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Postprint: Atmospheric Pollution Effects of a Strong Dust Storm Event in Northern China

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Abstract

Using conventional environmental monitoring data of pollutant concentrations, NCEP/NCAR $0.5^\circ \times 0.5^\circ$ reanalysis data, and conventional meteorological observation data, this study investigated a severe sandstorm air pollution process that successively affected 13 provinces (autonomous regions, municipalities) of China from May 3-6, 2017. The results indicate that the daily average PM10 concentration in major affected cities increased by 2-10 times relative to the monthly average, while the daily average PM2.5 concentration increased by 5-8 times relative to the monthly average. During the severe sandstorm outbreak, particulate matter concentrations exhibited a significant upward trend, with PM10 concentration values showing a more pronounced increase than PM2.5 concentration values, indicating that the sandstorm entrained substantial amounts of coarse particulate pollutants. Conversely, during the sandstorm period, the daily average concentrations of the three gaseous pollutants SO₂, CO, and NO₂ all exhibited a decreasing trend, suggesting that the sandstorm had a certain diffusion effect on gaseous pollutants, while having no significant impact on O₃ concentration variations. Furthermore, during the sandstorm outbreak, the locations of low visibility zones, high PM10 concentration zones, and 3-hour positive pressure change zones were essentially consistent, all situated in the rear region of the surface cold front, which provides a synoptic meteorological basis for the forecasting and prevention of sandstorms and their associated pollution.

Full Text

Analysis of a Severe Dust Storm Event and Its Air Pollution Characteristics

2.2 Pollutant Concentration Variations

During the dust storm period, the average daily concentrations of sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) exhibited a decreasing trend. Statistical analysis reveals the proportion of days with good air quality for these pollutants: SO_2 showed 13.04%, 29.41%, 23.08%, 62.5%, and 11.68% across different monitoring periods; CO showed 40.91%, 7.14%, 17.14%, 16.67%, and 50%; and NO_2 showed 88%, 40%, 33.33%, 21.43%, and 0.21%. In contrast, ozone (O_3) concentrations increased during the dust storm, indicating that the dust event had a diffusing effect on O_3 distribution. The primary pollutants during this period were SO_2 , CO, and NO_2 , with their concentrations varying by season and meteorological conditions. The dust storm's impact on air quality was particularly pronounced in regions with low visibility and high particulate matter concentrations.

The relationship between three-hour positive pressure anomalies and pollutant concentrations shows that SO_2 , CO, and NO_2 concentrations were generally lower during dust storm periods. Air quality monitoring data indicate that the proportion of days with good air quality for SO_2 , CO, and NO_2 was significantly affected by the dust storm's intensity and duration. The dust storm's diffusion effect on O_3 was evident, with O_3 concentrations showing an inverse relationship with the other gaseous pollutants.

3.2 HYSPLIT Trajectory Analysis

The Web-based HYSPLIT model was employed for trajectory analysis. Three representative cities were selected for 24-hour backward trajectory calculations at 500 m and 1500 m altitudes: Hohhot (41.087°N, 111.467°E), Zhangjiakou (40.826°N, 114.889°E), and Beijing (39.930°N, 116.396°E). The trajectory analysis covered the period from May 4 to 6, 2017, focusing on the transport pathways of dust aerosols.

[Figure 4: see original paper] shows the 24-hour backward trajectories at 1500 m and 500 m for these three cities. On May 4, the trajectories at both altitudes originated from the northwestern desert regions, indicating direct dust transport from source areas. On May 5, the 1500 m trajectories for Hohhot and Zhangjiakou showed transport from the Gobi Desert regions, while Beijing's trajectory indicated mixed sources. The 500 m trajectories revealed near-surface transport patterns that were more localized.

The PM_{10} concentrations corresponded with these trajectory patterns. On May 4, Hohhot recorded a PM_{10} concentration of $1465 \text{ g} \cdot \text{m}^{-3}$, Zhangjiakou $935 \text{ g} \cdot \text{m}^{-3}$, and Beijing $382 \text{ g} \cdot \text{m}^{-3}$. The higher concentrations in the northwestern

cities correlated with trajectories passing directly through dust source regions. The vertical distribution showed that 1500 m trajectories captured long-range transport, while 500 m trajectories reflected local and regional dust lifting mechanisms.

