Response to Comments of Reviewer 2

Manuscript number: egusphere-2024-955

Author(s): Falei Xu, Shuang Wang, Yan Li, and Juan Feng

Title: Synergistic effects of previous winter NAO and ENSO on the spring dust activities in North China

General comments:

Using multi-reanalysis datasets, the authors investigated the effects of the previous winter NAO and ENSO on the spring dust aerosols over North China. The pronounced influence of NAO and ENSO on dust aerosols was predominantly observed during their negative phases. Furthermore, this analysis examined meteorological conditions, atmospheric dynamics, and wave energy transport, elucidating the synergistic impacts of these negative phases on subsequent dust activities. The findings enhance our understanding of the formation mechanisms of dust events in North China. I recommend that this manuscript be accepted after minor revisions, as this study fits well within the scope of Atmospheric Chemistry and Physics.

Response:

Thanks to the reviewer for the helpful comments and suggestions. We have revised the manuscript seriously and carefully according to the reviewer's comments and suggestions. The point-to-point responses to the comments are listed as follows.

Specific comments are as follows:

1. The study primarily utilizes MERRA-2 reanalysis data for analyzing dust activities over North China. It is essential to assess whether the MERRA-2 data accurately captures dust activities in North China. Please provide further details on the reliability of the reanalysis.

Response:

Thank you for the comments.

Previous studies have demonstrated the accuracy and applicability of MERRA-2 reanalysis data for studying the evolution of dust events in Asia. "Its analytical results are similar to those obtained from MODIS, OMPS, CALIPSO, and Himawari-8 data (Kang et al., 2016; Yao et al., 2020; Wang et al., 2021)" (Lines 131-135 in the revised manuscript).

Additionally, we further employ the datasets from the China National Meteorological Centre, which include observations of floating dust, blowing dust, and dust storms, to validate the MERRA-2 reanalysis data. The frequency of dusty weather recorded at these stations has been converted into a Dust Index (DI) (Wang et al., 2008; Equations 1), effectively representing the concentration of dust aerosols.

$$\mathrm{DI} = 9 \times \mathrm{DS} + 3 \times \mathrm{BD} + 1 \times \mathrm{FD} \tag{1}$$

Where DS, BD, and FD represent the frequency of dust storms, blowing dust, and floating dust, respectively. Additionally, DI denotes the concentration of dust aerosols at each station.

We found that the variations of the DI and MERRA-2 dust aerosols concentration during the four seasons all show similar spatial characteristics. Especially for the dust source in Northwest China and the spring dust aerosols over North China, the spatial distribution characteristics are relatively consistent (Figure R1). The above results indicate that the MERRA-2 aerosol reanalysis data can simulate the spatiotemporal distribution characteristics of dust aerosol concentration in China, which is applicable and effective for us to understand the variations in dust aerosol concentration in China.

