

Referee #1

Major Comments:

“This is an interesting study exploring sources of black carbon to the Arctic during April 2008, using an adjoint model configuration. The paper is well-written and well-referenced. Overall I find this to be a suitable study for publication in ACP and a worthwhile contribution to the literature in general, but I include below some critiques that should be addressed before the study is published.”

1 *“The authors raise the important point that previous studies applying 5- or 10-day back trajectories probably underestimate the contribution of BC from Asia to the Arctic. Yet the authors here cite surprisingly long atmospheric lifetimes for some sources of BC (Table 1), including 71 days for springtime Asia anthropogenic emissions, 98 days for annual-mean South Asia biomass emissions, and 141 days for springtime South Asia biomass emissions. Since the model runs were initiated only on March 1, less than two months before the analysis period, the long atmospheric lifetimes of springtime Asia emissions imply that Asia contributions may also have been underestimated in this study. The authors should include some assessment of the potential magnitude of bias introduced by their short spinup period compared with the modeled BC atmospheric lifetime.”*

Response: Points well taken. The long lifetime reported previously in the manuscript only accounted for deposition. I revised the lifetime now to account for both deposition and transport (Table 1). The method was explained in the note of Table 1. The lifetimes for BC accounting for both deposition and transport are less than 12 days. Thus, the two-month spin up time before the starting date March 1 is long enough for the system.

2 *“More generally, the reported lifetimes (Table 1) seem substantially longer than those cited in previous studies, and imply that the simulated global atmospheric burden (and probably direct radiative forcing) of BC must be quite large in this model. Please comment on this, in the context of previous studies of global BC burdens and radiative forcing.”*

Response: Points well taken. As explained in Response for question #1, the revised BC lifetime in the Arctic is close to other studies now. Global BC burden is within the range of current AeroCom models (See details in Table 6 in our papers Qi et al., 2017a, b).

3 *“While it is fine to focus the study on a narrow timeframe (April 2008), there is large inter-annual variability in spring BC emissions, especially those associated with biomass burning, and probably also in transport pathways to the Arctic. I suggest acknowledging this a bit more clearly, and if possible briefly discussing how representative the conditions of April 2008 were of Aprils in general (say, over the period 2000-2015). I also suggest changing the title from "Sources of Springtime..." to "Sources of Springtime*

2008..." to communicate that this study only quantitatively examines one particular spring (unless the authors expand the analysis in a revised draft)."

Response: Points well taken. Revised accordingly in the title and in Sect. 3.1.

4 "The modeled biases with respect to observations are as large as 80% at some locations. The implications of such large biases for source apportionment should be described more thoroughly. It is unlikely that all sources are biased in the same proportion, implying the potential for considerable bias in the apportionment itself."

Response: Points well taken. Revised accordingly in Sect. 4.3.3.

Specific comments:

1. "p1,16: Do these percentages represent the fraction of anthropogenic sources or the fraction of total BC? Wording suggests the former, but please clarify."

Response: It is the former. Clarified.

2. "p2,2: Please clarify the spatial domains over which these sensitivity numbers apply. Presumably the temperature change is Arctic, but over what domain is forcing averaged over?"

Response: Clarified.

3. "p3,3: "ends" -> "end""

Response: Done.

4. "p3, second paragraph: This section highlights great features of the adjoint technique and provides good justification for the methods applied here, but I would also acknowledge clearly that the quality of an adjoint analysis still depends on the accuracy of the physical representations built into the forward version of the model."

Response: Points well taken. Acknowledged as such in Page 4 Lines 1–2.

5. "p5,21: Was the gridded flaring emissions inventory used in this study provided completely by Stohl et al (2013), or were additional assumptions adopted to create the inventory? Please clarify."

Response: The flaring emission inventory used in this study is completely from Stohl et al. (2013). Clarified in Sect. 3.1.

6. "p5: Were any shipping emissions included in this study? If not, please comment on this omission and its potential importance for the study. "

Response: Anthropogenic emissions used in this study (Bond et al., 2007) include

shipping emissions already.

7. *“p5,26-31: It wasn’t clear to me which aging scheme was applied in the main analysis of this paper. For the main analysis, was constant aging assumed or slower winter/spring aging assumed? Please clarify.”*

Response: Clarified.

