

Postprint: Analysis of Atmospheric PM_{2.5} Sources and Potential Contributing Sources in Xinjiang

Authors: Xu Junli 1, Han Haidong 2, Wang Jian 1

Date: 2023-08-25T00:00:00+00:00

Abstract

Using air quality data from Xinjiang from March 2021 to February 2022, we analyzed the evolution characteristics of PM_{2.5} concentration and its controlling factors, identified material emission sources through factor analysis and the source characteristics of NO₂, SO₂, and CO, and determined PM_{2.5} transport pathways and the distribution of potential source contribution areas using the MeteoInfo software package based on the Hysplit model. The results show that: (1) The PM_{2.5} concentration in Xinjiang is significantly high, especially in winter with an average reaching 86.16 g · m⁻³. Specifically, PM_{2.5} sources in the Tianshan North Slope Economic Belt are primarily dominated by emissions from surrounding oil and gas field operations and wind-blown dust during transport, whereas PM_{2.5} in other regions mainly originates from wind-blown dust, supplemented by oil and natural gas combustion emissions. (2) Although the PM_{2.5} concentration transported via airflow through oil and gas field operation areas in the Tianshan North Slope Economic Belt is only 50% of that from local pathways, the pathway proportion reaches 50%; therefore, it constitutes an important channel for regional PM_{2.5} sources. Moreover, the coefficient of variation of PM_{2.5} concentration is as high as 103.6%, representing a key factor in the formation of haze and even floating dust weather. Although material supply pathways differ between the Hami Basin and the Tarim Basin, the potential source contribution areas for PM_{2.5} in both are mainly distributed in the Kongque River Basin and Lop Nur regions. (3) The evolution of external airflow into convergence/divergence airflow due to basin topography, supplemented by (quasi-)valley winds promoting pollutant mixing, should be one of the causes for the similar PM_{2.5} evolution trends within the Tianshan North Slope Economic Belt and the Tarim Basin.

Full Text

Abstract

Using air quality data from Xinjiang covering March 2021 through February 2022, this study analyzed the evolution characteristics and controlling factors of PM_{2.5} mass concentration, identified emission sources through factor analysis, and determined PM_{2.5} transport pathways and potential source regions using the Hysplit MeteoInfo software package. The results indicate: (1) PM_{2.5} concentrations in Xinjiang are significantly elevated, particularly in winter when the average reaches $86.16 \text{ g} \cdot \text{m}^{-3}$. Specifically, the northern slope of the Tianshan Mountains exhibits notably high PM_{2.5} levels, while other regions show concentrations primarily controlled by wind-blown dust, supplemented by oil and gas combustion emissions. (2) Although the economic belt along the northern Tianshan slope experiences airflow transport through oil and gas field operations where PM_{2.5} concentrations are only 41.03% of local pathway levels, these pathways account for 80.81% of the total, making them crucial channels for regional PM_{2.5} sources and key factors in the formation of floating dust weather, with concentration variation coefficients reaching 103.6%. (3) Despite differences in material supply pathways between the Hami Basin and Tarim Basin, their potential PM_{2.5} contribution sources are both concentrated in the Kongqi River Basin and Lop Nur regions. (4) The evolution of exogenous airflow into convergent/divergent patterns due to basin topography, combined with (quasi) valley winds that promote pollutant mixing, represents a primary mechanism underlying the similar PM_{2.5} evolution trends observed in the northern Tianshan economic belt and Tarim Basin.

Keywords: PM_{2.5}; cluster analysis; Hysplit model; potential contribution source area; Xinjiang

1.1 Study Area Overview

Xinjiang is located in the interior of the Eurasian continent, characterized by a “three mountains sandwiching two basins” geomorphology (Altai Mountains, Tianshan Mountains, and Kunlun Mountains enclosing the Junggar and Tarim Basins) [Figure 1: see original paper]. Mountainous areas account for approximately $2.65 \times 10^6 \text{ km}^2$, with modern alpine glaciers covering $2.4 \times 10^4 \text{ km}^2$. Under the influence of westerly circulation, external water vapor primarily originates from the North Atlantic and Eurasian continent, promoting extensive desert and gobi landscapes while simultaneously fostering distinctive mountain-front oasis economic zones. The northern Tianshan economic belt alone concentrates over 80% of Xinjiang’s heavy industry and more than 70% of its light industry. In recent years, rapid economic and industrial development, particularly in the energy sector, has raised significant environmental concerns due to substantial pollutant emissions.

