Vertical Distribution and Post-Transport Imprint of Aerosols in Typical Dust Weather Processes in the Tarim Basin, Spring 2021

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Abstract

Using lidar observation data from the hinterland of the Taklamakan Desert in late April 2021, combined with ERA5 reanalysis data, the HYSPLIT model, and data from environmental monitoring and meteorological observation stations, the vertical distribution characteristics of dust aerosol optical information were analyzed, and the causes, development processes, potential sources, and transport pathways of large-scale dust weather in the Tarim Basin were investigated. The results show that: the desert hinterland experienced two strong dust weather processes during 20:00 on April 19 to 14:00 on April 21 and 14:00 on April 22 to 18:00 on April 26. Dust was concentrated at altitudes of 0–5 km, with the extinction coefficient at 0–2 km >0.3 km-1 and the depolarization ratio >0.6, far exceeding the dust aerosol identification threshold of 0.31. Both dust weather processes were jointly influenced by upper-level troughs and surface cold air. The first dust weather process was mainly caused by cold air crossing the Tianshan Mountains, resulting in blowing sand weather in Kashgar, Hotan, and Aksu. The PM10 concentration in Hotan peaked at 3763 μg·m-3 on the 22nd, with dust originating from the western part of the basin. The second dust weather event primarily originated from cold air intrusion in the northeastern part of the basin. The PM10 concentrations in Korla and Aksu suddenly increased to over 1200 μg·m-3 on the 25th–26th, with dust source areas located in the desert hinterland, northeastern and northern parts of the basin. The second dust weather process exhibited higher pollution transport altitudes, longer duration, and a wider impact range. The Tazhong region in the desert hinterland has abundant dust sources, with vertical distribution of dust aerosols exceeding 4 km during dust weather events, and dust transport heights significantly greater than those in Hotan and Minfeng, which are high-incidence areas for dust weather.

Full Text

Preamble

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Vertical Distribution and Transport of Aerosols During Typical Dust Weather Processes in the Tarim Basin, Northwest China in Spring 2021

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Abstract

Based on lidar observations from late April 2021 in the Taklamakan Desert hinterland, combined with ERA5 reanalysis data, the HYSPLIT trajectory model, and data from environmental monitoring and meteorological stations, this study analyzed the vertical distribution characteristics of dust aerosol optical properties and investigated the formation mechanisms, development processes, potential sources, and transport pathways of large-scale dust weather events in the Tarim Basin.

The results revealed two strong dust events occurring from 20:00 on April 19 to 14:00 on April 21 and from 14:00 on April 22 to 18:00 on April 26. Dust particles were concentrated within the 0–5 km atmospheric layer, with extinction coefficients exceeding 0.3 km^{-1} in the 0–2 km layer and depolarization ratios surpassing 0.6—far above the dust aerosol identification threshold of 0.31. Both dust events were influenced by the combined effects of an upper-level low trough and surface cold air. The first dust event was primarily caused by cold air crossing the Tianshan Mountains, resulting in blowing dust weather in Kashgar, Hotan, and Aksu, with the PM$_{10}$ concentration in Hotan peaking at 3763 g·m^{-3} on April 22. The dust originated from the western part of the basin. The second dust event mainly resulted from cold air intrusion from the northeastern basin, with PM$_{10}$ concentrations in Korla and Aksu sharply increasing to over 1200 g·m^{-3}. The source regions were located in the desert hinterland and the northeastern and northern parts of the basin. The second dust event exhibited higher pollution transport altitudes, longer duration, and broader impact range. In the desert hinterland at Tazhong, where dust sources are abundant, dust aerosols during dust events were distributed vertically beyond 4 km, with transport heights significantly greater than those in Hotan and Minfeng, which are high-frequency dust weather areas.

Keywords: Tarim Basin; dust weather; aerosol; vertical distribution; lidar; Tazhong; PM_{10}

1 Introduction

Dust weather is a meteorological phenomenon where sand particles and dust from soil surfaces are lifted by wind, resulting in reduced atmospheric visibility. It predominantly occurs in arid and semi-arid regions with low vegetation coverage, representing a severe hazard to both natural environments and human activities. As a major component of tropospheric aerosols, dust particles account for approximately 1700 Tg of global annual dust emissions. These suspended particles alter the radiation balance of the Earth-atmosphere system through direct radiative effects and indirectly influence weather and climate by serving as cloud condensation nuclei or atmospheric ice nuclei. Additionally, dust aerosols transport essential mineral elements such as iron and phosphorus to oceanic and rainforest ecosystems, while also undergoing chemical reactions with atmospheric pollutants like SO_2 and NO , leading to more severe secondary pollution. Consequently, aeolian dust disasters have become a focal issue in global change and ecological environmental research.

