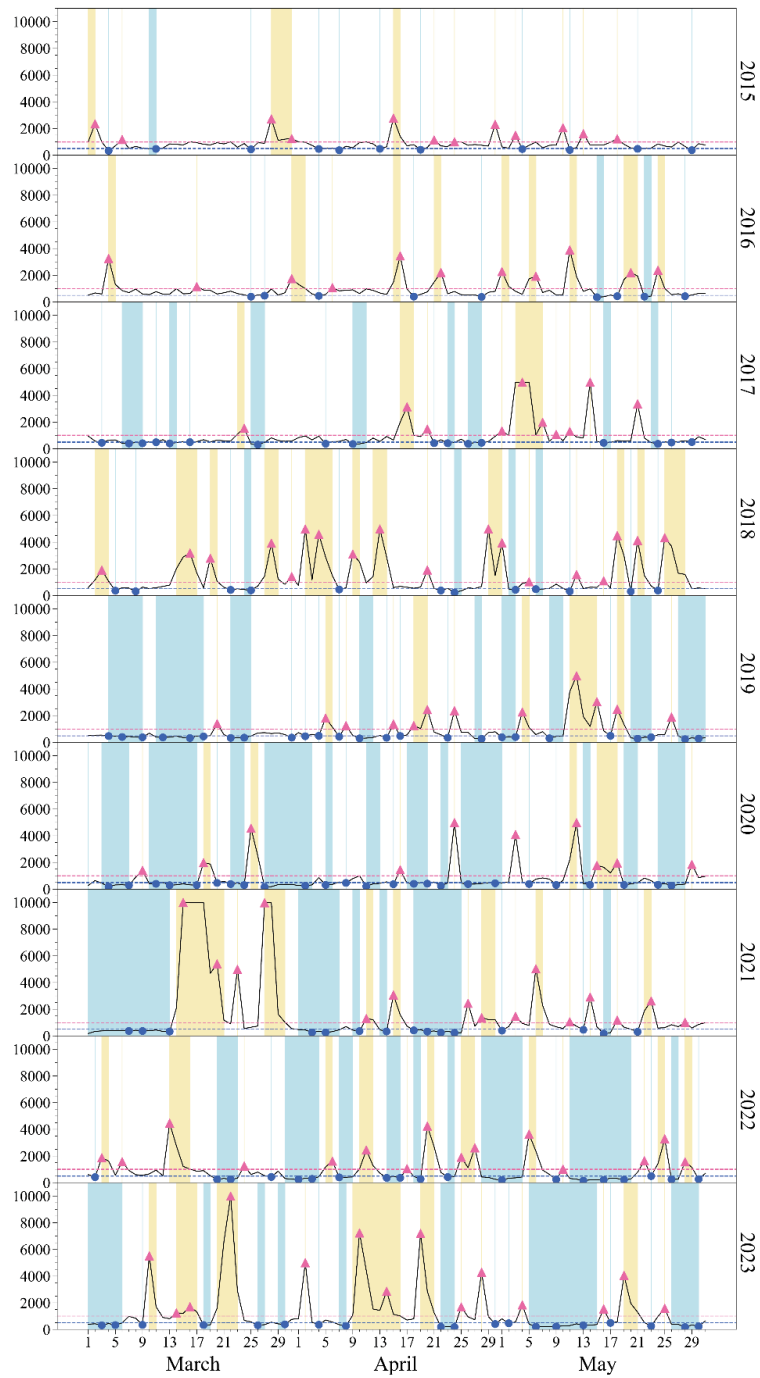**Figure S1.** (a) SLP (shading, units: hPa), SAT (contour, units: °C) and UV850 (vectors, units: m s^{-1}) on 14 March 2023. Panel (b) is the same as (a) but for 22 March 2023. (c) Composite SLP (shading, units: hPa) and SAT (contour, units: °C) during MC days. Panel (d) is the same as (c) but for CH days. The green boxes in panel (a)–(d) represent NC.

