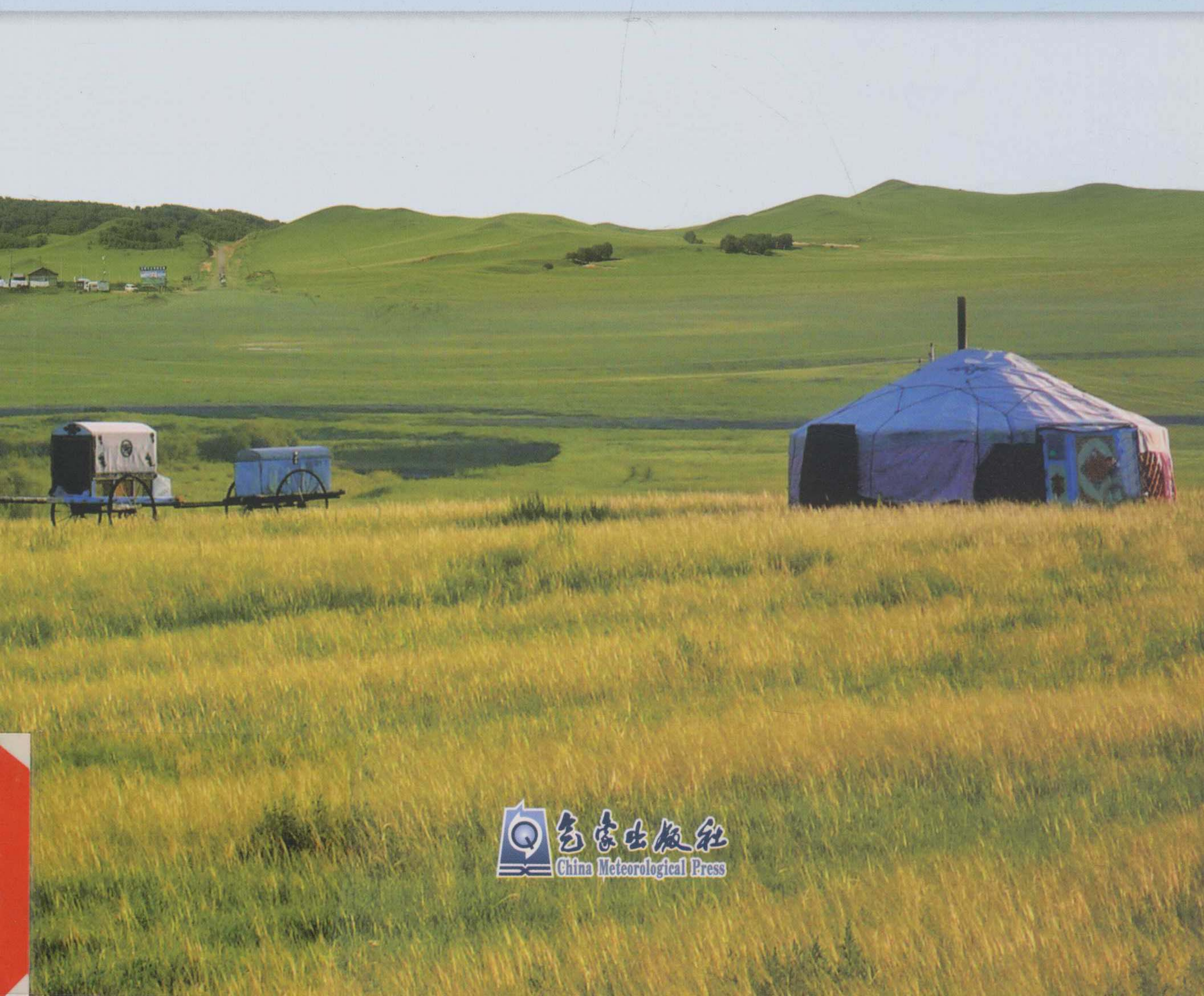
内蒙古

灾害性天气研究论文集

孙永刚 主编



气象出版社
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内容提要

2011年内蒙古自治区气象局组建了沙尘暴、暴雨、暴雪三个专家型预报创新团队，针对内蒙古主要气象灾害开展深入研究。本书收录了预报创新团队的研究论文，内容涵盖了内蒙古沙尘暴、暴雨、暴雪等主要气象灾害的时空分布特征及发生规律分析、发生机制及灾害成因研究、典型和特殊个例的诊断分析研究、预报技术方法研究等内容，是内蒙古预报团队创新工作的汇集。

