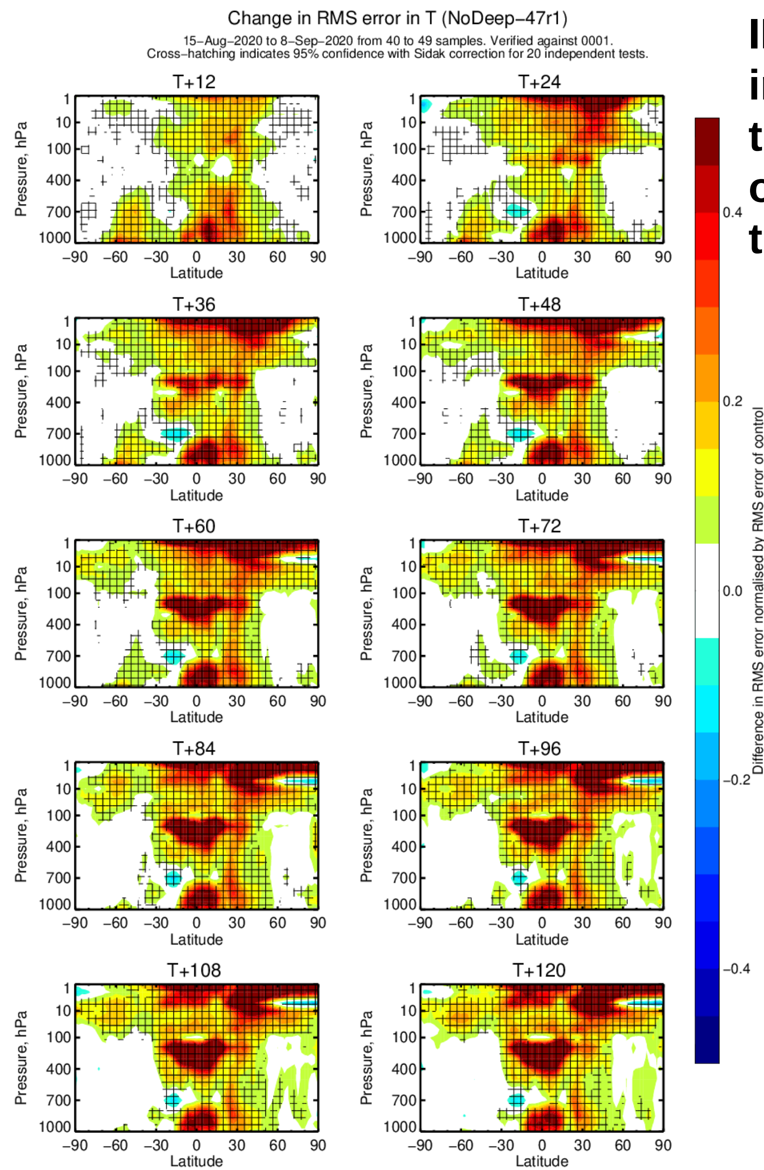