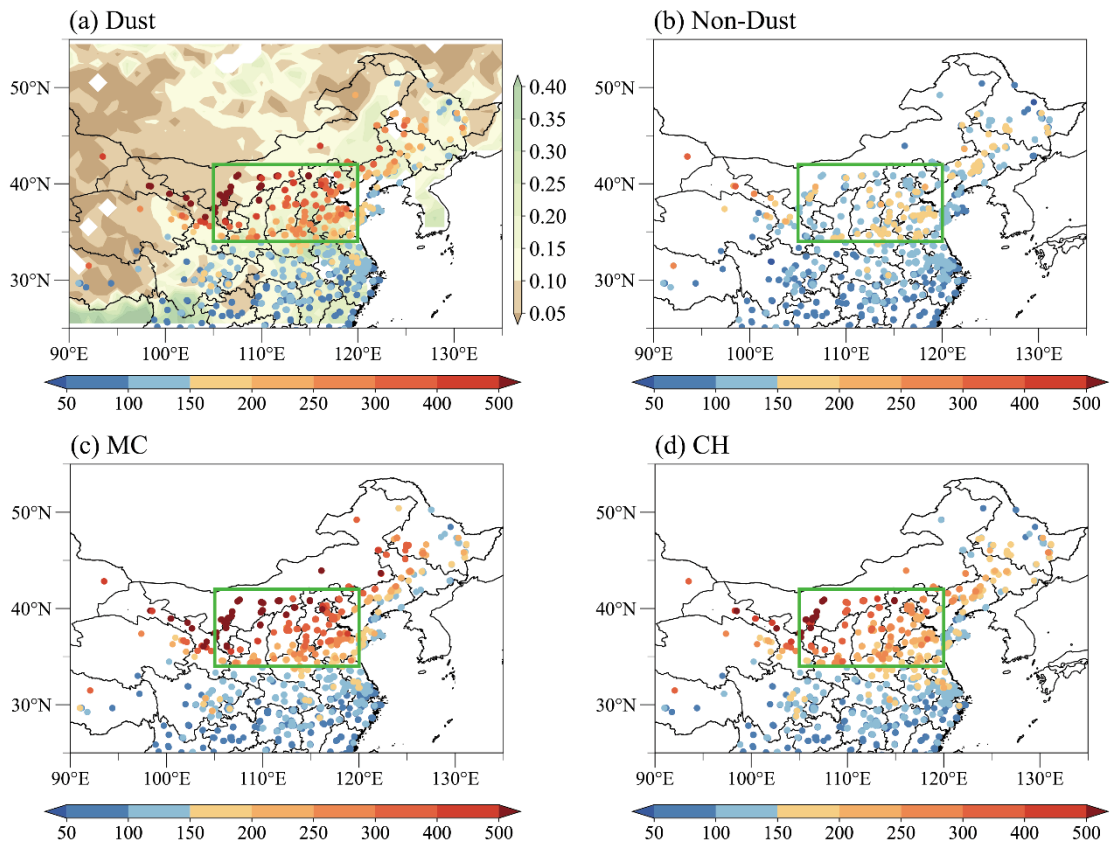**Figure S2.** Variations of observed daily maximum PM$_{10}$ concentrations (black lines, unit: μg m^{-3}) over NC in spring from 2015 to 2023. The yellow shadings represent periods of PM$_{10}$ concentrations exceeding 1000 μg m^{-3}, while the blue shadings represent periods with PM$_{10}$ concentrations below 500 μg m^{-3}. The pink triangles represent the maximum PM$_{10}$ concentrations exceeding 1000 μg m^{-3}, while the blue dots represent the minimum PM$_{10}$ concentrations below 500 μg m^{-3}. Dashed lines (blue and pink) depict threshold values for PM$_{10}$ concentration at 500 and 1000 μg m^{-3} respectively.