Scientific investigations into dust weather and soil wind erosion in arid regions began in the last century, with researchers such as Bagnold, Gillette, and Shao establishing foundational physical mechanisms and empirical models that continue to serve as the theoretical basis for aeolian dust research. The Tarim Basin, located in the interior of Central Asia, represents a key region for dust storm research in East Asia. Since the 1950s, China has conducted field observations in the Tarim Basin, though systematic and comprehensive monitoring only gradually expanded into the basin interior from the 1990s due to harsh natural conditions. The basin is dominated by mobile dunes, with fine and very fine sand fractions exceeding 50% of the surface sediment. Under the influence of cold air intrusions and the basin’ s large-scale topography, floating dust, blowing dust, and dust storm events occur frequently in spring and summer, with high-incidence areas concentrated along the southern margin and in the desert hinterland. The Tarim Basin serves as a natural laboratory for aeolian dust research.

Approximately only one-quarter of the dust can be transported over long distances to North China, and even across the Pacific to North America and Europe, due to blocking by surrounding high mountains. The remaining majority settles directly within the basin, particularly in the central and southern regions, where the annual dustfall at Tazhong in the desert hinterland far exceeds that at other stations around the basin. Overall, dust aerosols over the Tarim Basin exert a cooling radiative forcing on the Earth-atmosphere system, though a small portion transported to the Tibetan Plateau can warm the atmosphere by absorbing solar radiation, thereby accelerating snowmelt.

Understanding the vertical distribution of dust aerosols is crucial for investigating dust weather duration, long-distance transport, and radiative forcing. With advancements in remote sensing technology, ground-based lidar with excellent temporal and vertical resolution has been widely applied to detect and study dust aerosols in the Tarim Basin, effectively compensating for the limitations of stationary meteorological satellites in obtaining vertical distribution information and the challenges of polar-orbiting satellites like CALIPSO in achieving fixed-point observations. Lidar parameters such as depolarization ratio and extinction coefficient can reflect variations in dust pollution distribution at specific locations and altitudes, and when combined with other observational data, can significantly improve the accuracy of dust cycle processes, microphysical properties, and climate effect studies.

As a core region of China’s “Belt and Road” initiative, the Tarim Basin faces significant challenges from aeolian dust environmental issues that substantially impact local socioeconomic sustainable development and ecological security. However, due to harsh natural conditions, ground observation stations are primarily concentrated in oasis areas along the desert margins. Moreover, research on the vertical distribution characteristics of dust aerosols in the basin remains relatively weak and requires in-depth analysis. This study penetrated into the Tazhong area of the Taklamakan Desert hinterland, utilizing lidar data to investigate the vertical distribution and optical property variations of aerosol particles during two dust weather processes in late April 2021. Combined with the HYSPLIT model and multi-source data from surrounding environmental monitoring and meteorological stations, we analyzed the vertical distribution characteristics of dust aerosol optical information and examined the development processes, formation mechanisms, pollution levels, potential sources, and transport pathways of large-scale dust weather events in the basin, aiming to provide theoretical foundations and data support for early warning and prevention of aeolian dust disasters in northwest arid regions.

1.1 Study Area

The Tarim Basin is situated deep in the interior of the Eurasian continent, in southern Xinjiang, China, with a permanent population exceeding 10 million, primarily concentrated in oasis cities along the basin margins. The basin features a ring-shaped topography, bordered by the Tianshan Mountains to the north, the Pamir Plateau to the west, and the Kunlun Mountains to the south, with terrain sloping from high in the west to low in the east. Prevailing northeasterly and northwesterly winds persist year-round, while the southern Tibetan Plateau blocks warm moist airflow from the northern Indian Ocean, creating a continental extreme arid climate characterized by intense solar radiation, large diurnal temperature variations, annual evaporation exceeding 2000 mm, and precipitation consistently below 50 mm in most areas. The basin has extremely sparse vegetation, with extensive exposed mobile sandy soils, including the world' s second-largest shifting desert—the Taklamakan Desert—resulting in frequent and intense dust activity with a latitudinal distribution pattern of more in the south and less in the north, and annual dust weather days exceeding 100.