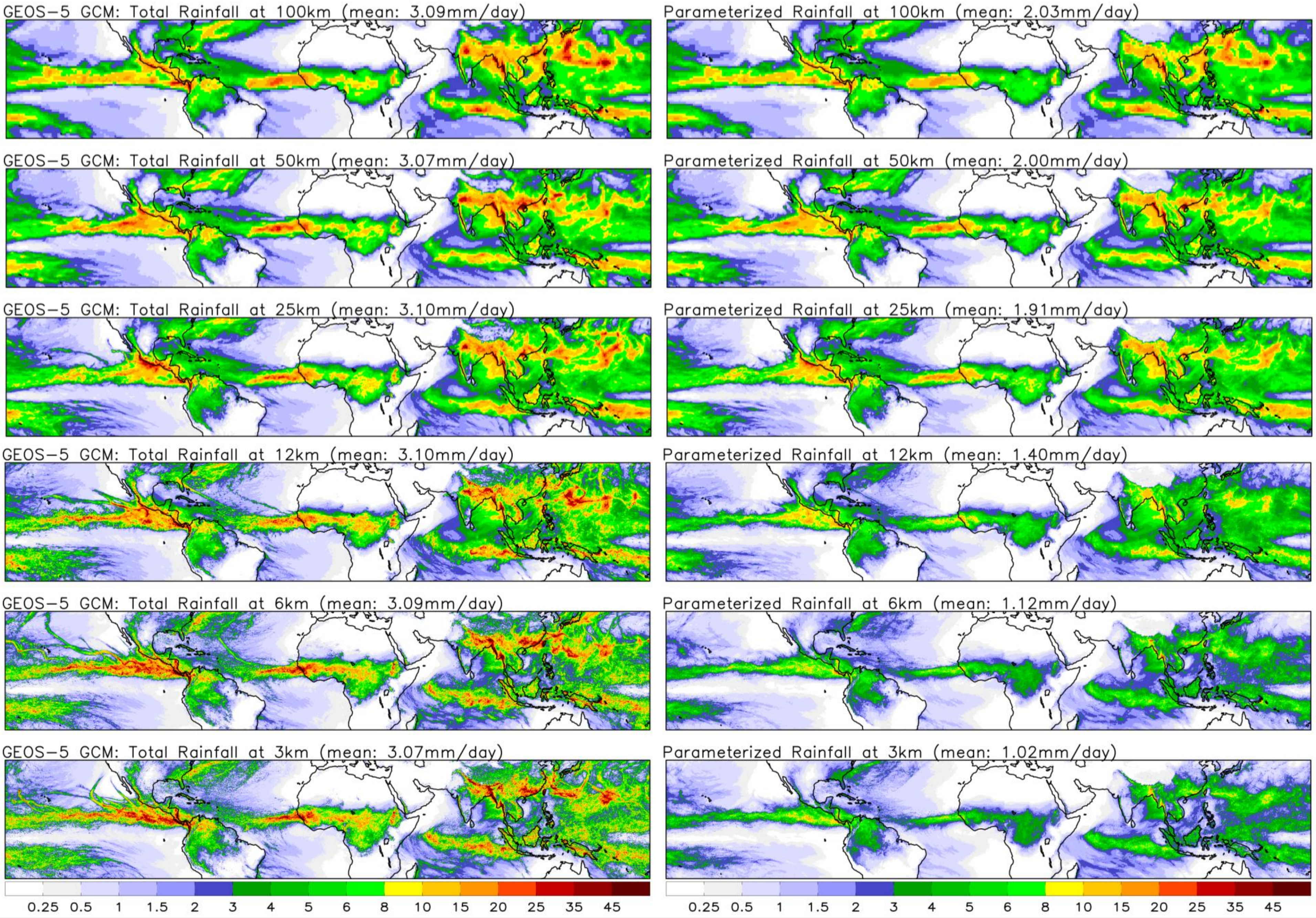


