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Spatiotemporal Variation Characteristics of Dust Weather in the Qaidam Basin over the Past 60 Years and Its Influencing Factors: Postprint

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Abstract

Utilizing meteorological data from 9 representative stations in the Qaidam Basin over a 58-year period, including sand-dust days, floating dust days, sandstorm days, temperature, precipitation, relative humidity, and other elements, the spatiotemporal variation characteristics of dust weather (sand-dust, floating dust, sandstorm) and their influencing factors were analyzed through statistical methods, Mann-Kendall test, wavelet analysis, and other approaches. The results indicate: (1) Over the past 58 years, the number of sand-dust days, floating dust days, and sandstorm days has shown an extremely significant decreasing trend overall, with the highest number of dust weather days occurring in the 1970s and the lowest in the early 21st century; (2) The number of sand-dust days experienced an abrupt change in 1997, showing a decreasing trend thereafter; (3) The number of sandstorm days exhibits a long cycle of 10–15 years and a short cycle of 5–7 years, the number of sand-dust days also shows a long cycle of 10–15 years, while the number of floating dust days shows no significant periodicity; (4) The spatial distribution pattern of dust weather in the Qaidam Basin is generally characterized by more occurrences in the southwest and fewer in the northeast; (5) The number of sand-dust days, floating dust days, and sandstorm days is positively correlated with atmospheric pressure, gale days, and the area and intensity of the Asian polar vortex, and negatively correlated with temperature, the Tibetan Plateau index, the India-Burma trough index, and the area and intensity of the Western Pacific subtropical high and the Indian Ocean warm pool.

Full Text

Spatiotemporal Variation Characteristics of Dust Weather and Its Influencing Factors in Qaidam Basin in Recent 60 Years

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Abstract: Using meteorological data from nine representative stations in Qaidam Basin, including daily observations of blowing sand, floating dust, sandstorms, temperature, precipitation, and relative humidity over a 58-year period, this study analyzes the spatiotemporal variation characteristics of dust weather and its influencing factors through statistical methods, Mann-Kendall tests, and wavelet analysis. The results indicate that the number of days with blowing sand, floating dust, and sandstorms in Qaidam Basin has shown an extremely significant decreasing trend over the past 58 years, with the highest frequency occurring in the 1970s and the lowest in the 2000s. The blowing sand days experienced an abrupt change in 1997, after which a declining trend became evident. Sandstorm days exhibited a long periodicity of 10–15 years and a short periodicity of 5–7 years, while blowing sand days also showed a 10–15 year cycle throughout the time series; floating dust days displayed no significant periodicity. The spatial distribution pattern of dust weather in Qaidam Basin is characterized by more frequent events in the southwest and fewer in the northeast. The number of dust weather days was positively correlated with atmospheric pressure, gale days, and the area and intensity of the Asian polar vortex, but negatively correlated with temperature and the area and intensity of the Western Pacific subtropical high, Tibetan Plateau index, Indo-Burma trough index, and Indian Ocean warm pool.

Keywords: blowing sand days; floating dust days; sandstorm days; spatiotemporal variation; Qaidam Basin

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1 Study Area Overview

Qaidam Basin is located in the northwestern part of Qinghai Province (Fig. 1), surrounded by the Altun, Kunlun, and Qilian Mountains, forming an intermontane basin approximately 800 km long from east to west and 300 km wide from north to south, covering an area of about 258,000 km^2. The basin elevation ranges from 2,651 to 6,151 m, with distinct vertical differentiation. Annual precipitation is 15-200 mm, relative humidity is 30%-40%, and the annual average temperature is below 5°C. The region experiences strong evaporation, scarce rainfall, and powerful winds, with 25-75 days of gale-force winds ($ 8 on the Beaufort scale) annually, occasionally reaching extreme speeds of 40 m· s^{-1}$. These conditions create a typical plateau continental climate with intense wind erosion and deposition processes [Figure 1: see original paper].

2.1 Data Sources

To ensure data integrity and representativeness, we selected nine meteorological stations in Qaidam Basin: Dachaidan, Nuomuhong, Xiazaohuo, Dulan, Lenghu, Mangya, Delingha, Golmud, and Chaka. The data, obtained from the China Integrated Meteorological Information Service System (CIMISS), includes daily observations of blowing sand, floating dust, sandstorms, temperature, precipitation, relative humidity, and gale days from 1961 to 2018. Seasonal divisions follow the standard climatic periods: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February). The Tibetan Plateau index is defined as the cumulative value of 500 hPa geopotential height field deviations from 580 dagpm across grid points within 30°-40°N, 75°-105°E, where larger values indicate higher geopotential heights.

