An Observational and Numerical Study on the Topographic Influence on Dust Transport in East Asia*

JIANG Xuegong[1†](姜学恭) and CHEN Shoujun[2](陈受钧)

1 *Inner Mongolia Autonomous Region Meteorological Observatory, Hohhot* 010051

2 *Department of Atmospheric Sciences, School of Physics, Peking University, Beijing* 100871

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ABSTRACT

Based on observations and numerical simulations, the topographic impacts on dust transport in East Asia were studied. Two regions frequently attacked by dust storms have been confirmed: one is the western part of Inner Mongolia and the southern Mongolia (namely the Mongolia Plateau), and the other is the Tarim Basin. The most frequent dust storm occurrence area within the first region appears in its hinterland while that of the second one lies in its southern boundary. Moreover, the region from the northeastern edge of the Tibetan Plateau (TP) to the Loess Plateau is attacked by dust storms second frequently. The dust storms frequently occurring over the Mongolia Plateau are related not only to the abundant sand and dust sources, but also to the special topographic conditions of East Asia. The most significant factor that influences the dust storms forming in the hinterland of the Mongolia Plateau is the canyon low level jet (CLLJ), which dominates around the southern areas of the Altay-Sayan Mountains with an east-west direction in the beginning of its formation, and is accompanied by significantly enhanced surface wind afterwards. Due to the obstructive effects of the CLLJ, a lot of dust particles carried by the southward down-slope cold air mass would pile up over the southern slope of the Sayan Mountains. Meanwhile, uneven surface conditions are favorable for the dust particles to go up into the upper atmosphere. With the dust particles piling up continuously, a dust layer is formed in the troposphere and can be recognized as a "dust accumulating container", which provides abundant dust particles to be transported later to the downstream areas. Additionally, the topographic features of East Asia also exert a great influence on dust transport. Generally, the easterly CLLJ enhances the easterly dust transport. The down-slope air current over the southern Sayan Mountains and the air flow surrounding the TP near its northeastern edge enhance the southward dust transport. Lastly, weather system influences are also examined. The weathers associated with cold fronts frequently appear over the areas of Mongolia and North China in springtime. The cold front system, in general, carries the sand and dust southwards. Among all topographic influencing elements, the rounding effect of the TP is the strongest. Under the combined influences of the cold front and the rounding effect of topography, most sand and dust particles are transported and then deposited over the Loess Plateau.

Key words: dust transport, topographic influence, observations and numerical simulations

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1. Introduction

The frequent occurrence of dust storms in East Asia has been drawing great attention in the world. According to long–term dust storm observations, the dust storm phenomenon not only appears around the dust source regions, but also spreads to the remote downwind regions as well. As a kind of disastrous weather, the dust storm seriously affects the local industry, agriculture, traffic, people's health and living environment. According to a primary estimate of Shi and Zhao (2003), annually, there is about 1.0–3.0 Gt dust aerosol emitted from the earth's surface into the atmosphere, and about 120 Mt (diameter $< 41\mu$m; Zhang et al., 2003) of which is from Asia. In the troposphere over the middle latitudes from eastern Asia to western North America, the dust aerosols are mainly originated from Asia. This is confirmed by observational and numerical simulation studies on spring dust emissions by Zhang et al. (2003, 2005) and Zhao et al.

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†Corresponding author: jiangxuegong@yahoo.com.cn.

(2006). In addition, it has also been reported that about 70% of the Asian dust comes from the deserts in Mongolia and Northwest China (Zhang et al., 2003). About 51% of these dust particles deposit to the source regions (Zhao et al., 2006), and the rest are uplifted into the free atmosphere (3–10 km) by cyclone systems and then transported to downwind regions along the belt of about 40°N, among which 21% deposit to Asian inland, 9% deposit to the coasts of the Pacific, 16% deposit to the Pacific Ocean, and 3% deposit to North America through the trans-Pacific transport (Zhao et al., 2006). Moreover, the process of trans-Pacific dust transport occurring in western Mongolia in May 1998 has been analyzed in the study of Hacker et al. (2001).

A dust storm, at the beginning, only influences a relative small area (the source region), but with the dust emission and long distance transport, the impacted area in the downstream regions may enlarge dramatically. Meanwhile, for the population density, productivity and economic level of the downwind regions are always higher than those of dust source regions, the dust impacts on the inhabitants, climate, environment, and ecosystem may increase enormously down along the dust transport route. When considering the measures to decrease the desertification, we should focus not only on the dust storm itself but also on the dust transport as well.

The crucial element of dust transport lies in a favorable atmospheric circulation system, which determines the direction, distance, and influencing areas of the dust transport (Song et al., 2007). Further, the more direct control of the transport is the dominant air current in the dust layer in the free atmosphere, especially over a plain area. For instance, the dust particles from the Sahara Desert, in general, are transported by the easterlies above the tropical zone to the Atlantic Ocean. The situation is different when a dust storm occurs over the areas with a higher altitude and uneven surface, i.e., East Asia, where the dust transport is mainly determined by the characteristics of local topography. Since there are many high mountains with an altitude over 1000 m on average in the sand and dust source regions, the dust particles are always uplifted into the mid to upper troposphere (Jiang et al., 2003). Furthermore, following the downwind direction of East Asian dust aerosol transport path, the altitude decreases gradually from northwest to southeast. Under this kind of surface condition, the East Asian dust aerosols can be easily moved by the northwest current to the large downstream areas. Sometimes the dust can be transported to the coasts of the Pacific or even to North America. So far, few studies on the impacts of the topography on dust storms in East Asia can be found in the related scientific literature. This article presents some statistical analyses based on historical observational data and a particular dust event analysis in comparison with the numerical simulation results. The potential influence of topography on dust transport in East Asia will be investigated herein.

2. The topography of East Asia and its potential influence on dust storms

A spatial distribution of annual dusty days (including days when there occurs floating dust, blowing sand, or a sand/dust storm) in East Asia is shown in Fig. 1. The data set is obtained from China Meteorological Administration (CMA). We give a day a dust weather score if there is a dust event recorded once among the four routine observations at 0000, 0600, 1200, and 1800 UTC. The length of the data set is from 1 January 1980 to 31 December 1999. There are two dust weather frequent occurrence regions in the Fig. 1: one is the area containing southern Mongolia and the western part of Inner Mongolia with 20–50 dusty days on average per year; the other is located in the Tarim Basin of the southern part of Xinjiang with averagely 30–100 days per year. The two regions are commonly recognized by scientists as the two major sand and dust source regions in East Asia (Qian et al., 2002).

