Effect of Merging of the Convective Cloud Clusters on Occurrence of Heavy Rainfall

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ABSTRACT

Sun et al., (1983) have given some favourable environmental conditions and have shown that there are four common features in convective rainstorms. In this paper, an important process of evolution of cloud systems was revealed when heavy rainfall occurred based on the diagnostic analysis of heavy rainfall cases. When the different cloud systems merge into a large one, the mesoscale heavy rainfall occurs and enhances. In other words, the process of evolution of cloud systems emphasized in this paper is the process of interaction between two cloud systems when the heavy rainfall occurs. The favourable environmental condition is also investigated.

1. INTRODUTION

The heavy rainfall is a kind of mesoscale weather system, for both space and time scales. However, its intensity of precipitation is very large and usually causes the serious disaster. Therefore, investigating the mesoscale heavy rainfall is an important problem concerning the national economy and people's livelihood.

By analyzing the cases of heavy rainfall in China, it is found that the heavy rainfalls always occur near the fringe of subtropical high and most of them are formed by the interaction between the cloud systems from middle and low latitudes. It can be shown clearly in satellite cloud imagery. One example is the case of the 30 July 1979 (Zhang et al., 1983). The cloud band of cold front moving eastwards and landed typhoon moving northwards are always getting closer and closer. Sometimes a series of convective cells can be found ahead of the cloud system of cold front, then the convective cells will be organized, causing a spell of heavy rainfall. As shown in Fig.1, though the centre of typhoon standed apart from Beijing more than 1000 km yet at 0000 GMT 30 July 1979, the series of convective cells can be seen clearly ahead of the cloud system of cold front, then came heavy rainfall in Zhaoyuan County of Shandong Province just in the evening of the 30 July 1979 (Li, 1981). The maximum precipitation within 24 hours was 412 mm.

The second case (Fig. 2) shows the interaction between the typhoon cloud system moving westwards in the area of 10° to 20°N and the monsoon cloud system with several convective cells moving northeastwards in the west edge of subtropical high. The convective cells on the wind shear line in east–west derection are scattered yet at 0000 GMT 3 July 1981, and organized at 0009 GMT 3 July 1981 owing to the interaction of between those two cloud systems. A spell of heavy rainfall occurred just in that time in Beijing and in the border area between Shanxi and Shaanxi Provinces. The maximum precipitation reached 66.1 mm (Haidian in the west of Beijing), the intensity reached 33.0 mm / h in Shijingshan, Beijing. Therefore, when the convective cloud cells are organized or the different cloud systems merge into a large one, the mesoscale heavy rainfall occurs and enhances. The most, the 64 percent of the cases of heavy rainfall in Beijing belong in this circumstance.

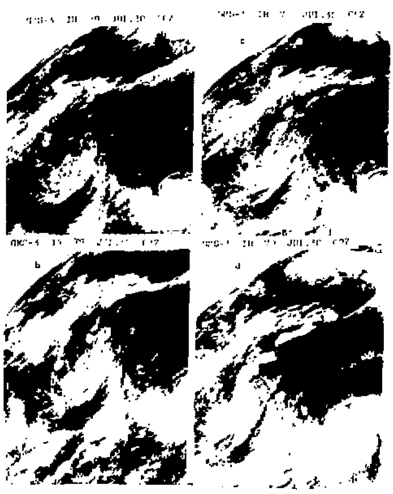

Fig. 1. The satellite cloud imagery at (a): 0000 GMT;(b): 0003 GMT; (c): 0006 GMT; (d): 0009 GMT; on 30 July 1979.

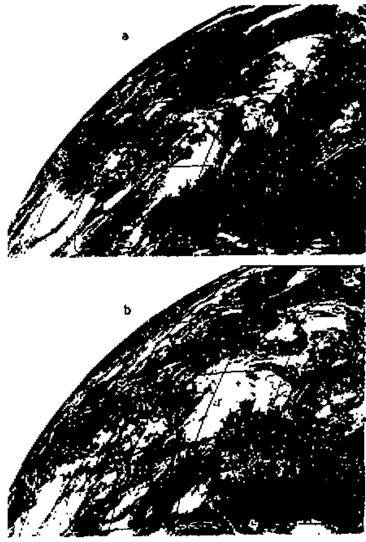

Fig. 2. The satellite cloud imagery at 0000 (a) and 0009 (b) GMT, on 3 July 1981.

