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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ocean mediation of tropospheric response to reflecting and absorbing aerosols" *by* Y. Xu and S.-P. Xie

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We thank the constructive comments from the reviewers. We made revisions to address the concerns of reviewers and improved the presentation of our paper. A revised manuscript with all changes since its last submission highlighted is uploaded as supplements to this response. Please see the detailed response below.

Reviewer #1:

Comments: In this paper, you proved the changes in the SST gradient and mid-latitude eddies are instrumental in creating a similar deep vertical temperature in response to BC and SO4. It shows the importance of ocean-atmosphere interactions. This is the pioneering study about climate effects of aerosols at present. In this regard, this paper

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is interesting and important. The results are convincing and the simulations used are appropriate. I thereby believe this manuscript is appropriate for publication in ACP and would recommend publication subject to primarily minor revisions outlined below. Hope the comments below are of help for the authors.

Responses: Thanks very much for the comments and suggestions. We have made revisions accordingly. Please see specific changes below.

Comments: (1) I am confused about how to conduct the model configuration in this paper. Parameterization schemes, spatial resolution, . . .should be shown in this study. And more information about the emission inventory of BC and SO4 should be mentioned. Furthermore, the introduction of the modeling performance about simulating BC and SO4 is inadequate in this paper. BTW, BC in snow could increase the surface temperature and reduce snow pack. These impacts may result in the change of soil moisture, surface fluxes, and East Asian monsoon (Huang et al., 2011, Wang et al., 2013 and Flanner et al., 2005). Is BC in snow considered in the paper?

Responses: We now included in the method section more details about model and experiment set-up. Some statements are copied below. Parameterization schemes: The three-mode modal aerosol scheme (MAM3) provides internally mixed representations of aerosol number concentrations and masses (Liu et al., 2012). Aerosol indirect forcing is included for both liquid and ice phase clouds (Gettelman et al., 2010). Model resolutions: The resolution of both atmosphere and ocean models is 1 degree by 1 degree for the coupled simulations (Experiments a and b) in this study. The resolution of atmospheric model is 2 degree by 2 degree for the uncoupled simulations (Experiments c and d) in this study. Emission inventory: The anthropogenic forcings in CESM1 include long-lived greenhouse gases (GHGs), as well as tropospheric ozone, stratospheric ozone, sulfate aerosols, and black and primary organic carbon aerosols. The aerosol emission inventory is from the standard Representative Concentration Pathway as described in Lamarque et al. (2010). However, the present-day emission level of BC is adjusted from the standard model emission inventory to account for the poten-

ACPD
15, C1365–C1372, 2015

tial model underestimation of BC atmospheric heating. Modeling performance about simulating BC: Our previous analysis (Xu et al., 2013) show that such a correction improves simulated radiative forcing compared to the direct observations. Without the observational constrains, simulated BC forcing (and associated temperature response) would be lower by about a factor of two. BC in the snow: In addition to the atmospheric heating, deposition of BC particles onto snow surface with high albedo would reduce surface albedo and contribute to surface warming (Huang et al., 2011). The land model of CESM incorporates SNICAR (Snow and Ice Aerosol Radiation) module, which represents the effect of aerosol deposition (BC, organic carbon and dust) on surface albedo (Flanner et al., 2007).

Comments: (2) “Reflcting and absoring aerosols” are always mentioned in this paper. However, only SO4 and BC4 were considered in the simulations. As we known, dust is one of the absorbing aerosols in the atmosphere, which can influence the climate directly by modulating the radiation budget, affect the microphysical properties of clouds, and alter the surface albedo of the ground covered by snow or glacier. Therefore, I think more aerosols species should be discussed in detail.

Response: This is a good point. We now added that " Note that in this study we used BC, a strong absorber, to characterize absorbing aerosols that also include dust and organic aerosols. Similarly, we used SO4 to characterize reflecting aerosols although dust and organic aerosols are also partially reflecting. This approach provided a clearer contrast between these two types of aerosol forcing."

Comments: (3) In this paper, you just showed the vertical profile of simulated results. I think the spatial distributions of the most relevant results are needed. It can help us decide whether the patterns of simulations are reasonable at global scales.

