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Observation of saltation activity at Tazhong area in Taklimakan Desert, China

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Abstract: A two-year field observation of saltation activity was carried out at Tazhong area, the hinterland area of the Taklimakan Desert with highly frequent dust storms. From 1 September 2008 to 31 August 2010, a piezoelectric saltation sensor (Sensit) was used to continuously collect the data on saltation activity at a level sand surface. Analysis on the data suggests that saltation activity can occur at any time of the year when conditions are favorable; however, the necessary conditions are rarely satisfied in most time. In the daytime of spring or summer, saltation activity can persist even over a continuous one-hour-or-so period. It is found that, from 1 September 2008 to 31 August 2010, saltation activity accounts for more than 3% of the total yearly time, and it tends to peak in spring and summer months with strong winds. During winter months when winds are weak, however, it is often at a minimum. It seems that precipitation does not appear to be significant in reducing saltation activity in arid regions like Tazhong.

Keywords: saltation activity; aeolian sand transport; piezoelectric saltation sensor (Sensit); Tazhong; Taklimakan Desert

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Aeolian sand transport is a serious problem in many arid regions in the world, and it is considered to be a significant part of global biogeochemical cycles (McTainsh et al., 2007; Liu, 2009). Saltation, a mode of airborne particle motion in the atmosphere, plays a key role in aeolian sand transport studies (Schönfeldt and von Löwis, 2003). The transportation of most aeolian sediments due to wind erosion is by means of saltation (Bagnold, 1941; Chepil, 1945).

Many researches on saltation have been carried out under ideal and controllable conditions including the wind tunnel experiment, theoretical analysis and numerical simulation (van Boxel et al., 1999; Zou et al., 2001; Zhou et al., 2002; Zheng et al., 2003; Zheng et al., 2004; Leenders et al., 2005; Zheng et al., 2006; Huang et al., 2007; Shao, 2008), and under natural field conditions including direct observation (Bagnold, 1941; Chepil, 1945), measurement of saltation sediment discharge (Gillette and Walker, 1977; Nickling, 1983; Leys and McTainsh, 1996), and small-scale aeolian sand transport measurement with impact recording devices such as Sensits and saltiphones (Gillette et al., 1997; Sterk and Spaan, 1997; Stout, 2003, 2010; Yang et al., 2011, 2012).

Wind tunnel and field experiments have improved our understanding of saltation and aeolian transport mechanisms under controllable conditions and unsteady wind conditions. However, further investigations are required, especially under complex field conditions.

An experiment to monitor saltation activity with the piezoelectric saltation sensor (Sensit) was developed from 1 September 2008 to 31 August 2010 in Tazhong, the hinterland of the Taklimakan Desert. The piezoelectric saltation sensor (Sensit) is an electronic device based on a sensible diode which can count impacts of saltation sand particles. This device has been used to monitor the saltation movement in many field experi-

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ments (Fryrear, 1995; Gillette, 1997; Stout and Zobeck, 1997; Stout, 2003, 2007, 2010; de Oro and Buschiazzo, 2009). In this paper, the characteristics of sand saltation activity and its relation with meteorological elements were analyzed based on the measured data, so as to gain new understanding of saltation activity and dust emissions and try to forecast and guard against the occurrence of windblown sand or sandstorms in the Taklimakan Desert.

1 Study area

The Taklimakan Desert, located in the central part of the Tarim Basin in Xinjiang Uygur autonomous region, Northwest China (Fig.1), is the second largest shifting sand desert in the world, with about 85% of shifting sand dunes (Sun and Liu, 2006). As an area where sandstorms occur frequently, it is known as an important sand-dust source in China (Wang et al., 2000; Qian et al., 2002; Zhou et al., 2002). Sandstorms caused by soil wind erosion in this region have produced great effects on the climatic change in East Asia (Zhao et al., 2006).

We took Tazhong as the research site for the saltation activity observation experiment. It is 220 km from the desert edge. The climate is very dry, with an annual precipitation of 25.0 mm and over 100 sand-blowing days per year. Vegetation is sparse, with about 90% of the area being occupied by sandy desert.

The site chosen for observation in this study is a level shifting sand surface. Laboratory test results show that the Sensit-H11LIN can not respond to suspended dust (lower than 50 μm) (Sensit Company, 2007), so twenty-one samples of surface sand (including dune sand and flat sandy land sand) were obtained from the site and its surrounding area, and were measured to obtain the grain size distribution. The results show that these sands are mainly ‘fine sand’ and ‘very fine sand’ with an average grain size of 147 μm, with about 0.3% of the grains smaller than 50 μm.

