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THE ANALYSIS OF THE RAPID ENHANCEMENTOF HAIKUI(1211) NEAR SEA SHORE AND ITS RELATED HEAVY RAINFALL IN ZHEJIANG PROVINCE

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ABSTRACT: Severe typhoon HAIKUI(1211)generated on August 3, 2012, near central maximum wind increased from 35 ms^{-1} to 48 ms^{-1}, increased 13 ms^{-1} during the six hours. The gust with the intensity above 13 grade has been lasting for 26 hours during the period. The maximum wind is 46.9 ms^{-1}, and 39.4 ms^{-1} as well as 36.8 ms^{-1} respectively at Dongji station, and Dachen station as well as Shippu station, which proof the rapid enhancement near sea shore. Analysis shows that rapid strengthening of HAIKUI in offshore due to suddenly increase of lower water vapor and vorticity input, and high-level divergence. The typhoon was symmetrical at this stage. The lower-level eyewall was small, while stretching out at upper level. At the same time, the radial and tangential wind speed was growing with the warm core expanding downward. The vertical speed of the vortex was generally small. All changes of the structures contributed to the maintenance and development of the typhoon. Development of TC conducive to the energy accumulation near the center, prompting the lower airflow enhancement and carrying rich water vapor transported to eastern Zhejiang coastal, formed the heavy rain. The evolution of the top level spiral degrees prompting changes of that of the low and the increase of 850hPa and decreased to zero for the formation and weaken signal of the heavy rain about 9 ~ 12 hours before respectively. Horizontal component of Moist Potential Vorticity(MPV) and wet vector can predict the distribution of rain-band before landfall, wet vector can better reflect the range of precipitation after landfall.

Key Words: Typhoon HaiKui, Rapid Enhancement near sea shore, Cause of Rainstorm

1. INTRODUCTION

Typhoon Haikui (1211) generated at 0000 UTC 3 August, on the northwest Pacific Ocean, 1360km southeast to Okinawa, Japan. At 0600 UTC 7 August, it developed into strong typhoon, and then made landfall in Hepu town, Xiangshan County of Zhejiang province at 1920 UTC 7 August, and decreased in Anhui Province at 0400 UTC 9. Its central pressure was 965hPa and maximum wind to its point was 14 degree(42ms^{-1}) when it made landfall. The typhoon had the characteristics of rapid strengthening inshore according to the National

Meteorological Center (Yu Yubing et al, 2008). From 0400 UTC to 0900 UTC 7 near central maximum wind increased from 35 ms^{-1} to 48 ms^{-1}, increased 13 ms^{-1} during the five hours, and the pressure decreased from 965hPa to 945hPa. The United States Joint Typhoon Warning Center (JTWC) and Tokyo typhoon center (RSMC Tokyo) business intensity didn't reflect the intense enhancement process(as shown in Exhibit 1), which, the highest levels were all 33 ms^{-1}. The standard of business intensity in America is the maximum average wind speed in one minute (Chen Lianshou et al, 2004), while two and ten minutes in China and Japan. In general, the business intensity determined by United States is the largest, and then by China and Japan, when it refers to the same typhoon and time level. But why business intensity has a significant difference when it comes to Haikui approaching the sea. Which one is more reasonable? It needs to be demonstrated.

Table 1:The Intensity of Haikui During Landfall(Maximum Wind near Central:ms^{-1})

Time	6.08	6.14	6.20	7.02	7.08	7.14	7.20	8.02	8.08	8.14	8.20
China	30	30	33	33	35	42	48	45	38	33	25
Japan	28	30	30	30	30	30	33	33	28	23	20
U.S.A	28	31	33	33	33	33	31	31	31	26	21

Typhoon is the strongest rainstorm system. Many extreme rainstorm records are related to typhoon. Reducing floods caused by typhoon is one of the main goals of meteorological science (Tao Shiyan, 1980). Distribution of rainstorm and whether it can cause floods is one of the biggest concerns. Forecast of rainstorm is about typhoon intensity and how long the typhoon can hold after making landfall. Besides, it also relates to Large scale circulation background, mesoscale weather system, water vapor condition, Local topography, Stratification stability, boundary-layer converge, discharge at high level and so on (Chen Lianshou et al, 2001). Although there are many breakthroughs in research of diagnosis of typhoon rainstorms, the point of prediction by using Moist Potential Vorticity (MPV), horizontal spiral and wet Q vector is still one of the difficulties in the research, which lack of systematic research. Therefore severe typhoon Haikui, which strengthened rapidly inshore and caused heavy rain, will be studied by using MPV, horizontal spiral and wet Q vector. The heavy storm it caused will also be diagnosed, in hope it will be help in forecasting typhoon rainstorm like this.

2. ANALYSIS OF RAPID STRENGTHENING INSORE

2.1 Observation and Analysis of Rapid Strengthening Inshore

According to the automatic meteorological service system, there was a gale≥15class coastal from 0600 UTC 7 to 0600 UTC 8 August (Nanjiu Mountain 48.7ms^{-1}, Liangheng Mountain 47.2ms^{-1},Shipu 50.9ms^{-1}, Dongji56.0ms^{-1}as Figure 1 and Dachen53.0ms^{-1}). In this period, the business intensity of National Meteorological Centre was greater than that of America and Japan. Analyzed of gust by automatic weather station, business intensity of National Meteorological Centre is more reasonable. According to the distribution of gust in Dongji, the winds more than 40ms^{-1} lasted up to 12 hours, and during 2200 UTC 7 to 0100 UTC 8 was more than 40 ms^{-1} again.

