Author's Response to Anonymous Referee 1

Anonymous Referee #1:

The study by Yu et al. investigates the impact of central (CP) and eastern (EP) Pacific El Niño events on the occurrence of winter haze days (WHD) in the JJJ region in northern China. Based on a statistical analysis of observational data and reanalysis products they conclude that EP El Niño increase the number of WHDs while CP El Niño events decrease their number. Variations in atmosphere circulation patterns over northern China during CP and EP events are suggested to cause this effect. The manuscript is well structured and presents a thorough analysis on an interesting topic. The presented numbers, however, do not support the claim of a strong effect of the different types of El Niño events on WHDs in the JJJ region (see detailed comments below). I believe that the study is interesting enough to be published but that the conclusions must be formulated much more carefully and worded more in terms of tendencies. I summarise my concerns and list some specific comments below.

Reply: Thanks for the referee's positive comments and constructive suggestions. We have taken the referee's comments into consideration and carefully revised the manuscript. Please see our detailed point-by-point reply below.

Major concerns:

Q1: All correlations between the ENSO indices and WHDs as well as changes (e. g. in circulation types) related to ENSO events are very low.

a) Fig.1 displays pretty low correlations and I have a hard time to believe that they are actually statistically significant when averaged over the region (Table 2). How were the degrees of freedom determined for the student t-test? Even if statistically significant, such low correlation values don't argue for a strong impact of ENSO.

   Reply: We sampled the monthly data in each winter (December, January, and February) from 1961 to 2012, which means that the degree of freedom is 154. According to the threshold table of correlation coefficient (Zhou and Zheng, 1997), the absolute values of correlation coefficients between the site-averaged WHDs and EP and CP El Niño indices (Table 2) are larger than the threshold of 0.154. This indicates that they are statistically significant. Compared to the single site-observed WHDs, the correlations between the site-averaged WHDs and El Niño indices are easier to pass the significance test because the disturbances of local emissions, urbanization, and topography on WHDs may be eliminated. In addition, the correlation analysis is the primary step. We further elaborated the opposite impacts of two types El Niño events on the WHD in the JJJ region via exhibiting the differences between the changes in WHDs in two type El Niño years (Figures 2 and 3).

   We agree with you that the low correlation values may not argue for a strong impact of ENSO. We have supplemented such description. Please see Lines 156-157 and 311-313 in the revised manuscript.

   References:

   Zhou, Y. H. and Zheng, D. W.: A new calculation method of correlation coefficient test table. Annals of Shanghai Observatory Academia Sinica, 18, 18-23, 1997.

b) The response to CP El Niño events to be more consistent (judging from the composite change shown in Fig. 2) but the response to EP El Niño events looks rather variable from station to station (Fig. 1 and 2).

Reply: Haze pollution is a sophisticated problem because it includes the comprehensive impacts of emissions, weather conditions, and even topography. This may lead to some biases of correlation coefficients among different sites when examining the correlations between the single-site WHDs and El Niño indices. But we can still find the consistently composite positive WHD anomalies, corresponding to EP El Niño years, at most sites (149 sites; accounting for 76.4% of all sites) in the JJJ region in Fig. 2b. In addition, the positive correlation between EP El Niño events and WHDs is also illustrated at 121 stations (accounting for 62.1% of all stations; Fig. 1b). The corresponding proportion will increase to 70.5% if we only consider the stations at which the correlations pass a significance level of 90%. We have supplemented quantitative descriptions to highlight the positive correlations between the WHDs and EP El Niño events. Please see Lines 147-154 and 161-164 in the revised manuscript.

c) The box-and-whisker plot (Fig. 3a) indicates that there is quite some spread in the response between individual EP and CP events.
Reply: The aerosol pollutants in the JJJ region are not only subject to the interannual change of emissions and the multiple-time scale climate changes as we discussed in the section 4, but also affected by the variations in local emissions, urbanization, and topography. These result in differences in distributions of WHD anomalies among individual EP and CP El Niño years and some spread of WHD anomalies in special El Niño year. However, we do find out the variations of WHD anomalies in phase with individual EP and CP El Niño years (Fig. 3a), which are characterized by a larger distribution in the positive range in response to most of EP El Niño years, but a larger distribution in the negative range in response to most of CP El Niño years. The site-averaged results also indicate the opposite distribution of changes in WHD corresponding to EP and CP El Niño years (Fig. 3b). We have supplemented more explanation about the box-and-whisker plot to elaborate our results. Please see Lines 171-173 in the revised manuscript.

