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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Hemispheric transport and influence of meteorology on global aerosol climatology" *by* T. L. Zhao et al.

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We thank the reviewer for the instructive comments which have improved the quality of the paper. The manuscript (acp-2011-980) has been revised following the comments. To help the readers of this reply, we have quoted the questions of the reviewer in brackets.

[In some parts of the paper there is insufficient quantification. The coefficient of variation of the anthropogenic loading is quantified in Fig 8 and in the conclusions, but there are other places where a similarly simple quantification would make the results clearer. How does the regional net flux vary from year to year? How does this flux (or loading) over the 10-year period compare between regions, and does it correlate with the ENSO index? How much do the wet and dry deposition fluxes actually vary, and how significant is this difference? Only the relative effects are currently described in the paper. At a more fundamental level, the paper also fails to quantify the overall importance of hemispheric transport for aerosols. While this has been described elsewhere, a brief sentence or two quantifying its importance would provide a clearer context for the reader.]

Response: We agree with the comments. The CV-values of aerosol loading and surface concentration in Fig. 8 without the inter-annual variability in anthropogenic aerosol emissions are used to quantify the meteorology influence on aerosol variations. Similarly to the interannual variations in aerosol concentrations and loadings as shown in Fig. 8, we have analysed the regional net transport fluxes, wet and dry depositions of aerosols over the four HTAP-regions. Since the regional net transport fluxes are determined by two factors, i.e. 1)aerosol emissions and 2)region domain size and locations, the absolute values may not necessarily represent the true features of the continental regional aerosol balances. As we pointed out in the manuscript that the regional net transport fluxes varies from region to region with EU being the only "exporting" region of aerosols. This was because the global sulphur emissions from GEIA, and climatological emissions representative of the end of 1980's for the tropical forest fires and savannah fires were considered in the modeling study. Furthermore, the mid-latitude westerlies prevail in the eastern EU boundary from summer to winter and resulted in the strongest aerosol export in the region. On the other hands, the GEIA sulphur emissions in this study would not represent the peak values in the Asia and the eastern EA boundary was far over the Pacific Ocean, which resulted in a negative net flux for the region as a whole, though the continental EA should be a net source of aerosol exports. Therefore, the net flux for each region has no comparisons as each has a different domain definition and geographic location where the wind regimes are quite different for inter-continental transports. Regionally, we see the SA has the largest variations in loading and concentrations from year to year (Fig. 8) while there is not a clear difference among other regions. Again, due to the large HTAP-region areas and positions, the averaged aerosol concentrations and loadings, net transport fluxes, wet and

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dry depositions in each region were not significantly correlated with the ENSO index. However, the spatial distribution of the relative effects of ENSO on the aerosol transport variations was derived in Figure 11 by using the composite analysis. Correlating with the ENSO, the most significant differences between El Niño and La Niña years appear along the mid-latitude transport pathways connecting all four HTAP-regions by the westerly jet. Positive and negative anomalies of the aerosol transport in El Niño and La Niña years are found over all the circumpolar intercontinental routes for transpacific, transatlantic and trans-Eurasian transport of aerosols in the NH scale (Fig. 11a-b) The wet and dry deposition fluxes actually vary from year to year. Figures 10a and 10b present the distribution of inter-annul variability in annual aerosol mass removed by dry and wet depositions in the NH with the standard deviations over 1995-2004. Following the suggestion by the reviewer, we have added Table 3 showing the regional averaged variations in dry and wet depositions over the HTAP-regions of EA, NA, EU and SA. The inter-annual variability in wet deposition is larger by a factor of 2-10 than in dry deposition over the source regions and particularly along the transport pathways. The over-all importance of hemispheric transport for aerosols for a specific region was not the purpose of this study as this has been done through a series of sensitivity studies of emission reductions organized by HTAP (HTAP, 2010). This paper is to characterize the importance of meteorology in the inter-annual variations of hemispheric aerosol transports by using a fixed emission but multiple-year simulations. In a sense, this paper extends and supplements the HTAP study, which only used the results of one year simulation.

[The paper would benefit from some discussion of the uncertainties involved, particularly regarding possible biases associated with the location of sources within particular regions. Are the same features seen for different aerosol types with different sources and lifetimes, or are the results presented here dominated by a single type of aerosol?]

Response: Based on our modeling results, there are different features for each aerosol type due to the different sources, lifetimes, regional and seasonal characteristics. In

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this study on hemispheric aerosol transport, we analyzed the transport flux and mass for all simulated aerosols, i.e. sulfate, soil dust and sea salt as well as organic carbon and black carbon, from both natural and anthropogenic emission sources to construct a mean HTAP-climate with the seasonal and inter-annual variability and the transport patterns. The results presented here could be dominated by a single type of aerosol depending on its tempo-spatial changes. Although the transport feature for each aerosol type will be further studied based on the 10 yr-modeling, we have added some discussion of the uncertainties involved, particularly regarding possible biases associated with the location of sources within particular regions in the revised version (section 5).

