Local convergence zones or discontinuous lines in the Taklimakan Desert, Northwest China

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Abstract: In order to study convergence zones or discontinuous lines formed locally in the Taklimakan Desert, we analyzed available MODIS images onboad TERRA or AQUA satellite for ten cases: 29 March 2002, 14 April 2002; 2 January 2003; 21 April 2003; 26 March 2004; 28 April 2004; 30 January 2005; 25 June 2005; 3 December 2005; and 26 July 2006. We used weather maps published by the Japan Meteorological Agency for the Asia and Pacific region at 500 hPa, 700 hPa and 850 hPa, at 00Z and 12Z to analyze the meteorological conditions occurring in each case. We estimated the positions of air streams, convergence zones or discontinuous lines between them, and thermal conditions on the maps and confirmed the presence of cumulus and cumulonimbus clouds through satellite images in particular. After a review of previous studies, this paper introduced the results of the present study. Closed warm areas in the Taklimakan Desert and on the Tibetan Plateau and local convergence zones or discontinuous lines in the Taklimakan Desert were discussed together with their diurnal changes, using composite maps of the ten cases. Along the long axis of the desert the convergence zones or discontinuous lines normally extend 70–80 km in a west-east direction, but are suspected to exceed 100 km in extreme cases. On the other hand, the convergence zones or discontinuous lines extending in a north-south direction on the southern fringe of the desert have a length of 40–60 km. The closed warm areas show clear diurnal changes, but they were not detected at the 500 hPa level. An example of a clear convergence zone running in a north-south direction on 26 July 2006 was presented in detail with corresponding satellite images.

Keywords: atmospheric circulation; convergence zone; discontinuous line; satellite image; Taklimakan Desert

1 Introduction

During the last 20 years, intensive studies have been conducted on the occurrence and transportation of sand-dust originating from deserts. During the same time, satellite images have accumulated and have come to be used in meteorological studies as well as weather forecasting. Analyses of satellite images of convective cloud formation, however, are relatively scarce.

In the study, we attempte to gain an understanding of atmospheric circulation at the local and regional scales, wind and air streams at ground level, and convergence zones or discontinuous lines, using satellite images. First, we review the results of previous studies and after that, we describe and analyze the ten selected cases. Because meteorological observation stations are located sparsely in the deserts, analysis of satellite images is a powerful tool for elucidating phenomena at the local and regional scales. Figure 1 showed a sketch of the study area. The study aims to deepen our knowledge of the problems at such spatial scales in this area.

2 Previous studies

2.1 Prevailing winds and air streams

Shifting directions of sand dunes in the Taklimakan Desert have been schematically illustrated since the 1970s (Laboratory of Desert, Lanzhou Institute of Glaciology, Geocryology and Desert Research, Chinese Academy of Sciences, 1974; Xinjiang Biology, Pedology and Desert Research Institute, Chinese

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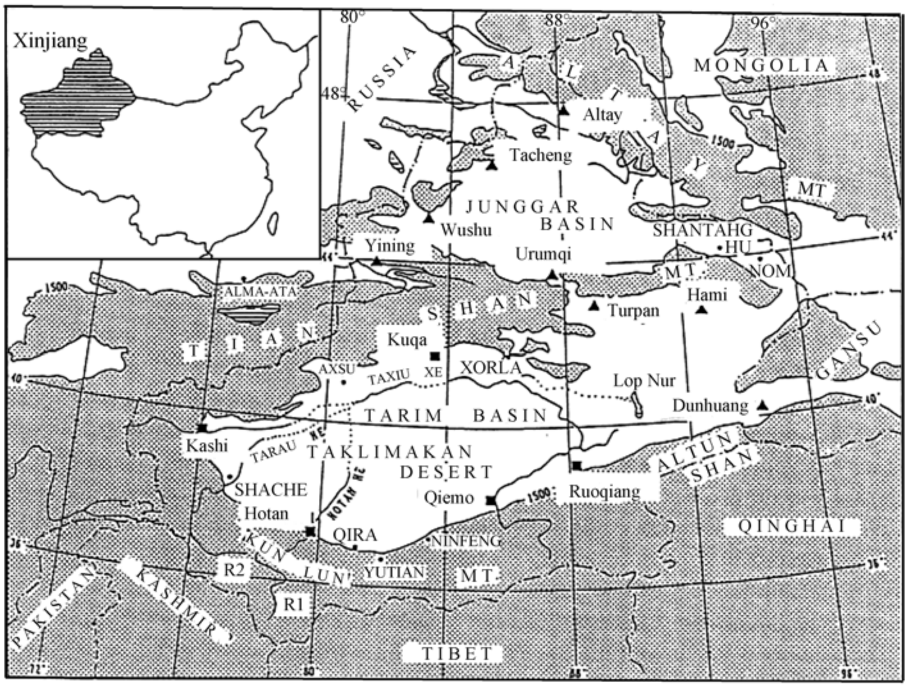

Fig. 1 Sketch map of the study region, meteorological observation stations and oases

Academy of Sciences, 1978; Xinjiang Institute of Geography, Chinese Academy of Sciences, 1987; Zhu *et al*., 1989). These maps have been good references for studies of air streams at ground level. On the other hand, Geng (1986) summarized the main air stream lines causing sand movement in the arid and semi-arid regions of China in January and July plus the annual average. A map of Taklimakan Desert Wind, Sand and Geomorphology was published by the Lanzhou Institute of Glaciology, Geocryology and Desert Research, Chinese Academy of Sciences (1980) and in a revised edition in 1990. These maps, made with the aid of interpretation of aerial photographs and early stage satellite images, have provided good information concerning the prevailing wind conditions at the respective stages of development of the studies.

