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Climate of the Past Discussions



# *Interactive comment on* "The climate in the Baltic Sea region during the last millennium" *by* S. Schimanke et al.

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First of all, we would like to thank the reviewer for his/her valuable comments.

The reviewer is absolutely right that the title should point out that our results are based on model simulations. Therefore, we will change the title to: Regional climate model simulations of the climate in the Baltic Sea region during the last millennium

Regarding the second general comment of the reviewer, we have to point out that the climatologies of used models with ERA40 boundary conditions are well documented in other publications, e.g. Samuelsson et al. (2011) for RCA and Meier (2007) for RCO. Regarding the present day climate (e.g. 1961-1990) of the used ECHO-G simulation we have to mention a major shortcoming of this simulation. There is no anthropogenic

increase of aerosols in the 20th century considered in the forcing of the ECHO-G simulation. Such an increase would have a significant cooling effect. The missing aerosols in combination with the increase of GHG concentrations leads to a too strong and therefore unrealistic global warming during the 20th century (see a figure for the Baltic Sea temperature evolution below among the specific points). Therefore, it does not make much sense to validate this period of the RCA simulation. With respect to the ocean model RCO, we have to remind that RCO was only forced for time slices of the MCA and the LIA. So, unfortunately, a present day climate for RCO with ECHO-G conditions at the boundaries is not available.

Herewith, we believe that it would not improve the manuscript if RCA climatologies with ECHO-G boundaries for the recent past climate would be included. Nevertheless, we will include 2m-temperature patterns of ECHO-G (see specific point below). These can be compared directly with RCA results to highlight the added value of the dynamical downscaling. We believe that this was an intention of the reviewer, too.

Specific comments.

p1373 l25 This time step is to big compared to other RCMs, even with the Regional Ocean Model. Is it the output recording time?

No, it is really the time step in RCA3 which is 30 minutes. And yes, it is longer than in many other RCMs but we do have a semi-lagrangian scheme that allows for long time steps so this is correct.

p1375 l24 It is the solar forcing as in ECHO-G model?

Yes, it is the forcing in ECHO-G. Moreover, the same forcing is used in RCA as mentioned in lines 15/16. We adapted the sentence slightly to make this point clearer: “The solar variability in the models is scaled to an insolation difference between present day and the Maunder Minimum of 0.3% (corresponds to 4 W/m$^2$), as estimated by Lean et al. (1995).”



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p1376 l6-10. The authors apply a bias correction to RCA output in temperature and wind speed. From my point of view one of the advantages of dynamical downscaling is that the outputs are physically consistent. By doing this bias correction, this consistency could be lost. On the other hand, it would be useful to describe some statistics such as mean value of this bias correction. Also I understand that this bias correction is applied month by month so some dangerous steps are implicit in the forcing conditions to the RCO.

The bias correction is necessary because RCA uses SSTs interpolated from ECHO-G. Especially, the Baltic Sea is only very rudimentary represented in ECHO-G. Therefore, SSTs are partly prescribed with conditions that reflect more or less the state of the Atlantic but less the conditions of the Baltic Sea. Hereby, 2m-temperature and due to turbulence also wind are most effected over the Baltic Sea whereas land points are much closer to observations. On the figure below, we show 2m-temperature differences between the pre-industrial period of RCA-ECHO-G and RCA-ERA40. For the winter month February, we see warm biases in the northern parts of the Baltic, which are related to an underestimation of sea ice. The warm bias in the Danish straits is likely due to the very wide opening of the Baltic Sea in ECHO-G. During summer, the 2m-temperature is strongly underestimated (5K and more) over large parts of the Baltic Sea. This is related to the prescription of cold SSTs, which reflect more the summer temperatures of the Atlantic. Too cold summer temperatures and too warm conditions during winter (at least partly) result in a strong underestimation of the seasonal cycle. This would have a significant effect on the biogeochemistry in RCO-SCOBI.

Note that the temperature difference over land points is much smaller. However, these points are not relevant for the bias correction, which is applied only over the Baltic Sea since it is done to force the ocean model RCO-SCOBI.

Moreover, it seems unlikely that the monthly applied bias correction introduces any dangerous step. First, the applied bias correction fields very rather smoothly from month to month. Second, even if there would be a change of let us say 5K from one



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month to the next this is still in the range of day-to-day variability. So, no particular artificial effect is expected due to the bias correction.