Responses: Thanks for the suggestions on including spatial pattern of the responses. We intend to focus on the tropospheric response in this paper, as it is a feature rarely explored before. As for spatial distribution of climate response at the surface suggested

ACPD
15, C1365–C1372, 2015

by the reviewer, we are now actively working on a complimentary paper on this issue. Nevertheless, we now included the SST response to all three forcings as Fig S1.

Comments: (4) Some parts of supplement materials including a detailed explanation should be put in the main body.

Response: Now Fig S1 is moved to be Fig 1. Fig S3 and Fig S4 are also consolidated into main text figures.

Minor comments: (1) Table S1: How to get these results in Table S1? Please give more details about background information.

Responses: The table caption is re-written to clarify the approach. It now reads " Table S1. (a) TOA forcing (W/m2, shortwave + longwave) due to BC (direct radiative forcing from pre-industrial to present-day; not including snow albedo effect), SO4 (direct+indirect forcing from pre-industrial to present-day, so called “adjusted forcing”) and CO2 (from pre-industrial to present-day at 400 ppm). The radiative forcing is diagnosed by contrasting two sets of five-year atmospheric-only simulations with pre-industrial and present-day emissions/concentrations, respectively. (b) Surface temperature change (ÌŁC) in response to different forcings in (a). These are calculated from the 60-year average of coupled model simulation. (c) Cumulative precipitation (cm) change in response to different forcings in (a). The relative changes in percentage are shown in parenthesis next to the absolute changes.

Comments: (2) Section 2.1: Introduce the model configuration including the modeling domain, the BC and SO4 emission inventory.

Response: This is addressed. Please see response to major comments.

Comments: (3) Figure 1 and Figure 3: The figures did not show the SST perturbation induced by BC. Why?

Responses: Due to limited computational resources, we did not conducted BC-induced SST perturbation simulation. We speculate this is merely reversing the sign of the SO4-

ACPD
15, C1365–C1372, 2015

induced SST perturbation.

Comments: (4) Figure 4 and Figure S4: These figures need to be more clearly. Please improve them.

Response: Thanks for the suggestions. We now consolidated them together to be Fig 5 and improved the presentation by showing color contour.

Reference: 1. Huang, J., Fu, Q., Zhang, W., Wang, X., Zhang, R., Ye, H., and Warren, S.: Dust and black carbon in seasonal snow across northern China, Bull. Amer. Meteor. Soc., 92, 175–181,doi:10.1175/2010BAMS3064.1, 2011. 2. Wang, X., S. Doherty, J. Huang, 2013: Black carbon and other light-absorbing impurities in snow across Northern China, Journal of Geophysical Research: Atmospheres, 118, doi:10.1029/2012JD018291. 3. Flanner, M. G. and Zender, C. S.: Snowpack radiative heating:InïnËĞCuence on Tibetan Plateau climate, Geophys. Res. Lett., 32, L06501, ′ doi:10.1029/2004GL022076, 2005. âĂČ Reviewer #2:

General comments: This study compares the atmospheric circulation responses to absorbing black carbon (BC) and reflective sulfate (SO4) aerosols. It had been previously hypothesized that the atmospheric responses to these 2 types of aerosols differ significantly, since BC aerosols alter the atmospheric vertical heating profile whereas SO4 do not. However, this study finds similar mid-latitude responses (of opposite sign) to BC and SO4 aerosols in the CESM model, both characterized by adjustments of the Hadley cell and mid-latitude jets. The authors attribute the SO4-related changes to the interhemispheric pattern of SST changes, which perturbs the atmospheric column even though SO4 aerosols cause very little direct forcing. This is an interesting study which contributes to the understanding of the dynamical effects of aerosols on the tropospheric circulation.

Responses: Thanks very much for reviewing our paper.

Comments: My main suggestion is that the contrast with the GHG response should be

ACPD

15, C1365–C1372, 2015

drawn out further. In particular, the difference in the jet stream response to aerosol v. GHG forcings [e.g. Lu et al. 2008; DOI: 10.1175/2008JCLI2200.1] should be made more explicit. More broadly, how can the conclusions of this study be reconciled with [Xie et al. 2013; DOI: 10.1038/NGEO1931], which finds fundamental similarities between the responses to aerosol and GHG forcing?

