

Responses to Anonymous Referee #2

This study investigates the interannual relationship between East Asian dust loading and the North Pacific storm track during boreal spring. Using reanalysis, the authors find that enhanced dust loading is associated with increased shortwave absorption and tropospheric warming, accompanied by an anticyclonic circulation anomaly over the North Pacific and a poleward displacement of the storm track. WRF-Chem sensitivity experiments for spring 2018 provide additional support for the proposed radiative and dynamical mechanism.

Overall, I find the idea interesting and potentially important. The study provides insights into the climate effects of springtime dust aerosols and complements a broader literature that has focused more heavily on anthropogenic aerosols and wintertime storm-track responses. The manuscript is generally well organized. Nevertheless, I have several major concerns that I hope the authors will consider in revising the study.

Responses: We greatly appreciate these comments and suggestions. The manuscript has been improved by considering these comments and suggestions. Our detailed responses are given point by point below in blue. The revised text is highlighted in red.

General comments:

1. I think the springtime focus deserves stronger motivation in the Introduction. Spring storm track variability is less frequently discussed than its wintertime counterpart but can have important downstream impacts over North America. The authors could elaborate on these implications, including potential connections to deep stratosphere-to-troposphere ozone intrusions (Breedon, M. L., Butler, A. H., Albers, J. R., Sprenger, M., and Langford, A. O.: The spring transition of the North Pacific jet and its relation to deep stratosphere-to-troposphere mass transport over western North America, *Atmos. Chem. Phys.*, 2021). It may also be useful to quantify the relative importance of dust versus other aerosol species over East Asia across seasons. For example, showing the seasonal contribution of dust to total aerosol optical depth or aerosol radiative forcing could help demonstrate why spring represents a distinct regime for aerosol-storm track interactions. Finally, I encourage the authors to demonstrate more directly why the diagnosed poleward storm track displacement matters for

downstream climate. A reanalysis-based analysis of the associated circulation, temperature, precipitation, or other weather impacts over North America would make the broader significance clearer to readers.

Responses: We thank the reviewer for this comment. We agree that the springtime focus was not sufficiently motivated in the original manuscript, and we have revised the Introduction and the Discussion accordingly.

In the first paragraph of the Introduction, we now explain why spring is a distinct season for the North Pacific storm track. Spring is when the storm track undergoes its most rapid meridional migration of the annual cycle, and the storm track configuration during this transition controls the frequency of deep stratosphere-to-troposphere mass transport over western North America (Lin et al., 2015; Breeden et al., 2021). We also note that spring storm track variability has received far less attention than its wintertime counterpart. We are grateful for the Breeden et al. (2021) reference, which fits our argument well.

We revised the paragraph in **Section 1 (Lines 33–40)** as follows: *“Through this transport, it heavily influences regional weather patterns and midlatitude extreme events, including severe winds and heavy precipitation over both the North Pacific and western North America (Salathé Jr., 2006; Pfahl et al., 2014; Chemke and Yuval, 2026). Spring is particularly important because the North Pacific storm track undergoes its most rapid meridional migration of the annual cycle (Hoskins and Hodges, 2019), and the storm track configuration during this transition governs the frequency of deep stratosphere-to-troposphere mass transport over western North America (Lin et al., 2015; Breeden et al., 2021). Yet springtime storm track variability has nonetheless received far less attention than its wintertime counterpart. Therefore, it is essential to understand its variability, particularly in spring, for regional weather forecasting and climate prediction (Shaw et al., 2016).”*

On the relative importance of dust, we have added a quantitative statement to the second paragraph. Dust accounts for more than 50% of the total aerosol column mass over the North Pacific in spring, the highest fraction among the four seasons (Hu et al., 2019). This supports our treatment of spring as a distinct aerosol regime and provides a clearer basis for the contrast with wintertime anthropogenic aerosols discussed later in the

Introduction.

Revised text (Section 1, Lines 42–45): *“East Asia is one of the world’s major source regions of mineral dust aerosols (Kok et al., 2023). Every spring, intense dust plumes originate from the Taklimakan and Gobi Deserts and are transported eastward by mid-latitude westerlies, forming an extensive aerosol belt over the North Pacific (Huang et al., 2014; Yu et al., 2019). Dust accounts for more than 50% of the total aerosol column mass over the North Pacific in spring, the highest fraction among the four seasons (Hu et al., 2019).”*

On the downstream significance, we agree that this question matters. A full assessment of the North American response would require a separate analysis of circulation, temperature, and precipitation, which we feel lies outside the scope of the present study. We have instead extended the second paragraph of Section 4 to review the documented consequences of a poleward storm track shift, covering the redistribution of moisture transport and precipitation over the western United States (Salathé Jr., 2006; Chemke and Yuval, 2026) and the modulation of deep stratospheric intrusions in spring (Lin et al., 2015; Breeden et al., 2021). We state explicitly that assessing these consequences is beyond the scope of this work, while noting that springtime dust variability deserves attention in regional climate assessments. We hope this conveys the broader relevance of our findings without diluting the focus on the dust storm track mechanism.