Referring to these illustrated figures and maps, Yoshino (1991, 1992) produced a three-dimensional schematic illustration of atmospheric circulations in the Taklimakan Desert. In the colder season, including March and April (Fig. 2), a strong westerly circulation is indicated under the influence of an upper level trough, and in the warmer season (Fig. 3), the region is under the influence of weaker upper westerlies. Thus five main air streams are found as follows: (1) Westerly or northwesterly winds prevail in the upper troposphere in the northern part of Xinjiang, particularly in the colder season or cooler periods (several days) of the warmer season. This circulation takes a roundabout route east of the Taklimakan Desert and enters its southern part as a northeasterly. It should be noted that this northeasterly is connected to the strong easterlies flowing from the northern part of Gansu Province, which on some occasions, transport water vapor, causing heavy rain along the southern fringe of the desert, as has been analyzed by Yatagai *et al.* (1998); (2) One branch of the air stream mentioned above, enters the northeastern part of the Taklimakan Desert as a northeasterly; (3) A northerly flow descends to the southern foot of the Tianshan Mountains; (4) A westerly wind blowing over the mountain passes descends to the western part of the Taklimakan Desert; (5) A south to southwesterly flow crosses over the mountain pass at Karakorum from Pakistan. This is dry and hot due to the foehn effect of descending flows over mountains. The situation with the five air streams has been accepted generally as an overview of the prevailing wind systems in this region (Wang, 2003).

2.2 Atmospheric circulation and convergence zones or discontinuous lines

The circulation patterns at the 1.5 km level (Fig. 4) and 3 km level (Fig. 5) can be summarized as follows: (1) The cyclonic circulation in the Tarim Basin found at the 1.5 km level was very shallow in summer. At the 3 km level, an anticyclonic circulation has already

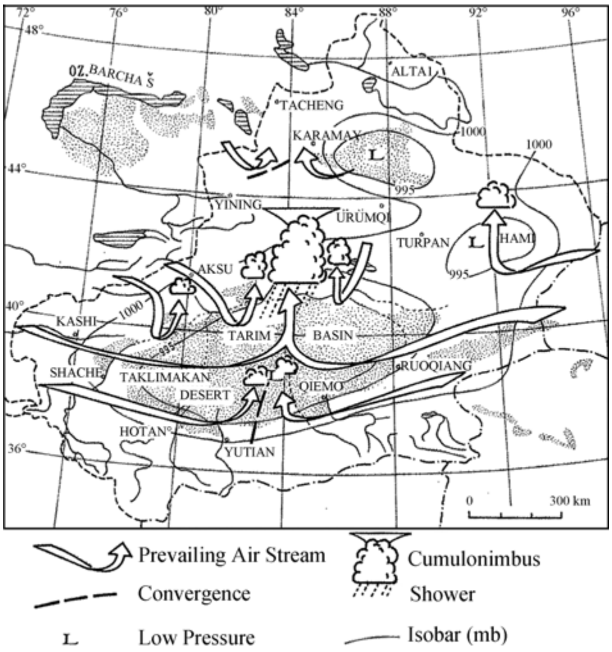

Fig. 2 Schematic illustration of atmospheric circulation in the lower troposphere/air layer near the ground in warmer seasons or summer (Yoshino, 1991, 1992)

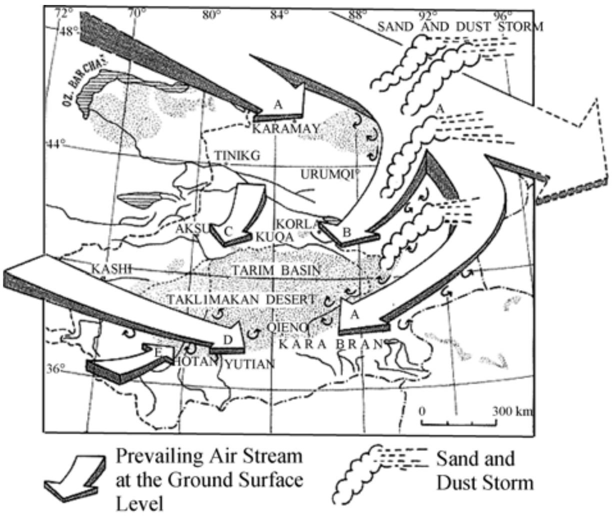

Fig. 3 Schematic illustration of atmospheric circulation in the lower troposphere/air layer near the ground in cooler seasons or spring (Yoshino, 1991, 1992)

been established by summer. Above this layer, a high pressure region was associated with a low pressure one with a warm core over the western and central parts of the Tibetan Plateau. It was thought that this pressure structure results in the very arid conditions of the Tarim Basin; (2) The anticyclonic circulation in the Tarim Basin in winter was thought to result mainly from the topographical effect of the mountain ranges, which formed a large cold air lake, because it did not appear at the 3 km level; (3) The anticyclonic circulation flowed into the southeastern Tarim Basin as a shallow layer near the ground.

The upper westerly flow over the study region became weak in summer resulting in an increased local circulation in the lower troposphere. The upper air stream was shown in Fig. 2 became weak in summer. This air stream converged with another air stream forming a convergence zone or discontinuous line in roughly a north-south direction at about 83°–84°E. Along this convergence zone or discontinuous line, convection should be stronger, particularly in the central part of the basin (Yoshino, 1991, 1992). This consideration was confirmed by Li (1993, 1995), as described later again.