本论文集可供从事天气预报服务的天气预报技术人员以及从事生态、资源与环境、农牧业、林业、交通运输等相关专业的技术人员参考。

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序

内蒙古自治区地处我国北部边疆，幅员辽阔，东西相隔 2500 千米，南北距离 1700 千米，总面积 118.3 平方千米，占全国总面积的约八分之一。自西向东跨越我国西北、华北、东北地区，从干旱、半干旱地区一直过渡到半湿润、湿润地区，气候复杂多样。

内蒙古大部分地区属于温带大陆性季风气候区，四季分明。春季气温骤升，干旱少雨，多大风天气；夏季短促温热，降水集中；秋季气温剧降，冷空气频繁；冬季漫长严寒，冬雪少，多寒潮天气。这样的气候背景造就了内蒙古地区气象灾害的复杂和多样性，暴雨、冰雹、雷电、龙卷、洪涝、暴雪、暴风雪、白灾、沙尘暴、寒潮、大风、霜冻、干旱、干热风、黑灾、凌汛等气象灾害均或多或少地出现在内蒙古地区。内蒙古地区几乎囊括了出现在我国的所有气象灾害种类。但在生成发展机理、演变过程、影响程度、服务方式又存在与我国其他地区有所差别。

频繁和严重的气象灾害给工农业生产和人民生活造成了巨大的危害。研究各类灾害性天气发生、衰亡演变过程规律与机理，开发灾害性天气预报、预警技术方法，是依靠科技、立足预防，有效降低气象灾害损失的必然途径，国家经济发展防灾减灾对气象的需求也是大气科学理论研究的基础需求。内蒙古自治区气象局以研究内蒙古主要灾害性天气成因及预报技术为目标，成立了暴雨、暴雪、沙尘暴专家型预报员创新团队，从业务实践工作中提炼出科学、技术问题，开展对这三类灾害为主的内蒙古主要灾害性天气形成机理、预报模型和指标、客观预报方法等较全方面的研究、科学思路正确。本论文集是这些研究丰硕成果的概况和总结，文集的出版能够成为内蒙古灾害性天气研究的良好开端，也必将推动这一工作持续和深入的开展。

李泽椿*

2015 年 4 月 20 日

* 中国工程院院士

前　言

暴雨、暴雪、沙尘暴是内蒙古自治区主要的灾害性天气。内蒙古暴雨集中出现在夏季，既有天气尺度、次天气尺度影响下的稳定性暴雨，也有中尺度天气系统导致的局地对流性暴雨。暴雨造成的灾害既包括系统性暴雨导致的如 1998 年松嫩流域的流域性洪水，也有对流性暴雨引发的中小河流山洪。对这些暴雨的预报历来都是内蒙古天气预报工作中的重点和难点。暴雪（暴风雪）是内蒙古地区具有地方特点的严重灾害性天气，暴风雪以及持续性暴雪形成的白灾，往往造成草原牧区牲畜的大面积走失和死亡。暴风雪是内蒙古非常严重的灾害性天气，也是内蒙古天气预报工作中的重要内容。沙尘暴是内蒙古地区主要的灾害性天气，内蒙古西部的沙漠及荒漠化地区是东亚沙尘暴的主要沙尘源地之一，内蒙古同时也是受到沙尘暴影响最为严重的地区，形成于内蒙古地区的沙尘暴往往对下游地区产生非常严重的影响。因而沙尘暴预报一直是内蒙古天气预报的重点。

因此，内蒙古自治区气象局于 2011 年成立了暴雨、暴雪、沙尘暴专家型预报员创新团队，针对三类灾害性天气的发生机理、预报指标、预报技术等开展了全面的研究。本论文集是暴雨、暴雪、沙尘暴创新团队相关研究工作的总结和积累。这些研究包括这些灾害性天气的气候特征、天气过程的影响系统分型、大尺度环流特征、三维动力、热力结构特征及其演变规律、天气学概念模型及预报指标和预报着眼点、数值模拟分析及数值预报性能检验、客观预报、预警技术及系统开发等。