Revised paragraph (Section 4, Lines 371–383): *“In contrast, our findings highlight that interannual variations in springtime dust aerosols mainly alter the latitudinal position of the storm track via aerosol-radiation interactions, a response attributable to the direct radiative heating of the dust layer. Because mid-latitude transient eddies transport heat, moisture, and momentum poleward (Shaw et al., 2016; Tamarin-Brodsky and Kaspi, 2017; Hoskins and Hodges, 2019), a shift in the storm track position redistributes these fluxes and carries consequences well beyond the North Pacific. The enhanced transient meridional heat flux near the Bering Sea (Figure 3b) may accelerate springtime Arctic sea ice melting and trigger subsequent climate feedbacks (Overland and Pease, 1982; Huang et al., 2019; Peng et al., 2021). Downstream over North America, a poleward shift redirects the landfall of moisture transport and has been linked to drier conditions over the southwestern United States and wetter conditions along the higher latitude coast (Salathé Jr., 2006; Chemke and*

Yuval, 2026). The storm track position also regulates the frequency of deep tropopause folds that bring stratospheric ozone into the lower troposphere over western North America, an effect that peaks in spring (Lin et al., 2015; Breeden et al., 2021). Assessing these consequences requires dedicated analysis beyond the scope of the present study, but they indicate that springtime dust variability, including its interannual component, deserves attention in regional climate assessments.”

2. Some expressions throughout the manuscript could be revised to more precisely convey the scope and novelty of the study. Aerosol influences on storm tracks are already a relatively crowded topic, so I think it is particularly important to distinguish the present study from work on long-term trends, anthropogenic aerosol forcing, and wintertime responses. For example, the interannual focus is also not immediately apparent in the current title.

Responses: We thank the reviewer for raising this point. We agree that the scope of the study was not stated precisely enough, and we have revised the manuscript to make the interannual focus explicit and to separate our work more clearly from studies of long-term trends, anthropogenic forcing, and wintertime responses.

The title has been revised to *"Springtime East Asian dust heating contributes to interannual poleward shift of the North Pacific storm track"*. The new title makes the interannual focus explicit. We have also replaced "driven by" with "contributes to", since our correlation analysis indicates that interannual dust variability accounts for roughly 15% to 22% of the variance in the storm track position, and we do not wish to imply that dust is the dominant control.

To further emphasize this interannual perspective, we have also revised the abstract to highlight the study's focus on year-to-year variability rather than long-term trends. The specific revisions are as follows:

Revised Abstract (Lines 12–14): *“The North Pacific storm track plays a key role in shaping climate across the Arctic and western North America by modulating precipitation and temperature, yet its interannual sensitivity to springtime East Asian dust remains poorly understood.” “*

Revised Abstract (Lines 21–23): *These findings indicate that natural dust aerosols can modulate large-scale North Pacific atmospheric dynamics on interannual timescales and suggest that springtime dust variability should be considered in regional climate assessments.”*

In the Introduction, we now note at the end of the third paragraph that earlier assessments of aerosol effects on the North Pacific storm track have mainly addressed the response to long-term emission changes, while the response to year-to-year aerosol variability remains unclear. This, together with the seasonal contrast already discussed in that paragraph, defines the gap that our study addresses. We have added the following text in **Section 1 (Lines 67–69)**: *“Moreover, previous assessments of aerosol effects on the North Pacific storm track have largely addressed the response to long-term emission changes, whereas the response to year-to-year aerosol variability remains unclear.”*

In **Section 3.1**, we have expanded the sentence explaining our focus on interannual variability. We have added this sentence at **Lines 208–210** in our revised manuscript: *“The interdecadal component is therefore removed (Section 2.2), so that the storm track response discussed below reflects year-to-year dust variations rather than the long-term change in dust loading”*

In the Discussion, we have added the missing qualifiers when contrasting our results with earlier work. The previous studies are now identified as concerning long-term changes in anthropogenic emissions and the wintertime storm track, whereas our result is described as the response to interannual variations in springtime dust loading. We hope these revisions make the distinct scope of the study clear to readers.