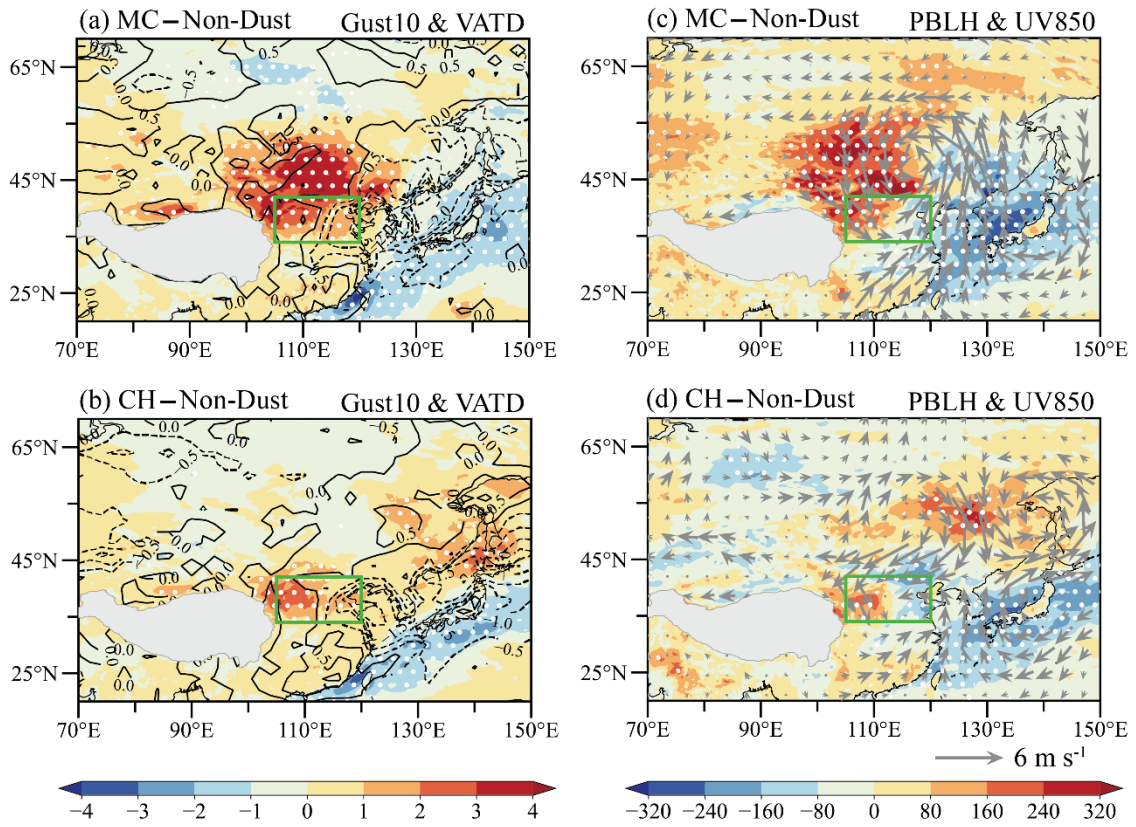
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Figure S3. (a) Composite distribution of observed daily maximum PM_{10} concentrations (scatter, unit: $\mu g\ m^{-3}$) during Dust days. Panel (b), (c) and (d) are the same as (a) but for Non-Dust days, MC days and CH days. The shading in panel (a) indicates NDVI in March 2023. The green boxes in panel (a)–(d) represent NC.
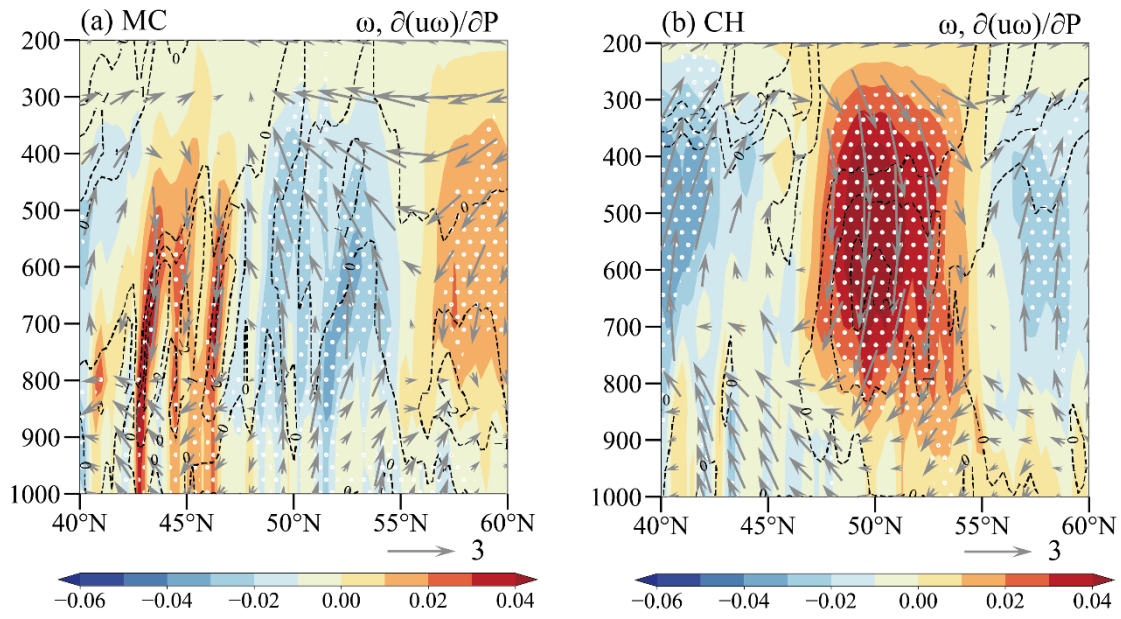
Figure S4. (a) Composite differences of Gust10 (shading, units: m s^{-1}) and VATD (contour, units: K) during MC days relative to Non-Dust days. White dots indicate that the differences of Gust10 exceed the 95% confidence level. Panel (b) is the same as panel (a) but for CH days. (c) Composite differences of PBLH (shading, units: m) during MC days relative to Non-Dust days and composite anomalies of UV850 (vectors, units: m s^{-1}). White dots indicate that the differences of PBLH exceed the 95% confidence level. Panel (d) is the same as panel (c) but for CH days. The green boxes in panel (a)–(d) represent NC.
