Thanks very much for the time and efforts that you have put into reviewing the previous version of the manuscript. We really appreciate all your comments and suggestions that have enabled us to improve the manuscript. The following is a point-to-point response to the reviewer's comments. We have studied comments carefully and have made correction which we hope meet with approval. Revised portion are marked in red in the revised paper.

The authors present a variety of information to characterize two major dust storms in the North China region during March 2021, which were exceptional events. They describe the spatial, temporal and vertical evolution of the dust events using satellite dust optical depths and lidar dust extinction profiles, visibility measurements and RGB Himawari imagery. They analyze the optical and radiative properties of the dust using AERONET data from a site in the Beijing region. They use MERRA-2 reanalysis data to identify dust source locations, and analyse the dynamical driving meteorology predominantly using 700hPa reanalysis data. Finally they put the scale of the month's dust events into context by analysing the historical record of the dust loading from satellite data and environmental reanalysis data. The study is of importance since it characterizes these unusual dust events in detail throughout their lifetime from emission, driving meteorology, characteristics in the atmosphere, transport patterns, optical properties, and radiative effects, providing a host of useful information to the aerosol and climate community. The work on classifying the dust events in their historical context is novel and is very important in understanding these properties. Overall the paper is very well written and presented.

The first round of reviewers pointed out several areas of overlap with two previously published papers (Filonchyk (2022) and Liang et al. (2022)). Liang et al. (2022) is a short, bulletin type of publication of 4 pages. Though it touches on some of the areas covered by this publication, the short length of the publication prohibits exploration of the science and data in any detail, as is done in this article. Filonchyk (2022) focuses on ground-based particulate matter concentrations during the 3.15 event, showing some satellite data (mostly different to that used here) to illustrate the links between the ground-based measurements and confirm dust presence. Some analysis of the synoptic situation is presented in Filonchyk (2022), though scope remains for much more detailed analysis and exploration, as aimed for in this article. Thus I think there is ample scope for an article such as this one, fitting for ACP, where the dust properties, evolution and effects, from several data sources, are explored in much detail.

Response: We would like to thank the reviewer for the positive comments on our work. These comments have given us more confidence to further improve the quality of this work.

The authors give a very strong justification of why their article is different to Filonchyk (2022) and Liang et al. (2022) in the response to reviewers. In my view these are strongly justified, and there is plenty of scope for exploring the event(s) in much more detail, and with a stronger link between the satellite data, dust transport and emission patterns, and the meteorology. However, given this strong justification I was surprised that this did not come through more strongly in the article – both in terms of setting the scene in the introduction, and in terms of the analysis of certain data elements. The authors certainly need to expand the introduction to include a more detailed summary of the published work on this event, setting out how their aims and approaches expand on what has already been done. They have done this in the response to reviewers, but it feels like it has not really made it through to the article itself. Secondly more could have been made of certain avenues of data analysis which are different to those already published – some even pointed out by the authors themselves. I describe these below, but it is up to the editor whether these is necessary to include. They would enhance the article's novelty, rather than be critical to its publication.

Response: We thank the reviewer for these constructive suggestions. We apologize for not providing a detailed and comprehensive summary of the existing studies in the introduction of the first revision, and for not highlighting new data and methods that differ from those in previous studies, although these were presented in the response to reviewers. In this revision, we have completely addressed these concerns of yours. For detailed revisions, please refer to the following sections.

General comments:

1. RGB Himawari imagery - I was surprised to see limited analysis of RGB Himawari imagery, given the response to reviewers. One immense advantage of the RGB imagery is that it's from geostationary satellites, therefore permitting analysis of dust events at higher temporal resolution than possible with polar-orbiters, providing data once a day. Analysis of hourly RGB data can be highly insightful to dust emission and transport mechanisms, and their interactions and influences by weather systems as a function of time. This simply cannot be determined from single-day overpass satellite data. In my opinion further expansion of the imagery along these lines would be highly beneficial.

Response: We feel great thanks for your professional suggests. In the revised manuscript, the following three figures and their descriptions have been included to enhance the understanding of the mechanisms of dust emission and transport, and their interactions with weather systems.

"Moreover, the dynamics of dust emissions are mainly regulated by the synoptic systems. The 3-h RGB dust imageries on March 14 clearly show the interaction between the synoptic systems and dust emissions, which is not always evident in the still images (Fig. S7). The dust plume formed at 12:00 CST on March 14 is triggered by the strong wind associated with the movement of the convective system."

"Although the 3-h RGB dust imagery has identified dust activity in south-central Mongolia associated with the incipient Mongolian cyclone at 18:00 CST on March 26 (Fig. S8), the enhancement of dust emissions is mainly controlled by the development and movement of the cyclone on March 27 (Fig. S9)."

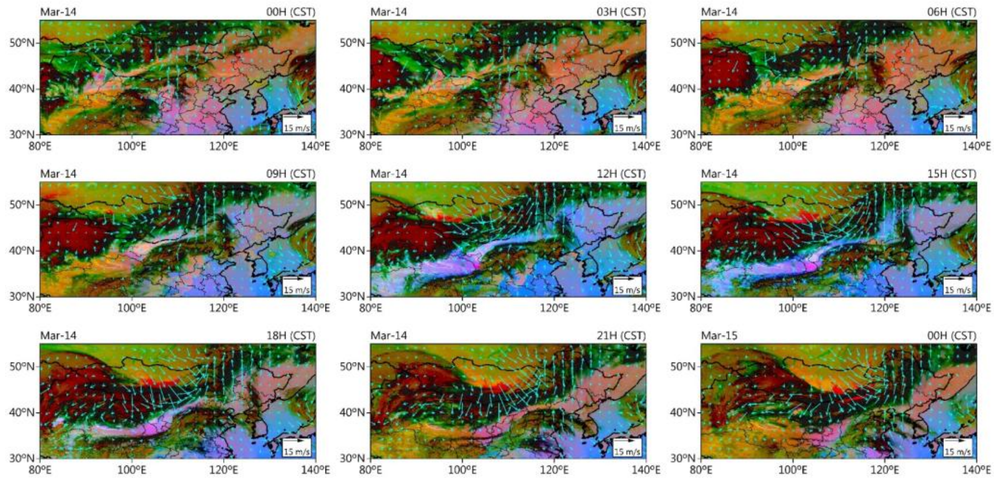


Figure S7: The 3-h evolution of dust plumes (magenta) as revealed by Himawari-8 dust RGB composite images on March 14, 2021. Overlaid on the RGB imagery is the 3-h ERA5 wind vectors at 10m.

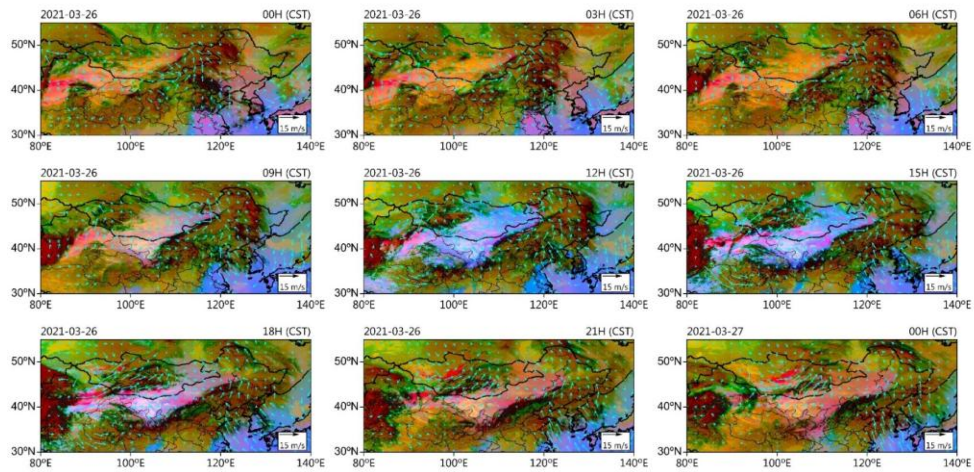


Figure S8. The 3-h evolution of dust plumes (magenta) as revealed by Himawari-8 dust RGB composite images on March 26, 2021. Overlaid on the RGB imagery is the 3-h ERA5 wind vectors at 10m.

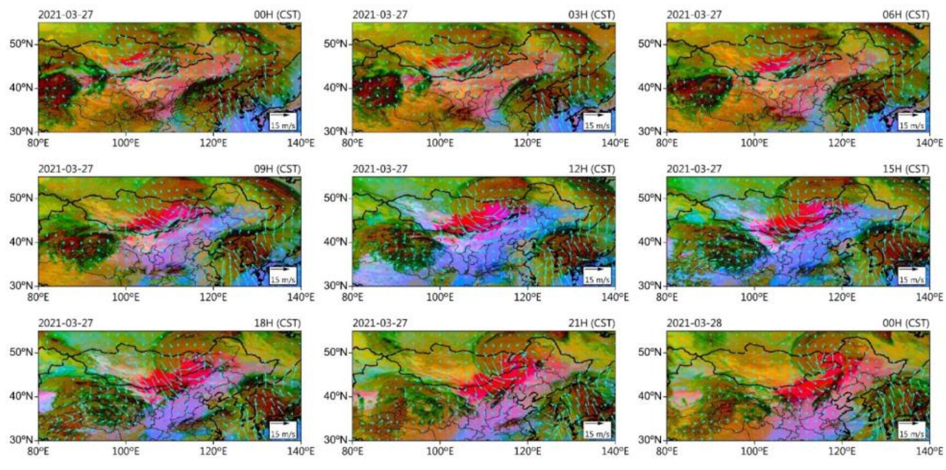


Figure S9. The 3-h evolution of dust plumes (magenta) as revealed by Himawari-8 dust RGB composite images on March 29, 2021. Overlaid on the RGB imagery is the 3-h ERA5 wind vectors at 10m.

