Temporal Distribution and Variation Characteristics of Dust Storms in the Hotan Region (Postprint)

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Abstract

Using sandstorm monitoring data from four meteorological stations spanning 1961–2018, this study analyzes the distribution characteristics and temporal variation trends of sandstorm frequency and duration in the Hotan region, and investigates the underlying causes of long-term changes. The results indicate: (1) The Hotan region experiences an annual average of 20.4 d, ranking among the areas with the highest sandstorm occurrence in China. (2) Sandstorm frequency peaks during spring and summer, reaching its maximum in May; sandstorm process duration is longest in December during winter and shortest in June during summer; sandstorms lasting 1-30 min occur most frequently. (3) Sandstorms can occur at any hour of the day in the Hotan region, with the highest frequency observed 18:00–23:00; sandstorms initiating from late night through morning exhibit the longest durations. (4) Sandstorms originate from all 16 wind direction sectors in the Hotan region, with western-path sandstorms exhibiting both higher wind speeds and greater frequencies compared to other pathways. (5) In the Hotan region, sandstorms may be triggered when maximum wind speeds reach 3.0 m·s-1, and in 87.5% of sandstorm events, the extreme wind speed does not meet the gale standard. (6) Over the past 58 years, the annual number of sandstorm days in the Hotan region has decreased significantly, concurrent with significant reductions in annual gale days and maximum wind speed; sandstorm frequency was highest during the 1960s and decreased markedly from the 1990s onward, while sandstorm process duration was longest during the 1970s–1980s and shortened significantly from the 2000s.

Full Text

Temporal Distribution and Variation Characteristics of Sandstorms in Hotan Prefecture

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Abstract

Using sandstorm monitoring data from 1961 to 2018, this study analyzes the distribution characteristics and variation trends of sandstorm frequency and duration in Hotan Prefecture, and explores the causes of long-term sandstorm variation. The results indicate that: (1) Hotan experiences an average of 20.4 sandstorm days annually, making it one of the regions with the highest sandstorm frequency in China. Sandstorms occur most frequently in spring and summer, peaking in May. December sandstorms exhibit the longest durations, while June sandstorms are the shortest. The most common sandstorms last 1–30 minutes, accounting for 75.9% of all events. Although sandstorms can occur at any time of day, they appear most frequently between 18:00–23:00, while those occurring from midnight to morning have the longest durations. (2) Sandstorms can originate from 16 wind directions in Hotan, with western path sandstorms showing higher wind speeds and frequencies than other paths. Sandstorms can be triggered by maximum wind speeds as low as $3.0\ \mathrm{m \cdot s^{-1}}$, with 87.5% of events occurring when maximum wind speeds do not reach gale-force criteria. (3) Over the past 58 years, annual sandstorm days, gale days, and maximum wind speeds have all decreased significantly. Sandstorm frequency peaked in the 1960s and began decreasing markedly from the 1990s. Sandstorm durations were longest during the 1970s–1980s and have shortened significantly since the 2000s. The decline in sandstorm frequency is closely related to decreasing gale frequency, weakening maximum wind speeds, and improving vegetation cover.

Keywords: sandstorm frequency; duration; variation characteristics; Hotan Prefecture

Introduction

Sandstorms are typical hazardous weather phenomena in arid and semi-arid regions, defined as strong winds lifting large quantities of sand and dust into the air, causing severe air turbidity with horizontal visibility below 1 km. Research on sandstorms has been internationally conducted since the 1960s, covering monitoring, spatiotemporal distribution, causes, and countermeasures. Chinese research began later, with early work by Xu Guochang et al. analyzing a severe sandstorm in Gansu's Hexi Corridor on April 22, 1977. A historically rare severe sandstorm on May 5, 1993, in northwestern China drew significant scientific, governmental, and public attention, promoting extensive sandstorm research. Current research encompasses sandstorm climatic characteristics, relationships with meteorological factors, elemental variations and physical features during sandstorm events, aerosol transport characteristics, numerical simulation, and satellite remote sensing detection methods.

For Xinjiang, numerous recent studies have documented sandstorm climatic characteristics, revealing a generally decreasing trend in sandstorm frequency, with southern Xinjiang experiencing approximately 10 times more sandstorm days than northern Xinjiang. Both regions show abrupt changes, though southern Xinjiang oasis areas surrounding the Taklamakan Desert exhibit varying frequencies due to differences in weather systems, topography, and vegetation cover, with Hotan showing higher frequencies than other regions.