8. *“p5,31: “We estimates” -> “We estimate””*

Response: Done.

9. *“p6,31: “reaching the sites”: Presumably you mean reaching the surface (i.e., lowest model layer) at these locations, but please clarify.”*

Response: Clarified accordingly.

10. *“p7,2: “entirely linear”: linear with respect to what? Please clarify.”*

Response: Linear with respect to emission. Clarified accordingly.

11. *“p7,25: their -> there ”*

Response: Done.

12. *“p8,13-14: But would this feature necessarily produce a positive bias, as seen in the analysis?”*

Response: Clarified.

13. *“p8,28: This is one place where the representativeness of 2008 could be briefly described (see major comment).”*

Response: Revised. See response for question #3.

14. *“p9,30+: Please clarify whether these lifetimes are Arctic or global lifetimes, and describe how they were calculated. Also see comment below about Table 1.”*

Response: Revised accordingly in the note of Table 1.

15. *“p10,28: “in the Arctic front” is used here and elsewhere. The front itself is a boundary, so it might be more clear to instead use something like “within the polar dome” or “poleward of the Arctic front”.”*

Response: Points well taken. Revised in the manuscript.

16. *“p11,10: just for clarity I suggest changing “mean BC concentrations” to “mean forward simulated BC concentrations”.”*

Response: Done.

17. *"p12,22: meaning of "against deposition in the Arctic" is unclear to me."*

Response: Explained in the notes of Table 1.

18. *"p13,5: "Denali, Barrow" -> "Denali and Barrow" (?)"*

Response: Done.

19. *"p14,27: "Overall, the 3-hourly inventory leads to weaker polar-ward transport of BC. For instance, the contribution is 50% lower at Denali,..." - Do these changes improve or worsen the agreement with measurements? Presumably, they should improve the comparison, no? "*

Response: Clarified.

20. *"p14,29-30: "The lower contributions are likely because the temporal variation of the 3-hourly inventory is out of phase of the sensitivities at all sites" - But this should be a physically realistic phenomenon since the sensitivities were derived from high temporal resolution re-analysis data, shouldn't it? Perhaps the importance of this passage could be clarified by re-phrasing it in terms of physical processes rather than model sensitivities.*

Response: Revised accordingly.

21. *And finally, why were monthly emissions used for the main analysis? It seems that 3-hourly emissions should produce more realistic assessments."*

Response: Explained in Sect. 3.1.

22. *"p15,6: "thereby" -> "and thereby" "*

Response: Done.

23. *"p16,4: "sources of BC" -> "sources of BC to the Arctic" "*

Response: Done.

24. *"p16,11: "contributions": contributions to what? Arctic atmospheric BC? Please specify.*

Response: Clarified.

25. *"Table 1: Again, please clarify exactly what these "lifetimes" represent. Are they residence times of BC within the Arctic? If so, how were they computed? If a parcel of BC enters, leaves, and re-enters the Arctic, how would this affect the "lifetime"? Or are these global lifetimes of BC that reaches the Arctic? "*

Response: Clarified in notes of Table 1.

26. *“Figure 5: Maybe clarify that these are sensitivities with respect to hypothetical unit emissions occurring everywhere.”*

Response: Clarified.

27. *“Figure 8: Are the sensitivities for 3-hourly or monthly resolved emissions? What are the units of the right panel?”*

Response: They are the contributions (ng m^{-3}) from Siberia biomass burning emissions with 3-hourly and monthly resolutions, respectively. Figure 8 is revised.

28. *“Figure 9: What are the units? Please describe.”*

Response: It is unitless. The figure plots the ratio of sensitivities without and with the WBF effect.

References

Bond, T. C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S. K., Roden, C., Streets, D. G., and Trautmann, N. M.: Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850-2000, *Global Biogeochem Cy*, 21, doi 10.1029/2006gb002840, 2007.

Qi, L., Li, Q., Li, Y., and He, C.: Factors Controlling Black Carbon Distribution in the Arctic, *Atmos. Chem. Phys.*, 17, 1037-1059, doi:10.5194/acp-17-1037-2017, 2017a.

Qi, L., Li, Q., He, C., Wang, X., and Huang, J.: Effects of Wegener-Bergeron-Findeisen Process on Global Black Carbon Distribution, *Atmos. Chem. Phys.*, in press, 2017b.