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THE ENERGETIC AGGREGATION AND RESLEASE IN THE HEAVY RAIN REGION

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ABSTRACT: Using the new formula of moist available energy (MAE), the value of the MAE's key terms of three heavy rainfall cases in Guangdong province in 1998 was calculated. The energetic aggregation and energetic discharge are analyzed. It shows that the value of the key terms in the formula appears different feature clearly in the different precipitation period, as well as the function of each term presents in the heavy rain region.

Key words: energetic aggregation; energetic discharge; heavy rainfall

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1 INTRODUCTION

It is well known that there are many strong rainstorms in South China (Huanan). Much research on its heavy rainfall has been carried out. In order to investigate the structure and the feature of the heavy rainfall, the Huanan Rainstorms Meso-scale Experiment (HUAMEX) organized an intensity observation in 1998. Based on this experiment, meteorologists have studied various aspects of the Huanan heavy rainfall using circulation character analysis, mesoscale numerical simulation, TRMM data and wind profiler data. All these works were very useful to understand the Huanan heavy rainfall in detail[1-6].

As we known, the moist available energy (MAE) plays important role on the heavy rainfall. Many meteorologists in China have studied it in detail[7-9]. But all these studies were limited to the heavy rainfall in North China. Can this theory and method been used to analyze the heavy rainfall in South China? We have analyzed the MAE of heavy rainfall on 24 May[10]. The result was quite good. In this work, based on the budgets formula of the MAE, the values of all the terms in the budgets formula are calculated. This paper investigates the relationship between these terms and the precipitation using these calculations.

2 BUDGETS FORMULA FOR MAE AND DATA

The budgets formula of the moist available energy in a limited region is defined as follows[11]

$$\frac{\partial A_j}{\partial t}=\frac{1}{g}\iint_s\int_0^{P_S}N\dot{Q}\,\mathrm{d}p\,\mathrm{d}s+\frac{1}{g}\iint_s\int_0^{P_S}Nwa\,\mathrm{d}p\,\mathrm{d}s-\frac{c_p}{g}\iint_s\int_0^{P_S}N\vec{V}\cdot\nabla_pT_{se}\,\mathrm{d}p\,\mathrm{d}s-\frac{c_p}{g}\iint_s\int_0^{P_S}Nw\frac{\partial T_{se}}{\partial p}\mathrm{d}p\,\mathrm{d}s-\frac{c_p}{g}\iint_s\int_0^{P_S}T_{se}\frac{\partial N}{\partial t}\mathrm{d}p\,\mathrm{d}s+\frac{c_p}{g}\iint_s NT_{se}\frac{\partial p_S}{\partial t}\mathrm{d}s$$

where

$$A_j=\frac{C_p}{g}\iint_s\int_0^{P_S}NT_{se}dpds$$

$$N=1-\left(\frac{p_r}{p}\right)^{R/C_P}\qquad T_{se}=q_{se}(\frac{P}{1000})^{R/C_p}.$$

Here, the right terms in the budgets formula denote the generation term, the conversion term(release term), the horizontal transport term, the vertical transport term, local change term for efficiency factor, and

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surface pressure variation term respectively. A_j denotes the MAE in a limited region (σ), N denotes efficiency factor, P_r denotes reference pressure, P_s denotes the surface pressure. All other notations are conventional in a meteorological context. The grid point dataset is provided by T106 model. The surface and the top are set at 1000 hPa and 100 hPa respectively.

3 BRIEF INTODUCTION TO THE HEAVY RAIN CASES

The three heavy rainfall cases in Guangdong province in 1998 are studied, one case is on 14 – 15 May, the other two cases are on 23 – 24 May and on 8 – 9 June, respectively. The three heavy rainfall cases cover a large region. It is shown in Fig.1 that there is strong rainstorm in the centre part of Guangdong province where the peak centre is located in Pearl River Delta. The domain is about 300 km×300 km with the centre in Guangzhou because all these three heavy rainfall occurred in this region. We analyze the relationship between the terms and the heavy rainfall based on the calculation of the budget formula in this domain. The feature of the energetic aggregation and release is investigated based on the case on 24th May.

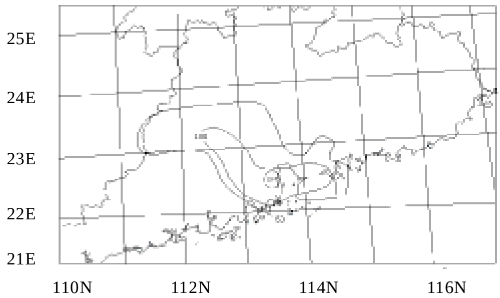

Fig.1 The distribution of 24-h heavy rain (unit: mm) from 20:00 May 23rd to 20:00 May 24th 1998.

