

Feedback processes between radiances and the ICON model

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1. Introduction

DWD introduced a new global nonhydrostatic model on 20 January 2015. During the adaptation of the operational data assimilation system to the new model several problems occurred, that were traced back to feedback processes between radiances and model physics/dynamics. Three feedback processes are presented and discussed here.

Assimilation of radiances:

- AMSU-A: channels 9-14 everywhere, 5-8 sea only
- ATMS: as AMSU-A, but 3x3 superobbing
- IASI: 46 channels, sea only
- McNally-Watts cloud detection
- HIRS: channels 4-7 and 14,15; sea only and cloud-free
- „Online“ bias correction (ECMWF predictors)

ICON (ICOsaedral Nonhydrostatic modelling framework):

- Nonhydrostatic model, mass-conserving
- Icosahedral grid, C-grid stag., 13km resolution
- Convection: Bechtold, radiation: RRTM
- Terrain-following hybrid σ -z coord.: 90 Levels up to 75km
- Multiple high-resolution nests (1 and 2 way)



2. Convection scheme feedback

Mechanism:

The model stratification in the Tropics is too stable: it is too cold in the boundary layer and too warm in the middle and upper troposphere. As a consequence obs-fg for tropospheric channels is negative on average. The assimilation of these channels results in the following feedback:

- 1) Negative obs-fg
- 2) Cooling between 700-200hPa and humidification below, since the „temperature sensitive“ channels have a small negative humidity sensitivity with a peak slightly below the temperature peak. (See Fig. 2)
- 3) Destabilization
- 4) More convection
- 5) Heating in the middle and high troposphere
- 6) Even more negative obs-fg → 1)