2. Lidar data - The exploration of lidar (both from CALIOP and a ground-based lidar) dust

extinction is beneficial, in comparison to the vertical feature dust masking data that has previously been published. However, I found limited discussion of the intensity of the plume at different altitudes – a feature which is identifiable with the extinction data used, rather than discussion of the plume behaviour and altitude in general – which could have been done with the vertical feature mask.

Response: We feel great thanks for your professional suggests. In the revised manuscript, we go deeper to highlight the variation of dust intensity through the dust extinction coefficient and also explore its impact on CALIPSO retrieval. Meanwhile, in response to the reviewer's mention that the point nature of the lidar sites should be taken into account when describing the vertical distribution of dust. We double-checked our description of the single-site lidar observations. We have also revised descriptions that may be incorrect. Some new descriptions below have been added to the revised manuscript (For detailed revisions, please refer to the revised manuscript.).

"In contrast, the strong dust plume (DEC > 1.0 km^{-1}) located in the upper layers carrying a large amount of dust aerosols was maintained at an altitude of 1−3 km for nearly 1 day before being transported far from the observation site at 18:00 CST March 19. After this, the high-altitude dust plume gradually dissipated as the dust aerosols diffused and were partially deposited, and the observation site was only intermittently affected by surrounding dust transport."

"Similar to the 3.15 event, north-central Inner Mongolia was also influenced by the transport of dust plumes during the 3.27 event. Specifically, two moderate dust plumes (DEC ~0.05 km^{-1}) had affected the lower (0–2km) and upper layers (3–4km) in north-central Inner Mongolia, respectively, on March 26. Subsequently, the observation site may have been affected by a combination of lower-layer and high-altitude transport. Clearly, the dust plume with a DEC of about 0.2 km^{-1} at an altitude of about 3.0 km started to transport downward since 08:00 CST March 27 and reached the near-surface 5 hours later."

"On March 15, a large amounts of dust aerosols forming an enhanced dust layer within 2–6 km between 36°N and 41°N, where dust with DEC > 1.0 km^{-1} was located in the lower layer (2–3 km). Notably, we found that the CALIOP-derived DEC profiles appear to be missing throughout the entire height range between near-surface and 2 km in the dust source area. Most studies show that the official cloud-aerosol discrimination algorithm are usually able to correctly identify dust aerosols (Omar et al., 2009; Kim et al., 2018), but dust aerosols may be misclassified as clouds when severe dust storms are encountered (Han et al., 2022). So, when the dust concentration is extremely high and the DOD is over 3.0, it is difficult to obtain an accurate and complete dust profile because the attenuation signal received by CALIOP may be biased beneath the thick dust layer (Han et al., 2022; Pu and Jin, 2021)."

"In terms of intensity, the thick near-surface dust layer observed on March 27 was comparable to that of March 15, which led to the unavailability of the DEC profiles retrieved from CALIPSO at some locations."

3. Historical analysis - The historical analysis of the dust event, and setting in into context of the previous years in terms of DOD and also environmental factors, such as soil moisture and precipitation, is extremely useful and important. However, I missed a key point of the analysis which was the question of how unusual the anomalously strong Mongolian cyclones driving the dust emission were. In my opinion this is the missing piece of the puzzle. This is also key to discussing how dust emissions in North China will change in the future.

Response: We feel great thanks for your professional suggests. In the revised manuscript, we examined the magnitude of the anomaly of the Mongolian cyclone during these two SDSs by defining a cyclone intensity index. The following description and analysis are added to clarify how anomalous is the Mongolian cyclone in March 2021.

"To determine how anomalous was the Mongolian cyclone during these two SDSs, we examined the intensity of the Mongolian cyclone in March and during the combined period of March 15 and 27 (representing the starting day of these two SDSs) from 2000 to 2021 (Fig. S16). Following Zhu et al. (2008), we defined the cyclone intensity by the 850 hPa GH averaged over the GD (black box in Fig. 16: 36°–47°N, 96°–112°W). Over the GD, the GH in 2021 is higher than the climatology by up to 54.4 gpm (Fig. S16a). In terms of ranking, the 2021 cyclone intensity over the GD is the highest over the last 2 decades. Moreover, the monthly regional analysis shows that such two anomalous Mongolian cyclones resulted in more than 6.7 gpm higher GH than climatology in March 2020. This analysis suggests that the two Mongolian cyclones in March 2021 was highly anomalous in terms of intensity, which creates favorable dynamical conditions for the record-breaking regional dust loading in March 2021 over the past 20 years."

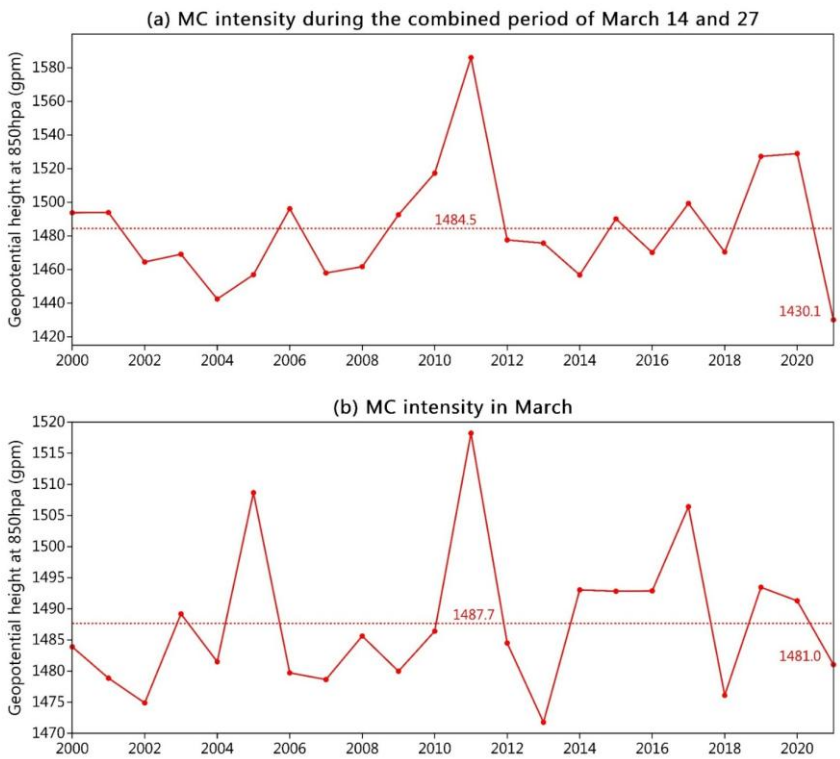


Figure S16. Time-series of the Mongolian cyclone (MC) intensity index (a) during the combined period of March 15 and 27 and (b) in March from 2000 to 2021.

4. Introduction – I would like to see an expansion of the discussion of previous work on the 3.15 event (and the 3.27, if it exists), working up to an outline of aims for the article in relation to what has or has not been done before. The authors currently do this in the introduction very briefly, and not in much detail. I have seen the authors detailed and well-justified response to the first round of reviews on this subject, and believe that much of this information and argument should be added to the actual manuscript. The introduction is the fitting part of the manuscript for this to be laid out. For example, new presentation of Himawari data, more detailed analysis of CALIOP data, more thorough analysis of dynamical driving mechanism, etc, and what these additional sources bring to the article. The authors have already explained this in their response to reviewers, but the article would benefit from its inclusion. This would significantly improve the novelty of the paper and make the article stand out from those studies already published.

Response: We sincerely thank the reviewer for this valuable feedback. After a detailed summary of previous work, we have rewritten this part of the introduction in the revised manuscript to highlight the differences and the innovations of this study.

This paragraph in the original text: "Most of these studies have focused on investigating the evolution and transport processes of the dust plume during the 3.15 event and assess its impact on the air quality by using particulate matter (PM_{10}) concentration observations and individual satellite retrieval products. However, few studies have been carried out on the optical, microphysical, and radiative properties of aerosols during the March 2021 SDS events, which are critical to accurately assess the weather and climate effects associated with enhanced dust loadings. Furthermore, these existing studies focus on the 3.15 event, and the 3.27 event, which also has a huge impact, has not received sufficient attention. Therefore, it is essential to combine the two events to elucidate their similarities and differences in terms of dust sources, aerosol optical, microphysical, and radiative properties, and meteorological drivers." has been rewritten as

"Liang et al. (2021) revealed the changes in dust composition and transport processes during the 3.15 SDS event in NC using geochemical analyses and remote sensing combined with backward trajectories analysis. Filonchyk (2022) and Filonchyk and Peterson (2022) preliminarily analyzed the synoptic conditions during the development of the 3.15 SDS event and assessed its impact on urban air quality using particulate matter (PM_{10}) concentration observations. Also, the predominance of dust particles during the storm and the uplifted height of the dust plume were confirmed by using the Moderate Resolution Imaging Spectroradiometer (MODIS) observations and the Vertical Feature Mask (VFM) data from the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). These studies have focused on describing the transport processes of dust and its impact on air quality without elucidating in detail how atmospheric circulation patterns control the emission and transport of dust, and how anomalous are these atmospheric circulation patterns and local meteorological factors? These existing studies focus on the 3.15 event, and the 3.27 event, which also has a huge impact, has not received sufficient attention. Furthermore, there are still several critical gaps for a better understanding of these two mega SDS events, such as, where are the source areas of these two SDS events? How extreme were the regional dust loadings during these two SDS events from a historical

perspective? How does the enhanced dust aerosol loading affect the optical, microphysical, and radiative properties of aerosols? What are the similarities and differences between the two events in terms of dust sources, aerosol optical, microphysical, and radiative properties, and meteorological drivers?

