1 Response to Reviewer #1's comments

The manuscript by Thanh Le and Deg-Hyo Bae attempt to investigate the influences of El Niño Southern Oscillation (ENSO) on global dust activities by using the historical simulations of Global Climate Models (GCMs) from CMIP6 and developing the multivariate predictive model. The authors find that the ENSO displays significant impacts on dust deposition and transportation, while exhibits almost no impact on the dust emission of major dust sources. These findings emphasize the important role of ENSO in global dust activities. Overall, this paper is well written, and their findings exhibit promising potential for the predictions of future dust events. I would like to recommend an acceptation after these comments as follows are addressed.

Response: We thank the reviewer for your comments. We modified the manuscript based on your suggestions as below.

Major comments:

1.1 (1) To estimate the influences of ENSO on dust deposition, the authors selected the multivariate predictive model that has already considered the contribution of past dust deposition events and the confounding factors. In the multivariate predictive model, three factors, including Indian Ocean Dipole, Southern Annular Mode, and the North Atlantic Oscillation, have been considered as the major confounding factors that may display important roles in global dust deposition. However, the authors didn't elaborate on the reasons why they only selected the above three factors. I suggest the authors to provide sufficient justification for selecting the three factors to improve the reliability and robustness of the predictive model and their corresponding findings.

Response: We thank the reviewer for raising this point. We added the following sentences to Section 2.2 to explain the selection of the three factors Indian Ocean Dipole, Southern Annular Mode, and the North Atlantic Oscillation:

"The climate modes SAM, the IOD and the NAO are the important sources of global climate variability (Hurrell et al., 2003; Luo et al., 2012; Roxy et al., 2015). For instance, the NAO is the prominent mode of atmospheric circulation variability over the North Atlantic and surrounding regions (Delworth et al., 2016; Hurrell et al., 2003) and variations in NAO are crucial for the

environment and society (Hurrell et al., 2003). The IOD affects climate extremes over the Indian Ocean and surrounding areas (Abram et al., 2008; Kripalani et al., 2009; Kripalani and Kulkarni, 1997) and might cause severe economic consequences (Ummenhofer et al., 2009). The SAM is the major mode of atmospheric circulation variability in the southern Hemisphere (Cai et al., 2011; Raphael and Holland, 2006). In addition, changes in these modes may affect the variations of ENSO (Abram et al., 2020; Cai et al., 2011, 2019; Le et al., 2020; Le and Bae, 2019). Nevertheless, it is likely that these factors may alter the influences of ENSO on dust activities."

1.2 (2) In Tables S1, a total of 12 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) are selected to estimate the influences of ENSO on dust deposition. However, I cannot find the criteria for selecting these GCMs which are generally required for a scientifically sound paper. In addition, three models and one model in Table S2 cannot provide the od550dust and emidust, respectively. Why were these models kept instead of eliminating them?

Response: We thank the reviewer for raising this point. We selected all the models with accessible dust deposition data. Considering the total models is somewhat low (i.e., 12 models), we kept all these models. To our knowledge, dry and wet deposition of dust are key variables which directly affect local environment, thus we selected all models having these data.

We add the following sentences to Section 2.1 to clarify this point:

"We limited our study to all the models having both dry dust and wet dust data (i.e., there is total of 12 models with accessible dry dust and wet dust data as described in Table S2). Dust deposition on land and ocean surface are important metrics to assess the impacts of dust activities on ecosystems and environment (Bao et al., 2017; Fan et al., 2006; Jickells et al., 2005; Jiménez et al., 2018; Kanakidou et al., 2018; Schulz et al., 2012). Additional data of od550dust and emidust supplied by these 12 models provide further understanding of ENSO impacts on dust activities."

1.3 (3) In the Discussion part, the authors listed the possible reasons for the influences of ENSO on the dust deposition. In my opinion, ENSO also plays significant role in modulating the atmospheric circulation patterns that could substantially affect the spatial pattern of dust deposition. I think that it will be very interesting if the authors could discuss some impacts of atmospheric circulation patterns induced by ENSO on the dust deposition and transportation.

Response: We thank the reviewer for this suggestion. We added the following sentences to the Section 4 Discussion as below:

"As dust particles might be carried by winds between different regions (Guo et al., 2017; Yang et al., 2017), the influences of ENSO on global atmospheric circulation and rainfall (Yeh et al., 2018) lead to ENSO-induced changes in spatial pattern of dust deposition. For example, ENSO impacts on winds and precipitation over the tropical Pacific (Dai and Wigley, 2000; Le and Bae, 2020) contribute to the causal effects of ENSO on dry and wet dust deposition over this region (Figure 1). In addition, ENSO atmospheric teleconnections over Australia, North and South Americas (Ashok et al., 2007; Garfinkel et al., 2013; Taschetto and England, 2009; Yu and Zou, 2013) play an important role on dust deposition in these regions (Figure 1)."