In contrast, there is a zonal belt, where upward motion can easily be enhanced due to its position in the lee of the mountains roughly along the Tarim River. These convection areas are illustrated in Fig. 3. Relatively strong showers can be expected, even though their temporal frequency is low, whereas the spatial variability is high.

Li (1995) presented a distribution of the prevailing wind at many stations in the Taklimakan Desert, pointing out the convergence areas between opposite prevailing wind directions, as shown in Fig. 6. He indicated in particular the convergence zones along the Keriya River, Yarkant River and another river on the northern fringe. Farmers living in oases hear rolls of thunder in some occasion. This is a sign of strong convection in the convergence zones.

2.3 Rainfall traces

Rainfall traces on the surface of deserts can be seen as marks on satellite images (TIROS-n/NOAA). These have been studied since the beginning of the 1990s (Xu, 1995a, b). It was found that 56.2% of the rainfall traces occurred under situations in which the northern and the southern cloud systems were connected or under frequent intensifications.

Monthly changes in occurrence of rainfall traces seen on satellite images from 1991 to 1997 are shown in Table 1 (Xu, 1998). The monthly maximum, 28, occurred in July and the seasonal maximum, 63, in June, July and August, which accounted for 80.8% of the annual total rainfall traces.

The locations of rainfall traces in the satellite images were found most frequently in the western part of

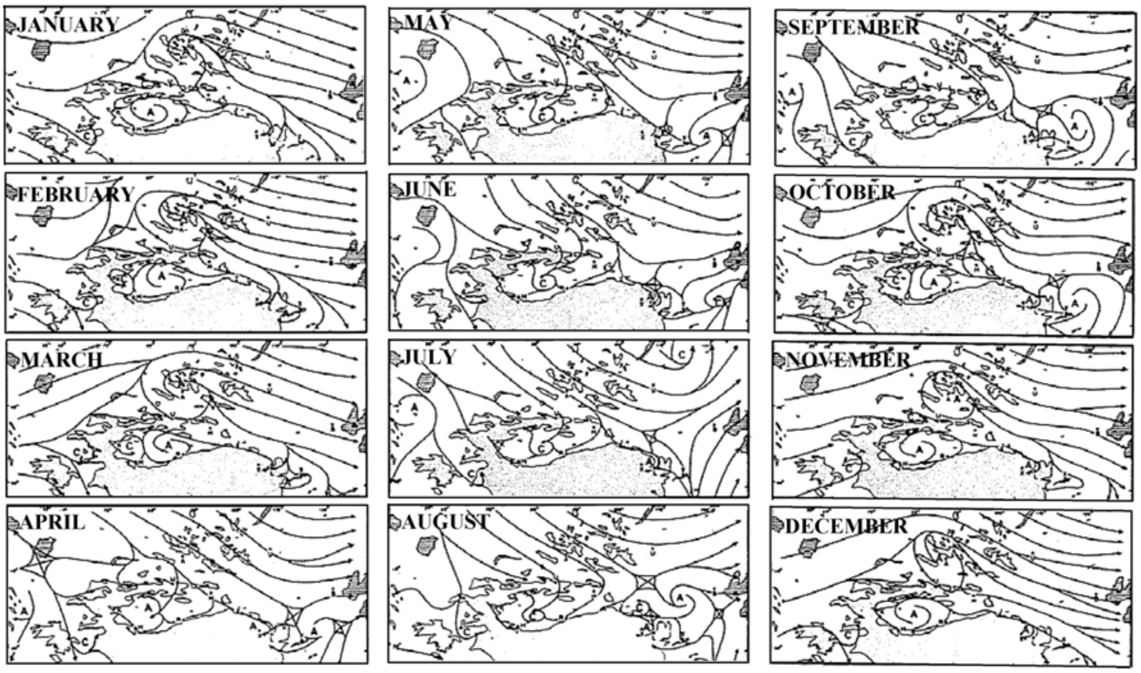

Fig. 4 Monthly atmospheric circulation patterns at the 1.5 km level in Northwest and North China (Yoshino, 1995)

