Spatiotemporal Evolution Characteristics of Dust Weather and Climatic Influencing Factors in the Turpan-Hami Region (Postprint)

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Abstract

Utilizing ground meteorological observation data from 11 national meteorological stations and wind direction and speed observations from 192 regional stations in the Turpan-Hami region during 1974–2024, this study analyzes the spatiotemporal variation characteristics of dust weather and its correlation with meteorological elements. The results indicate: (1) Among annual dust weather events in this region, floating dust occurs with the highest frequency, dust storms are the least frequent, and blowing dust is intermediate; spring represents the peak incidence period for dust weather, with blowing dust and dust storms being the second most frequent in summer and least frequent in winter; conversely, floating dust is the second most frequent in autumn and least frequent in summer. (2) The number of dust weather days exhibits a distribution pattern characterized by more in the west and less in the east, and more in basins and less in mountainous areas; Toksun County and Gaochang District in Turpan City are high-incidence regions for floating dust, while blowing dust and dust storms are mainly concentrated at Toksun, Dongkan' er Station, and Naomaohu Station, with very few dust weather events in mountainous regions such as Barkol and Yiwu in Hami City; significant differences also exist in the distribution of wind direction and speed for dust weather across different regions. (3) Over the past 50 years, the number of dust weather days has shown an overall decreasing trend, with floating dust decreasing at the fastest rate of 7.1 d · $(10a)^{-1}$; dust weather was most frequent in the 1970s and least frequent in 2013, while in the recent 10 years, the days of total dust, floating dust, and blowing dust have all exhibited a significant increasing trend; the abrupt change years for annual dust, floating dust, and blowing dust days are 1991, 1995, and 1991, respectively, whereas the abrupt change characteristics of dust storm days are not significant. (4) The number of dust days shows a significant positive correlation with the number of strong wind days and average wind speed, a significant negative correlation with average temperature, but no significant correlation with precipitation, sunshine duration, and other meteorological factors.

Full Text

Abstract

Sand-dust weather refers to a meteorological phenomenon where strong winds lift large quantities of dust and sand from the ground surface, reducing horizontal visibility. Based on horizontal visibility and wind force, sand-dust weather is classified into floating dust, blowing sand, and sandstorms [1]. This is a common hazardous weather event in arid and semi-arid regions. Against the backdrop of global climate warming, sand-dust weather has become a research focus worldwide due to its extensive impact range and severe disaster consequences [2]. Globally, East Asian dust source regions and the Sahara Desert are recognized as major sources of dust [3]. Research indicates that dust activity in East Asia exhibits pronounced spatiotemporal variation characteristics, with increased dust activity during 2000–2019 compared to 1974–1999 [4]; however, since 2000, both the frequency of dust events and the number of sandstorm days in Northwest China have shown a significant decreasing trend [5], though a rebound has been observed in recent years, particularly in sandstorm days [6]. This change has been confirmed to be closely related to the dust transport process from Mongolia to northern China [7].

Xinjiang is one of the high-incidence areas for sandstorms in China [8], with significant regional differences in dust activity: although the number of sandstorm days in southern Xinjiang has decreased, the periphery of the Taklimakan Desert remains a high-incidence area [9]; spring sandstorms in northern Xinjiang are mainly concentrated along the southern edge of the Junggar Basin from Jinghe to Qitai, as well as in the Tacheng Basin and other regions [10]. The Tuha Area (Turpan-Hami region) is not only an important channel connecting mainland China with Central Asia but also a core node of the "Silk Road Economic Belt." Geological studies show that this region developed from northwestern early to middle Jurassic coal-bearing basins, with abundant coal, oil, and other mineral resources [11], and has been designated as a national comprehensive energy base, playing a significant role in ensuring national energy security and promoting the "dual carbon" goals [12]. However, the typical arid and semi-arid climate characteristics make the ecological environment extremely vulnerable, with frequent sand-dust weather events that profoundly impact local socio-economic development, atmospheric environmental quality, and human health, particularly posing serious threats to railways, transportation infrastructure, and energy industries [13]. For example, on May 16, 2023, strong wind and sand-dust weather in Hami City caused 226 km of railway to be buried, vehicle damage and personnel trapped on some road sections, a freight train derailment, and forced interruption of the Lanzhou-Xinjiang Railway. On December 16, 2023, a sandstorm in Turpan City caused direct economic losses of 1.5 billion yuan.

