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ANALYSIS OF MESOSCALE CONVECTIVE SYSTEMS OVER TIBETAN PLATEAU IN SUMMER

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ABSTRACT: In this paper, Geostationary Meteorological Satellite (GMS) infrared black-body temperature (T_{bb}) data from June to August 1998 are used to automatically track the activity of Mesoscale Convective System (MCS) over the Tibetan Plateau in China. Consequently, the features of MCS, such as area, intensity, life cycle, activity region and shape, are obtained. High Resolution Limited Area Analysis and Forecasting System (HLAFS) values provided by China National Meteorological Center are used to study the relationships between the MCS trajectories and their environmental physical field values, based on the distribution and trajectories of MCSs over the Tibetan Plateau. Favorable environmental physical field charts of influencing MCS movement out of the Tibetan Plateau in different UTC (Universal Time Coordinate) are developed by using spatial data mining techniques at levels of 400hPa and 500hPa, respectively.
KEY WORDS: Tibetan Plateau; Mesoscale Convective Systems; black-body temperature; automatically tracking

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1 INTRODUCTION

In meteorological satellite cloud images, the features of Mesoscale Convective System (MCS) are shown in white bright cloud cluster, cloud band, cloud line, vortical cloud system, etc. The MCS life cycle and spatial size usually vary from several hours to one day and 100km to approximately 1000km, respectively. In the last two decades, it has been proven that storm and intensive convective weather, such as spasmodic thunderstorm and gale, tornado and short macro-precipitation are directly caused by MCS under special weather situations (SCHUUR et al., 1990; GARREAUD and WALLACE, 1997; YU et al., 2001). The cause of the formation and development of MCS due to intensively vertical and horizontal activity of atmosphere is multi-factorial. In addition, the dynamic and thermal impact caused by terrain is also an important factor influencing MCS formation and development, especially over such large areas of terrain as the Tibetan Plateau in China. However, due to limitations of data accuracy in time and space through usual meteorological observation methods, there is no clear understanding of MCS structure and the principle of influencing MCS formation and development. Consequently, the analysis and forecasting of MCS and accompanying intensive weather are also heavily influenced. Therefore it is difficult to obtain accurate and complete knowledge about MCS formation and development, especially over the Tibetan Plateau in China.

The relationships between heavy rainfall processes in the Changjiang (Yangtze) River basin and the activity of convective clouds over the Tibetan Plateau have been the subject of many studies over a long period. For example, SHI et al. (2000) analyzed the relationships between some main features of mesoscale convective cloud clusters and heavy rainfall processes in the Changjiang River basin from June to August 1998. The results indicated that heavy rainfall in the Changjiang River basin from June to August 1998 was directly caused by 315 meso-β and meso-α convective cloud clusters under special weather conditions. JIANG and FAN (2002) indicated that the MCS moving out of the Tibetan Plateau is a main factor influencing heavy rainfall processes in the Changjiang River Basin. Furthermore, the MCS that

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cause heavy rainfall in the Changjiang River basin mainly form in the southeast region of the Tibetan Plateau. In another project, SHAN et al. (2001) analyzed some main features of initial MCS using the Polar Satellites infrared (IR) data for 182 days of the summers of 1998-2000 over the Tibetan Plateau.

In this paper, in order to discover the features of MCS and reveal the conditions influencing MCS eastward trajectories over the Tibetan Plateau, the methods of automatic tracking and spatial data mining techniques are applied, consequently, some information about MCS features and favorable environmental physical field features are obtained. This is an important method in improving the accuracy of forecasting heavy rainfall processes and intensive convective weather in the Changjiang River basin.

2 DATA AND METHODS

The data used in this paper firstly include Geostationary Meteorological Satellite (GMS) infrared black-body temperature (T_{bb}) from June to August 1998, with 0.5 ° latd. × 0.5 ° long. spatial resolution and 1h time resolution. By means of T_{bb} data, an automatic method of monitoring the evolution of MCS according to the variability of MCS area in consecutive hours is applied to tracking the trajectories of MCS that initiate over the Tibetan Plateau, i.e., the region of 27-40 °N, 80-105 °E (GUO et al., 2005). Besides, according to previous analyses of satellite cloud images (MADDOX, 1980), the study focuses on MCS that cover at least 3 connected pixels having $T_{bb} \leq 241$K in each T_{bb} image, and lasting for at least 3 consecutive hours.