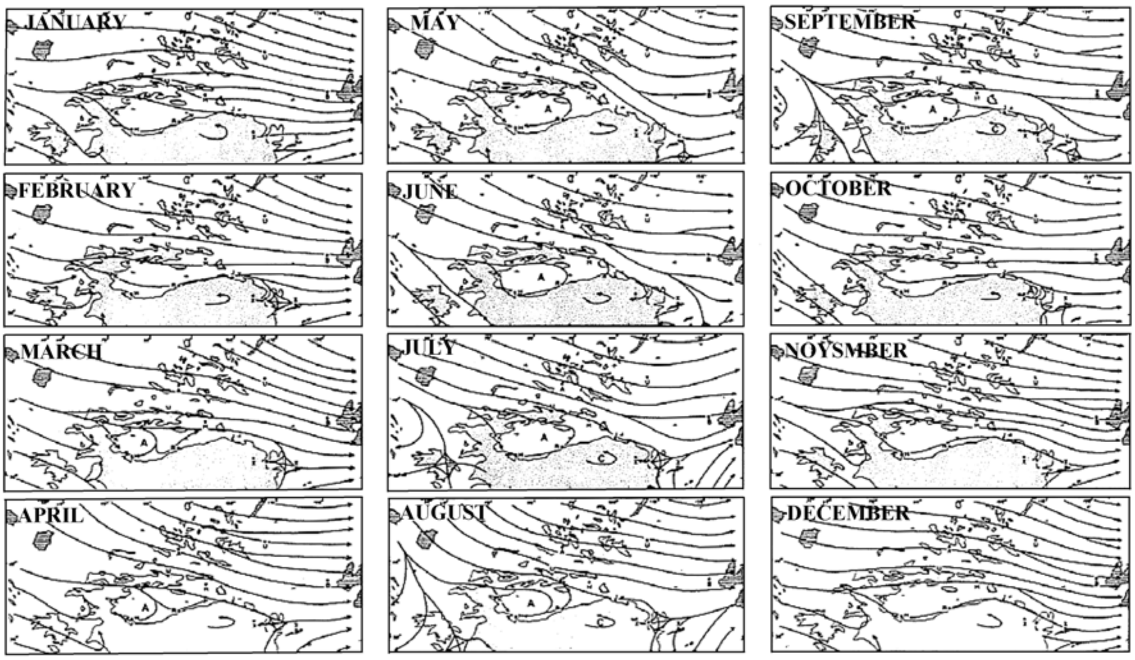

Fig. 5 Monthly atmospheric circulation patterns at the 3 km level in Northwest and North China (Yoshino, 1995)

the Taklimakan Desert followed by the northern part, as shown in Table 2. It must be noted, however, the traces running from west to east and those in the central part of the desert accounted for 52.5%. This meant that all of the convergence zones and discontinuous lines forming in an east-west direction and/or in the central part of the basin account for about half of the rainfall traces.

The monthly total rainfall at Xiaotang (40°50′N, 80°10′E), a station located in the northeastern part of the desert, occasionally showed a large amount of rainfall from May to August (Xu, 1998). These inform us of high variability of occurrence of the convergence zones or discontinuous lines from month to month.

Fig. 6 Distribution of prevailing wind directions and the discontinuous lines (broken line) in the Taklimakan Desert (Li, 1995)

3 Convergence zones or discontinuous lines revealed by satellite images

3.1 Data and method of analysis

We selected ten cases of available MODIS satellite images onboard TERRA or AQUA satellite (Table 3), which shows convective clouds, such as cumulus and cumulonimbus, formed presumably by the convergence of air streams or by discontinuous lines. We disregarded cases that were seen as a clear sand-dust layer boundary with strong frontal activities, because they did not coincide with the aims of our present study.

Special attention was paid to lines of cumulus and cumulonimbus clouds in order to check the relationships between positions/activities of cloud lines and convergence zones or discontinuous lines. Cloud activities were estimated by the diameter of the white part, representing cloud size, and by color, which indicated development of vertical motion or status of reaching the tropopause, where they formed an *incus* (anvil cloud). These criteria were decided on for the first step of the analysis.

We used synoptic weather maps distributed by the Japan Meteorological Agency: Asia Pacific 500 hPa, 700 hPa, and 850 hPa Weather Maps at 00Z and 12Z. The time 00Z is about 4 o'clock a.m. in the study area, and 12Z is 16 o'clock. Therefore, the status at 00Z corresponds roughly to that at the time of the daily minimum temperature and the status at 12Z, the time of the daily maximum temperature.

When making composite maps of the ten cases, we first analyzed the closed warm areas and convergence zones or discontinuous lines using the weather maps. We also drew stream lines on each weather map to determine the local circulations. Then we compared the locations and the direction and length of extension between them. Finally, we studied the case on 26 July 2006 in detail.

3.2 Lines of convective clouds

Examples of satellite images which reveal local convective clouds were shown in Fig. 7. The most interesting cases were found in the images of 29 March

Table 1 Occurrence of rainfall traces in the Taklimakan Desert revealed by the satellite images

Year	Month							Annual sum
	Apr.	May	June	July	Aug.	Sep.	Oct.	
1991	1	1	2	2	3	0	0	9
1992	0	0	3	3	1	1	0	8
1993	0	2	4	5	4	0	0	15
1994	1	1	3	3	2	0	0	10
1995	0	1	2	5	3	2	1	14
1996	0	1	5	6	0	0	0	12
1997	0	3	2	4	1	0	0	10
Total	2	9	21	28	14	3	1	78

Data source: Xu (1998).

Table 2 Occurrence frequency of the rainfall traces in the respective parts of the Taklimakan Desert during the period of 1991–1997

Part	East	South	West	North	From west to east and central	Total
Occurence freqency	6	2	16	13	41	78
(%)	7.7	2.6	20.5	16.7	52.5	100

Data source: Xu (1998).

