Analysis of Moist Potential Vorticity of Two Similar Super Typhoons Affecting South China

Duan Peng JiaFengWeng WenboWang
JieTang RongquanChen JingZhou FanweiZeng
(Zhaoqing Meteorological Observatory, Guangdong, China 526060)

Abstract:With conventional meteorological data as well as NCEP 1 °×1 ° reanalysis data, the processes of the super typhoon Rammasun(1409) and Mujigae (1522) are diagnosed and compared. The result indicates that the re-strengthening of the typhoon Mujigae after its landing and denaturing was due to intense development of a frontal cyclone, which was incarnated by downwards moving of the up-per level potiential voticity, the tropical low pressure circulation and the low-level front. But in the process of the denaturing of the typhoon Rammasun, there was no downwards moving of the up-per level potential voticity, no low-level front, and the atmospheric slanting piezotropy was weaker. So the mutual influence of downwards moving of the up-per level potential voticity, the tropical low-pressure circulation and the low-level front did not exist. And that is the reason why more severer rainstorm in south China caused by Mujigae than Rammasun. In the two processes, the negative MPV (Moist Potential Vorticity) center at 925hPa agrees well with the severe precipitation region located the side of warm and moist airflow 110 kilometers away from the negative MPV center, whose size can reflect the precipitation. And the size of the negative MPV center of Mujigae are larger than that of Rammasun. The positive MPV center and the turning point of θse equivalent surface are indexes for predicting the strong precipitation center. So the MPV at low levels can be used to forecast falling areas of rainstorm 6 hours in advance.

Key words: Super Typhoons; South China rainstorm; Potential Vorticity

1. Introduction

Moist Potential Vorticity is an comprehensive physical quantity reflected the effect of atmospheric dynamic, thermodynamic and moisture. It can describe the typhoon degeneration and development of the typhoon storm.In the literature[1-3] , from the complete original equation,it proved that in the adiabatic frictionless saturated atmosphere,Moist Potential Vorticit(or vortexes) in the atmosphere is of conservation. And the development theory of oblique vortex in wet baroclinic process was studied. According to this theory, Yuhui et al[4]studied the potential relationship between the evolution of the temperature structure and the intensity of the tropical cyclone. There have been many studies on typhoons and rainstorms.And the literature [5-9] has been used in the diagnosis and research of rainstorm and other weather, and has obtained meaningful results.Literature [10] compared the Moist Potential Vorticity of two similar path typhoons that affected Hebei Province. Rammasun(1409) and Mujigae (1522) is situated in the background of under the stable control of the western Pacific subtropical ridge. The two typhoon path and the landing sites are similar, but the more severer rainstorm in south China was caused by Mujigae than Rammasun. In this paper, for the two typhoons as an example, Moist Potential Vorticity theory is used to analyze and discusses the characterization of the Moist Potential Vorticity in typhoon rainstorm in south China.

2. Circulation background and rainfall distribution characteristics

In 2014, Super typhoon Rammasun (1409) was a typhoon that landed in south China and strengthened offshore. Rammasun situated at 7:30 on July 18, 2014(world time,the same below) in Hainan Wenchang WengTian coastal town and the biggest wind near the center was 60ms^{-1} (17 level), the lowest pressure was 910mpa, as shown in FIG.1 (a), caused the south China especial serious wind and heavy rain floods of Hainan province, as shown in FIG.1 (b). Heavy rainfall was mainly distributed in the southern coast of Hainan and Guangxi. The rainfall affected Guangdong was relatively small, only 50-100mm of precipitation.

At 6:10 on October 4,2015, Mujigae (1522) was landed, the center biggest wind was 50 m.s^{-1} (15 level), the center of the lowest pressure was 940 mpa. After the landing, Mujigae continued to move northwestward, moving from the Lianjiang city of zhanjiang to the territory of bobai county of Guangxi on the 4th, and weakened.It was reduced to a tropical storm, which was reduced to a tropical depression at 1 on October 5, and reduced to a low pressure area on October 6, as shown in FIG.1(b). Mujigae is the strongest typhoon to affect Guangdong in October since 1949. It has the characteristics of "strong intensity, rapid offshore development, serious wind and heavy rain floods". Due to the influence of Mujigae, there were heavy rainstorms in the west, pearl river delta and Qingyuan city in southern China, as shown in FIG. 2(b), Guangdong province. A total of 273 towns and villages recorded the accumulate precipitation of more than 250mm, the number of station which precipitation greater than 100mm accounts for 42.1% of the terminal number. The precipitation of Yangjiang yongning town recorded the largest accumulated rainfall of Guangdong province: 592.9 mm. But only about 50mm of precipitation in Hainan province.

