Enhancing Precipitation by the Special Topography

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Abstract: Enhancing precipitation by mountain is topographic forcing effect, this paper has analyzed on enhancing precipitation by the Da Bie Mountain(DBM). DBM， a special mountain, is located in the southwest of the Huaihe River Basin(HRB), upper reaches of HRB. Its ridge is toward from southeast to northwest. During flood period each year, the humid and warm air flow from southwest intersects to DBM, the dynamical convection and thermal are forced by the topography, positive vorticity is increased and also dynamic trough is strengthened when air flow is over the mountain, as well caused the more stronger and frequent rainstorm at northern of DBM. The phenomenon can been explained by the theory of conservation of potential vorticity. Diagnostic study by use of Petterssen theory shows enhancing precipitation is because of the change of vorticity advection, temperature advection and adiabatic heating in the special topography situation.

Keywords: topography enhancing precipitation Da Bie Mountain

1. Introduction

There are many research results about special topography, such as Wu Zi mountain in Hainan island (China). Previous research works have indicated the physical mechanism of the mountain-valley breeze and sea-land breeze. Himalaya mountain(Everest) , being concerned influence on atmospheric circulation in any GCM modal, is a typical example. Because so many mountains are different in the world, the results of orographic precipitation is different. The topographic rainfall often occur in HRB each year. For instance, the severe torrential rain on August in 1975 was a typical orographic rainfall, the precipitation was 1060mm in one day, it appeared at "bell-mouth " mountain and resulted from the local convection forced, and convective convergence developed rapidly, the special topography can lead to the persistent and intensity heavy rainstorm and then bring on severe flood.

2. Observation fact

2.1 Landform of the Huaihe river basin

The Huaihe river basin is located in east part of China, between 112 ° E and 121 ° E, from 31 ° N to 36 ° N. The Fu Niu mountain is on the western of the basin, the northeast is the Yi Meng mountain(Fig.1), the southwest is DBM and Tong Bai mountain. The average height of Fu Niu mountain is 200-300metre. The top of mountain is ,Shi Renshan, 2153metre. The average altitude of DBM is 300—500metre. The Bai Majian is, the peak of mountain, 1774metre high.

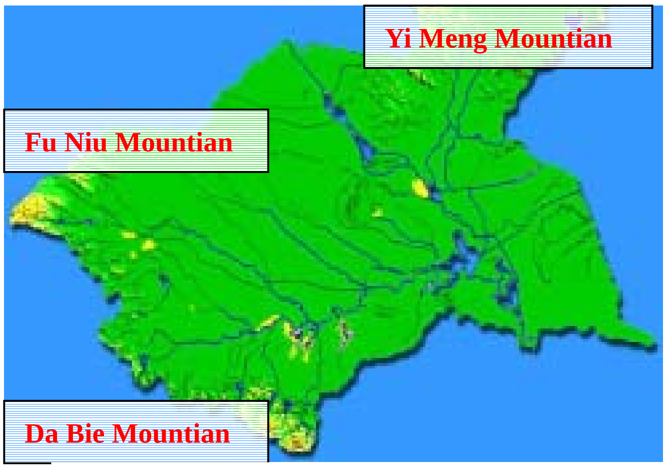

Fig.2.1 Landform of the Huaihe River Basin

The average height of Yi Meng mountain is from 200 to 500metres, the top of mountain is 1155meres. In this paper, only DBM is considered to affect rainfall.

2.2 Precipitation

2.2.1 Secular mean annual rainfall

Fig.2.2.1 shows rainfall distribution increases from north to south, the maximum amount of rainfall is at DBM, it seems as if the rainfall is related to the special topography besides the rain belt of Meiyu front.