2 Monitoring methods

The period from 1 September 2008 to 31 August 2010, except the time from 27 October to 15 November 2009 and from 26 December 2009 to 6 January 2010, was selected for measurement, covering a period of twenty three months.

An instrument system was set up at the observation site, which consists of a 2-m tall meteorological tower, two piezoelectric saltation sensors (Sensit) and a data collector (CR1000, Campbell) (Fig. 2). The wind speed inspectors (WAA151, Vaisala) were mounted at the heights of 5, 10, 20, 50, 100 and 200 cm, respectively. To measure relative humidity, air temperature sensors (HMP45D, Vaisala) were mounted at a height of 1.5 m above the surface. All meteorological variables were measured at a frequency of 1 Hz and the

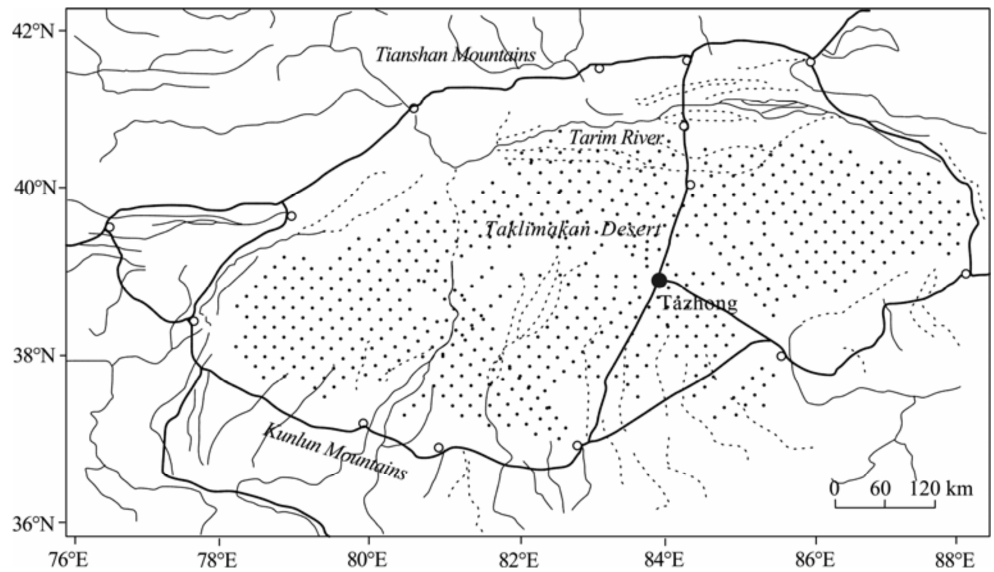

Fig. 1 Location of the Taklimakan Desert in the Tarim Basin; Tazhong is located at the center of the desert.

Fig. 2 The 2-m meteorological tower and piezoelectric saltation sensors (Sensit)

values were averaged at an hourly interval.

Saltation activity was monitored with piezoelectric saltation sensors (Sensit). The Sensit can produce a pulse signal each time. The transducer is impacted by a saltating sand particle, and the transducer area is 17 cm^2 (with a width of 2 cm, and a perimeter of 8.5 cm). During the periods of active saltation, the piezoelectric transducer produced a series of signals that were used simply as on-or-off indicators of saltation activity. Each pulse signal generated by each particle impact was detected, and if one or more impacts were detected during a given second, then that second was registered as one 'saltation second' (Stout, 2003). At the end of each hour time, the total number of saltation seconds were summed and outputted into the data collector. As measured by Stout (2003, 2007) and Sankey et al. (2009), the transducers of the Sensit were located about 5 cm above the surface. In this study, the transducers were located 5 cm and 10 cm above the surface, and the data at the height of 5 cm was used to analyze the variation of saltation activity.

Saltation activity is expressed as a dimensionless ratio of the total number of saltation seconds divided by the total number of seconds within the period of measurement (Stout, 2003). Thus, the hourly saltation activity is simply the hourly total saltation seconds divided by 3,600 seconds. Using the same data, the daily, monthly, seasonal or yearly saltation activity can also be calculated.

