Atmos. Chem. Phys. Discuss., 15, C11595–C11602, 2016
www.atmos-chem-phys-discuss.net/15/C11595/2016/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "North Atlantic Oscillation model projections and influence on tracer transport" *by* S. Bacer et al.

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Received and published: 15 January 2016

We would like to thank the Referees for their careful reading of our manuscript. We are very grateful for the comments, constructive criticism and very useful suggestions received on how to improve the paper, and we appreciate the effort that the Referees put in reviewing the manuscript. We add below replies to the Referee common comments, together with the planned analysis to overcome the issues present in the manuscript. More detailed comments regarding each Referee review can be found at the end.

We recognize in the comments from all Referees that the paper lacks of a well organized structure and that the novelty of the work has not been well-communicated. We aim to drastically improve the paper in order to give a clear message and to stress

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the novelty with respect to previous studies. This would imply a large revision of the manuscript and substantial changes in the analysis. Therefore, we propose to withdraw the paper in its current form and submit a new (fully revised) manuscript, which will take account of all Referee comments.

The main goal of the submitted work was to investigate the influence on pollutant transport of the NAO in the 21st century by analysing:

1. the ability of our model system to describe the NAO;
2. future NAO and its trends;
3. consequent influence on pollutant transport.

Following the Referee suggestions we will reformulate the manuscript as described here below, so to assure that the goals are more clearly defined and reached in our new manuscript.

Even if it has been observed that the NAO influences the transport of tracers, aerosols and pollutants [e.g., Li et al. 2002, Creilson et al. 2003, Eckhardt et al. 2003, Duncan et al. 2004, Jerez et al. 2013, Pausata et al. 2012, 2013 and 2015, Christoudias et al. 2012] and the future trends of the NAO have been already presented [e.g., Fyfe et al. 1999, Shindell et al. 1999, Hu et al. 2003, Stephenson et al. 2006], we note that, to the best of our knowledge, no study has addressed the topic of **the NAO influence on the pollutant transport in the 21st century**. Therefore, we believe this to be an interesting and, to our knowledge, **novel topic**, worth investigating.

By means of new EMAC model simulations (performed under the "Earth System Chemistry Integrated Modelling" (ESCiMo) initiative, Jöckel et al. 2015) we carried out for the first time the analysis regarding the influence of the NAO on transport of pollutants in a future scenario. We believe EMAC to be a valuable and relevant tool, providing a careful treatment of all chemical processes (including also dynamical feedbacks). In

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particular, the presence of the CO tracer (and CO_{25} with 25 day lifetime) would allow a clear analysis of the transport pattern and facilitate the interpretation. Nevertheless, we note the Referee concern on the simulations chosen for the analysis, as the SST forcing from another model would make the results not independent when compared to the HadGEM2 coupled simulations.

In order to overcome the weakness of our analysis due to the dependency of the results to the HadGEM2-ES model, we will now consider a free-running simulation performed by the same model (EMAC) coupled with the Ocean GCM MPIOM (Max Planck Institute Ocean Model [Marsland et al., 2003]). This atmosphere-chemistry coupled model simulation, covering the period 1950-2100, will allow for a more coherent analysis that is completely independent from the performance of the HadGEM2-ES model. By focusing purely on a free-running simulation and removing all references to the simulation forced by HadGEM2-ES SST, we are convinced that the study will gain more value and robustness, as pointed out by all Referees.

Using the new setup for the simulation we will be presenting results and their analysis, paying particular attention to future pollutant transport and its differences with respect to the past. The analysis will concern entirely the free-run: we will repeat the EOF analysis and discuss in more detail the results when relevant. We will also separate the analysis in two periods (e.g., 1950-2000, and 2050-2100) in order to detect the future changes of the NAO and pollutant transport (as Referee #1 suggested).

As noted by the Referees, it was to be expected that the results of the nudged simulation agree well with the observations. Considering such a simulation served solely as a check of the model capability to reproduce the NAO, in order to validate the results of the future simulation. As pointed out by Referee #3 this analysis serves as a "sanity check". We think that this is a reasonable step to take before analyzing model future projections, so we propose to repeat an analogous comparison in the future manuscript. However, we will remove the comparison of the nudged simulation with the observations (since the results are unsurprising, as the Referees pointed out). The

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analysis will therefore only be limited to confirm that the model is able to reproduce the NAO and to assess the degree of similarity of the results of the free-running and nudged ('truth') simulations over the known past, before projecting into the future.

