

Response to the Comments of Referees

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Title: Exploring the Mechanisms of Dust Emission and Transport based on Observations and GEOS-Chem Simulations

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We thank the reviewers and editor for providing helpful comments to improve the manuscript. We have revised the manuscript according to the comments and suggestions of the referees.

The referee's comments are reproduced (black) along with our replies (blue). All the authors have read the revised manuscript and agreed with the submission in its revised form.

Anonymous Referee #1

Review comments of “Exploring the Mechanisms of Dust Emission and Transport based on Observations and GEOS-Chem Simulations” by Zou et al., 2025

General comments

The authors present a detailed and well-documented case study of a dust storm originating in western Inner Mongolia that affected southern regions of China, including Hainan Island. The manuscript provides a thorough analysis of the physical processes driving dust emission, wet deposition, and long-range transport, and the comparison with historical records from the past 30 years as well as two recent dust storms is informative. However, while the results are clearly presented and internally consistent, many of the findings align closely with existing understanding of dust storm behavior. As a result, the study's broader scientific significance and novelty are somewhat limited.

The manuscript would benefit from improved conciseness. While the discussion of the physical factors controlling dust emission and transport (e.g., wind, temperature, soil moisture, and precipitation) is relevant and informative, this material is repeated in multiple sections of the paper (lines 143–154, 236–244, 247–248, 271–273, etc.). Consolidating these discussions would reduce redundancy and improve the overall flow of the manuscript.

We thank the reviewer for recognizing the detailed analysis and comparative work in this study, especially for the valuable suggestions to enhance the scientific significance and conciseness of the manuscript. In response to your suggestions, we have revised the manuscript while preserving the core scientific findings, as follows:

1. Highlighting the Scientific Significance and Novelty:

(1) Clarifying the Research Motivation: We have explicitly stated that the April 2025 dust event is a rare documented case of transport reaching Hainan Island, and that its ability to effectively transport southward under heavy precipitation conditions is distinctive (lines 78–84).

(2) **Emphasizing Unique Findings:** In section 4.3.2 and the Summary and Conclusion section., we have focused more on contrasting the fundamental differences in the combination of key driving factors between the 2025 event and two severe historical events. We highlight that the specific synergistic configuration of an abnormally southward-displaced and intensified Mongolian cyclone and an exceptionally strong and persistent Siberian High, along with the resulting special transport mode of “sustained strong northerly winds pushing dust and the rainband to move southward in coordination,” collectively constituted the key dynamic mechanism enabling the extreme southward transport. This specific configuration and process are uncommon in previously reported cases, thereby enhancing the uniqueness of the study.

2. Condensing Content and Eliminating Redundancy

We have systematically reviewed the entire manuscript and substantially consolidated or removed redundant discussions of controlling factors (wind, temperature, humidity, precipitation), particularly in the sections indicated by the reviewer.

- (1) The text preceding Section 4.3.1 has been condensed, while the remaining relevant paragraphs have been retained and reorganized to ensure conciseness without compromising coherence.
- (2) Subsequent chapters now focus on presenting data, conducting comparisons, and delving into the specific, underlying mechanisms behind the observed differences, thereby directing the reader’s attention to the new findings of this study.
- (3) In the Conclusion section, we have reorganized and emphasized the distinctive aspects of this case that go beyond typical understanding and their underlying mechanisms, making the scientific contribution clearer.

We hope that through these revisions, the manuscript has been significantly improved in terms of highlighting novelty, enhancing logical flow, and increasing conciseness. Once again, we sincerely thank the reviewer for the highly constructive comments, which have greatly helped improve the quality and readability of the paper. All revisions have been highlighted or annotated in the revised manuscript for your review.

Specific comments

1. Line 87-91: Why do the authors use ERA5 instead of MERRA2 meteorological data in the analysis? It’s worth noting that the latter is the meteorological data used to drive the GEOS-Chem atmospheric chemical transport model simulations.

We appreciate the reviewer’s comment. We agree that MERRA-2 is a widely used meteorological dataset for driving the GEOS-Chem model and has advantages in aerosol and radiation variables.

In this study, we chose ERA5 for the following reasons:

- (1) Higher spatiotemporal resolution

ERA5 has a horizontal resolution of ~31 km and hourly output, compared to ~50 km in MERRA-2. The finer resolution is beneficial for capturing detailed dust emission, transport, and boundary-layer processes in our case.

(2) ERA5's superior performance in representing large-scale circulation

Existing research demonstrates that ERA5 exhibits superior performance in representing large-scale circulation backgrounds and associated meteorological elements (e.g., temperature, pressure, humidity). This provides a more reliable foundation for analyzing processes dependent on circulation conditions, such as dust transport. Relevant references:

①Kara G T, Elbir T. (2025). *Atmospheric Research*, 325: 108233.

This study compares hourly ERA5 and MERRA-2 data over Turkey using 14 years of observations, showing that ERA5 outperforms MERRA-2 in simulating near-surface temperature, pressure, and humidity — indicating better representation of regional dynamic and thermodynamic structures.