On the other hand, HLAFS values, including geopotential height (H), temperature (T), vorticity (VOR), divergence (DIV), water vapor flux divergence (IFVQ), vertical wind speed (W), pseudo-equivalent potential temperature (θse), K index (K) and relative humidity (RH) are used to study the relationships between the trajectories of each MCS and its environmental physical field values in different UTC (Universal Time Coordinate, 00:00 UTC, 12:00 UTC, 24:00 UTC) by developing favorable environmental physical field charts of influencing MCS to move out of the Tibetan Plateau. And the spatial resolution of HLAFS is 1 ° latd. × 1 ° long., and the time resolution of HLAFS is 12 hours. Furthermore, the elevation of the Tibetan Plateau is 4000-5000m, and the levels of 400hPa and 500hPa represent air conditions of nearly ground and lower layers at the plateau, respectively. Consequently, 400hPa and 500hPa are included in this study.

3 RESULTS AND DISCUSSION

3.1 Frequency and Intensity of MCS

According to the previous definition, all the MCS over the Tibetan Plateau from June to August 1998 are automatically tracked. Some features of MCS, with an area greater than 1000km^2, which tend to cause disaster weather, are statistically analyzed (Table 1). From Table 1, it can be seen that there were 749 MCSs over the Plateau from June to August 1998. Moreover, the number of MCSs in July is similar to that of August. However, the number is less in June than either July or August. On the other hand, the ratio of MCS with area between 1×10^4km^2 and 1×10^6km^2 is 95% of total, while the ratio of MCS with area greater than 1×10^6km^2 and less than 1×10^4km^2 is only 1.9% and 3.1% of total, respectively. Furthermore, the average area of MCS having $T_{bb} \leq -32$℃ is 3-4 times greater than that of MCS having $T_{bb} \leq -54$℃, while the maximum area of MCS having $T_{bb} \leq -32$℃ is 1-2 times greater than that of MCS having $T_{bb} \leq -54$℃. And, the average T_{bb} value of cloud top is between -55℃ and -58℃. Therefore, it can be found that the ratio of intensive convective clouds is less among the convective clouds over the Tibetan Plateau, most of which are common convective clouds, i.e., most accompanying heavy rainfall and convective weather is not intensive. The average life cycle of MCS is between 8 and 9 hours, showing that the MCS is mainly influenced by the terrain and thermal factors of the plateau. While the reason for the formation of MCSs that have a few days life cycle is that they exist between the stable shear line of the plateau and cold vortex weather system.

From Fig. 1, the features of daily variation of MCS activity and convective intensity can be clearly shown over the Tibetan Plateau. Most MCSs develop between 09UTC and 23UTC, with more than 55 MCSs in each UTC. The number of MCS reaches peaks during the night, and the number is least between 03UTC and 08UTC. This result shows one important thermal feature of the Plateau, i.e., the air layer becomes unstable after being heated in daytime, which leads to the development of the convective system during the night.

For these MCSs, the difference of central average minimum T_{bb} values and minimum T_{bb} values of cloud top between night and daytime is small, respectively, varying from only -4℃ to -7℃, but the T_{bb} values are all very low. This indicates that once the convective clouds have developed over the plateau, whether at night or in daytime, MCS intensity will be very strong. From Fig. 2, it can also be seen that the daily variation of MCS spatial size is obvious. The MCSs having $T_{bb} \leq -32$℃ and

Table 1 Frequency and intensity feature of MCS over Tibetan Plateau from June to August 1998