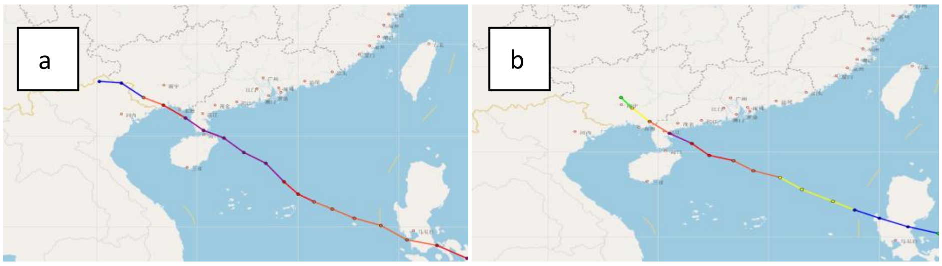


Fig.1（a） **Rammasun(1409)** situated path diagram （b）**Mujigae (1522)** situated path diagram

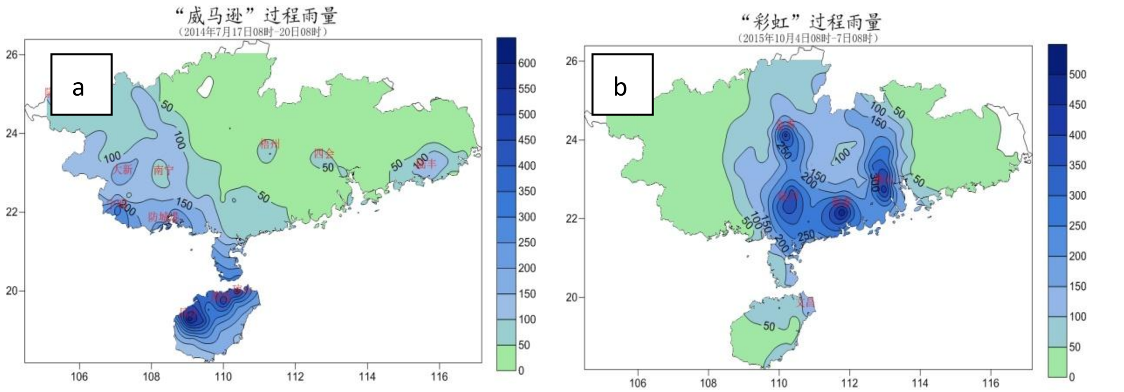


Fig.2（a） **Rammasun(1409)** Process rainfall map （b）**Mujigae (1522)** Process rainfall map

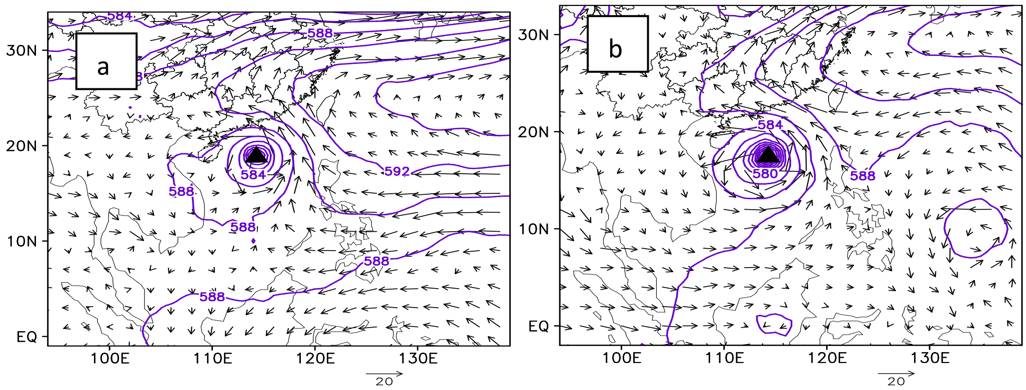


Fig.3 （a）**Rammasun (1409)** 500hpa map （b）**Mujigae (1522)** 500hpa l map

Rammasun is the summer typhoon in southern China, its main characteristic is by the strong belt southern side of the southeast air flow guide to the northwest, the path is very stable. All the way to Wenchang city, Hainan Province.

Mujigae is a typhoon in southern China. Its main features are the interaction between the strong band and the cold air. Mujigae maintain northwest path. At the beginning, by the edge of subtropical high airflow guide moving northwest, southeast south after entering our province and the west coast speed slowed, continue to move northwest log in Zhanjiang. Then high jump of the west north subtropical was abate, but was still in the southeast of the west edge of subtropical high in the air, Mujigae continue moving northwest, its peripheral circulation cause continuous heavy rains to Guangdong province precipitation, and move left in Guangxi province again, northwest to weaken and die.

The above analysis shows that: **Rammasun** and **Mujigae** occurred in the western Pacific subtropical high and stable extending to strengthen, position of subtropical high north, the subtropical high ridge line has remained steady at around 20~30°N. Two typhoon landing site is similar, it is along the 120 ° E moving northwest, has made landfall at northern and southern Zhanjiang Hainan island. After landing, they continued to move in the northwest direction. After entering Guangxi, the **Rammasun** continued to move rapidly to the northwest, and disappeared after entering Vietnam. **Mujigae** entered Guangxi after 48 hours of stagnation and died. The distribution of heavy rainfall caused by these two typhoons is quite different. **Rammasun** has heavy rainfall in Hainan and the southern coastal areas of Guangxi, while the **Mujigae** are mainly concentrated in the central, western and eastern parts of Guangdong province. What is the difference between them? The following is a comparative analysis from the theory of the Moist Potential Vorticity.

