Thank you very much for your kind and helpful suggestion. We have taken all of the specific comments into account in the revised version of the manuscript. These suggestions make the manuscript more complete, logical and standard to publish on the scientific journal. Please see the detailed response marked blue below and the changes marked red in the revised manuscript.

Introduction

#1. The introduction part is missing the literature survey on dust simulations using WRF model. The authors should provide a detail on how WRF model has been used for dust simulation in the past (please provide a brief description on the state-of-the-art on the use of WRF model for dust simulation (in Tibetan plateau or elsewhere)) and what new has been done in this manuscript.

[Response] Thank you for your comment. The latest results of dust simulation using the WRF model (Zhao et al., 2020; Shukla et al., 2021) and details about what new has been done in this manuscript were added in manuscript. Besides, in introduction part, the citations from Chen and Hu mentioned on line 49 and line 63 used WRF-Chem to simulate dust, which have a high number of citations.

"Zhao (Zhao et al., 2020) used WRF-Chem to simulate a dust process in Northwest China during May 2018 and compared results between the simulations based on five dust emission schemes within WRF-Chem and the observations show that, WRF-chem has good performance in simulating the emission flux, the spatial pattern of source region, as well as the spatiotemporal variation of dust mass concentration, except Shao 11 scheme. Shukla (Shukla et al., 2021) used a high-resolution WRF-Chem to analyze the dust storm that occurred during 12 17 June 2018 over the northwest Indo-Gangetic Plain, the horizontal and vertical distributions of dust aerosols reproduced by the WRF-Chem agree with the observations and the evolution of dust storm and associated changes in atmospheric and air quality conditions were well simulated."

"A quantitative study of the spatial and temporal variability of dust fluxes and atmospheric dust properties of different climatic regions in the interior of the plateau was conducted using WRF-Chem in three regions over a three-year period (2004-2006) with high resolution to see the finer dust source distribution and dust characteristics on the plateau under different climate zones."

#2: Line 65: "from the northern part of the plateau to the plateau". What does the authors mean here? Please explain.

[Response] Thank you. This error has been corrected.

"Hu (Hu et al., 2020) studied the total amount of dust transported to the TP from different dust sources at different altitudes, and dust from North Africa and East Asia was primarily transported to the northern part of the plateau and from the Middle East was transported southward and lifted up to the TP."

#3: Line 82: "there are a few studies on dust inner the plateau". May be this sentence needs restructuring.

[Response] Thank you. This error has been corrected.

"At present, there are a few studies focused on dust aerosols within the plateau, and conclusions regarding the distribution of dust sources inner the plateau, the spatial and temporal variability of dust initiation, and the contribution of dust to the air column above the TP are still controversial."

Study region and Data

#4: Line 114: "Therefore, we divided the study area into three regions according to climatic characteristics (Figure 1)." The previous lines have references Zheng, 1996; Xu et al., 2013. Which one of these does the authors have used for "climatic characteristic". If some other reference is used, then please mention here.

[Response] Actually, the literature of Zheng was used for "climatic characteristic". And the literature of Xv was used to demonstrate that the distribution of precipitation and vegetation on the plateau is in good agreement with climatic zonation, which further proves the accuracy of regional division.

#5: The methodology used to perform the WRF simulations has not been explained well in this manuscript. The authors provide a brief description of the schemes that they have used in Section 2.2.1 But they have not provided any details on the on-line coupling of the WRF-Chem model as they mention in line 123. The authors are suggested to provide a detail on the simulations performed and how the on-line coupling of meteorology and chemistry is performed. Also, the authors should provide details on how the simulations are performed for the three different regions mentioned in Section 2.1. Are they performed independent of each other or through nested domains?? If the simulations are performed independently for each domain, then the authors should provide a reasoning for this i.e., if the boundary conditions will be accurately represented for each domain. If nested domains are used, then the authors should provide details of these simulations.

[Response] Thank you for your comment. A detail on the simulations performed and how the on-line coupling of meteorology and chemistry is performed and details on how the simulations are performed for the three different regions mentioned in Section 2.1 were provided.