Month	No. of MCS	No. of MCS with different area (km^2)				Area ($\times 10^3 km^2$) $T_{bb} \leq -32$℃		Area ($\times 10^3 km^2$) $T_{bb} \leq -54$℃		Life cycle of MCS (h)		T_{bb} value of MCS (℃)	
		$\geq 10^3$	$\geq 10^4$	$\geq 10^5$	$\geq 10^6$	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Min.
Jun.	224	5	147	72	0	127	991	24	265	8	138	-55	-82
Jul.	261	9	159	86	7	167	1353	42	594	9	91	-58	-83
Aug.	264	9	160	88	7	166	1738	40	738	9	65	-57	-81
Σ	749	23	466	246	14	-	-	-	-	-	-	-	-

Notes: $\geq 10^3$: the area of MCS is greater than $1\times10^3 km^2$, but less than $1\times10^4 km^2$; $\geq 10^4$: the area of MCS is greater than $1\times10^4 km^2$, but less than $1\times10^5 km^2$; $\geq 10^5$: the area of MCS is greater than $1\times10^5 km^2$, but less than $1\times10^6 km^2$; $\geq 10^6$: the area of MCS is greater than $1\times10^6 km^2$; $T_{bb} \leq -32$℃: the value of T_{bb} is less than -32℃, but greater than -54℃; $T_{bb} \leq -54$℃: the value of T_{bb} is less than -54℃. The same in below table.

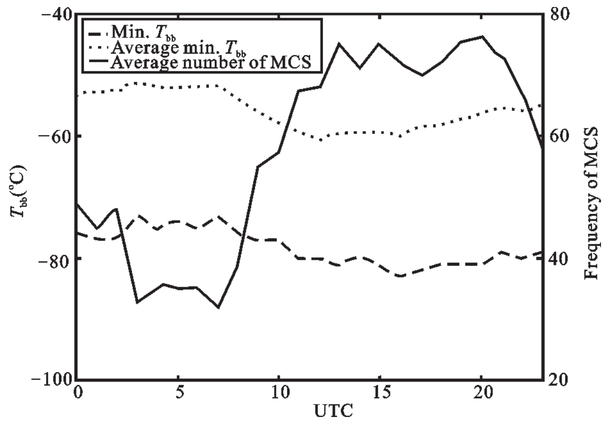

Fig. 1 Daily variation of average number of MCS, central average minimum T_{bb} value and minimum T_{bb} value over Tibetan Plateau from June to August 1998

$T_{bb} \leq -54$℃ usually accompany intensive convective weather, such as strong thunderstorm. Fig. 2 shows that their average area is larger during the period of 09UTC-23UTC than at other UTC, while the greatest area is shown at 20UTC and the smallest at 03UTC. Consequently, the obvious daily variation of the Tbb value and area of MCS further demonstrates the important thermal and dynamic impact caused by the Plateau.

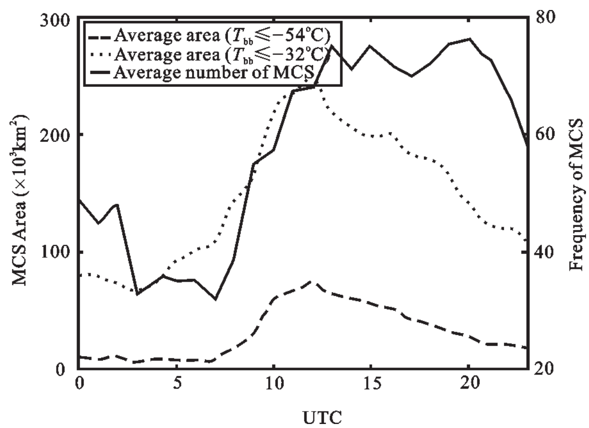

Fig. 2 Daily variation of average number and area of MCS over Tibetan Plateau from June to August 1998

3.2 Shape and Intensity of MCS During Its Initial Stage

To date, the knowledge of the theorem of MCS formation is far from complete. As a result, the accuracy for forecasting intensive disaster weather is directly influenced. However, some results have indicated that the intensity and formation of MCS are closely related to its initial shape. Consequently, in this project, the least square method is used to track and analyze the initial shape and related features of MCS. When the ratios of the short axis length to the long axis length are in [0.9, 1] and [0.7, 0.9], the shapes of MCSs are defined as circle and ellipse, respectively, otherwise, the shape of MCS is defined as "others". Table 2 shows the classification results of the shape and intensity of MCSs during their initial stage over the Tibetan Plateau from June to August 1998.

