Manuscript # acp-2020-3

Responses to Referee #3

Review of "Source attribution of Arctic aerosols and associated Arctic warming trend during 1980-2018" by Ren et al.

This paper presents a modelling study of the impacts of changing SO_4 and BC on the Arctic atmospheric composition, radiative forcing, and temperature. Modelled and measured SO_4 and BC are presented in the Arctic from 1980-2018 at a handful of surface measurement sites. A tagged version of CAM5 is used to quantify the source contributions from different continental geographic regions to the Arctic BC and SO_4 concentrations both at the surface and in the vertical column. The paper present interesting results that are important for understanding the rapidly warming Arctic. The authors conclude that about 20% of Arctic warming can be attributed to the combination of BC and SO_4.

We thank the reviewer for all the insightful comments. Below, please see our point-by-point response (in blue) to the specific comments and suggestions and the changes that have been made to the manuscript, in an effort to take into account all the comments raised here.

I suggest only the following minor revisions below before publishing:

lines 130-131: is there a primary reference for CAM5 and CESM that you can reference here?

Response:

Thanks for the suggestion. We have now added the primary reference for CESM as follows: "The global aerosol-climate model CAM5, which is the atmospheric component of the earth system model CESM (Community Earth System Model, Hurrell et al., 2013) developed at the National Center for Atmospheric Research (NCAR), is used to simulate Arctic aerosols and climate for years 1980–2018 (after one-year model spin-up)."

lines 143-144: what is the source for the specified sea surface temperatures, sea ice concentrations, etc?

Response:

Sea surface temperatures and sea ice concentrations are created from the merged Reynolds/HADISST products, as described in Hurrell et al. (2008). Solar radiation and GHGs follow the CMIP6 configuration for AMIP-type of simulations. We have now included these details in the manuscript.

lines 209-210: was the modelled precipitation compared to measured precipitation? Was wet deposition of model validated against measurements?

Response:

The performance of CAM5 in aerosol wet deposition and transport to the Arctic has been specifically evaluated and improved in previous studies (e.g., Liu et al., 2011; Wang et al., 2013; Qian et al., 2014; Yang et al., 2018a. To address this comment and follow a suggestion from one of the other reviewers, we have revised the sentence to "According to previous CAM5 studies on aerosol wet removal and long-range transport, the model underestimates aerosol concentrations in spring, likely due to biases in parameterizations of convective transport and wet scavenging of aerosols (Bond et al., 2013, Liu et al., 2011, Wang et al., 2013; Qian et al., 2014; Yang et al., 2018a)."

Fig 5/line 241: it needs to be clarified that Fig 5 is the model average in the Arctic (>66.5 ˚N).

Response:

Following the suggestion, we have now revised the sentence to "The absolute and relative source contributions of emissions from the major source regions to the simulated annual mean near-surface sulfate and BC concentrations averaged over the Arctic (66.5°N–90°N) are shown in Fig. 5."

line 252: was that rise in BC seen in the observations? e.g., consistent with BC seen at Alert?

Response:

Yes, we have now revised the sentence to "Simulated Arctic BC concentration also shows a considerable decline before 2000, but a slight rise after 2000, which is consistent with the BC observations at Alert."

line 263: "in the Arctic" ... and Russia?

Response:

Yes, we have now revised the sentence to "To further reduce present-day or future aerosols in the Arctic, efforts can be made to control local sources in the Arctic as well as emissions from Russia."

line 316: is the effect of BC deposition on snow/reduction of albedo included in this? I think not because that effect is discussed later, but could clarify here that this value is just for atmospheric BC effect.

Response:

No, the effect of BC deposition on snow/reduction of albedo is not included in it. This value is for atmospheric BC effect only. We have now revised the text to "The Arctic sulfate exerts a negative RF_{ari} primarily by scattering incoming solar radiation back into the space, with the forcing in a range of -0.4~0 Wm^{-2}. The atmospheric BC can absorb solar radiation in the atmosphere and leads to a positive RF_{ari} of 0.1~0.4 Wm^{-2} in the Arctic."

Section 5/line 400: Can you add some discussion as to how the model bias affects your conclusions? E.g. would your estimates of SO_4 and BC temperature impacts be greater or lesser if the model were corrected to accurately reflect the measurements?

Response:

Thanks for the suggestion. We have now revised the sentence to "Considering that the model underestimates the magnitude of sulfate and BC concentrations, the estimated impact on Arctic temperature from sulfate and BC could be even larger if the model were able to accurately reproduce the measurements in the Arctic."

Data availability: please add where the Arctic BC & SO_4 measurements can be found in this section (e.g., EBAS database link).

Response:

Added.

Figs 1-2, and 5-7: please make sure the regional colours are consistent in all of these plots. e.g., colour X for RBU, colour Y for EUR, etc, in all 5 figures the same.

Response:

We have now made the regional colors consistent in all plots.

Fig 3 (4): Clarify in the caption that the black is from measurements, and the blue and green are modelled. E.g., "Measured seasonal means are denoted by...". "Stacked contours represent the modelled Arctic..."

Response:

Thanks for the suggestion. We have now revised the figure caption to:

Figure 3. Surface concentrations of sulfate aerosols (μg m^{-3}) in spring (March–May) and summer (June–August) at four locations (Alert, Station Nord, Ny-Alesund, Kevo) in the Arctic during 1980–2018. Seasonal means are denoted by solid black circles, medians as short horizontal bars, and the 25th to 75th percentile ranges as vertical bars. Stacked colors represent modeled contributions from the Arctic (blue) and non-Arctic anthropogenic source region (green). The observations denoted by solid black circles are obtained from European Monitoring and Evaluation Programme and World Data Centre for Aerosols database (http://ebas.nilu.no) and Breider et al. (2017). Black triangles at Ny-Alesund for the period 1980–1981 show mean observations from Heintzenberg and Larssen (1983). Black diamond at Ny-Alesund in summer shows median non-sea-salt sulfate concentration from Maenhaut et al. (1989). Open circles in the spring for Ny-Ålesund are March–April mean values (Sirois and Barrie, 1999). Note that the vertical coordinates use logarithmic scales.

Fig 3: why is Barrow not shown? Fig 4: why is St Nord not shown? Fig 5: specify that this is the Arctic (>66.5 °N) average. As mentioned above, use the same regional colour scheme here as in Fig 1(a) & Fig 2. Fig 6 & 7: match the regional colours to Fig 5.

Response:

The data of Barrow and St Nord sites are relatively scarce. We only selected sites with more than 20 observation samples.

Following the suggestion, the caption Figure 5 has been revised to “Time series (1980–2018) of absolute (left, μg m^{-3}) and relative (right, %) contributions of emissions from the major source regions to the simulated annual mean near-surface sulfate and BC concentrations averaged over the Arctic (66.5°N–90°N).

Fig 2, Fig 5, Fig 6 and Fig 7 have now been revised to use the same regional color scheme.

Reference:

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