Atmos. Chem. Phys. Discuss., 11, C13154–C13160, 2011
www.atmos-chem-phys-discuss.net/11/C13154/2011/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Climatic effects of 1950–2050 changes in US anthropogenic aerosols – Part 2: Climate response" *by* E. M. Leibensperger et al.

E. M. Leibensperger et al.

eleibens@mit.edu

Received and published: 13 December 2011

We thank the reviewer for their valuable comments and suggestions. The reviewer's input has improved the clarity and content of the manuscript.

Referee's comments are in plain text, our responses are **boldface**, and changes to the manuscript are ***italicized***.

"Climatic effects of 1950–2050 changes in US anthropogenic aerosols – Part 2: Climate response" by Liebensperger et al presents the results of a study examining the response to US aerosols in a climate model. The study is generally well written and informative, and the results are interesting and well-worth presenting to the commu-

nity. In general I feel the authors have done an excellent job describing the motivation, experimental setup, and the results. The figures are also clear and informative, and overall I commend the authors on a very good discussion paper. I have only three main issues I would like to see addressed in revision before I would consider this paper acceptable for publication in ACP.

The first issue is that I would like to see more attention given to the statistical significance of some of the trends. In particular, on P24143, l11-16, the authors should discuss the statistical significance of the results in Table 1 when drawing their conclusions. It looks like none of the differences between simulations are statistically significant in any time periods, and differences between either simulation and the observations are also not significant. The insignificance of the Table 1 results suggests that this may simply be too short a trend to get reliable climate information. While more ensemble members could have reduced the uncertainty in the model runs, the 1960-1979 and 1980-2010 periods in the observational record do not have statistically different trends.

We find that the differences between the trends are significant between the 90-95th percentile. We have added references to the difference in trends being significant at 90th percentile or higher in Sect. 4.

The second issue is that there are two issues in particular where I do not feel that the authors have fully put their results into context with the literature. These concern the relationship of the location of forcing with the pattern of temperature response in this study vs prior work, and the relationship of the BC results from the GEOS-Chem model used here in comparison with other published studies (see my detailed comments on these two issues below).

Response is below with the specific comments.

The final issue is that the 'Conclusions' section starts with 6 paragraphs summarizing what we've just read, with only two short paragraphs at the end discussing the implications. A broader discussion of the implications and relationship to other works (as in issue 2) would make for a much more valuable conclusion, and I'd suggest that a very short summary followed by a substantially enhanced discussion could provide a good way to address the issues raised above.

The Conclusions section has been modified to make our summary more concise and the following was added:

Relating aerosol radiative forcing to regional climate change is challenging. There are many model uncertainties involved in the mechanisms of aerosol-cloud interactions, the response of the hydrological cycle, the lateral transport of heat in the ocean (the Q-flux parameterization used here does not allow for change in that transport), and other aspects of the climate model. Multi-model analyses are needed to address the robustness of results (National Research Council, 2005). Our ability to reproduce observed 1950-2010 temperature trends lends some confidence to our conclusions.

And to Sect. 3.2 we have added the following:

We find that the cooling effect of US anthropogenic aerosols is largely confined to the US and North Atlantic. As pointed out in the Introduction, Shindell et al. (2010) estimated the spatial extent of the climate response to aerosol radiative forcing to span 3500 km in the meridional direction and 12,000 km in the zonal direction. We find in our simulation that some cooling from US anthropogenic aerosols extends to these distances but is only marginally significant or insignificant. The cooling within the US caused by US anthropogenic aerosols shown in Fig. 3 is not apparent in the simulations of Shindell et al. (2010) which perturbed all anthropogenic aerosols. However, cooling within the US can be found in other simulations of the climate effects of anthropogenic aerosols (Mitchell et al., 1995; Hansen et al., 2005; Wilcox et al. 2009; Mickley et al., 2012).

Specific context issues: P. 24131, l. 6-18: This paragraph discusses prior modeling of the climate impact of regionally inhomogeneous aerosol forcing. It present a somewhat

black and white picture, with several studies cited initially that show 'a strong regional climate sensitivity to aerosols' and then another group of studies that show 'patterns similar to (but opposite in sign) to greenhouse gas forcing'. The implication is that the climate response to aerosols is either entirely local or is just the same as for homogeneous greenhouse gas forcing. The latter is not an accurate description, as the four recent studies cited there (Shindell et al., 2007, 2008; Levy et al., 2008; Kloster et al., 2009) all show climate responses that are quite distinct from those seen in response to greenhouse gases. Figure 7 of Shindell et al (2008), for example, compares the climate responses to short- and long-lived species forcings in the GISS, NCAR and GFDL models, and in all three there are distinct differences. The Northern and Southern Hemispheres, for example, behave rather differently in these cases, and the Arctic response in some models is strong compared with elsewhere for both long- and short-lived forcings, and in others it is not. Similarly, Figure 3 in Kloster et al (2009) shows a much weaker Southern Hemisphere response to aerosol forcing than to greenhouse gases while the Northern Hemisphere response is fairly similar. An overall conclusion from a visual inspection of these climate response patterns suggests a more nuanced effect, with the response often being largest in areas where forcing is large, but not necessarily being highly localized to the forcing location.