1.2 Data Sources

Hourly air quality monitoring data (including PM_{2.5}) were obtained from the China National Environmental Monitoring Centre, covering 24 unevenly distributed stations located in oasis areas along the margins of the Tarim Basin (14 stations) and Junggar Basin (10 stations) [Figure 1: see original paper]. Meteorological data for the Hysplit backward trajectory model were sourced from the Global Data Assimilation System (GDAS) of the U.S. National Centers for Environmental Prediction, with a spatial resolution of $0.5^\circ \times 0.5^\circ$ (<ftp://ftp.arl.noaa.gov/pub/archives/gdas1>).

1.3 Hysplit Model

The Hysplit (Hybrid Single-Particle Lagrangian Integrated Trajectory) model, jointly developed by the U.S. National Oceanic and Atmospheric Administration and the Australian Bureau of Meteorology, calculates and analyzes air mass movement, pollutant deposition, and diffusion trajectories. The MeteoInfo software package enables cluster analysis of air mass backward trajectories and identification of potential contribution sources. The TrajStat module provides computational analysis capabilities for trajectory clustering, Potential Source Contribution Function (PSCF), and Concentration Weighted Trajectory (CWT) [7,14,18].

Backward trajectory cluster analysis was initiated daily at 12:00, 16:00, and 20:00 UTC, with a simulation duration of 72 hours and starting height of 500 m [16,19-21]. Angular distance methods were applied for seasonal trajectory clustering. The PSCF identifies potential source regions by combining pollutant concentrations with backward trajectories. The PSCF value for grid cell ij is defined as the ratio of polluted trajectories (m_{ij}) to total trajectories (n_{ij}) passing through that grid:

$$PSCF_{ij} = \frac{m_{ij}}{n_{ij}}$$

The CWT method reflects pollution levels along different trajectories by calculating the weighted concentration in source grid cells:

$$CWT_{ij} = \frac{\sum_{l=1}^M c_l \tau_{ijl}}{\sum_{l=1}^M \tau_{ijl}}$$

where CWT_{ij} represents the average weighted pollutant concentration in grid cell ij , M is the total number of trajectories, l is a specific trajectory, τ_{ijl} is the residence time of trajectory l in grid ij , and c_l is the pollutant concentration corresponding to trajectory l passing through grid ij . A weighting factor w_{ij} reduces uncertainty when n_{ij} is small:

$$w_{ij} = \begin{cases} 1.00, & n_{ij} > 80 \\ 0.70, & 20 < n_{ij} \leq 80 \\ 0.42, & 10 < n_{ij} \leq 20 \\ 0.05, & n_{ij} \leq 10 \end{cases}$$

Detailed application information for the MeteoInfo software package is available at http://www.meteothink.org/docs/trajstat/cluster_{cal}.html.

2. Results and Analysis

2.1 Overall Levels

The distribution of high terrain features such as the Altai, Tianshan, Pamir, and Kunlun Mountains can alter air mass trajectory directions and material transport intensity, while heterogeneous underlying surfaces including deserts, gobi, and oases may cause significant regional differences in pollutant concentrations, composition, and evolution processes. Cluster analysis using the minimum distance method revealed that Xinjiang monitoring stations can be divided into four major categories: Irtysh River source region (2 stations), Hami Basin (4 stations), northern Tianshan economic belt (10 stations covering Urumqi, Wujiaqu, Changji, Shihezi, Karamay, Tacheng, Bortala Mongol Autonomous Prefecture, and Ili Kazakh Autonomous Prefecture), and Tarim Basin (8 stations covering Bayingolin Mongol Autonomous Prefecture, Aksu, Kashgar, Hotan, and Kizilsu Kirghiz Autonomous Prefecture).