Revised sentence (Section 4, Lines 369–371): *“Previous studies have shown that long-term changes in East Asian anthropogenic emissions predominantly intensify the wintertime storm track through aerosol-cloud interactions and associated latent heat release (Zhang et al., 2007; Wang et al., 2014b).”*

Revised sentence (Section 4, Lines 371–373): *“In contrast, our findings highlight that interannual variations in springtime dust aerosols mainly alter the latitudinal position of the storm track via aerosol-radiation interactions, a response attributable to the*

direct radiative heating of the dust layer.”

3. I suggest that the authors soften some of the statements regarding causality inferred from the WRF-Chem sensitivity experiments. As the authors acknowledge, the experiments are performed for a single year (2018), whereas the primary results concern interannual variability. The experiments therefore provide useful process-level evidence, but they cannot establish that dust forcing is the dominant cause of the observed interannual relationship. In particular, I do not think the current analysis fully rules out the possibility that large-scale atmospheric circulation anomalies simultaneously influence dust emission/transport and the North Pacific storm track. Such circulation variability could therefore contribute to, or potentially confound, the statistical relationship between dust loading and storm track position. I recommend additional analyses using the reanalysis to characterize this relationship. For example, the authors could define an index describing the meridional position of the North Pacific storm track and examine its relationship with EADI and/or dust PC1.

Responses: We thank the reviewer for this thoughtful comment and agree with all three points.

The causal statements based on the WRF-Chem experiments have been softened throughout the manuscript. Section 2.3 now states at the outset that the simulations test whether dust radiative heating alone can reproduce the pathway inferred from the reanalysis, and that a single-year experiment cannot reproduce the interannual relationship or determine whether dust is its dominant cause. **Section 3.3** has been retitled "*Process-level verification of the proposed mechanism with WRF-Chem sensitivity experiments*". Expressions such as "causal evidence" and "sufficient to drive" have been replaced in Section 3.3, the Abstract and the Conclusions. To keep the focus on the mechanism, the evaluation of the CTRL simulation (former Figure 7) and the heating rate profiles (former Figure 9) have been moved to the Supplement (Figures S7 and S8), and the corresponding text has been shortened.

Revised text (Abstract, Lines 16–23): "*It is revealed that shortwave absorption by the trans-Pacific dust plume coincides with warming in the 850–400 hPa layer and an anomalous anticyclonic circulation over the North Pacific. This thermal perturbation restructures the meridional temperature gradient and shifts the zone of maximum Eady*

growth rate poleward, thereby relocating the preferred region for baroclinic eddy development to higher latitudes. The Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) sensitivity experiments *reproduce the spatial pattern of the storm track response, supporting the proposed radiative–dynamical pathway.*”

Revised text (Section 2.3, Lines 165–176): “We design two sets of simulations to *test whether dust radiative heating alone can reproduce the physical pathway inferred from the reanalysis. The control experiment (CTRL) incorporates full dust emissions. In contrast, the sensitivity experiment (NoDust) completely disables dust emissions. We attribute the atmospheric differences between the CTRL and NoDust simulations directly to the effects of dust aerosols. We select the year 2018 as our study period because the East Asian dust loading during this year significantly exceeded the climatological mean (Figure 2b). To enhance the statistical robustness of our results, we conduct seven ensemble members for each experiment. These ensemble members are initialized one day apart from 19 to 25 February 2018. All simulations conclude on 31 May 2018. We treat February as the model spin-up period and exclude it from the final analysis. Consequently, our analysis focuses strictly on the boreal spring season from March to May 2018. Because the experiments cover a single spring, they cannot reproduce the interannual relationship diagnosed from the reanalysis or determine whether dust is its dominant cause. They are instead designed as a process-level verification of the proposed mechanism. Since the two experiments share identical meteorological initial and boundary conditions, their difference isolates the dust effect from concurrent circulation variability.*”

Revised title of Section 3.2 (Lines 350): “*Possible radiative–dynamical mechanism linking dust aerosol and the storm tracks*”

Revised title of Section 3.3 (Lines 328): “*Process-level verification of the proposed mechanism with WRF-Chem sensitivity experiments*”

Revised paragraph (Section 3.3, Lines 329–332): “*To test the pathway inferred above, we compare the CTRL and NoDust ensemble simulations for spring 2018. The CTRL experiment reasonably reproduces the observed spring circulation at 500 hPa, the trans-Pacific transport pathway of the dust plume, and the spatial patterns of both storm track metrics (Figure S7). The model is therefore suitable for examining the*

process-level response of the storm track to dust radiative forcing.”