The reviewer is correct that the response is likely more nuanced than either entirely local or dispersed. We have modified the introduction to add the following:

... ***However, other studies have found that the climate response to aerosol radiative forcing is more hemispheric or global in scale with patterns similar (but opposite in sign) to greenhouse forcing (Mitchell et al., 1995; Shindell et al., 2007; Levy et al., 2008; Shindell et al., 2008; Kloster et al., 2009). Shindell et al. (2010) estimated the spatial extent of the climate response to aerosol radiative forcing in four GCMs and found it to extend 3500 km in the meridional direction and 12,000 km in the zonal direction.*** ...

The addition to Sect. 3.2 quoted above is also relevant to this comment.

One need not rely solely on visual inspection, however, as there is another study that the authors have missed that attempts to quantify this link. Shindell et al (2010) examined exactly this question using the results of four GCMs and quantified length scales of influence. They found that inhomogeneous aerosol forcing does indeed tend to cause a strong impact locally in those GCMs, but the impacts is not confined to those areas and extends quite far in the zonal direction while not extending nearly as far in the meridional (consistent with transport timescales in the atmosphere). The surface temperature response presented in the authors' Figure 3 is in fact consistent with the general pattern of the other GCMs, showing a response to US emissions that is greatest for the Eastern US but which extends broadly around the Northern Hemisphere midlatitudes while having little impact on the tropics or the Southern Hemipshere. Hence the response in this model relative to other GCMs should be put into context with the prior work showing that the spatial structure is not black or white (purely local or insensitive to the spatial structure), but somewhere in between. It may be that the response in this model is a bit more localized than the others – the authors could calculate the same metric as in the Shindell et al (2010) paper to see – but the broad relationship appears similar to me. Currently, this topic is raised in the introduction, but the authors do not return to it when they present their forcing and temperature results nor in their conclusion. In my opinion, it would be useful to revise the introduction to better reflect the other GCM results, and to discuss how the current results fit into context with those in the conclusion.

The enhanced autocorrelation metric is less useful for our simulation setup (i.e. isolating the effects of one regional forcing rather than all locations at once). The results of Shindell et al. (2010), however, are a fair comparison and we now mention that study (included in text changes listed above).

P24146, l 16-19: The authors concluded that BC has minimal effect on temperatures for the US. There result needs to be put into context as well, as there is ample literature on the uncertainties in modeling BC. The authors use the Chen et al (JGR, 2010)

representation of aerosol indirect effects. They conclude that 'BC sources in the US are too small for their climatic impact to be significant'. The model they use was shown in Chen et al (GRL, 2010) to give a net warming for reductions in BC. In that sense, it's no surprise that mitigation of BC does not give cooling in this study, regardless of their size. However, there are multiple other studies that give very different results from Chen et al (e.g. Bauer et al., 2010; Koch and Del Genio, 2010 and the many papers reviewed therein; Jacobson, 2010). A useful discussion would be to put the current results into context with these other studies.

In this work, the effect of BC is assessed solely in terms of its direct radiative forcing (in Part 1). In the US we find the present day forcing to be small compared to the other aerosol components. The climate response is similarly small.

While both studies use GISS GCM 3, the model setup used here is different than Chen et al. (2010). We employ a mass-CDNC parameterization based on results from TOMAS, while Chen et al. (2010) conducted detailed microphysical calculations directly with TOMAS.

The question being asked here: "does reducing BC from the US have a significant climate effect?" is different than Chen et al. (2010). Besides having a different model setup, Chen et al. (2010) did not assess the semi-direct effect (an important part of the net BC effect), present regional radiative forcing (important given different meteorological and pollutant conditions), or isolate BC from BC/OC emissions. The net effect of BC from the US is not immediately obvious from Chen et al. (2010).

We find that US BC is not large enough to cause changes in surface air temperature or cloud cover (through the semi-direct effects).

The following text has been added to Sect. 2.2:

More generally, we find that a regional radiative forcing of about 1.0 W m^{-2} is

necessary to produce a climate response greater than natural variability in the GISS GCM 3 with a 5-member ensembles. The climate effects of BC may differ when considering coemitted species and microphysical effects (Bauer et al., 2010; Chen et al., 2010a; Jacobson, 2010). The climate effects of BC are additionally sensitive to the vertical profile of BC and modeled cloud cover (Koch and Del Genio, 2010). Koch et al. (2011) found surface air temperature to be less sensitive to BC than a similar amount of sulfate radiative forcing due to compensating changes in stability and cloud cover.

New References:

Koch and Del Genio, ACP, 10, 7685, 2010
Koch et al., J Climate, 24, 2693, 2011
Bauer et al., ACP, 10, 7439, 2010
Jacobson JGR, 115, D14209, doi:10.1029/2009JD013795, 2010
NRC, Radiative forcing of climate change: Expanding the concept and addressing the uncertainties, 2005
Shindell et al., JGR, 115, D19110, doi:10.1029/2010JD014108, 2010
Wilcox et al., Ann Geophys, 27, 4009, 2009

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 24127, 2011.