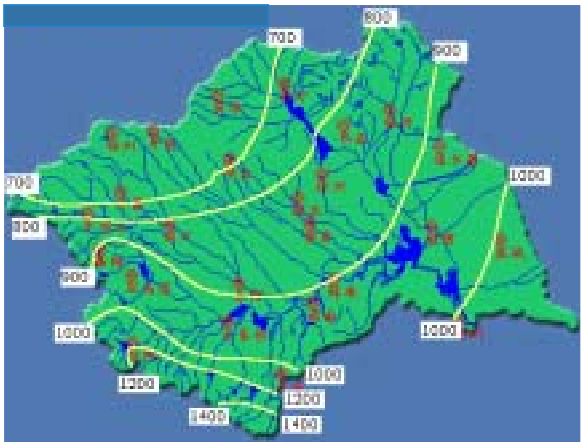

Fig.2.2.1 Secular mean annual rainfall

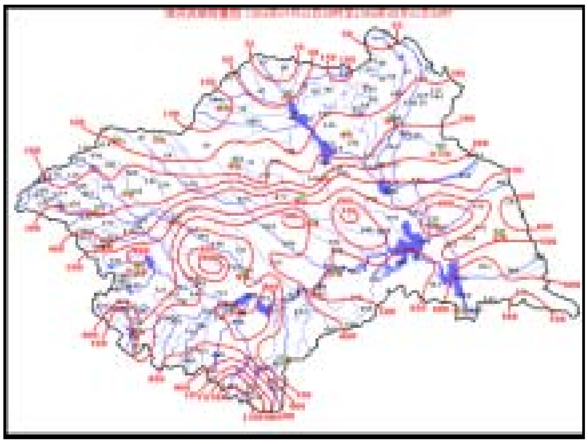

Fig.2.2.2 Precipitation on 1 Jul.-1 Aug.,1954

2.2.2 Precipitation in the severe flood years

The greatest flood Since 1949 happened in HRB in the summer(July—August) of 1954, the Fig.2.2.2 shows main rain belt distributed at DBM, north part of HRB.

2.2.3 A case of heavy rainstorm process

The severe flood in 2003 appeared in HRB since 1954, during the second period of flood-causing torrential rain on 8 to 11 July, 100mm isohyet covered DBM, the southern of HRB and along the main river. 200mm isohyet covered the area including northern of DBM, as well as the center of heavy rain was here.(Fig 2.2.3)

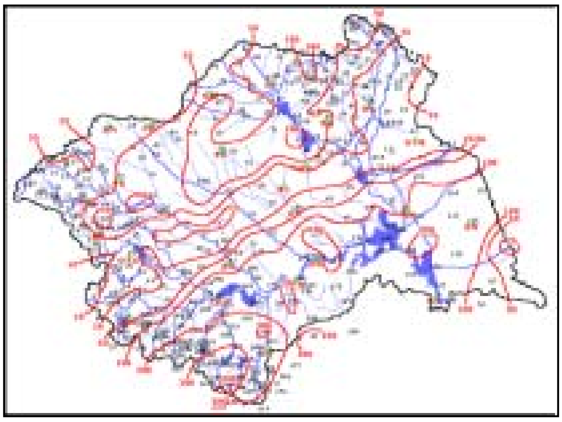

Fig.2.2.3 Rainfall on 8-11 Jul.2003

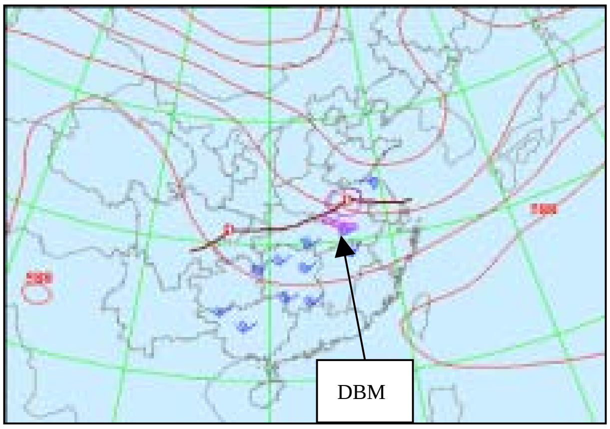

Fig.3.1 Heavy rainstorm pattern

From above facts, it has been illustrated obviously that whether secular mean annual precipitation, the rainfall in severe flood or a case of heavy rain, north part of DBM is often the center of heavy rainstorm, it is no doubt that heavy rain is relation to the special topography except weather system.