②Hou C, Huang D, Xu H, et al. (2023). *Theoretical and Applied Climatology*, 151(1): 801–816.

Despite overestimating precipitation, ERA5 accurately captures the spatial patterns and long-term warming trends of temperature over northern China's desert regions, highlighting its strength in depicting large-scale thermal fields.

③Sun Y, Yang F, Liu M, et al. (2023). *Atmospheric Research*, 285: 106664.

Using radiosonde data, this work shows that ERA5's weighted mean temperature over China is significantly more accurate than MERRA-2, reflecting its superior ability to represent vertical profiles of temperature and humidity — key components of atmospheric thermal structure.

(3) Similar daily mean meteorological fields in the studied case

We evaluated the daily mean meteorological fields during the specific dust event, and found that differences between ERA5 and MERRA-2 were small, with both able to reasonably reproduce the synoptic situation (figure 1). Under this condition, we selected ERA5 for its higher resolution and superior performance in representing large-scale circulation.

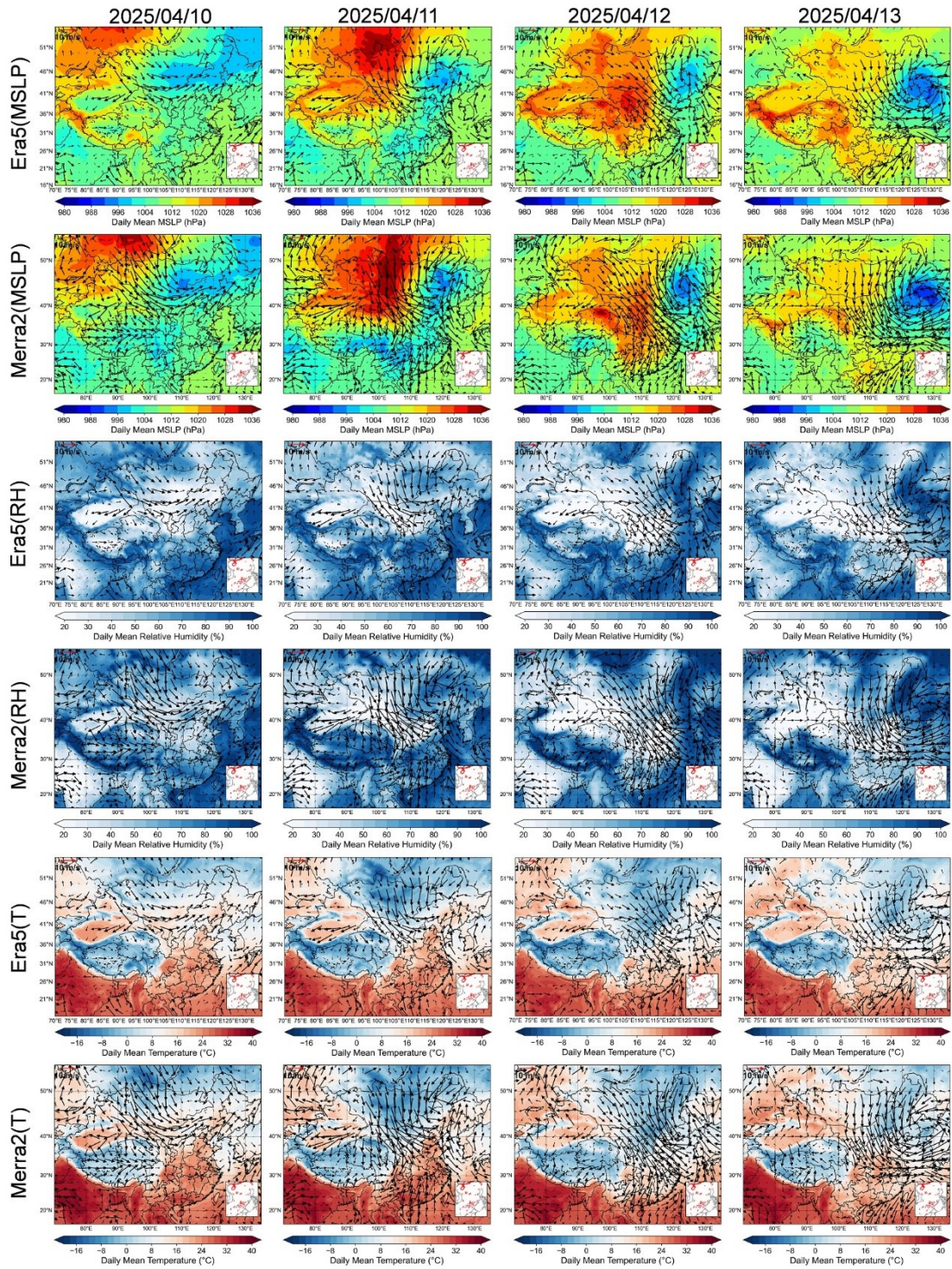


Figure 1. Spatiotemporal variations of daily mean temperature ($^{\circ}\text{C}$), mean sea level pressure (MSLP, unit: hPa), relative humidity (%), and wind fields over China from ERA5 and MERRA-2 during 10–13 April 2025 (Beijing Time, BJT).

