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Geoscientific Model Development Discussions

Interactive comment on "Impacts of using spectral nudging on regional climate model RCA4 simulations of the Arctic" *by* P. Berg et al.

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Author final response

First we would like to thank the referees R. Laprise and P. Liu for useful comments and recommendations for improving the paper. Below, we respond to the referees' comments (reproduced in part in italics).

RC – C27 – R. Laprise *Main comment Page 499, Paragraph 5: In the historical review, it should be noted that SN was initially introduced not for correcting systematic biases as applied here, but rather as a kind of "poor man data assimilation" to prevent "intermittent divergence in phase space", a phenomenon that has later been found to be associated with inter-member (internal) variability in ensembles of simulations with nested climate*

models (e.g. Alexandru et al. 2009, Šeparovi̇́c et al. 2012, Laprise et al. 2012). It would be worth stressing that, while SN is also effective at correcting systematic model biases, this application is different from it initial purpose. In this respect, it would be interesting to present a figure analogous to Fig. 2, but for the domain average bias rather than RMSE.

We have added some discussion of the ideas behind spectral nudging in the introduction of the paper including the mentioned references. Also the domain average bias was investigated, with similar improvements as for the RMSE. This analysis is mentioned in words in the revised manuscript, but it does not add enough information to merit a separate figure, in our opinion.

Page 496, Paragraph 25: "GCMs have shown problems with anomalously high MSLP values in summer, and with simulating the North Atlantic storm track route into the Arctic region in winter." Fig. 3 shows the RCA4 bias to be somewhat similar in summer, but rather different in winter. Do the authors have any potential explanations for this different behaviour?

The storm tracks are dependent on the horizontal resolution of the model, which in this case is the GCM as the main cyclogenesis regions are outside of the RCM domain. For ERA-Interim, the storm tracks are resolved rather well due to the horizontal resolution of around 80 km and due to the assimilation process. With a good description of the storms at the lateral boundary, the RCM seems to do a fair job in simulating the end phase of the storm tracks in the Arctic region. This is not expected to be the case for a GCM driven simulation with the above mentioned deficiencies. The summer bias is more confined to the North Pole in the RCM; a feature it shares with many GCMs. Unfortunately we have not gotten closer to isolating the reason for this bias than earlier investigations. A potential reason for the MSLP bias can be seen in imperfect radiation parameterizations, but in order to avoid too speculative arguing, we choose not to include a discussion.

Page 500, Paragraph 10: The text refers to "longitude-latitude boxes ÂËŹz while it would rather appear from eq. 1-5 that the model uses some transformation to operate in an effective Cartesian grid.

This was indeed confusing and misleading. We have made clear that the model works on a rotated grid, and have adjusted the text to that extent.

Page 507, Paragraph 25" "However, the method relies on the driving model to handle the large scale circulation well. For reanalysis data, this is a minor problem, but for free running GCMs it is not obvious that the circulation improves. There is ongoing work with analysing the effects of the method when applied to GCM downscalings directly, within the CORDEX framework." As shown by the cited reference to Chapman and Walsh, some major deficiencies in polar-region MSPL occur at fairly large scales. The alleged purpose of a high-resolution coupled RCM is to correct deficiencies of coarse-mesh AOGCM. Clearly SN will prevent this from occurring, as the RCM will inherit large-scale biases from the driving AOGCM. The paragraph should stress this point, and admit that the use of SN should be seen simply as an interim, pragmatic approach to allow the development of the coupled version, but that the use of the coupled version will require fixing the regional model's components responsible for the noted biases, and eventually to get rid of SN.

There are different potential uses for an RCM. Ideally, the RCM improves on all aspects compared to the GCM. However, given certain simplifications in the RCM, e.g. the radiation scheme, vertical resolution and process description above the troposphere, the RCM might not be able to improve e.g the large-scale modes. Indeed this is the case here, and in several other cases for downscaling of the Arctic region as mentioned in the paper. Furthermore, if the GCM problems with the Arctic region are connected to the simulation of the storm tracks, the RCM domain would have to extend to the cyclogenesis zones to be able to correct this, which results in a huge domain. With constrained large-scale modes by the spectral nudging, the RCM can still add value especially closer to the surface, through a better resolution of the orography, improved

PBL description and related processes. The near surface circulation is important for the coupled atmosphere-ocean model, with increased resolution of circulation near the coast-lines etc. The application of the spectrally nudged version of the model does have value also for a GCM driven simulation, although one should indeed be clear about the limitations as the referee is pointing out. The discussion has been extended on this topic in the revised version.

RC – C302 – P. Liu

1. The authors mentioned that a nudging strength factor is applied, which is a function of the model level, with linearly increasing values from the lowest level to highest level. Is there any reason to choose the linear increase, instead of other method to make it change smoothly with height? I brought up this point because the choice of nudging strength with height is supposed to be consistent with the relaxation time of introduced disturbances at different height. For example, the characteristic relaxation time of upper troposphere is a couple of hours. The key point is whether the nudging strength chosen in this paper is able to reflect the different relaxation time at different height according to the time-step of RCA4 model?