3. Introduction to the theory of the Moist Potential Vorticity

Wuguoxiong[2] define the Moist Potential Vorticity as follow : The absolute vorticity of a unit mass gas block is defined as the product of the projection of the equivalent temperature gradient direction and the absolute value of this gradient. For A frictionless, wet-insulated saturated atmosphere that satisfies the characteristics of wet-level Vorticity, the unit is Pvu, 1 Pvu = 10^{-6} mm ^{2}. S^{-1}. K. Kg^{-1}.

$$\mathrm{MPV} = -\mathrm{g}(\mathrm{fk} + \nabla\mathrm{p} \wedge \mathrm{V}) \cdot \nabla\mathrm{p}\theta\mathrm{e}$$

The Moist Potential Vorticity is expanded on the isostatic surface, and its vertical and horizontal components are defined respectively as MPV1,MPV2

$$MPV_1 = -g\zeta_p \frac{\partial \theta e}{\partial p}$$

$$\zeta p = f + \left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right]_p$$

$$MPV_2 = -gk \times \frac{\partial v}{\partial p} \cdot \nabla p\theta e$$

MPV_1 is the wet positive pressure of the Moist Potential Vorticity, whose value depends on the product of the vertical component of the absolute vorticity of the air block and the vertical gradient of the corresponding temperature(ζp is the vertical vorticity of the P coordinate system ，f is vorticity，θe is Equivalent potential temperature)

MPV_2 is the wet oblique pressure term of a wet bit vortex, Its value is determined by the vertical shear of the wind (horizontal vorticity) and the horizontal gradient of the equivalent temperature.

4. The diagnosis and analysis of the Moist Potential Vorticity current of low pressure circulation in tropical cyclone

From the FIG. 3, 4,we can find that at 06 on October 4, 2015 (world time, the same below), after the **Mujigae** landing on 500 hpa, the MPV shows the value of 3.0 PVU, which is the strongest. At 12 on October 4, **Mujigae** shows that the low pressure circulation loss has obvious attenuation of 2.4 Pvu value due to landing. At the same time in the center of the 925 hpa suddenly added 1.8 Pvu value of MPV disturbance. MPV disturbance is the characteristic of the "funnel" hang down. The high level positive MPV extends downward and connects to the south and lower levels of the MPV area. From 12 to 5 PM on the 4th, the upper MPV perturbation and the lower pressure of the lower typhoon are superimposed, and the extension and widening of the MPV perturbation is more obvious. Near the typhoon center in addition to the surface layer, a nearly vertical form over the high value of wet vortex column. At the same time, the north of the typhoon center has a column is MPV, its strong value region located in the lower troposphere and up into the high MPV disturbance area. Due to the downward extension of the MPV at the top, the

MPV was significantly increased in the south of the tropical cyclone circulation at 12am on the 4th day (the 6-hour variable of MPV was 1.5 pvus). Correspondingly, the distribution of the corresponding θ_e shows that the increased positive MPV gas block causes the lower cold air to be strengthened, and the contrast of the cold and warm air is increased, and so on, which is more intense, that is, the wet barocline enhancement. According to the conservation principle of MPV, the gas block must be elongated in the direction of lead, so that the intensity of the contour line of the plane is reduced [11]. At the same time, it must shrink in the horizontal direction, leading to the growth of ζ_P. Therefore, the high-level positive MPV can induce cyclonic circulation in the lower frontal zone. The " **Mujigae**" low pressure has been redeveloped due to the acquisition of an additional ζ_P. The typhoon low - pressure circulation increased significantly.

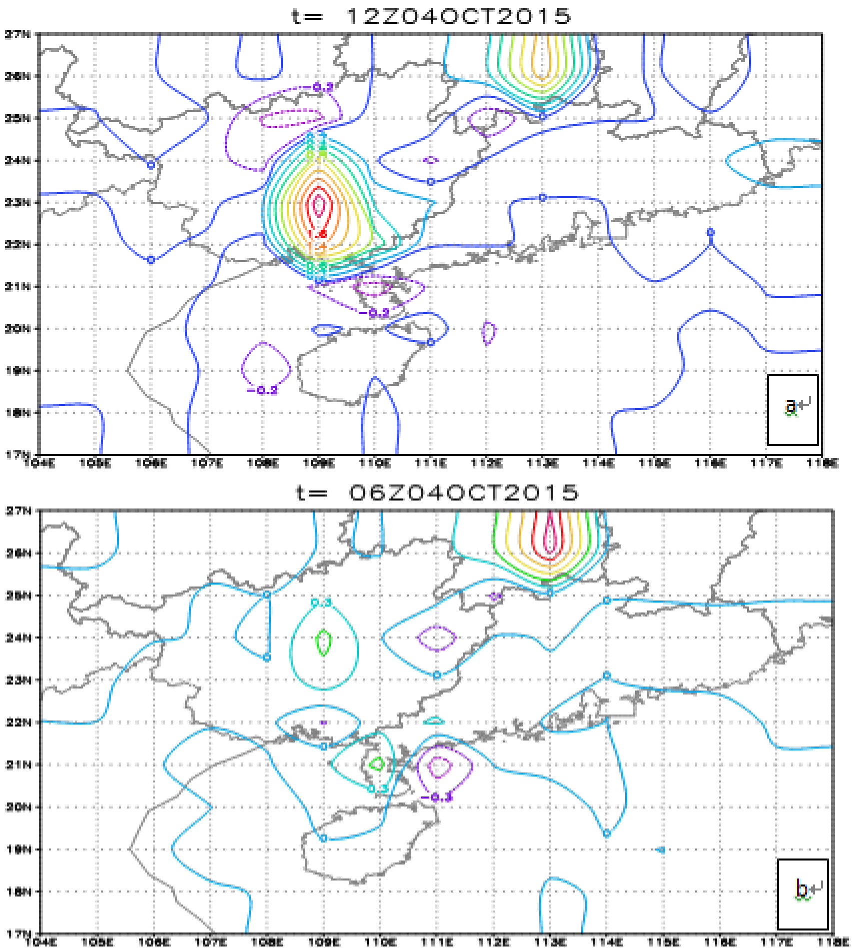


FIG .4 (a) 925 hPa MPV map, at 12：00 4 October 2015
FIG .4 (b) 925 hPa MPV map, at 06：00 4 October 2015