3 Results

3.1 Hourly saltation activity

Measured hourly saltation activity values were plotted in Fig. 3. The data provide a continuous saltation activity at the observation site from 1 September 2008 to 31 August 2010.

Saltation activity appears to be quite intermittent. Recent research suggested that saltation is often an unsteady and intermittent process because winds are highly unsteady under natural conditions (Stout and Zobeck, 1997; Sterk et al., 1998; Stout, 2003, 2010). The highly intermittent nature of saltation suggests that the necessary conditions are not always satisfied for aeolian transport. For the whole period from 1 September 2008 to 31 August 2010, 66% of the measured hours have no detected saltation activity, and the detected no saltation activity hours occupy a little less than 93% at Yellow Lake (Stout, 2003). The field experiment in this study proves that sand blowing events in the Taklimakan Desert occur more frequently than reported in the previous studies.

Saltation is often unsteady. However, during some sand blowing events, the hourly saltation activity reaches or approximates unity, indicating a continuous or nearly continuous aeolian transport over a one-hour period. The highest values of hourly saltation activity measured during this experiment are listed in Table 1. The highest value, 1.0, was recorded at 12:00 LST (Local Standard Time) on 10 March 2009, and at 13:00 LST on 29 April 2009. During the same two days there are another twelve hours with saltation activity greater than 0.9. Overall there are a total of 72 values of hourly saltation activity greater than 0.9 from 1 September 2008 to 31 August 2010. The highest value measured by Stout (2003) on a high plains is only 0.96 and there have only been a total of 20 values of hourly saltation activity greater than 0.9 in a four-year experiment, which indicates that sand blowing events occur more easily at Tazhong.

From Table 1, we can find that the top 72 hourly values occurred during March, April, May, June, July, September and October, and all of the top 72 hourly values were recorded during daylight hours between

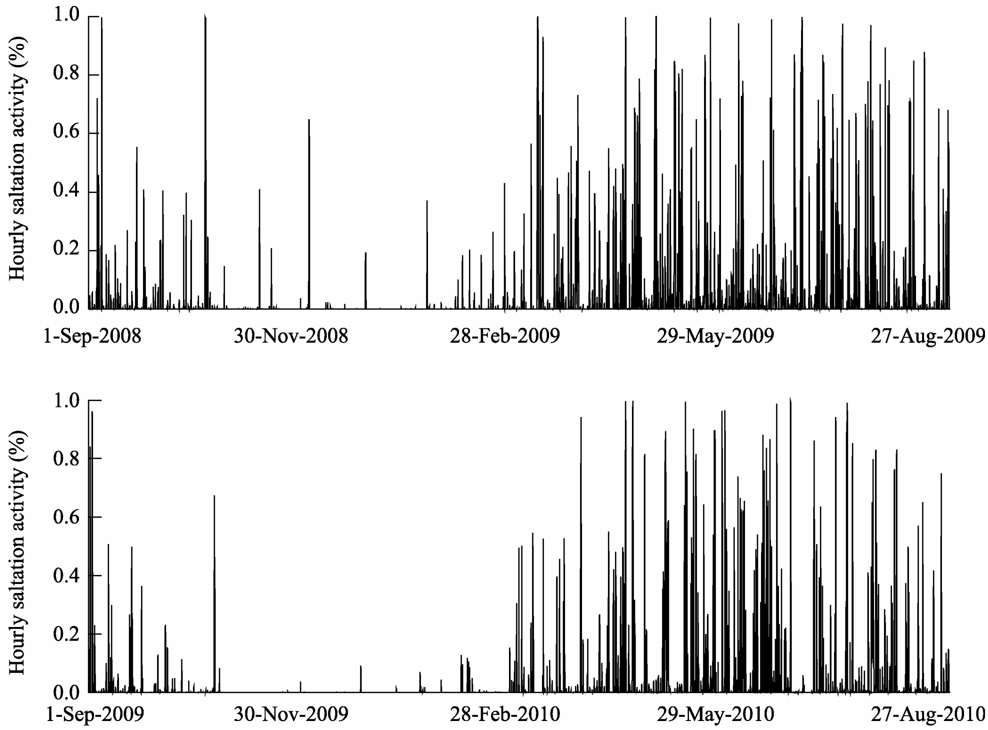

Fig. 3 Hourly saltation activity measured at Tazhong

Table 1 Top 72 values of hourly saltation activity measured at Tazhong from 1 September 2008 to 31 August 2010