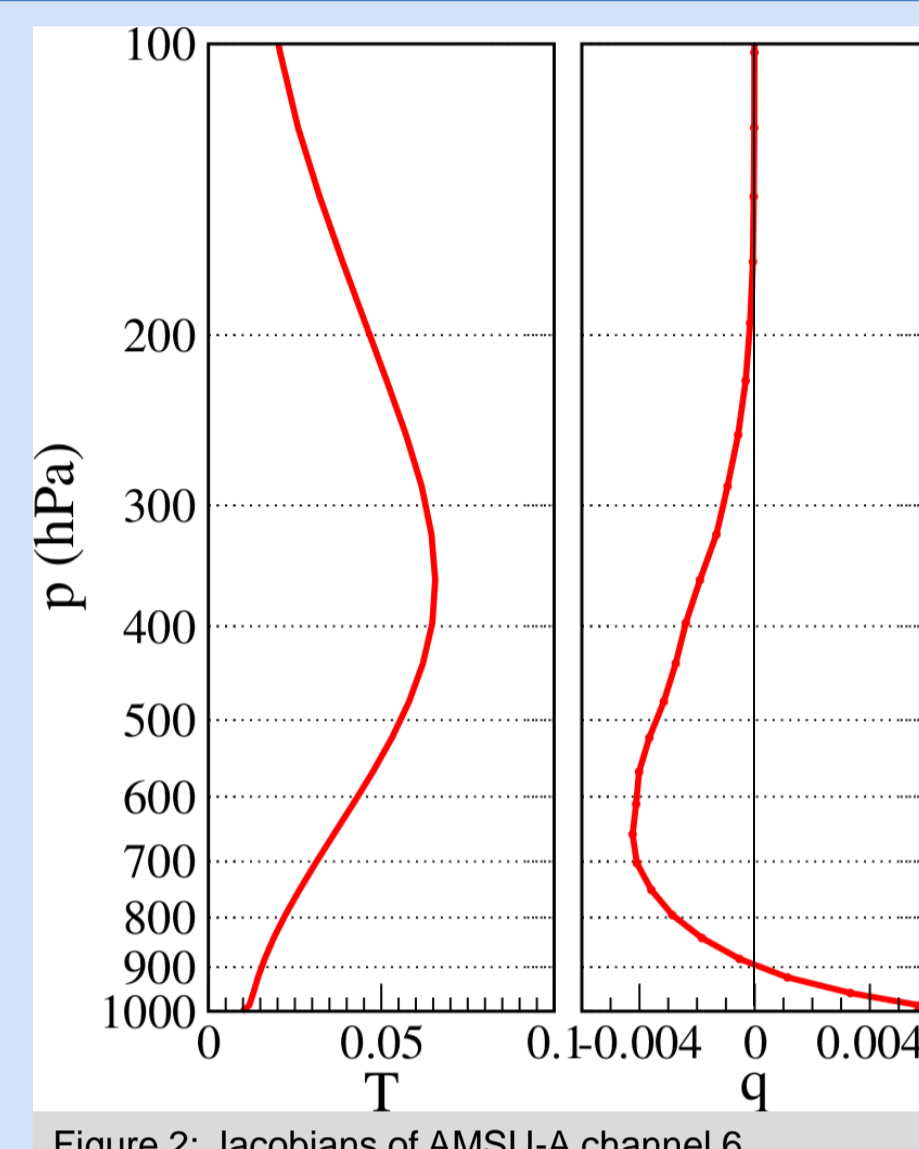


Figure 2: Jacobians of AMSU-A channel 6

Initial tests with ICON: feedback catastrophe

Problem: In first data assimilation tests with ICON this feedback was so strong, that the model behaved completely unrealistic in the tropics: the excessive convection caused an excessive warm model bias in the middle and upper troposphere. As a consequence the online bias correction tried to correct for this excessive bias in the tropics and got out of control. This caused catastrophic results on the whole globe.

Solution: By decreasing the humidity background error variances by 30% the humidity background got more weight in the assimilation, and consequently observations had less influence onto the humidity analyses. Therefore, the humidification and destabilization mentioned above became weaker. With the new setting the catastrophic feedback outlined above did not occur any more.

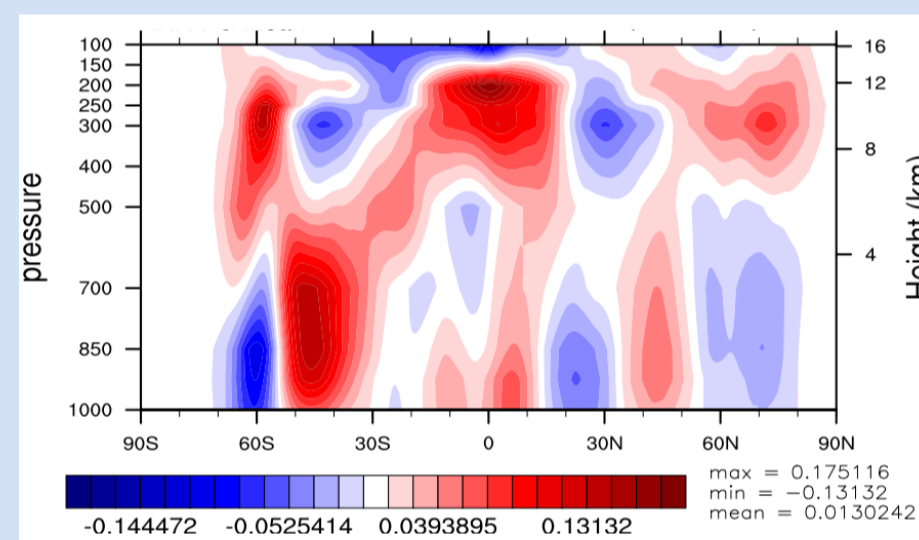


Figure 3a: Mean analysis increment by radiances with first guess fields from „no radiances“ experiment