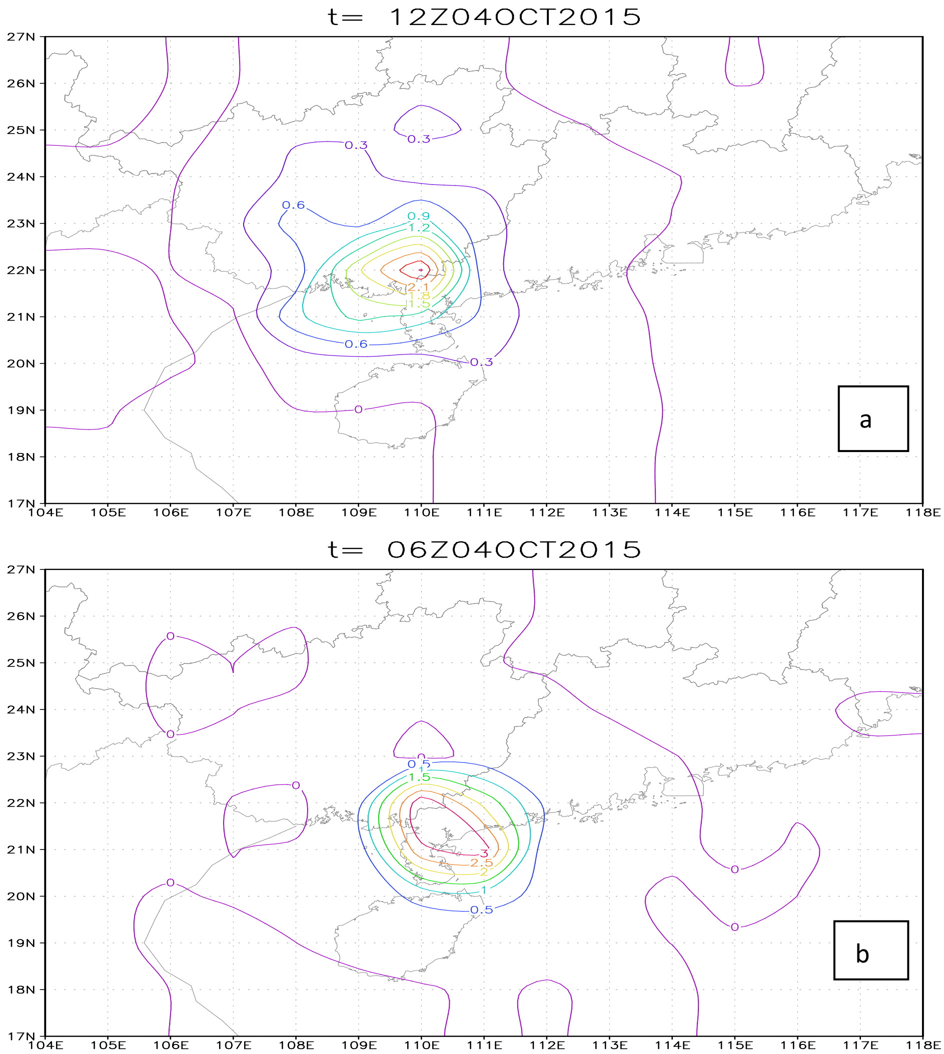


FIG. 5 (a)500 hPa MPV map, at 12：00 4 October 2015

(b) 850 hPa MPV map, at 06：00 4 October 2015

The situation of Rammasun is obviously different. Figure 5 shows that the low-pressure circulation of 500hpa Rammasun is still relatively obvious at 12 o 'clock on July 18, 2014, but the MPV growth is very weak (the maximum 6-hour variable of MPV is 1.1PVU). There is no downward extension of the high level positive MPV, and there is no further strengthening process without the interaction between the transmission of the high level vortex disturbance and the low-pressure circulation of the tropical cyclone. Correspondingly, the distribution of θse indicates that the typhoon is located in the relatively warm area. Unlike **Mujigae**, Rammasun situated around the warm and cold temperature contrast is not obvious, there is no internal θse isoline concentration areas, and the wet atmospheric baroclinicity is very weak, and ther is no apparent striation at the lower level. Here, the typhoon area Δ 6 MPV growth is not obvious. At 08 on 20th, the lower area of the typhoon occupied by a same temperature field, Rammasun was gradually filling.