[It would be useful to include a brief discussion of the role of the NAO in the variability in mid-latitude/Arctic transport.]

Response: Yes, we have included a brief discussion of the role of the NAO in the variability in mid-latitude/Arctic transport as follows: Eckhardt et al. [2003] predicted that during positive phases of the North Atlantic Oscillation (NAO) surface concentrations of tracers in the Arctic winter were elevated by about 70% relative to negative phases of the NAO. Consistent with that prediction, Sharma et al. [2006] found that observed BC at Alert was 40% higher during the positive phase of the NAO. However, a recent study [Osborn, 2006] found no significant trends in NAO from 1981 to 2005, which exerts a significant control on pollutant transport to the Arctic. The NAO exhibits a less influence on the interannual variability of mid-latitude/Arctic transport (Gong et al., 2010) and in transpacific transport (Liu et al., 2005). Eckhardt, S., et al. (2003), The North Atlantic Oscillation controls air pollution transport to the Arctic, Atmos. Chem. Phys., 3, 1769–1778. Osborn, T. J. (2006), Recent variations in the winter North Atlantic Oscillation, Weather, 61, 353–355, doi:10.1256/wea.190.06. Sharma, S., et al. (2006), Variations and sources of the equivalent black carbon in the high Arctic revealed by long-term observations at Alert and Barrow: 1989–2003, J. Geophys. Res., 111, D14208, doi:10.1029/2005JD006581.

[The English in the paper is generally reasonable, but there are quite a number of places where the grammar remains awkward, and these issues needed to be resolved before publication, ideally through editing by a native speaker.]

Response: The grammar issues have been edited following the reviewer's suggestion.

[Bracketed or slashed alternatives are used in a number of places (e.g., abstract lines 21-22). These break up the flow of the text and make interpretation of the meaning more difficult for the reader, and therefore they should be avoided entirely. Please rewrite these sentences replacing the alternatives or rephrase in full. For an entertaining explanation of this, see the article by Alan Robock in EOS, Vol 91, No.49, Nov 9, 2010. (Other cases in the text: p.10192 l.24-26; p.10200 l.16; p.10202 l.14-20).]

Response: Following the article of Alan Robock in EOS, Vol 91, No.45, Nov 9, 2010, all the mentioned sentences have been rewritten in the revised version.

[Please try to reduce the number of acronyms, as unfamiliar acronyms can significantly hinder comprehension. The acronym "HAT" does not seem necessary here, as it can be replaced with "aerosol transport" (or "hemispheric aerosol transport" if needed) in most places.]

Response: Yes, we have replaced "HAT" replaced with "aerosol transport" or "hemispheric aerosol transport " in the revised manuscript. Specific Comments

[Abstract l.14-15: "HTAP regions" are not defined here. This could be rephrased as main northern hemisphere source regions, or alternatively the regions should be identified.]

Response: It has been rephrased as main northern hemisphere source regions of Europe, North America, South and East Asia.

[10189, l.10: How do the natural emissions vary? The meteorological variation in emissions is an important component of the interannual variability, and it would therefore be useful to quantify this briefly here.]

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Response: Yes, the meteorological variation is an important component causing the interannual variability in emissions, especially for the natural aerosol emissions of soil dust and sea salt. For the GEM-AQ/EC modeling, the natural emissions of soil dust and sea salt are on-line calculated with their emission parameterizations on basis of the current understanding on the physical processes involved in the wind forced movement of sea salt and soil dust particles (Gong et al., 2003b; Gong et al., 1997). The natural emissions by boreal and temperate fires are changed from year to year, which are prepared in the emission inventory dataset. The detailed variations of natural emissions are given by Gong et al. (2012).

[How do the patterns described in section 3.2 and Figs 3-6 vary between years?]

Response: The 10-year averaged HTAP-transport patterns of Figs. 3-6 in winter and summer could vary year to year depending on the inter-annual variability in meteorology and aerosol emissions. In section 3, we have only presented the mean climate of hemispheric aerosol transport and not discussed the inter-annual variability in HTAP-transport patterns of Figs. 3-6.

[10193, l.1-3: You should relate these changes to the migration of the ITCZ .]

Response: The sentence has revised into "During summertime, the tropical and subtropical easterlies extend northwards to 30 °N in the free troposphere accompanying the northward migration of the ITCZ or Intertropical Convergence Zone and the withdrawal of westerly zone" .