Revised paragraph (Section 3.3, Lines 334–340): *“The simulated responses are consistent with the pathway inferred from the reanalysis. Dust radiative forcing produces a pronounced warming in the mid-troposphere (850 to 400 hPa) over the North Pacific, accompanied by an anomalous anticyclonic circulation at 500 hPa (Figure 7c). The spatial pattern of this warming closely follows the simulated dust AOD. The heating modifies the atmospheric baroclinicity, so that the EGR at 700 hPa increases on the northern flank of the climatological storm track and decreases on the southern flank (Figure 7d). Correspondingly, both $Z'Z'_{300}$ and $V'T'_{850}$ shift poleward (Figures 7a and 7b). These results indicate that dust radiative heating alone can shift the North Pacific storm track poleward, which supports the physical pathway inferred from the reanalysis.”*

Revised paragraph (Section 3.3, Lines 347–350): *“The heating rate budget averaged over the main warming region (150°E–150°W, 35°–53°N; blue dashed box in Figure 7c) further identifies the source of this warming (Figure S8). Shortwave radiation is the only positive heating term and peaks near 400 hPa, whereas longwave radiation and latent heating make weak negative contributions. The net heating profile therefore closely follows the shortwave term, indicating that the simulated warming arises mainly from dust shortwave absorption.”*

Revised text (Section 4, Lines 359–361): *“Model sensitivity experiments for spring 2018 reproduce the spatial pattern of this response, indicating that dust shortwave absorption alone can produce a poleward shift of the storm track.”*

Following the reviewer's suggestion, we have defined two storm track position indices from $Z'Z'_{300}$ and $V'T'_{850}$ as the difference between area-averaged anomalies on the poleward and equatorward flanks of the climatological storm track (Figure S3). Both indices are significantly correlated with the EADI and dust PC1, with correlation coefficients between 0.36 and 0.47. The EADI explains about 15% to 22% of the interannual variance in storm track position (r^2), and we now describe dust as one contributor among several rather than the dominant control. The high-dust spring of 2018 selected for the simulations is accompanied by a pronounced poleward displacement in both indices. These results are described at the end of Section 3.1.

Revised text (Section 3.1, Lines 235–241): *“To further quantify this relationship, we define storm track position indices as the difference in area-averaged $Z'Z'_{300}$ and $V'T'_{850}$ between a northern box and a southern box on the poleward and equatorward flanks of the climatological storm track (Figures S3a-b). Positive indices therefore denote a poleward displacement of the storm track. Both position indices covary with the interannual variations of the EADI and dust PC1 (Figure S3c), with correlation coefficients ranging from 0.36 to 0.47, all significant at the 95% confidence level. The EADI alone explains about 22% and 15% of the interannual variance in the $Z'Z'_{300}$ and $V'T'_{850}$ position indices, respectively. The remaining variance likely reflects internal atmospheric variability and other drivers, including large-scale circulation anomalies that may influence both dust emission and the storm track.”*