Located in southernmost Xinjiang (34°22 -39°38 N, 77°31 -84°55 E), Hotan Prefecture spans 570–648 km east-west and 420–580 km north-south. The terrain slopes downward from south to north, bordering the Kunlun Mountains and Tibet Autonomous Region to the south, the Taklamakan Desert and Aksu to the north, Bayingolin Mongol Autonomous Prefecture to the east, and Kashgar to the west. With a total area of 24.78$\times10^{4}$ km^2 (33.3% mountains, 63.7% desert and Gobi, and only 3% oasis), Hotan represents one of China' s most severely sandstorm-affected regions. While Liu Haitao et al. examined spatiotemporal distribution characteristics, their study had a relatively short time series and rarely addressed duration variations, climate abrupt changes, or relationships with meteorological elements. This study utilizes daily sandstorm monitoring data from 1961–2018 to analyze frequency and duration distribution characteristics and trends, employs cumulative anomaly methods to detect climate abrupt changes, and discusses long-term variation causes to provide scientific basis for comprehensive understanding, forecasting, warning, and disaster prevention of sandstorms in Hotan.

[Figure 1: see original paper] The geographical characteristics of Hotan Prefecture

1 Data and Methods

Data were obtained from four meteorological stations in Hotan Prefecture: Hotan City and Minfeng (national reference stations), and Pishan and Yutian (national basic stations). All stations record weather phenomena with start/end times, providing complete datasets. Sandstorm statistics follow the *Surface Meteorological Observation Standards*: for daily variation analysis, the meteorological day boundary is 20:00 Beijing Time; if a sandstorm crosses 20:00, it is counted as occurring on the day it began. If multiple sandstorms occur in one day, each is counted separately.

Sandstorm start-time frequency refers to the count of sandstorms beginning within a given hour (e.g., 18:00–18:59 counted as 18:00). If a sandstorm spans multiple hours, only the starting hour is recorded. Duration is calculated as the time interval from start to end (e.g., 18:05–19:43 = 1 h 38 min). Sandstorms crossing 20:00 are treated as continuous processes; if a process records two or more sandstorms, start times and durations are counted separately for each period. Since meteorological departments ceased nighttime weather phenomenon observations after 20:00 starting in 2001, duration statistics for 2001–2018 only include sandstorms ending before 20:00.

Maximum wind speed refers to the 10-minute average wind speed during sandstorm events, with wind direction defined as the most frequent direction during the maximum wind period. Data were organized annually and seasonally (March–May: spring; June–August: summer; September–November: autumn; December–February: winter). Regional averages represent the mean of all four stations. All statistical analyses were performed using linear regression, cumulative anomaly, and signal-to-noise ratio methods.

2 Distribution Characteristics of Sandstorm Frequency and Duration

2.1 Sandstorm Frequency Distribution Characteristics

From 1961–2018, Hotan Prefecture averaged 20.4 sandstorm days annually. Minfeng recorded the highest frequency at 32.3 days/year, followed by Hotan City (20.2 days/year), Pishan (17.6 days/year), and Yutian (11.4 days/year). Regional sandstorm days peaked in 1985 at 62 days and reached a minimum of 6.8 days in 2012. Minfeng alone peaked at 48 days in 1962 and bottomed at 17 days in 2012—exceeding frequencies in Minqin, another major sandstorm region, making Hotan one of China' s most sandstorm-prone areas.

2.1.1 Monthly and Seasonal Distribution Monthly sandstorm frequency in Hotan shows a single-peak pattern (Figure 2), with frequencies exceeding 10% during March–July and above 15% during April–June. The peak occurs in May at 20.4%. Seasonally, spring accounts for 44.9% of annual sandstorms and summer for 33.2%, while autumn and winter contribute only 15.6% and 6.3%, respectively. Spring' s high frequency aligns with frequent cold air activity in southern Xinjiang, intense warming of the Taklamakan Desert in late spring/early summer forming thermal lows, and exposed, loose soil surfaces during key agricultural periods—providing favorable conditions for sandstorm development when weather systems become active.

2.1.2 Diurnal Distribution Hourly analysis reveals a triple-peak pattern (Figure 3), with the primary peak at 18:00–23:00 (38.0% of total frequency), secondary peaks at 11:00 and 14:00 (11.0% and 10.4%, respectively), and the lowest frequency at 05:00–07:00 (1.1%). Sandstorms occur mainly in morning and evening, with the primary peak in the evening. This diurnal pattern matches high-frequency periods for extreme precipitation, suggesting atmospheric instability during afternoon-to-evening hours facilitates both phenomena.

2.2 Sandstorm Duration Distribution Characteristics

2.2.1 Monthly and Seasonal Distribution Average sandstorm duration is 49 minutes. The most frequent durations are 1–30 minutes (75.9% of events), with frequencies decreasing progressively as duration increases. Yutian and Pishan show 1–30 minute frequencies of 84.8% and 82.1%, respectively, while Hotan and Minfeng show 71.2% and 68.3%. For durations exceeding 120 minutes, Hotan and Minfeng have higher frequencies (9.3% and 11.1%) than Yutian and Pishan (2.8% and 3.2%).