The topographic features of East Asia can be viewed in Fig. 2. By comparing it with Fig. 1, the difference of the influences of the two frequent regions on the dust storms can be found. Although the dust weather frequency of the second region is higher than

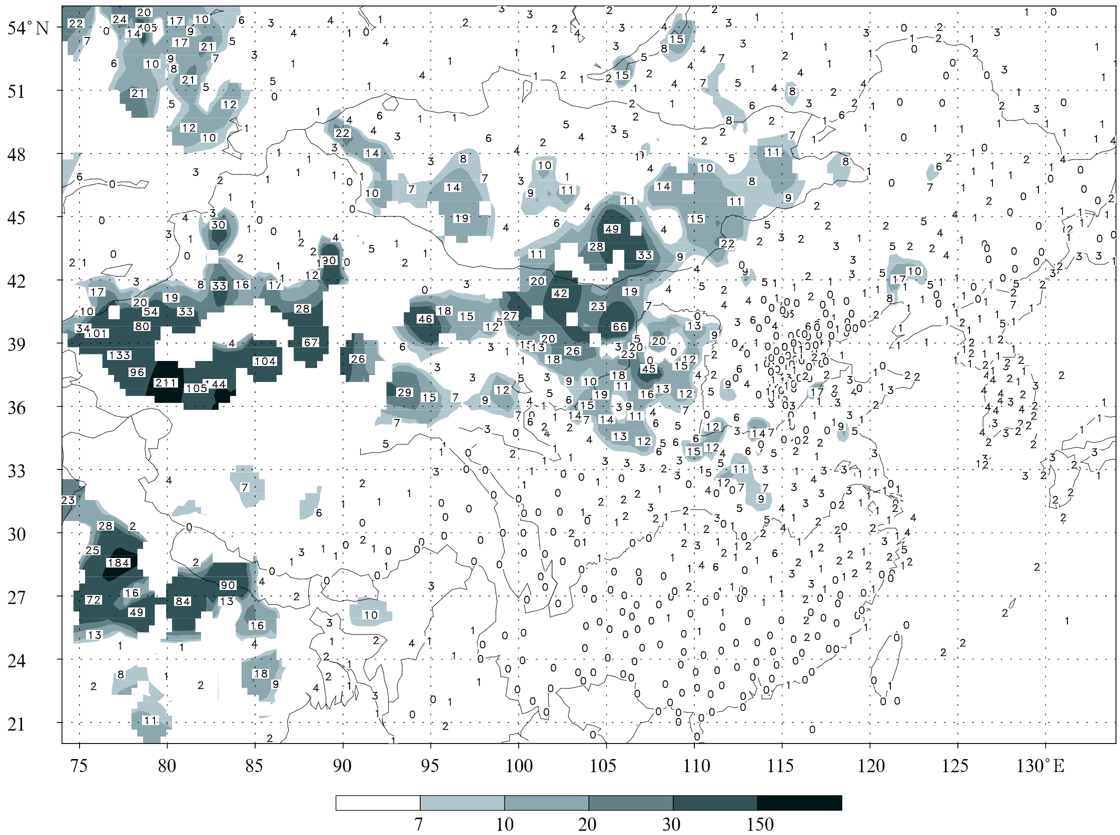

Fig. 1. A spatial distribution of annual mean dust days in East Asia.

that of the first one, the impacts that it exerts are not as serious as those of the first region. Due to the special basin features of the second region, only a few of all dust storms can move out of the basin. Therefore, its impact scale is relatively small. On the other hand, depending on the plateau characteristics of the first region (the Mongolia Plateau) and appropriate weather conditions, most of the dust storms originated from the first region can usually make their way to the downstream regions, even approach to the eastern shore of the Pacific. Comparing the topographic conditions of the two source regions, we find some similar and different features. The similarity lies in that both of the two source regions are relative lower in altitude compared to their surrounding terrains. The first region covers a large territory between the Sayan Mountains and the Qilian Mountains, and the second one lies in the area between the Tianshan Mountains and the Tibetan Plateau. The dissimilar feature is that the second region is surrounded by the Tianshan Mountains in the north, the Pamir Plateau in the west, and the Altum Mountains in the south. The Hexi Corridor is the only out gate for dust exportation. Due to the special topographic layout, the uplifted dust is trapped by the surrounding mountains and can rarely be moved out of the basin. Consequently, along the path of the Hexi Carridor, there is a small part of the dust which can make severe influences onto its downstream regions. Contrarily, the situation of the first source region is different. The Sayan Mountains lie to its northwest and are oriented from northwest to southeast while the Qilian Mountains are located to its southwest, heading also from northwest to southeast. The particular relief of these two mountains makes a bell-mouthed valley around the first source region. Actually, the wide mouth of the bell-shaped topography opens to the downwind regions (Fig. 2). As a result, the dust particles lifted by upwind and produced by cold air attacks over the Mongolia Plateau are easily transported outside the source region, heading south-