From Table 2, it can be seen that the MCSs of other shapes are in the majority at the initial stage. However, the difference in ratios of circle and ellipse is small. By and large, as for MCS having $T_{bb} \leq -32$℃, the ratios of circle and ellipse are 19.4% and 25.5% of total, respectively, and the ratio of others is 55.1%. While as for MCS having $T_{bb} \leq -54$℃, the whole ratio of circle and ellipse is only 26.3% of the total, and the ratio of others is 73.7% of the total. The results indicate that most of the MCSs develop over the Tibetan Plateau by the combination of the thermal convective cells over the plateau, which act in westerlies weather system or South Asian monsoons climbing up the Plateau. Furthermore, it can also be found that the average minimum Tbb value of cloud top of ellipse and circle is the lowest and highest, respectively, while that of "others" is between ellipse and circle. On the other hand, according to previous studies, MCS having Tbb value of cloud top less than -54℃ usually accompany with strong thunderstorm. So it can be concluded that MCS usually accompany with intensive convective weather, such as thunderstorm at MCS initial stage over the Tibetan Plateau.

Table 2 Shape and intensity of MCSs during their initial stage over the Tibetan Plateau from June to August 1998

Shape	No. of MCS with different area and T_{bb}								Average min. T_{bb}	Frequency (%)	
	$\geq 1\times10^3 km^2$		$\geq 1\times10^4 km^2$		$\geq 1\times10^5 km^2$		$\geq 1\times10^6 km^2$				
	≤-32℃	≤-54℃	≤-32℃	≤-54℃	≤-32℃	≤-54℃	≤-32℃	≤-54℃		≤-32℃	≤-54℃
Circle	48	23	63	19	31	6	3	0	-53.2	19.4	12.1
Ellipse	0	3	127	39	59	14	5	0	-56.1	25.5	14.2
Others	33	155	249	96	128	41	3	0	-55.2	55.1	73.7
Σ	81	181	439	154	218	61	11	0	-	100.0	100.0

3.3 Activity Frequency and Geographic Distribution of MCS

The activity frequency and geographic distribution of MCS over the Tibetan Plateau can provide important information to understand the formation and development of MCS and its impact on the intensive precipitation in the Changjiang River basin. Fig. 3 shows the activity frequency and geographic distribution of MCS over the Tibetan Plateau from June to August 1998. It can be seen from Fig. 3 that MCSs act very frequently over the Tibetan Plateau in summer. MCSs are mainly distributed to the south of 35 °N over the Plateau and concentrated to the south of 33 °N. Meanwhile, there are two activity centers at the southeast and southwest part of the plateau. Moreover, the activity frequency of MCS increases gradually from June to August. These phenomena are possibly related with summer monsoon activity and the features of ground surface and terrain of the Tibetan Plateau. It can be concluded that the MCS high frequency center at the southeast area of the plateau probably forms by the convergence of summer monsoons that rise north along the Hengduan Mountains canyon, while the MCS high frequency center at the southwest area of the plateau probably forms by the monsoons of the Bengal Bay and the Arabian Sea to India climbing up the plateau and numerous lakes being distributed in that region.

3.4 Trajectory and Propagation of MCS

According to previous studies, disaster weather, such as heavy rainfall and intensive convective weather in the Changjiang River basin and in the southwest region of China is closely related to MCS moving out of the Tibetan Plateau. Therefore, in this project, the MCS was automatically tracked over the plateau from June to August 1998 by the previous tracking method. And, 105 °E is defined as a boundary of the plateau, i.e., when an MCS moves across 105 °E, the MCS is considered to have moved out of the Tibetan Plateau, and its movement direction is classified into E, NE and SE, respectively. Otherwise, it is defined "stay in the plateau".

The results of MCS tracking show that there are 749 MCSs over the plateau from June to August 1998 (GUO et al., 2005). Among these, there are 55 MCSs moving out of the plateau, with a ratio of only 7.34% of total. Furthermore, among the MCSs moving out of the plateau, there are 41, 5 and 9 MCSs moving to east, southeast and northeast, with the ratio of 74.5%, 9.1% and 16.4% of the total, respectively.