The Tuha Basin is a high-value area for disaster potential from wind-blown sand environments in Xinjiang [14]. Although sand-dust weather in the Turpan Basin showed an overall decreasing trend from 1971 to 2015, it slowly increased after 2000 [15]. During sandstorm processes in Hami City, vertical sinking motion centers of -0.40 m·s^{-1} appear within the boundary layer [16]. However, existing research has mostly focused on local areas, lacking systematic studies on the long-term climatic characteristics of sand-dust weather across the entire Tuha Area and its impact mechanisms. This paper systematically analyzes the climate change characteristics of sand-dust weather in this region over the past 50 years and explores its key climatic driving factors, aiming to clarify the climate evolution patterns and driving mechanisms of dust activity in the area, providing scientific basis and decision-making support for government and relevant departments in sand control, ecological restoration, and air pollution prevention, thereby contributing to sustainable energy-economic development in the region.

1.1 Study Area Overview

The Tuha Area is located in eastern Xinjiang (87°16 -96°23 E, 40°52 -45°05 N), covering Turpan City and Hami City with a total area of 2.1$×10^{5}$ km^2. This region borders Gansu Province to the east, connects with Urumqi to the west, and neighbors Mongolia to the north, serving as an important channel connecting mainland China with Central Asia and West Asia [17]. The Tianshan Mountains traverse the central part of the region, dividing it into southern and northern parts: the north comprises Barkol Kazakh Autonomous County and Yiwu County, while the south comprises the Tuha Basin. The terrain features the central Tianshan Mountains as a high point, with elevation gradually decreasing to the north and south, showing significant topographic relief and complex landforms. The Tuha Area has a typical continental arid climate, with average annual precipitation below 60.0 mm, average annual temperature of 10.7 °C, and extreme high temperatures reaching 48.0 °C, earning it the reputation of "extreme drought" and "extreme heat." The region lies at the intersection of the Tianshan fold belt and the Altun fault zone, with complex geological structures, primarily composed of Jurassic, Cretaceous, and Cenozoic sedimentary rocks, and abundant coal, oil, and natural gas resources. The soil is dominated by desert soil, brown desert soil, and sandy soil, with severe land desertification and sandy desertification in some areas.

The Tuha Area is an important energy and agricultural base in Xinjiang, rich in wind, solar, and coal resources [18]. Large-scale energy development projects such as the Tuha Oilfield and the Sandaoling Coal Mine have been established, undertaking important tasks of "coal transport from Xinjiang" and "power transmission from Xinjiang" [19]. The regional hydrological system is unique, with scarce surface water resources mainly dependent on snowmelt from the Tianshan Mountains, low vegetation coverage, and a fragile ecological environment.

1.2 Data Description

Meteorological element data for the Tuha Area were obtained from the "Tianqing" National Comprehensive Meteorological Information Sharing Platform of the National Meteorological Information Center. Specific datasets include: (1) Temperature and weather phenomenon data: daily average temperature, maximum temperature, minimum temperature, precipitation, and weather phenomenon observations from 11 national meteorological stations in the Tuha Area from 1974 to 2024. (2) Wind direction and speed data: due to equipment iteration and network improvements, early national stations had insufficient wind speed observation equipment, resulting in different data start times. Therefore, daily maximum wind speed, wind direction, and extreme wind speed and direction data from 192 regional meteorological observation stations from 2017 to 2024 were selected to compensate for the spatial observation limitations of national stations and analyze detailed wind field information.

According to the sand-dust weather grade standard (GB/T 20480-2017), sand-dust weather is classified into floating dust, blowing sand, and sandstorm, with occurrence dates counted separately. When any of these phenomena occurs at an observation station within a day (20:00–20:00 Beijing Time), it is recorded as one sand-dust weather day at that station. The average of 11 stations represents the Tuha Area average, with climate values calculated for 1991–2020. Based on local climate characteristics, spring is March–May, summer is June–August, autumn is September–November, and winter is December–February of the following year. Since 2017, sand-dust weather observations in the Tuha Area have changed from manual observation to automatic monitoring by weather phenomenon instruments. Both observation methods follow national standards GB/T 20479-2006 and GB/T 20480-2017 for monitoring and identification, and this change in observation method has no significant impact on the continuity of sand-dust day monitoring data.