Finally, we will follow the advice of the reviewer and include a new table with some statistics of the bias correction. The table will show the monthly and spatial averages of the bias corrections for January through December. In reference to the table, the following text will be included into the manuscript: "The coarse scale of the ocean in the global model leads to a relatively poor representation of the Baltic Sea area. The bias adjustment was made as a change in the mean value by adding (temperature) or multiplying (wind speed) spatially variable fields for each month. The correction fields are derived from a comparison of the pre-industrial state of the presented RCA simulation with an RCA simulation forced with ERA40 for the period 1961–2008. Table 2 gives an overview over the amplitude of the bias adjustment. Due to the coarse scale in the Baltic Sea of the global model and the interpolation of SSTs from the surrounding oceans the 2m-temperature is mainly underestimated. The mean bias is considerable larger during summer (up to 3.87 K in July) where the Baltic Sea becomes warmer than the surrounding ocean. Only during winter months, for some regions a negative bias correction has to be applied (not shown). This is mainly connected to missing sea ice cover and occurs therefore mainly in the northern part of the Baltic Sea. A consequence of the generally underestimated near-surface temperatures is too strong static stability in the lower atmosphere over the Baltic Sea. Therefore, wind speeds are considerable underestimated especially during summer and autumn. Here, the wind speed is adjusted by up to 15% whereas changes in winter and spring are general smaller than 5%. Note that the variability of the forcing parameters remains unchanged by the used bias adjustment."

This comment is also applied to the sensitivity experiment RCO-3K.

See response to the previous point.

Why do not use HOPE output as boundary conditions for the RCO?



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HOPE is a global ocean model with a horizontal resolution of 2.8 degrees. The vertical resolution is 20 levels with only eight levels within the top 200 meters. Boundary conditions for RCO-SCOBI could be taken only from a single grid box, which represents more or less the entire North Sea. This information is by far not accurate enough to force our regional model.

Moreover, the Baltic Sea is an outflow regime. Changes at the boundary must be substantial to have any impact on the Baltic Sea and there is no indication in observations or reconstructions that the boundary conditions changed considerable during the last millennium.

What is the sense of performing experiment by changing the air temperature 3K if the maximum variation in figure 3 is of about 1.5K?

Paleo reconstructions indicate that the temperature difference between the MCA and the LIA have been larger than modelled by our setup (ECHO-G and RCA3). Therefore, we did this simulation as a sensitivity test to examine the effect of a temperature amplitude comparable to reconstructions. To make this clearer we added also a new reference (Kabel et al., 2012) and changed the text to: "Proxy studies suggest that temperature differences between the MCA and LIA have been stronger than simulated in our model setup. That is suggested for reconstructed 2m-air temperature (e.g. Ljungqvist et al., 2012) as well as SSTs (Kabel et al., 2012). Hence, a sensitivity experiment is performed with 2 K higher air temperatures compared to RCO-MCA."

RCA simulations extend till near 2000. It would be of interest to see the temperature evolution during the last century in figure 3.

As mentioned earlier, results for the 20th century are not trustworthy since an aerosol forcing is missing. Therefore, the temperature increase is too strong towards the end of the simulation and we limit the plot (as well as all others) to the earlier period on purpose. However, in case the reviewer is still curious to see the figure, it can be found below.



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Figure 4 presents that NAO and temperature are sometimes perfectly coupled while in other periods not. Have the authors some explanation for that?

There are other factors that influence the temperature, e.g. the solar and GHG forcing (see also response to reviewer 2). Moreover, other internal dynamical features are relevant for the temperature in the Baltic Sea region. Examples are the Barents Sea oscillation (a modulation of the NAO), which can have a strong effect on the temperature (Kauker and Meier, 2003) or atmospheric blocking.

p1381 l5 Since you have a RCM with a high resolution, why do not compare with the Grahan et al (2009). You should be able to isolate a similar area.

Yes, we would be able to extract a similar area. However, a direct in detail comparison does not make sense for several reasons. First, they used an older RCA version with a coarse resolution, which was restricted to the small area of the northern Baltic only. Second, they used a different ECHO-G run as boundary condition. Both circumstances imply that the results can differ in the timing (mainly due to the different forcing) and in space. Therefore, a more precise conclusion than that given in the manuscript is not possible.