Minor/Technical Points

1. Fig 1 – the chosen color scheme makes it nearly impossible to identify the dust plume in this imagery, both on my screen and on print-out. The authors have added the notation 'dust' in several locations to aid this, though it's still nearly impossible to differentiate this from other land areas, forcing the reader to take their word for dust presence. It's impossible to identify the spatial extent and intensity described in lines 68-75. The authors should strive to present this more clearly. If the color scheme cannot be altered, perhaps a 'dust' contour could be drawn, with information in the caption to state what that definition is based on.

Response: We sincerely thank the reviewer for this valuable feedback. Figure 1 was changed to the following. In the updated Figure 1, we first adjusted the saturation and brightness of the display to highlight the presence of dust aerosols. In addition, we have drawn the main outline of the dust plume as you suggested.

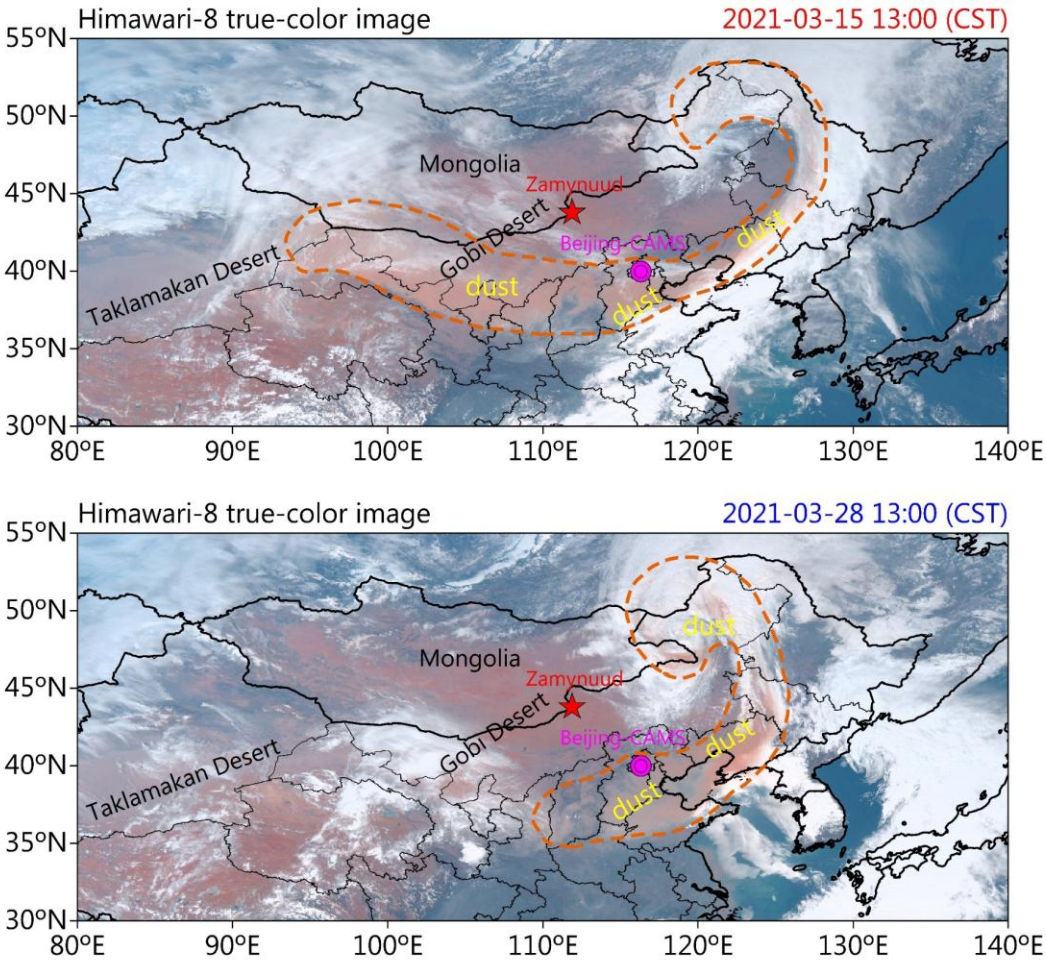


Figure 1: True-color image of dust plumes above the Earth's surface captured by the Himawari-8 at 13:00 CST (China standard time) of March 15 (top) and March 28 (bottom), 2021. The location of the AD-Net Lidar site named "Zamynuud" (43.72°N, 111.90°E; 962 m) and the sun photometer site named "Beijing-

CAMS" (39.93°N, 116.32°E; 106 m) are marked on the map with a red star and a magenta circle, respectively. Orange dashed lines outline the area covered by the dust plume.

2. L79-82, "To date, several studies (e.g., Liang et al., 2021; Filonchyk, 2022; Filonchyk and Peterson, 2022) have been conducted to characterize the severe SDS event in March 2021. Most of these studies have focused on investigating the evolution and transport processes of the dust plume during the 3.15 event and assess its impact on the air quality by using particulate matter (PM10) concentration observations and individual satellite retrieval products." – The authors should separate these studies rather than generalizing ('most of these studies..'), and for each describe what has previously been done, leading up to the main differences in this article.

Response: We sincerely thank the reviewer for this valuable feedback. After a detailed summary of previous work, we have rewritten this part of the introduction in the revised manuscript to highlight the differences and the innovations of this study.

This paragraph in the original text: "Most of these studies have focused on investigating the evolution and transport processes of the dust plume during the 3.15 event and assess its impact on the air quality by using particulate matter (PM_{10}) concentration observations and individual satellite retrieval products. However, few studies have been carried out on the optical, microphysical, and radiative properties of aerosols during the March 2021 SDS events, which are critical to accurately assess the weather and climate effects associated with enhanced dust loadings. Furthermore, these existing studies focus on the 3.15 event, and the 3.27 event, which also has a huge impact, has not received sufficient attention. Therefore, it is essential to combine the two events to elucidate their similarities and differences in terms of dust sources, aerosol optical, microphysical, and radiative properties, and meteorological drivers." has been rewritten as

"Liang et al. (2021) revealed the changes in dust composition and transport processes during the 3.15 SDS event in NC using geochemical analyses and remote sensing combined with backward trajectories analysis. Filonchyk (2022) and Filonchyk and Peterson (2022) preliminarily analyzed the synoptic conditions during the development of the 3.15 SDS event and assessed its impact on urban air quality using particulate matter (PM_{10}) concentration observations. Also, the predominance of dust particles during the storm and the uplifted height of the dust plume were confirmed by using the Moderate Resolution Imaging Spectroradiometer (MODIS) observations and the Vertical Feature Mask (VFM) data from the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). These studies have focused on describing the transport processes of dust and its impact on air quality without elucidating in detail how atmospheric circulation patterns control the emission and transport of dust, and how anomalous are these atmospheric circulation patterns and local meteorological factors? These existing studies focus on the 3.15 event, and the 3.27 event, which also has a huge impact, has not received sufficient attention. Furthermore, there are still several critical gaps for a better understanding of these two mega SDS events, such as, where are the source areas of these two SDS events? How extreme were the regional dust loadings during these two SDS events from a historical perspective? How does the enhanced dust aerosol loading affect the optical, microphysical, and radiative properties of aerosols? What are the similarities and differences between the

two events in terms of dust sources, aerosol optical, microphysical, and radiative properties, and meteorological drivers?

3. L105 – do you mean they agree well as demonstrated by those studies, or do you mean specifically for your case study?

Response: They agree well as demonstrated by those studies. The phrase has been changed to: "*Previous studies (Hsu et al. 2019; Sayer et al. 2019) have shown that MODIS and VIIRS AOD agree well with the Aerosol Robotic Network (AERONET) observations*".

4. Section 2.1.3 – CALIOP – was there a reason you did not use the dust extinction profile provided directly by NASA? What are the differences between your algorithm and the standard NASA CALIOP retrievals for dust-only extinction?

Response: We have included the following description to clarify why we do not use the standard NASA CALIOP retrievals for dust-only extinction: "*We did not directly use the extinction profile of the "dust" or "polluted dust" type as determined by the CALIPSO aerosol type classification algorithm. Using "dust" alone would result in an underestimation of the actual atmospheric dust loading, while introducing the sum of "dust" and "polluted dust" would overestimate the dust loading (Han et al., 2022).*"

Reference:

Han, Y., Wang, T., Tang, J., Wang, C., Jian, B., Huang, Z. and Huang, J.: New insights into the Asian dust cycle derived from CALIPSO lidar measurements, Remote Sens. Environ., 272(2), 112906, doi:10.1016/j.rse.2022.112906, 2022.

5. Section 2.1.4 – Himawari – An assessment of the advantages and assumptions/limitations of using the Himawari RGB data should be given here – e.g. high time resolution diurnal sampling ability, assumption of aerosol properties/altitude, interference from clouds. Much of this is covered in Brindley et al. (2012).

Response: In the revision, the following description is included to illustrate the advantages and assumptions/limitations of using Himawari RGB data:

"Note that although the high temporal resolution of Himawari-8 combined with the RGB composite images offers the potential to identify specific features forward or backward in time, the ability of the dust RGB imagery to identify dust, via its characteristic magenta coloring, is strongly dependent on the column water vapor, the lower tropospheric lapse rate, and dust altitude (Brindley et al., 2012)."

