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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The North Atlantic Oscillation controls air pollution transport to the Arctic" *by* S. Eckhardt et al.

S. Eckhardt et al.

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Response to both reviewers:

We thank both reviewers for their constructive reviews, which certainly helped in providing a revised version of this paper. In the following, we will first address those points that were raised by both reviewers, before answering the other questions raised by reviewer 1 and 2.

Both reviewers have asked for a more detailed description of methodology:

Reviewer 1: p 3224, 2nd paragraph; p 3226, line 26; p 3227, lines 16-18; p 3228, line 4

Reviewer 2: p 3227, line 16; p 3225, line12; p 3226, line 7

We admit that we have kept the description of the methodology quite short in the ACPD

version of the paper. In order to better inform the reader on the methods we have used, we have now substantially extended the methods section. We explain the model setup in more detail (e.g., how FLEXPART treats the dispersion process, how many particles were released, that particles were released continuously and not in pulses, and how the age classes were derived) and more systematically refer the readers to other papers for further details on FLEXPART. We now describe the NAO index and how we created the ensembles for both NAO phases in more detail. We added tables showing the NAO indices for each of our NAO composites (model results as well as satellite data), respectively. Also some details about the linear regression analysis were added. Furthermore, various changes in the text have been made, in order to improve the clarity of the presentation, according to the detailed suggestions of both reviewers.

Response to Reviewer 1:

Which improvements, if necessary, in (ocean) atmosphere models would the authors recommend?

We think that it is out of the scope of this paper to discuss this question. We studied the influence of the NAO on pollution transport based on analysis data, and these data contain the NAO through the assimilation of observation data. Based on our results, unfortunately, we cannot make suggestions about (climate) model improvements.

Which percentage of MSLP variation is explained by the NAO? (p 3224, lines 9-11)

In the method section we added the following statement:

In wintertime the NAO index explains 33 % of the total variance of the SLP field over the Atlantic (Hurrell and v. Loon, 1997).

(p 3224, lines 19-21)

We rephrased the text to make clear that the results are based on a 15 year simulation and removed the expression "signal".

We rephrased following lines, corresponding to the reviewer's suggestions: p 3226, line 2; p 3227, line 1; p 3229, line 25

The NAO dependence decreases with the e-folding time is not clear at all from figure 4 apparently rather showing independence. (p 3227, lines 12-13)

This actually is clear from figure 4. Note the magnitude of the relative differences between the two NAO phases, which are much larger for short lifetimes (even though the absolute difference increases with increasing e-folding lifetime). We also have given some values for different lifetimes, which should make that clear, and we have added the following text: .., as can be seen by the relative differences between NAO+ and NAO- being the greatest for the European tracer and at the shortest lifetime.

Comparison of GOME NO2 with model tracer (p 3230, lines 3-6)

To further corroborate our NO2 analysis, we have calculated correlation coefficients of the NO2 columns obtained from the GOME instrument with the NAO. They, too, show that outflow to the north is enhanced during NAO+ and, thus, we think that the comparison actually is convincing. A table showing which months were used and the corresponding NAO indices were included. We also changed the figure caption for Fig. 6. As the NO2 from the model does not correspond in values to the NO2 from satellite observations we left the colour scales like we had it. The geographical scale was adjusted.

In principle it would be possible to transform the model CO-tracer to a NOx-tracer by taking into account the differences between molecular mass and emission fluxes of CO and NOx respectively. However, any factor to convert CO to NOx emissions would vary geographically, as this factor is not a constant but depends on the emission source. Therefore, we have not converted CO to NOx, but only assumed a very short (i.e., 1 day) lifetime of the tracer.

We have added two references (Atkinson, 2000; Jacob, 2003) on the chemistry of NOx,

as suggested by the reviewer.

Response to Reviewer 2:

We rephrased following lines, corresponding to the reviewer's suggestions: p 3224, line 5; p 3224, line 9; p 3224, line 26; p 3229, line 1; p 3229, line 3; p 3229, line 13

Are there substantial fluctuations among the months in these ensembles?

We studied the figures for high and low NAO months in detail, there are some fluctuations in the images, but the identified structures described in this paper are always very clearly visible. We have now calculated and plotted correlation coefficients, which show where there are systematic differences between high and low NAO conditions (i.e., high correlations), indicating little variability within a particular ensemble.