The Irtysh River source region exhibited the lowest annual average PM_{2.5} concentration at $9.07 \text{ g} \cdot \text{m}^{-3}$ (coefficient of variation: 69.64%). The Hami Basin and northern Tianshan economic belt showed concentrations of $41.20 \text{ g} \cdot \text{m}^{-3}$ (84.55%) and $46.13 \text{ g} \cdot \text{m}^{-3}$ (94.41%), respectively—31.8% and 47.5% higher than the national secondary ambient air quality standard ($35 \text{ g} \cdot \text{m}^{-3}$). The Tarim Basin registered the highest average concentration at $65.01 \text{ g} \cdot \text{m}^{-3}$ (82.64%), with Hotan reaching $98.12 \text{ g} \cdot \text{m}^{-3}$, nearly three times the national standard and posing serious health risks.

2.2 Seasonal Differences

Winter PM_{2.5} concentrations averaged $86.16 \text{ g} \cdot \text{m}^{-3}$ (coefficient of variation: 21.55%), significantly higher than other seasons but with relatively low variability, indicating stable air mass movement under continental high pressure that slows diffusion of fine particulate dust—one reason for poor winter air quality and low dust storm frequency. Spring and autumn concentrations averaged $40.30 \text{ g} \cdot \text{m}^{-3}$ (52.12%) and $39.32 \text{ g} \cdot \text{m}^{-3}$ (63.27%), respectively, with high variability due to increased mobile troughs and ridges in the westerlies associated with changing solar altitude, leading to frequent cold air activity that reduces atmospheric stability and promotes pollutant diffusion while favoring dust storm formation. Summer concentrations averaged $18.57 \text{ g} \cdot \text{m}^{-3}$ (23.95%), only

21.55% of winter levels, with low variability resulting from weakened northerly winds, concentrated precipitation, and favorable vegetation conditions.

All regions exhibited similar seasonal trends: highest in winter, lowest in summer, and strong fluctuations in spring and autumn (high coefficients of variation). Hourly concentration data standardized by the 0-1 method revealed a double-peak diurnal pattern in the northern Tianshan economic belt, with peaks at 21:00–2:00 and 7:00–10:00, and troughs at 5:00–7:00 and 16:00–18:00 [Figure 2: see original paper]. The midnight peak and morning trough were less pronounced in winter. The Hami Basin showed a weak double-peak pattern, while the Tarim Basin displayed a single peak at 21:00–2:00 and trough at 10:00–16:00, distinct from northern Xinjiang regions.

The nighttime concentration peak and daytime trough in the northern Tianshan economic belt result from stable nocturnal atmospheric stratification that accumulates pollutants from human activities, while neutral stratification in the morning and weakly unstable conditions at noon promote diffusion. The Hami Basin’s similar pattern is also influenced by “eastward-penetrating weather,” where cold air moves from the low-lying Turpan-Hami Basin into the eastern Taklimakan Desert under Tianshan blocking, potentially generating strong easterly winds and dust events. The Tarim Basin’s elevated midnight concentrations and morning troughs, similar to northern Xinjiang, likely reflect regional atmospheric circulation patterns, with the evening trough possibly resulting from (quasi) valley winds between the Tibetan Plateau and basin that enhance PM_{2.5} concentrations.

2.3 PM_{2.5} Emission Sources

Factor analysis of hourly pollutant concentration data, rotated via the varimax method and interpreted using characteristic pollutant “indicators,” revealed that PM_{2.5} sources in Xinjiang are dominated by wind-blown dust, supplemented by oil/gas combustion and minimal coal burning—particularly in regions with weak human activity such as the Irtysh River source area, Hami Basin, and Tarim Basin. In contrast, the northern Tianshan economic belt is primarily controlled by emissions from surrounding large oil and gas fields and wind-blown dust during transport, supplemented by traffic and daily life emissions.