Table 3 The date and sources of selected cases

Source	Date					
TERRA/MODIS	27 March 2002	14 April 2002	2 January 2003	28 April 2004	30 January 2005	25 June 2005
AQUA/MODIS	21 April 2003	26 March 2004	3 December 2005	26 July 2006		

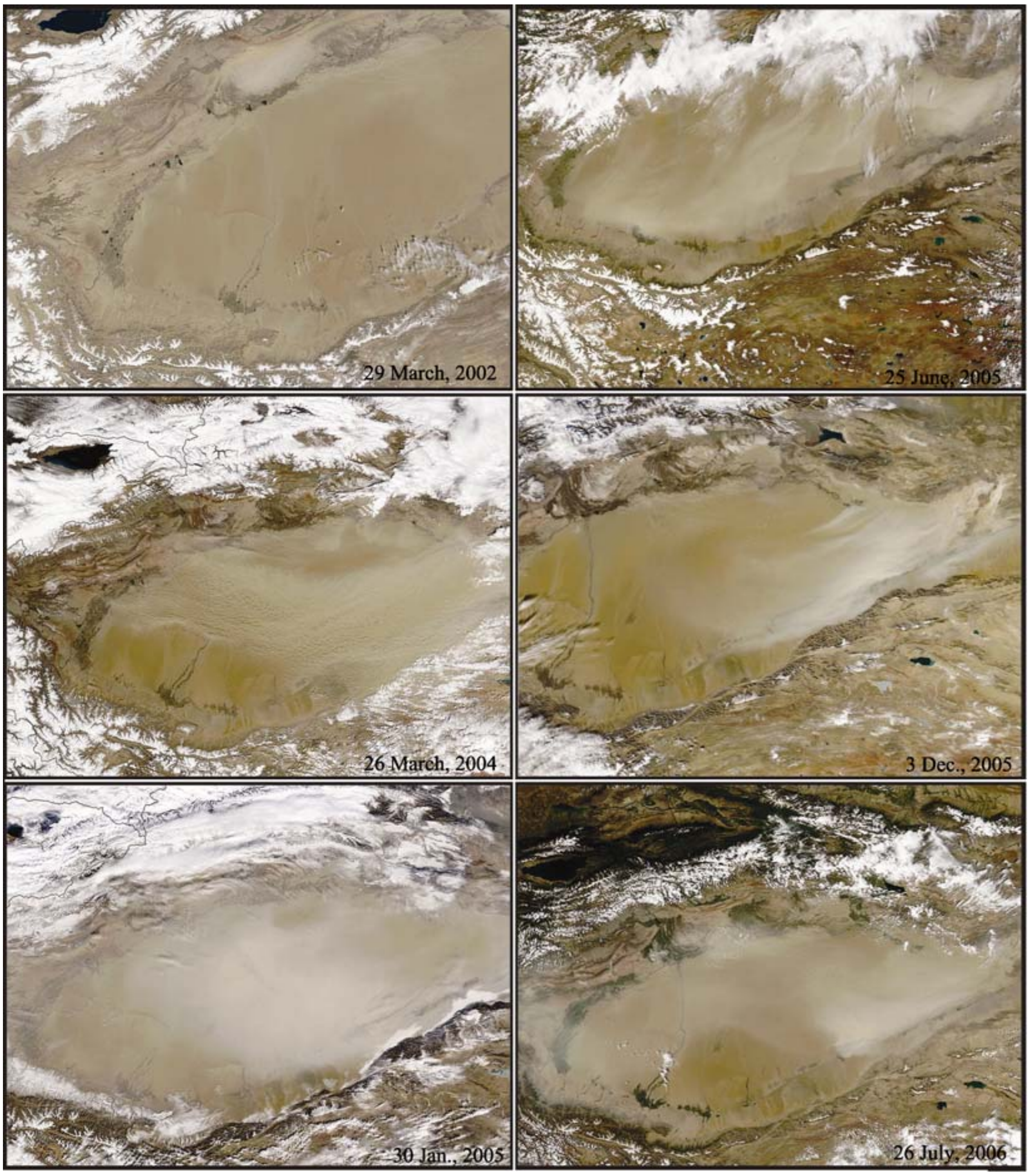

Fig. 7 Satellite images of several typical cases, in which convective clouds are seen in the Taklimakan Desert

2002 (Fig. 7) and 26 July 2006 (Fig. 7), showing lines of white cumulous and cumulonimbus clouds on the southern fringe of the Taklimakan Desert. Others, showing the lines of these clouds in the northern part of the desert, are the images of 25 June 2005 (Fig. 7)

The longest lines stretched roughly 100 km. The size of the individual cumulus clouds was about 10 km at maximum. The completely white parts must be the tops of the cumulonimbus clouds, where they have reached the tropopause.

The length of the cloud lines is normally 70–80 km when they had a west-east directional component, but shorter, 40–60 km, when they had a north-south directional component.

At first glance it may be thought that the length of the lines is very short compared to the size of the Taklimakan Desert. It is interesting, however, to note that the lengths of these cloud lines forming in relation to convergence zones or discontinuous lines in arid regions is at almost the same spatial scale as the local discontinuous lines appearing in regions with temperate humid climates, which has been summarized by Yoshino (1975).

Figure 8 showed the case of 28 April 2004, in which clouds have formed in the center of the Tarim Basin. Many cloud lines, extending in a north-south direction, have developed on the left half of Fig. 8, in contrast, massive cloud groups, indicating weak horizontal winds, are seen in the right hand part. It seems that the yellow part of the image (upper right with a sharp boundary) is a sand-dust layer. The convective clouds appear to have developed to a height above this sand-dust layer. Therefore the white color of the cloud groups was almost the same as that of the clouds in the left hand part. The case of 28 April 2004 was exceptional because of the local strong development of such cloud lines and cloud groups, forming in the central part of the Tarim Basin.

Figure 9 showed another interesting case, 26 July 2006, which had a representative cloud feature in the southwestern part of the Taklimakan Desert. In other words, it occured relatively often at a place of north in the Hotan oasis, which is on the lower reaches of the Hotan River. The northern part of the cloud line became bigger in diameter, indicating stronger convective activity. Small, thin clouds were seen on the Mazartak Mountains forming in a west-east direction.