Figure 6. Is there any reason for the strong jump of runoff around 1700?

We checked the data carefully but could not find any particular reason for this jump. Moreover, we would like to notice that there are more jumps scattered over the entire millennium and not only around 1700. That the correlation with precipitation looks better for other jumps is due to the chosen scaling. Consequently, looking more closely reveals that precipitation and runoff are not always highly correlated. That is due to the fact that the areas for the computed runoff and the precipitation are not identical and, in addition, runoff is also affected by changes in evaporation.

p1387 l25. It is the RCA in agreement with ECHO-G ? i.e. ECHO also simulate the same temperature evolution. From my point of view the added value of using the RCA



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should be shown. For example, change patters respect ECHO-G, etc.

In general, large scale features as the NAO index or large area temperature means (e.g. over Europe) evolve quite similar in ECHO-G and RCA. In fact, RCA is not supposed to change such features. The added value comes from the finer resolution including a much more realistic land-sea mask and a more accurate topography. To demonstrate this we will expand Fig. 7 by including patterns of the ECHO-G simulation (see the new figure below, right column is ECHO-G). Moreover, we will add the following paragraph at the end of section 3.4 in a new manuscript version:

"Finally, 2m-temperature patterns are shown for the global model ECHO-G (right column of Fig. 7). The coarse resolution and therefore the missing relation to real land-sea surface differences are obvious when compared to the temperature response of RCA. This effect is clearest along the Norwegian coastline for the 50 yr periods. Here, RCA simulates a very sharp temperature anomaly gradient from the Atlantic towards land points over Scandinavia. On the other hand, such a clear signal cannot be simulated in ECHO-G. However, the general amplitude is very comparable for RCA and ECHO-G with somewhat stronger signals in ECHO-G over the most eastern land areas. Overall, the contrast between the patterns of RCA and ECHO-G clearly highlights some of the added value of the dynamical downscaling approach."

References:

Kauker and Meier (2003, JGR): Modeling decadal variability of the Baltic Sea: 1. Reconstructing atmospheric surface data for the period 1902-1998, doi 10.1029/2003JC001797

Kabel et al. (2012, Nature Climate Change): Impact of climate change on the Baltic Sea ecosystem over the past 1,000 years, doi 10.1038/NCLIMATE1595

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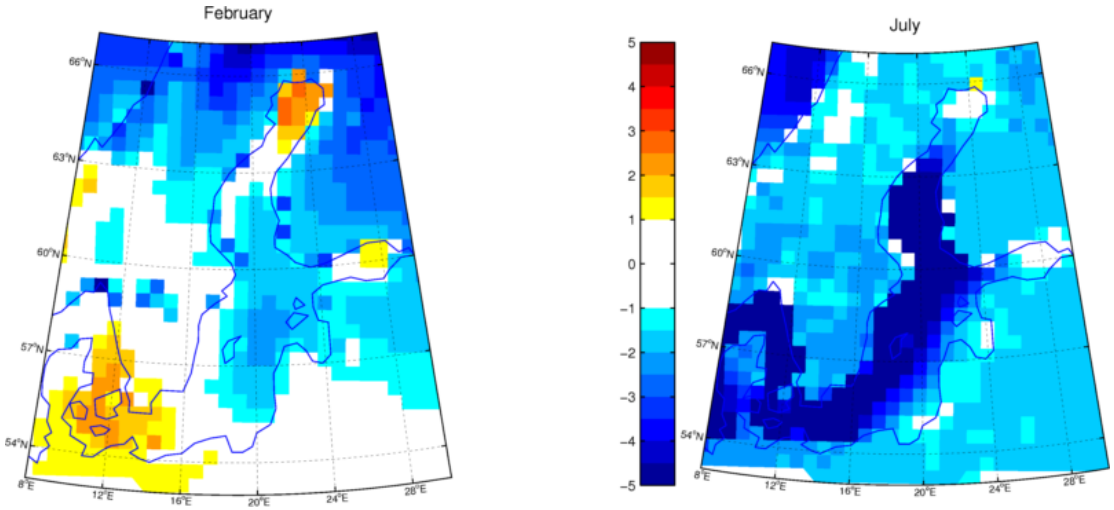


**Fig. 1.** 2m-air temperature differences between the pre-industrial period of RCA-ECHO-G and RCA-ERA40 for February (left) and July (right).



