Dear reviewer,

We appreciate your insightful comments and constructive suggestions. We have incorporated these suggestions in the revised manuscript. Key modifications include:

(1) Adding the cyclone-controlled sensitivity experiments to quantify the contribution of extratropical cyclones on wind speed and dust emission.
(2) Further validating the simulated dust emission from a spatiotemporal perspective based on station observational datasets.
(3) Expanding the discussion to include dust-initiating wind sources other than cyclones and the impact of non-photosynthetic vegetation on dust generation.

The line numbers refer to the clean version of the revised manuscript. We hope these modifications have strengthened our manuscript.

Yiting and Yan on behalf of all authors

Reviewers' comments:

Reviewer #1 (Comments for the Author):

This manuscript by Yiting Wang et al. present a solid and well-documented investigation into the decadal variability of springtime dust emissions across East Asia and North America, emphasizing the role of extratropical cyclone regimes. The authors combine multi-source observations and modeling to bridge the gap between regional and synoptic-scale processes. The topic is timely and of high relevance to the atmospheric and climate research community. I believe it is well-suited for publication in ACP, pending clarification and some revisions on several methodological and interpretative aspects for potential improvements.

General comments

In the data validation section, only the trend consistency between the simulation results and the observed data is compared, and no quantitative validation indicators (such as correlation coefficient, root mean square error, etc.) are provided. Supplementing these quantitative indicators can more intuitively reflect the simulation accuracy of the model.

Reply: Thank you for your valuable suggestions regarding the validation of the simulation datasets. In the revised manuscript, we have evaluated the temporal and spatial consistency of the simulated dust emissions using station observational datasets (Fig. 1), and provided correlation coefficients and significance tests to quantify the model's performance (Fig. 2, 3).

"To assess the reliability of the off-line dust emission model over East Asia and North America during April and May, spatial distributions and temporal correlations between simulated dust emissions and ground-based observations of dust abundance over the past four decades are evaluated (Fig. 1). The simulated dust emission patterns geographically align with ground-observed dust abundance for both regions and seasons (Fig. 1a-d). Statistically significant positive correlations are widely obtained across both regions, especially over areas close to the dust sources (Fig. 1e-h). These results indicate that this model successfully captures the spatial and temporal patterns of observed dustiness." (lines 238-245)

"The East Asian dust emission in April shifts from a rising to declining trend after the onset of the 21st century, with a significant (p-values < 0.05, based on the Mann-Kendall trend test) reduction of 9.37 Tg

month^{-1} decade^{-1} or 16.5% per two decades from 2000 to 2021 (Fig. 2e). Consistent with this simulated decrease in April dust emission in 2000-2021, the observation dataset shows a significant (p-values < 0.001) positive correlation with the simulations, with a correlation coefficient (r) of 0.79 (Fig. 2a). Meanwhile, regional dust emission in North America shows a reversed multidecadal trend, with a significant (p-values < 0.05) increase of 0.406 Tg month^{-1} decade^{-1} or 23.4% per four decades in April during the period 1980-2021 (Fig. 3c). This increase is corroborated by a significant positive correlation (r = 0.79, p-values < 0.001) with surface fine dust concentrations from 1988 to 2021 (Fig. 3a). However, this increase is followed by a decrease in the regional total dust emissions by 0.235 Tg month^{-1} decade^{-1} or 2.52% per two decades in April for the period 2000-2021, which is also significantly positively correlated (r = 0.76, p-values < 0.001) with station-observed data (Fig. 3a, e)." (lines 281-293)

The authors attribute the May dust emission increase to longer-lasting strong winds, but the respective contributions of cyclone-induced and non-cyclone winds are not quantitatively separated. A more explicit comparison between Figures 7 and 9 could clarify how much of the wind-driven dust increase is attributable to cyclone activity.

Reply: Thank you very much for your valuable suggestions on the quantification of extratropical cyclones (ECs) contribution! We have added a cyclone-controlled experiments to clarify the effect of ECs on dust emission across East Asia and North America.

The cyclone-controlled sensitivity experiments are introduced as:
"In addition, to analyze the specific contribution of ECs, we perform an additional cyclone-controlled experiment in which cyclone-affected wind speeds (section 2.5) are replaced with climatological surface wind speed. This approach allows direct quantification of the contribution of ECs to near-surface wind variability and, consequently, its effect on springtime dust emission." (lines 270-273)

The quantification of ECs' contribution on dust emission is outlined in Abstract:
"*Specifically, ECs are responsible for 60-70% of the April-May total dust emissions in East Asia and 30-40% of that in North America; meanwhile, ECs explain a larger portion of the decadal variations in April dust emission from East Asia (up to ~80%), compared with May and from North America."* (lines 25-28)