Monthly duration analysis shows December with the longest average duration (2 h 12 min) and June the shortest (1 h 35 min). Seasonally, winter durations are longest, followed by spring, with summer shortest. This pattern reflects stable autumn-winter weather patterns, weakened cold air activity in southern Xinjiang, and high atmospheric stability in winter—making sandstorms rare but typically longer-lasting when strong synoptic systems occur.

2.2.2 Diurnal Distribution Sandstorms can occur at any hour, but those starting at 18:00–23:00 have the shortest average durations (1 h 28 min), while those from midnight to morning last longest (2 h 28 min). Minfeng shows the longest durations starting at 11:00 (4 h 43 min), while other stations show longer durations for sandstorms beginning in the post-midnight to morning period compared to afternoon to pre-midnight starts. This reflects atmospheric stability patterns and reduced local convective sandstorms during more stable overnight hours.

2.3 Maximum Wind Speed During Sandstorm Events

Analysis of wind direction and speed during sandstorm events across 16 directions shows sandstorms can occur from any direction, but western directions (W, WSW, NW) dominate, accounting for 75.9% of events. The highest frequencies occur at WSW in Minfeng (44.9%), W in Hotan (37.5%), and NW in Yutian (33.2%). Western-path sandstorms exhibit higher wind speeds and frequencies than other paths, indicating that cold air from the west is the primary driver.

The average maximum wind speed during sandstorms is 8.1 $\mathrm{m \cdot s^{-1}}$, ranging from 3.4 to 20.0 $\mathrm{m \cdot s^{-1}}$. The strongest winds occur from the W direction (average 8.3 $\mathrm{m \cdot s^{-1}}$, maximum 17.9 $\mathrm{m \cdot s^{-1}}$), while the weakest occur from the E direction (average 5.0 $\mathrm{m \cdot s^{-1}}$, minimum 3.4 $\mathrm{m \cdot s^{-1}}$). Notably, 87.5% of sandstorms occur when maximum wind speeds do not reach gale-force criteria (\$ $17.2m \cdot s$^{-1}\$), demonstrating that sandstorms in Hotan can be triggered by relatively low wind speeds.

Average wind speed, maximum and minimum wind speed during sandstorm in Hotan Prefecture

3 Climate Change Characteristics of Sandstorms

3.1 Linear Trend of Sandstorm Frequency

Annual sandstorm frequency in Hotan shows a significant decreasing trend at a rate of -4.4 $d \cdot (10a)^{-1}$ (Figure 8). The 1960s–1980s exceeded the 58-year average (20.4 days), with a marked decline thereafter. All stations show decreasing trends, with rates of -6.2, -5.6, -2.7, and -2.1 $d \cdot (10a)^{-1}$ for Hotan, Pishan, Yutian, and Minfeng, respectively (all passing 0.001 significance tests). This trend aligns with national and Xinjiang-wide patterns but exceeds the Xinjiang average decrease, particularly in Hotan and Pishan.

Seasonal analysis shows decreasing trends in all seasons, with spring and summer reductions (-2.1 and -1.7 $d \cdot (10a)^{-1}$) exceeding autumn and winter (-0.6 and -0.4 $d \cdot (10a)^{-1}$). Spring and summer trends in Hotan and Pishan are particularly significant, passing 0.001 significance tests.

Climatic tendency of seasonal sandstorm frequency in Hotan Prefecture

3.2 Abrupt Change in Sandstorm Frequency

Cumulative anomaly analysis reveals the absolute maximum in 1997, marking a transition from high to low frequency periods that continues today, with a signal-to-noise ratio of 1.6 (significant at 0.05 level). Thus, 1997 is identified as the abrupt change year for regional sandstorm frequency, consistent with changes across northern and southern Xinjiang. Individual stations show abrupt changes in 1997 (Hotan, Pishan, Yutian) and more complex patterns in Minfeng (1981 and 1997), with all stations currently in low-frequency post-mutation cycles.

[Figure 9: see original paper] The cumulative anomaly curves of sandstorm frequency in Hotan Prefecture

3.3 Decadal Variations

Sandstorm frequency was highest in the 1960s and began decreasing from the 1990s, dropping below the long-term average after 2000. Hotan, Pishan, and Yutian peaked in the 1960s, while Minfeng peaked in the 1970s. The 2010s show the lowest frequencies for all stations.