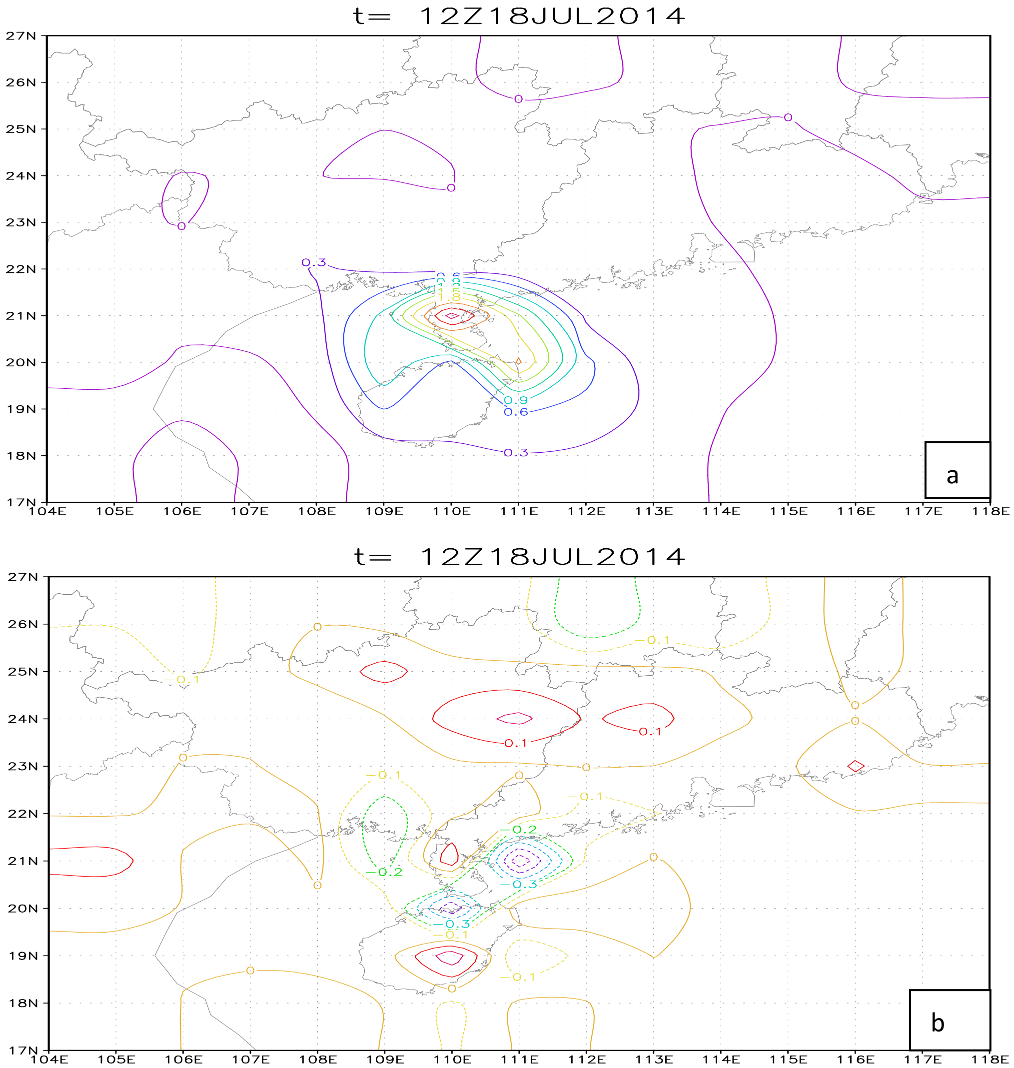


FIG. 6 (a)500 hPa MPV map, at 12：00 18 July 2014

(b) 850 hPa MPV map, at 12：00 18 July 2014

From what has been discussed above, after the **Mujigae** landing, the reinforcement process is mainly related to the interaction between the low pressure circulation and the low pressure circulation of the tropical cyclone. Compared with the **Mujigae**, there is no further process of the interaction between the vortex disturbance of the high temperature and the low-pressure circulation of the tropical cyclone in the process of the arrival of the Rammasun. This is one of the reasons for the intensity and scope of rainstorm in south China caused by the **Mujigae** typhoon.

5.The analysis of the Moist Potential Vorticity of the two typhoon

rainstorm process

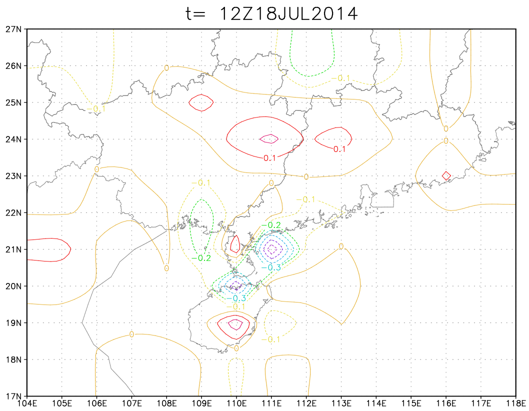
The Moist Potential Vorticity contains water vapor, which has a great relationship with precipitation. In this paper, the corresponding analysis of the positive pressure (MPV1) negative center and rainstorm zone is carried out to investigate the representation of the Moist Potential Vorticity in the typhoon rainstorm in south China.