1.3 Research Methods

Linear trend testing and the Mann-Kendall (M-K) test [20] were used to analyze climate change trends and transition characteristics of sand-dust weather. Pearson correlation analysis was applied to examine relationships between sand-dust days and meteorological elements, with F-test for significance testing at the $\alpha = 0.05$ level. Spatial distribution characteristics were analyzed using inverse distance weighting interpolation. Since climate abrupt change is an important nonlinear phenomenon in climate systems, and considering the multidimensional nature of climate abrupt change detection, the Standard Normal Homogeneity Test, cumulative anomaly method, and STARS (Sequential T-test Analysis of Regime Shifts) method were employed to reveal changes in meteorological elements. Each of these three abrupt change detection methods has its advantages and limitations: the Standard Normal Homogeneity Test checks whether data conform to normal distribution but has limited sensitivity to skewness and kurtosis; the cumulative anomaly method is intuitive and accurate but suffers from baseline dependence and endpoint effects; the STARS method maintains statistical characteristic stability but has greater uncertainty in precipitation prediction; the M-K test is suitable for detecting monotonic trends but less effective for non-monotonic patterns. To comprehensively and accurately capture the complex changes of climate abrupt changes, these three methods were combined to comprehensively analyze abrupt change characteristics of sand-dust days. This approach effectively overcomes the limitations of single methods in nonlinear, multi-scale abrupt change detection and enhances the reliability of abrupt signal identification through cross-validation.

Mann-Kendall Test: For a time series x with n samples, construct a rank sequence S . Under the assumption of random independence of the time series, define the statistic:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{Var(S_k)}}$$

where UF is the defined statistic, S is the sum of the rank sequence, E(S) is the mean of S , and Var(S) is the variance of S [21]. The reversed sequence UB = -UF . The intersection point of UF and UB (where |UF | > 1.96) indicates an abrupt change point.

STARS Method: (1) Based on t-test, determine the mean values of two consecutive data groups with significant differences:

$$\bar{x}_{diff} = \bar{x}_1 \pm t \cdot \sigma \cdot \sqrt{\frac{2}{l}}$$

where l is the selected regime length for variable X, and t is the t-distribution value at a given confidence level with degrees of freedom l-1. The null hypothesis assumes that variables in both regimes are identical, with the mean value within l years equal to σ^2/l. (2) Calculate the average of the first l values of X as a measure of the regime; in the next l years, the value must reach $\bar{x}_2 = \bar{x}_1 \pm t \cdot \sigma \cdot \sqrt{\frac{2}{l}}$ to be recognized as a regime shift to pattern 2. (3) For each new value x , recheck whether it exceeds $\bar{x}_1 \pm t \cdot \sigma \cdot \sqrt{\frac{2}{l}}$ starting from i; if not, no regime shift has occurred. Recalculate the average $\bar{\text{x}}_1$ to include x and the previous l values of X, then wait for the next value. If x exceeds the $\bar{x}_1 \pm t \cdot \sigma \cdot \sqrt{\frac{2}{l}}$ range, that year is considered the starting point j of the new regime. (4) After determining the new regime starting point, each new x (i > j) is tested using the same method to confirm whether a regime shift has occurred. The same applies in reverse. If the same conditions persist at i = j+1, confidence in the regime shift at time j increases. This confidence change can be measured by the Regime Shift Index (RSI): RSI = Σ $_0$ (x - $\vec{x}$ $_1$)/σ, *where m = 0,1,···,l-1. If the regime shifts upward, x* = x ; if downward, x^* = -x . If RSI is positive, it indicates a regime shift in year j (with confidence level P). Calculate the mean of the new regime, which becomes the new baseline regime, and continue detection to find the next regime shift. For multiple variables, the final result is the average of each variable at the corresponding time.

2.1 Temporal Evolution Characteristics of Sand-Dust Weather

The monthly distribution of total sand-dust days in the Tuha Area shows a unimodal pattern, with the highest number in April (5.5 days), accounting for 17.9% of annual total sand-dust days; the lowest occurs in December (1.2 days), accounting for 3.9%. The sand-dust days in May and March are 4.5 days and 3.8 days, respectively, together comprising 26.7% of the annual total. All intensities of sand-dust days show unimodal distributions. From a seasonal perspective, spring is the concentrated occurrence period for all types of sand-dust weather, accounting for 48.6% of floating dust, 52.6% of blowing sand, 45.6% of sandstorms, and 48.6% of total sand-dust days. Blowing sand and sandstorms are second most frequent in summer and least in winter, while floating dust is second most frequent in autumn and least in summer (Figure 2). No sandstorms occur in December and January. This seasonal distribution is closely related to regional climate and environmental conditions. In spring, frequent cold air outbreaks lead to increased strong wind days, scarce precipitation, thawing soil, rapid temperature rise, and unvegetated surfaces with loose soil, providing abundant dust sources that, combined with topographic effects, result in high sand-dust weather incidence. In summer, as the subtropical high pressure moves northward and the westerly circulation adjusts, precipitation increases significantly and vegetation coverage improves, enhancing surface resistance to wind erosion and weakening overall dust activity. However, rapid surface warming can trigger local convective weather causing gusty winds, leading to blowing sand or sandstorms; therefore, summer sand-dust weather mainly consists of blowing sand and sandstorms.