Rank	Date	Time	Hourly saltation activity	Rank	Date	Time	Hourly saltation activity	Rank	Date	Time	Hourly saltation activity
1	10-Mar-2009	12:00	1.000	25	17-Jun-2009	13:00	0.991	49	30-Jun-2009	08:00	0.953
2	29-Apr-2009	13:00	1.000	26	25-Jun-2010	16:00	0.990	50	03-Jun-2009	15:00	0.948
3	10-Mar-2009	11:00	1.000	27	19-Jun-2010	17:00	0.989	51	30-Jun-2009	14:00	0.943
4	29-Apr-2009	14:00	1.000	28	19-Jul-2010	16:00	0.989	52	28-Mar-2010	18:00	0.942
5	10-Mar-2009	13:00	0.999	29	20-Oct-2008	17:00	0.988	53	14-Jul-2010	19:00	0.942
6	30-Jun-2009	12:00	0.999	30	16-Apr-2009	17:00	0.986	54	29-Apr-2009	16:00	0.940
7	19-Apr-2010	17:00	0.998	31	16-Apr-2010	17:00	0.986	55	29-Apr-2009	11:00	0.938
8	06-Sep-2008	16:00	0.997	32	19-Jul-2010	14:00	0.985	56	29-Jul-2009	15:00	0.938
9	16-Apr-2009	16:00	0.997	33	25-Jun-2010	14:00	0.978	57	02-Sep-2009	15:00	0.936
10	16-Apr-2010	16:00	0.997	34	03-Jun-2009	16:00	0.977	58	17-Jul-2009	14:00	0.936
11	29-Apr-2009	12:00	0.997	35	30-Jun-2009	13:00	0.975	59	17-Jul-2009	17:00	0.931
12	20-Oct-2008	11:00	0.996	36	17-Jul-2009	16:00	0.975	60	12-Mar-2009	15:00	0.929
13	22-May-2009	16:00	0.996	37	16-Apr-2009	15:00	0.974	61	25-Jun-2010	17:00	0.926
14	20-Oct-2008	14:00	0.996	38	16-Apr-2010	15:00	0.974	62	30-Jun-2009	07:00	0.925
15	25-Jun-2010	15:00	0.996	39	19-Jul-2010	13:00	0.971	63	30-Jun-2009	10:00	0.921
16	10-Mar-2009	09:00	0.995	40	29-Jul-2009	14:00	0.971	64	17-Jul-2009	15:00	0.920
17	30-Jun-2009	11:00	0.995	41	28-May-2010	18:00	0.966	65	30-Jun-2009	15:00	0.920
18	20-Oct-2008	15:00	0.994	42	10-Mar-2009	08:00	0.964	66	06-Sep-2008	17:00	0.918
19	12-May-2010	02:00	0.994	43	27-May-2010	13:00	0.964	67	12-Mar-2009	16:00	0.912
20	29-Apr-2009	15:00	0.994	44	02-Sep-2009	13:00	0.963	68	19-Jul-2010	12:00	0.906
21	20-Oct-2008	13:00	0.993	45	10-Mar-2009	14:00	0.961	69	16-Apr-2009	19:00	0.904
22	20-Oct-2008	12:00	0.992	46	19-Apr-2010	18:00	0.959	70	16-Apr-2010	19:00	0.904
23	10-Mar-2009	10:00	0.991	47	02-Sep-2009	14:00	0.957	71	10-Mar-2009	15:00	0.903
24	19-Jul-2010	15:00	0.991	48	19-Apr-2010	16:00	0.953	72	15-May-2010	12:00	0.902

07:00 and 19:00 LST, with only one being recorded at 02:00 LST. The result shows that strong sand blowing events are more likely to occur during the day in spring, summer and autumn. In those periods, the necessary conditions for aeolian transport are more easily satisfied. The statistic results show that 53 of the 72 top values appeared on sandstorm days, including all the top 5 values, which indicates that sandstorms always cause serious aeolian sand transport.

3.2 Daily saltation activity

Daily saltation activity values were plotted in Fig. 4, and daily saltation activity was calculated by summing all saltation seconds within a single day and then dividing the sum by 86,400 seconds.