II. THE PHYSICAL PROCESSES OF OCCURRENCE OF HEAVY RAINFALL

The mechanisms of physical process mentioned above are summarized as follows according to the diagnostic analysis and statistical analysis:

1. *The Transfer of Water Vapour and the Variation of Stratification*

There is an easterly or southwesterly jet with the maximum wind velocity more than 12 m / s at 850 hPa between the typhoon and the subtropical high when the typhoon moves westwards or northwards along the fringe of the subtropical high. If there were no typhoons moving northwards, the strong wind near the fringe of the subtropical high would still exist because of the active monsoon. By calculating the moisture flux, we find that the axis of low level jet coincides with the belt of moisture flux and the intensity of moisture flux's centre may increase rapidly to tens g / (cm • hPa • s) within 12 hours (Fig.3). In this case the intensity reached more than 18 g / (cm • hPa • s), and the area of heavy rainfall was located at the down wind side of moisture flux's centre. Generally speaking, the area of saturated water vapour ($T - T_d \leqslant 3$℃) may stretch up to 200 hPa around the region of heavy rainfall. This means that the jet and moisture transfer in the fringe of subtrpical high play an important role in the interaction between the two cloud systems and in the variation of stratification in rainy region.

The warm and moist air coming from the transfer belt forms a strong unstable stratification. The main characteristics of mean pseudo–equivalent potential temperature (θ_{se}) averaged over 45 samples of heavy rainfall and saturated one (θ_{se}^*) in Beijing (Fig.4) are as follows (Tian et al., 1985):

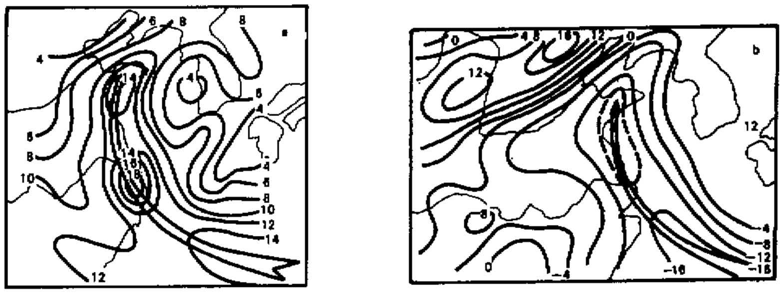

Fig. 3. a. The distrbution of moisture flux at 850 hPa for 0000 GMT 31 July 1979 (g / hPa · cm · s). b: The distribution of $\theta_{se} = \theta_{se}$ 500$-\theta_{se}$ 850 for 0000 GMT 31 July 1979 (℃). The double arrow in the map denotes the axis of jet stream at 850 hPa. (Quoted from Zhang et al., 1983).

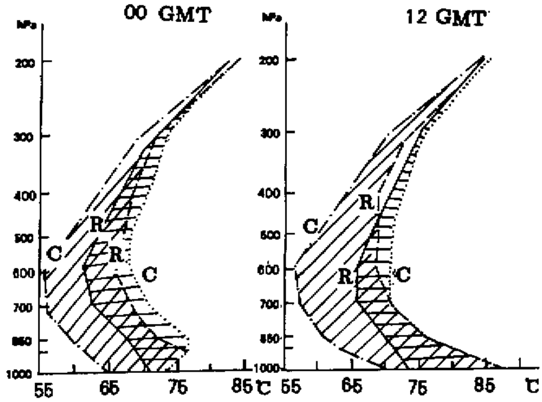

Fig. 4. Vertical profiles of average pseudo–potential temperature (θ_{se}) and saturated θ_{se} (θ^*_{se}) in Beijing. The solid line and dotted line are θ_{se} and θ^*_{se} in rainfall (marked by R), respectively. The dot–dashed line and dashed line are θ_{se} and θ^*_{se} in climate (marked by C), respectively.