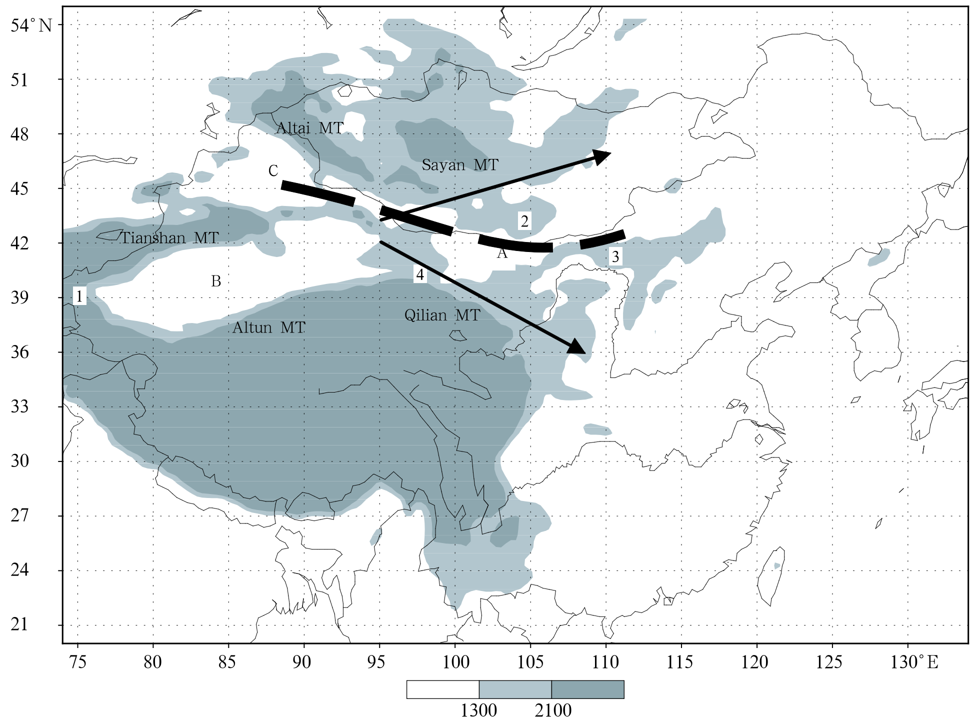

Fig. 2. Topographic conditions of East Asia. Labels 1–4 denote the Pamir Plateau, the Gobi Altay Mountains, the Yinshan Mountains, and the entrance of Hexi Corridor, respectively. Labels A–C refer to the desert area from the western Mongolia to the Inner Mongolia of China, the Tarim Basin, and the Junggar Basin. Here A and B also indicate the dusty weather frequently happening areas. The arrows represent a bell-mouthed feature. The thick dashed line represents the canyon.

eastwards. In spite of this, the down-slope terrain condition of the large zone which is from the first source area to the downwind region is helpful for dust particle diffusion.

3. Observation of a severe dust storm

The bell-shaped topography of the Mongolia Plateau should be a favorable condition for dust spreading. In order to investigate the mechanism of the spreading, synoptic analysis and numerical simulation are employed to analyze the topographic effects on dust transport. A severe dust storm event occurring from 18 to 22 March 2002 is analyzed, as it is the biggest dust event observed in recent years. The intensity distribution of the dust storm can be seen in Fig. 3. We can find two centers appearing in the Inner Mongolia: one is the western area dominated by deserts and sandy lands, and the other is the middle and southeastern parts of the Inner Mongolia. The two dust storm centers influenced areas that cover more than 90 percent of all the dust weather frequently attacked areas in China. Meanwhile, the dusty weather also appeared in Mongolia, the western shore of the Pacific such as Korea, Japan, etc.

This serious dust case was mainly caused by the Mongolian cyclone. The corresponding weather situation is shown in Fig. 3. The dusty weather area can be seen as a volute shape that indicates the influence of the Mongolian cyclone. At 0000 UTC 18 March 2002, a trough appeared in the middle troposphere (500 hPa) over the central Asia and deepened gradually while moving eastward. When it reached eastern Xinjiang (95°E) at 0000 UTC 19 March 2002, a cyclone formed at the lee side of Sayan Mountains. Meanwhile, abundant sand and dust were blown up into the high sky by the cyclone over the western Mongolia. At 1200 UTC 19 March 2002, associated with the deepening trough and the cyclonic cold front of the strengthening Mongolian cyclone at surface, the dust storm started to invade the Inner Mongolia of China. The cyclone became stronger on the next day and the

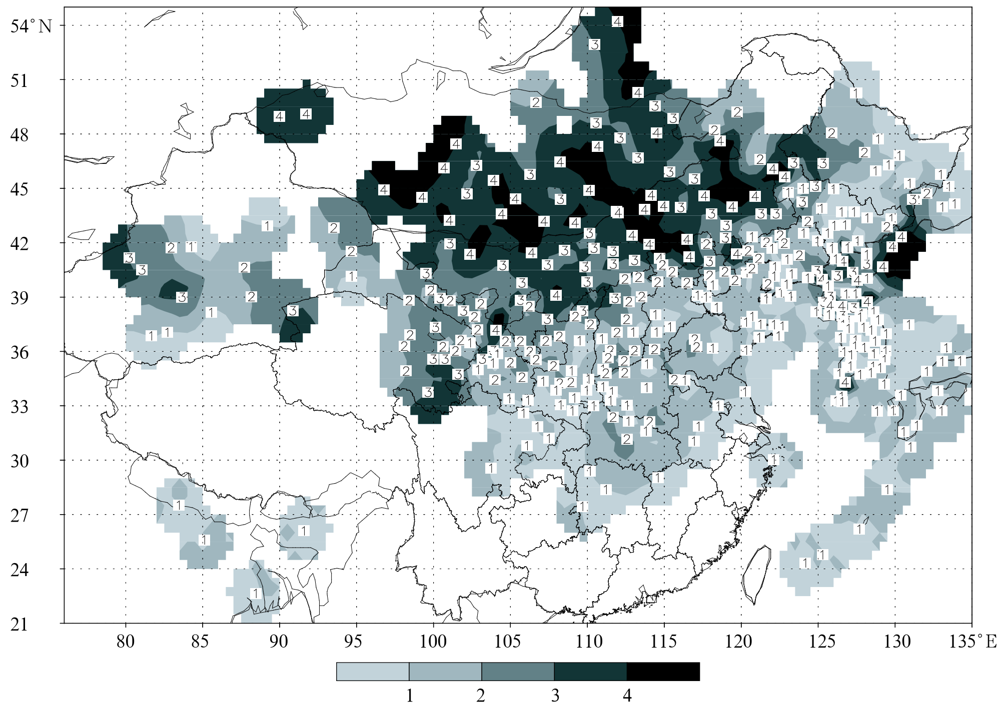

Fig. 3. The distribution of dusty weather in East Asia from 18 to 22 March 2002. The numbers 1, 2, 3, 4, and different levels of darkness denote floating dust, blowing dust, dust storm, and severe dust storm, respectively.

dust storm led by the cyclone swept most part of North China. On 21 March 2002, following the movement of the front, the dust storm expanded to Jilin and Liaoning provinces. Although the dust storm disappeared gradually with the weakening of the cyclone during the later days, the suspended sand and dust still stayed in the upper atmosphere and spreaded continuously to the western Pacific Ocean.

4. Model configuration

The numerical model developed by Beijing Institute of Urban Meteorology, CMA, is used in this study. It is constructed by coupling MM5 and a set of mass conservation equations for the dust particles. In order to distinguish the dust particles precisely, the diameters of the particles are sorted into 16 degrees. The dust lifting process is parameterized, which is related to surface topography, canopy, and soil moisture. The simulated dust deposition scheme includes dry and wet processes. The crucial dust blowing element is the fricative velocity on the surface (Cheng et al., 2004).