The environmental monitoring stations are located in Kashgar (39.47°N, 75.98°E), Hotan (37.13°N, 79.93°E), Aksu (41.17°N, 80.23°E), and Korla (41.75°N, 86.13°E). The lidar was deployed at the Tazhong Botanical Garden in Qiemo County, Xinjiang (38.97°N, 83.66°E, 1099.3 m), where the surrounding terrain is flat without tall obstructions, ensuring good detection performance. The distribution of observation stations is shown in [Figure 1: see original paper].

1.2 Data Sources

PM$_{10}$ concentration and dust weather data were obtained from the China National Environmental Monitoring Centre (http://www.cnemc.cn) and the China Meteorological Data Service Centre (https://data.cma.cn). According to the national standard GB/T 20480–2017 "Classification of Sand and Dust Weather," horizontal visibility <10 km is classified as blowing dust, 1-10 km as floating dust, 500-1000 m as dust storm, and <500 m as severe dust storm (no severe dust storms occurred in the Tarim Basin during the study period). Lidar observation data from Tazhong were collected using a portable atmospheric particulate monitoring lidar (MPL) manufactured by Wuxi Zhongke Optoelectronics Company, with observations conducted from April 16 to May 1, 2021. Meteorological field data at different altitudes, including pressure, temperature, wind speed, wind direction, and geopotential height, were derived from ERA5 (the fifth-generation atmospheric reanalysis dataset from the European Centre for Medium-Range Weather Forecasts), which provides hourly atmospheric state parameters based on extensive historical observations using advanced numerical modeling and data assimilation systems, with a spatial resolution of 0.25°$×0.25°.Thisstudyutilizedwindandtemperaturefieldsat500hPaand850hPaisobaricsurfacestoanalyzeth horizontal resolution, we set air mass heights at 500 m, 1000 m, and 2000 m above ground level and simulated 48-hour backward trajectories during the two dust events.

1.3 Research Methods

The lidar operates based on the Mie scattering principle, remotely sensing the atmosphere by detecting radiation signals from laser-atmosphere interactions. The system comprises three components: an optical receiving system, an optical collection system, and a data acquisition and control system, with retrieval products including aerosol depolarization ratio, extinction coefficient, and atmospheric boundary layer height. The instrument emits and receives laser pulses at a wavelength of 532 nm, with a temporal resolution of 3.75 m and spatial resolution of 2-7 kHz, and a maximum detection range exceeding 15 km. In this study, the lidar scanning interval was 22.5 km, with a detection altitude of approximately 15 km. The backscattered echo signals received by the lidar can be expressed by the lidar equation. This study employed the Fernald method to retrieve extinction coefficients and depolarization ratios. A larger aerosol extinction coefficient (α) indicates higher aerosol concentration. Different-shaped aerosol particles produce varying degrees of polarization when interacting with laser light. The depolarization ratio (δ) is defined as the ratio of perpendicular backscattered signal (P) to parallel backscattered signal (P). A higher depolarization ratio indicates more pronounced non-spherical characteristics of aerosols and greater dust content.

Technical parameters of the MPL are summarized in .

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2 Results

2.1 Lidar Observations

Lidar can retrieve vertical distribution information of aerosols. Since aerosols in the Tarim Basin are dominated by dust, with dust aerosol content significantly higher than other aerosol types such as continental aerosols, polluted continental aerosols, and smoke, the depolarization ratio and extinction coefficient observed by lidar in the basin can be used to determine dust content and pollutant concentration. When the depolarization ratio exceeds 0.31, the pollutant is identified as dust aerosol; when the extinction coefficient surpasses 0.085 km^{-1}, dust or anthropogenic pollution is present.

Figure 2 shows the vertical distribution of extinction coefficient and depolarization ratio at Tazhong from April 16 to May 1, 2021. Overall, two distinct dust events occurred at Tazhong: from 20:00 on April 19 to 14:00 on April 21, and from 14:00 on April 22 to 18:00 on April 26. The extinction coefficient and depolarization ratio demonstrated good temporal and vertical consistency, indicating that non-spherical dust particle pollution dominated at Tazhong during these periods, with dust concentrated within the 0–5 km altitude range. High-value zones of extinction coefficient and depolarization ratio appeared at 5–15 km altitude. Meteorological observations indicate cloudy conditions on April 19–20 and overcast conditions on April 25–26. Under these conditions, low temperatures at high altitudes cause cloud particles to condense into irregularly shaped ice crystals, which, like dust aerosols, exhibit large depolarization ratios. Therefore, these high-altitude regions likely represent clouds or mixed dust-cloud layers.