3.3 Closed warm areas

Viewing the composite map of the ten cases, we can observe closed warm areas on the weather maps at the 850 hPa level (Fig.10, bottom). They predominate at 00Z, which is about 4 o'clock a.m. in the study area, as mentioned above. The warm core area was located in the western part of the Taklimakan Desert. This area occupies the same place in some cases at 12Z, but at a low frequency. Over the Tibetan Plateau, warm areas appeared in some cases.

At the 700 hPa level, warm areas developed clearly in the western part of the basin at 00Z (Fig.10, middle), but the concentrated areas shifted to the Tibetan Pla teau. Such diurnal shifts can be observed clearly.

At the 500 hPa level, (Fig.10, upper), no closed warm areas developed over the Tarim Basin and no diurnal changes in their position are detected.

Summing up the warm area behavior described above, knowledge of thermal conditions over the Tarim Basin seems to be the most essential to understanding the nature of the airflow patterns. Because no warm areas were found at the 500 hPa level, this warm layer is shallow and probably forms locally, due to the high ground surface temperature of the desert. The reason they formed more predominantly and frequently at night time in the Tarim Basin is not clear at present. One reason, however, was thought to be the relatively higher wind velocities occurring in the boundary air layer during the daytime. Because of the higher wind velocity, the vertical gradient of the air

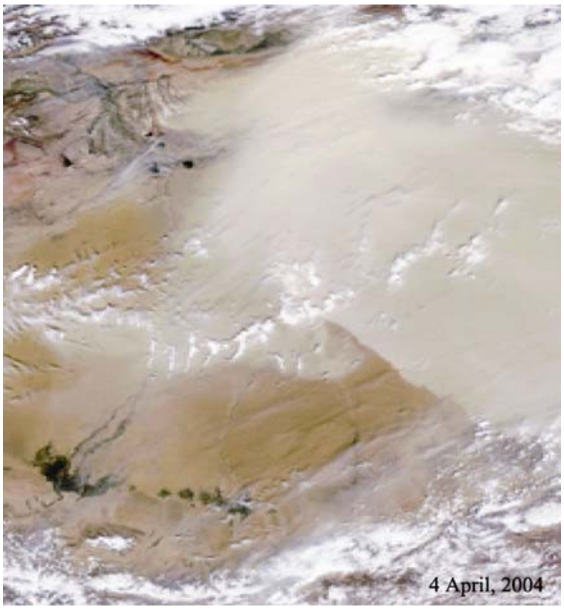

Fig. 8 Satellite image of the western part of the Taklimakan Desert on 28 April, 2004. The oasis of the lower left of picture shows Hotan

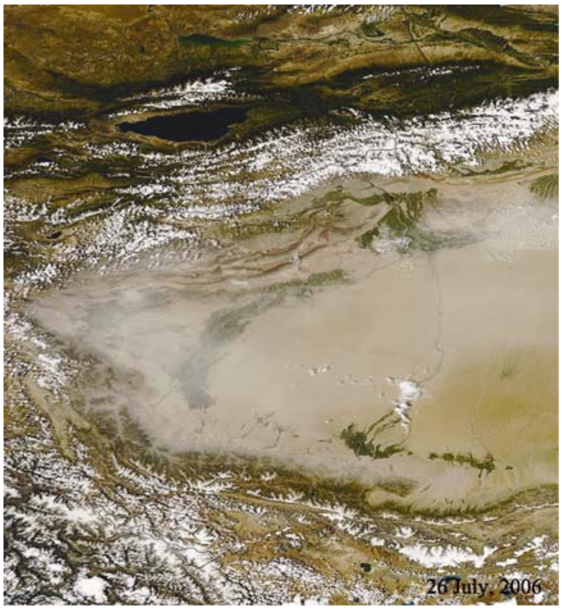

Fig. 9 Satellite image of the western part of the Taklimakan Desert on 26 July, 2006. The oases of the lower left of picture shows Hotan and the central part Yarkant

temperature reduced, resulting in a decrease in air temperature at the lower levels. On the other hand, the air layer near the ground on the Tibetan Plateau was warmer at 12Z, implying development of local warm areas.

3.4 Local convergence or discontinuous lines

Viewing the composite maps of local convergence zones and discontinuous lines, one can observe the following phenomena in Fig. 11. At the 500 hPa level, they do not occur as seen in Fig. 11 (upper). At the 700 hPa level, shown in Fig. 11 (middle), it is strikingly clear that convergence zones and discontinuous lines running in a west-east direction predominate, particularly in the northern half of the Taklimakan Desert at 00Z. On the other hand, several convergence zones or discontinuous lines running from northwest to southeast were seen in the southern half of the desert at 00Z. It was interesting to note that they formed in a due north-south direction at 12Z, probably under the influence of stronger valley wind systems, which developed during the afternoon hours.

At the 850 hPa level, the contrast between the northern half and southern half of the desert became clear at 00Z. The numbers of convergence zones or discontinuous lines decreased, particularly at 12Z. In contrast, those running in a north-south direction be came more apparent. These different conditions between the northern fringe and the southern fring were summarized in Table 4. These contrasts with valley wind systems, which were dominanted in the lower air layer at 12Z, and more clearly established at the 850 hPa level than that at the 700 hPa.