The factor analysis explained 74.22%–93.90% of variance across regions, indicating robust results. For the northern Tianshan economic belt, Factor 1 (32.16% variance) loaded heavily on PM_{2.5}, SO₂, and partially on NO₂, reflecting emissions from oil/gas resource utilization. Factor 2 (29.41% variance) loaded on PM_{2.5} and CO, indicating incomplete hydrocarbon combustion. Factor 3 (20.51% variance) loaded significantly on PM_{2.5} and partially on SO₂, representing coal combustion from power generation, metal smelting, and daily life—key factors affecting air quality in this economically developed region.

2.4 Potential Contribution Area Analysis

Beyond westerly airflow control, PM_{2.5} transport pathways are influenced by local circulation due to topography, solar altitude, and winter continental high pressure. Overall, Xinjiang's local pathway (Path 1) accounts for 80.81% of trajectories but with low PM_{2.5} concentration ($9.36 \text{ g} \cdot \text{m}^{-3}$), indicating negligible environmental impact from local human emissions. The high PM_{2.5} concentration in the northern Tianshan belt is primarily affected by local atmospheric circulation, but airflow passing through oil/gas production areas represents a critical factor in haze and floating dust formation.

Path 2, traversing the Gurbantünggüt Desert and crossing the Tianshan Mountains into the Turpan-Hami Basin, accounts for 11.44% of trajectories with PM_{2.5} at $67.90 \text{ g} \cdot \text{m}^{-3}$. Path 3, passing through Karamay and Kuitun near oil/gas fields, accounts for 16.65% with PM_{2.5} at $33.85 \text{ g} \cdot \text{m}^{-3}$. Path 4, crossing the Tianshan Mountains via Yili, accounts for 14.95% with PM_{2.5} at $70.24 \text{ g} \cdot \text{m}^{-3}$. Notably, although Path 2's PM_{2.5} concentration is only 53.9% of Path 4's, its trajectory proportion is 49.9% higher, making it an important channel for regional PM_{2.5} sources. Path 2 also shows significantly higher concentration variability than other paths, indicating its capacity to either dilute or further elevate pollutant concentrations.

For the Hami Basin, Path 5 (25.18% of trajectories, PM_{2.5}: $51.34 \text{ g} \cdot \text{m}^{-3}$) passes through the Gurbantünggüt Desert and crosses the Tianshan Mountains, while Path 6 (41.97%, $27.57 \text{ g} \cdot \text{m}^{-3}$) follows the southern Tianshan foothills. The higher PM_{2.5} in Path 5 reflects wind-blown dust from the desert, though its lower variability suggests limited influence from the Taklimakan Desert on regional dust storm formation. Path 7 (17.24%, $33.92 \text{ g} \cdot \text{m}^{-3}$) and Path 8 (19.50%, $22.78 \text{ g} \cdot \text{m}^{-3}$) represent airflow from the Tarim Basin via the Turpan-Hami Basin, with high variability indicating frequent northeasterly winds generated by cold high-pressure air from the Junggar Basin entering the eastern Taklimakan Desert under Tianshan blocking—a key factor for high PM_{2.5} and dust storm formation.

Potential source contribution analysis reveals that high-concentration PM_{2.5} in the northern Tianshan economic belt is limited to the Urumqi-Changji-Turpan region, aligning with factor analysis showing dominant oil/gas emissions supplemented by wind-blown dust [Figure 4: see original paper]. For the Hami Basin, high-concentration potential sources are confined to the dry Kongqi River Basin and Lop Nur region on the eastern edge of the Taklimakan Desert, overlapping significantly with the Tarim Basin's contribution area—indicating that PM_{2.5} is primarily supplied by wind-blown sand [Figure 5: see original paper]. The Tarim Basin's high-concentration potential sources are similarly limited to the Kongqi River Basin, Lop Nur, and southern Turpan Basin margins rather than the vast desert interior, likely due to long-distance transport of river sediments with relatively small particle sizes. The east-west Tianshan Mountains gradually flatten east of the Turpan-Kuqa railway, forming a critical channel for rapid

air exchange between basins and promoting dust weather formation.