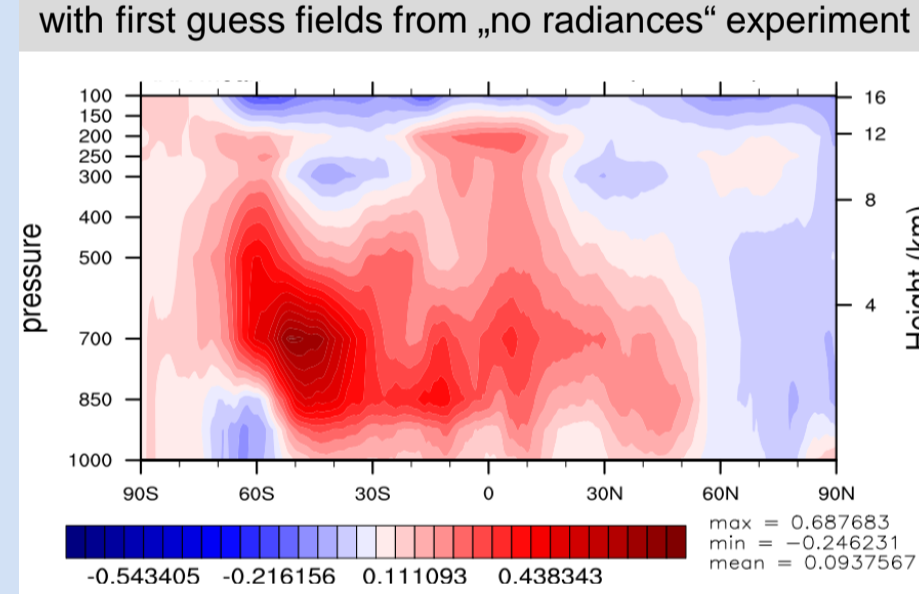


Figure 3b: Mean difference between analyses by assimilating radiances

Feedback in current system:

Fig. 3a displays the zonal mean temperature analysis increments caused by first guess fields taken from a 1-month assimilation cycle without radiances. Fig. 3b displays the zonal mean change of temperature caused by assimilating radiances. In Fig. 3a we see in which way the radiances *want to change the system*. In Fig. 3b we see, in which way the radiances *change the system* if they are assimilated. If nonlinear feedbacks were unimportant, the figures would look very similar. The obvious differences demonstrate that nonlinear feedback processes play a major role. In particular, the differences in the Tropics are due to the above mentioned feedback with the convection scheme.

3. Bias correction feedback

„Online“ bias correction scheme:

At each assimilation step the new coefficients for the bias correction are calculated. The statistics required to calculate the coefficients are updated at each assimilation step in the following way:

$$s_{new} = e^{-\frac{\Delta t}{\tau}} s_{old} + s(t) \quad (1)$$

where $\Delta t = 3h$ is the assimilation time step, $\tau = 30d$, and $s(t)$ is the contribution to the statistics at the actual time step. s_{old} is the „memory“ of the bias correction scheme.

Accidental bad initialization:

- 1) When ICON was put into the DWD preoperational suite, the bias correction was accidentally **initialized with the bias correction statistics (s_{old}) from the old GME model**. Since the higher stratosphere was not well represented in the old GME model, the bias correction of the high peaking channels is not adequate for ICON with a much better modelled stratosphere. As a consequence a **strong bias** in the tropical stratosphere evolved, which was not in agreement with the expectations from previous experiments as visible in radiooccultation obs-fg statistics (see Fig.4a and 4c).
- 2) After a **reset of the memory of the bias correction** ($s_{old} = 0$ in equation 1), it was expected that the bias disappears, but nothing happened (see Fig. 4b), i.e. the **bias did not disappear**.
- 3) Finally, only a **model coldstart** (based on IFS analyses) helped to bring the model in line with the expectations.

Interpretation: multiple climate states

- 1) Due to the inadequate initialization of the bias correction, the model was trapped in a different stable climate state, i.e. the full system (including „online“ bias corrected radiances) has multiple stable climate states
- 2) Since the bias correction is constructed to minimize a kind of „distance“ between the model first guess and the corrected radiances, the corrected radiances are not able to move the system towards the „natural“ climate state. Moreover, the bias corrected radiances might help to trap the system in a (secondary) stable climate state that is far from reality.