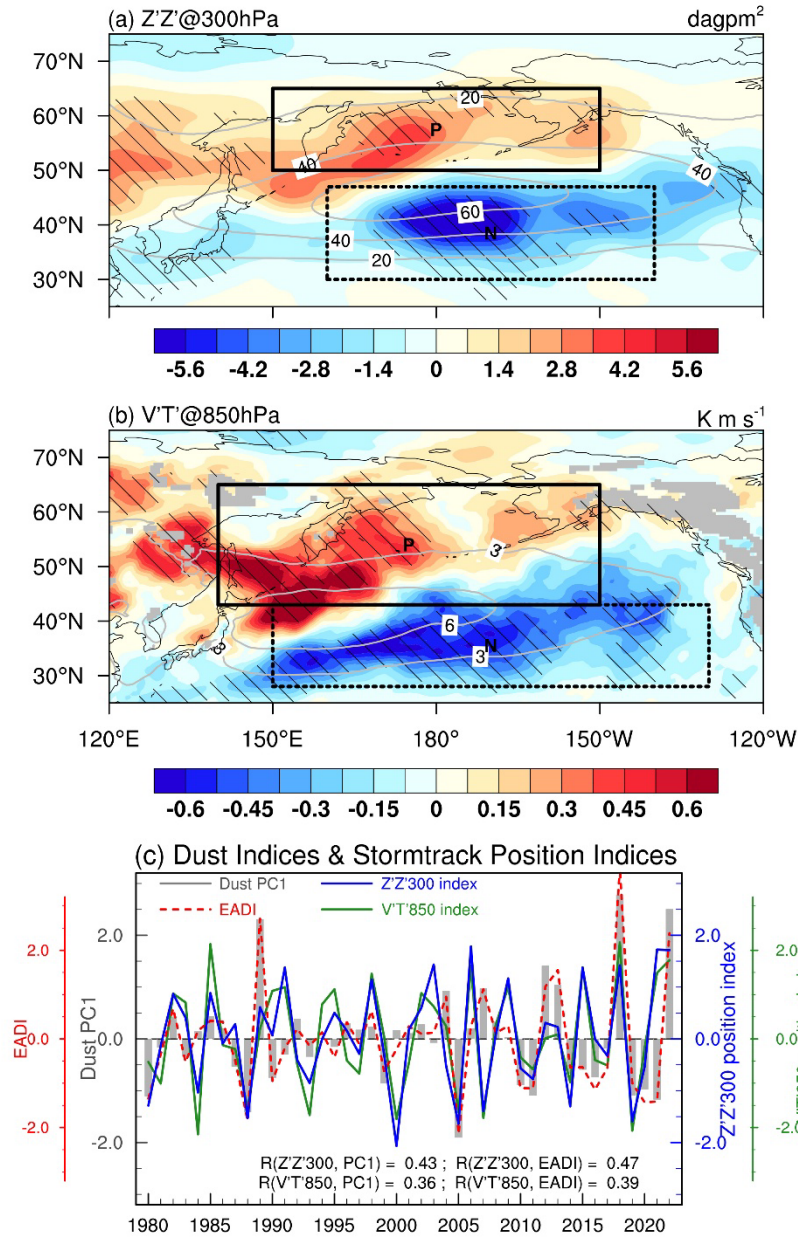


Figure S3. (a, b) Same as Figure 3, with the black solid (dashed) boxes denoting the northern (southern) regions used to define the storm track position indices. For (a) $Z'Z'_{300}$, the northern and southern boxes are 50° – 65°N , 150°E – 150°W and 30° – 47°N , 160°E – 140°W . For (b) $V'T'_{850}$, they are 43° – 65°N , 140°E – 150°W and 28° – 43°N , 150°E – 130°W . (c) Time series of the standardized interannual components of dust PC1 (grey bars), the EADI (red dashed line), and the $Z'Z'_{300}$ (blue line) and $V'T'_{850}$ (green line) position indices during 1980–2022. Each position index is defined as the area-averaged value over the northern box minus that over the southern box. The correlation coefficients between the storm track position indices and the dust indices are shown in (c).

We agree that large-scale circulation anomalies could influence dust emission and the storm track at the same time, and that this cannot be fully excluded with reanalysis data alone. Three steps partly address this concern. The ENSO signal is removed before the regression, and removing the NAO signal in addition leaves the dipole essentially unchanged (Figure S4). Regressing the storm track metrics onto an independent,

satellite-vegetation-based estimate of dust emission (Fu et al., 2026) reproduces the same dipole (Figure S5), which suggests that the signal is not simply an artefact of the transport circulation. In the WRF-Chem experiments, the CTRL and NoDust ensembles share identical meteorological initial and boundary conditions, so their difference isolates the dust effect from concurrent circulation variability. We now make these points in Sections 2.3 and 3.1 and state explicitly that a common driver cannot be excluded. Taken together, the reanalysis and the model results support dust radiative heating as a physically plausible contributor to the interannual storm track shift, rather than as its sole driver.

Added sentences (Section 2.1, Lines 99–105): *“We also use the satellite-vegetation-based estimate of East Asian spring dust emission from Fu et al. (2026) as an independent dust metric. It is derived from Global Inventory Modeling and Mapping Studies (GIMMS; 1982–2015) and MODIS (2001–2023) vegetation products, which agree closely over their overlap period. Regressions onto this emission index are performed for 1982–2022, the period covered by both datasets. Both the spring North Atlantic Oscillation (NAO) index and the preceding-winter (December to February) Oceanic Niño Index (ONI) are obtained from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center.”*

Added paragraph (Section 3.1, Lines 243–249): *“The relationship is robust to the choice of dust index and to the removal of other circulation modes. The dipole in Figure 3 is essentially unchanged when the concurrent spring NAO signal is removed in addition to ENSO (Figure S4). Regressing the storm track metrics onto the independent emission estimate of Fu et al. (2026) reproduces the same dipole with the same sign and location (Figure S5). Because dust emission is governed mainly by source-region surface wind and land surface conditions, this agreement suggests that the storm track signal is not simply an artefact of the circulation that transports dust across the Pacific. Source-region wind is nevertheless related to the large-scale circulation, so a common driver cannot be fully excluded with reanalysis data alone.”*