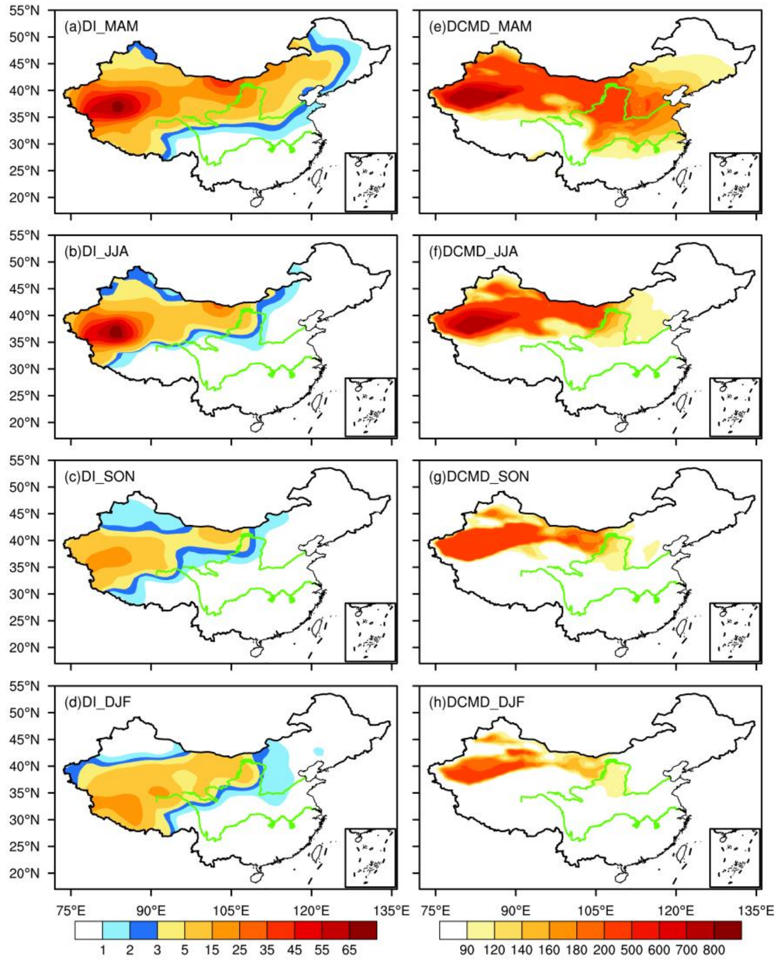

Figure R1. (a-d) Seasonal distribution of DI from station data, (e-h) As in (a-d), but for dust column mass density from MERRA-2 reanalysis data during 1980-2018 (units: mg m^{-2}).

2. The preceding role of NAO and ENSO on the spring dusty weather over North China is investigated, and it is of interest why the preceding role is focused. And whether their simultaneous role in the dust content is significant or not.

Response:

Thank you for the comments.

Previous studies have found that previous NAO and ENSO play important role in impacting the following climate over North China, particular the cross-seasonal impacts (e.g., Zheng et al., 2016; Feng et al., 2019; Sun et al., 2021). Moreover, the one season ahead signals can provide as the useful predictors for the spring dust activities in North China.

The standard deviation of the NAO peaks during December, January, February, and March. By analyzing the trend of the three-month average standard deviation, we observe that it is highest during the preceding winter. This indicates that the NAO exhibits stronger variability in the winter compared to other seasons (Figure R2 a). Similarly, ENSO also shows greater variation during boreal winter (Figure R2 b). Based on these findings, we have chosen to focus on the relationship between NAO, ENSO during the pre-previous winter period, and spring dust activities over North China.

We have examined the role of previous autumn, winter and simultaneous spring NAO and ENSO on the spring dust aerosols over North China, and it is found the influences of NAO and ENSO on the spring dust aerosols are most significant in the previous winter (Figure R2 c-h). Thus, the role of previous winter NAO and ENSO on the spring dust aerosols over North China are discussed in the present work.