4. CONVERSION TERM

In order to study the relationship between the right terms and the precipitation, the vertical profiles of the terms in the rain region are given.

Fig.2 gives the vertical profiles of the conversion term ($\frac{1}{g}Nwa$) in the heavy rainfall region. Curve *a* stands for the vertical profile before the heavy rainfall, *b* for the early period of the precipitation, and *c* for the later period of the precipitation (the same as in Fig.3, Fig.4 and Fig.5). Before the precipitation, the conversion term has positive contribution for the MAE in the heavy rainfall region that it is limited at the low and middle layer of the troposphere. At the upper troposphere, the contribution is slightly negative. The value of the term is positive, whereas it is negative at the upper troposphere. The positive contribution of the conversion term increases the MAE in the heavy rainfall region. This configuration increases the instability in the heavy rainfall region. It is well known that the rainstorm often occurs in the unstable region with moist and high temperature (large MAE)[12].

In the period of the precipitation, the conversion term releases the energy because the value of the conversion term is less than zero. Fig.2 shows that the peak value of the released energy is at the lower troposphere. In the later period of the precipitation, the conversion term still releases the energy.

In brief, the conversion term increases the MAE and the stratification instability for the heavy rainfall region before the precipitation; on the contrary, it releases the MAE in the period of the precipitation. It is shown in Fig.2 that the absolute value of the conversion term is the greatest in the period of the precipitation. For the effect on precipitation, the process in which the conversion term released the MAE is more important.

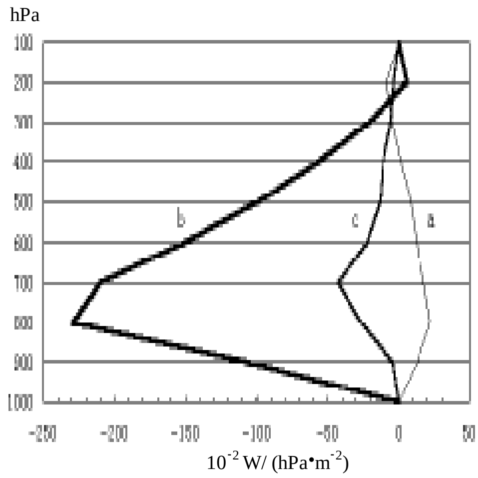

Fig.2 The vertical profiles of the conversion term in the heavy rainfall region (unit: 10^{-2}W/hPa/m^2) a. 20:00 May 22; b. 08:00 May 24; c. 20:00 May 24.

5 HORIZONTAL TRANSFROM TERM

Fig.3 gives the vertical profiles of the horizontal transport term in the different period of the precipitation. The value of the horizontal transport term at the troposphere is positive before the heavy rainfall.

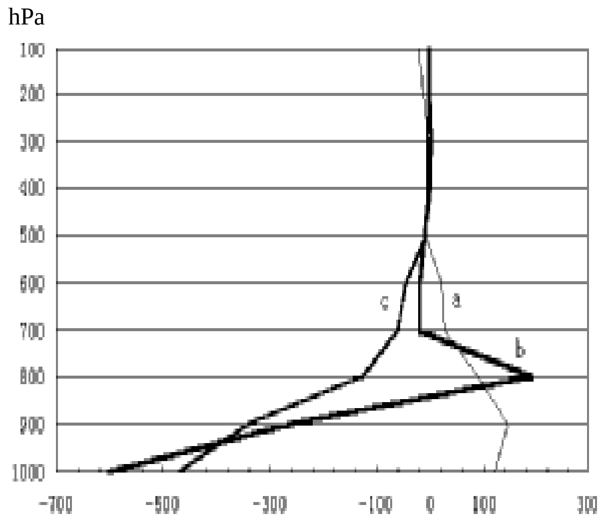

Fig.3 As in Fig.2 but for the horizontal transport term (unit: 10^{-3}W/hPa/m^2)

In the early period of the precipitation, it is positive too. It means that the horizontal transport term transports the MAE to the heavy rainfall region in these two periods. It is negative in the late period of the precipitation, meaning that it reduces the MAE. In the period of the precipitation, the horizontal term at the low and middle level of the troposphere changes the sign. The value is positive at the upper troposphere, whereas it is negative at the lower troposphere. It is the same for the precipitation period on 15 May. The heavy rainfall on 9 June is quite different from the other two cases. Shi studied the three heavy rainfall cases[13]. It shown that the heavy rainfalls on 14 – 15 May and 24 May are caused by cold font. On the other hand, the southwest low-level jet stream and lower-level jet stream play important role on the heavy rainfall on 9 June. The horizontal transport term always transported the energy to the heavy rainfall region, because the value of this term is more than zero in the early and later period of the precipitation on 9th June. The value of the horizontal transport term is quite different in the three periods. The value is largest before the precipitation, small in the pre-heavy rainfall period, and smallest in the later period.