Beginning at 20:00 on April 19, near-surface dust began to accumulate, with the extinction coefficient abruptly increasing from less than 0.2 km^{-1} to 1.3 km^{-1} and the depolarization ratio rising from 0.4 to 0.6, indicating high dust particle content during the pollution episode. Between 04:00 and 06:00 on April 20, dust diffused upward to 1.7 km altitude, with near-surface extinction coefficients approaching 1.9 km^{-1}, indicating intensified dust pollution. By 14:00 on April 21, the extinction coefficient decreased to 0.3 km^{-1} and the depolarization ratio declined, marking the gradual end of the dust event. The second dust event began at 14:00 on April 22, with near-surface extinction coefficients increasing again and reaching maximum values for late April over the subsequent two days. On April 22, Tazhong experienced clear skies with minimal cloud interference in lidar observations, revealing a dust band at 7-12 km altitude. On April 23-24, high-altitude pollution gradually subsided, mixing and accumulating with near-surface dust, exacerbating surface pollution. After 18:00 on April 26, both extinction coefficient and depolarization ratio decreased significantly as dust began to dissipate.

On the morning of April 27, under clear sky conditions, extinction coefficients above 12 km exceeded 0.4 km^{-1}, indicating dust pollution at high altitudes, while near-surface extinction coefficients and depolarization ratios remained relatively small, suggesting that high-altitude dust likely resulted from a combination of external transport and surface diffusion.

We discuss the two typical dust events separately, considering dust distribution heights and high-altitude cloud effects. The analysis altitudes were set at 0–5 km for the first dust event and 0–12 km for the second. Figures 3 and 4 present profiles of extinction coefficient and depolarization ratio at four characteristic moments for each event: before pollution, at pollution onset, during pollution accumulation, and during pollution dissipation (from left to right). Before the first dust event, extinction coefficients at 3–5 km altitude exceeded 0.4 km^{-1} while depolarization ratios were relatively small, indicating low near-surface dust concentrations and significant cloud interference in high-altitude detection. After dust pollution began, near-surface extinction coefficients increased rapidly, with depolarization ratios throughout the 0–5 km layer approaching 0.6. As dust continued to accumulate, both extinction coefficient and depolarization ratio increased further until gradually returning to pre-pollution levels after dissipation at 14:00 on April 21. During the second dust event, extinction coefficient and depolarization ratio followed similar increasing then decreasing trends, but during the accumulation stage, dust content in the lower 3–6 km layer was relatively reduced while a distinct dust band appeared at high altitudes, with dust content in the 3–6 km layer significantly lower than in the layers above and below. At 18:00 on April 25, surface dust concentrations decreased while dust remained present at 5-6 km altitude.

Using an extinction coefficient of 0.085 km^{-1} as the dust aerosol identification threshold, lidar observations during the study period revealed that dust aerosol distribution at Tazhong in the desert hinterland frequently exceeded 2 km altitude, with transport heights significantly greater than those at Hotan (a high-frequency floating dust center) and Minfeng (a high-frequency dust storm center). During dust pollution episodes, extinction coefficients within 0–2 km at Tazhong generally exceeded 0.3 km^{-1}, consistent with previous lidar studies of dust weather in the Tarim Basin. Throughout the entire observation period, even during non-dust weather, extinction coefficients in the 0–2 km layer remained above 0.085 km^{-1}, with depolarization ratios generally exceeding 0.31—far surpassing the dust aerosol identification threshold. This is attributed to Tazhong' s location in the desert hinterland, where the surface is covered with abundant loose sand requiring low threshold wind speeds for entrainment, resulting in persistently high dust content.

2.2 Circulation Background of Dust Events

The Tarim Basin is situated in the mid-latitudes of the Northern Hemisphere, primarily influenced by westerly circulation and the Mongolian-Siberian High. Figures 5 and 6 illustrate the 500 hPa geopotential height, temperature, and wind fields during the first dust event, showing circulation patterns at four characteristic moments: 20:00 on April 19, 08:00 on April 20, 05:00 on April 21, and 14:00 on April 21. At 20:00 on April 19, the 500 hPa pattern exhibited a distinct "two troughs and one ridge" configuration, with cold air continuously moving southward from Novaya Zemlya, accumulating and intensifying over West Siberia to form an east-west oriented trough over eastern West Siberia and the Ural Mountains. Both the low-pressure center and cold center were located over eastern West Siberia, while a high-pressure ridge existed over the Lake Baikal-Mongolia region. The Tarim Basin was positioned ahead of the trough and behind the ridge, with the temperature trough lagging behind the height trough, favoring the development of the height trough. Over the subsequent two days, the low-pressure system over northern Xinjiang gradually shifted southward, with the transverse trough evolving into a southwest-oriented trough whose base approached the northern Xinjiang region, bringing substantial cold air to Xinjiang while simultaneously causing the Lake Baikal-Mongolia high-pressure ridge to shift eastward and extend northward, reaching northeastern China by 14:00 on April 21.