本书的大部分论文已经在科技刊物上发表。由于作者水平有限，书中难免有疏漏和错误之处，敬请读者批评指正。

作者

2015 年 1 月

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

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Abstract: Based on observations and numerical simulation techniques, the topographical impacts on dust transportations in East Asia were studied. According to the results of investigations in dust weathers in East Asia, two areas frequently attacked by dust storms have been confirmed, one is the region includes the western part of Inner Mongolia and the southern region of Mongolia (the region named the Mongolia Plateau), and the other is the Tarim basin. The most frequently dust storm occurrence area of the first one appears in its hinterland while for the second one, the south margin of it is the most frequently happening zone. In addition, there is a sub-frequently dust storm attacked region in the area from the northeastern edge of the Tibetan Plateau to the Loess Plateau. The dust storms frequently occurred in the Mongolia Plateau is not only due to the abundant sand and dust sources, but also based on the special topographic conditions of East Asia as well. Three influence factors have been found to be helpful for dust storm forming in the hinterland of the Mongolia Plateau. The most significant one is the 'canyon low level jet' (CLLJ), which is formed around the south areas of Altay-Sayan Mountains with an east-west direction at the beginning, then, it enhances the surface wind speed significantly. Due to the obstruct effects of the CLLJ, a lot of dust particles carried by the southward down slop cold air mass would pile up over the south slop of the Sayan Mountains. Moreover, the uneven surface conditions are very favorable for raising the dust particles into the upper air. With the dust particles pile up continuously in the atmosphere, the dust layer in the troposphere can be recognized as 'dust accumulating container', which provides abundant dust particles for the later transportations to the downstream areas. In spite of this, the topographical features of East Asia also conduct great influence on dust transportations. Generally, the easterly CLLJ enhances the easterly dust transportation. The down slope air current at southern Sayan Mountains and the rounding effect of current at the northeastern edge of the Tibetan Plateau enhance the southerly dust transportation. Considering of weather system influences, the weathers caused by cold fronts frequently appear over the area including Mongolia Republic and North China in springtime. The cold front system, in general, carries the sand and dust to southward. Compared to all topographic influence elements, the rounding effect of current is the strongest one and head to southward. Under the combined influence of the cold front and the rounding effect of current, most part of the transported sand and dust depose in the region of the Loess Plateau.

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

1 Introduction

The frequently occurrences of dust storms in East Asia have been drawing great attention of the people in the world. According to a long term dust storm observation, the dust storm phenomenon appears not only around the dust source regions, but also spreads to the remote downwind regions as well. As a kind of disaster weather, the dust storm seriously affects the local industry, agriculture, traffic, people' s health and living environment. According to Shi's (2003) primary estimate, annually, there is about 1.0~3.0 Gt dust aerosol emit from the earth surface into the atmosphere and about 120 Mt (diameter < 41μm, Zhang et al., 2003)of the dust particles from Asia. In the troposphere over the zone of the middle latitudes throughout eastern Asia to western North America, the dust aerosols mainly source come from Asia which fact is confirmed by means of observation and numerical simulation analyses on spring dust emissions in the studies of Zhang et al., (2003 and 2005) and Zhao et al., (2006). In addition, it has been also indicated that about 70% of the Asia dust come from the deserts in Mongolia and Northwest China (Zhang et al., 2003). 51% of these dust particles deposits to the source regions (Zhao et al., 2006), the left are uplifted into the free atmosphere (3 ~ 10km) by cyclone systems and then transported to the downwind regions along the belt region around 40°N, among which 21% deposit to Asia inland, 9% deposit to the seacoast of Pacific, 16% deposit to the Pacific Ocean and 3% deposit to North America through the trans-Pacific transportations(Zhao et al., 2006). Moreover, the process of dust trans-Pacific transportation occurred in western Mongolia on May, 1998 has been analyzed in Hacker's (2001) study.

A dust storm, at the beginning, only influences a relative small area (the source region), but with the dust emission and long distance transportation, the area of its impacted downstream regions may enlarge dramatically. Meanwhile, for the population density, productivity and economic level of the downwind regions are always higher than that of dust source regions, the dust impacts on the inhabitants, climate, environment and ecosystem may increase by a hundred times following the dust transportation. Equally important, the measurement of decreasing the desertification which should be seriously considered not only focus on the dust storm itself but also needs to know the rule of dust transportations as well.