[Figure 2: see original paper]

Figure 2 shows the interannual variation curves and trend coefficients of average sand-dust days in the Tuha Area from 1974 to 2024. Over the past 50 years, the annual average numbers of total sand-dust days, floating dust days, blowing sand days, and sandstorm days are 30.7 days, 20.4 days, 14.0 days, and 3.8 days, respectively. Floating dust accounts for 66.4% of total sand-dust days, followed by blowing sand at 45.6%, with sandstorms comprising only 12.4%. All intensities show significant decreasing trends: total sand-dust days at -7.1 days $\cdot$ $(10a)^{-1}$, floating dust at -8.5 days $\cdot$ $(10a)^{-1}$, blowing sand at -2.5 days $\cdot$ $(10a)^{-1}$, and sandstorms at -2.0 days $\cdot$ $(10a)^{-1}$. Floating dust decreases fastest, with blowing sand and sandstorms showing similar rates, consistent with trends in western southern Xinjiang [22]. The 1970s had the most sand-dust weather (72.2 days in 1974), while 2013 had the least (27.5 days). Cubic function fitting shows (Figure 3) that total sand-dust days remained in a stable high period before the mid-1980s, began decreasing after the mid-1980s, dropped below the average in the mid-1990s, reached a valley in 2013, then increased after 2013, rising above the average in 2021 to reach the highest value since 2013. Floating dust shows similar variation characteristics. Blowing sand days increased during the 1970s, peaked in 1984, then continuously decreased, dropping below the average in the early 1990s. Sandstorm days decreased from the 1970s, fell below the average in the mid-1990s, then increased after 2013 but remained below average in a low period (Figure 3).

[Figure 3: see original paper]

Trend analysis (Table 1) shows that total sand-dust days decrease in all seasons, with rates of -3.5 days$\cdot$(10a)$^{-1}$ in spring and -2.5 days$\cdot$(10a)$^{-1}$ in winter (both significant at $\alpha = 0.01$), while summer and autumn trends are not significant. Floating dust decreases fastest in spring and winter, with summer and autumn trends slower and winter not passing significance tests. Blowing sand decreases faster in spring and summer, slower in autumn and winter, but none pass significance tests. Sandstorm days in spring show a decreasing trend but do not pass significance tests. Thus, the overall decrease in total sand-dust weather days is mainly caused by significant reductions in floating dust in winter-spring and sandstorms in spring-summer-autumn.

2.2 Abrupt Change Characteristics of Sand-Dust Weather

Abrupt change tests for sand-dust days in the Tuha Area were conducted at $\alpha = 0.05$ significance level. The UF curve for total sand-dust days shows a decreasing trend after 1985 (Figure 4). The UF value exceeds the 0.05 confidence level critical line after 1994, indicating a highly significant decreasing trend. The UF and UB curves intersect in 1995, with the intersection point within the critical lines, suggesting 1995 as an abrupt change year. The Standard Normal Homogeneity Test calculates the abrupt change year as 1995, the cumulative anomaly method as 1994, and the STARS method as 1995. Comprehensive judgment identifies 1995 as the abrupt change year for total sand-dust days. Similar calculations identify abrupt change years for floating dust and blowing sand days as 1991 and 1995, respectively, while sandstorm days show no significant abrupt change characteristics (Figure 4).