6 VERTICAL TRANSPORT TERM

The vertical transport term reduces the MAE of the heavy rainfall region before the precipitation. On the other hand, the vertical transport term increase the MAE in the early and later period of the precipitation. But the increment in the early period of the precipitation is more than that one in the later period. Fig. 4 reveals these features clearly.

Compared the vertical transport term $(-\frac{c_p}{g}Nw\frac{\partial T_{se}}{\partial p})$ with the conversion term $(\frac{1}{g}Nwa)$, the two terms include such factors as g^{-1}, N and w. The specific volume $(a=\frac{RT}{p})$ in the conversion term is more than zero. Because the air temperature and the specific humidity decrease with height in the real atmosphere, the term of $C_P\frac{\partial T_{se}}{\partial p}$ is more than zero too. It has two effects when a parcel moves along the vertical direction. Assuming that it decreases the MAE through the conversion term, it must increase the MAE through the vertical transport term and vice versa. The calculation verifies it. From the comparison of the two vertical cross graphs of the vertical transport term and the conversion term, the pattern of the two graphs are quite similar except their signs. So it is necessary to analyze the effect of the vertical transport term and the conversion term.

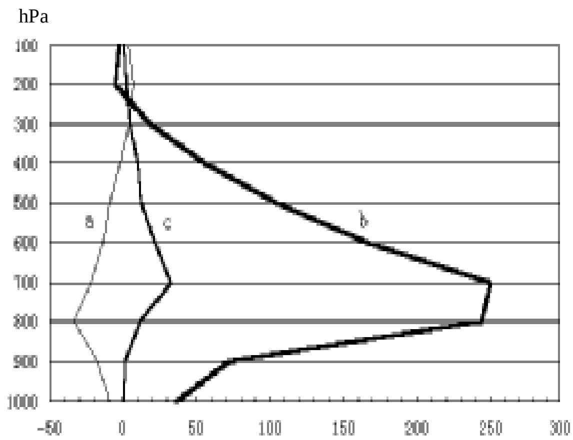

Fig.4 As in Fig.2 but for the vertical transport term (unit: 10^{-2}W/hPa/m^2).

The two terms reduce the MAE before the precipitation, whereas they increase the MAE in the early period of heavy rainfall. Nevertheless, they reduce the MAE in the late period of the precipitation. From Fig.5, it is noted that the summation of the absolute value of the two terms increases the MAE notably in the period of heavy rainfall.

7 MAE BUDGETS AND PRECIPITAION

Fig.6 gives the temporal variation of the hourly-accumulated precipitation over the heavy rain region on May 24. The region has no rain before 06:00 May 23, and there is no rain after 18:00 May 24 either (with hourly accumulated precipitation less than 20mm). The precipitation lasted for 31 hours from 06:00 May 23 to 18:00 May 24, except that there is no rain from 16:00 to 21:00 May 23.

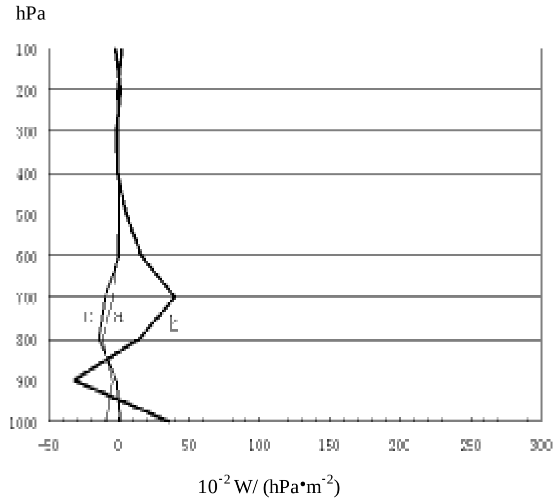

Fig.5 As in Fig. 2 but for the summation of the conversion term and the vertical transport term (unit: 10^{-2}W/hPa/m^2).

The major precipitation period is from 22:00 May 23 to 16:00 May 24. The rainstorm lasted for 16 hours and the hourly precipitation was more than 50 mm. The precipitation peak occurred on 07:00 May 24.