3.5 Favorable Environmental Physical Field Chart

The trajectory and propagation of MCS are very complex problems that have not been full comprehended thus far, especially, in the regions lack of traditional meteorological observation data. However, in recent years, studies have indicated that the trajectories and propagation of MCS are closely related to the dynamic and thermal features of its environmental physical field. Therefore, in this project, HLAFS values, including geopotential height, temperature, vorticity, divergence, water vapor flux divergence, vertical wind speed, pseudo-equivalent potential temperature, K index and relative humidity are used to develop the favorable environmental physical field charts of influencing MCS to move out of the plateau. Besides, spatial data mining techniques, including association and classification rule of mining (QUINLAN, 1993), are used to study the relationships between MCS trajectories and their environmental physical field values at the levels of 400hPa and 500hPa, respectively. The results indicate that at the level of 400hPa, the MCSs moving eastward out of the plateau are mainly influenced by geopotential height, divergence and vorticity. While at the level of 500hPa, geopotential height and K index are two main factors influencing MCS movement out of the plateau.

Fig. 4 shows the favorable environmental physical field charts of influencing MCS to move out of the plateau in an east direction in 00UTC, 12UTC and 24UTC, by taking geopotential height (H: gpm), divergence (DIV: 10^{-6}/s) and vorticity (VOR: 10^{-6}/s) field at 400hPa level for instance. The MCS is located at the center of each figure with the size of 10 ° latd. ×10 ° long. From Fig. 4a-c, it can be seen that the MCS lying between 104 °E-105 °E is located in the strong wind divergence zone, and moves toward the convergence zone