The severe dust event of 19–22 May 2002 is simulated. The grid resolution is 30 km and the grid number is 131×121. The T213 analysis and forecast data obtained from the National Meteorological Center of China are used as the initial and boundary conditions. The simulation starts from 0000 UTC 19 March 2002 and lasts for 48 h. The real topography is utilized in the control run (Fig. 4a), while in the sensitivity test, we adjust the altitude around the Altay-Sayan Mountains and reduce the highest altitude from about 2500 to 1500 m. The adjusted topography in the sensitivity test is presented in Fig. 4b. The following description will focus on an intensive period from 0000 UTC 19 to 0000 UTC 20 March.

5. Numerical simulation results

5.1 Dust weather

By comparing the observed and simulated intensity of the dust storm (Fig. 5), it can be identified that the control run preferably captured the dust concentration at 0600, 1200, 1800 UTC 19 March, and 0000 UTC 20 March 2002 (Fig.5). A large area along the boundary between Inner Mongolia and Mongolia, which is covered by dense dust clouds can be seen in

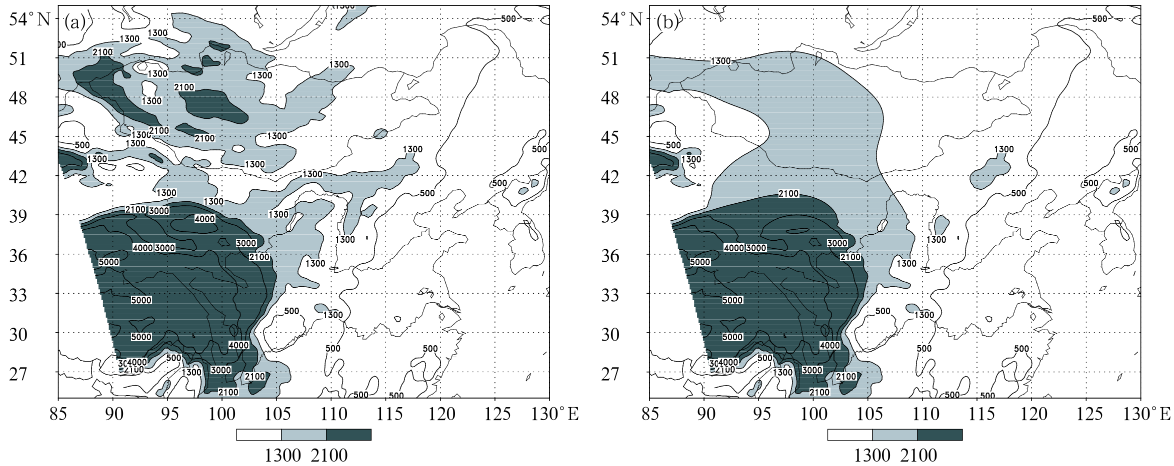

Fig. 4. The topographic elevation in the control run (a) and the sensitivity run (b) (interval: 400 m).

Fig. 5a. Meanwhile, compared with the simulation, a region with higher observed dust concentrations appears around the same area. At 1200 UTC 19 March 2002, the suspended dust cloud moved eastward and became stronger than the original dust clouds (Fig. 5b). Meanwhile, higher simulated dust concentration appeared over the same region. From 1800 UTC 19 March to 0000 UTC 20 March 2002, the observed dust storm split and moved in two directions: one headed eastward, and then reached south of the middle-eastern Inner Mongolia; the other moved to southern Shaanxi Province. A similar process is simulated in the control run (Figs. 5c and 5d). Therefore, the production and spread of the dust storm are successfully simulated.

5.2 Analysis of the dust storm event

Different characteristics of the dust event in evolution periods are shown in Fig. 5. From 0600 to 1200 UTC 19 March 2002, the main feature of dust storm evolution was strengthening and the dust areas appeared within the southern Mongolia and western Inner Mongolia. On the next day, the main characteristics of the dust spread were the southeastward moving from 1800 UTC 19 March to 0000 UTC 20 March 2002 (Figs. 5c and 5d). During this period, the dust storm intensity did not change too much.

The evolution characteristic of the dust storm is a typical dust storm pattern observed in North China, which always starts from the Mongolia Plateau (the first dust source region), enhances quickly, and then spreads southeastwards and influences the downwind region. It can be easily recognized that the developing patterns of dust storms of the two source regions in North China are similar. In fact, according to our analyses, they are different in evolutions and transport. From Fig. 1, we can find that in hinterlands of the deserts in the boundary areas of Mongolia, and Inner Mongolia the dust weather frequency is significantly higher than that of its southern and northern edges. The special topographic conditions of the region are helpful for dust storm quickly strengthening. On the other hand, the situation in Taklimakan Desert (hinterland of Tarim Basin) is different. The frequency of dust weathers in central area of the Taklimakan Desert Chinter-lands of Tarim Basin is obviously below the frequency of the southern rim of the desert. For instance, the annual mean dust weather frequency is 33 times at Bachu Station (39.48°N, 78.34°E) which lies near the center of the desert. Moreover, at Tazhong Observatory (39°N, 83.40°E), the annual mean frequency is 24 which is counted from the constant dust weather records from 1999 to 2002. On the contrary, the frequency of the southern rim of the desert reaches 100 times or more. It can be deduced that the condition of the Taklimakan hinterlands is unfavorable for dust storm enhancement. In the earlier stage of dust storm formed