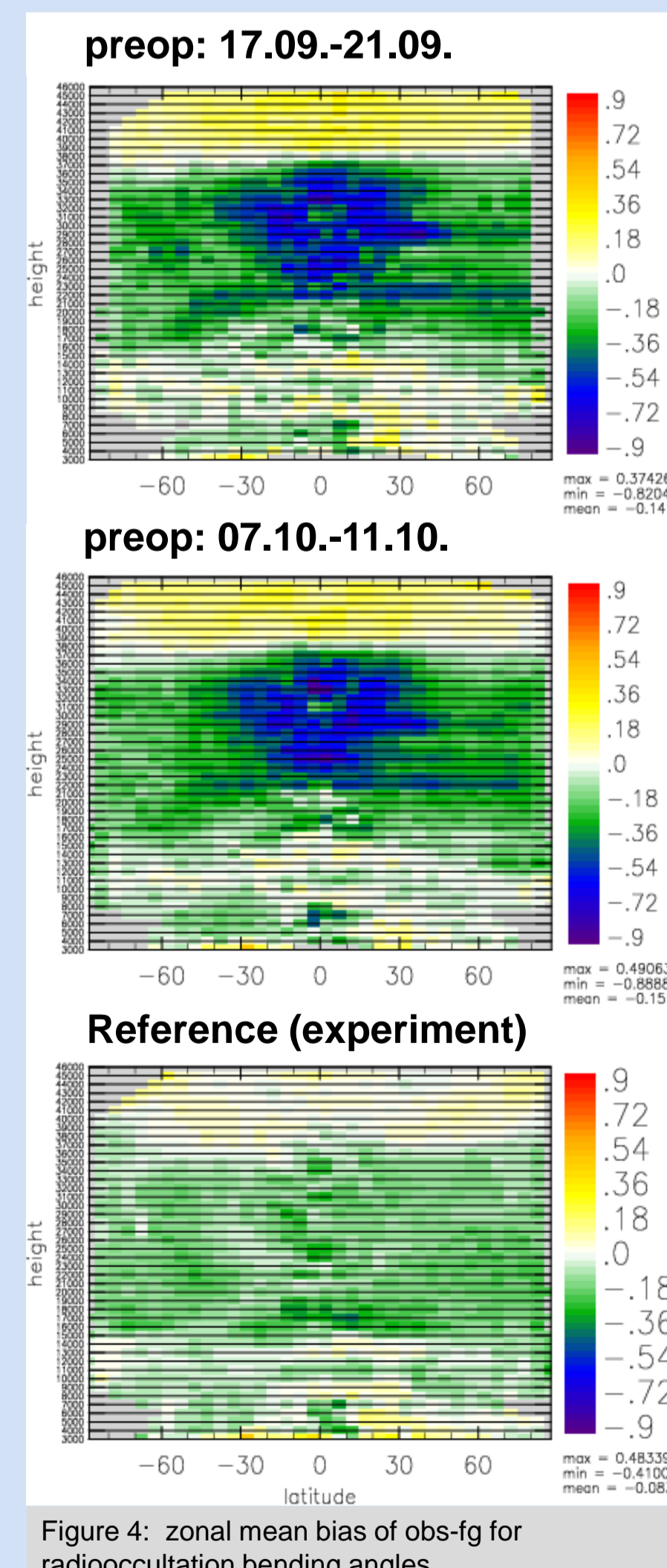


Figure 4: zonal mean bias of obs-fg for radiooccultation bending angles.

4. Tropical checkerboard pattern feedback

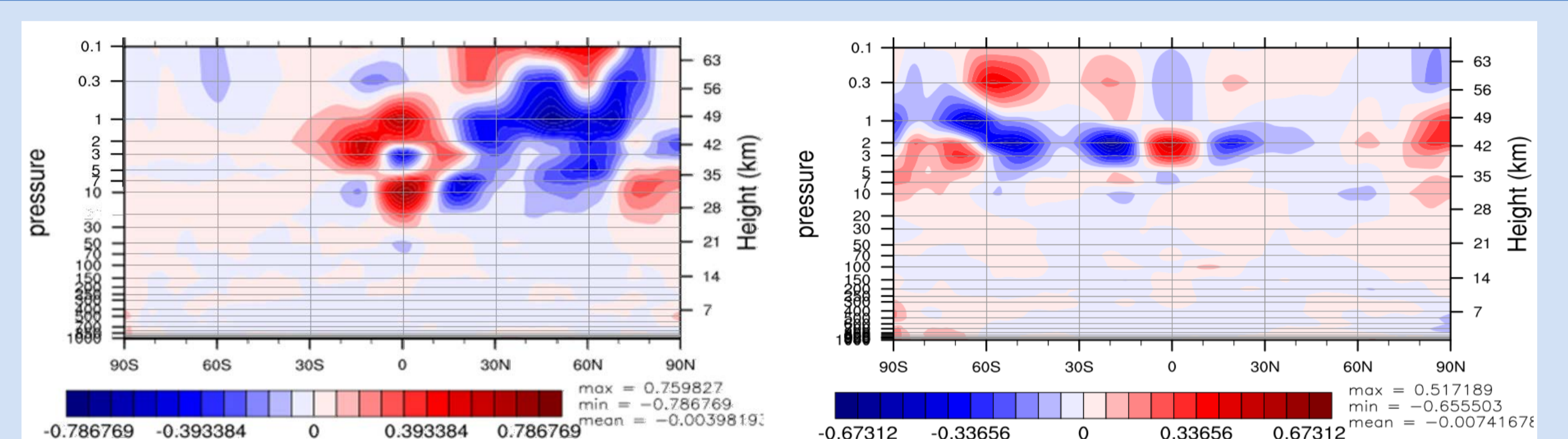


Figure 5: zonal mean time averaged temperature analysis increments for two different periods. Left: fall 2014 (preop.), right: September 2015 (op.)