At 850 hPa (Figure 6), under the influence of the Siberian low-pressure system, northwesterly winds carrying abundant cold air crossed the Tianshan Mountains and Pamir Plateau into the Tarim Basin, converging with dry warm air within the basin to form a cold front. Due to the basin being surrounded by mountains on three sides, another branch of northwesterly flow entering northern Xinjiang turned into northeasterly currents at the eastern opening of the basin or invaded through the two major wind gaps at Dabancheng and Baili in the northeastern basin. The combined influence of these two airflow streams significantly increased low-level wind speeds across multiple locations in the basin, with the 10 $m \cdot s^{-1}$ isotach reaching 850 hPa at Tazhong at 08:00 on April 20. Most areas experienced upward airflow, with strong winds and ascending currents promoting the lifting of large amounts of surface dust.

By 14:00 on April 21, northern Xinjiang shifted from northwesterly to northerly winds. The blocking effect of the Tianshan Mountains significantly reduced low-level wind speeds in the basin, ending dust weather at Tazhong, Hotan, and Korla. After the event, upward airflow persisted across the basin, hindering dust particle sedimentation, which is why floating dust conditions continued in Korla, Aksu, and Kashgar until 16:00 on April 21.

Figures 7 and 8 show circulation patterns at four characteristic moments during the second dust event. At 14:00 on April 22, the 500 hPa low-pressure and cold centers were located in northern Xinjiang, with a southwest-oriented trough extending to Iran and a high-pressure ridge over Yunnan-Mongolia, placing the Tarim Basin behind the trough and ahead of the ridge. By 17:00 on April 24, the low-pressure center and cold vortex extended southward, with the trough reaching northern Xinjiang and the high-pressure ridge deepening northward, resulting in prevailing southwesterly winds at 500 hPa over the basin. Over the following days, the low-pressure center moved eastward across Xinjiang, significantly increasing upper-level wind speeds and causing floating dust, blowing dust, and dust storm weather in multiple locations. By 16:00 on April 26, the trough reached northern Inner Mongolia while a deep high-pressure ridge developed over northern Xinjiang-western Siberia, with warm advection rapidly decreasing wind speeds over the basin.

The 850 hPa wind field (Figure 8) reveals that the cold air causing widespread dust weather also originated from northeastern basin intrusion. At 14:00 on April 24, 850 hPa wind speeds exceeded 10 $\mathrm{m \cdot s^{-1}}$ over most areas with upward airflow, favoring surface dust lifting.

2.3.1 Backward Trajectory Analysis

To investigate pollution sources and transport processes of dust weather in the desert hinterland, we used HYSPLIT to simulate backward trajectories of air masses at different altitudes over Tazhong at four characteristic moments: pollution onset (500 m), accumulation (1000 m), and dissipation (2000 m) during the first dust event (06:00 on April 20) and the second dust event (02:00 on April 24). Since dust is primarily concentrated near the surface, trajectory heights were set at 500 m, 1000 m, and 2000 m, with a trajectory duration of 48 hours.

The results indicate that dust sources for the first dust event were mainly located in the western part of the basin. The 500 m air mass originated from the northwestern basin, entraining surface dust and gradually diffusing upward while moving toward Tazhong. The 1000 m air mass slowly subsided from the southwest, while the 2000 m air mass originated from the western basin, gradually descending during eastward transport.

During the second dust event (Figure 10), 500 m backward trajectories show that at 02:00 on April 24, the air mass was located in the northeastern basin, carrying near-surface dust and reaching Tazhong via Korla, demonstrating that the northeastern basin served as a major dust source region for the second event, with Korla and Tazhong successively affected. The 1000 m air masses originated from the northern basin, while 2000 m air masses came from northwest of Tazhong, suggesting that pollution sources for the first dust process were primarily from the northwestern basin.