Reference:

Brindley, H., Knippertz, P., Ryder, C. and Ashpole, I.: A critical evaluation of the ability of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) thermal infrared red-green-blue rendering to identify dust events: Theoretical analysis, J. Geophys. Res. Atmos., 117(7), 1–20, doi:10.1029/2011JD017326, 2012.

6. L200-210 – Are you using the DARF using fluxes at the TOA and BOA as given by the

AERONET algorithm (rather than applying the aerosol properties in a radiative transfer code of your own)? This should be clearly stated.

Response: The phrase has been changed to *"The shortwave direct aerosol radiative forcing (DARF in W m^{-2}) was calculated by the radiative transfer module of AERONET"*.

7. 2.2.2 Visibility – Why are the effects of RH discounted? RH is an important contributor to visibility, and is a relative unknown in terms of how much it affects dust-induced decreases in visibility. On reading section 3.1 perhaps this is done to avoid spatial variations in visibility due to relative humidity. In this case it would be useful to include the uncorrected visibility map in the supplement.

Response: Yes, the purpose of using the RH-corrected visibility is mainly to assess the changes in visibility caused by aerosols (mainly dust here), which avoids the misunderstanding of attributing low visibility caused by high relative humidity (e.g. fog) to dust loading. In addition, as suggested by the reviewers, we also include the uncorrected visibility map in the supplement. The following sentences are also summarized in the revised version to clarify the differences.

"*The RH-corrected visibility filters out the effects from high RH events and instead highlights the effect of dust in weakening visibility (see Fig. 3 and Fig. S2).*"

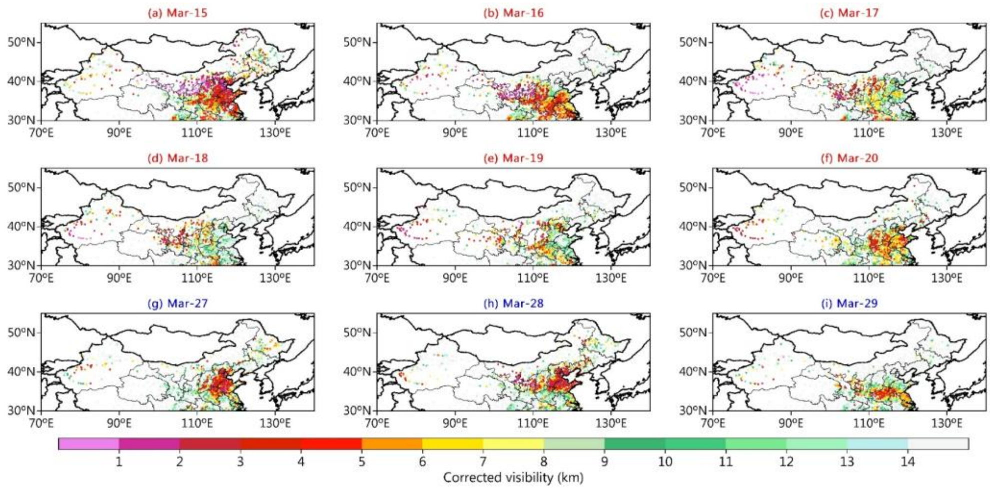


Figure 3: Evolution of observed daily mean (presented as averages close to the MODIS and VIIRS observation time range, i.e., approximately 10:00 to 14:00 CST) corrected visibility during (a–f) the 3.15 SDS event (March 15–20, 2021) and (g–i) the 3.27 SDS event (March 27–29, 2021), respectively.

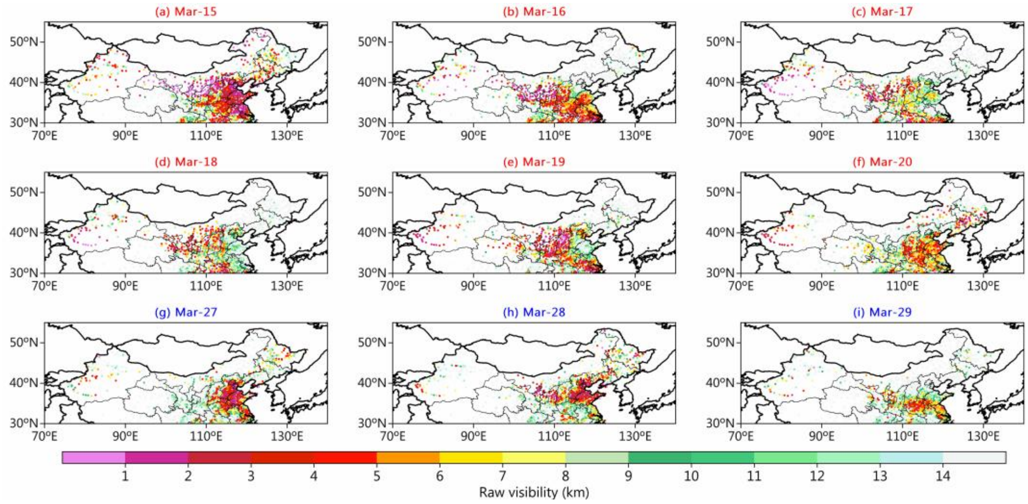


Figure S2: Evolution of observed daily mean raw (uncorrected) visibility during (a–f) the 3.15 event (March 15–20, 2021) and (g–i) the 3.27 event (March 27–29, 2021).

8. L264 – ‘Clearly, the dust RGB composite images are able to provide a more spatially continuous evolution of the dust plume than the satellite inversion of aerosol-related variables, as it does not need to rely on various retrieval assumptions.’ – this is not clear, since other satellite aerosol products have not been presented at this point. Himawari RGB data does require other assumptions and have other limitations (see comment for section 2.1.4).

Response: We sincerely thank the reviewer for this valuable feedback. We have removed this unclear or incorrect description.

9. L268 – ‘pulled’ > ‘uplifted’

Response: corrected.

10. L274-280 – This paragraph is a bit disappointing in that it points out differences in cyclone intensity, extent and location, yet does not really provide the evidence to explain these.

Response: We sincerely thank the reviewer for this valuable feedback. In fact, section 3.5 (also see Figure 12 below) provides detailed evidence to explain these. Therefore, in the revised version, we have added the following explanation after this paragraph: *“(for detailed information please see Section 3.5)”*

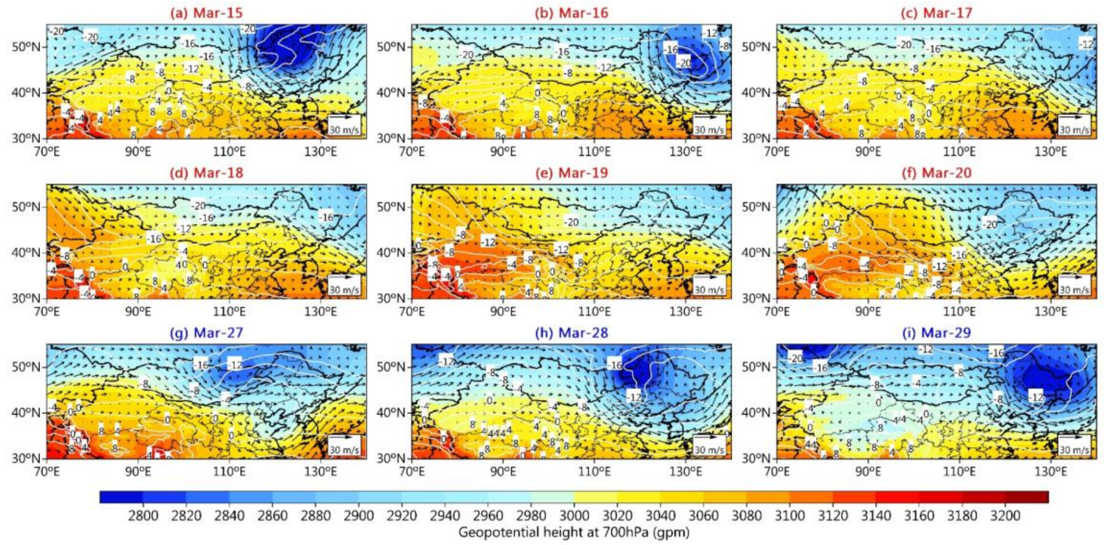


Figure 12: Pattern evolutions of ERA5 geopotential height (shading; gpm), temperature (contours; °C), and wind vectors (black arrows; m s^{-1}) at 700 hPa on (a) March 15, (b) 16, (c) 17, (d) 18, (e) 19, (f) 20, (g) 27, (h) 28, and (i) 29, 2021.

11. Fig 3 – a better color bar should be used, with fixed thresholds for different visibility levels (rather than a graduated color bar), so that readers can easily pick out the actual visibility values.

Response: We sincerely thank the reviewer for this valuable feedback. Following your suggestion, Figure 3 has been updated as follows. At the same time, some similar visibility maps in the supplement have been updated.