- Figure 2: Why is the coverage of MODIS AOD so sparse in the China region? The data shown in the figure makes it difficult to distinguish between PM10 and AOD. Please change "scatter plot represents PM10 concentration" to "solid circles represent PM10 concentration".

We thank the reviewer for pointing out this issue. Regarding the sparse coverage of MODIS AOD in the China region, this is consistent with the limitations of passive

satellite remote sensing noted by Jia et al. (2021, Nature Communications): under conditions of cloud cover, high surface reflectance, or complex terrain, AOD retrieval success decreases, and quality control filters out low-confidence pixels, leading to reduced data density. Concerning the difficulty in distinguishing between PM₁₀ and AOD in the figure, we have revised the label from “scatter plot represents PM₁₀ concentration” to “solid circles represent PM₁₀ concentration”, so that PM₁₀ is now clearly differentiated from the AOD data points.

We have revised the figure captions.

3. Figures 2: Please explain that the wind speed scale is located in the upper right corner of each subplot, and explain what the small inset in the lower right corner represents.

We have revised the caption of Figure 2 as suggested. The caption now states that the wind speed scale is located in the upper right corner of each subplot, and it describes the meaning of the small inset in the lower right corner.

4. Line 121 and Figure 3: If the PM₁₀ and PM_{2.5} concentrations in the WIM region remain around 100 $\mu\text{g}/\text{m}^3$ and 20 $\mu\text{g}/\text{m}^3$, respectively (Figure 3), then why is the ratio of PM_{2.5} to PM₁₀ 0.3 instead of 0.2?

We thank the reviewer for the careful identification of this issue. The value of 0.3 was a rough estimate based on the trend line; it is not precise in itself and, indeed, is numerically inconsistent with the PM₁₀ ($\sim 100 \mu\text{g}/\text{m}^3$) and PM_{2.5} ($\sim 20 \mu\text{g}/\text{m}^3$) concentrations given in the text, which could easily mislead readers. Therefore, we have revised the relevant statement in the main text, removing the inaccurate ratio and correcting it to describe its decreasing trend over time (lines 137–139).

5. Line 122 and Figure 3: Figure 3 shows that the dust storm began in the WIM region at 10:00 on April 11th, not at 17:00 as stated in line 122. In fact, the dust storm reached its peak at 17:00 at the WIM source region.

Figure 3 shows that the dust storm started in the WIM region at 10:00 Beijing Time on 11 April, and reached its peak in the WIM source region at 17:00. We have corrected the time in line 122 from 17:00 to 10:00 in the revised manuscript to accurately reflect the onset time of the dust storm (line 138).

6. Line 126-127: Figure 4 does not show AOD values exceeding 2 in WIM.

We have revised it as follows:

“On April 12, the dust reached the Yangtze River Basin, where the PM₁₀ concentration exceeded 1000 $\mu\text{g}/\text{m}^3$ and the ratio of PM_{2.5} to PM₁₀ dropped below 0.2 (Figure 4). Meanwhile, the AOD in WIM exceeded 2 (Figure 2).”

This revision ensures that the statement regarding AOD > 2 corresponds correctly to the spatial coverage in Figure 2, avoiding any confusion in the figure references (line 144).

7. Line 246-249: Please delete these two sentences, as they do not provide any necessary information.

We have deleted the two sentences in lines 246–249.

8. Line 275: What does “both” refer to?

The word “both” was inadvertently retained during the revision and led to ambiguous reference. We have removed it in the revised manuscript (line 292).

9. Figure 9: Please specify the geographical coverage in the caption.

We have specified the geographical coverage in the caption of Figure 9 as suggested (line 312).

10. Figure 10: Please specify the geographical coverage for “western Inner Mongolia” in the caption.

We have specified the geographical coverage for “western Inner Mongolia” in the caption of Figure 10 as suggested (lines 316–318).

11. Line 312-314: Please rephrase this sentence.

We thank the reviewer for the suggestion. We have rephrased it to improve clarity and logical flow. The revised text now reads:

“During the April 2025 dust event, a rainbelt was present over eastern China. However, because dust aerosols consistently remained behind the rainbelt, and thus their southward transport was not largely affected by wet scavenging. As a result, the dust storm was able to reach the far south of China, primarily owing to favorable meteorological conditions, namely strong and persistent northerly winds that enhanced both dust emission and long-range transport, combined with limited wet removal by precipitation.” (lines 330–334)

12. Figure 11: Please change “scatter plots” to be “filled circles”.

We have already made the revisions.

Technique correction:

Figure 1: change “WIM” to “Western Inner Mongolia (WIM)” and change “western Inner Mongolia” to “WIM”.

We have already made the necessary technical modifications.

Line 271-272: Change “to compare” to “we compare”.

We have corrected this issue.