Sandstorm durations were longest during the 1970s–1980s (regional average 1 h 49 min) and shortened significantly from the 2000s (52 min). Minfeng had the longest durations in the 1970s and shortest in the 2010s; Yutian peaked in the 1960s and bottomed in the 2010s.

The decadal distribution of sandstorm frequency in Hotan Prefecture
The decadal distribution of sandstorm durations in Hotan Prefecture

4 Relationship Between Sandstorm Changes and Meteorological Elements

4.1 Sandstorm Variation and Gale Days

A gale is defined as instantaneous wind speed $ 17.2m·s{-1}.Hotanaverages2.7galedaysannually,withstrongcorrelationstos
1}$.

Annual gale days decreased significantly at -0.9 d $\cdot$ (10a)$^{-1}$ (1980s peak: 4.3 days; 2010s: 1.4 days), with a strong correlation to sandstorm days (r = 0.73). This decreasing gale frequency is a primary factor in sandstorm reduction.

[Figure 10: see original paper] Interannual variation of gale frequency in Hotan Prefecture

4.2 Sandstorm Variation and Maximum Wind Speed

Annual maximum wind speed decreased at -1.1 m $\cdot$ s^{-1} $\cdot$ (10a)$^{-1}$, strongly correlating with sandstorm frequency (r = -0.71, significant at 0.001 level). Cumulative anomaly curves show an abrupt change in 1997 (signal-to-noise ratio = 1.26), coinciding with the sandstorm mutation year. All stations except Minfeng show significant decreasing trends and 1997 abrupt changes. The weakening of maximum wind speed is thus a major cause of sandstorm frequency reduction.

[Figure 11: see original paper] The cumulative anomaly curves of maximum wind speed in Hotan Prefecture

4.3 Sandstorm Days and Other Meteorological Elements

Sandstorm days show significant negative correlations with annual mean temperature, surface temperature, precipitation, evaporation, and sunshine hours (Table 8). Correlations with surface temperature are particularly strong across all stations. Rising temperatures, increased precipitation and evaporation, and extended sunshine hours all contribute to sandstorm reduction.

The correlation between annual mean sandstorm frequency and meteorological factors in Hotan Prefecture

4.4 Sandstorm Days and Vegetation Changes

EOS/MODIS satellite data show that maximum vegetation coverage during the growing season (April–October) increased at a rate of 6.342 km^2 $\cdot$ (10a)$^{-1}$. The minimum coverage occurred in 1997 (12.4% of total area), while 2017 reached 15.2%. Forestland area increased significantly, particularly since 2000, due to afforestation and intercropping of fruit trees with crops. Grassland remained stable while cropland increased. Improved vegetation cover is thus another important factor in sandstorm reduction.

[Figure 12: see original paper] The variation of vegetation coverage area in Hotan Prefecture

The variation of arable land, grassland and forest area in Hotan Prefecture

5 Conclusions

Under global warming, sandstorms in Hotan show decreasing interannual trends with regional variations. This study reveals detailed characteristics and potential causes:

1. **Frequency:** Hotan averages 20.4 sandstorm days annually (32.3 days in Minfeng), among China’ s highest. Spring-summer accounts for 78.1% of events, peaking in May. The diurnal distribution shows three peaks, with the primary peak at 18:00–23:00 (38.0%). Minfeng shows bimodal distribution (morning and evening), while other stations peak in the evening.

2. **Duration:** Average duration is 49 minutes, with 75.9% lasting 1–30 minutes. December events are longest (2 h 12 min), June shortest (1 h 35 min). Winter durations exceed spring, which exceed summer. Midnight-to-morning starts last longest (2 h 28 min average).

3. **Wind:** All 16 directions can produce sandstorms, but western directions dominate (75.9% of events). Western-path sandstorms have higher speeds and frequencies. Sandstorms can be triggered at wind speeds as low as 3.0 $\mathrm{m \cdot s^{-1}}$, with 87.5% occurring below gale force.

4. **Trends:** Annual sandstorm frequency decreased at -4.4 $\mathrm{d \cdot (10a)^{-1}}$, with significant spring-summer reductions (-2.1 and -1.7 $\mathrm{d \cdot (10a)^{-1}}$). Frequency peaked in the 1960s, decreasing markedly from the 1990s. Durations were longest in the 1970s–1980s, shortening significantly from the 2000s. The abrupt change year was 1997.

5. **Causes:** Decreasing sandstorm frequency is closely related to reduced gale frequency (-0.9 $\mathrm{d \cdot (10a)^{-1}}$), weakening maximum wind speed (-1.1 $\mathrm{m \cdot s^{-1} \cdot (10a)^{-1}}$), and improved vegetation cover. Both gale days and maximum wind speed show 1997 abrupt changes coinciding with sandstorm changes.

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