And discussed in detail in Section 3.3:
"Such wind speed changes associated with the regime shift in ECs have been largely responsible for the decadal variations in dust emissions from these two mid-latitude sources, with generally stronger influences across East Asia than North America (Figs. 8 and 10). According to our cyclone-controlled experiments, ECs account for 60.3% and 38.7% of April dust emissions in East Asia and North America, respectively, and 70.6% and 31.5% of May dust emissions in these two regions during 1980-2021. Similarly, during 2000-2021, ECs contribute to 60.1% and 42.6% of April dust emissions in East Asia and North America, respectively, and 61.9% and 32.5% of May dust emissions in these regions (Fig. 10). The generally lower contribution of ECs to North American dust emission is consistent with the weaker modulation of ECs on the frequency and duration of strong wind (Fig. 8a-d).

Based on the cyclone-controlled sensitivity experiments (section 2.7), we further quantify the influence of extratropical cyclones on the decadal variability of dust emissions in April and May. After constraining the cyclone-affected wind speed to its climatological state, the decadal variability of dust emissions shows substantial changes, accompanied by a shift in the dominant environmental drivers (Fig. 11). Specifically, the magnitude of dust emission changes across both East Asia and North America is markedly reduced over the past two to four decades. The increase in East Asian dust emissions over 1980-2021 declines from 5.18 Tg to 1.08 Tg in April, representing a reduction of 79.2% (Figs. 4a, 11a). Similarly, in North America, the April dust emission increment over same period is reduced from 0.978 Tg to 0.179 Tg, corresponding to a reduction of 81.7% (Figs. 4e, 11e). In May of these four decades, nudging the cyclone-affected strong winds *to their climatology leads to a reduction of 31.3% and 37.8% in the decadal changes of East Asian and North American dust emission. During 2000-2021, such contribution of ECs to dust emission shrinks to 62.7% and 58.4% for East Asia in April and May and becomes negligible for North America in both months.*

Apart from that, the dominant environmental drivers of dust emission also shift when cyclone-affected wind speeds are removed. For instance, soil moisture emerges as the primary positive contributor, accounting for 6.17% of the East Asian dust emission increase in April during 1980-2021, while the total dust emission increased by only 6.44% in the cyclone-controlled experiments (Fig. 11a). By contrast, the contribution of wind speed to dust emissions is reduced to merely 0.62% after cyclone-affected winds are constrained (Fig. 11a). Naturally, such shift in the dominant environmental drivers of dust emission is muted during 2000-2021, especially in North America, when and where ECs contribute negligibly to the decadal variations in dust emission." (lines 468-501)

Through sensitivity experiments and LAI trend analysis, this study demonstrates that "the interdecadal changes in vegetation cover contribute minimally to dust emission," and the conclusion is reliable. However, it is important to note that this conclusion only focuses on "the contribution of vegetation changes." In contrast, the background sand-fixing effect of vegetation itself (such as the continuous inhibitory effect of stable vegetation cover on dust) falls under the category of "absolute contribution," which has not been directly quantified by the current experimental design. It is recommended to supplement some explanations in the discussion section

Reply: Thank you for raising the vegetation and surface temperature issue. In the revised manuscript, we have discussed the contribution of non-photosynthetic vegetation on dust emission:

"At the same time, non-photosynthetic vegetation present in spring over arid and semi-arid regions, such as senescent plants and crop residues, can exert a persistent suppressive effect on dust emission by modifying surface roughness and soil exposure, thereby providing a form of absolute but relatively stable constraint on dust emission (Huang and Foroutan, 2022)." (lines 570-574)

The study clearly identifies the significant impact of extratropical cyclones on near-surface strong winds but fails to elaborate on how cyclone regime shifts specifically regulate the frequency and duration of local strong winds. It is recommended to supplement the analysis of correlations between key cyclone parameters (e.g., central pressure gradient, vorticity distribution, and interaction between influence range and local topography) and near-surface wind fields to enhance the physical logic coherence of cyclone changes, strong wind variations, and dust emission changes.

Reply: Thank you for your constructive issue. We have analyzed the cyclone characteristics provided by the Cyclone TRACKing framework (CyTRACK, section 2.5), including central pressure and radius of extratropical cyclone. We take your advice and add the connection between EC characteristics and surface wind:

"*Furthermore, the spatiotemporal variations in wind speed are closely connected to characteristics of ECs in East Asia and North America in both April and May. According to the compilation of all cyclone events across both regions and in both months, the maximum surface wind speed within the cyclone radius shows a significant positive correlation with the central pressure and radius of ECs from 1980 to 2021 (p-values < 0.001). Next, we explore the decadal variations in wind attributable to EC characteristics.*" (lines 402-407)