d) From the numbers on the change in circulation types (Table 3 and corresponding text), I would actually conclude that there is hardly any effect of El Niño but maybe I am missing something here?
Reply: Indeed. These composite changes in the occurrence frequency of both pollution and clean circulation types seem to be small corresponding to EP and CP El Niño years. However, it is more complicated when we examine those changes for each circulation type. For example, in the winter of EP El Niño years, the changes in the occurrence frequency of the pollution (clean) circulation types range from -0.53% (-0.95%) to 1.97% (0.45%). The corresponding changes range from -2.33% (-0.4%) to 1.55% (0.84%) in the winter of CP El Niño years. The values may be small when calculating the composite changes. In addition, it is more difficult to further link the changes in WHDs to variation of a specific circulation type due to the lack of long-term daily haze pollution data. But we can generally explain the WHD anomalies in EP and CP El Niño years according to the composite changes in occurrence frequency of both pollution and clean circulation types. Finally, there is no formula currently to quantitatively describe the relationship between synoptic-scale circulation anomalies and haze pollution. More detailed works are needed in the future. We have supplemented more details in Table 3 and corresponding text. Please see Lines 268-277 in the revised manuscript.

Q2: It is stated that the number of haze days changes roughly by 2 during El Niño events (Fig. 2 and corresponding text). How does that compare to the average number of haze days?

Reply: The changes of 2 haze days account for 17% to 79% and -13% to -70% of the average numbers of haze days, respectively, at these sites. We have added the figure of percentages of WHD anomalies in all El Niño, EP El Niño, and CP El Niño years, respectively, relative to the climatological means (new Figure S2). We have also supplemented some descriptions in the revised manuscript. Please see Lines 161-164 in the revised manuscript.

Q3: Regarding the eight circulation types identified in section 3.3 I find it very hard to see the difference between some of them. What determines the number of these types? Since they are grouped together in the following anyway, is it necessary to distinguish between all of them?

Reply: We have supplemented the difference in each circulation type in Table 3. In this study, we used the K-means clustering algorithm to classify different circulation types. The optimal number of classifications is determined by the inflection point of criterion function. More detail descriptions are reported in Liu and Gao (2011). There remain some differences in the patterns of circulation anomalies among different pollution or clean circulation types in Figures 5, 6 and 7, although their common variations can be used to explain the WHD anomalies in response to EP and CP El Niño years. The differences may further relate to the intraseasonal changes in haze pollution. However, as answered in Q1 (d), exploring this link needs long-term daily haze pollution data, which is lacking at present.

References:

Liu, D. and Gao, S. C.: Determining the number of clusters in K-means clustering algorithm. Silicon Valley, 6: 38-39, 2011.

Specific comments:

Q4: line 9: The first sentence of the abstract sounds strange to me. Maybe use "The El Niño-Southern Oscillation" instead of just "El Niño".

Reply: We have changed this sentence into "El Niño is complicated due to its diverse distribution features and intensities.". Please see Line 9 in the revised manuscript.

In this study, we only focus on the impacts of El Niño, but not the La Niña. Therefore, it may be more accurate to only mention "El Niño" here.

Q5: line 53: What is meant by "Integral El Niño events"?

Reply: The "Integral El Niño events" used here means the overall El Niño events without classification. We have revised it. Please see Line 53 in the revised manuscript.

Q6: line 55 to 57: EP and CP El Niño are different flavours of the same climate mode

Reply: It may be an ambiguity here. We agree with you that both types of El Niño events are the warm conditions of El Niño–Southern Oscillation—the leading climate mode of interannual variability in the tropical Pacific. However, we want to emphasize two dynamic modes of quasi-quadrennial and quasi-biennial oscillations at here. These independent modes coexist in the tropical Pacific and may modulate the features of ENSO due to their interannual and interdecadal changes (Bejarano et al., 2008; Wang and Ren, 2017). Their interplay also contributes to the spatial diversity of the observed ENSO events, like EP and CP El Niño (Timmermann et al., 2018). We have revised the manuscript to avoid the ambiguous expression. Please see Lines 55-59 in the revised manuscript.

References:

Bejarano, L. and Jin, F. F.: Coexistence of equatorial coupled modes of ENSO. Journal of Climate, 21(12): 3051-3067, doi:10.1175/2007jcli1679.1, 2008.