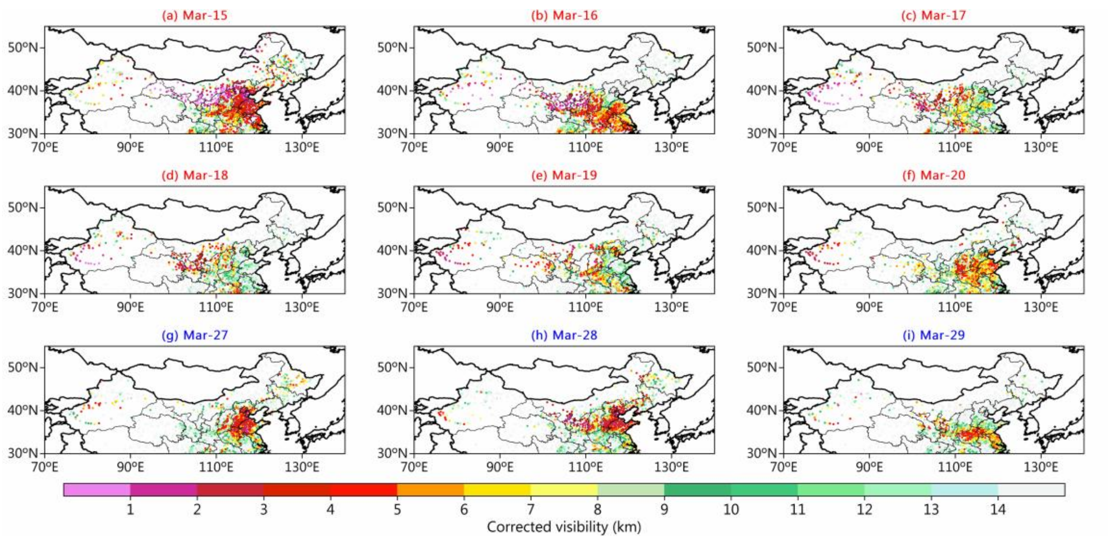


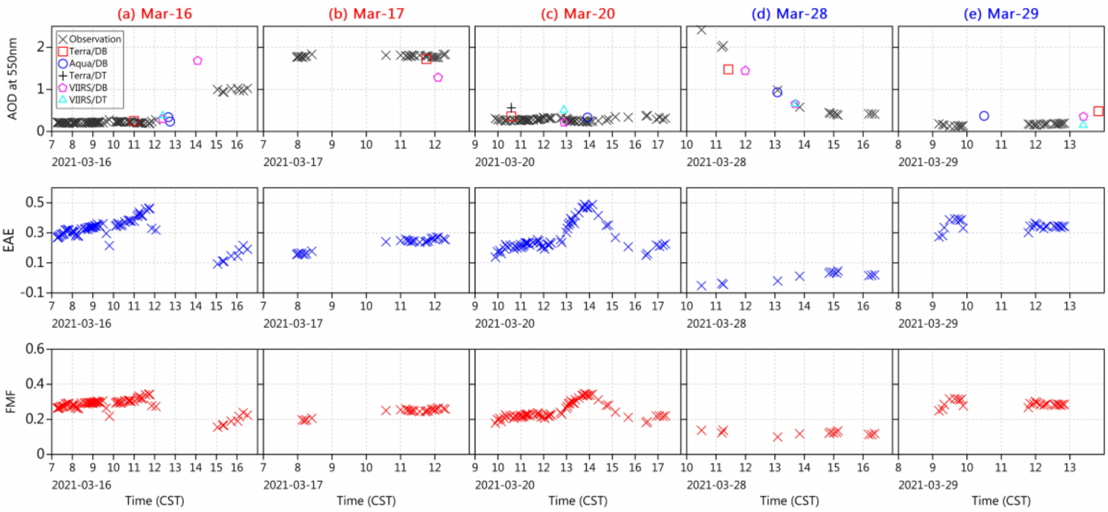
Figure 3: Evolution of observed daily mean (presented as averages close to the MODIS and VIIRS observation time range, i.e., approximately 10:00 to 14:00 CST) corrected visibility during (a–f) the 3.15 SDS event (March 15–20, 2021) and (g–i) the 3.27 SDS event (March 27–29, 2021), respectively.

12. All map figures – it would be useful to distinguish between the outlines of national boundaries vs regional boundaries within China to aid interpretation from figures. Perhaps the authors could use a bold outline for national boundaries to make them more distinct?

Response: We sincerely thank the reviewer for this valuable feedback. Following your suggestion, all map figures have been updated by bolded outlines of national boundaries. Please see the revised manuscript for details of the changes.

13. Fig 5 – figure quality is poor – markers very light and blurred.

Response: We sincerely thank the reviewer for this valuable feedback. Following your suggestion, Figure 5 has been updated as follows.



14. L331-2 = "Notably, an enhancement of DOD at the dust source on March 28 was not captured, which implies that the intensity of dust emissions was significantly lower on March 28 than on March 27." – if it was not captured, how do you know there was an enhancement? Which source?

Response: We apologize for the misrepresentation here. "Notably, an enhancement of DOD at the dust source on March 28 was not captured" has been changed to *"Notably, a low DOD value (< 0.5) was observed at the dust source on March 28".*

15. L336 – "the AOD in Beijing increased significantly during the period from 8 to 12 h (CST) on March 17" – fig 5 shows that the AOD mostly increased on March 16th – by 17th March the AOD is already ~2. Similarly, this means that the event lasted longer than ~ 4 hours, as stated.

Response: We sincerely thank the reviewer for this valuable feedback. We apologize for the unclear description. These sentences have been revised to *"the AOD in Beijing increased significantly during the period from 13 to 17 h (CST) on March 16, reaching a maximum value of about 2.0 on March 17, which was about 10 times higher than the AOD (i.e., 0.2) under clean condition in the morning of March 16. Temporally, the enhanced AOD in Beijing lasted for nearly one day."*

16. L339-341 – 'On March 17, EAE values between 0.1 and 0.3 and FMF values between 0.2 and 0.3 together reveal that the enhanced aerosol loading is dominated by coarse-mode particles, with a smaller contribution from fine-mode particles.' – The FMF does not seem to relate to the dust-related AOD – FMF drops somewhat at the end of 16th March, drops very slightly on 17th March, but the differences are not exceptional.

Response: We sincerely thank the reviewer for this valuable feedback. This misunderstanding is mainly caused by the inaccurate representation of the time range. In the revised draft, “On March 17” has been changed to “*From 15 h on March 16 until 09 h on March 17*”.

17. Fig 7 – has cloud-screening been performed in constructing this figure?

Response: No, this figure is not cloud screened. In the final dataset for AD-Net, height profiles of extinction coefficient are provided up to cloud base or maximum height determined by SNR. If clouds are detected, cloud base/top heights are indicated, and the region above cloud and rain conditions are marked as non observable (missing data) (Shimizu et al., 2010).

Reference:

Shimizu A, Sugimoto N, Matsui I. Detailed description of data processing system for lidar network in East Asia[C]//25th International Laser Radar Conference. 2010: 911-913.

18. L358 and next 2 paragraphs – the authors should consider the point-nature of the lidar site in their description of the vertical distribution of the dust. This data is great for fully describing the temporal evolution of the dust, but it is only a single point. Thus when a plume at upper levels mostly dissipates and one appears at lower levels, this does not necessarily mean the plume has descended to the surface (as described for 26th March). It’s more likely that the upper plume dissipated or was transported away from the point observation, and the lower plume entered the observing region due to transport.

Response: We sincerely thank the reviewer for this valuable feedback. We double-checked our description of the single-site lidar observations. We have also revised descriptions that may be incorrect. Some new descriptions below have been added to the revised manuscript.

“In contrast, the strong dust plume (DEC > 1.0 km^{-1}) located in the upper layers carrying a large amount of dust aerosols was maintained at an altitude of 1−3 km for nearly 1 day before being transported far from the observation site at 18:00 CST March 19. After this, the high-altitude dust plume gradually dissipated as the dust aerosols diffused and were partially deposited, and the observation site was only intermittently affected by surrounding dust transport.”

“Similar to the 3.15 event, north-central Inner Mongolia was also influenced by the transport of dust plumes during the 3.27 event. Specifically, two moderate dust plumes (DEC ~0.05 km^{-1}) had affected the lower (0–2km) and upper layers (3–4km) in north-central Inner Mongolia, respectively, on March 26. Subsequently, the observation site may have been affected by a combination of lower-layer and high-altitude transport. Clearly, the dust plume with a DEC of about 0.2 km^{-1} at an altitude of about 3.0 km started to transport downward since 08:00 CST March 27 and reached the near-surface 5 hours later.”

19. Fig 8 – please zoom the map plots in more to make them more readable. Lat/lon values on the map would be useful to relate them to the extinction figure.

Response: We sincerely thank the reviewer for this valuable feedback. Following your suggestion, Figure 8 has been updated as follows.