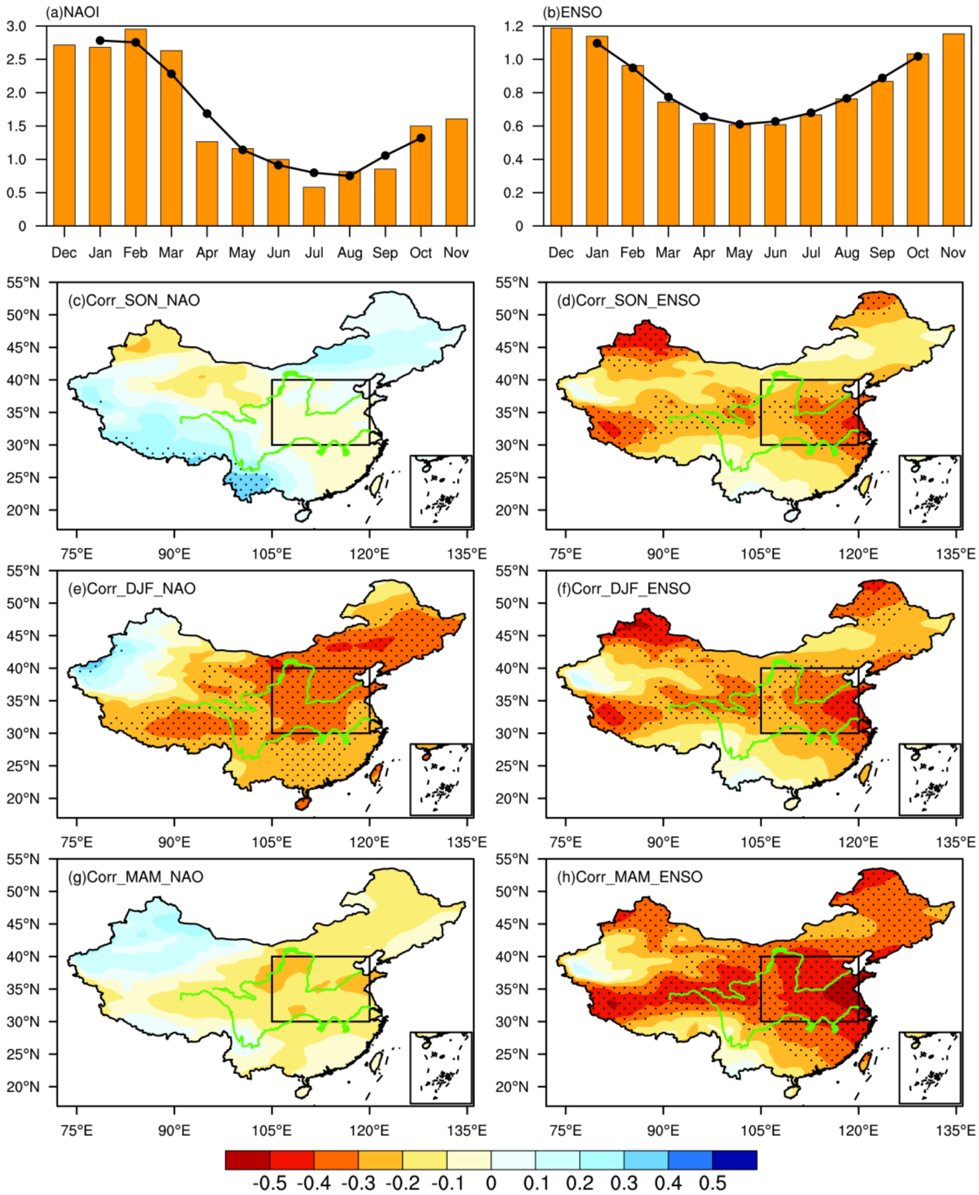

Figure R2. The monthly standard deviation of the (a) NAOI and (b) Niño3.4 index, respectively. Black line represents the trend of the three-month average standard deviation. Spatial distribution of correlation coefficients between the previous autumn NAOI and spring dust content (c). (d) As in (c), but with Niño3.4 index. (e-f) and (g-h) As in (c-d), but for the previous winter and simultaneous spring NAOI and Niño3.4 index. The black box represents North China. Stippled areas are statistically significant at the 0.1 level.

3. Dust aerosols are important components of atmospheric aerosols, alongside other constituents such as sulfates, nitrogen oxides, black carbon, and so on. Why did the authors choose the dust aerosols in North China as the research objects to be discussed and studied? Please explain and justify this point.

Response:

Thank you for the comments.

The dust aerosols are characterized by their significant role within the broader category of atmospheric aerosols. Dust aerosols originate from the mechanical breakdown of rocks and soil into fine particles, which are subsequently transported by the wind (Wang et al., 2018). They are noteworthy for their ability to influence climate systems by affecting solar radiation and cloud formation (e.g., Sokolik and Toon, 1996; Sassen et al., 2003; Zhang et al., 2019). Dust aerosols can pose a formidable threat to socio-economic development, natural ecological environment, as well as human health and safety (e.g., Zhao et al., 2020; Yin et al., 2021; Li et al., 2023). The study of dust aerosols is essential, because understanding their properties and dynamics helps us to better predict weather patterns, assess climate change impacts, and implement effective environmental and public health policies.

4. Line 36-37, "The Gobi Desert in East Asia, especially for the Mongolian Plateau and North China, is a major source of dust". Whether the author is trying to express the meaning of Northern China here, Northern China and North China are two different meanings, please confirm and revise.

Response:

Thank you for the comments. We have checked the whole manuscript and revised similar errors.

5. Line 77-78, the authors mentioned that "NAO and ENSO often co-occur and have complex interactions". As well as by citing previous work, the facts of a possible relationship between the two factors are enumerated. However, the authors have not thoroughly explored their relationship. It is suggested that further details be provided to enhance the understanding.

Response:

Thank you for the comments.