In contrast to ICON IFS gets too warm in upper tropical troposphere without deep convection scheme

GEOS-FV3 results: scale-aware deep convection scheme

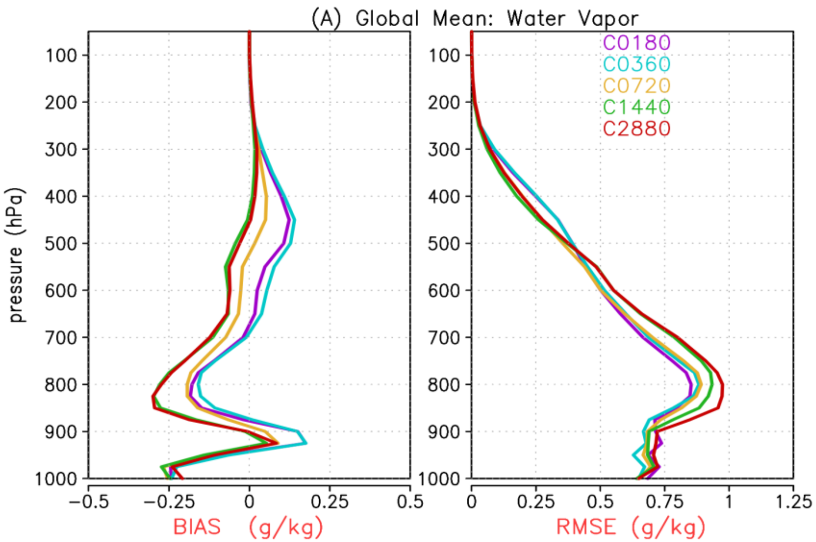


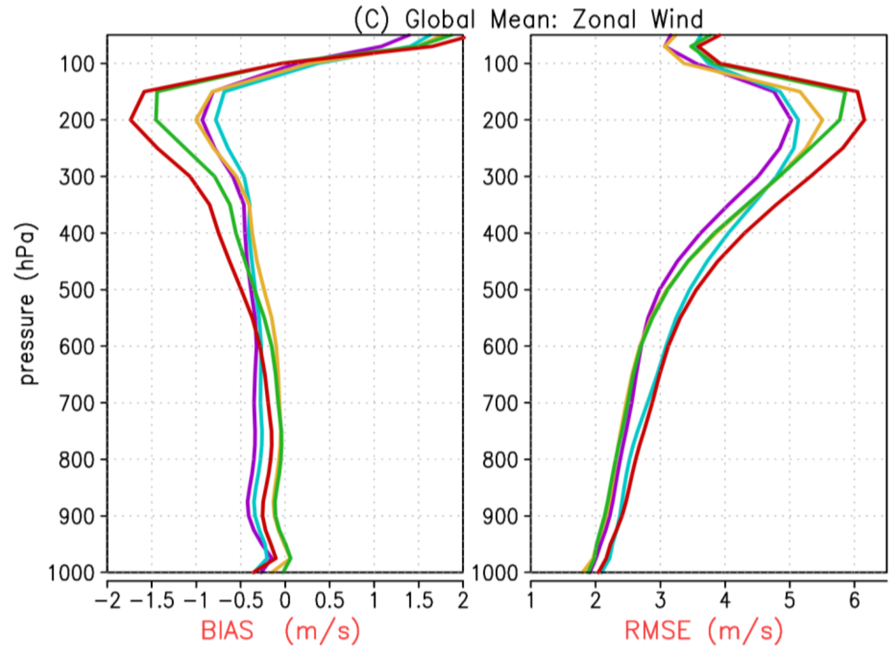
Summary of the scale dependence of precipitation of GEOS GCM in the DYAMOND runs

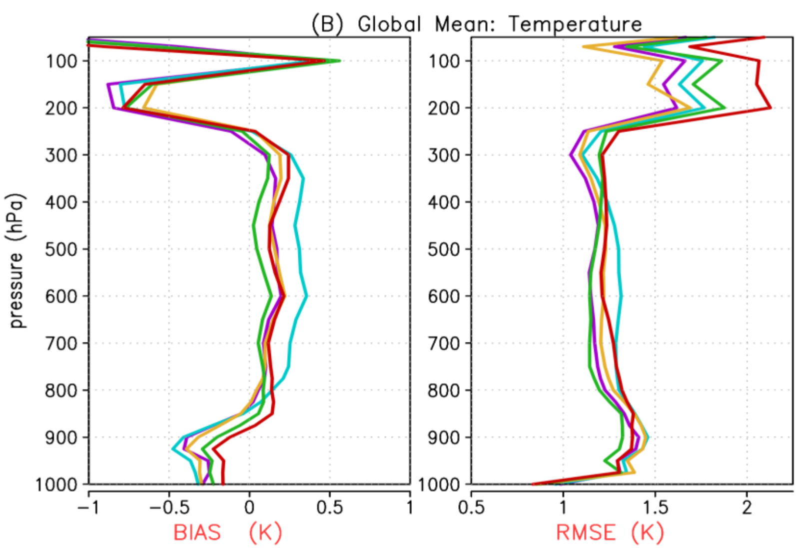
GEOS GCM horizontal resolution		Global Mean for Aug 2016		
		Precipitation (mm/day)		Fraction (parameterized /total)
		Parameterized	Total	
C0090	~100km	2.03	3.09	66%
C0180	~ 050km	2.00	3.07	65%
C0360	~ 025km	1.91	3.10	62%
C0720	~ 012km	1.40	3.10	45%
C1440	~ 006km	1.12	3.09	36%
C2880	~ 003km	1.02	3.07	33%