A, The values of θ_{se} in rainy days are higher than climatic value;

B, The variation of θ_{se} in vertical for those cases is less than the climatic one;

C, In heavy rainfall the saturated degree is higher than, the averaged free convection level is lower than and the instability energy is bigger than in climatic.

D, The release of convective instability energy depends on whether the warm and moisture air can be lifted quickly to the level of free convection. Therefore, the maximum θ_{se} in the boundary layer (below the 900 hPa) is much larger than the maximum seturated one between the levels of 600–900 hPa. It gives a very unstable structure for the heavy rainfall cases and this is the main unstable characteristic.

(2) The Wind Field Convergence

Generally speaking, the maximum of total precipitable water in a column is less than 70 mm, however, the observational precipitation amount reaches more than 100 mm within an hour in heavy rainfall case. Therefore, the occurrence of heavy rainfall depends not only upon the amount of precipitable water cantained in the column of cloud itself, but also upon the convergence of water moisture in the circumstance. The convergence mainly concentrates in the middle and lower troposphere. The warm moist air from transfer belt of water vapour meets with the colder and drier air current from the north, forming a discontinuous band of θ_{se}. A body of cloud accompanied with heavy rainfall occurs just at the downwind side of the centre of water vapour flux. When the two kinds of air contact or interact with each other the convergence occurs, so the abundant water vapour acsending with the strong convergence at the lower levels condensates in the upper levels and produces the heavy rainfall. At this time, the intensity of water vapour convergence reaches tens of 10^{-7}g / (hPa · cm^{-2} · s) and the area of convergence is larger than the area of heavy rainfall (Fig.4), and the strong ascending velocity is about 10×10^{-3} hPa / s in the diagnostic analysis of the large scale system.

Under the condition mentioned above, there is a strong divergence and negative vorticity in upper levels and the positive vorticity with convergence in lower levels. It is favourable for the process of the development of convective cloud and the occurrence of the heavy rainfall. It can be seen from Fig.5 that the vertical transfer passageway is very clear because the