Finally, let us stress the differences between our paper and the previous study by Christoudias et al. 2012 (hereafter indicated as CH-2012). The present paper both extends and complements the previous study with several differences and new features:

- In CH-2012 only one simulation from 1960 until 2010 was considered and it was forced by SSTs and SIC of AMIP II. In our case we used simulations performed by the same atmospheric-chemistry GCM (EMAC) but the degree of similarity between the SST-forced model and a 'truth' nudged simulation (1979-2013) was assessed in order to validate the model system, before analyzing an SST-forced simulation with future projection (1950-2099), to improve the confidence in the modelling ability.
- CH-2012 does not compare its findings to any observations or measurements of atmospheric CO concentrations. In our case, we have used station measurements to compare and evaluate the results of the modelling study, again to improve the confidence in the robustness of the outcomes.
- In CH-2012 the study of pollutant transport concerned carbon monoxide (CO) influenced by chemical variability. In the present study we considered a CO tracer with invariant e-folding time equal to 25 and 50 days and constant emissions in order to investigate the pure transport of CO.
- In our paper we deal with the NAO future changes and trends, to particularly address the topic of pollutant transport influenced by NAO well beyond the time span (1950-2010) considered by CH-2012 and into the future.

We hope that the planned modifications to the manuscript will adequately address all the concerns raised. We again wish to thank all Referees for their work and we would

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be very pleased if the same Referees could accept the revision of our resubmitted paper.

Finally, we would like to address all major Referee comments which were not already commented on. The minor comments will be obviously also taken into account during the revision of the manuscript, although we will not address them here (as the manuscript will drastically change).

Major comments Referee #1
We plan to split the period of the free-running simulation in two parts (as mentioned before and suggested by the Referee) in order to investigate the changes of the NAO pattern in the future with respect to the past. We will consider the results of the EOF analysis on the new model simulation and present as appropriate, i.e. if relevant and with implications for pollution transport. Moreover we will motivate the choice of considering the PC instead of the NAO-Index as appropriate.

We will reduce the analysis of the nudged simulation, and remove the comparison between the nudged model simulation and the observations concerning the CO mixing-ratio. Please note that we did not forget stations in the bottom plot in Fig. 6. Rather, we indicated (with green dots) all existing stations in the upper plot, while only the stations (colored dots with the values of the correlation) with at least 8 winter values in the bottom are shown (see text in the manuscript). We choose to consider a subset of the stations in order to have long enough temporal series together with a reasonable number of stations satisfying our requirement.

Finally, we are going to improve our main analysis (the NAO influence on tracer transport in the future) investigating the differences between the correlations of the CO mixing ratio and the PC in two different periods, in order to detect changes on the transport. This analysis will base only on the climate version of the EMAC model

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[Pozzer et al, 2011].

Major comments Referee #2
We compared the nudged simulation with observations (NAO Indices and trends) in order to validate and check the capability of the model before analyzing future projections. We agree that the results could not be a surprise. As mentioned before, this section must indeed be reduced, but we are reluctant in removing it completely.

We computed the NAO Indices (station-based definition and PC) with our modeled data, instead of using the observed NAO-Index, for consistency with the analysis computed with the long-simulation data. Thus, the whole analysis was based on our modeled results and not from observations. This was indeed not clearly stated in the manuscript.

The analysis of the NAO trends in the 21st century is not a novelty in itself but we do think that our presentation (with the triangular plots) is both concise and complete, as the Referee reported. Our findings sustain some studies which also did not identify significant linear trend of the NAO [e.g., Fischer et al. 2008].

We plan to clarify the differences with the previous study by Christoudias et al. (2012) in order to highlight the new aspects and results of our study.

Major comments Referee #3
As noted by the Referee we compared the NAO trends for observations, nudged and SST forced simulations as a “sanity check” for the model. The first comparison (observations-nudged simulation) must show a good agreement, otherwise the remaining analysis would have been useless. The second comparison between the two simulations was found to give also similar results, meaning that we could trust on the projection results. We propose to repeat a similar analysis, but considering the free-running simulation.

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Regarding the analysis of CO, we plan to investigate in more detail the changes of the transport in the future, again only considering the free-run (and splitting the simulation in periods).

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