Response to Comments of Reviewer #1

Manuscript number: acp-2019-306
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Title: Severe winter haze days in the Beijing-Tianjin-Hebei region from 1985-2017 and the roles of anthropogenic emissions and meteorology

General comments:

This paper investigates the roles of meteorology and emission on the long-term changes of winter haze in the BTH region. To my knowledge, this is the first attempt to quantify these two effects for historical periods. The results shown here thus have important implications for the understanding of haze formation and air quality control in north China. The paper is also well organized and easy to follow. I only have a few minor comments as listed below.

Response:

Thanks to the reviewer for the helpful comments and suggestions. We have revised the manuscript carefully and the point-to-point responses are listed below.

Specific Comments:

1. *It is better to include some more quantitative results in the abstract, such as those in Table 1 and Figure 12.*

Response:

We have added the following quantitative descriptions in the abstract to summarize the major results from Table 1 and Figure 12:

"Process analysis on all SWHDs during 1985-2017 indicated that transport was the most important process for the formation of SWHDs in BTH with a relative contribution of 65.3 %, followed by chemistry (17.6%), cloud processes (-7.5%), dry deposition (-6.4%) and PBL mixing (3.2%). Further examination showed that SWHDs exhibited large interannual variations in frequency and intensity, which were mainly driven by changes in meteorology."

2. *Historical visibility data usually have higher uncertainty and noise level, I wonder if any quality control is enforced?*

Response:

Yes, quality control was enforced in this work. First, the downloaded daily visibility data from National Climatic Data Center (NCDC) have already undergone extensive quality control (see ftp://ftp.ncdc.noaa.gov/pub/data/gsod/readme.text and ftp://ftp.ncdc.noaa.gov/pub/data/noaa/ish-qc.pdf for details), which to a large extent have eliminated many random errors in the original data.

Second, to ensure the consistency and continuity of the downloaded data, further quality control was carried out to remove unreliable outliers/stations following the methods in previous studies (Li et al., 2016; He et al., 2017). For each station:

1) If the standardized daily visibility (V_i) exceeds ± 4, the daily data is then marked as outlier and removed from the original time series.

2) A 3-year sliding window was applied to the series and the mean and variance within that window were calculated. If the standardized mean or standardized variance of a certain window exceeds ± 3, a jump is identified, and the station is eliminated. Note that the discontinuity before and after 2013 is neglected in this process, because we have tackled this problem as described in Section 2.4.

3) If the ratio between 75^{th} and 50^{th} percentile is less than 1.07 or if the ratio between the 90^{th} and 75^{th} percentile is less than 1.1, we treat this station as the one with unreliably low visibilities and this station is eliminated.

After filtering with the above criteria, only the stations with sufficient valid samples (> 90 % availability) were selected for identifying SWHDs in this work as described in Section 2.4.

3. *Section 2.3.1: The authors perform nested simulation with high resolution. However, the input meteorology data is still of low resolution. I wonder if this will affect the simulation results. Or is nested simulation really necessary?*

Response:

Sorry we didn't describe clearly in the previous version of manuscript. For the nested domain of Asia (11° S-55° N, 60°-150° E), the simulations had high horizontal resolution of 0.5° latitude by 0.625° longitude. Only the input lateral boundary conditions of tracer concentrations were taken from a global simulation at a lower resolution of 2° latitude by 2.5° longitude. The resolution of meteorological data that drove the chemical simulations was the same as that of the simulated chemical tracers.

4. *Section 4.2: I suggest adding some discussion about the uncertainty of the trend of each species, as this can be significantly affected by uncertainties in emission (especially historical emission data) and chemistry processes in the model.*

Response:

We have added the following discussions in the second paragraph of Section 4.2:

"Note that these simulated trends of $PM_{2.5}$ components are of uncertainty, which can be influenced by the uncertainties in emission inventories of aerosols and aerosol precursors (Crippa et al., 2018; Li et al., 2017b; Zheng et al., 2018) as well as by the chemistry scheme in the model (Chen et al., 2019)."

5. *Section 5: When using equation (1) to make the partition, the contribution of each factor is assumed to be linear. This may not always be true. For example, both transport and PBL mixing can be affected by horizontal wind speed. So maybe a note is needed here when interpreting the results?*

Response:

Thanks for pointing it out. We have added the following sentence in Section 5:

"It should be noted that although process analysis is a helpful tool to quantify the contribution of each factor, it assumes linear contribution from each factor. This may not always be true because of the covariation of meteorological parameters."

6. *Figure 9 is very interesting and important. I wonder if the results are similar for different periods with different haze day trends.*

Response:

Figure 9 shows the process analysis for SWHDs in BTH for the whole period of 1985-2017. Following the reviewer's suggestion, we have done similar analyses for the two periods with different SWHD trends, 1992-2001 with a decreasing trend and 2003-2012 with an increasing trend, as shown in Figure S4. The results from these two periods (Fig. S4) are similar to those for 1985-2017 (Fig. 9), with transport, chemistry, cloud processes, dry deposition and PBL mixing contributed 70.2 % (67.2 %) , 14.5 % (16.2 %), -7.1 % (-8.3 %), -5.9 % (-5.9 %) and 2.3 % (2.3 %), respectively, to the SWHDs during 1992-2001 (2003-2012). The similarity can be explained by that the process analysis carried out for SWHDs during 1992-2001 (or 2003-2012) was compared to that for mean wintertime conditions of 1992-2001 (or 2003-2012). Therefore, the mechanism of the occurrence of SWHDs relative to the mean condition is the same, with transport process playing a dominant role. So, we present only the results obtained for the period of 1985-2017 in Fig. 9 of our manuscript.

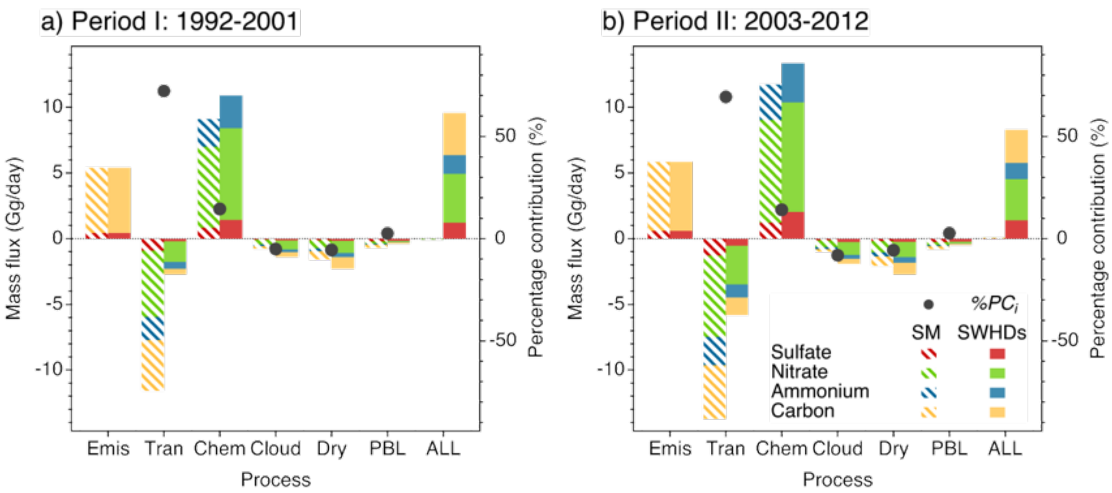

Figure S4. Same as Figure 9 but for periods of **(a)** 1992-2001 and **(b)** 2003-2012.

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Thank you very much for your comments and suggestions.