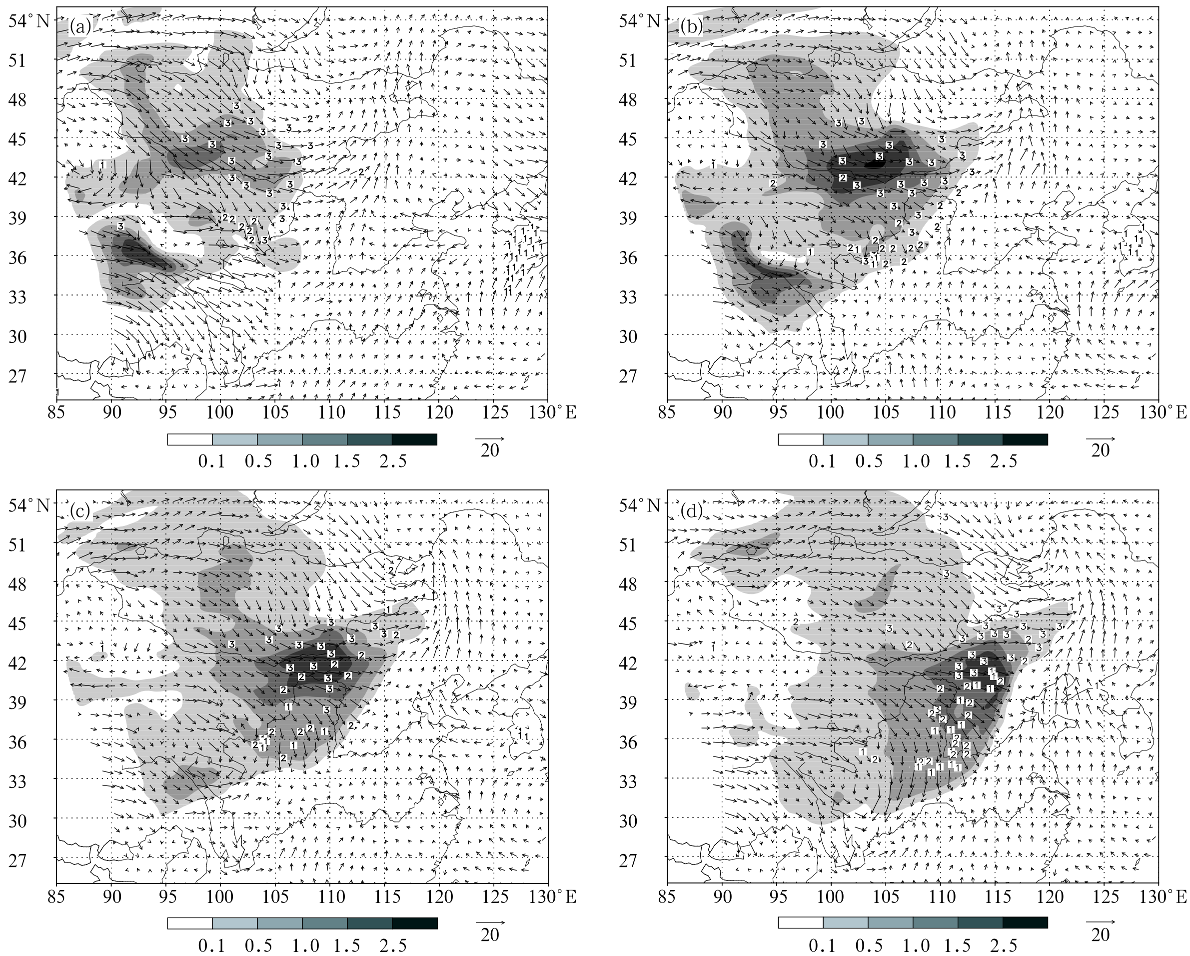

Fig. 5. The observed dusty weather (numbers), the simulated surface dust concentration (shadings; mg m^{-3}), and wind field (vectors) at 10 m above the surface in the control run at (a) 0600 UTC, (b) 1200 UTC, (c) 1800 UTC 19 March 2002, and (d) 0000 UTC 20 March 2002. Numbers 1, 2, and 3 represent floating dust, blowing dust, and dust storm, respectively.

in the central area, it does not develop quickly. With the help of the southward current, it enhances fastly when it moves to the southern rim of the desert basin, where an uplift dynamic power for dust storms can be provided.

The dust storm evolution process in the boundary region between Mongolia and Inner Mongolia are identified through the control and sensitivity runs simulating the dust case at 1200 UTC 19 March 2002 (Figs. 6a and 6b). In spite of the fact that the same dust cloud covered areas are displayed in the two tests, the dust intensity (concentration) was different. The maximum concentration revealed in the control run was 2.8 mg m^{-3}, while it was 1.2 mg m^{-3} in the sensitivity run. Therefore, it can be deduced that the topographic conditions exert a great influence on dust storm development in the beginning period.

The topographic features can be seen in Fig. 2, which rereals that in the hinterland of the Mongolia Plateau, there are two quasi east-west oriented mountains. One is the Gobi Altay Mountains located in southern Mongolia, and the other is the Yinshan Mountains in the central area of Inner Mongolia. The two mountains make a canyon between them. This canyon connects with another canyon which lies at the south side of the Altay-Sayan Mountains. These two linked canyons stretch from west to east of the Mongolia Plateau with a length of about 2000 km

(90°–110°E). The low level currents over the canyon zone are always controlled by the narrow canyon conditions. Aimed at identifying this topographic influence, the simulation has been run with two different surface conditions (Figs. 7a and 7b). Comparing the two simulations, we can find that the current directions were quite different in the canyon region (rectangular area marked in Fig. 7). The winds in the first test blew along an obvious west-east direction. Outside the canyon, the winds headed to south unanimously both in the south and in the north (Fig. 7a). The situation in the sensitivity test was different. When the surface conditions were not considered, the wind directions inside and outside the canyon zone were mostly northwest-southeast (Fig. 7b). This confirms the existence of the topographic influence. Therefore, it can be recognized that the wind directions near the surface were changed by the topography of the canyon, which most likely produces a rounding effect on air current in the canyon when strong winds approach the high mountains from both sides. Due to this rounding effect of topography, the air current is forced to become stronger, and then, a canyon low level jet (CLLJ) is formed. It can be proved by comparing the wind velocity changes in the two tests that wind speed in the canyon is affected significantly by the special topography. The difference of the simulated velocity in the canyon between the control and sensitivity runs is 2–4 m s^{-1}, with the velocity in the first run larger than that of the second (Fig. 8). (On contrast, a different situations is found in the Taklimakan Desert. Since the surface of the desert is relative even, especially in