3 The heavy rainstorm pattern

HRB is situated in the eastern of China, its weather is influenced by the east Asia monsoon, here is a typical monsoon climate. There ware so much rainy and heavy rain often occur in the flood season, flood or drought in a year is determinated by total amount of rainfall in flood period. According to statistic, total amount of rainfall in flood season(Jun.-Sep.)occupy 60%--80% through all-year. In first half of flood season, the Yangtze-Huaihe Meiyu front can result in the rainfall, another half of flood season it is influenced by rainy season of north China, so Huaihe’s rainy season is more longer.

As generally, the flood-causing torrential rain is the main factors leading to flood, the synoptic systems include the Yangtze-Huaihe shear line, the southwest low vortex, low level jet stream and typhoon sometimes. Fig 3.1 shows a typical pattern of heavy rainstorm. There is a trough from northern China moving to southeast at 500hPa, the Yangtze-Huaihe shear line occurs from western prolonging to the Yangtze-Huaihe basin and low vortexes along the shear line move eastward at 700hPa. Southwest low level jet spreads widely to HRB, it carries a lot of moisture and transported humid air to the Yangtze-Huaihe basin, the low vortexes often presents to the northern of DBM, the shear line strengthens after the low level jet over DBM, the cyclonic convection get more stronger and bring on the heavy rain. As general, it is a sign when the shear line set up before heavy rainstorm, the moisture from southwest is with humidity and high available potential energy， what the moisture is transported to HRB that the thermal and dynamic convection converge at DBM, in this situation, meso-scale cyclones occur easily and conduce sustaining heavy rainstorm.

4 Enhancing precipitation by DBM

In fact, when air flow is head-on a mountain, the topographic rainfall is not persisting for a long time, the rainfall area cover only at small region. But at the backside of mountain, the rain is sustaining and intensity, heavy rain area can expand to hundreds of kilometer widely.

4.1 The special topography

DBM's ridge is toward from northwest to southeast, when the moisture come from the Bay of Bengal and southwest of China to HRB, the low level jet intersects DBM, air flow is influenced by mountain, and formed the maximum wind speed at top of the mountain. Lee trough would be appeared at backside of DBM when low level jet over the mountain, and then induces the gravity wave, it can be moved to the shear line and bring on meso-scale vortex, heavy rain may occur and be intensity due to the convection strengthened. On the other hand, due to the moisture from southwest can be raised by DBM, humid and warm air is transported up to 1000-2000metres high, then warm secter can be formed there, that is one of factors bringing on the meso-scale systems. When the southwest air flow change the direction and wind shift eastward, the warm and humid air become westerly air with cold and dry, the air flow intersects at small angle cross DBM, the mountain forcing have to be decreased. In this situation, heavy rain would be weakened rapidly.

4.2 The potential vorticity by topographic forcing

Under the adiabatic non-friction atmospheric circulation, it is conservation of potential vorticity, that is: $\frac{d}{dt}(\frac{\zeta+f}{\delta z})=0$. When west wind across the mountain, because the vorticity of the air column does not change and then the relative vorticity increase, the air flow move along the cyclonic curvature, moreover, result in the topographic trough. Due to the relative vorticity build up and bring on anti-cyclonic ridge. So, a series of troughs and ridges would be brought on after air flow over the mountain. According to this principle, when southwest wind with west component across over DBM, it also can induce the lee trough and strengthen rain intensity.

4.3 Petterssen's theory

Petterssen put forward to the equation of vorticity tendency in 1956, there are two physical variables in the equation. He assumed that there was nondivergent at 500hPa, the vorticity advection near surface can be ignored to compare with one at 500hPa. Now the equation of vorticity tendency at 1000hPa can be obtained as follow：

$$\frac{\partial \zeta_5}{\partial t}=-V_5\cdot\nabla_p(\zeta_5+f)=\frac{\partial \zeta_0}{\partial t}+\frac{\partial \zeta_T}{\partial t}$$