Are the high slopes over Asia an artefact of the regression analysis? (p 3227, line 22)

This is a very good point. For showing the significance of the slope, we performed a correlation analysis of the same data as used for the regression analysis and overlaid the contour plots with correlations drawn as lines. This makes it clear that the slopes over Asia are not significant, whereas the slopes for transport to the Arctic and the European dipole pattern (compare figure 6) are highly significant. This analysis shows also very nicely the enhanced westward transport of European and Asian emission caused by the intensive Azores high during high NAO phases. If we perform the same analysis with the Arctic Oscillation Index (see our website) a significant slope over the Asian east coast is found. We also adjusted the scales of the four figures to make them better comparable.

Are only 3 months per winter used for the composites? (p 3228, line 4)

For the analysis with the GOME data 17 winter months (from 1996-2001) were available. We used 5 months for each NAO+ and NAO- composite. The months used and the corresponding NAO values were added in a table.

It is not clear what is meant by ... NAO+ and NAO- conditions revealed no correspondence to the identified spatial structures. (p 3228, line 9)

We changed the text as following:

NO2 data are less reliable in regions where clouds are present, and they also reflect patterns in stratospheric NO2. Both cloud patterns and the amount of stratospheric NO2 may vary with the NAO. Stratospheric NO2 may particularly vary because tropopause heights change with the NAO. To rule out that the dipole pattern seen in Fig 6a could have been produced by one of these mechanisms, careful analyses of cloud data from GOME itself, the International Satellite Cloud Climatology Project (Rossow and Schiffer, 1999), and ECMWF tropopause heights for NAO+ and NAO- were done. These analyses showed that neither cloud patterns nor tropopause heights showed residuals that corresponded to the identified spatial structures.

How did we achieve the significant correlations? (p 3229, lines 11-14)

For the CO time series, we had on average 7 winters available, i.e. 21 months of data (a sample size of 21). A correlation coefficient larger than 0.52 gives a 99 % significance for a sample of this size.

How much does the North Atlantic Oscillation differ from the Arctic Oscillation? (p 3229, line 21)

We have carried out an additional analysis using the AO instead of the NAO. At the lowest level, the main difference for the tracer with 30 days lifetime is that the very high positive correlations over northern Scandinavia disappear when using the AO. However, high positive correlations remain over the entire Arctic area. Positive slopes with significant correlations are also found in the Asian region for the AO, which are not seen with the NAO. We have added a comparison between the AO and the NAO at our supplementary website and direct the reader to this website for more detailed information.

... correlation with the NAO index was strongest ... Which correlations are referred to here? (p 3230, line 3)

We referred to Fig. 4. Maybe the word correlation was misleading in this sentence. The relative difference in the total concentration of the European tracer in the Arctic region was greatest for short-lived tracer.

Discussion on the last paragraph (p 3230, lines 10-18)

We fully agree with the reviewers that the hypotheses put forward in the last paragraphs are very speculative, but they are - as the reviewer notes - interesting. We don't have the tools to test these hypotheses, but we nevertheless want to put them forward in order to attract the attention of others who have these tools. We have partly re-formulated this paragraph, being more careful with our statements, and particularly state that they need to be checked with coupled chemistry-climate models.

What is meant by...short-lived greenhouse gases? (p 2230, line 3)

These are greenhouse gases that are much shorter-lived than CO2, such as ozone, and show considerable regional differences in their concentrations. We have given ozone as an example in the text.

References:

Atkinson, R.: Atmospheric chemistry of VOCs and NOx, Atmos. Environ., 34, 2063-2101, 2000.

Jacob, D. J.: The oxidizing power of the atmosphere, Handbook of Weather, Climate and Water, ed. by T. D. Potter and B. Colman, Wiley, 2003.

Hurrell, J. W., and H. v. Loon, Decadal variations in climate associated with the North Atlantic Oscillation, Clim. Change, 36, 301-326, 1997.

Rossow, W. B., and Schiffer, R. A., Advances in understanding clouds from ISCCP. Bull. Am. Met. Soc., 80, 2261-2287, 1999.

Interactive comment on Atmos. Chem. Phys. Discuss., 3, 3223, 2003.