Checkerboard pattern:

Fig. 5 shows two examples of zonal mean time averaged temperature analysis increments. In both examples there is a prominent checkerboard pattern in the tropical stratosphere. These patterns look unphysical and meteorologically not reasonable.

They occur only, if radiances are assimilated. Fig. 6 illustrates a strong increase of noise in the tropical stratosphere, if radiances are added to the assimilation system. This result supports the above statement, that the checkerboard pattern is meteorologically not reasonable.

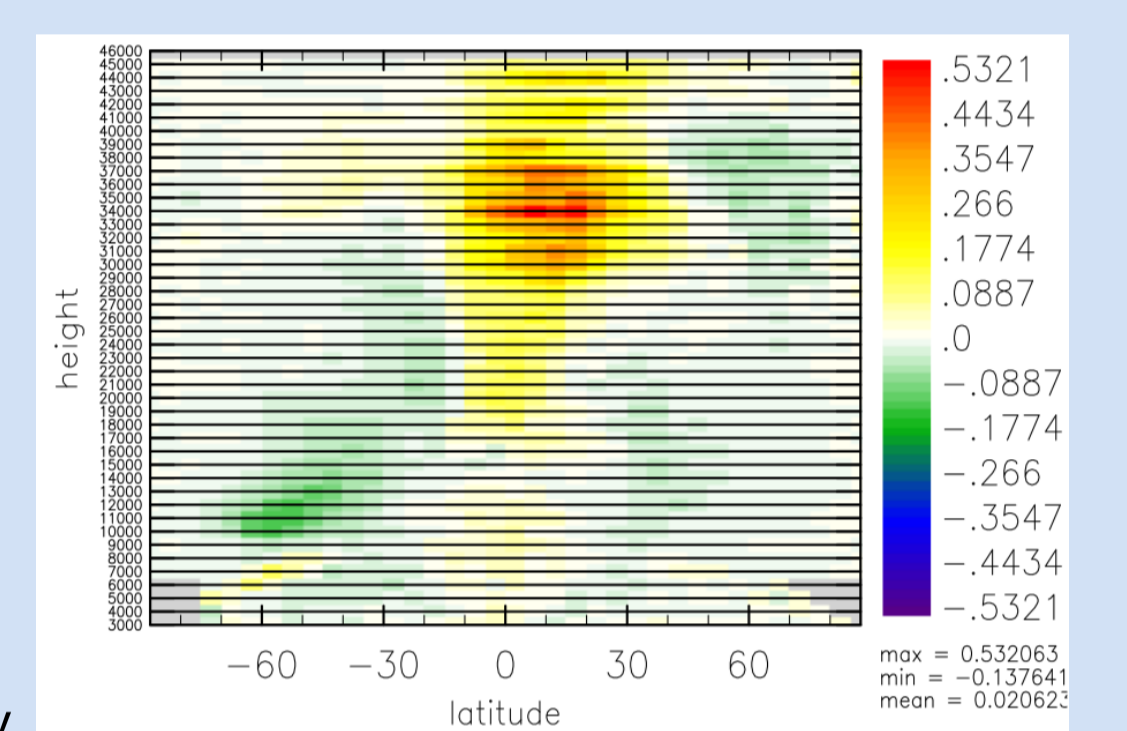


Figure 6: increase/decrease in zonally averaged standard deviation of obs-fg for radiooccultations, when radiances are added to the assimilation system (based on an earlier version of ICON).

Sketch of mechanism:

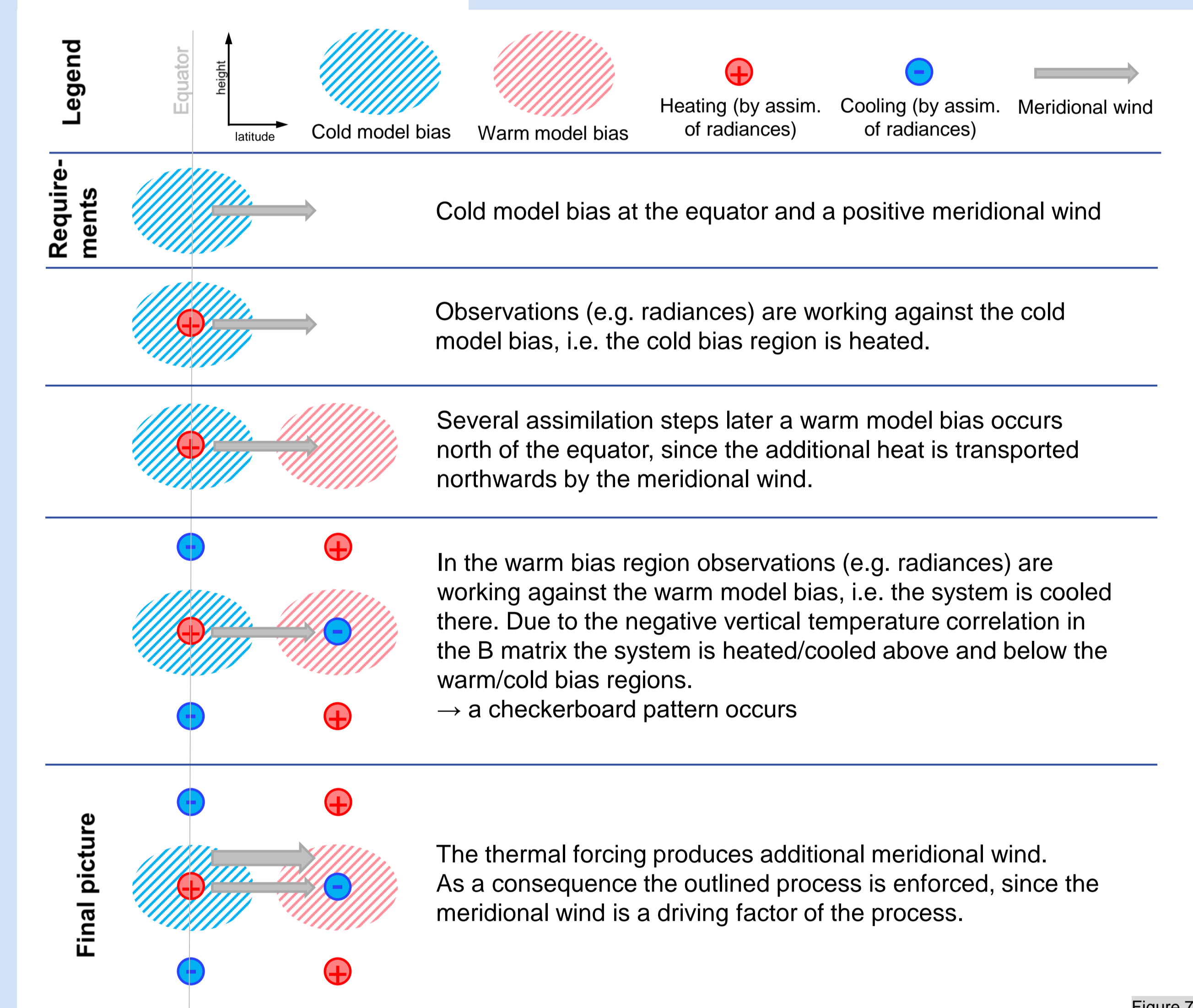


Figure 7

Possible solutions:

- 1) **Remove the source of the problem:** the pattern should not occur, if the model was bias free. This is supported by experiments with a tuned ozone climatology, which considerably reduced the model bias. However, the tuned ozone climatology is too far from observed ozone values to be used operationally.
- 2) **Reduce the response of the model:** during the investigation of this problem, we found that the minimal diffusion of the model was too small. Increasing the minimal diffusion significantly reduces the checkerboard pattern. However, it is still apparent (see Fig. 5 right).

5. Conclusions/Outlook

- **Panel 2:** radiances are interacting with the convection scheme in a strongly nonlinear way. We suppose, that this feedback is a reason for the currently only small positive impact of radiances in the Tropics in our system.
- **Panel 3:** we found, that the assimilation system has multiple stable climate states. We suppose, that the bias correction is crucial for this result. With a variational bias correction scheme the system might be less prone to be trapped in a secondary climate state.
- **Panel 4:** the checkerboard pattern in zonal mean temperature increments in the tropical stratosphere is caused by a complex feedback between radiance assimilation and model dynamics. The feedback was much reduced by increasing the minimal diffusion. As yet, this feedback is not fully understood.