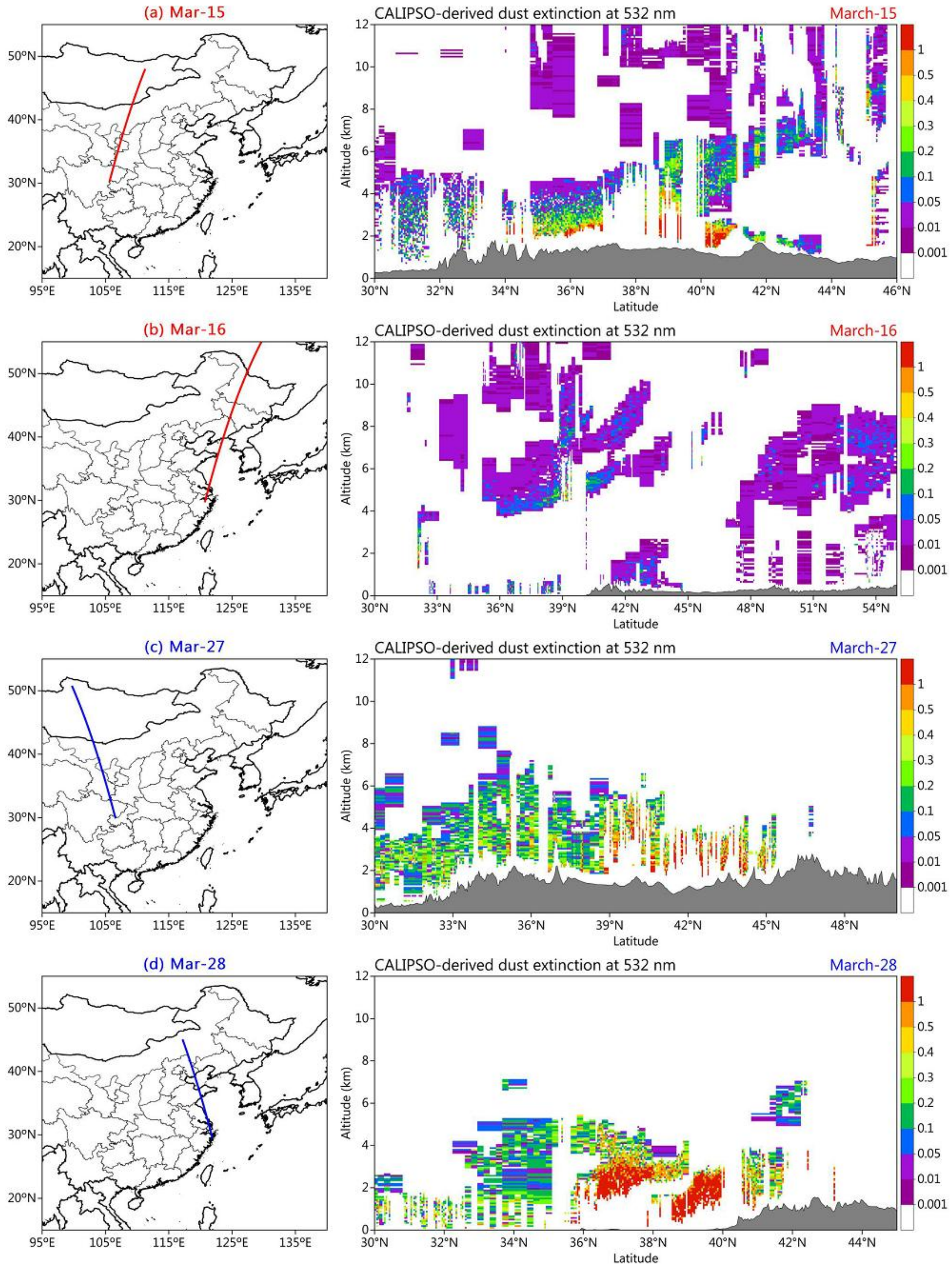


Figure 8: CALIOP/CALIPSO snapshots of dust plumes for (a) March 15, (b) March 16, (c) March 27, and (d) March 28, 2021. The first column presents the CALIPSO tracks (red or blue lines) and the second column shows the 532 nm dust extinction coefficients (km^{-1}). Surface elevation is indicated by the gray filled line.

20. L384-388 (wrt fig 8) – This is rather underwhelming. The figure (8b) seems to show

only a small amount of data, which may be due to the lidar signal being extinguished by the heavy dust loadings. If this is so, the authors should discuss this. This section of writing does not add much to the manuscript.

Response: We sincerely thank the reviewer for this valuable feedback. We need to clarify that the retrieval of the CALIPSO-based dust extinction profile on March 16 seems reasonable. As demonstrated by the H8 RGB dust composite image (see Fig. 2b) and MODIS AOD observations (Fig. 4b), no significantly enhanced dust signal was detected in the Bohai Sea, the eastern coast of China (except for the eastern coast of Jiangsu Province), and the eastern part of China on March 16. Therefore, the small amount of dust signals detected by satellites are mainly located at upper levels. The only exception is the high value of dust extinction detected at about 32°N (eastern Jiangsu Province and its coastal areas), which is also captured by the retrieval of the CALIPSO-based dust extinction profile.

However, this suggestion of the reviewer allows us to provide a substantial reference value for a reasonable explanation of the absence of the near-surface dust signal on March 15 (Fig.8b). The following discussion has been added to the revised manuscript.

"Notably, we found that the CALIOP-derived DEC profiles appear to be missing throughout the entire height range between near-surface and 2 km in the dust source area. Most studies show that the official cloud-aerosol discrimination algorithm are usually able to correctly identify dust aerosols (Omar et al., 2009; Kim et al., 2018), but dust aerosols may be misclassified as clouds when severe dust storms are encountered (Han et al., 2022). So, when the dust concentration is extremely high and the DOD is over 3.0, it is difficult to obtain an accurate and complete dust profile because the attenuation signal received by CALIOP may be biased beneath the thick dust layer (Han et al., 2022; Pu and Jin, 2021)."

References:

Kim, M., Omar, A. H., Tackett, J. L., Vaughan, M. A., Winker, D. M., Trepte, C. R., Hu, Y., Liu, Z., Poole, L. R., Pitts, M. C., Kar, J. and Magill, B. E.: The CALIPSO version 4 automated aerosol classification and lidar ratio selection algorithm, Atmos. Meas. Tech., 2, 6107–6135, 2018.

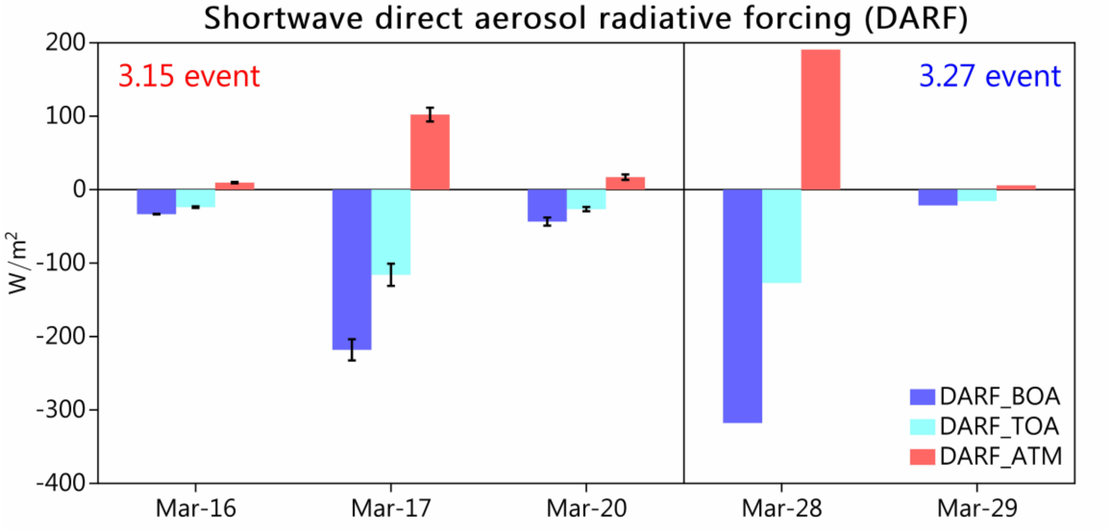
Omar, A. H., Winker, D. M., Kittaka, C., Vaughan, M. A., Liu, Z., Hu, Y., Trepte, C. R., Rogers, R. R., Ferrare, R. A., Lee, K. P., Kuehn, R. E. and Hostetler, C. A.: The CALIPSO automated aerosol classification and lidar ratio selection algorithm, J. Atmos. Ocean. Technol., 26(10), 1994–2014, doi:10.1175/2009JTECHA1231.1, 2009.

Han, Y., Wang, T., Tang, J., Wang, C., Jian, B., Huang, Z. and Huang, J.: New insights into the Asian dust cycle derived from CALIPSO lidar measurements, Remote Sens. Environ., 272(2), 112906, doi:10.1016/j.rse.2022.112906, 2022.

Pu, B. and Jin, Q.: A record-breaking trans-Atlantic African dust plume associated with atmospheric circulation extremes in June 2020, Bull. Am. Meteorol. Soc., 1–41, doi:10.1175/bams-d-21-0014.1, 2021.

21. Fig 9 – presumably this is shortwave DARF. This should be clearly added to the figure caption and methodology section, as well as the results section of the text.

Response: We sincerely thank the reviewer for this valuable feedback. Following your suggestion, Figure 9 has been updated as follows. In addition, "shortwave DARF" is also clearly added to the figure caption and methodology section, as well as the results section of the text.



22. L403 – SSA of 0.915 is actually fairly low as far as dust is concerned. For example, climate models tend to use values of ~0.95-0.97 at 550nm

Response: We sincerely thank the reviewer for this valuable feedback. This sentence has been revised to *"Meanwhile, the enhanced absorption capacity (SSA = 0.915) associated with increased dust loading led to the weakened scattering of atmospheric aerosols….."*

23. L435 – 'It is worth noting that on March 15 the dust emissions from the GD located in northwestern Inner Mongolia were significantly higher than the intensity of dust emissions from the GD located in southern Mongolia, which raises the question as to whether the GD in China was the original source of the 3.15 SDS event.' – this is rather unclear. It's difficult to make out from the maps exactly what is meant by this.