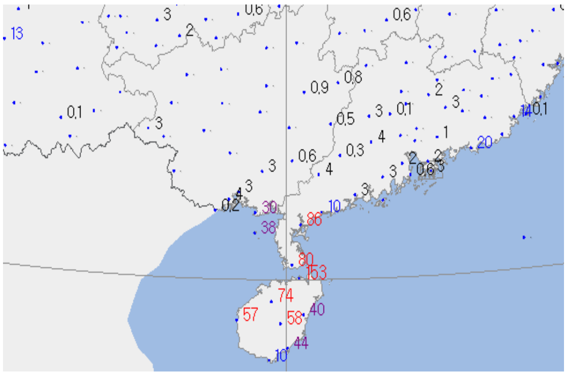
5.1 Vertical distribution of MPV1

According to the Moist Potential Vorticity theory of Wu guoxiong[2]. It can be considered that the negative Moist Potential Vorticity represents the unstable warm and humid air flow, and the positive Moist Potential Vorticity is used to trace the cold air activity. MPV1 is an order of magnitude larger than MPV2, and the distribution of MPV1 is roughly the same as that of the MPV, and the position of negative center is more consistent. Analysis of the vertical distribution of MPV in south China by two typhoons (FIG is omit.) shows that these two rainstorm processes, over 700hPa and above south China, are the positive zone of MPV1, indicating that the upper troposphere is the convective stabilization zone. Heavy rains produced twice before have positive MPV1 from the upper troposphere to the storm zone "funnel" sagging to 850 hpa, the typhoon **Mujigae**, process of 6-48 hours after landing at MPV1 "funnel" prolapse to lower to 925 hpa, shows that the high-level cold air in the form of high value a vortex column down invasion, induce lower the development of the low pressure circulation. Typhoon landing process of **Mujigae**, 48-66 hours after this period of time of the 925 hpa presents obvious negative MPV1 zonal distribution, to show that the weak cold air by lowering the lower stability and lower cold pad forming force middle relatively warm air lift, can lead to convective instability energy and latent heat release, is advantageous to the heavy rain. The typhoon Rammasun process after landing without sagging to lower "funnel", strengthening process, just and low-level negative MPV1 interaction, make the negative center warm moist air flows to one side of the heavy rain area is maintained.

5.2 The corresponding analysis of MPV1 negative center and rainstorm zone

Is there a good relationship between the negative center and the strong precipitation region in the troposphere during the two typhoons? Through the analysis of the distribution of MPV1 925 hpa layer, as shown in figure 7 and figure 8 and figure 9, the typhoon Rammasun process and the strong typhoon **Mujigae** process in precipitation in the 925 hpa layer of warm moist air flows in the center of the MPV negative side, and negative center from one weft is apart from the left and right sides. Or positive and negative gradients with the greatest turning point, and 6 hours of presage meaning. As shown in FIG. 10, FIG. 11, FIG. 12, FIG. 13, and FIG. 14, the number and range of the MPV negative center of typhoon **Mujigae** are both larger than that of typhoon Rammasun. Through the analysis of θse level can be concluded that the 925 hpa MPV negative on the area and θse level sudden falls to ground turn with overlap is a good criterion of forecasting heavy rain center area, and is a good indicator for the typhoon heavy rain.



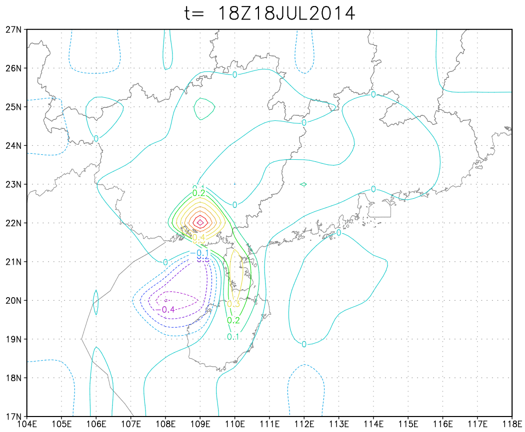


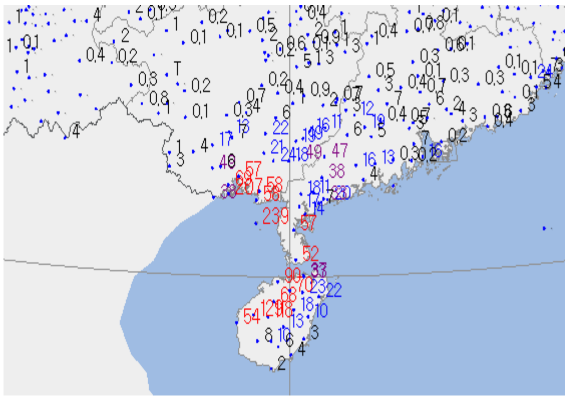
（b）

（a）

FIG.7 (a) The 925hPa MPV of the typhoon "Rammasun" process at 12 On 18 July ,2014