A contrast between the northern half and southern half of the Taklimakan Desert was also found in the distribution of extremely strong rainfall, which has been shown on a map illustrating the trends of days with strong rainfall for 1951–2000 in China (Ding *et al*., 2009). At the present stage of studies, we have not

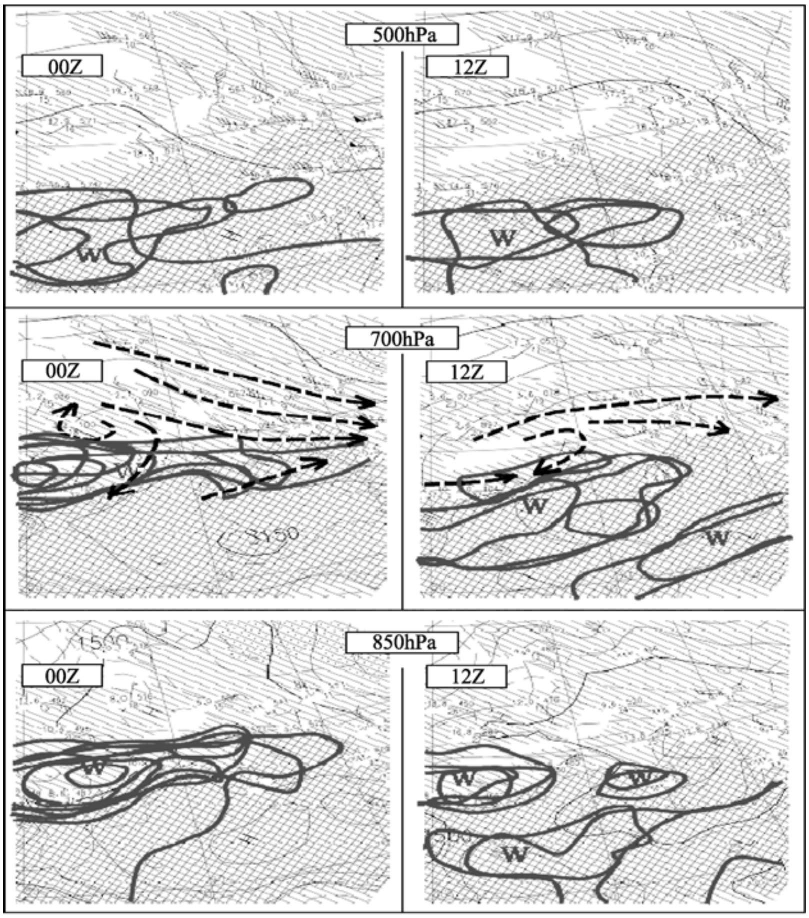

Fig.10 Composite maps of the ten cases showing the closed warm areas in the Tarim Basin and its surroundings at the 500 hPa, 700 hPa, and 850 hPa levels at 00Z (left) and 12Z (right)

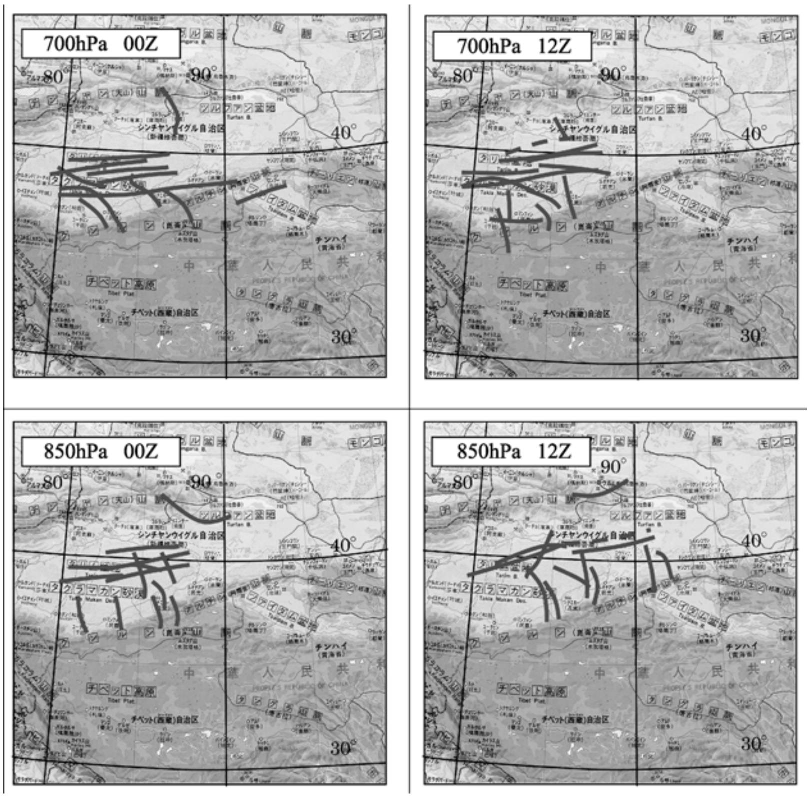

Fig. 11 Composite maps of the convergence zones or discontinuous lines in the Taklimakan Desert at the 700 hPa and 850 hPa levels at 00Z (left) and 12Z (right)

Table 4 Number of convergence zones or discontinuous lines at the 850 hPa levels among 10 cases in the Taklimakan Desert

Extending direction	00Z		12Z	
	Central region	Southern fringe	Central region	Southern fringe
West-east	6	0	4	1
North-south	0	7	1	7

yet analyzed statistically and synoptic climatologically severe rainfall occurrences in relation to convergence zones and discontinuous lines. Further studies on this point are needed.