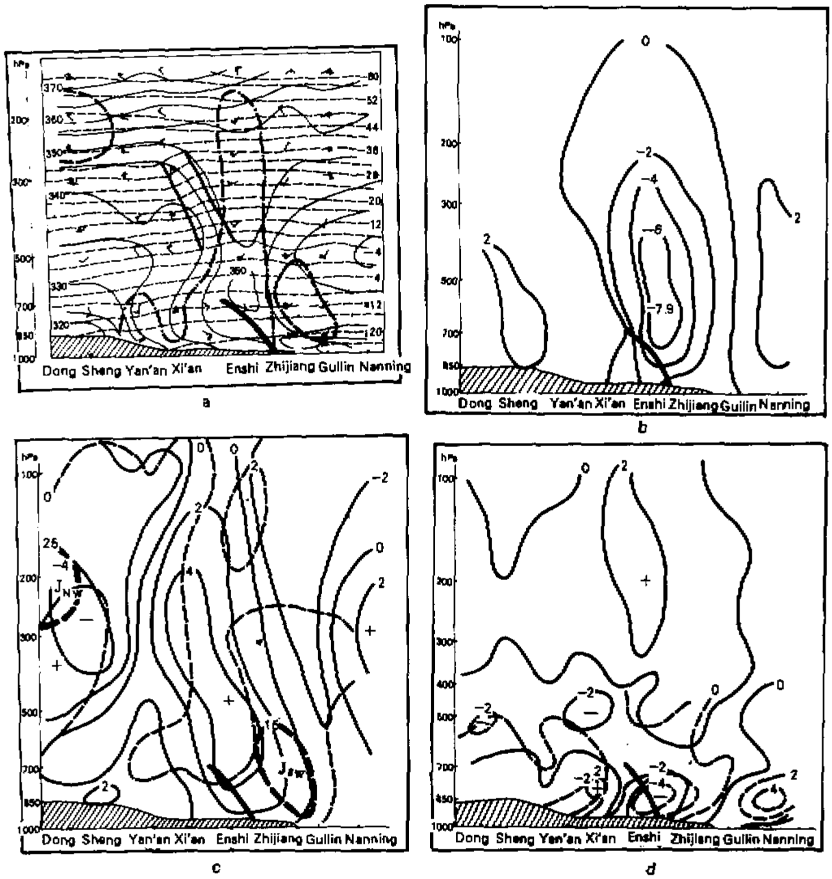

Fig. 5. The longitudinal cross section over the area of heavy rainfall solid line: (a) θ_{se}; (b) vertical velocity (10^{-3} hPa / s); (c) vorticity; (d) divergence (10^{-5} / s); dashed line: (a) temperature; (c). advection of vorticity; (d) convergence of water vapour (10^{-7} g / hPa · cm^2 · s).

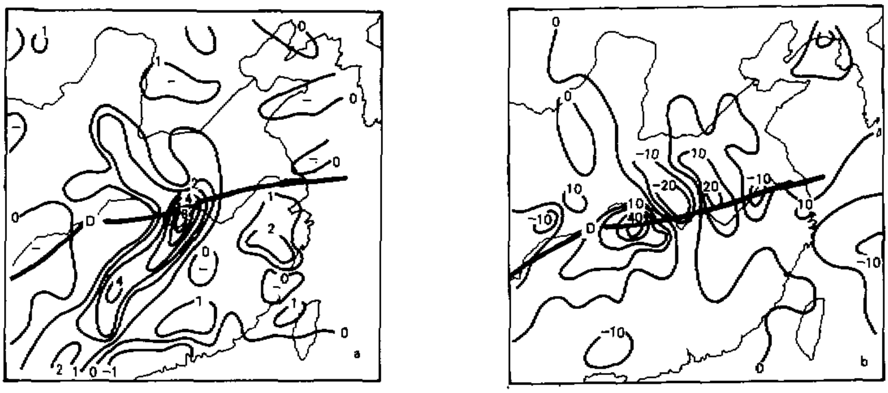

Fig. 6. Distribution of two terms in vorticity equation at 850 hPa ($10^{-10} \cdot s^{-2}$). (a) twisting term: (b) divergence term; Thick solid line is the shear line at the northwestern fringe of subtropical high.

upper and lower levels are just in a good match and heavy rainfall comes on.

Just owing to the important role of divergence in heavy rainfall, Sun (1987) used it to forecast the mesoscale system and met with good results. All of those elucidate that the process of the different cloud systems merging into a big one is an important physical process when heavy rainfall occurs and that the divergence is an important factor in that physical process.

(3) Other Favourable Factors for the Interaction of Cloud Cells

It is obvious that the increase of positive vorticity at low levels is favourable for the occurrence of heavy rainfall. We have calculated the various terms of vorticity equation and found that both the twisting term and divergence term make a positive contribution to the increase of cyclonic vorticity. Fig. 6 gives the distribution of those two terms. We may see that *the positive variation of vorticity is just located in a mesoscale region in which heavy rainfall occurs*.

III. SUMMARY

An important process of evolution of cloud systems when heavy rainfall occurs is revealed according to the diagnostic analysis of heavy rainfall cases in this paper. When the convective cloud cells are organized or the different cloud systems merge into a big one, the mesoscale heavy rainfall occurs and enhances. The favourable environmental condition for interaction of them are as follows:

1. A lump of cloud appears at the downwind side of the strong centre of water vapour flux belt which accompanies with the interaction between the cold and dry air from north and warm and moist currents from south respectively.

2. There is a strong convergence area with cyclonic vorticity in the lower and middle troposphere while in the upper level there is a strong divergence with anticyclonic vorticity. They are bounded together by a vertical transfer passageway. It fosters the development of vertical circulations and also the maintenance of convective cloud, so that the local cycle process and the cloud development can be maintained.

3. Both the terms of twisting and divergence in the vorticity equation make a positive contribution to the increase of vorticity, hence, formation of heavy rainfall.

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