（b）The 6 hour Rainfall distribution at 18 On 18 July ,2014

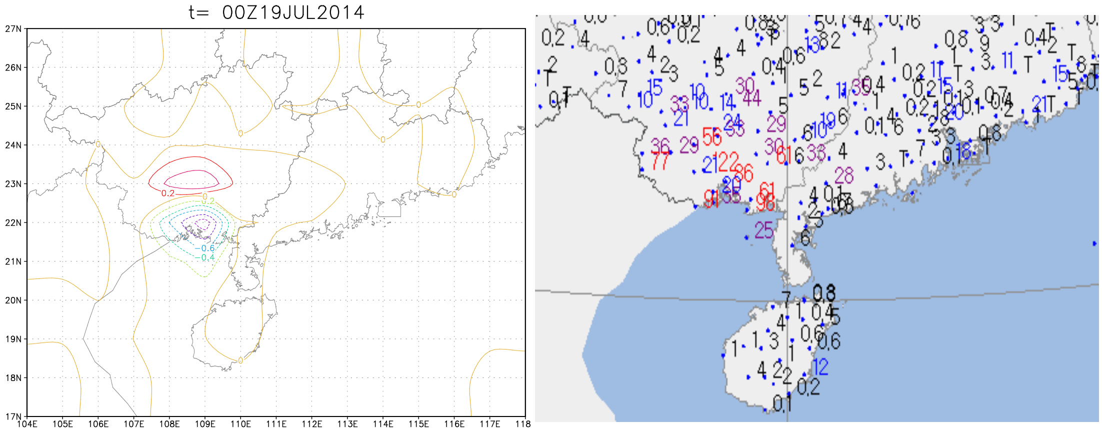




（a） （b）

FIG.8 (a) The 925hPa MPV of the typhoon "Rammasun" process at 18 On 18 July ,2014

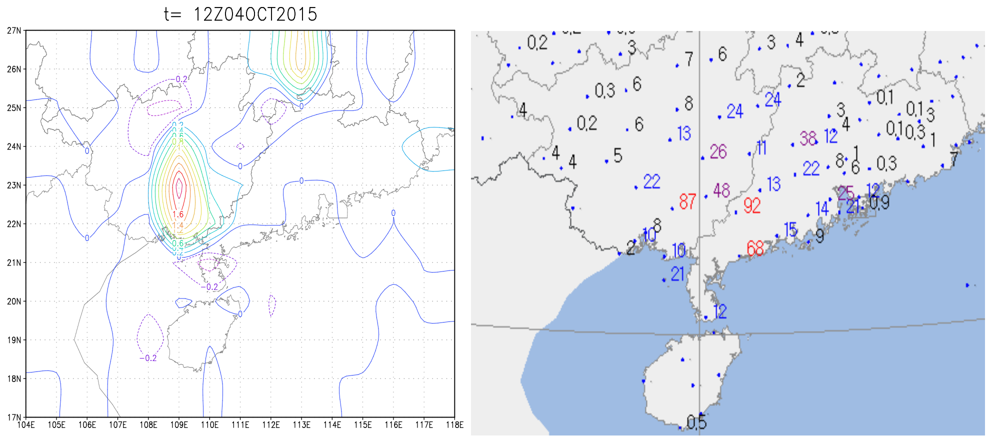
（b）The 6 hour Rainfall distribution at 00 On 19 July ,2014



（a） (b）

FIG.9 (a) The 925hPa MPV of the typhoon "Rammasun" process a t 00 On 19 July ,2014

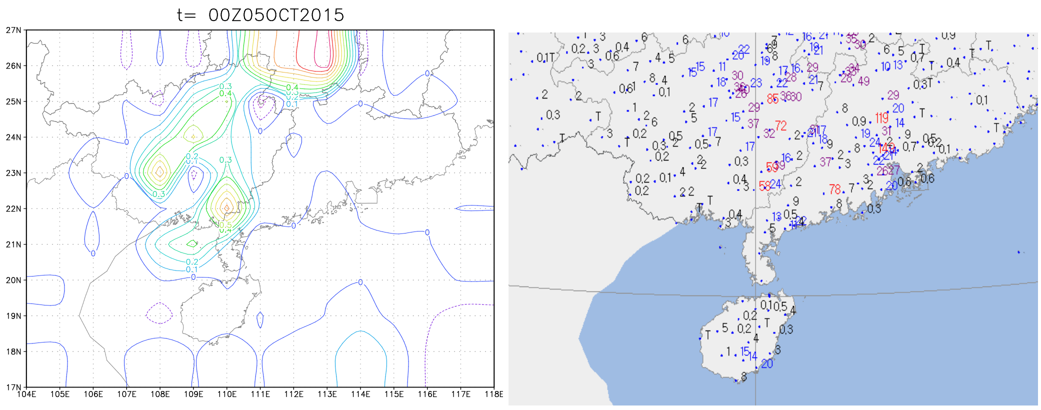
（b）The 6 hour Rainfall distribution at 06 On 19 July ,2014



（a） (b）

FIG.10 (a) The 925hPa MPV of the typhoon**"Mujigae"** process a t 12 On 4 OCT ,2015

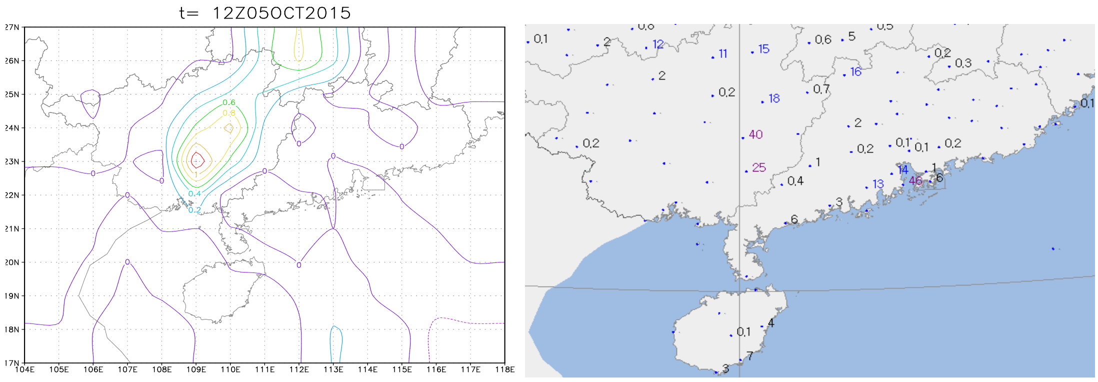
（b）The 6 hour Rainfall distribution at 18 On 4 OCT ,2015