4.1 500 hPa Circulation Patterns

At 500 hPa, the geopotential height field on May 3 showed a ridge pattern over the Mongolian region, with a trough developing over northwestern China. By May 4 at 08:00, a cold vortex system was established over the Gobi Desert region, with a strong pressure gradient developing between the Mongolian high and the low-pressure system over northern China. This configuration created favorable conditions for strong northwesterly winds.

On May 4 at 20:00, the cold vortex intensified, with the geopotential height gradient reaching its maximum. The trough axis oriented northeast-southwest facilitated the southward transport of cold air masses. The 500 hPa chart [Figure 5a: see original paper] clearly shows this pattern, with contour lines tightly packed over the dust source regions, indicating strong upper-level support for surface dust lifting.

By May 5 at 08:00, the system began to weaken, but the pressure gradient remained sufficient to maintain dust transport. The 500 hPa pattern shows the cold front's position clearly, with the dust-affected region located in the post-frontal area, where strong subsidence and northerly winds persisted.

4.2 200 hPa Jet Stream Analysis

The 200 hPa jet stream analysis reveals the upper-level dynamics during the dust event. On May 4 at 08:00 [Figure 5a: see original paper], the jet stream exhibited a zonal pattern with wind speeds exceeding $52 \text{ m} \cdot \text{s}^{-1}$ over the dust source regions. The jet core was located near 45°N , with the exit region positioned over northern China, favoring upper-level divergence and surface convergence.

By May 4 at 20:00 [Figure 5b: see original paper], the jet stream maintained its intensity, with wind speeds of $54\text{-}56 \text{ m} \cdot \text{s}^{-1}$. The jet axis showed a slight meridional tilt, enhancing the vertical coupling between upper and lower levels. This configuration strengthened the surface pressure gradient and sustained the dust transport.

On May 5 at 08:00 [Figure 5c: see original paper], the jet stream began to shift eastward, with wind speeds decreasing to $48\text{-}60 \text{ m} \cdot \text{s}^{-1}$. The jet's influence on dust transport remained significant, as the exit region still covered parts of northern China. By May 5 at 20:00 [Figure 5d: see original paper], the jet stream weakened considerably, leading to the dissipation of the dust event.

The relationship between the jet stream and surface dust concentrations shows that periods of maximum jet intensity corresponded with highest PM_{10} concen-

trations. The upper-level divergence associated with the jet exit region enhanced surface wind speeds, promoting dust emission and long-range transport.

Key Findings

- (1) During the dust storm, the ratio of $PM_{2.5}$ to PM_{10} decreased significantly, indicating a higher proportion of coarse particles. The $PM_{2.5}/PM_{10}$ ratio ranged from 0.2 to 0.5 during the event, compared to 0.6-0.8 under normal conditions. This shift in particle size distribution confirms that dust storms primarily transport coarse-mode aerosols.
- (2) The dust source regions identified through trajectory analysis correlate well with the Gobi Desert and arid regions of Mongolia. The meteorological analysis indicates that the combination of a deep cold vortex at 500 hPa and a strong jet stream at 200 hPa created ideal conditions for dust emission and transport. The ground cold front provided the necessary surface convergence and strong winds for dust lifting.

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Air Pollution Characteristics During a Severe Dust Storm in North China

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Abstract: In this study, routine environmental monitoring data of pollutant concentrations, NCEP/NCAR 0.5°×0.5° reanalysis data, and conventional meteorological observation data were used to analyze the characteristics of air pollution in the main cities affected by the dust storm. The average daily concentration of PM_{2.5} increased by 2-10 times relative to the monthly average. The average daily concentration of PM_{2.5} increased by 5-8 times relative to the monthly average concentration. During the intense dust storm, the concentration of particulate matter exhibited a clear upward trend, and the increase in PM₁₀ concentration was more obvious than that of PM_{2.5}, which indicated that the dust storm carried a large amount of coarse particle pollutants. Conversely, during the dust storm occurrence, the average daily concentrations of SO₂, CO, and NO₂ showed a decreasing trend, while O₃ concentrations increased, revealing that the dust storm had a certain effect of diffusing O₃. In addition, the locations of regions with low visibility, high PM₁₀ concentration, and three-hour positive pressure anomalies were basically

accorded with and located in the rear of the ground cold front, which could provide a synoptic basis for predicting and preventing dust storms and their associated pollution.

Keywords: dust storm; inhalable particles (PM_{10} and $PM_{2.5}$); circulation feature; gaseous pollutants (SO_2 , CO, and NO_2)

Note: Figure translations are in progress. See original paper for figures.

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