The crucial element of dust transportations is an appropriate atmospheric circulation system, which determines the directions, distances and influence areas of the dust transportations (Song et al., 2007). In a deeper view, the more directly controlling power of the transportations is the dominant air current in the dust layer in the free atmosphere, especially over a plain area. For instance, the dusts from the Sahara Desert, in general, are transported by the easterlies above the tropical zone to the Atlantic Ocean. Otherwise, it is different when a dust storm occurred in the areas with a higher altitude and uneven surface, for example, East Asia, where the dust transportation style is mainly determined by the characteristics of local topography. Since there are many higher mountains in the sand and dust source regions with an altitude over 1000 m on average, the dust particles are always uplifted into the middle-upper layer of the troposphere (Jiang et al., 2003). Furthermore, following the downwind direction of East Asian dust aerosols transportation path, the altitude decreases gradually from the northwestern region to southeast areas. Under this kind of surface conditions, the East Asian dust aerosols can be easily moved by the northwest current to the large areas in its downwind direction. Sometimes the dust can even be transported to the coast line of the Pacific Ocean or to North America.

Few literatures talking about the impacts of the topography on dust storms in East Asia can be found in issued scientific journals. Therefore, some referential analysis results have been presented in this article, including statistically analyzing the historical observational data, particular dust event analysis compared to the outputs of numerical simulations to deduce the potential influence of the topography on dust particle transportations in East Asia.

2 The topography characteristics of eastern Asia and its potential influence on dust storm

The spatial distribution of annual dusty days (including the weather phenomena floating dust, sand blowing and dust storm) of eastern Asia is shown in Fig. 1. The data set used to draw the figure is obtained from China Meteorological Administration (CMA). We give a day with a dust weather score if there is a dust phenomenon recorded within four daily regular observations (00:00, 06:00, 12:00 and 18:00 UTC). The time scale of the data set is from January 1, 1980 to December 31, 1999. There are two dust weather frequent occurrence regions can be found in the figure, one is the area contains southern Mongolia and the western part of Inner Mongolia with 20—50 dusty days on average per year. The other one is located in the Tarim basin of southern part of Xinjiang with 30—100 days on average 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 topographical features of East Asia can be viewed in Fig. 2. By comparing it to Fig. 1, the difference between dust storm influences of the two frequent regions can be found.