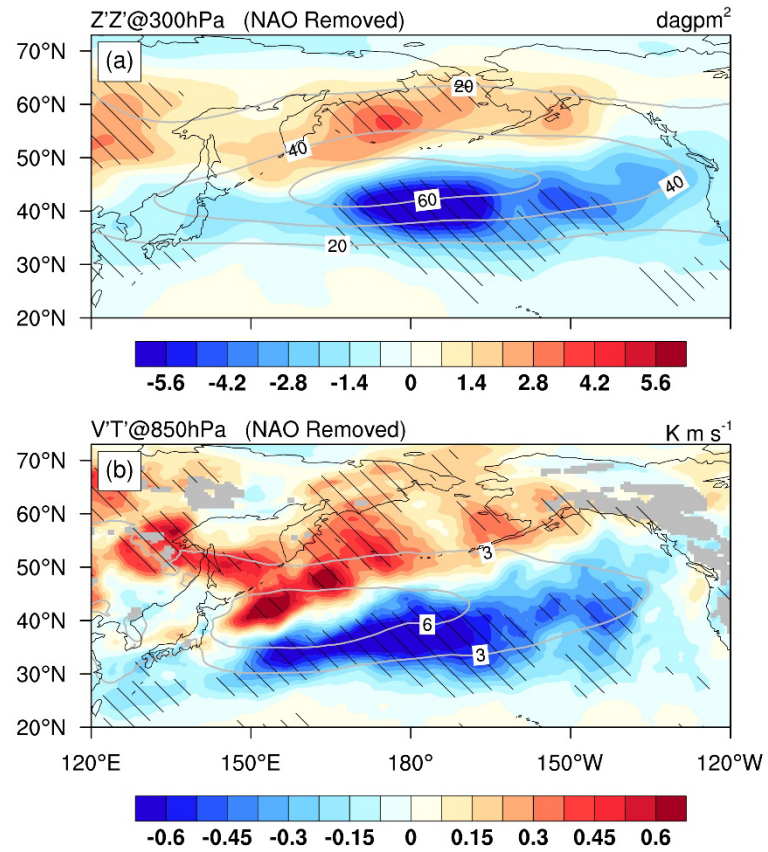


Figure S4. Same as Figure 3, but with the concurrent spring (MAM) NAO signal linearly removed from all variables before the regression. Grey contours denote the climatological spring mean of (a) $Z'Z'_{300}$ and (b) $V'T'_{850}$. Hatching denotes the anomalies statistically significant at the 95% confidence level based on the Student's t test.