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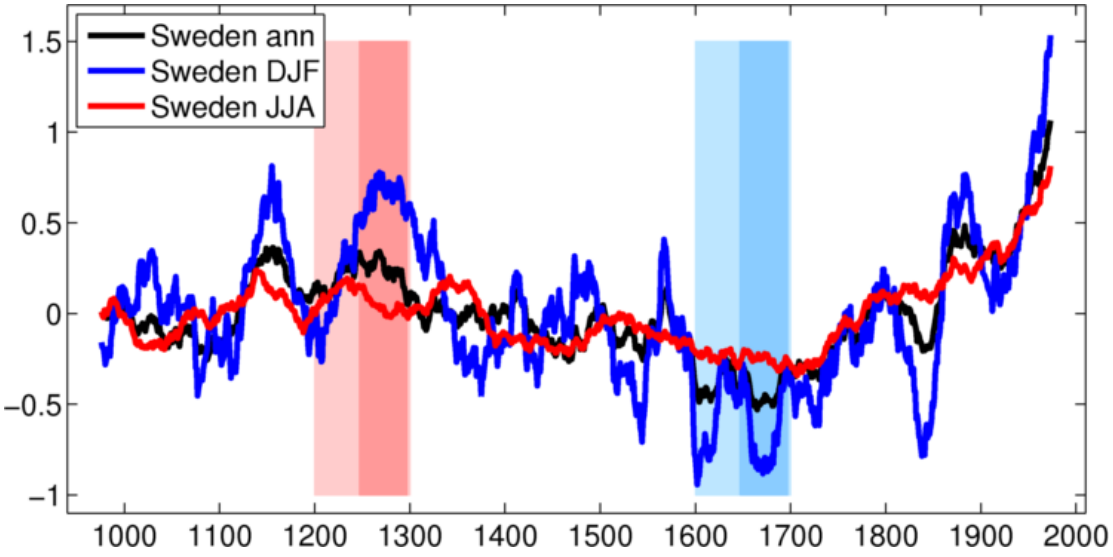


**Fig. 2.** Similar to Fig.3 in the manuscript but including the 20th century. 2m-temperature averaged over the Baltic Sea area as 50 yr running means.



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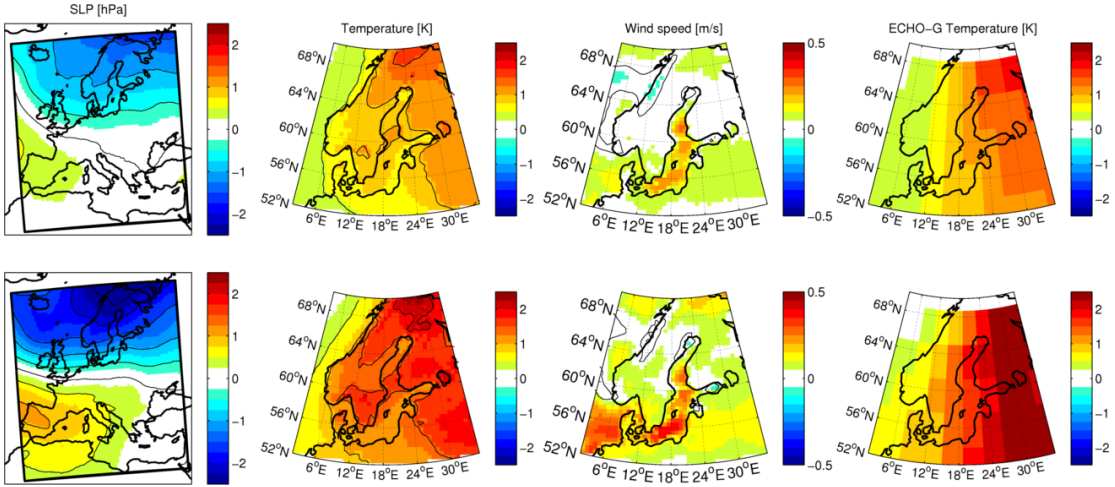


**Fig. 3.** The new figure 7 including patterns from ECHO-G.



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