The distribution pattern of saltation activity was not remarkably changed with the variation in the time scale from hour to day. However, the daily saltation activity values were typically much lower than the hourly values. Extreme values of hourly saltation activity occasionally reached or approached unity, whereas peak values of daily saltation activity rarely exceeded 0.5. The 20 highest values of daily saltation activity recorded during this experiment were listed in Table 2. The highest value, 0.503, was recorded on 30 Jun 2009, and the second highest value, 0.476, was recorded on 19 July 2010, and 12 of the 20 top values appeared on sandstorm days, including all the top 10 values except the sixth. For the two years from 1 September 2008 to 31 August 2010, 4.3% of all the measured days have daily saltation activity greater than 0.2, and 12.2% greater than 0.1, which is much higher than 1.5%. The percentage with daily saltation activity values is greater than 0.1, which was measured at Yellow Lake (Stout, 2003).

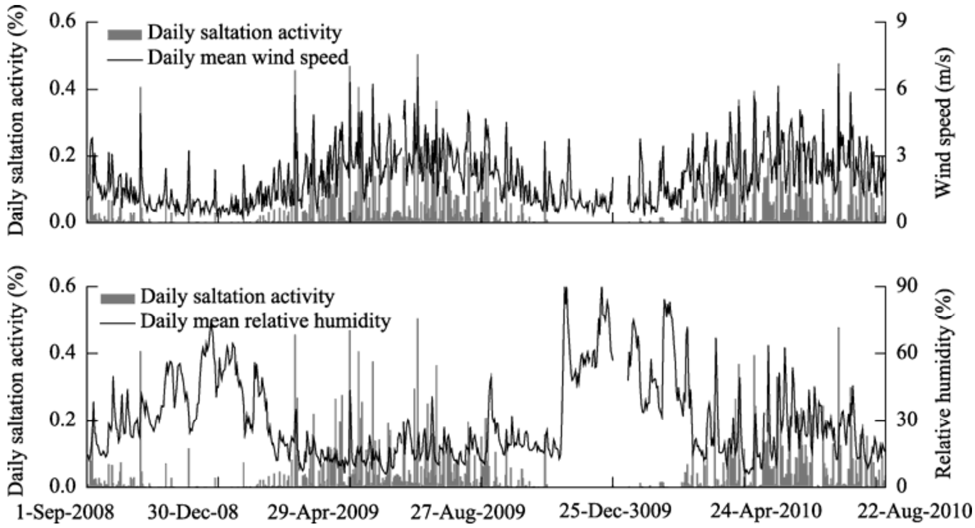

Fig. 4 Daily saltation activity, daily mean wind speed at 2 m and relative humidity at 1.5 m measured at Tazhong

Table 2 Top 20 values of daily saltation activity measured at Tazhong from 1 September 2008 to 31 August 2010

Rank	Date	Daily saltation activity	Rank	Date	Daily saltation activity
1	30-Jun-2009	0.503	11	24-May-2010	0.331
2	19-Jul-2010	0.476	12	30-Jul-2010	0.299
3	29-Apr-2009	0.468	13	27-Jun-2009	0.294
4	10-Mar-2009	0.455	14	22-Apr-2009	0.275
5	20-Oct-2008	0.406	15	12-Mar-2009	0.267
6	07-May-2009	0.405	16	16-Apr-2009	0.265
7	03-May-2010	0.394	17	16-Apr-2010	0.265
8	20-May-2009	0.376	18	10-May-2009	0.254
9	19-Apr-2010	0.368	19	09-Jul-2009	0.250
10	17-Jul-2009	0.364	20	04-May-2010	0.243

Variations in saltation activity reflect the changes in environmental conditions. The important environmental factors such as daily wind speed, relative humidity were plotted in Fig. 4. Wind speed followed an annual cycle with typical peaks during spring and summer; and during late autumn and winter the wind speed tended to be at a low point. Accordingly, high-level saltation activity occurred in the spring and summer, and generally low-level saltation activity occurred in the late autumn and winter. There is a typical power function relationship between saltation activity and wind speed, and the correlation coefficient R^2 is 0.69. Variation of the daily relative humidity was just contrary to wind speed, and it tended to be at a low point during spring and summer and at a peak point during late autumn and winter. The research shows that threshold wind speed depends significantly on air humidity in air-dry soils (McKenna-Neuman, 2003; Ravi et al., 2004; Ravi and D'Odorico, 2005; Mckenna-Neuman and Sanderson, 2008; Sankey et al., 2009), and the critical threshold declines with decreasing values of relative humidity (Ravi et al., 2004; Ravi and D'Odorico, 2005). So, in the study area, the critical threshold would keep at a relatively low level during spring and summer, which is beneficial to the occurrence of saltation activity combining with high wind speeds.