[The discussion in Section 4.2 would benefit from some tightening, and from further quantification, particularly for the deposition section where a table of deposition fluxes and variability could be provided for each region for wet and dry removal.]

Response: Following this suggestion, we have added the Table 3 for the inter-annual variations in dry and wet aerosol depositions with the standard deviations averaged during 1995-2004 over four HTAP-regions. The inter-annual variability in wet deposition

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is larger by a factor of 2-10 than in dry deposition over the source regions and especially along the transport pathways.

[Section 4.3 presents an interesting and useful analysis. It would be helpful if the anomaly distributions presented in Fig 11 could be supplemented by a simple quantification of the overall impact of ENSO: do you see net regional changes in fluxes (if so, how much?) or just changes in inflow/outflow location within the region?]

Response: we analysed the regional net transport fluxes, aerosol inflow/outflow location over four HTAP-regions. The weak correlations with the ENSO index were found for all the HTAP-regional aerosol net transport, inflow and outflow fluxes, which could be resulted from the regional averages over the large HTAP-region domain and from the region positions.

[It would be valuable to include a final line in Table 2 that gives the coefficient of variation for the net flux out of each region.]

Response: In section 3.1, we presented the following discussion: Based on the annual net transport masses shown in Figure 1, EU is the only "exporting" region of aerosols with the net flux out of the region, and its export mass at the eastern boundary is more than two times greater compared to that of EA, and more than 2.5 times greater than that of NA. There could be two reasons of aerosol emissions and meteorology for that. As described in Gong et. al. (2012), the global sulphur emissions are based on the data of Global Emissions Inventory Activity (GEIA), and climatological emissions representative of the end of 1980's were considered for the tropical forest fires and savannah fires in the modeling study. The EU-boundaries of 25°N to 65°N are mostly located in the mid-latitudes compared to the EA- and NA- boundaries (Table 1). As shown in Figures 7a and 7b, the mid-latitude westerlies prevail in the eastern EU boundary from summer to winter with the strongest aerosol export, while aerosols are imported by the easterlies in the low-latitudes of EA- and NA- boundaries with reducing the aerosol export mass at the EA- and NA- boundaries. Therefore, we have not included a final

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line in Table 2 that gives the coefficient of variation for the net flux out of each region.

[Fig 2 would be clearer if the lines used 4 colors (one for each region) and two line styles (one for W, one for E). Currently NAW and EUE are difficult to distinguish.]

Response: Following this suggestion, we have redrawn the Figure 2

[Figs 3-6 currently contain both shading and contours, and the winter shading is much easier to interpret than the summer contours. The figures would be clearer if the summer fluxes were plotted separately (i.e., 4 panels for each figure rather than the current 2) so that winter and summer fluxes can be compared side by side. All panels in a single figure should use the same color scale so that they can be directly compared with each other. The figures would also be clearer if the vertical scale was presented in km rather than m.]

Response: To give the clear contrast of inflow and outflow flux variations between winter and summer, we plotted Figs 3-6 containing both shading for wintertime flux and contours for summertime flux, which also reduces the number of figures. Based on the reviewer's suggestion, we have re-plotted Figs 3-6 with 1) enhancing the contour line and label thickness and 2) changing the vertical scale from m to km.

[Fig 8: remove "changes of" in the caption.]

Response: We have removed "changes of" in the caption of Fig. 8.

[Fig 11: The panels contain too much detail and the resulting figure is difficult to interpret. Please consider plotting fewer streamlines and reducing the line thickness so that the underlying shading can be seen.]

Response: Fig. 11 presents the streamlines for the anthropogenic aerosol transport flux patterns averaged in three El Niño years (1995, 1997 and 2003) and three La Nina years (1996, 1999 and 2000) and the filled contours with warm and cold colours for the positive and negative anomalies in the transport flux values relative to the 10-yr mean. Following the reviewer's suggestion, we have plotted Fig.4 with no streamlines

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in the Arctic region. But it is difficult to distinguish the aerosol transport patterns and directions when reducing the line thickness (too small arrows) in Fig. 11. Therefore we have doubled the sizes of Figs. 11a-11d so that the streamlines the underlying shading can be seen and also added a few sentences interpreting Figure 11 in the section 4.3.

Technical corrections

10183, l.5: add Northern Hemisphere and remove the acronym NH.

10185, l.1: "Only 1 yr" -> "A single year"

10189, l.13: form -> from

10191, l.14: built

10197, l.2: Sect 4. -> the next section.

10203, l.4: financial

Response: We have done all the technical corrections.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 10181, 2012.