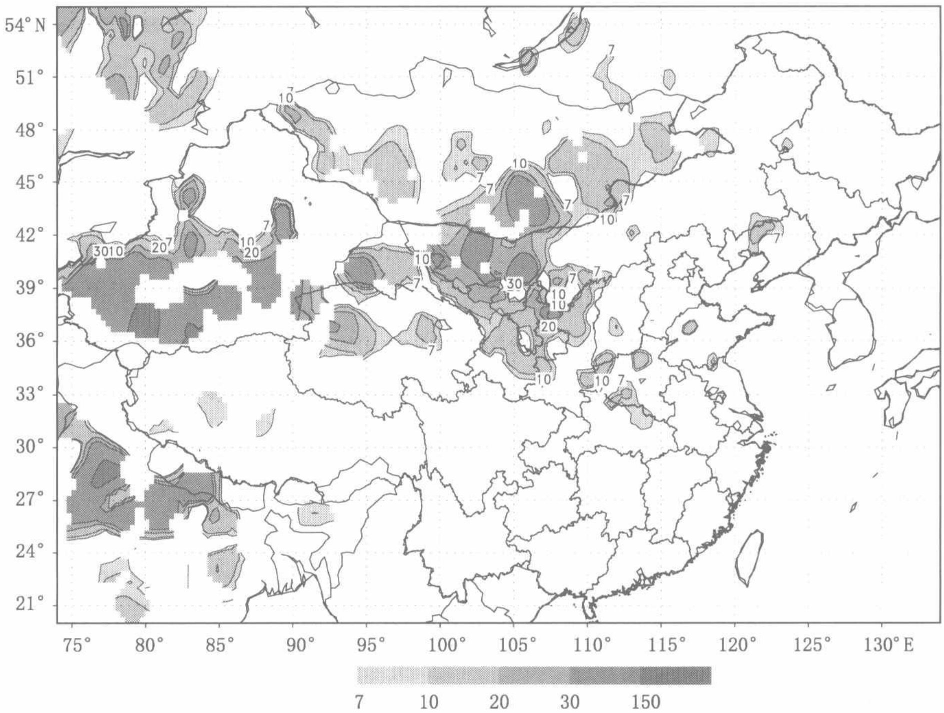

Fig. 1 Spatial distributions of annual mean dust days in East Asia

Although the dust weather frequency of the second region is higher than that of the first region, the impacts of it are not as serious as that of the first region. Due to the special basin features of the second region, there are just few of dust storms can move out of the basin. Therefore, its impact scope is relatively small. On the other hand, depending on the plateau characteristics of the first region (the Mongolia Plateau) and helped by favorable weather conditions, most of the dust storms can usually make their way to reach the downstream regions, even approach to the eastern shore of the Pacific. Compared to the topographical conditions of both source regions, we can found some similar and dissimilar features. The similar condition is that both of the two source regions are located in relative lower areas comparing to their surrounding terrains. The first one covers 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 of the two regions is that the second one is surrounded by the Tianshan Mountains in the north, the Pamir Plateau in the west and the Altyn Tagh Mountains in the south. The Hexi Corridor is only the out gate for dust exportation. Due to the special topographic conditions, the uplifted dust was trapped by the surrounding mountains and can scarcely be moved out from the basin. Consequently, tracking the path of the Hexi Corridor, there is a small part of the dust can make severe influence onto its downstream regions. Contrarily, the situation of the first source is different. The Sayan Mountains lies in its North West area and directing from northwestwards to southeastwards while the Qilian Mountains Locates in its southwest region heading from northwest direction to southeast. The particular surface shape with those two mountains makes a bell-mouthed terrain around the first source region. Actually, the wide mouth of the bell-shaped topography opens to its downwind regions (Fig. 2). As a result, the dust particles lifted by upwind and produced by cold air attacks over the Mongolia Plateau are very easy to be transported outside of the source region, heading to the southeastwards. 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 diffusions.

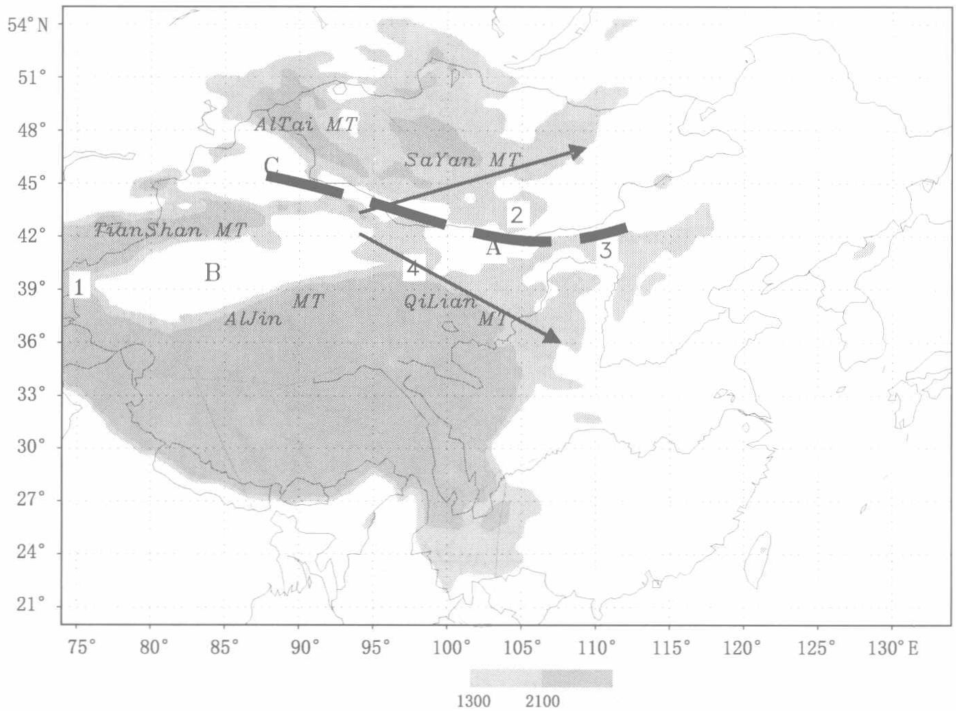

Fig. 2 Topographic conditions of East Asia. (1: the Pamir Plateau; 2: the Gobi Altay Mountains, 3: the Yinshan Mountains; 4: the entrance of Hexi Corridor; A: the desert area from western Mongolia to Inner Mongolia, China; B: the Tarim basin; C: the Junggar basin. Here A and B also indicate the dusty weather frequently happening areas. The arrows act as a bell-mouthed terrain. The thick dashed line represents the canyon).