3.3 Monthly saltation activity

Monthly saltation activity values and its relationship with wind speed, precipitation, sandstorm days and occurrence time of sandstorm were plotted in Fig. 5. The monthly saltation activity values were much lower than hourly and daily values. The highest value, 0.081, was recorded in May 2010. Clearly, saltation activity seldom accounts for more than 10% of the time in any month. Saltation activity at Tazhong mainly occurs in April, May, June and July and these months accounts for 67.2% of the total two years.

Figure 5 shows that monthly saltation activity is strongly correlated with wind speed, and poorly correlated with precipitation, sandstorm days and occur-

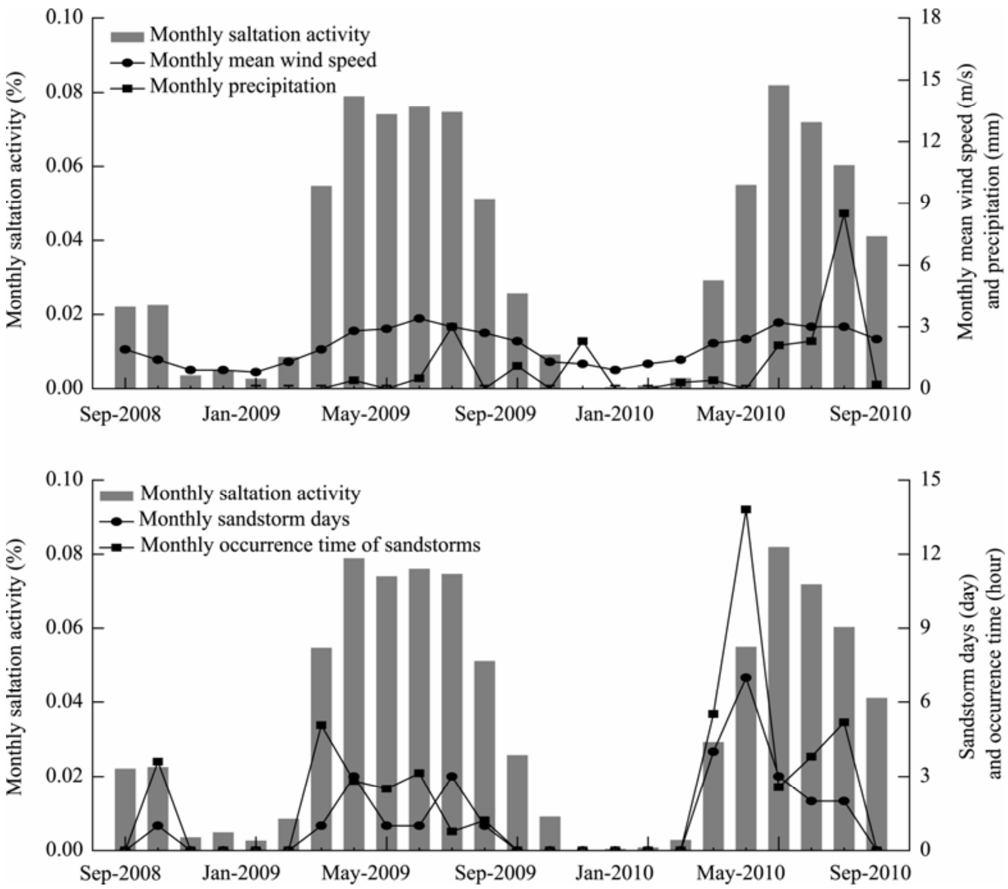

Fig. 5 Monthly saltation activity and its relationships with monthly mean wind speed, monthly precipitation, monthly occurrence time of sandstorms at Tazhong

rence time of sandstorms. The correlation coefficient R^2 is 0.885, 0.076, 0.318 and 0.196, respectively (Fig. 6). The poor correlation between saltation activity and precipitation indicates that precipitation does not appear to be significant in reducing aeolian transport in an arid region as Tazhong, and wind plays a main role in aeolian transport. This seems to be in contradiction with the result of relationship between daily saltation activity and relative humidity. Actually, there is no contradiction between the two results. From Fig. 5, we can know that the precipitation in the whole observation period is only 21.1 mm (mean annual value is 25.0 mm), while the evaporation is up to 8,010.5 mm (data not shown) in the whole observation period. Comparing with the evaporation, the precipitation is negligible. In addition, about 68.7% of the precipitation is concentrated in summer, and only 44.0% of saltation activity occurs in summer. So the correlation is poor between saltation activity and precipitation, while relative humidity has significant hourly or daily variations, and it can bring hourly or daily variations of critical threshold, and then impact the saltation activity.