Fig.7 gives the temporal variation curve of the horizontal transport term and the conversion term. It shows that the pattern of the conversion term curve is consistent with the precipitation. The period of the precipitation is in the phase of a negative conversion term. The lager the absolute value of the conversion term is, the stronger the precipitation is. The precipitation peak is identical with the valley of the conversion term. The curve of the conversion term in Fig.7 further proves that the conversion term is a MAE release term in the period of the precipitation, which we have explored in Section 4.

Because the energy is released in the period of the precipitation, the MAE must be accumulated in the rain region and its surrounding areas. It is one of the conditions for large region rains. Compared with many other strong rainstorm cases, the rainstorm occurred on 24 May has this precondition. Because the strong rainstorm in the large region releases more MAE in the period of the precipitation, the MAE in the rainfall region is not enough for the heavy rainstorm. So the MAE must be supplied from the environment. Before the precipitation, the MAE is supplied to the region. It is the same for the early period of the precipitation. The supplement is transported horizontally so that it is limited within the lower layer of the troposphere. Fig.7 shows that the strongest supplement occurred 12 hours before the precipitation peaked.

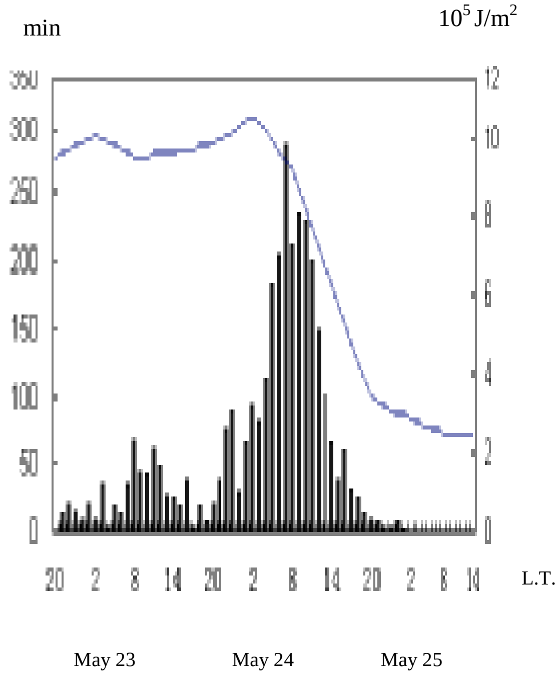

Fig.6 The temporal variation of hourly accumulated precipitation and MAE over the heavy rain region, right for precipitation (unit: mm) and left for MAE (unit: 10^5J/m^2).

As shown in the last chapter, the vertical transport term transports energy to the region in the period of the precipitation too. As we know, the energy transport is positive upward. If the vertical transport term increases the energy in the special level in the period of precipitation, the energy must be transported from the lower level. In order to transport the MAE from the lower layer to the upper layer, the low layer must supply the MAE. Supplied energy is transported from two sources. It can be transported horizontally or vertically. It has been shown that the supplied energy is transported along the vertical direction, the energy must be from the lower layer. The land and the water surface are the energy source with sunshine. The land is the sensible heat source and the water is the latent heat source. The underling surface is not the major energy source in the period of precipitation. So the energy is supplied mostly horizontally in the period of precipitation.

We have analyzed the MAE of the rainstorm on 24 May[10]. In the period of the rainstorm, a tongue of high energy is located near the estuary of Pearl River, and the center of the heavy rainfall is located near the energy front of the high-energy tongue. The energy is transported to the heavy rain region horizontally compared with the horizontal wind.

In short, the energy is first transported from the surrounding region to the heavy rain region by the horizontal transport term. Then, it is transported upwards by the vertical transport term. It is shown that the wave phase of the horizontal transport term forms earlier than the vertical transport term. The vertical profile's peak of the horizontal transport term is lower than the vertical one.

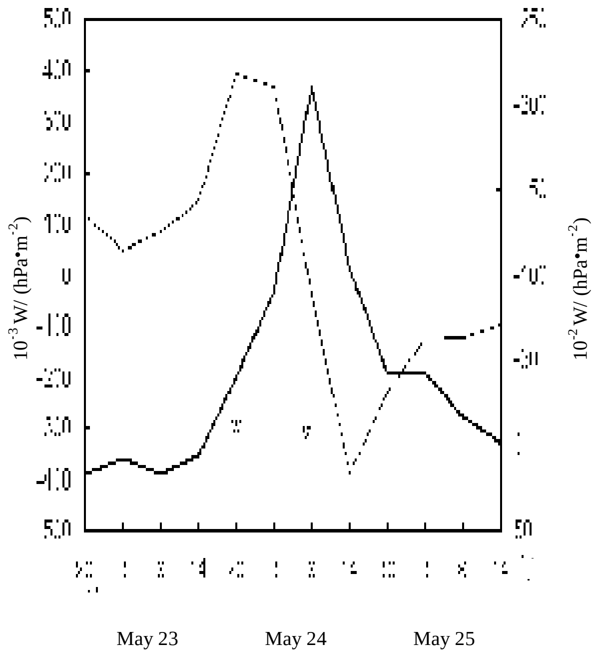

Fig.7 Temporal evolution of 850-hPa horizontal transport term (*V*, left ordinate) and 700-hPa conversion term (*W*, right ordinate).