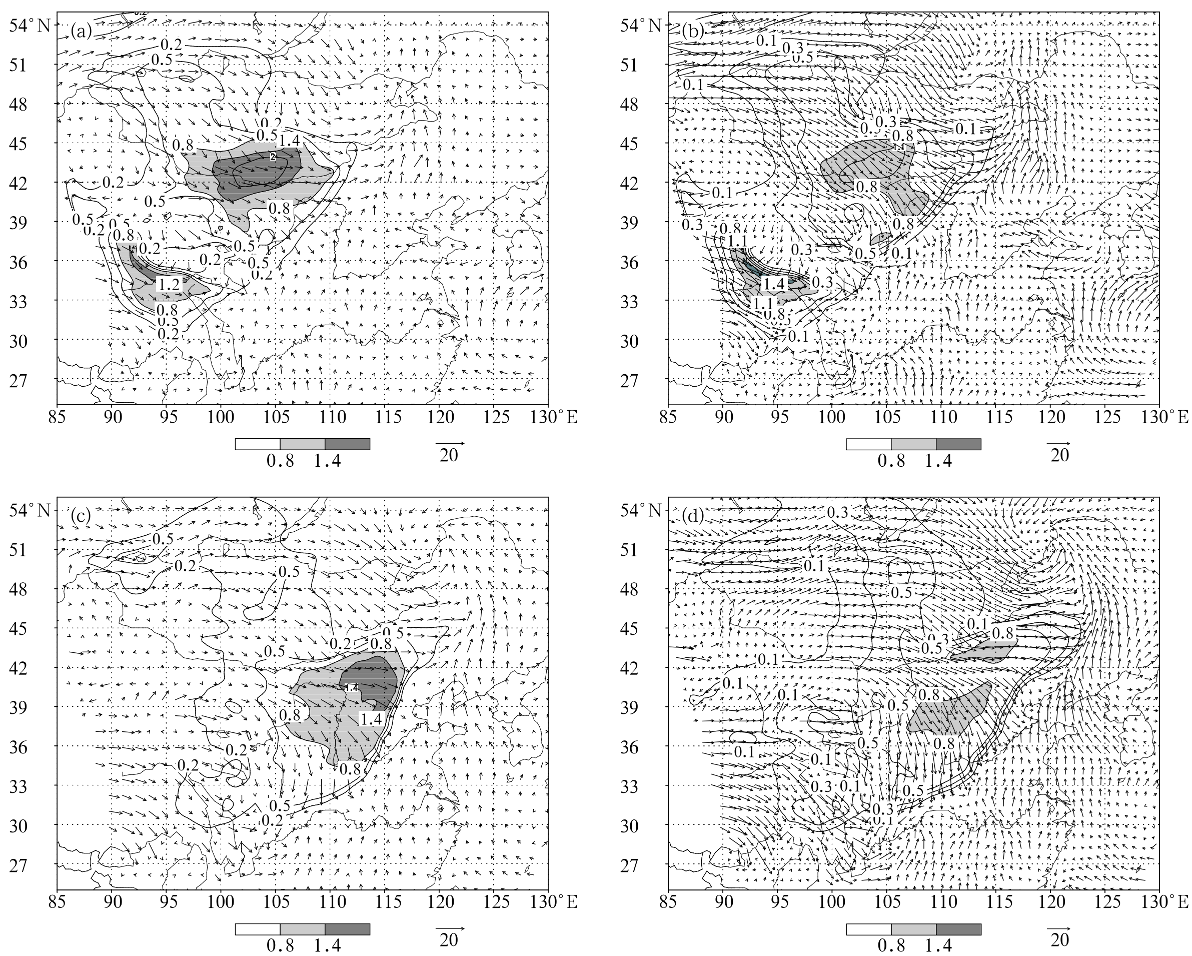

Fig. 6. Surface dust concentration (mg m^{-3}) and wind field (vectors) at 10 m above the surface in the control run at (a) 1200 UTC 19 March and (c) 0000 UTC 20 March, and in the sensitivity run at (b) 1200 UTC 19 March and (d) 0000 UTC 20 March 2002.

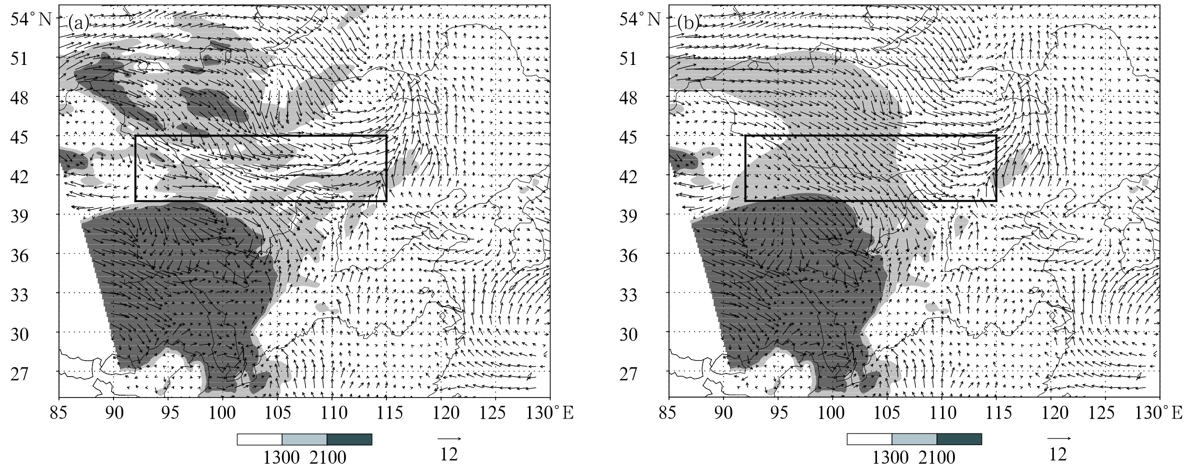

Fig. 7. The topographic elevation (shaded, above 1300 m) and the simulated surface wind fields (vectors) at 1200 UTC 19 March 2002 for the (a) control run and (b) sensitivity run.

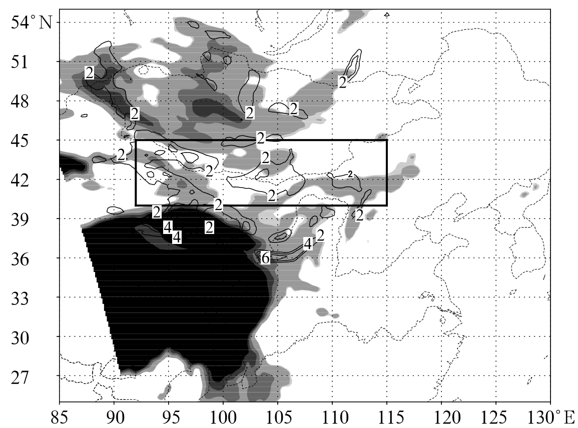

Fig. 8. The difference of wind speed (m s^{-1}) at 10 m above surface at 1200 UTC 19 March 2002 between the control and sensitivity runs. Topography higher than 1300 m is shaded.

its central part, the topographic effect is small.) Therefore, the canyon condition of the region containing Mongolia and western Inner Mongolia is the crucial element for rapid strengthening of winds.