（a） (b）

FIG.11 (a) The 925hPa MPV of the typhoon**"Mujigae"** process a t 08 On 5 OCT ,2015

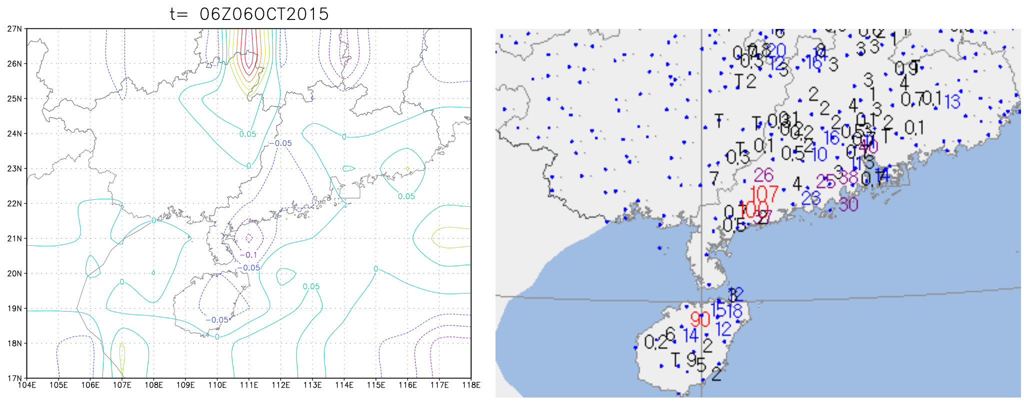
（b）The 6 hour Rainfall distribution at 14 On 5 OCT ,2015



（a） (b）

FIG.12 (a) The 925hPa MPV of the typhoon **Mujigae** process a t 12 On 5 OCT ,2015

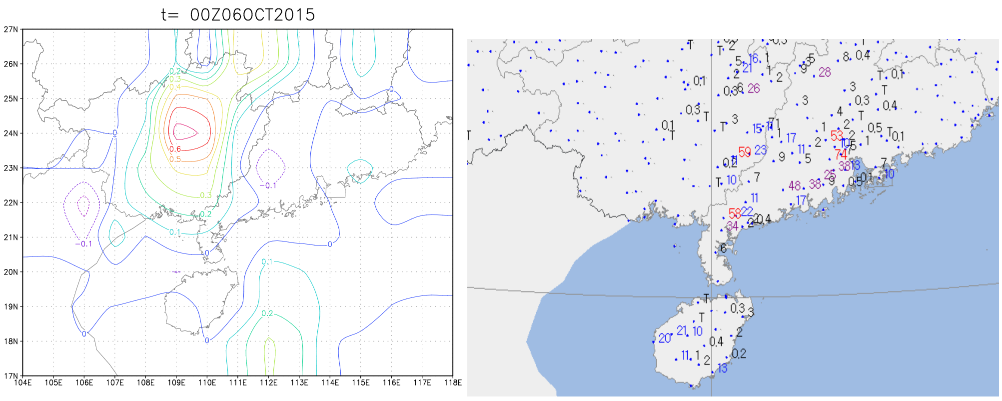
（b）The 6 hour Rainfall distribution at 18 On 5 OCT ,2015



（a） (b）

FIG.13 (a) The 925hPa MPV of the typhoon"**Mujigae**" process a t 06 On 6 OCT ,2015

（b）The 6 hour Rainfall distribution at 14 On 6 OCT ,2015



（a） (b）

FIG.14 (a) The 925hPa MPV of the typhoon"**Mujigae**" process a t 00 On 6 OCT ,2015

（b）The 6 hour Rainfall distribution at 08 On 6 OCT ,2015

6 Conclusion

(1) The **Mujigae** and Rammasun is situated in the western Pacific subtropical high and stable control of the background, the two typhoon path and the sites are similar, the storm of the serious effects on the south China, rainfall intensity and scope of the **Mujigae** is bigger than Rammasun.

(2) The re-strengthening of the typhoon Mujigae after its landing and denaturing was due to intense development of a frontal cyclone, which was incarnated by downwards moving of the up-per level potiential voticity, the tropical low pressure circulation and the low-level front. But in the process of the denaturing of the typhoon Rammasun, there was no downwards moving of the up-per level potential voticity, no low-level front, and the atmospheric slanting piezotropy was weaker. So the mutual influence of downwards moving of the up-per level potential voticity, the tropical low-pressure circulation and the low-level front did not exist. And that is the reason why more severer rainstorm in south China caused by Mujigae than Rammasun.

(3) In the two processes, the negative MPV (Moist Potential Vorticity) center at 925hPa agrees well with the severe precipitation region located the side of warm and moist airflow 110 kilometers away from the negative MPV center, whose size can reflect the precipitation.

(4) The size of the negative MPV center of Mujigae are larger than that of Rammasun.

(5) The positive MPV center on 925 hpa and the turning point of θse equivalent surface are indexes for predicting the strong precipitation center. So the MPV at low levels can be used to forecast falling areas of rainstorm 6 hours in advance.

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