[Figure 4: see original paper]

2.3 Spatial Distribution Characteristics of Sand-Dust Weather

Total sand-dust days, floating dust, blowing sand, and sandstorm days in the Tuha Area all show a distribution pattern of more in the west and less in the east, and more in basins and less in mountainous areas (Figure 5). Tuokexun in Turpan City has the most total sand-dust days (87.6 days), followed by Gaochang District (74.3 days). Barkol and Yiwu in Hami City have very few sand-dust days (only 3.1–3.2 days). Floating dust days are highest in Gaochang District (69.9 days), followed by Tuokexun (64.4 days), with Barkol having less than 1.0 day. Blowing sand shows two high-value centers: Tuokexun and East Kan’ er Station in Turpan City (31.5–37.0 days), and Naomaohu Station in Hami City (21.3 days). Sandstorm days are highest at East Kan’ er Station (16.0 days), followed by Naomaohu Station (9.0 days), while Yiwu, Barkol, Shisanjianfang, and Hongliuhe stations have less than 1.0 day. Due to the basin terrain in southern Tuha Area, surrounded by mountains, cold air descending into the basin creates downslope wind effects that increase wind speed. The region is mostly Gobi desert with the Kumtagh Desert, making it highly susceptible to wind erosion. Additionally, stable atmospheric stratification after blowing sand and sandstorm events favors long-term suspension of fine dust particles in the air [23]. Therefore, sand-dust weather occurs more frequently in basins than in mountainous areas. The western Turpan Basin has significantly lower elevation than the eastern part, making topographic effects more pronounced.

[Figure 5: see original paper]

2.4 Climatic Impact Factors of Sand-Dust Weather

To further analyze the climatic driving mechanisms of sand-dust weather changes, factors including annual strong wind days, average wind speed, average temperature, maximum temperature, minimum temperature, annual precipitation, and relative humidity were selected to analyze relationships between dynamic, thermal, and moisture factors and sand-dust weather. Due to Shisanjianfang Station’ s location in a wind gap area with 131.5 strong wind days annually and only 9.5 sand-dust days, to accurately reflect the relationship between sand-dust weather and strong winds, this station was excluded, and the average of the remaining 10 stations was used. Correlation coefficients and climate tendency rates between sand-dust days and meteorological elements were calculated (Table 2).

Strong wind days and average wind speed have the greatest impact on sand-dust weather in the Tuha Area. Correlation coefficients between all intensities of sand-dust weather and strong wind days exceed 0.70 (significant at $\alpha = 0.01$), and correlation coefficients with average wind speed exceed 0.60 (significant at $\alpha = 0.01$). Wind is the core condition for dust “lifting-transport-maintenance.” Over the past 50 years, the climate tendency rates for strong wind days and average wind speed in the Tuha Area are -2.64 days $\cdot$ $(10a)^{-1}$ and -0.02 $m \cdot s^{-1} \cdot (10a)^{-1}$, respectively (both significant at $\alpha = 0.05$). The decrease in strong wind days and reduction in average wind speed weaken the dynamic capacity for dust emission and transport, resulting in decreased sand-dust weather days.

Further analysis using daily wind speed and direction data from 192 regional meteorological stations shows that wind speed varies widely during sand-dust weather events. Maximum wind speed for floating dust ranges from 4.4–10.3 $m \cdot s^{-1}$, with extreme wind speed of 7.9–15.2 $m \cdot s^{-1}$, highest at Hongliuhe Station. For blowing sand, maximum wind speed is 7.5–22.2 $\mathrm{m \cdot s^{-1}}$, extreme wind speed 10.2–29.5 $\mathrm{m \cdot s^{-1}}$. For sandstorms, maximum wind speed is 18.7–39.0 $\mathrm{m \cdot s^{-1}}$, extreme wind speed 13.8–28.9 $\mathrm{m \cdot s^{-1}}$. Both blowing sand and sandstorm maximum wind speeds occur at Shisanjianfang Station (Figure 6). During floating dust events, the most frequent wind directions are easterly at Turpan East Kan' er Station and Gaochang District, northeasterly at Yizhou District (Hami), northerly at Shisanjianfang Station, and between northwesterly and southwesterly at other stations. For blowing sand, Yizhou District shows northeasterly winds, Shisanjianfang and Shanshan have northerly winds, while other stations are between northwesterly and westerly. For sandstorms, Shisanjianfang Station has northerly winds, other stations are between northwesterly and westerly, and Yiwu has equal frequency of northerly and northwesterly winds.

[Figure 6: see original paper]

Temperature shows significant negative correlation with sand-dust days. Correlation coefficients between total sand-dust days, floating dust days, and sandstorm days with average, maximum, and minimum temperatures are all <-0.5 (significant at $\alpha = 0.01$). Correlation coefficients between blowing sand days and average, maximum, and minimum temperatures are -0.45, -0.44, and -0.42, respectively (significant at $\alpha = 0.05$). Over the past 50 years, climate tendency rates for average, maximum, and minimum temperatures are 0.54 $°\mathrm{C} \cdot (10\mathrm{a})^{-1}$, 0.43 $°\mathrm{C} \cdot (10\mathrm{a})^{-1}$, and 0.72 $°\mathrm{C} \cdot (10\mathrm{a})^{-1}$, respectively, showing significant warming trends. Temperature increase favors vegetation growth, reduces surface bareness, enhances sand fixation capacity, and thereby suppresses sand-dust weather. Correlations between sand-dust days and relative humidity or precipitation are not significant, indicating they are not major influencing factors causing sand-dust weather changes.