8 CONCLUSIONS AND DISCUSSIONS

It was shown that the conversion term, the horizontal transport term and the vertical transport term in the balance formula of the MAE are closely related with the precipitation. The conversion term and the horizontal transport term supply the energy for the heavy rainfall region before the precipitation. The conversion term becomes the release term in the period of the precipitation. The horizontal term and the vertical transport term supply the energy for the rainstorm at the same time. The horizontal transport term decreases the energy for the font rain. The summation of the conversion term and the vertical transport term increased the MAE in the heavy rain region in the precipitate period, but they decreased the MAE before the precipitate period. They decrease the MAE after the precipitation too. Furthermore, the peak value of the energy released by the conversion term is corresponded with the peak value of the precipitation. The maximize value of the horizontal energy transport emerged before the period of the peak value of the precipitation.

In brief, the energy aggregation and release in a heavy rainfall is summarized. Firstly, the energy is transported from the surroundings to the heavy rain region by the horizontal transport term. Secondly, the energy is transported to the upper level of the heavy rain region by the vertical transport term. Lastly, the energy is released by the conversion term, and the rain appears with the energy release. The analysis of the horizontal transport term is very helpful if only the time for heavy rainfall to begin is to be determined.

REFERENCES:

[1] WANG Yong-ming, SU Bai-xing, CHANG Yue. Cooperation of the system and feature of the circulation from south china rainstorm trial in 1998 [J]. Journal of Tropical Meteorology, 2000, 16 (2): 123-130.

[2] GU Zhi-ming, FONG Soi-kun, WU Chi-sheng ,et al. A modeling case study of heavy rain event over south china in may l994 [J]. Journal of Tropical Meteorology, 2000, 16(2): 173-179.

[3] LU Yan-bin, GU Lei, LI Ya-ping, et al. Observation research for the measuring rainfall capacity of trmm/tmi-85.5g based on the precipitation data during the heavy rain experiment in southern china [J]. Journal of Tropical Meteorology, 2001,17(3):251-257.

[4] YAN Jing-hua, XUE Jin-shan. Numerical simulation and analysis on the structure of a rainstorm system [J]. Journal of Tropical Meteorology, 2002, 18(4): 302-308.

[5] LIU Shu-yuan, ZHENG Yong-guang, TAO Zu-yu. The analysis of the relationship between pulse of LLJ and heavy rain using wind profiler data [J]. Journal of Tropical Meteorology, 2003, 19(3): 285-290.

[6] LI Chen-guang, LIU Shu-yuan, TAO Zu-yu. Review of wind profiler data of Hong Kong during IOP of HUAMEX and SCSMEX [J]. Journal of Tropical Meteorology, 2003, 19(3): 269-276.

[7] WU Bao-jun. The application of the moist available energy in the heavy rain analysis and forecast[J]. Meteorological Monthly, 1982, 8(11): 4-7.

[8] LIU Yan-ying, XU Chen-hai, WU Bao-jun. An analysis of three cases of heavy rains in Jing-Jin-Ji area of China [J]. Journal of Applied Meteorological Science, 1993, 4(3): 349-355.

[9] LIU Yan-ying, YI Qing-ju, ZHOU Li, et al. A analysis of the moist available energy during the Meiyu period in 1991[J]. Acta Meteorologica Sinica, 1999, **57**(6): 741-750.

[10] ZHOU Hai-guang, LIU Yan-ying, SHI Ding-pu. An analysis of the "5.24" heavy rain in Guangdong [J]. Journal of Nanjing Institute of Meteorology, 2003, **26**(6): 859-864.

[11] WU Bao-jun, JIANG Feng-ying. The budgets of the moist available potential energy in a limited region [J]. Acta Meteorologica Sinica, 1983, 41(3): 338-342.

[12] Tao Shi-yan. Study on China heavy rain [M]. Science Press, 1980, 8-24.

[13] SHI Ding-pu. The application of the data in the Hunan heavy rain analysis. The abstracts of the workshop on HUAMEX [C]. Zhuhai,China, 2002, 5.