In Fig. 7a, it can be found that there is a great difference between the two current directions. One is the obvious northwest down slope current over the southern side of the Sayan Mountains; the other is the CLLJ with actually west direction in the canyon located in the downwind region of the first current. Therefore, with the southeastward movement of the first current, it is blocked by the second one. Meanwhile, some dense dust clouds above the down slope area can be seen from the observed surface dust distributions of the period from 0600 to 1200 UTC 19 March 2002 in Fig. 5. Under this condition, the northwest current, in fact, brought a lot amount of sand and dust heading southeastward, and then, the sand and dust particles assembled around the canyon when the northwest current encounter the CLLJ. This dust assembled phenomenon also can be proved in the surface observations (Fig. 1). From the figure we can find a significant dust storm frequently attacked area which is fitted to the area around the canyon. Inevitability, the block effect of the canyon is another reason of the quickly strengthening of dust storm in the boundary region between Mongolia and Inner Mongolia, China.

Compared with the orographic conditions of the Taklimakan Desert, there are many mountains and hills making an uneven surface in the South Mongolia and West Inner Mongolia (Fig. 2). The uneven surface condition induces orographic waves, which can produce ascending motion on the frontal slope of the mountains and descending motion at the back sides. On the frontal slope, the sand and dust can be easily lifted up into the upper atmosphere due to the ascending motion of the upward slope. That is one cause why dust storms are always enhanced in the region of the frontal slope. More importantly, orographic waves in

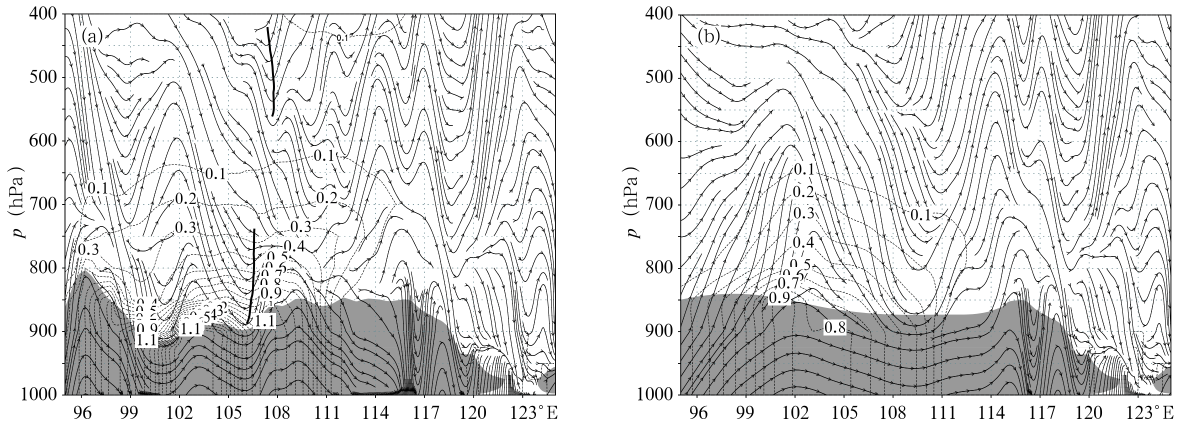

Fig. 9. The cross-section along 42°N at 1200 UTC 19 March 2002 in the control run (a) and sensitivity run (b). The dashed isolines represent dust concentration (mg m^{-3}). The streamline is the resultant wind circulation by u and $w\times50$. The thick solid line represents the orographic-wave-induced ascending motion.

general can expand upward to the free atmosphere and uplift the dust particles into the upper atmosphere. This kind of impact, however, can rarely be seen in the Taklimakan Desert. Some obvious differences are revealed in the zonal cross-sections along 42°N (Fig. 9) from the two tests. The significant orographic waves can be seen in the control test. This wave effect not only appears in the boundary layer, but also expands into the free atmosphere. Furthermore, the friction area of the current and the earth's surface is surely enlarged by the uneven earth surface. That is also helpful for dust rising (Fig. 9a). Conversely, there is no short length waves displayed in the sensitivity simulation (Fig. 9b).

In ordinary recognition, it is possible that the variation of the simulated dust storm intensities in the two tests may be induced by the difference of cyclone intensity and the change of topographic conditions. In order to identify which one is the major influence factor, the simulated strength and evolution of the cyclone in the two tests are compared: at 1200 UTC 19 March 2002, the difference of cyclone central pressure values between the two tests is very small, 1006 hPa for the sensitivity test and 1005 hPa for the control test. At 0000 UTC on the next day, both of the central pressure values of those two tests are 997 hPa. Additionally, the central positions of the cyclone can be seen almost in the same point in model output wind fields of the two tests. Therefore, it can be confirmed that the variations of dust storm intensities between the outcomes of the two tests are mainly caused by the changes of topographic conditions.

The dust storms in the Mongolia Plateau are initially enhanced in the dust source region, and then, expanded to its downwind regions. This is absolutely different to the dust storm evolution pattern of the Taklimkan Desert, where the dust particles are immediately transported southwards after they are lifted up into the sky. Only when the dusts encounter an obstacle, for example, the north slope of the Altun Mountains, will it become stronger. For the former one, the dust particles originally gather in the atmosphere over the region where can be recognized as a "dust accumulating container"; the latter transport of the suspended dust is crucially determined by the weather systems.

5.3 The spreading of dust storms

Generally, the dust storms spread continuously to the downwind regions after it had enhanced on the Mongolia Plateau. The impacts of the topography also played an important role in dust transport in this stage. The obvious topography influence was revealed in the outputs of the two tests in which the surface dust concentrations are simulated at 0000 UTC 20 March 2002 (Figs. 6c and 6d). In the control run, the main body of the suspended dust moves directly eastwards, while it moves southwards in the sensitivity test. Therefore, a deduction can be made that the topographic conditions restricted the eastward movement of the dust storms occurring on the Mongolia Plateau.

The spreading direction of the dust clouds is crucially determined by weather systems, such as the Mongolia cyclone. The cyclonic air current always exists in the whole stage of the Mongolia cyclone evolution. There is a southward component in the circular current which leads to southward transport of the dust particles. The southward component is revealed in the output field of the sensitivity simulation (Fig. 6d). Contrarily, under the real topography condition, the influence of the CLLJ significantly weakens the southward dust transport (Fig. 6c). It can also be identified that the southward transport (v component) is weaker with the actual topography according to Fig. 10.