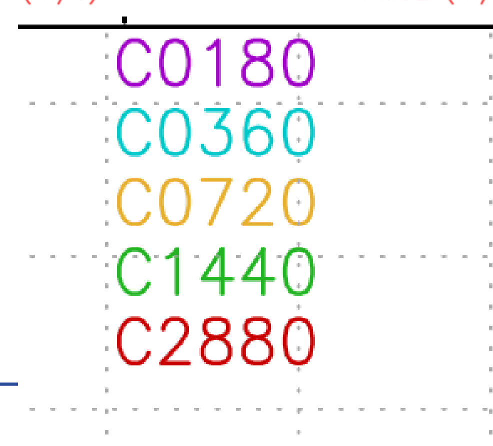
GEOS-FV3 results

Global Monthly Mean of BIAS/RMSE using ERA-5 as the reference









GEOS-FV3 results

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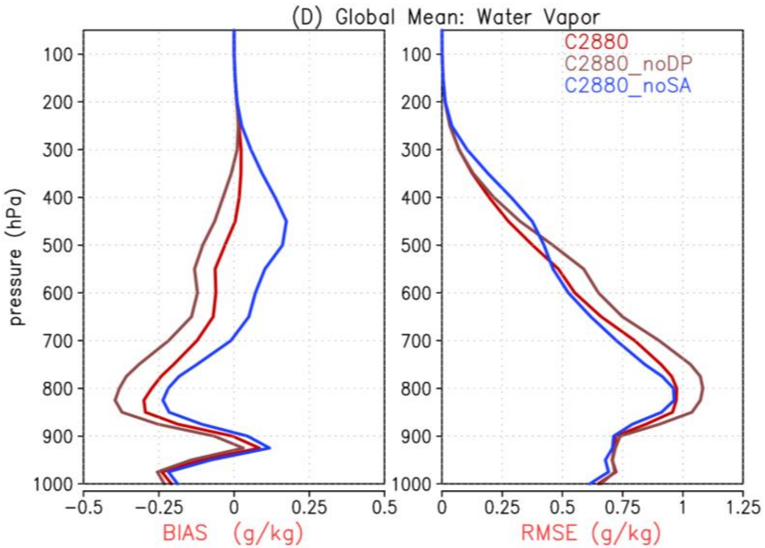
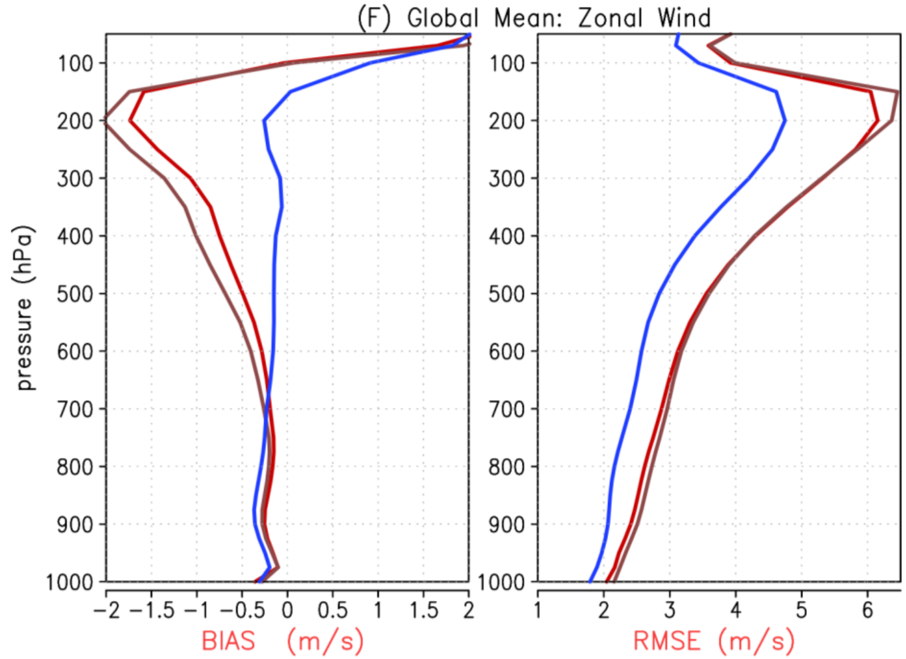
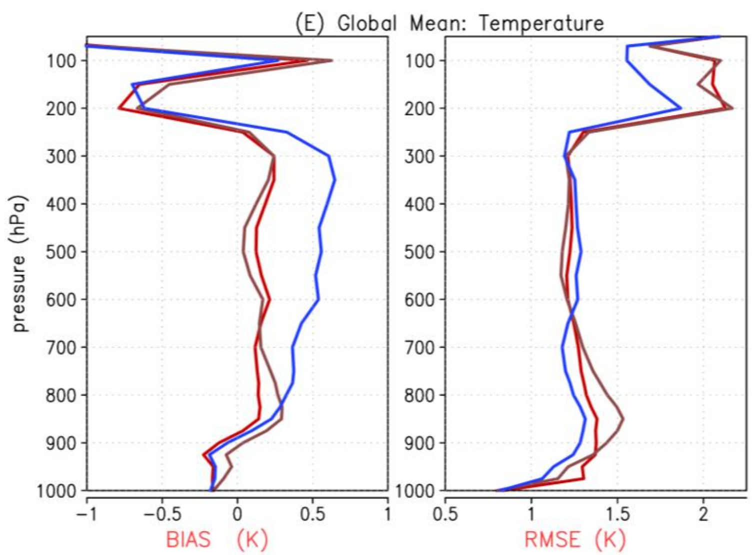
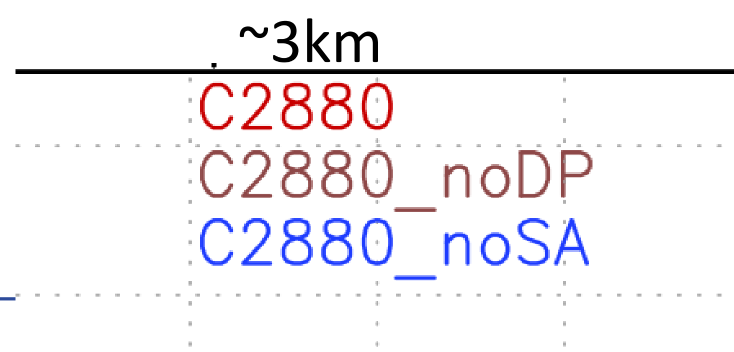
Global Monthly Mean of BIAS/RMSE using ERA-5 as the reference









Final summary

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- All three models considered here exhibit pronounced deficits without a parameterization for deep convection, but their characteristics differ strongly from each other:
- ICON shows a large cold bias in the middle and upper tropical troposphere because triggering resolved convection requires a larger amount of instability than the parameterization does.
- On the other hand, IFS generates more precipitation and thus more latent heat release and a warm bias without deep convection scheme. In addition, the organization of convection is not as good as with the revised closure.
- GEOS-FV3 shows comparatively little temperature bias change when deep convection is turned off, but humidity and wind profiles degrade. The scale-awareness of the deep convection scheme allows for a gradual decrease of the parameterized precip fraction in the gray zone, but wind profiles (and some other aspects) are better without this option.