1.4 (4) The two paragraphs in the section of Methods have only one sentence, I thus suggest the authors to combine them into one paragraph.

Response: We thank the reviewer for this suggestion. These two paragraphs are reorganized. In addition, we moved part of the supplementary to Section 2.2 to further clarify the Methods used in this study:

"We use the following multivariate predictive model (Mosedale et al., 2006; Stern and Kaufmann, 2013) to estimate the causal links between the ENSO and dust deposition:

$$\boldsymbol{X_t} = \sum_{i=1}^{p} \boldsymbol{\alpha_i X_{t-i}} + \sum_{i=1}^{p} \boldsymbol{\beta_i Y_{t-i}} + \sum_{j=1}^{m} \sum_{i=1}^{p} \boldsymbol{\delta_{j,i} Z_{j,t-i}} + \boldsymbol{\varepsilon_t} \quad (1)$$

where X_t is the annual mean (or seasonal mean) dust deposition for year t, Y_t is the ENSO index, and $Z_{j,t}$ is the confounding factor j for year t. In the predictive model presented in equation 1, while assessing the effect of Y on X (i.e., the contribution of the term $\sum_{i=1}^{p} \beta_i Y_{t-i}$ in predicting X), the possible influence of past X events are considered by adding the term $\sum_{i=1}^{p} \alpha_i X_{t-i}$. Thus, the causal influence of Y on X, if detected, is robust and the impact of past X events are accounted in the analyses. Here, m is the number of confounding factors and $p \geq 1$ is the order of the multivariate predictive model. The optimal order p is computed by minimizing the Schwarz criterion or the Bayesian information criterion (Schwarz, 1978). The optimal orders may be different for each model.

Here we take into account the impacts of confounding factors and therefore provide further information of the real-world teleconnections. In the analyses, we use three different confounding factors; hence, m is equal to 3. The noise residuals ε_t and the regression coefficients α_i, β_i and $\delta_{j,i}$

are computed by using the multiple linear regression analysis of the least squares method. We detrend and normalize all the climate indices."

Specific comments:

1.5 L24: "feedback" can be revised to "feed back"

Response: We thank the reviewer for pointing this out. We corrected to "have impacts" to avoid confusing the readers.

1.6 L32: Some important references can be cited here to strengthen the statement concerning the role of dust on environment, including https://doi.org/10.1029/97JD00260; https://doi.org/10.1016/j.atmosenv.2017.07.036; https://doi.org/10.1029/2019JD030758

Response: We thank the reviewer for this suggestion. We included these references to line 32 and other places in the Introduction:

"…and environments (Guo et al., 2017; Li et al., 2019; Perry et al., 1997; Xu et al., 2017; Zhang et al., 2018)."

1.7 L40: "earth" -> "Earth"

Response: We corrected as your suggestion.

1.8 L46-47: what is the difference

Response: We thank the reviewer for raising this point. We further clarify the role of other modes on the linkage between ENSO and global dust activities in Section 2.2 as below:

"In the analyses, we investigated the confounding effects of other main climate modes (i.e., the SAM (e.g., Cai et al., 2011), the IOD (Saji et al., 1999; Webster et al., 1999), and the NAO (Hurrell et al., 2003)) on the links of ENSO and dust activities. The climate modes SAM, the IOD and the NAO are the important sources of global climate variability (Hurrell et al., 2003; Luo et al., 2012; Roxy et al., 2015). For instance, the NAO is the prominent mode of atmospheric circulation variability over the North Atlantic and surrounding regions (Delworth et al., 2016; Hurrell et al., 2003) and variations in NAO are crucial for the environment and society (Hurrell et al., 2003). The IOD affects climate extremes over the Indian Ocean and surrounding areas (Abram et al., 2008; Kripalani et al., 2009; Kripalani and Kulkarni, 1997) and might cause severe economic consequences (Ummenhofer et al., 2009). The SAM is the major mode of atmospheric circulation

variability in the southern Hemisphere (Cai et al., 2011; Raphael and Holland, 2006). In addition, changes in these modes may affect the variations of ENSO (Abram et al., 2020; Cai et al., 2011, 2019; Le et al., 2020; Le and Bae, 2019). Nevertheless, it is likely that these factors may alter the influences of ENSO on dust activities."

1.9 L116: "original"-> "originated"

Response: We corrected as your suggestion.

1.10 Lines 44-46 of the Supplement, this paragraph only has one sentence. I suggest the authors to combine Lines 44-51 into one paragraph.

Response: We combined the lines 44-51 (Supplement) into one paragraph as your suggestion.

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