The sub-frequent dust storm occurrence region is identified stretching from northeastern edge of the TP to the central part of the Loess Plateau (Fig. 1). Evidently, most of the dust weathers observed in this region are caused by invading dusts originated from its upstream regions. There are two recognized topographic forcing elements which carry the dust particles southwards to the Loess Plateau: the down-slope air current in the southern side of the Sayan Mountains, and the rounding effect of the air current produced around the northeastern edges of the TP. Due to the powerful impact of the huge mass of the TP in both vertical and horizontal directions, the rounding current is very strong (Fig. 7). In the vertical, the current can even reach the middle level of the troposphere. (The intensity of southward transport in this region is stronger than that of the eastward movement of the dust clouds, because there is no effect of the canyon jet.) Otherwise, concerning only the weather conditions, for most dust cases the eastward movement is led by the Mongolian cyclone while the southward transport of dust particles is usually steered by cold fronts. A statistical survey of the historical dust weather events in North China shows that 76% of the severe dust storms are produced by cold fronts. The dust storms led by the Mongolian cyclone take only 12% of the total number (Liu et al., 2004). To summarize, all factors influencing the dust transport in East Asia can be sorted into two kinds: one is associated with weather systems consisting of two weather types (the hollow arrows in Fig. 11), and the other is

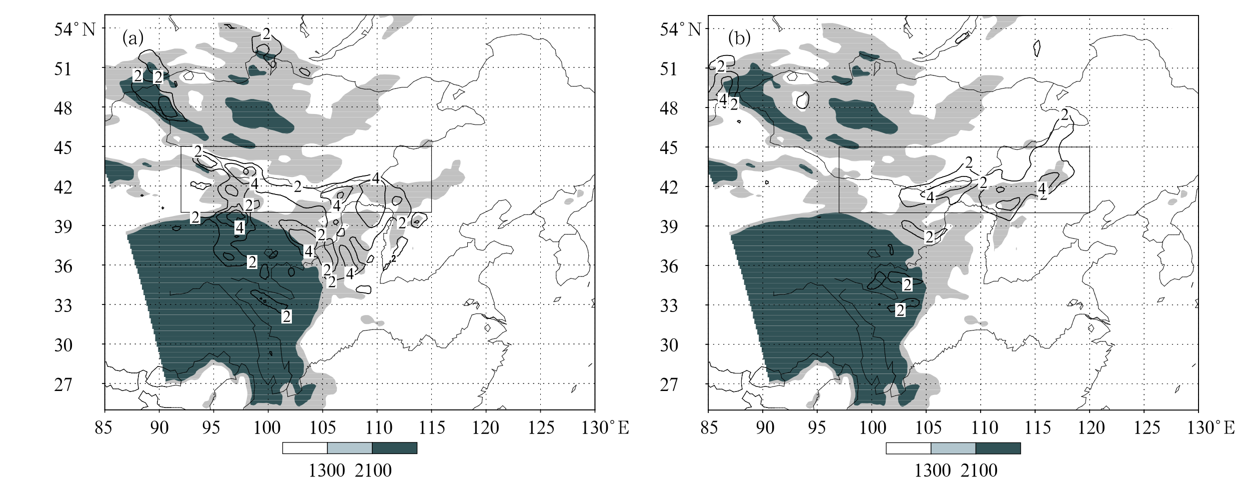

Fig. 10. Differences of u (a) and v components (b) of the wind fields (m s^{-1}) at 10 m above the surface at 1200 UTC 19 March 2002 between the control and the sensitivity run. Shaded areas represent the topography.

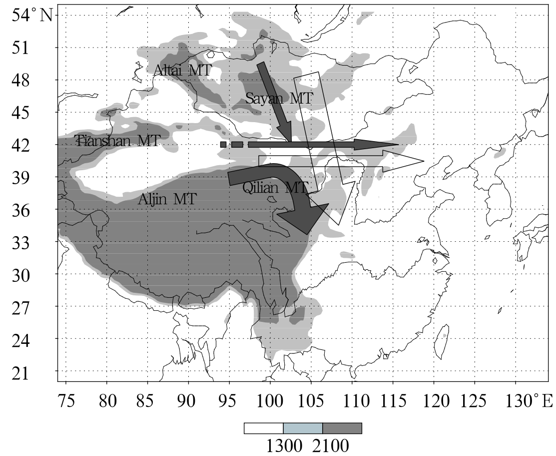

Fig. 11. The conceptual model of dust transport in East Asia. Black arrows represent the dust moving directions impacted by topography, and hollow arrows indicate the dust transport directions led by weather systems.

related to topographic conditions including three terrain types (the black arrows). The dust transport pattern induced by all five types is displayed in Fig. 11. Compared with all other topographic influences, the rounding effect of air current near the northeastern edge of the TP is the strongest. In addition, the most frequent weather system causing dust storms in East Asia is the cold front. In both the rounding current and the cold front cases, the dust particles are transported southward. Therefore, most of the transported dust particles deposit to the surface of the Loess Plateau.

6. Summary

Based on the observations of dust weathers in East Asia and by employing numerical simulations, the influences of the topographic conditions on dust transport in East Asia have been analyzed in this study. It is shown that there are two dust storm source regions: one is the boundary region between South Mongolia and the western part of Inner Mongolia, and the other is the Tarim Basin. The most frequent dust storm happening area within the first source region is confirmed to be the central part of the region. For the second source region, it is found to be in the south rim of the Taklimakan Desert. In addition, a dust storm sub-frequently attacked region is identified from the northeastern edge of the TP to the Loess Plateau.

The major cause for the quick enhancement of dust in the first source region is the combined effects of the favorable topographic conditions. The canyon feature of the region increases the wind speed, and facilitates the development of a CLLJ from west to east. The suspended dust particles, which are carried by the down-slope current south of the Sayan Mountains, are accumulated when they encounter the CLLJ in the canyon. Besides, the uneven earth surface induces orographic waves which are helpful for lifting more dust particles into the upper air. This process of dust gathering in the atmosphere and then moving to the downwind regions can be recognized as a “dust accumulating container” effect.

The canyon layout of the southern Altay-Sayan Mountains is confirmed to be the crucial force for eastward dust transport. In addition, the combined effects of the topographic forcing of the TP and the down-slope current south of the Sayan Mountains is the major cause of the southward dust transport. Moreover, by taking into account the weather influences, it is found that the southward dust movement is mainly controlled by cold fronts while the eastward transport of dust particles is led by the northwestern current behind the Mongolian cyclone during its full development. The great impacts of the rounding current near the northwestern edge of the TP combined with frequent cold front attacks bring most of the dust particles southward. This is why the dust transport is more likely concentrated in the region from the northeastern side of the TP to the Loess Plateau.

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