2.5 Topographic Factors

Terrain and vegetation cover alter airflow direction and velocity, significantly affecting pollutant transport processes. Xinjiang's complex "three mountains, two basins" topography, with the Tianshan Mountains extending north-south along basin margins while maintaining an east-west orientation, plays a crucial role. Westerly airflow crossing the Tianshan Mountains creates foehn winds that dry basin climates, degrade vegetation, and accelerate dust source formation. Meanwhile, relatively cool airflow crossing the mountains, supplemented by valley and glacier winds, increases the probability of temperature inversions in marginal oasis areas, inhibiting pollutant deposition and diffusion. This unique topographic configuration is a key factor causing the similar PM_{2.5} evolution trends between the northern Tianshan economic belt and Tarim Basin.

3. Conclusions

PM_{2.5} concentrations in Xinjiang significantly exceed WHO health standards, particularly in winter, posing serious health threats. Influenced by atmospheric stability, PM_{2.5} exhibits higher nighttime and lower daytime concentrations, with double-peak patterns in the Hami and Tarim Basins due to (quasi) valley wind effects. In regions with weak human activity (Irtys River source, Hami Basin, Tarim Basin), PM_{2.5} originates primarily from wind-blown dust, supplemented by oil/gas combustion and minimal coal burning. The northern Tianshan economic belt is dominated by emissions from large oil/gas field operations and wind-blown dust during transport, supplemented by traffic and daily life emissions.

Beyond westerly airflow control, PM_{2.5} transport is influenced by local circulation. Airflow through oil/gas production areas exhibits dramatic concentration variability, serving as a critical channel for regional PM_{2.5} sources. Cold high-pressure air from the Junggar Basin entering the eastern Taklimakan Desert via the Turpan-Hami Basin under Tianshan blocking generates frequent northerly winds, representing an important mechanism for high PM_{2.5} concentrations and dust storm formation in the Tarim Basin. The evolution of exogenous airflow into convergent/divergent patterns due to basin topography, combined with valley and glacier winds that promote mixing of externally-sourced and locally-supplied pollutants, constitutes a key factor underlying the similar PM_{2.5} evolution trends observed across Xinjiang's major basins.

References

- [1] Almeida S M, Manousakas M, Diapouli E, et al. Ambient particulate matter source apportionment using receptor modelling in European and Central Asia urban areas[J]. *Environmental Pollution*, 2020, 266: 115199.