$\zeta_T=\zeta_5-\zeta_0$ is the vorticity of thermal wind from 1000hPa to 500hPa, where h is the depth between 1000hPa and 500hPa. We can use the static equation, the first law of thermodynamics, then the follow equation can be obtained:

$$\frac{\partial \zeta_0}{\partial t}=-V_5\cdot\nabla_p(\zeta_5+f)-\frac{R_d}{f_0}\nabla_p^2\int_{p_5}^{p_0}\left[-V\cdot\nabla T+\omega(\gamma_d-\gamma)+\frac{1}{C_p}\frac{dQ}{dt}\right]d(\ln p)$$

whether a cyclone may develop or not can be judged by the vorticity variation through the Petterssen's equation. The first term in the equation right side $-\mathbf{V}_5 \cdot \nabla_p (\zeta_5 + f)$ is vorticity advection at 500hPa, when $-\mathbf{V}_5 \cdot \nabla_p (\zeta_5 + f)$ >0, it means that the westerly trough just reached the Huaihe river basin or the southwest cyclonic curvature extend to the Yangtze-Huaihe river basin, then Yangtze-Huaihe cyclone can be developed and result in torrential rain. $\frac{R_d}{f_0}\nabla_p^2\int_{p_5}^{p_0}[-\mathbf{V}\cdot\nabla T]d(\ln p)$ is the temperature advection, it is large than zero in the southwest humid and warm air transportation, average temperature may rise among 1000-500hPa because of topography and thermal advection. The thickness of air column can be increased, then $\frac{R_d}{f_0}\nabla_p^2\int_{p_5}^{p_0}[-\mathbf{V}\cdot\nabla T]d(\ln p)$ >0, so it can add the vorticity near surface at north side of DBM, it is propitious to lee trough to develop. $\frac{R_d}{f_0}\nabla_p^2\int_{p_5}^{p_0}[\omega(\gamma_d - \gamma)]d(\ln p)$ is adiabatic change, it may reduce to development of the cyclone or anticyclone. It is a negative feedback for synoptic system through the advection of vorticity and temperature. Anti-cyclonic vorticity generate on windward side. But the cyclonic vorticity appears at north side of DBM, it is propitious to develop the orographic depression. $\frac{R_d}{f_0}\nabla_p^2\int_{p_5}^{p_0}\left[\frac{1}{C_p}\frac{dQ}{dt}\right]d(\ln p)$ is diabatic change. In which there are two effects, one is cold source on surface, another one is the condensation thermal forcing. It profits the cyclone development.

4.4 Topographic forcing in dynamic model

With the equation of quasi-geostrophic vorticity, the equation of mean lay vorticity can be obtained by integral among all atmospheric depth. The vorticity equation of diagnostic trough and ridge can be got by use of predigestion the relative between thermal wind, geostrophic vorticity and geopotential height, that is as follow: $\frac{\partial \zeta_m}{\partial t} = -\mathbf{V}_m \cdot \nabla_p \zeta_m - \overline{B(p)^2}\mathbf{V}_T \cdot \nabla_p \zeta_T - \beta\bar{v} - \frac{f_0 g}{RT_S}\mathbf{V}_s \cdot \nabla h_s$

here, the subscript m is mean lay, V_s is velocity on surface, T_s is temperature on surface, h_s is altitude. For simple and convenient, it is considered the relation of topographic forcing, just the third item in the equation: $-\frac{f_0 g}{RT_S}\mathbf{V}_s \cdot \nabla h_s$. On the side of windward, $-\mathbf{V}_s \cdot \nabla h_s$ <0, the amount of vorticity decreases, it means that the westerly trough moves to mountain and it will be weakened. by contraries, on the lee side, $-\mathbf{V}_s \cdot \nabla h_s$ >0， the amount of vorticity increases, and lee trough gets stronger. So if only the low-pressure system is over DBM, the lee trough has to be appeared by the mountain, it is no amazed that the torrential rain often happens at north part of DBM in HRB.

5 Summary

It is a typical problem for enhancing precipitation by topographic forcing. Although orographic rainfall have been studied by many hydrometeorologists for a long time, there are different effect of topographic forcing in different area in the world. DBM is a special mountain, its ridge toward northwest-southeast. Among the flood season each year, the low level jet stream from southwest orthogonalizes with DBM, dynamic and thermal forcing due to topography. When moisture is over DBM, the positive vorticity and cyclonic circulation got stronger, and lee trough lead to frequent and intensity heavy rain. The precipitation observation facts have proved the enhancing precipitation at DBM. In east Asia monsoon, if there are similar to mountain like DBM, it would be same enhancing precipitation.