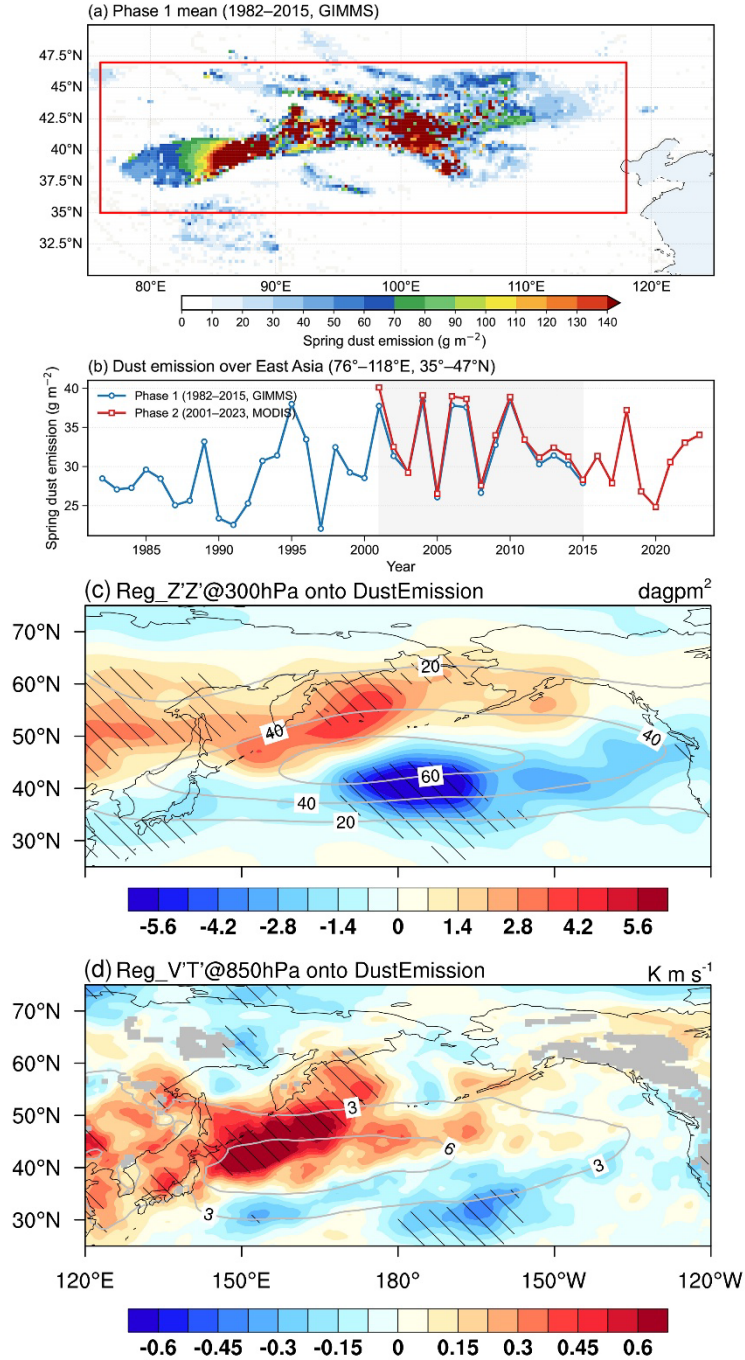


Figure S5. East Asian spring dust emission from Fu et al. (2026) and the associated storm-track anomalies. (a) Mean spring dust emission (g m^{-2}) for 1982–2015, derived from GIMMS vegetation data. The spatial distribution for 2001–2023 derived from MODIS data is similar and is not shown. The red box marks the EADI source region (35°–47° N, 76°–118° E). (b) Time series of spring dust emission averaged over the red box in (a). The blue line is based on GIMMS (1982–2015) and the red line on MODIS (2001–2023). Grey shading marks their overlap period (2001–2015). (c, d) Regressions of spring (MAM) (c) $Z'Z'_{300}$ (dagpm^2) and (d) $V'T'_{850}$ (K m s^{-1}) from MERRA-2 onto the standardized interannual component of the dust emission index for 1982–2023. The index is built from the GIMMS-based series for 1982–2000 and the MODIS-based series for 2001–2022. Grey contours show the climatology. Hatching marks regions significant at the 95 % confidence level.

Individual comments:

1. L13: remove “how”

Responses: Revised.

2. L46: lower case

Responses: Revised.

3. L100: please be more specific about the vertical wind shear. Is it zonal wind only or the full wind field? Which levels did you use to calculate EGR?

Responses: The vertical shear refers to the zonal wind only. N and the vertical wind shear are calculated from daily MERRA-2 data on 17 pressure levels from 1000 to 100 hPa. This information has been added to **Section 2.2, Lines 114–117** “where f is the Coriolis parameter; N is the Brunt-Väisälä frequency, and $\left| \frac{\partial U}{\partial z} \right|$ is the vertical shear of the zonal wind (Lindzen and Farrell, 1980). Both N and the vertical wind shear are calculated from daily MERRA-2 data using finite differences between adjacent pressure levels, based on 17 levels from 1000 to 100 hPa (1000, 950, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 200 and 100 hPa).”

4. L104: It appears both daily and monthly data are used. To which data did you apply the Fourier analysis exactly?

Responses: $Z'Z'_{300}$, $V'T'_{850}$ and EGR are first calculated from daily data and then averaged over spring. All other variables are spring averages of monthly means. The Fourier analysis is applied at each grid point to these spring-mean time series, which contain one value per year. We have clarified this in **Section 2.2, Lines 119–125**: “The MERRA-2 and CMAP data span the period from 1980 to 2022. $Z'Z'_{300}$, $V'T'_{850}$ and EGR are first calculated from daily data and then averaged over spring (March to May). All other variables are obtained by averaging monthly means over spring. This yields one value per year for every variable. To isolate interannual variability, Fourier analysis is applied at each grid point to these spring-mean time series. The first four harmonics, which represent fluctuations with periods longer than about 10 years, are defined as the interdecadal component. The residual after removing the time mean and

these harmonics is defined as the interannual component (Awan and Bae, 2016; Zhu et al., 2021). All quantities analysed below refer to interannual anomalies unless otherwise stated.”