Timmermann, A., An, S. I., Kug, J. S., Jin, F. F., Cai, W. J., Capotondi, A., Cobb, K., Lengaigne, M., McPhaden, M. J., Stuecker, M. F., Stein, K., Wittenberg, A. T., Yun, K. S., Bayr, T., Chen, H. C., Chikamoto, Y., Dewitte, B., Dommenget, D., Grothe, P., Guilyardi, E., Ham, Y. G., Hayashi, M., Ineson, S., Kang, D., Kim, S., Kim, W. M., Lee, J. L., Li, T., Luo, J. J., McGregor, S., Planton, Y., Power, S., Rashid, H., Ren, H. L., Santoso, A., Takahashi, K., Todd, A., Wang, G. M., Wang, G. J., Xie, R. H., Yang, W. H., Yeh, S. W., Yoon, J., Zeller, E., and Zhang, X. B.: El Niño–Southern Oscillation complexity. Nature, 559(7715): 535-545, doi:10.1038/s41586-018-0252-6, 2018.

Wang, R. and Ren, H. L.: The linkage between two ENSO types/modes and the interdecadal changes of ENSO around the year 2000. Atmospheric and Oceanic Science Letters, 10(2): 168-174, doi:10.1080/16742834.2016.1258952, 2017.

Q7: line 71 to 73: Does this classification differ from other commonly used ENSO classifications?

Reply: Yes, it does. This classification is based on an equation set that contain two ENSO indexes (Niño 3 and Niño 4 index) as shown in section 2.2, although it still employs the common monitoring areas of sea surface temperature anomalies. At present, there are quite some differences among the monitoring results for the same ENSO event due to employ differently single index, like the Japan Meteorological Agency (JMA) index, the Multivariate ENSO Index (MEI), and the El Niño Modoki Index (EMI). The classification used in this study shows the better performance in monitoring different types of historical ENSO events and determining the characteristics of the ENSO events than any single index. This has been reported in previous studies (Cao et al., 2013; Ren et al., 2017).

References:

Cao, L., Sun, C. H., Ren, F. M., Yuan, Y. and Jiang, J.: STUDY OF A COMPERHENSIVE MONITORING INDEX FOR TWO TYPES OF ENSO EVENTS. Journal of Tropical Meteorology, 29(1):66-74, 10.3969/j.issn.1004-4965.2013.01.008, 2013.

Ren, H. L., Sun, C. H., Ren, F. M., Yuan, Y., Lu, B., Tian, B., Zuo, J. Q., Liu, Y., Cao, L, Han, R. Q., Jia, X. L. and Liu, C. Z.: Identification method for El Niño/La Niña events. The People's Republic China's National Standard GB/T 33666-2017, May 2017. Beijing: Standards Press of China, 1-6, 2017.

Q8: line 150-152: Obviously the averaged correlation values are higher if only values above a certain threshold are considered. I am not sure what to learn from that.

Reply: As mentioned in Q1, the variations in local emissions, urbanization, and topography make haze pollution in the JJJ region more complicated. These factors not only lead to some biases of correlation coefficients among different sites when examining the correlations between the single-site WHDs and El Niño indices, but also contribute to the lower correlations between the site-averaged WHD and El Niño indices. Therefore, we selected the stations at which the correlations pass a significance level of 90% and calculated the correlations between different El Niño indices and the averaged WHDs at these stations. These higher correlation coefficients of 0.31 and -0.43, corresponding to EP and CP El Niño events, further illustrate the significant opposite impacts of two types El Niño on the WHDs in the JJJ region.

Q9: line 190: "worsening meteorological conditions": worse in what respect and compared to what?

Reply: As reported in the previous studies (Chen et al., 2015; Chang et al., 2016), the lower sea surface pressure and the higher surface air temperature in the northeastern Eurasia are favorable for the maintenance and development of atmospheric pollutant and defined as the worsening meteorological conditions (Zhang et al., 2018). In this study, the above anomalies are apparent in the winter of EP El Niño years.

References:

Chang, L. Y., Xu, J. M., Tie, X. X., and Wu, J. B.: Impact of the 2015 El Nino event on winter air quality in China. Scientific Reports, 6(1):34275, doi:10.1038/srep34275, 2016.

Chen, H. P. and Wang, H. J.: Haze Days in North China and the associated atmospheric circulations based on daily visibility data from 1960 to 2012. Journal of Geophysical Research Atmospheres, 120(12):5895-5909, doi:10.1002/2015jd023225, 2015.

Zhang, X. Y., Zhong, J. T., Wang, J. Z., Wang, Y. Q., and Liu, Y. J.: The interdecadal worsening of weather conditions affecting aerosol pollution in the Beijing area in relation to climate warming. Atmospheric Chemistry and Physics, 18(8), 5991-5999, doi:10.5194/acp-18-5991-2018, 2018.

Q10 line 312: “greatly worth concern” Please rephrase.

Reply: We have changed the description here into “The impacts of worsening meteorological conditions caused by annual climate change on the haze pollution process are worthy of concern.”. Please see the Lines 343-344 in the revised manuscript.