The purpose of the linear function is to have a smooth introduction of the spectral nudging, and has been used frequently in previous literature [e.g. Alexandru et al., 2009]. Others have used a pressure dependency for the vertical profile [von Storch et al., 2000] as suggested by the referee. In connection to point 4 below, we have made sensitivity tests to the choice of the vertical profile. A simulation with the vertical profile used in von Storch et al. [2000] was found to reduce the improvements (as described in our manuscript) from the linear profile, due to the weaker nudging strength at the higher pressure levels. We also made a sensitivity test with a linear profile for the top 15 model levels, which approximates the von Storch et al. [2000] profile for 30 model levels. These two profiles produce similar results. See also point 4 below for more information.

2 Has nudging also been applied to levels under PBL and why?

The nudging was only applied above PBL as noted in the results chapter. To be clear, this information was also added to the methods section.

3, As to the tuning experiments shown in Fig.2, it would be interesting to include cases with T nudged, so that the test cases are more comparable with the final case (UVTs16w800) chosen for the simulation.

The additional nudging of temperature was a fine tuning of the final set up, and we did not repeat a complete set of tuning simulations for that reason.

4. The authors mentioned that the performance of low-level clouds is worse with spectral nudging and possible explanation is that the temperature profile becomes deeper. However, I did not see this in Fig 4d and f. Could you please explain more about this? And if this is true, does it also mean there may be some problem with how the nudging coefficients change with height?

We agree that the figures are not carrying this information across very well, so in the revised version we have added a figure (Fig. 7, also added in this comment below) of the vertical temperature profiles north of 84N, for the remapped data on the ERA-Interim grid. This approximates the region where we see the largest deviations in the low clouds. Here, one can clearly see that SN (red) follows CON (blue) for the lowest levels, and transitions towards the ERA-Interim profile (black) for the higher levels. Thus having a steeper vertical profile (more unstable) on average for the layers above the PBL, which could influence convection. Obviously this is a speculative explanation, and a more in-depth investigation would have to be carried out to confirm it.

Following the referee comment 1 (above), a different vertical profile similar to that of von Storch et al. [2000], here referred to as vS-profile, was tested in a shorter five year long sensitivity test. It resulted in no significant change in the low clouds compared to the control simulation, i.e. a different result from the SN simulation. To investigate

whether this was simply due to a weaker nudging of the lower model levels, a simulation with a linear nudging profile for only the uppermost 15 levels (which approximates the vS-profile for the top 30 levels quite well) was conducted. This leads to similar results as for the vS-profile, i.e. again different from SN. Our initial hypothesis of the steepness of the temperature gradient remains plausible, however, we have added a statement that a different vertical profile for the nudging strength could resolve this problem. Note, however, that the weaker nudging in these two additional sensitivity simulations have less effect on the MSLP bias, and are thus not useful candidates for the study at hand.

References Alexandru, A and R. de Elia and R. Laprise and L. Separovic and S. Biner (2009) Sensitivity study of regional climate model simulations to large-scale nudging parameters, Mon. Wea. Rev., 137, 1666-1689, doi:10.1175/2008MWR2620.1

von Storch, H and H. Langenberg and F. Feser (2000) A spectral nudging technique for dynamical downscaling purposes, Mon. Wea. Rev., 128, 3664-3673

Interactive comment on Geosci. Model Dev. Discuss., 6, 495, 2013.

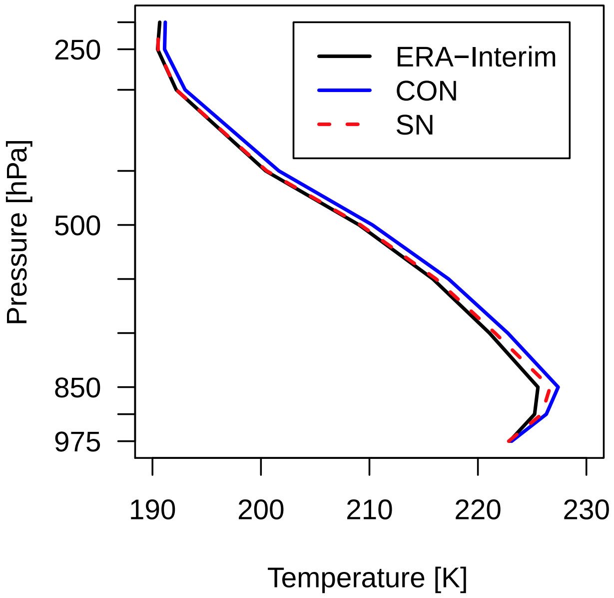

Fig. 1. Vertical temperature profiles for ERA-Interim (black), CON (blue) and SN (red) for the region north of 84N.