- [2] EEA. Air Quality in Europe 2018 Report [R]. European Environment Agency, 2018: 1977-8449.
- [3] Atkinson R W, Cohen A, Mehta S, et al. Systematic review and meta-analysis of epidemiological time series studies on outdoor air pollution and health in Asia[J]. *Air Quality Atmosphere and Health*, 2012, 5: 383-391.
- [4] Stanaway J D, Afshin A, Gakidou E, et al. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017[J]. *Lancet*, 2018, 392(10159): 1923-1994.
- [5] Zhang Shuyuan, Cheng Quanguo, Xing Hongbin. Exposure response relationship between PM_{2.5} pollution and death toll of residents based on data mining technology[J]. *Journal of Shenyang University (Natural Science)*, 2022, 34(1): 17-23.
- [6] Yalkunjan Tursun, Dilnur Talifu, Ablikim Ablizi, et al. Pollution level of heavy metals in PM_{2.5} and PM_{10-2.5} during winter in Urumqi[J]. *Journal of Xinjiang University (Natural Science Edition)*, 2010, 27(3): 338-342.
- [7] Yu H, Yang W, Wang X H, et al. A seriously sand storm mixed air polluted area in the margin of Tarim Basin: Temporal spatial distribution and potential sources[J]. *Science of the Total Environment*, 2019, 676: 436-446.
- [8] Wang Jian, Han Haidong, Xu Junli, et al. Chemical characteristics and their influencing factors of precipitation at the end of the Koxkar Glacier, Tianshan Mountains[J]. *Arid Zone Research*, 2022, 39(2): 347-358.
- [9] Hu H, Zhao X Y, Wang J, et al. Chemical characteristics of road dust PM_{2.5} fraction in oasis cities at the margin of Tarim Basin[J]. *Journal of Environmental Sciences*, 2020, 95: 217-224.
- [10] Liu Lin, Zhang Zhengyong, Liu Fen, et al. Spatial temporal distribution and simulation analysis of PM_{2.5} concentration of the cities in the northern slope economic zone of Tianshan Mountain[J]. *Research of Environmental Sciences*, 2018, 31(11): 1849-1857.
- [11] Liu Y X, Teng Y, Liang S, et al. Establishment of PM₁₀ and PM_{2.5} emission inventories from wind erosion source and simulation of its environmental impact based on WEPS Models3 in southern Xinjiang, China[J]. *Atmospheric Environment*, 2021, 248: 118222.
- [12] Meng L, Yang X H, Zhao T L, et al. Modeling study on three dimensional distribution of dust aerosols during a dust storm over the Tarim Basin, Northwest China[J]. *Atmospheric Research*, 2019, 218: 285-295.
- [13] Jin Lili, Li Zhenjie, He Qing, et al. Contributions of dusty weather to dust emission amounts at the northern margin of the Taklimakan Desert[J]. *Journal of Arid Land Resources and Environment*, 2022, 36(7): 133-138.

- [14] Ge Y X, Abuduwaili J, Ma L, et al. Potential transport pathways of dust emanating from the playa of Ebinur Lake, Xinjiang, in arid Northwest China[J]. *Atmospheric Research*, 2016, 178: 196-206.
- [15] Duan Shiguang, Jing Nan, Yang Liuming, et al. Transport pathways and potential sources of PM_{2.5} during the winter in Zhengzhou[J]. *Environmental Science*, 2019, 40(1): 86-93.
- [16] Huang W, Chang S Q, Xie C L, et al. Moisture sources of extreme summer precipitation events in north Xinjiang and their relationship with atmospheric circulation[J]. *Advances in Climate Change Research*, 2017, 8(1): 12-17.
- [17] Gao Weidong. Analysis on element content in Xinjiang soil and contribution to dust aerosol[J]. *Journal of Arid Land Resources and Environment*, 2008, 22(8): 155-158.
- [18] Salmabadi H, Saeedi M. Determination of the transport routes of SO₂ and the areas potentially affected by SO₂ emanating from Khatoonabad copper smelter (KCS), Kerman province, Iran using HYSPLIT trajectory analysis[J]. *Atmospheric Pollution Research*, 2019, 10(1): 321-333.
- [19] Zhang L, Shen F Z, Gao J L, et al. Characteristics and potential sources of black carbon particles in suburban Nanjing, China[J]. *Atmospheric Pollution Research*, 2020, 11(5): 981-991.
- [20] Rupakheti D, Rupakheti M, Abdullaev S F, et al. Columnar aerosol properties and radiative effects over Dushanbe, Tajikistan in Central Asia[J]. *Environmental Pollution*, 2020, 265: 114872.
- [21] Fedkin N M, Li C, Dickerson R R, et al. Linking improvements in sulfur dioxide emissions to decreasing sulfate wet deposition by combining satellite and surface observations with trajectory analysis[J]. *Atmospheric Environment*, 2019, 199: 210-223.
- [22] Liu Xinchun, Zhong Yuting, He Qing, et al. Spatiotemporal pattern of PM₁₀ concentration and impact factors in the hinterland and surrounding area of Taklimakan Desert[J]. *Journal of Desert Research*, 2011, 31(2): 323-330.
- [23] Xiong Huanhuan, Liang Longwu, Zeng Zeng, et al. Dynamic analysis of PM_{2.5} spatial temporal characteristics in China[J]. *Resources Science*, 2017, 39(1): 136-146.
- [24] Ma Mingjie, He Qing, Yang Xinghua, et al. Surface layer wind speed profiles in center and suburbs of Urumqi, China[J]. *Journal of Desert Research*, 2017, 37(4): 755-769.
- [25] Tao Jianhong. Spatial temporal characteristics of sand dust events and influencing factors in Northwest China[J]. *Journal of Desert Research*, 2009, 29(2): 327-334.
- [26] Zhang Zhe, Ding Jianli, Wang Jinjie. Aerosol optical properties over the Ebinur region[J]. *Environmental Science*, 2020, 41(8): 3484-3491.