Response: This unclear expression is caused by the inaccurate description of the geographical location. The Gobi Desert is located between China and Mongolia and covers southern Mongolia and western Inner Mongolia, China. Therefore, the point we are trying to make is that although the intensity of dust emissions on March 15 located in northwestern Inner Mongolia, China (part of the Gobi Desert) was significantly higher than those located in southern Mongolia (also part of the Gobi Desert), the Gobi Desert in the Chinese region was not the source of this event. To avoid unclear, "northwestern Inner Mongolia" has been changed to *"northwestern Inner Mongolia, China"*.

24. Fig 10 – it would be useful to add the preceding dates of 14 Mar (as in fig 11) and 26 Mar. Fig 11 and associated analysis in the paper show that the emissions peak the day before peak dust concentrations and load are experienced across China. Therefore it would be relevant to include emissions from the preceding day for each event, as these are most useful to illustrate the evolution of the dust event. Although 14 Mar is shown in fig 11, it would be useful to add it to fig 9 to complete the temporal evolution shown.

Response: We greatly appreciate this suggestion from the reviewers. However, to avoid redundancy, we did not choose to put the dust emissions on 14 Mar in Figure 11 again in Figure 10, as we do not think that the current presentation would affect readability. Nevertheless, we have included emissions from the preceding day for each event, as shown in the Fig. S6 below.

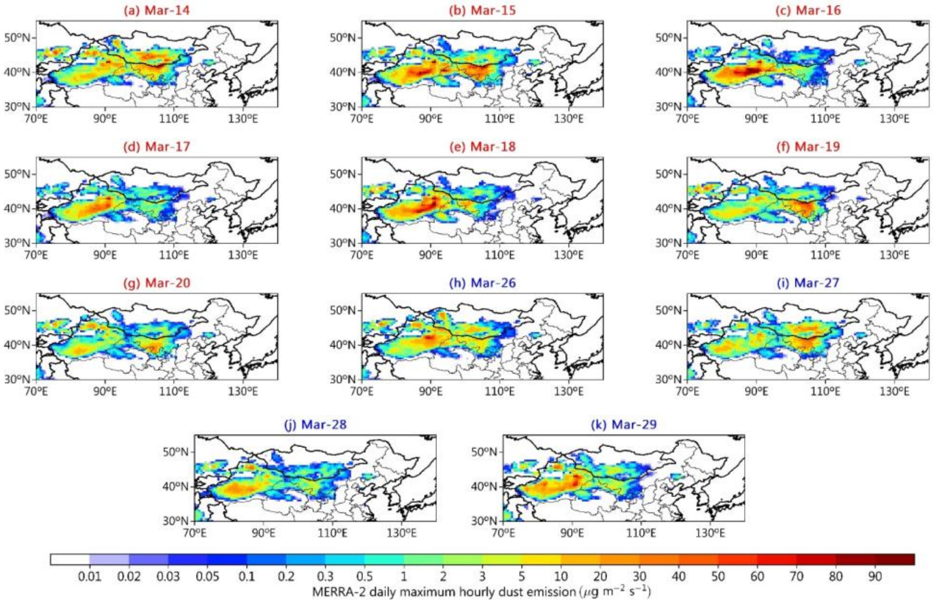


Figure S6: Evolution of MERRA-2 daily maximum hourly dust emissions for all size bins during (a–g) March 14–20, 2021 and (h–k) March 26–29, 2021.

25. L443-444 – what do your results of emission here add to the description of this event, in addition to confirming those of Jin and Liang? Backward trajectory analysis for dust can often be inaccurate due to poorly represented meteorology at low resolution driving the back trajectories, and the fact that the trajectories do not include dust being deposited out of the air mass tracked.

Response: We sincerely thank the reviewer for this valuable feedback. The dust emission intensity and the dust RGB images together identified the sources of these two dust processes. To avoid citing controversial results, we removed the reference of Liang et al. (2020).

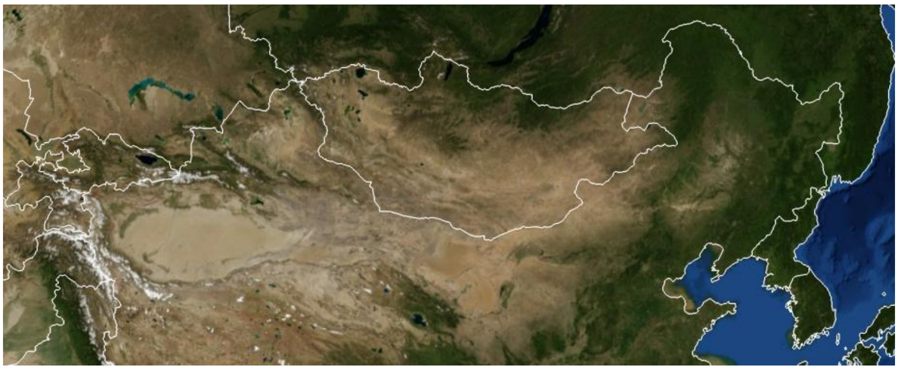
26. L481 – 'This configuration of synoptic systems established an unfavorable atmospheric circulation condition for dust emissions from the GD and transported along the direction of cyclone movement, which directly led to visibility reaching the minimum of this process on March 15.' – unclear. Do the authors mean an unfavorable situation for strong transport and dispersion of dust in the atmosphere? I.e. the airmass was relatively stagnant after the cyclone moved away, leading to the build up of the emitted dust?

Response: We are sorry to present some unclear expressions. We actually would like to express that this configuration of synoptic systems is favorable for dust emissions. To avoid ambiguity, we have revised this sentence to "*This configuration of synoptic systems provides favorable dynamic conditions for dust emissions from the GD….*".

27. L488-491 – what about difference in location (and therefore availability of erodible surface material) in addition to cyclone intensity?

Response: We sincerely thank the reviewer for this valuable feedback. The following description of the difference in cyclone position was included in the revised manuscript.
"In addition, although we observed a more westerly cyclone position on March 27 than on March 15, its rear was not configured with a cold high-pressure system of the same intensity as on March 15, which explains the difference in near-surface wind speed and direction in the dust source area (Fig. S11), thus regulating the dust transport path."

As for the differences in the availability of erodible surface material: it is difficult to characterize the amount of dust in the different dust sources because we did not find observations related to availability of erodible surface material. Nevertheless, the satellite image(https://visibleearth.nasa.gov/images/57752/blue-marble-land-surface-shallow-water-and-shaded-topography) below show that the locations corresponding to the strong winds near the surface on March 15 and 27 are both relatively bare Gobi Desert areas.



28. Section 3.5 – I was surprised not to find more analysis of the surface pressure distribution and evolution presented here, given the arguments in the response to reviewers about the surface pressure being the missing link between what has previously been published.

Response: We feel great thanks for your professional suggests. In the revised manuscript, the following Fig. S11 and descriptions have been included.

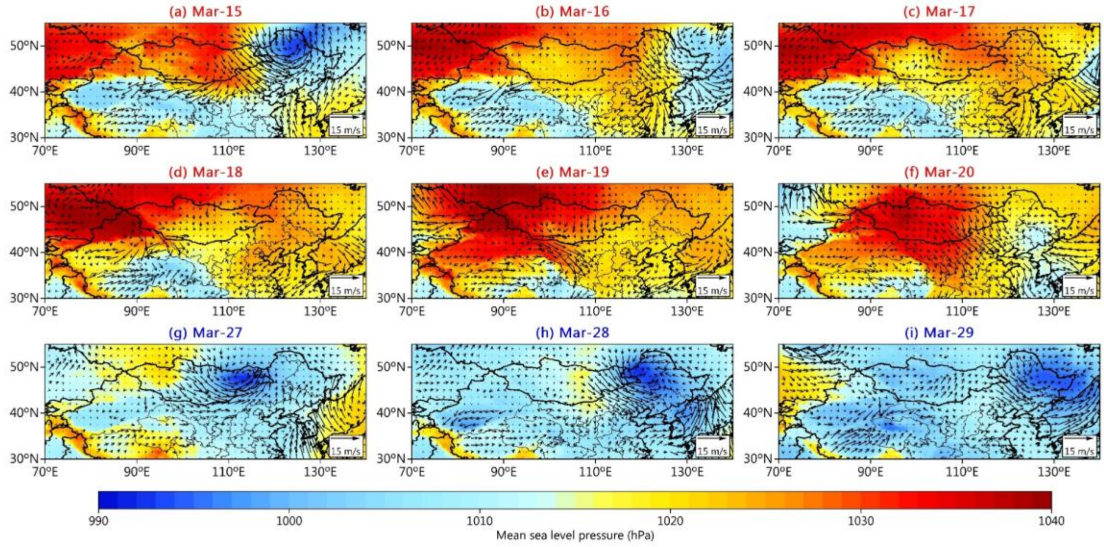


Figure S11: Pattern evolutions of mean sea level pressure (shading; hPa) and 10m wind vectors (black arrows; m s^{-1}) on (a) March 15, (b) 16, (c) 17, (d) 18, (e) 19, (f) 20, (g) 27, (h) 28, and (i) 29, 2021.

"This synoptic system has been broken since March 16 with the eastward movement of the Mongolian cyclone, resulting in weakened near-surface cold high pressure and near-surface winds (see Fig. S11)."

"Such a strong cyclone caused a rapid decrease in near-surface pressure, with the lowest value of SLP being about 990 hPa (Fig. S11). Under the control of such a strong low-pressure system, northwesterly gusts exceeding 15 m s^{-1} ensued at the surface near eastern Mongolia (Fig. S11)."

29. L529-536 – this is a fairly substantial section discussing material only in the supplement. I urge the authors to include important information and figures in the manuscript itself, and if not crucial, do not discuss the` detail in the text.