5. Figure 2: please define the interannual and interdecadal components. How did you calculate them?

Responses: As explained in our response to the previous comment, the interdecadal component is the sum of the first four Fourier harmonics of the 43-year spring-mean series, corresponding to periods longer than about 10 years. The interannual component is the residual after removing the time mean and these harmonics. The definitions have been added to Section 2.2 and to the caption of Figure 2.

Added to the caption of Figure 2 (Section 3.1, Lines 215–216): *“The interdecadal component is the sum of the first four Fourier harmonics (periods longer than about 10 years), and the interannual component is the residual.”*

6. L186: dagpm^2

Responses: Revised.

7. L192: Why does a poleward shift of the storm track correspond to strengthened eddy heat transport? Isn't that a poleward shift as well in Figure 3b?

Responses: We thank the reviewer for this careful reading. The reviewer is correct. $V'T'_{850}$ shows a dipole similar to that of $Z'Z'_{300}$, with increased heat flux on the poleward flank and decreased flux on the equatorward flank, which indicates a poleward shift rather than an overall strengthening. The sentence (Section 3.1, Lines 226–228) has been revised to *“These results suggest that increased springtime East Asian dust loading is associated with a poleward shift of both the North Pacific storm track and its transient meridional heat transport on interannual timescales.”*

8. L367: There is a recent study that argues that dust absorption in East Asia is weaker than previously estimated: Yuan, Y., Wang, H., Wu, C. et al. Weaker absorption of Asian dust than previously estimated based on observation-constrained simulation. npj Clim Atmos Sci 9, 19 (2026).

Responses: Thank you for bringing this study to our attention. Yuan et al. (2026) showed that climate models using conventional refractive indices such as OPAC tend to overestimate the absorption of Asian dust. The dust refractive index in our WRF-Chem configuration follows Zhao et al. (2012) and is less absorptive than OPAC (Jin et al., 2016), so the dust heating in our experiments is unlikely to be overestimated for this reason. This point has become directly relevant to the revised Discussion. In response to Referee #1, we performed an additional pair of CESM2 experiments, which produce a storm track response about four to five times larger than WRF-Chem for a similar North Pacific dust burden. We now cite Yuan et al. (2026) in Section 4 to note that differences in dust optical properties are a likely contributor to this spread, and that the quantitative sensitivity of the storm track to dust therefore remains uncertain.

Revised paragraph (Section 4, Lines 398–410): *“The magnitude of the simulated response also differs considerably between models. A pair of CESM2 experiments with and without dust emission reproduces the same meridional dipole in both storm track metrics (Figure S9), but the response is about four to five times larger than in WRF-Chem for a similar North Pacific dust burden. Part of this spread likely arises from dust optical properties. Climate models using conventional refractive indices such as Optical Properties of Aerosols and Clouds (OPAC) tend to overestimate the absorption of Asian dust (Yuan et al., 2026), whereas the refractive index adopted in our WRF-Chem configuration (Zhao et al., 2012) is less absorptive (Jin et al., 2016). The two models may therefore bracket the true dust heating from opposite sides. After rescaling to a common dust burden, the amplitudes follow the order regression, CESM2 and WRF-Chem. The regression estimate should be regarded as an upper bound, because it may include circulation anomalies that covary with dust, and the response need not scale linearly between a single high-dust spring and a one-standard-deviation anomaly. Taken together, the reanalysis and the two models consistently support the radiative pathway, but the quantitative sensitivity of the storm track position to interannual dust variability remains uncertain by a factor of several. Constraining it will require multi-model, multi-year dust sensitivity experiments with observation-constrained dust optical properties, realistic aerosol mixing, and aerosol-cloud interactions.”*

References

Jin, Q., Yang, Z.-L., and Wei, J.: High sensitivity of Indian summer monsoon to Middle East dust absorptive properties, *Scientific Reports*, 6, 30690, 10.1038/srep30690, 2016.

Yuan, Y., Wang, H., Wu, C., Hu, T., Wu, F., Zhang, D., and Cao, J.: Weaker absorption of Asian dust than previously estimated based on observation-constrained simulation, *npj Climate and Atmospheric Science*, 9, 19, 10.1038/s41612-025-01290-8, 2026.

Zhao, C., Liu, X., and Leung, L. R.: Impact of the Desert dust on the summer monsoon system over Southwestern North America, *Atmos. Chem. Phys.*, 12, 3717-3731, 10.5194/acp-12-3717-2012, 2012.