"The WRF-Chem model (V3.9.1) is based on the WRF model with the introduction of the Chem module and full on-line coupling of meteorology and chemistry, the chemistry package consists of dry deposition (''flux-resistance'' method), biogenic emission, the chemical mechanism from RADM2, a complex photolysis scheme (Madronich scheme coupled with hydrometeors), and a state of the art aerosol module (MADE/SORGAM aerosol parameterization). (Grell et al., 2005). In this study, the simulated area had a horizontal resolution of 6 km, with 99 × 99 grid points in the west, 99 × 334 grid points in the south and 115 × 334 grid points in the north. Each area was simulated separately to better reflect local dust emission and loading characteristics without allowing them to interfere with each other. The depth from the surface to 50 hPa was vertically divided into 40. The simulation process began on January 1, 2004, with monthly updates of the initial field to avoid bias in the boundary conditions and initial fields due to long simulation times, and 24 h after 00:00 on the last day of the previous month was used to allow the model to spin up. The boundary and initial conditions were obtained from FNL global reanalysis data provided by the National Centers for Environmental Prediction at a resolution of 1 °, which were available every 6 h. The model was output in netcdf format at half-hour intervals. The following parameters were chosen for the simulation: Purdue Lin microphysical scheme (Gustafson et al., 2007), Yonsei University planetary boundary layer scheme (Noh et al., 2006), RRTMG long-wave and short-wave radiation scheme (Mlawer et al., 1997; Iacono et al., 2000), Noah scheme (Chen et al., 1996), and Grell cumulus scheme (Grell et al., 1994); other parameter settings refer to Chen (Chen et al., 2013) and Zhao (Zhao et al., 2020).

In GOCART model all topographic lows with bare ground surface are assumed to have accumulated sediments which are potential dust sources, and the uplifting of dust particles for each grain size is expressed as a function of surface wind speed and wetness. (Ginoux et al., 2001), and the dust emission flux equation is calculated as follows:

$$G = CSs_p U_{10}^2 \ (U_{10}\text{-}U_t)$$

where C ($\mu g s^2 m^{-5}$) is a constant; S is a source function that defines the area of potential dust sources, consisting of vegetation, snow, and other surface factors; s_p is the proportion of dust emissions for the different classifications. Dust was classified into five classes in the GOCART scheme, with particle size intervals of 0.2-2, 2-3.6, 3.6-6, 6-12 and 12-20 μm. U_{10} is the horizontal wind speed at 10 m above ground level. U_t is the threshold wind speed; when the wind speed is less than this value, the dust will not be blown up into the atmosphere. The threshold wind speed is a function of particle size, air density, and surface soil moisture."

Model evaluation:

#6: Line 170: "three regional models". What does the author mean by "three regional models"?? The authors are only using WRF-Chem model in this manuscript. May be the authors are referring to the three regions of the model. If not, then provide an explanation here. Please rephrase this sentence to avoid confusion.

[Response] Thank you. This error has been corrected.

"The model results of the three regions were gridded and averaged to compare the annual variation in the regional average characteristics with the corresponding areas in the reanalysis data."

#7: Line 175: "The model results were slightly lower than the reanalysis results.". This means that the model is underpredicting these values as comapred to the reanalysis values. Can the authors provide a probable reason for this underprediction??

[Response] Thank you for your comment. There are a number of reasons why the simulation results are lower than the reanalysis results. A few possible reasons should be taken into consideration, including incapability of the model to simulate all the thermal and dynamic processes in the real world. In particular, the Tibetan Plateau has large topography and complex underlying surface, the mechanisms involved are more complex. Therefore, the simulation results cannot be exactly the same as the observation results and the reanalysis results.

Besides, many studies have compared the various reanalysis data with the observations and concluded that the MERRA-2 reanalysis data is the most consistent with the observations (Carvalho., 2019. https://journals.ametsoc.org/view/journals/clim/32/23/jcli-d-19-0199.1.xml). The reanalysis data can make up for the lack of observation data in the area of harsh natural environment, such as the Tibetan Plateau. In Figure 4, we also compared the results of observation data, reanalysis data, and model result in the southern region, it shows that the results of three kinds of data are consistent in the annual trend, but there are slight differences in the value. The relative error of temperature above 2 m between simulation results and reanalysis data is 0.8% (west), 0.7% (south), and 0.1% (north), this indicates that the simulation results are satisfactory.

What's more, through literature reading, we found that in many studies, there were small numerical errors between the reanalysis data and the model results when the model was verified, and generally the simulation results are smaller than the reanalysis data (Chen et al., 2013; Zhao et al., 2021). As described above, such errors are unavoidable due to technical reasons.

#8: Line 179: "The model results and reanalysis data showed a significant difference in wind speed in summer, with the model results being significantly lower than the reanalysis data, with a difference of 1 m/s". Can the authors provide an explanation for this finding?

[Response] Thank you for your comment. The main explanation was provided at #7. And the relative error of wind above 10 m between simulation results and reanalysis data is 3.3% (west), 21.8% (south), and 22.8% (north). In the simulation results, temperature is the closest to the observation results, followed by wind speed, and the worst is precipitation (Clark and Gerhard, 2017 https://www.tandfonline.com/doi/full/10.1080/07055900.2017.1282345), so we think the simulation results are satisfactory.

#9: Figure 3: There is something wrong with the legend of this figure. What does the dashed line and the solid lines represent?? The legend only has description of solid lines.

[Response] Thank you. This error has been corrected.