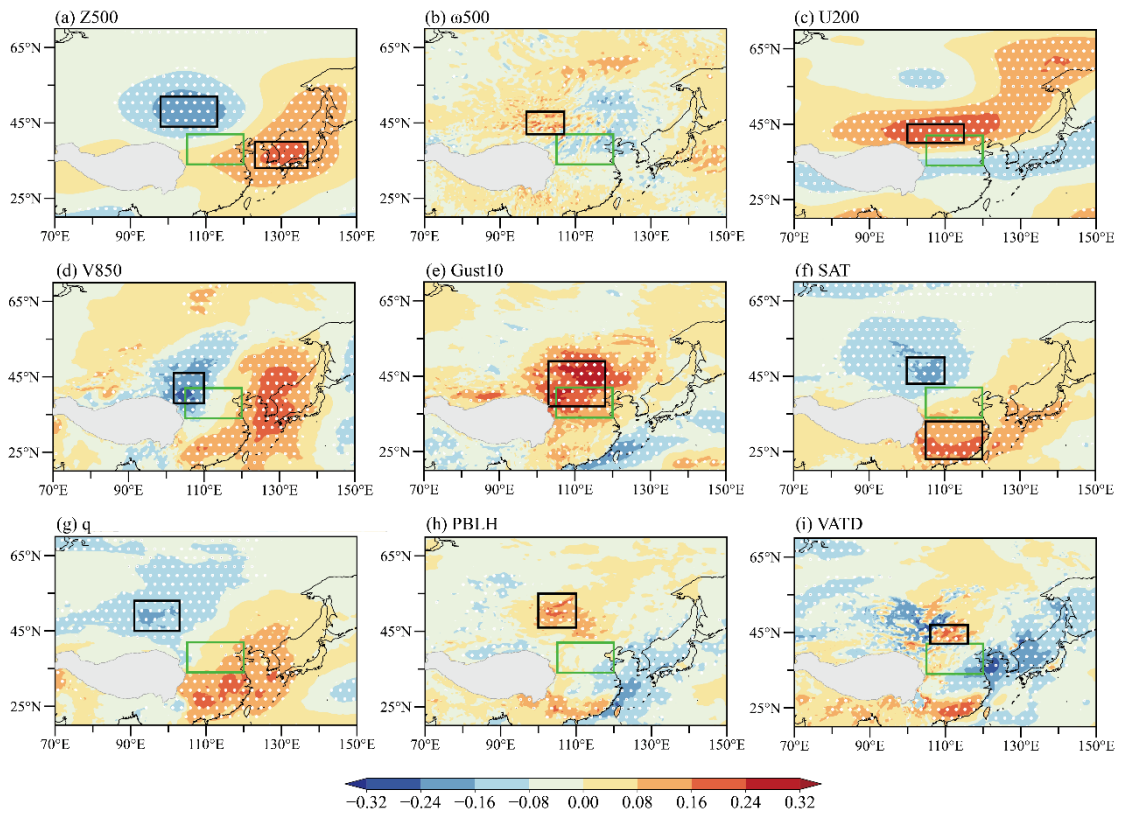
Figure S5. (a) Composite anomalies of meridional component of the vertical circulation average over 40–60° N, 90–120° E during MC days. The variables include ω (shading, units: Pa s^{-1}) and downward transport of westerly momentum (<0, dashed contour, units: 10^{-3} m s^{-2}). White dots indicate that ω anomalies exceed the 95% confidence level. The vectors represent ω (magnified 100 times) and zonal wind. Panel (b) is the same as (a) but for CH days.

Figure S6. Correlation coefficients of observed daily maximum PM$_{10}$ concentrations over NC with daily mean (a) Z500, (b) ω500, (c) U200, (d) V850, (e) Gust10, (f) SAT, (g) q, (h) PBLH, and (i) VATD in spring from 2015 to 2023. White dots indicate that correlation coefficients exceed the 95% confidence level. The green boxes in panel (a)–(i) represent NC. The black boxes in panel (a)–(i) represent the regions for calculating the indices respectively (Table 1).