In this study, the saltation activity is poorly correlated with sandstorm days and occurrence time of sandstorms too, indicating most of the saltation activity occurs on non-sandstorm days. Sandstorms can cause serious aeolian sand transport, but its production always needs strong weather process, while the saltation activity can occur when the local environmental conditions are satisfied.

3.4 Seasonal saltation activity

A seasonal summary of saltation activity and associated environmental conditions was presented in Table 3. The values of precipitation, wind speed, relative humidity, ground temperature, sandstorm days and its occurrence time represent the totals or the averages taken over an entire season. The results suggest that the ground surface at Tazhong is more erodible during spring and summer when winds are strong, with high ground temperatures and generally low humidity. The whole top 4 values of seasonal saltation activity were recorded during spring and summer. The spring in 2009 is especially active with a total of 548,311 saltation seconds and a seasonal saltation activity of 0.0689.

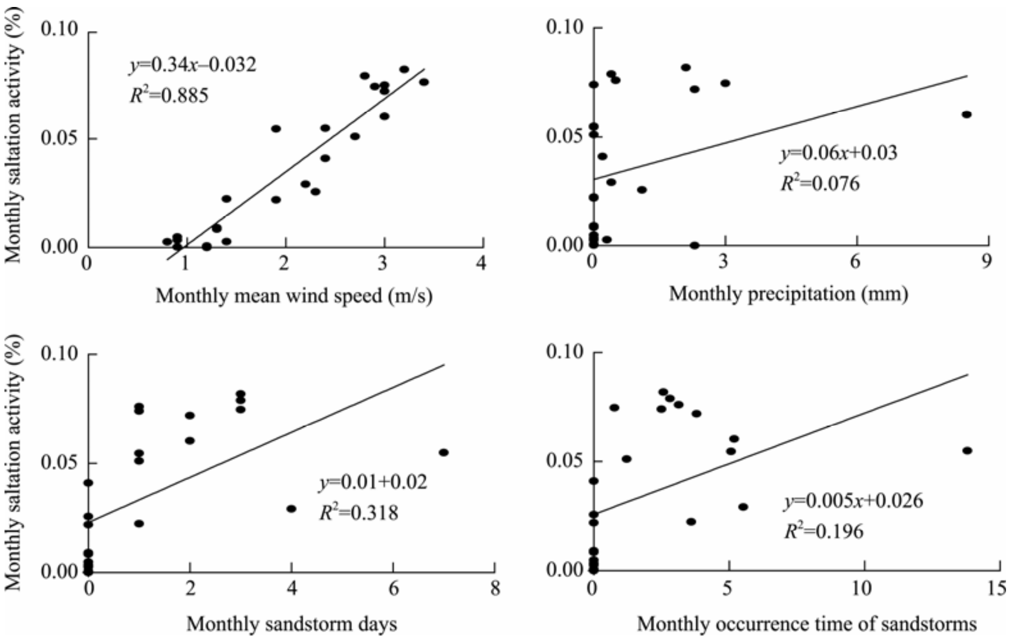

Fig. 6 Correlation analyses between monthly saltation activity, monthly mean wind speed, monthly precipitation, and monthly occurrence time of sandstorms at Tazhong