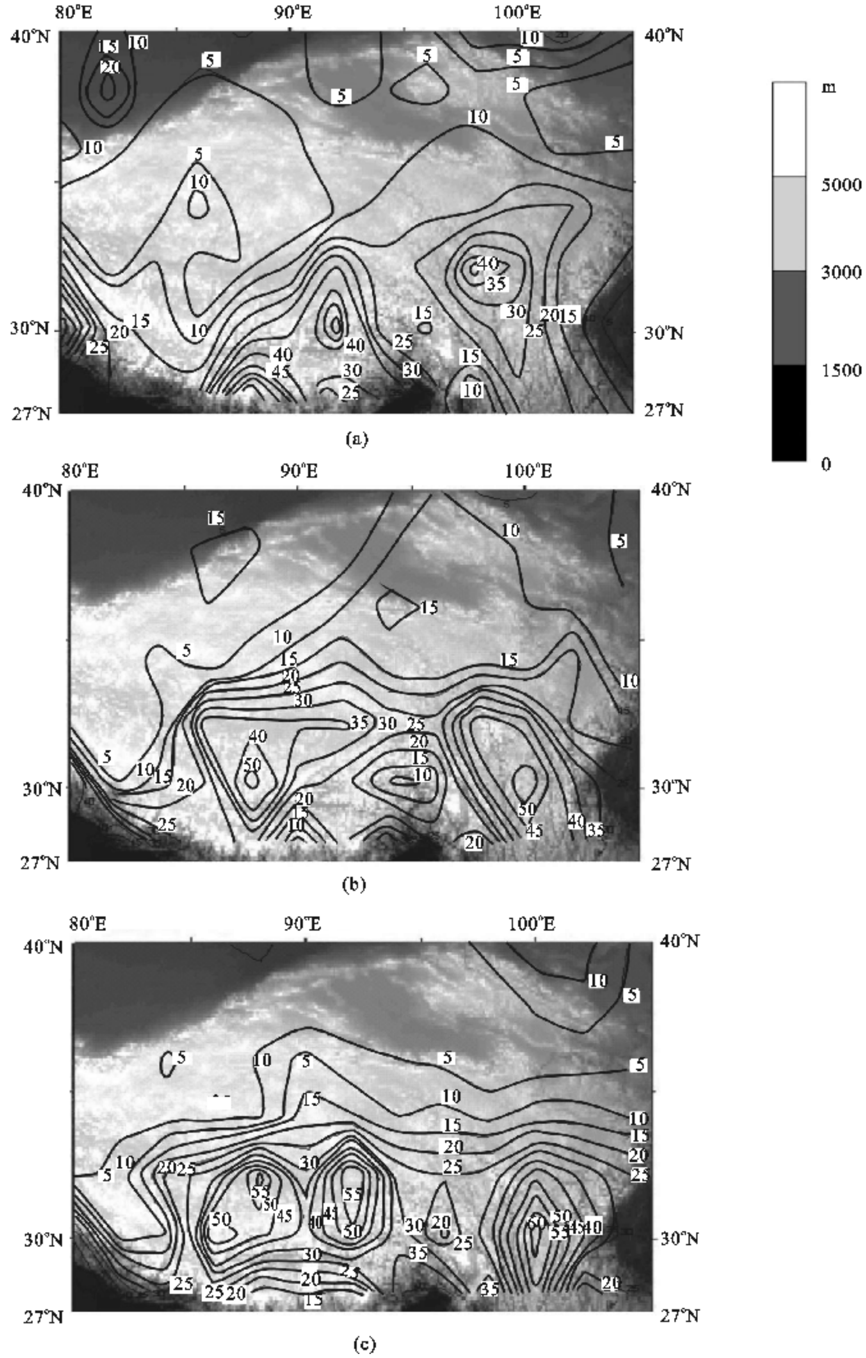

Fig. 3 MCS frequency and geographic distribution over Tibetan Plateau in June (a), July (b), and August (c) 1998

by the effect of airflow. On the other hand, Fig. 4d-f show the favorable vorticity field charts, in which the MCS lies between 102 °E- 104 °E. The positive vorticity center is located at the west of MCS central position, the MCS exists in the strong vorticity gradient between the positive and negative vorticity center, and, MCS tends to move out of the Plateau eastward by the effect of strong eastward positive vortictiy flow.

4 CONCLUSIONS

Various features of MCS, such as area, intensity, life cycle, activity region and shape, have been revealed by automatically tracking the trajectories of MCS over the Tibetan Plateau in summer. The results of MCS tracking show that among the 749 MCSs over the plateau from June to August 1998, there are only 41 MCSs moving