The relationship between the NAO and the ENSO remains unclear. Statistical analyses largely indicate no significant linear association between them. For instance, a correlation analysis of the NAO and ENSO indices during period 1950-2000 shows that their correlation coefficient is only 0.09, suggesting a weak linear correlation (Wang, 2002). Additionally, a significant correlation exists between the La Niña events in autumn and the positive phase of the NAO. However, this is not the case during El Niño events (Pozo-Vazquez et al., 2005).

Recent researchers have further detected the relationship between the NAO and the ENSO, particularly following the identification of two distinct types of ENSO events: the Eastern Pacific (EP) and Central Pacific (CP) El Niño events. It is suggested that the EP El Niño can transmit the Pacific signal to the North Atlantic through a subtropical bridge mechanism, potentially triggering a negative phase in the NAO. However, this relationship is not notably significant (Graf and Zanchettin, 2012). Moreover, the atmospheric circulation in the North Atlantic region reacts differently to the two types of La Niña events. During an EP La Niña, when the North Atlantic jet is weakened, the NAO tends to be in a negative phase. Conversely, CP La Niña would strengthen the North Atlantic jet, and the NAO is more likely to exhibit a positive phase (Zhang et al., 2015).

The above discussion suggests that there may be a nonlinear link between NAO and ENSO, and the relationship between them is still inconclusive and requires further study. Therefore, this paper analyzes the synergistic effect of NAO and ENSO on dust activities over North China.

6. In Figure 3 (a), it is notable that there is a point during the negative phase of the NAO that deviates from the majority of the points, potentially qualifying it as an outlier. If this point is removed from the sequence, it is important to verify whether the relationship between the NAO and dust aerosol content remains robust.

Response:

Thank you for the important comments.

It is important to consider whether the influence of the negative phase of the NAO on dust activities in North China persists after removing the outlier. When the outlier is excluded, we observe a reduction in the correlation between the two factors, yet a significant correlation remains and passes the 0.2 statistical significance test (Figure R3). This suggests that the impact of the NAO on dust activities in North China is robust during its negative phase.

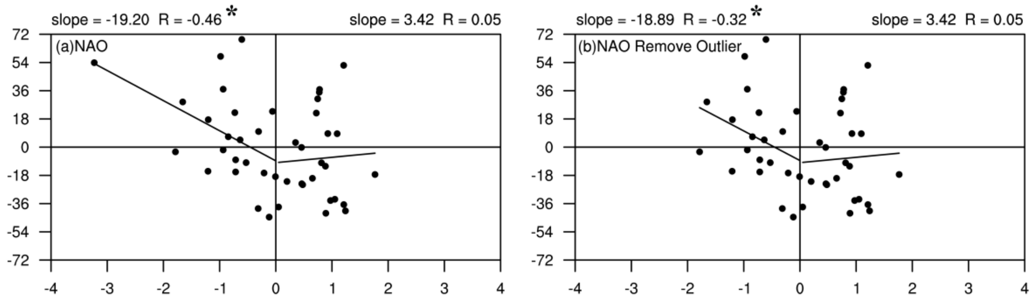

Figure R3. Scatterplots of the spring dust content in North China against previous winter (a) NAOI and (b) NAOI (Remove Outlier). Also shown are lines of best fit for positive and negative NAO/Niño3.4 index values and correlation coefficients (R), slope (slope), * indicates significant at the 0.2 level.

7. In Figure 5, by describing the precipitation and humidity fields under different scenarios, the authors illustrate the synergistic effect of NAO and ENSO on dust activities in North China. However, the large values of the variables in the graphs do not seem to be well highlighted. Consider modifying the color-coded intervals to enhance the reader's understanding of the section.

Response:

Thank you for the comments and suggestions. We have revised the figures to highlight large values of the precipitation and humidity fields under different scenarios. “When the NAO is in its negative phase, humidity in the spring dust source regions and North China generally reduced, particularly in areas near the dust source regions, indicating that these areas are conducive to dust transport and prone to causing dust weather in North China (Figure 5a of Manuscript). As for the precipitation, there is more spring precipitation in the northwest region of China, while precipitation in the Mongolia and the North China is relatively less (Figure 5b of Manuscript). In the negative ENSO phase, the variation in humidity is similar to that during the negative NAO phase, but with a greater amplitude (Figure 5c of Manuscript), indicating that ENSO has a stronger impact on the humidity conditions in North China. Moreover, the precipitation shows a significant abnormal decrease over Mongolia and North China, which is highly conducive to dust activities and the generation of dust weather (Figure 5d of Manuscript). When both the NAO and ENSO are in the negative phases, the humidity anomalies in the dust source regions and North China are more intense than the individual factor (Figure 5e of Manuscript). The variation in precipitation are similar to those in humidity, the reduction in precipitation in the dust source regions and North China exceeds the sole role (Figure 5f of Manuscript)" (Lines 335-348 in the revised manuscript).