2.2 Calculation Methods

Linear trend estimation was employed to calculate the temporal trends in dust weather days, with t-tests used to determine statistical significance. The Mann-Kendall test identified abrupt changes, while wavelet analysis revealed periodic variations in dust weather events.

3.1.1 Interannual Variation of Dust Weather

Figure 2 shows the interannual variation of blowing sand, floating dust, and sandstorm days in Qaidam Basin from 1961 to 2018. All three types of dust weather exhibited extremely significant decreasing trends ($\alpha = 0.01$), with rates of -2.6 days $\cdot$ (10a)$^{-1}$ for blowing sand, -4.3 days $\cdot$ (10a)$^{-1}$ for floating dust, and -0.8 days $\cdot$ (10a)$^{-1}$ for sandstorms. The average annual frequencies were 14.6 days for blowing sand, 6.2 days for floating dust, and 1.5 days for sandstorms. Peak occurrences were observed in 1962 (blowing sand: 45 days; floating dust: 28 days; sandstorm: 9 days), while minimum values occurred in 2014 for blowing sand (1 day) and sandstorms (0 days), and in 2017 for floating dust (0 days).

Notably, the 1970s showed the highest dust weather frequency, whereas the early 21st century had the lowest [Figure 2: see original paper].

3.1.2 Seasonal Variation of Dust Weather

Dust weather in Qaidam Basin exhibits pronounced seasonal characteristics, with frequencies decreasing in the order: spring (March–May) > summer (June–August) > winter (December–February) > autumn (September–November). Spring accounts for 44.8% of annual dust events, followed by summer (24.2%), winter (16.8%), and autumn (14.2%), making spring the primary season for dust weather occurrence. This pattern aligns with Qinghai Province' s climate characteristics of concurrent rainfall and heat during the growing season. In spring, floating dust and blowing sand days are similar (both exceeding 6 days), more than double the sandstorm frequency. In summer, the frequency order is blowing sand > floating dust > sandstorm, while autumn and winter show similar patterns to summer, though with overall lower frequencies [Figure 3: see original paper].

3.1.3 Monthly Variation of Dust Weather

Monthly analysis reveals that dust weather frequency increases significantly before June at a rate of 6.4 days $\cdot$ $(10a)^{-1}$, peaking in May with 6.4 days of floating dust, 2.9 days of blowing sand, and 1.1 days of sandstorms. After June, the trend reverses with a decreasing rate of -1.9 days $\cdot$ $(10a)^{-1}$. The second-highest frequency occurs in April (floating dust: 2.6 days; blowing sand: 2.6 days; sandstorm: 0.9 days). Minimum frequencies appear in December (blowing sand: 0.4 days; floating dust: 0.3 days; sandstorm: 0.1 days). The 1970s peak in dust activity corresponds to a period dominated by La Niña events, which increased cold wave activity and strong winds in northern China. Research indicates that dust weather days and gale days show consistent temporal trends with significant correlation, confirming that strong winds are a necessary condition for dust events. The maximum gale days in Qaidam Basin occurred during the 1970s, with the highest frequency in 1972, matching the dust weather peak.

3.1.4 Interdecadal Variation of Dust Weather

Table 1 presents the decadal anomalies of dust weather days relative to the climatic average. The 1970s had the highest frequencies (blowing sand: +5.8 days; floating dust: +3.4 days; sandstorm: +1.6 days), while the 2000s had the lowest (blowing sand: -6.1 days; floating dust: -3.1 days; sandstorm: -0.9 days). Positive anomalies occurred from the 1960s through the 1970s, indicating an upward trend, while negative anomalies from the 1980s onward reflect a decreasing trend. The 1970s peak coincided with reduced precipitation and increased human activities such as blind reclamation and overgrazing, which accelerated desertification. Combined with peak gale days and dry climatic conditions, these factors created optimal conditions for dust weather .

3.2 Abrupt Change Detection in Dust Weather

Mann-Kendall tests reveal that blowing sand days underwent a significant abrupt change in 1997 (Fig. 4). The UF statistic shows an increasing trend before the 1990s, followed by a decreasing trend afterward, with the UF and UB curves intersecting within the critical lines in 1997, indicating a significant downward shift. Floating dust and sandstorm days showed intersection points outside the critical lines, preventing definitive identification of abrupt change points. Previous research indicates that global warming since the mid-1980s, particularly after 1997, has led to warming and wetting trends in Qaidam Basin, with decreasing cold air activity and gale days corresponding to reduced dust weather. This suggests that climate warming and wetting are primary drivers of the abrupt change in dust activity [Figure 4: see original paper].