Table 3 Seasonal saltation activity and environmental conditions at Tazhong

Season	Total precipitation (mm)	Mean wind speed (m/s)	Average relative humidity (%)	Ground temperature (ºC)	Sandstorm days (day)	Occurrence time of sandstorm (hour)	Total saltation seconds (s)	Seasonal saltation activity
Autumn of 2008	0.0	1.4	32.1	15.0	1	3.6	125,549	0.01597
Winter of 2008–2009	0.0	1.0	42.2	–3.2	0	0.0	39,714	0.00511
Spring of 2009	0.4	2.5	14.6	22.2	5	10.4	548,311	0.06898
Summer of 2009	3.5	3.0	17.1	34.9	5	5.1	533,266	0.06709
Autumn of 2009	3.4	1.6	30.3	14.9	0	0.0	90,545	0.01152
Winter of 2009–2010	0.3	1.2	57.9	–3.7	0	0.0	8,729	0.00112
Spring of 2010	2.5	2.6	23.9	20.2	14	21.9	438,941	0.05522
Summer of 2010	11.0	2.8	24.9	35.2	4	9.0	456,997	0.05749

Saltation activity is often at a low value during winter. Only 8,729 saltation seconds were recorded for the entire winter of 2009–2010, which yields a seasonal saltation activity of 0.001. A seasonal saltation activity value of as low as 0.005 was also recorded for the winter of 2008–2009. Relative humidity is the highest and ground temperature is the lowest during winter. High relative humidity and low ground temperature generally indicate a surface with a high threshold wind erosion condition (Stout, 2010). Nevertheless, weak wind speed during winter coupled with a high threshold condition contributed to low saltation activity during this period.

There can be significant differences in the saltation activity from one year to the next. These data suggest that saltation seconds are 1,246,840 with an annual saltation activity of 0.0395 during 2008–2009. Saltation seconds for 2009–2010 is 995,212 with an annual saltation activity of 0.0316. Overall, the results suggest that saltation activity rarely accounts for more than 3% of the total time within a year at Tazhong.

4 Discussion

Two years of continuous monitoring of saltation activity have been developed on a level sand surface at Tazhong by using a piezoelectric saltation sensor, which allows the number of seconds with active sand movement within a given sampling interval to be counted and the number of saltation seconds to be summed for each specific day over a period of months to provide a relative measure of saltation activity. The results provide a detailed view of the variations in saltation activity. Compared with the variations of wind speed, relative humidity and other meteorological conditions, the variation characteristics of the saltation activity at each scale are rational and believable, which indicates that the Sensit has better applicability to monitor the aeolian activity in the Taklimakan Desert, and this technique effectively allows the variations of saltation to be defined with great precision.

From the variations of saltation activity, daily wind speed, relative humidity and the poor correlation between saltation activity and precipitation, we can conclude that wind plays a key role in aeolian transport in such an arid region as Tazhong. However, relative humidity is an unneglectable factor in arid regions, which can change topsoil moisture, inter-particle forces and critical threshold, and indirectly impact the saltation activity (Ravi et al., 2004; Ravi and D'Odorico, 2005). We should carry out more detailed researches on the effect of relative humidity on the saltation activity in future work.

Compared with previous results (Stout, 2003; de Oro and Buschiazzo, 2009), the saltation activity is higher and the surface is more erodible with lower wind speeds at Tazhong. Our analyses show that the poor precipitation (the precipitation of the whole observation period is only 21.1 mm), the lack of vegetation (the ground surface consists of shifting sand) and the composition of ground surface sands (mainly fine sand and very fine sand) provide the advantageous conditions for wind erosion. The differences in variations of saltation activity in different seasons or study areas may reflect the differences in natural environment and climatic factors.

5 Conclusions

Overall, our experimental results suggest that hourly saltation activity can occur nearly continuously over a one-hour period during some daytime, especially sandstorm days because of winds. Most of the high hourly values occurred during daylight hours between 07:00 and 19:00 LST in March, April, May, June, July, September and October, because of higher wind speeds and lower relative humidity in those time .

The peak values of daily activity rarely exceeded 0.5, and most of the high daily values occurred during sandstorms, too. During the whole observation period, 4.3% of all the measured days have daily saltation activity greater than 0.2, and 12.2% greater than 0.1, and daily saltation activity has a good power function relationship with wind speed.

High monthly saltation activity mainly occurred in April, May, June and July and these months accounted for 67.2% of the total two years. The highest monthly value is only 0.081, recorded in May 2010. Monthly saltation activity is strongly correlated with wind speed, and is poorly correlated with precipitation, sandstorm days and occurrence time of sandstorm.

Seasonal saltation activity tended to peak during spring and summer and it is often at a minimum during winter because of meteorological conditions. The highest value is 0.0689, recorded in the spring of 2009, and the lowest is only 0.001, recorded in the winter of 2009–2010.

Acknowledgements

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