Results:

#10: Line 248: "maximum dust emission in January". Can authors explain the reason why the dust emission was maximum in a winter month of January and it was lower in summer months, in fact minimum in summer month of August. Why is the emission maximum in Winter and not in summer?? If the frequency of dust storms are more in winter months, then is it possible that the maximum dust emission values are arising due to the frequency, but is it possible that the dust emissions are more in summers but when averaged for the month, then the values comes out to be less?? If so, then has the authors take the frequency of these events into account?? Also, these emission are at what level (at the surface or the averaged values over the 40 vertical layers used in the simulation)??

In line 252, the authors mention “This annual trend was consistent with the observed annual trend in dust storm frequency”. But has the frequency of occurrence of these events taken into account and considered while averaging the emissions for a month?

[Response] Thank you for your comment. Figure 3 shows that the maximum wind speed at 10 m occurring in January, which mostly explained why the dust emission was maximum in a winter month of January and it was lower in summer months. In Tibetan Plateau, the precipitation in winter is less than that in summer, and the soil moisture is lower. Dry underlying surface conditions will reduce the threshold wind speed (Yang et al., 2019 https://doi.org/10.1007/s11069-019-03686-1). High wind speeds in winter are more likely to reach the wind speed threshold and more likely to blow dust off the ground in TP. As described in Section 2.2.1, the uplifting of dust particles for each grain size is expressed as a function of surface wind speed and wetness.

Actually, the amount of dust emissions we calculate is the total amount of dust raised per month, that means accumulation of dust emissions of all dust events in a month. So it may be that there are more dust storms in winter but the amount of dust emissions each time is small but that doesn't affect the fact that in terms of the monthly total, the total amount of dust emissions in the three months of winter is higher than in summer. However, it is a good inspiration for the following work to analyze the total amount of dust emissions in a single process of winter and summer, respectively.

“This trend of higher winter and lower summer is also influenced by soil moisture, dry soil conditions in winter reduce the wind speed threshold, making it easier for dust to be lifted into the atmosphere at the same wind speed (Yang et al., 2019).”

#11: Line 263: “Wu (Wu et al., 2019) used multiple models to simulate the annual variation in the multiyear average optical thickness of dust over the plateau; they also showed a similar bimodal structure.”. In this work by Wu et. al., authors have presented that for TP, the dust emission is more in March-April than in January. While in this (current manuscript) work, the authors have presented that the emissions are maximum in January and then decreases to a minimum in August. Can the authors support this claim??? Also, which bimodal structure are the authors talking about??? Please explain this.

[Response] Thank you for your comment. In fact, Wu compared the results of several models simulating the characteristics of plateau dust. What you are talking about is only one model (K14_f09) and the other models all show a gradual decline in the maximum in January to a low value in the summer and then a slow recovery. Perhaps the numerical results of other models are smaller than that of K14_f09 model, making them not stand out.

The bimodal structure refers to the occurrence of two peaks of DOD in April and June or June and August, or April and August.

#12: Figure 7: I assume that the solid lines represent the model simulation in figure 3, then in North region the simulated temperature is higher from April to September, while wind speed remains mostly constant. Figure 6 shows that the dust emission is low in these months. Can the authors explain why the dust loading in North region is quite high from April to September (Figure 7).

[Response] Thank you for your comment. The reasons of the dust loading in North region is quite high from April to September are listed as following:

1. The most important reason is that the unique topographic features of the northern region. The Qaidam Basin of northern region is not a high-value area for dust emissions in winter, but in summer. The impact of unique basin topography on a cold frontal system, a large amount of cold air invading the TP in three main tracks of near-surface winds, which allowing dust to remain over the plateau for longer (Meng et al., 2019 https://www.sciencedirect.com/science/article/pii/S0169809518306410?via%3Dihub)
2. The role of heat pumps in the Tibetan plateau. The summer heat effect enhances the transport of dust to higher altitudes, allow more of the dust to reach the upper troposphere and remain in the atmosphere. However, in the southern region, with frequent summer rains and lush vegetation, it is difficult for dust to stay in the atmosphere for a long time.

“The main reason make the dust loading of northern region quit higher in summer is that the unique topographic features of the northern region. The Qaidam Basin of northern region is not a high-value area for dust emissions in winter, but in summer. The impact of unique basin topography on a cold frontal system, a large amount of cold air invading the TP in three main tracks of near-surface winds, which allowing dust to remain over the plateau for longer (Meng et al., 2019)”

“The southern region is wet year-round, with lush ground vegetation and snow-covered mountains, which make dusts difficult to stay in the atmosphere for a long time; therefore, there are more factors influencing dust deposition and dispersion and the correlation is low.”

#13: Figure 8: How is the explanation provided for Figure 8 related to Figure 7? It would be nice if the authors can link these two figure along with a proper explanation.

[Response] Thank you for your comment. The description of Figure 8 is not clear enough, the detailed description and additional content has been added to the article.

“Therefore, we calculated the proportion of dust above 8km to the total dust content of the whole air column to quantitatively calculate how much of the dust suspended in the atmosphere can be transported to the upper troposphere and further outwards (Figure 8).”