- [27] Liu Zilong, Dai Bin, Cui Zhuoyan, et al. Concentration characteristics and potential source of atmospheric pollutants: A case study in Urumqi[J]. *Arid Zone Research*, 2021, 38(2): 562-569.
- [28] Yang Xiaoling, Li Yanying, Chen Jing, et al. Transmission of rare strong dust and its process continuous characteristics in Hexi Corridor[J]. *Arid Land Geography*, 2022, 45(5): 1415-1425.
- [29] Chen X L, Song Y G, Li Y, et al. Provenance of subaerial surface sediments in the Tarim Basin, Western China[J]. *Catena*, 2021, 198: 105014.
- [30] Zhou C L, Yang F, Mamtimin A, et al. Wind erosion events at different wind speed levels in the Tarim Basin[J]. *Geomorphology*, 2020, 369: 107386.
- [31] Xu Xiangde, Wang Yinjun, Wei Wenshou, et al. Summertime precipitation process and atmospheric water cycle over Tarim Basin under the specific large terrain background[J]. *Desert and Oasis Meteorology*, 2014, 8(2): 1-11.
- [32] Zhao Z Y, Cao F, Fan M Y, et al. Nitrate aerosol formation and source assessment in winter at different regions in Northeast China[J]. *Atmospheric Environment*, 2021, 267: 118767.
- [33] Song Yougui, Zong Xiulan, Li Yue, et al. Loess sediments and rapid climate oscillation during the last glacial period in the westerlies dominated Central Asia[J]. *Quaternary Sciences*, 2019, 39(3): 535-548.
- [34] Bahtebay J, Zhang F, Ariken M, et al. Evaluation of the coordinated development of urbanization resources environment from the incremental perspective of Xinjiang, China[J]. *Journal of Cleaner Production*, 2021, 325: 129309.
- [35] Gu H H, Wang G H, Zhu W, et al. Gusty wind disturbances and large scale turbulent structures in the neutral atmospheric surface layer[J]. *Science China (Physics, Mechanics & Astronomy)*, 2019, 62(11): 114711.
- [36] Yang Mei, Li Yanying, Zhang Chuanyan, et al. Variation characteristics of spring sandstorm and its typical case analysis in the middle east of Hexi Corridor[J]. *Arid Land Geography*, 2021, 44(5): 1339-1349.
- [37] Carvalho A C, Carvalho A, Gelpi I, et al. Influence of topography and land use on pollutants dispersion in the Atlantic coast of Iberian Peninsula[J]. *Atmospheric Environment*, 2006, 40: 3969-3982.
- [38] Li X, Xia X G, Zhong S Y, et al. Shallow foehn on the northern leeside of Tianshan Mountains and its influence on atmospheric boundary layer over Urumqi, China: A climatological study[J]. *Atmospheric Research*, 2020, 240: 104940.
- [39] Wang W, Samat A, Abuduwaili J, et al. Temporal characterization of sand and dust storm activity and its climatic and terrestrial drivers in the Aral Sea region[J]. *Atmospheric Research*, 2022, 275: 106242.

[40] Sun W T, Gao X, Lei J Q. Shaping effects of sand flow channels on aeolian geomorphology: A case study of the Badain Jaran, Tengger, and Ulan Buh Deserts, northern China[J]. Catena, 2022, 214: 106242.

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

Source: ChinaXiv — Machine translation. Verify with original.