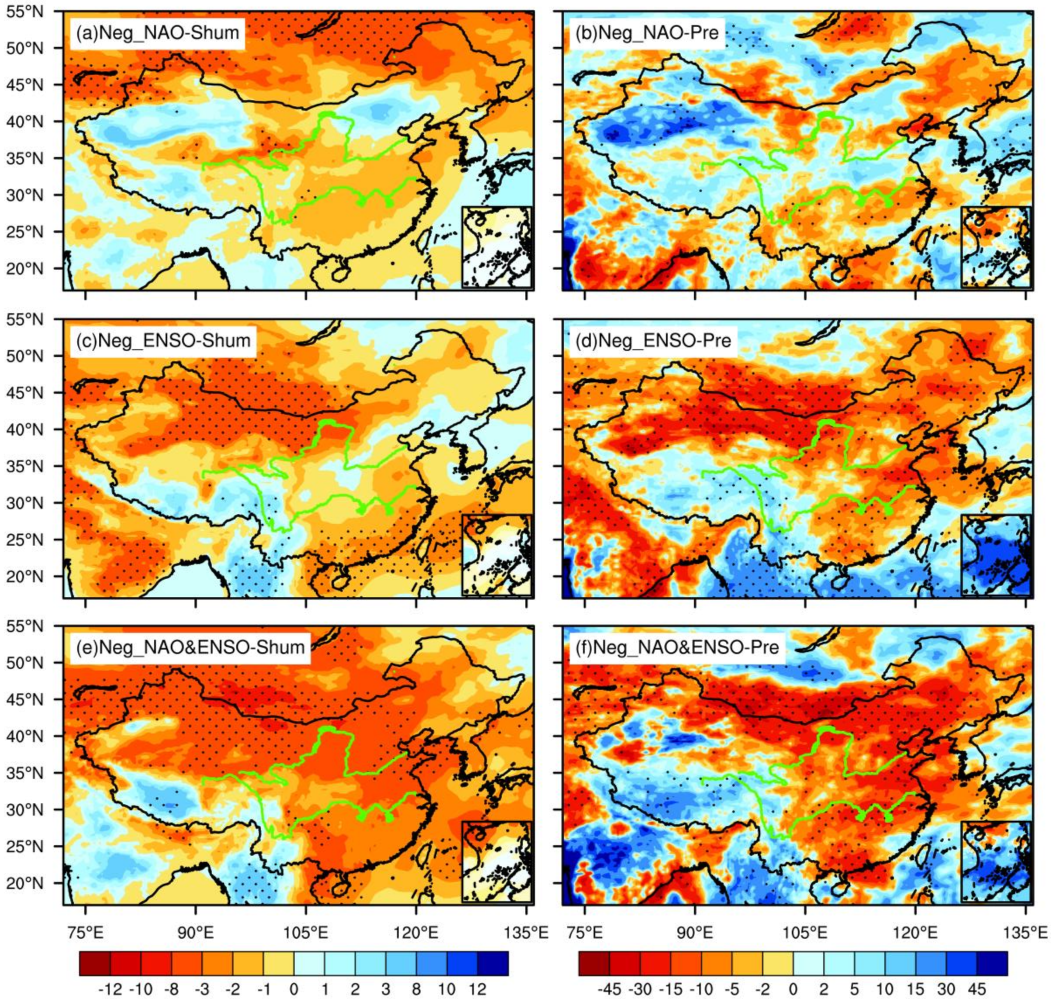

Figure 5 of Manuscript. Upper, composite percentage anomalies of (a) specific humidity and (b) precipitation during negative NAO phases. Middle-Lower, as in the upper, but during negative ENSO phases and concurrent negative phases of NAO and ENSO, respectively. Stippled areas are statistically significant at the 0.2 level.

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