3 Discussion

As a typical region in the arid zone of Northwest China, the temporal evolution, spatial distribution, and climatic driving mechanisms of sand-dust weather in the Tuha Area are important for understanding dust activity patterns in arid regions. This study uses statistical analysis to examine changes, trends, and main climatic impact factors of sand-dust days over the past 50 years, and analyzes dust-raising wind directions and speeds for different sand-dust intensities using regional automatic station data, providing basis for sand-dust weather research and disaster prevention in the region.

The high incidence of various sand-dust weather types in spring and higher frequency in basins than mountains result from combined effects of geographical environment, meteorological conditions, and seasonal atmospheric circulation changes [24]. The overall decreasing trend of sand-dust days in recent decades, but significant increase in total, floating dust, and blowing sand days in the past decade, is consistent with sandstorm trends in northern China [6]. Strong wind days and average wind speed are the core dynamic factors driving sand-dust activity in the Tuha Area, with their significant correlations with sand-dust days (correlation coefficients >0.60) and significant decreasing trends directly explaining the overall reduction in sand-dust days, consistent with the consensus that "wind is the key condition for dust lifting-maintenance" in arid regions [25]. The insignificant impact of precipitation and relative humidity on sand-dust processes is related to the characteristics of low total precipitation and strong locality in arid regions, which make it difficult to effectively improve surface resistance to wind erosion, reflecting the low sensitivity of dust activity to moisture conditions in arid regions.

The spatiotemporal characteristics of sand-dust weather in the Tuha Area result from combined effects of regional climate, topography, and underlying surface conditions. Future research should integrate finer surface parameters (such as vegetation coverage and soil moisture) and numerical simulations to further reveal the driving mechanisms of the recent rebound in dust activity, providing scientific basis for precise prevention and control of sand-dust disasters in arid regions.

4 Conclusions

Analysis of spatiotemporal variations of sand-dust weather in the Tuha Area and its correlation with meteorological elements yields the following main conclusions:

(1) Over the past 50 years, monthly variations in sand-dust days show a unimodal distribution, peaking in April. Floating dust occurs most frequently, followed by blowing sand, with sandstorms being the least frequent. Sand-dust weather concentrates in spring, with the least floating dust in summer and least blowing sand and sandstorms in winter. The 1970s had the most sand-dust days, while 2013 had the fewest. In the past decade, total, floating dust, and blowing sand days have shown significant increases, reaching the highest values since 2013. Abrupt change years for total, floating dust, and blowing sand days are 1995, 1991, and 1995, respectively, while sandstorm days show no clear abrupt change.

(2) Influenced by topography, all types of sand-dust days show a distribution pattern of more in the west and less in the east, and more in basins and less in mountainous areas. High-incidence floating dust areas are Tuokexun and Gaochang District in Turpan City, while blowing sand and sandstorms concentrate at Tuokexun-East Kan' er Station and Naomaohu Station. Mountainous areas such as Barkol and Yiwu in Hami City experience very little sand-dust weather. Basin terrain facilitates dust raising and floating dust retention, with more pronounced topographic effects in the lower-elevation western areas.

(3) All sand-dust weather types show significant decreasing trends annually and in all seasons, with floating dust decreasing fastest, followed by similar rates for blowing sand and sandstorms. The decrease in total sand-dust

weather days is mainly caused by significant reductions in floating dust in winter-spring and sandstorms in spring-summer-autumn.

(4) The reduction in sand-dust days in the Tuha Area is primarily influenced by decreasing average wind speed, reducing strong wind days, and rising temperatures. Wind speed varies widely during sand-dust weather events, with maximum wind speeds of 4.4–29.5 $\mathrm{m \cdot s^{-1}}$ and extreme wind speeds of 7.9–39.0 $\mathrm{m \cdot s^{-1}}$; stronger winds correspond to more intense sand-dust weather. Floating dust wind directions show significant regional differences, while blowing sand and sandstorms at Shisanjianfang Station are consistently northerly, and mostly northwesterly to westerly at other stations.

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