3.3 Periodic Variation of Dust Weather

Wavelet analysis reveals that sandstorm days exhibit a significant 10–15 year periodic oscillation throughout the time series, with a central scale of 13 years and alternating positive/negative phases. A shorter 5–7 year cycle exists during 1970–1990. Blowing sand days also show a pronounced 10–15 year periodicity with a central scale of 12 years. Floating dust days display no significant periodicity. These periodicities reflect the influence of large-scale atmospheric circulation patterns on dust weather variability [Figure 5: see original paper].

3.4 Spatial Variation Characteristics of Dust Weather

Using inverse distance weighting interpolation on data from nine representative stations, we analyzed the spatial distribution of dust weather days. Blowing sand occurs most frequently in Xiazaohuo and Golmud in the southern basin (20–25 days), with a secondary center in Mangya in the northwest (14–17 days), forming a southwest-to-northeast decreasing gradient. Floating dust shows a similar pattern but with lower frequencies, concentrated in Mangya and Golmud (17–21 days), affecting primarily the southern and western regions. Sandstorms are most frequent in Mangya and Xiazaohuo (6–7 days), with a secondary center in Golmud (7–9 days), decreasing eastward due to abundant sand sources in the west and westerly wind control. This creates a clear west-to-east diminishing pattern [Figure 6: see original paper].

3.5.1 Analysis of Meteorological Factors

Partial correlation analysis (Table 2) shows significant relationships between dust weather days and meteorological elements. Atmospheric pressure and gale days are positively correlated with all three dust types ($p < 0.01$), indicating that higher pressure and more gale days increase dust frequency. Temperature is negatively correlated with dust days ($p < 0.01$), suggesting that warmer conditions reduce dust activity. Total cloud cover is positively correlated with floating dust days ($p < 0.05$). These relationships confirm that dynamic conditions (wind) and thermal conditions (temperature) are critical factors for dust weather formation .

3.5.2 Analysis of Atmospheric Circulation Factors

Dust weather formation is closely linked to large-scale circulation patterns. Table 3 shows that blowing sand, floating dust, and sandstorm days are negatively correlated with the area and intensity of the Western Pacific subtropical high ($p < 0.01$), but positively correlated with the area and intensity of the Asian polar vortex ($p < 0.01$). Negative correlations also exist with the Tibetan Plateau index, Indo-Burma trough index, and Indian Ocean warm pool area/intensity ($p < 0.01$). When the Western Pacific subtropical high is strong, westerly flow is blocked, reducing dust transport. A weak polar vortex results in weaker cold air activity and reduced wind-driven dust lifting. A high Tibetan Plateau index indicates lower geopotential heights and increased precipitation, suppressing dust. A deep Indo-Burma trough enhances precipitation over the plateau, while a strong Indian Ocean warm pool brings warm air masses that inhibit cold air intrusion, all contributing to reduced dust weather .

4 Conclusions

1) Over the past 58 years, Qaidam Basin has experienced an extremely significant decreasing trend in blowing sand, floating dust, and sandstorm days. The 1970s had the most frequent dust weather, while the 2000s had the least. Blowing sand days underwent an abrupt change in 1997, while no clear abrupt change points were identified for floating dust or sandstorm days. Periodic analysis reveals a 10–15 year cycle for sandstorm days throughout the series, with an additional 5–7 year cycle during 1970-1990, and a 10–15 year cycle for blowing sand days, while floating dust days show no significant periodicity.
2) Spatially, blowing sand is most frequent in Xiazaohuo and Golmud (southwest), forming a southwest-to-northeast decreasing pattern. Floating dust

is concentrated in Mangya and Golmud (southwest and west). Sandstorms are most frequent in Mangya and Xiazaohuo, decreasing from west to east.

3) Dust weather days are positively correlated with atmospheric pressure, gale days, and Asian polar vortex area/intensity, but negatively correlated with temperature and the area/intensity of the Western Pacific subtropical high, Tibetan Plateau index, Indo-Burma trough index, and Indian Ocean warm pool. These relationships underscore the combined influence of local meteorological conditions and large-scale atmospheric circulation on dust weather variability in Qaidam Basin.

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