One can anticipate increasing trends of rainfall activity along the convergence zones or discontinuous lines during recent years, based on recent findings that intense precipitation was clearly increasing in Northwest China (Endo *et al*., 2005; Fujibe *et al*., 2005; Yamazaki, 2005).

According to a study on the space-time features of summer rainfall anomalies at 50 stations in Xinjiang, the interannual fluctuation and interdiurnal variation were smaller in the period before the 1980s. They have been increasing, however, since the 1980s (Zhang *et al*., 2007). They found that unusual amounts of summer rainfall maxima increased during the 40 years from 1960 to 2000.

Summarizing the facts mentioned above, we can surmise that severe weather events related to local convergence zones and discontinuous lines have been increasing in numbers and activities.

4 Conclusion

Using synoptic weather at the 500 hPa, 700 hPa and 850 hPa levels, we analyzed local air streams, closed warm areas in the Tarim Basin and local convergence zones or discontinuous lines in the Taklimakan Desert. On the other hand, we selected ten cases of MODIS images onboard TERRA or AQUA satellite for studying convective cloud behaviors in the Taklimakan Desert. The convergence zones or discontinuous lines extending in a west-east direction along with the long axis of the desert develop most frequently at the 850 hPa level, showing stronger activity. In contrast, they appeared most frequently in a north-south direction on the southern fringe. The former normally extended 70–80 km, but was suspected to exceed 100 km in extreme cases. The latter, however, has a length of 40–60 km. Closed warm areas, appeared in the western part of the desert, show diurnal change, but they are not detected at the 500 hPa level.

Rainfall was not analyzed in the present study, but presumably, the frequencies and activity of intensive rainfall along the convergence zones or discontinuous lines may increase. Also, there has been no analysis yet on severe sand-dust storms in relation to severe weather associated with local convergence zones or discontinuous lines found on satellite images. Future studies are needed.

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References

Ding Y H. Climate Change Research over China: Science, Impact, Adaptation and Strategy Policy. Beijing: China Environmental Science Press, 2009. 418–425.

Endo N, Ailikun B, Yasunari T. Trends in precipitation amounts and the number of rainy days and heavy rainfall events during summer in China from 1961 to 2000. Journal of Meteorology Society, 2005, 83: 621–631.

Geng K H. Climate of Desert Regions in China. Beijing: Science Press, 1986. 1–236.

He G, Xiang M, Li L. Analyses on a heavy precipitation in the hinterland of Taklimakan Desert. Arid Zone Research, 1998, 15(1): 15–20.

Laboratory of Desert, Lanzhou Institute of Glaciology, Geocryology and Desert Research, Chinese Academy of Sciences. General Introduction of Deserts in China. Beijing: Science Press, 1974.

Lanzhou Institute of Glaciology, Geocryology and Desert Research, Chinese Academy of Sciences. Map of the Taklimakan Desert Wind, Sand and Geomorphology, Beijing: Science Press, 1980, 1990.

Li J F. New understanding and discoveries about the climate in Taklimakan Desert. In: Proceedings of International Science Conference on the Taklimakan Desert. Urumqi, 1993. 193.

Li J F. New understanding and discoveries about the climate in Taklimakan Desert. Arid Zone Research, 1995, 13(Suppl.1): 252–264.

Wang T. Desert and Desertification in China. Shijiazhuang: Hebei Science and Technology Publishing House, 2003. 663–665.

Xinjiang Biology, Pedology, and Desert Research Institute, Chinese Academy of Sciences. Deserts and their Modification and Use in Xinjiang. Urumqi: Xinjiang People Press, 1978. 1–124.

Xinjiang Institute of Geography, Chinese Academy of Sciences. Brief Summary of Integrated Natural Division of Xinjiang. Beijing: Science Press, 1987. 1–97.

Xu X H. Analysis and studies on the satellite cloud pictures of rainfall traces in the Taklimakan Desert. Scientia Sinica B, 1995a, 324–328.

Xu X H. Influence by connecting the southern and the northern cloud systems on heavy rainfall in the Taklimakan Desert. Xinjiang Meteorology, 1995b, 18(1): 14–17.

Xu X H. Re-study on the characteristics of the satellite cloud pictures of rainfall traces in the Taklimakan Desert. Xinjiang Meteorology, 1998, 21(5): l4–16.

Yamazaki N. Change of rainfall in East Asia during the recent years. Global Environmental Research Center News, 2005, 16(8): 11–12.

Yatagai A, Yasunari T. Variation of summer water vapor transport related to precipitation over and around the arid region in the interior of the Eurasian continent. Journal of Meteorology Society. 1998, 76(5): 799–815.

Yuan Y J, Li J F, Ye W. The wet-dry change in recent 40 years in Taklimakan area. Arid Land Geography, 1998, 21(1): 18–24.

Yoshino M. Wind and rain in the desert region of Xinjiang, Northwest China. Journal of Arid Land Studies, 1991, 1(1): 1–15.

Yoshino M. Wind and rain in the desert region of Xinjiang, Northwest China. Erdkunde, 1992, 46: 203–216.

Yoshino M. Atmospheric circulation in the arid and semi-arid region in China. Arid Zone Research, 1995, 13(Suppl.1): 212–223.

Zhang Y S, Shi Y G, Zhang H D, *et al*. Space-time features of summer rainfall anomaly of Xinjiang and the effect of north polar vortex and blocking. Arid Land Geography, 2007, 30(6): 879–887.

Zhu Z D, Liu S, Di X M. Desertification and Rehabilitation in China. Beijing: Science Press, 1989. 1–12.