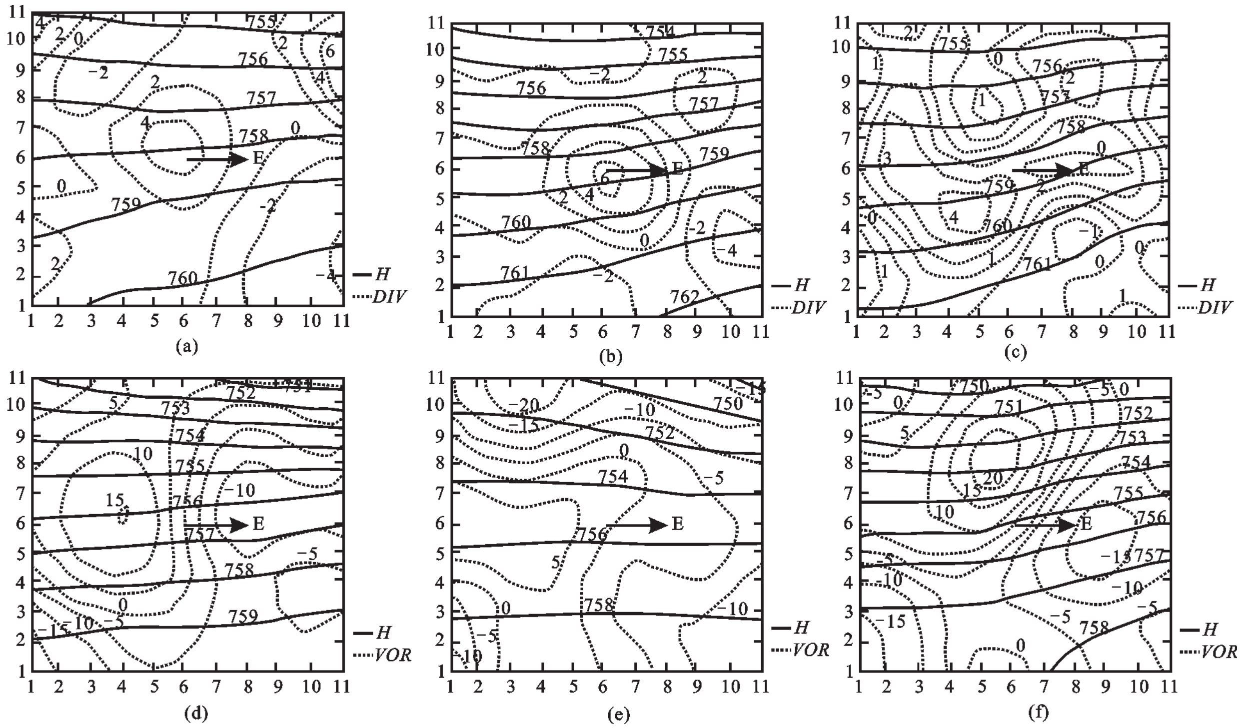

Fig. 4 Favorable environmental physical field charts of influencing MCS movement out of Tibetan Plateau (H: gpm, DIV: 10^{-6}/s, VOR: 10^{-6}/s)

eastward out of the plateau. Furthermore, in order to study the relationships between MCS trajectories and their environmental physical field values, the favorable environmental physical field charts of influencing MCS movement out of the plateau are developed by using spatial data mining techniques. Results indicate that at 400hPa, the MCSs moving eastward out of the plateau are mainly influenced by geopotential height, divergence and vorticity, while at 500hPa, geopotential height and K index are two main factors influencing MCS movement out of the plateau. Consequently, this information is of great value in further study of MCS and improving the accuracy of the forecast of heavy rainfall and intensive convective weather in the Changjiang River basin and in the southwest region of China. In future research, different spatial data mining techniques will be used to develop the mathematical model of MCS trajectories and their environmental physical field values.

REFERENCES

GARREAUD R D, WALLACE J M, 1997. The diurnal march of convective cloudiness over the Americas [J]. Monthly Weather Review, 125: 3157- 3171.

GUO Zhong-yang, DAI Xiao-yan, WU Jian-ping et al., 2005. Image analysis of Geostationary Meteorological Satellite for monitoring movement of Mesoscale Convective Systems over Tibetan Plateau [J]. Chinese Geographical Science, 15(3): 231-237.

JIANG Ji-xi, FAN Mei-zhu, 2002. Convective clouds and mesoscale systems over the Tibetan Plateau in summer [J]. Journal of Atmospheric Sciences, 26(2): 263- 270. (in Chinese)

SHAN Yin, LIN Hui, JIANG Ji-xi et al., 2001. The features of MCS during their initiation over Tibetan Plateau in summer [A]. In: Proc. 22nd Asian Conference on Remote Sensing [C]. Singapore: CRISP, SISV, AARS, 418 - 421.

MADDOX R A, 1980. Mesoscale convective complexes [J]. Bulletin of the American Meteorological Society, 61: 1374- 1387.

QUINLAN J, 1993. C4.5: Programs for Machine Learning [M]. Detroit: Morgan Kaufmann, 302.

SCHUUR T J, HUNTER S M, RUST W D et al., 1990. Charge structure of a midlatitude mesoscale convective system [A]. In: Proc. 16th Conference on Severe Local Storms [C]. Boston: American Meteorological Society, 663- 668.

SHI Chun-xiang, JIANG Ji-xi, FANG Zhong-yi, 2000. A study on the features of severe convective cloud clusters causing serious flooding over Changjiang River Basin in 1998 [J]. Climate and Environmental Research, 5(3): 279- 286. (in Chinese)

YU C K, ROUX F, SMULL B F et al., 2001. Airborne doppler observations of a mountainous convective system during MAP IOP5 [A]. In: Proc. 30th Conference on Radar Meteorology [C]. Boston: American Meteorological Society, 530- 532.