3 Description of the dust storm case

The bell-shaped topographic condition of the Mongolia Plateau should be a favorable factor for dust spreading. In order to investigate the mechanism of the spreading, the methods of synoptic study and numerical simulation are employed to analyze the topographic effects on dust transportations. Therefore, the severe dust storm event occurred in the days from Mar. 18 to Mar. 22, 2002 has been analyzed, for it was a tremendous one observed in recent years. The intensity distribution of the dust storm can be seen in Fig. 3. In a deep view, we can find two centers appearing in Inner Mongolia, one is in the west area where is dominated mainly by the deserts and sandy lands, and the other can be found in the region which contains the middle area and the southeastern part of Inner Mongolia. The influenced area of those two centers covers more than 90 percent of the dust weather frequently attacked areas in China. Meanwhile, the dusty weather also appeared in Mongolia, the western shore of Pacific such as Korea, Japan and soon.

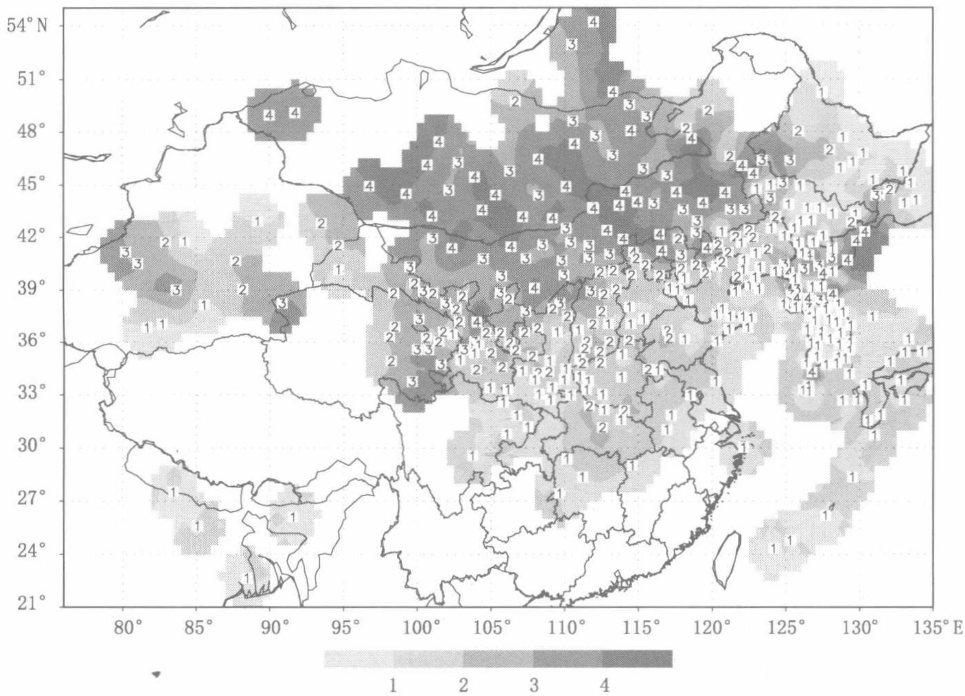

Fig. 3 The distribution of dusty weather in East Asia from Mar. 18 to Mar. 22, 2002. (1, 2, 3, 4 and different darkness denote floating dust, blowing dust, dust storm and severe dust storm, respectively).

The mentioned serious dust case was mainly caused by the Mongolian cyclone. The previous 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 00:00 UTC, Mar. 18, 2002, a trough appeared at middle layer of the troposphere (500hPa) above the central Asia and deepened gradually along with an eastward movement. When it reached to eastern Xinjiang (95°E) at 00:00 UTC, Mar. 19, 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 western region of Mongolia. At 12:00 UTC, Mar. 19, 2002, associated with deepening trough and the cyclonic cold front of the strengthening Mongolian cyclone on the surface, the dust storm started to invade Inner Mongolia, China. The cyclone became stronger on the next day and the dust storm led by the cyclone swept most part of North China. On Mar. 21, 2002, following the front movement, the dust storm expanded to Jinlin