Response: Thanks for the suggestions. We intended to focus on comparing absorbing and reflecting aerosols, as this is less studied before. We are currently working on another paper draft giving a more thorough discussion of GHGs vs aerosols response. Basically, the similarity of GHG and aerosols are profound at the surface and boundary layer, and the distinction is revealed in the free troposphere. Nevertheless, we moved Fig S1 to the main text as Fig 1 and gave more discussions on the GHGs response in the beginning of Section 3.

Specific comments / questions: 1: The extremely small magnitude of the SO4 fast component in Figure 2 is striking. Are all of the aerosol cloud indirect interaction effects accounted for by the fast component, or could some be decomposed into the slow component?

Response: The aerosol cloud indirect forcing is indeed included in the fast component as we only fixed SST in the experiment and clouds are allowed take fast response. If not with aerosol indirect effect, the surface and atmospheric response would be even smaller.

Comments: 2. In Figure 3, it is not clear that the Hadley cell responses are similar except in magnitude. The BC Hadley cell change appears to be mainly in the northern cell, whereas the SO4 change appears to be mainly the southern cell. Please explain this difference (or alternatively, why it is not important).

Response: This is a good observation. First, note that color for SO4 response in original Fig 3 (now Fig 4) is not reversed as in previous temperature figures, in order to depict the real direction of circulation change. The magnitude of the response in

ACPD
15, C1365–C1372, 2015

BC is weaker due to a smaller forcing (Table S1), and we selected the color scale in BC case to be 50% of SO4 case. As for the location of maximum circulation change reviewer pointed out, SO4-induced Hadley cell change is over the equator while BC-induced Hadley cell change appears slightly more on the north side. The same for the jet stream shift. The subtle difference is probably related to the geographic difference in BC and SO4 forcing (amid both are stronger in NH), which may influence Pacific and Atlantic branch of jet differently. We now include above discussions in the paper, and will further investigate in the complimentary paper.

Comments: 3. In the conclusion, the authors suggest that projected SO4 reductions may result in deep mid-latitude warming. However, would future air pollution controls also reduce BC emissions, and thus produce a mid-latitude cooling response?

Response: That's true. We feel that the tropospheric heating from future SO4 decline is rarely recognized as a threat for mountain snow pack in the future. That's why we point it out in the conclusions and imply more stringent control on heating BC and CO2 is needed to mitigate the snow retreat.

Technical and clarification comments: a. [Page 5539, line 2]: The singular "dust" is the more proper usage.

Responses: Fixed.

Comments: b. [Page 5539, lines 9-11]: It is not clear what previous studies are being referred to.

Responses: It now reads "While previous studies (e.g. Xie et al., 2013; Ocko et al., 2014) focused on radiative forcing and climate impacts of aerosols on surface temperature and precipitation (Table S1), few looked at the tropospheric response."

Comments: c. [Section 2.2.d]: It would be helpful to include a supplementary figure of the SST perturbation pattern, considering its importance for the mechanism.

Response: We now included the SST response to all three forcings as Fig S1.

ACPD
15, C1365–C1372, 2015

Comments: d. [Figure S1]: This is a key overview of the main heating and temperature responses. Perhaps it could be included as a main figure rather than supplementary?

Response: Thanks for the suggestion. We now move it to be Fig. 1.

Comments: e. [Figure 3]: Would it be clearer if the sign convention for Figures 3a and 3b were reversed to match Figures 1 and 2?

Responses: We now clarify in the text by stating that " Note that color for SO4 response in Fig. 4 is not reversed as in the temperature figures, in order to depict the real direction of circulation change." This is consistent with the following EP flux and refractive index diagnostics.

Comments: f. [Page 5543, bottom; and Figure S5 caption]: I suggest the wording should be "the climatology."

Responses: Fixed.

Comments: g. [Page 5544, bottom paragraph]: The use of parenthesis to indicate opposites in this way is difficult to read. See http://climate.envsci.rutgers.edu/robock/Parentheses2010EO450004.pdf

Responses: Thanks for the suggestion. We fixed this.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/15/C1365/2015/acpd-15-C1365-2015-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 15, 5537, 2015.