Analysis of 48-hour backward trajectories before the end of the second dust event reveals that air masses moved rapidly from Kazakhstan and Afghanistan to Aksu, which experienced persistent blowing dust. As shown in Figure 10, air masses arrived in Korla from west to east around noon on April 25, when blowing dust was observed with PM_{10} concentrations of 1100 $g \cdot m^{-3}$. Subsequently, the 1000 m air mass circled around Tazhong, indicating that Tazhong may have been simultaneously influenced by dust transport from the northwestern basin and transboundary pollution from neighboring countries.

2.3.2 Basin-wide Dust Weather Variations

To comprehensively understand basin-wide dust weather variations and pollution transport processes, we further analyzed PM_{10} concentrations and dust weather types at Tazhong in the desert hinterland and four surrounding oasis cities, as shown in Figure 11. All four stations successively observed dust weather, with PM_{10} concentrations peaking in Hotan, Korla, Aksu, and Kashgar on April 22, April 25, April 25, and April 26, respectively. Hotan reached its maximum of 3763 $g \cdot m^{-3}$ at 03:00 on April 22.

In the early morning of April 21, cold air crossing the Tianshan Mountains caused dust lifting in the western basin, leading to sharp PM_{10} increases in Kashgar and Hotan, with persistent blowing dust in Aksu. Under the influence of westerly airflow, the first dust event passed through Tazhong at 20:00 on the same day. Following cold air intrusion from the northeastern basin, PM_{10} concentrations in Korla and Aksu surged on April 25 and remained elevated for an extended period. Located near the dust source region of the second event, both cities experienced significant depolarization ratio increases at Tazhong on the evening of April 24 under the combined influence of local dust lifting and external transport. The second dust event persisted until late April, with PM_{10} concentrations in Korla, Aksu, and Kashgar significantly exceeding 1000 $g \cdot m^{-3}$, suggesting these areas were affected by dust transport from the desert hinterland.

Integrating HYSPLIT-simulated air mass transport trajectories during the two strong dust events with PM_{10} concentrations and dust weather variations at typical basin locations effectively captures the dynamic processes of large-scale dust weather across the Tarim Basin in late April. Overall, the second dust event exhibited higher pollution transport altitudes, longer duration, and broader impact range.

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3 Conclusions

This study utilized lidar data combined with surface observations, ERA5 reanalysis data, and the HYSPLIT trajectory model to analyze the development processes and transport pathways of two dust events at Tazhong in spring 2021, yielding the following conclusions:

(1) Two strong dust events occurred in the Taklamakan Desert hinterland from 20:00 on April 19 to 14:00 on April 21 and from 14:00 on April 22 to 18:00 on April 26. The lidar-retrieved extinction coefficient and depolarization ratio increased during dust generation and accumulation, then decreased during dissipation. Dust exhibited clear stratification, concentrated within the 0–5 km layer. During dust events, extinction coefficients within 0–2 km exceeded 0.3 km^{-1}, far surpassing the dust aerosol identification threshold of 0.085 km^{-1}, while depolarization ratios exceeded 0.6, well above the threshold of 0.31.

(2) Both dust events were influenced by the combined effects of an upper-level low trough and surface cold air. The first dust event was primarily caused by cold air crossing the Tianshan Mountains, which increased wind speeds across the basin and favored surface dust lifting. The second dust event mainly resulted from cold air intrusion from the northeastern basin, with upward airflow across multiple basin locations promoting surface dust entrainment while maintaining floating dust conditions at some stations until late April.

(3) For the first dust event in the desert hinterland, pollution sources were mainly from the northwestern basin, with dust gradually diffusing upward during transport while potentially being influenced by dust pollution from the western and southwestern basin. The second dust event originated from local dust lifting and sources in the northeastern and northern basin. The second event exhibited higher pollution transport altitudes, longer duration, and broader impact range.

(4) Oasis cities including Hotan, Korla, Aksu, and Kashgar experienced multiple episodes of floating dust, blowing dust, and dust storms. Hotan’ s PM$_{10}$ concentration peaked at 3763 g · m^{-3} on April 22. On April 21, dust lifting in the western basin caused blowing dust weather in Kashgar, Hotan, and Aksu, and under westerly airflow influence, the first dust event passed through Tazhong at 20:00 on the same day. The Korla and Aksu oases, located closer to the dust source region of the second event, experienced sharp PM$_{10}$ increases on April 25 that remained elevated for an extended period.

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