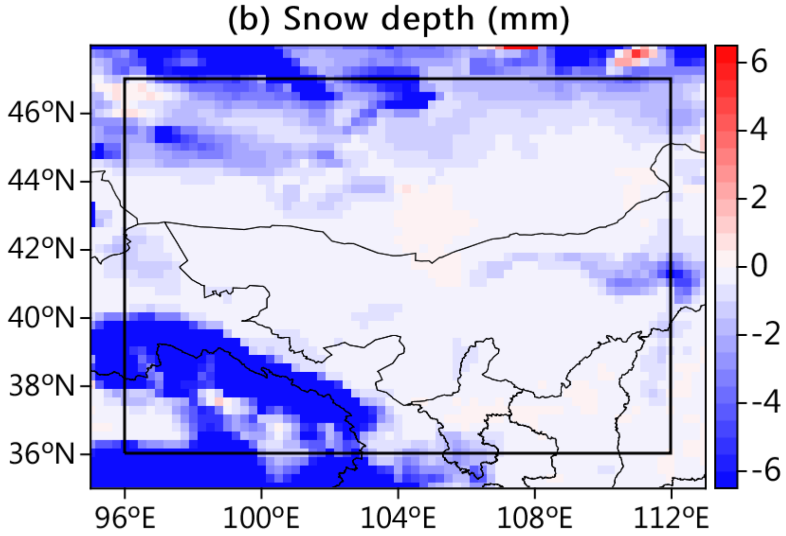
Response: We sincerely thank the reviewer for this valuable feedback. Figs. S13 and S14 have been moved to the text as Figs. 16 and 17.

30. Fig 16 caption – is the data in the figure instantaneous at 2d preceding the 3.15 event, or averaged over a fixed time period? I.e. averaged over days -14 to day zero preceding the event? This should be clarified in the caption.

Response: The data presented are averaged over a fixed time period (i.e., March 1–14, 2021). In the revised manuscript, this has been clarified in the caption.

31. Fig 16 – why does fig b show approximately zero snow depth anomaly, yet fig f shows a negative anomaly compared to the mean?

Response: We sincerely thank the reviewer for this valuable feedback. This may be a misunderstanding due to the large range of values displayed by the color scale. In fact, the snow depth anomaly is not close to 0 (see below). Differences in the magnitude of negative snow depth anomalies over different regions of GD contribute to a negative anomaly compared to the mean.



32. L558-563 – "Yin et al. (2021) utilized site observations, reanalysis data, and historical simulation outputs from CMIP 6 to analyse the dynamical mechanisms of Mongolian cyclones influencing dust occurrence and development, and revealed that the climate variabilities at different latitudes and synoptic disturbances jointly facilitated the strongest SDS event in NC over the past decade." – this is not a very useful statement – it doesn't allow the reader to learn anything new. The authors should make their statement clearer, and in addition explain how their own analysis here adds understanding/information to previously published studies.

Response: We sincerely thank the reviewer for this valuable feedback. In the revised manuscript, "In addition to these typical local meteorological anomalies, Yin et al. (2021) utilized site observations, reanalysis data, and historical simulation outputs from CMIP 6 (phase 6 of the Coupled Model Intercomparison Project) to analyse the dynamical mechanisms of Mongolian cyclones influencing dust occurrence and development, and revealed that the climate variabilities at different latitudes and synoptic disturbances jointly facilitated the strongest SDS event in NC over the past decade." has been changed to *"The climatic anomalies of these local meteorological factors in the dust source area may be closely related to the anomalies of sea ice shift in the Barents and Kara Sea, and sea surface temperatures in the east Pacific and northwest Atlantic (Yin et al., 2021).*"

33. Section 3.7 – how anomalous were the Mongolian cyclones in March 2021 which drove the dust events? The authors have identified the record breaking nature of March 2021 dust, and identified that the environment was effectively 'pre-loaded' via reduced precipitation, surface temperature and soil moisture to be ready for a massive dust storm. But the key missing factor appears to be how unusual was the dynamical situation? Or was the surface so dry that the typical average Mongolian cyclone would result in a massive dust storm? This is also key to discussing how dust emissions in North China will change in the future.

Response: We feel great thanks for your professional suggests. In the revised manuscript, we examined the magnitude of the anomaly of the Mongolian cyclone during these two SDSs by defining a cyclone intensity index. The following description and analysis are added to clarify how anomalous is the Mongolian cyclone in March 2021.

“To determine how anomalous was the Mongolian cyclone during these two SDSs, we examined the intensity of the Mongolian cyclone in March and during the combined period of March 15 and 27 (representing the starting day of these two SDSs) from 2000 to 2021 (Fig. S16). Following Zhu et al. (2008), we defined the cyclone intensity by the 850 hPa GH averaged over the GD (black box in Fig. 16: 36°–47°N, 96°–112°W). Over the GD, the GH in 2021 is higher than the climatology by up to 54.4 gpm (Fig. S16a). In terms of ranking, the 2021 cyclone intensity over the GD is the highest over the last 2 decades. Moreover, the monthly regional analysis shows that such two anomalous Mongolian cyclones resulted in more than 6.7 gpm higher GH than climatology in March 2020. This analysis suggests that the two Mongolian cyclones in March 2021 was highly anomalous in terms of intensity, which creates favorable dynamical conditions for the record-breaking regional dust loading in March 2021 over the past 20 years. ”

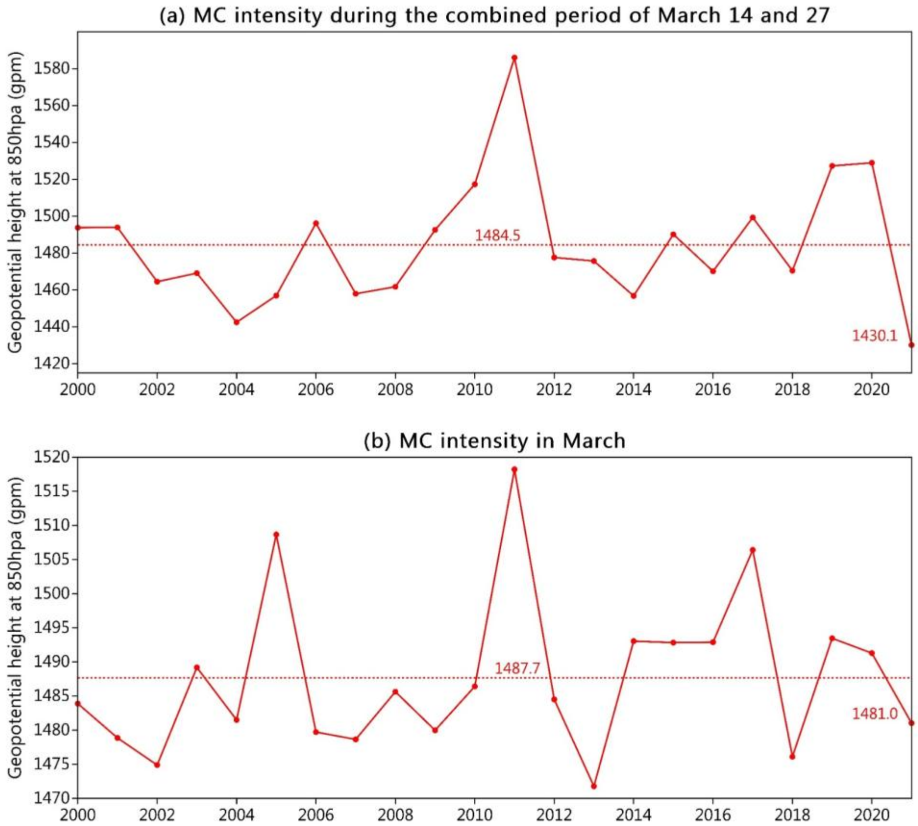


Figure S16. Time-series of the Mongolian cyclone (MC) intensity index (a) during the combined period of March 15 and 27 and (b) in March from 2000 to 2021.

34. Section 3.7 – snow melt – how does this relate to the soil moisture? To what extent does earlier/more snow melt lead to a moister soil due to the meltwater?

Response: We thought that the variation of soil moisture is mainly controlled by precipitation and surface temperature. First, the negative precipitation anomaly indicates the severe drought in Mongolia. The high surface temperature also indicated a strong ground surface evaporation, which accelerated land drying. Although snowmelt resulting from atmospheric heating alleviated the drought in the dust source area to some extent, it could not overcome the joint impacts of deficient precipitation and strong surface evaporation. The snow depth was significantly lower than the climate mean (Fig. 18f) and thus further caused the ground to become bare and loose.

In the revised manuscript, "the near-surface temperature in western Inner Mongolia and Mongolia was more than 4.0 °C warmer than the climatology (Fig. 18a), leading to early melting of snow covering the ground (Fig. 18b)." has been changed to "*the near-surface temperature in western Inner Mongolia and Mongolia was more than 4.0 °C warmer than the climatology (Fig. 18a), leading to early melting of snow covering the ground (Fig. 18b) and thus further caused the ground to become bare and loose. The high surface temperature also indicated a strong ground surface evaporation, which accelerated land drying.*"

35. Conclusions – the authors may also like to add Pu and Ginoux (2018) to their discussion of future dust changes, as these authors provided some valuable contributions. (Manuscript already in references of main article).
Response: We feel great thanks for your professional suggests. The work of Pu and Ginoux (2018) has been cited to support predictions of a possible future decrease in dust aerosols in northern China, due to increased vegetation and weakened wind speeds.

36. Throughout manuscript: 'blown up' > 'uplifted'.
Response: corrected.