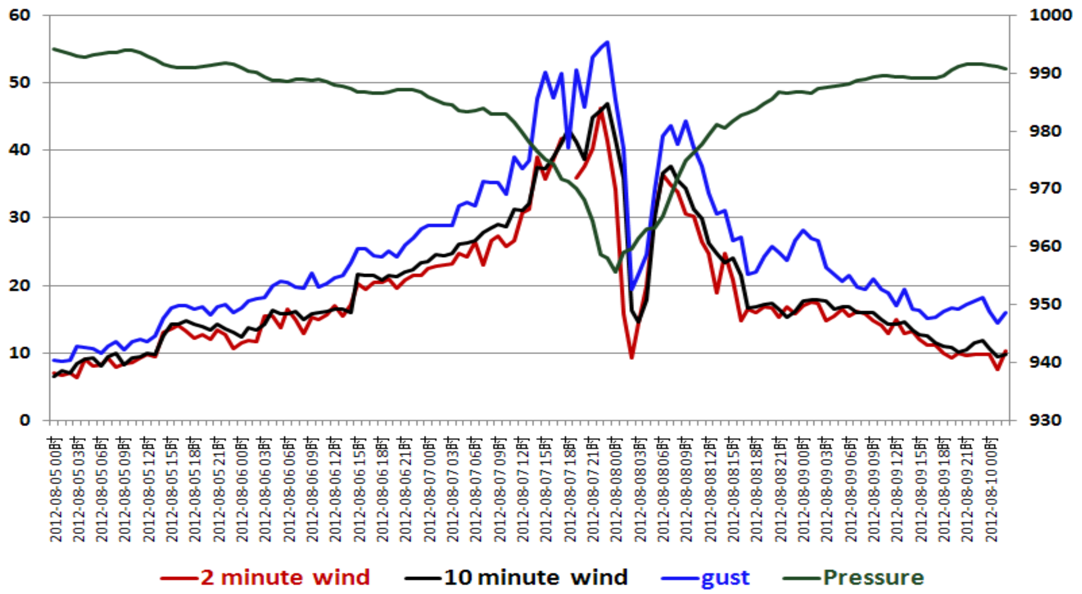


Fig.1 The Time Series of Wind Speeds and Pressure about Dongji Stations of the Maximum Wind near the Landing Point of Typhoon(4pm,Aug 5th to 4pm, Aug 9th)

2.2 Numerical Studies of Rapid Strengthening Inshore

2.2.1 Simulation of path and intensity

Figure 2 shows the results of numerical modeling of intensity and path of Haikui. The path of numerical modeling is close to that of truth, but there is still a gap at the end of the model integration (Figure 1a). Variation of intensity of numerical modeling is close to that of truth as well, that is to say it can model the process of intensity strengthening.Especially in the period of rapid strengthening from 0000 UTC to 0600 UTC Aug 7th, the pressure decreases 9.2hPa in just 6 hours in the numerical modeling, about the same as the range of intensity variation and period of business intensity. Therefore, the results of numerical modeling can reproduce the process of path and intensity of Haikui well and on the basis we can focus on these results to study the reason why intensity of Haikui strengthened so rapidly.

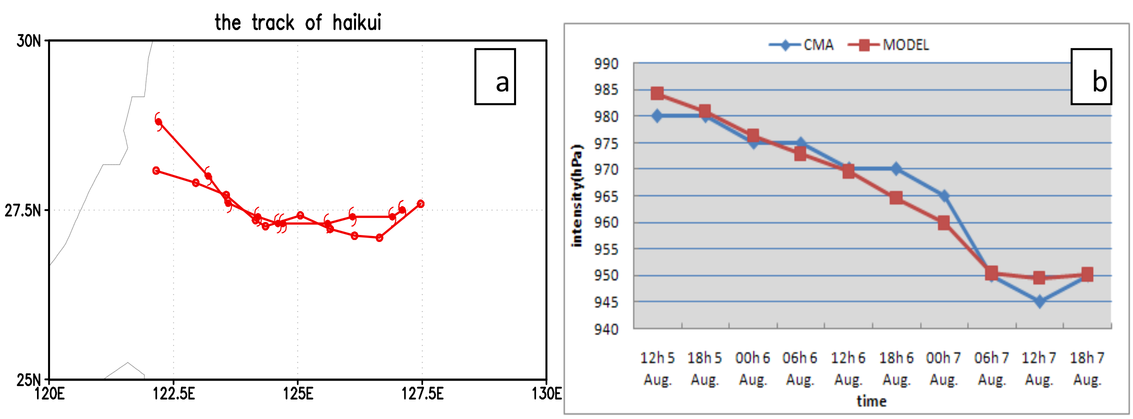
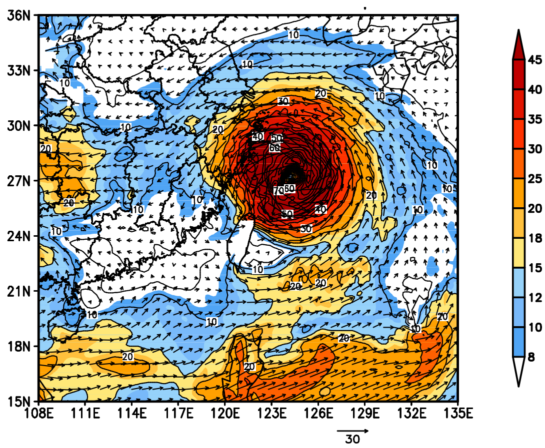


Fig2: Business Intensity and Location According to National Meteorological Center and Path and Intensity of Numerical Modeling a: Path (◉:Business Location;○:Location of Numerical

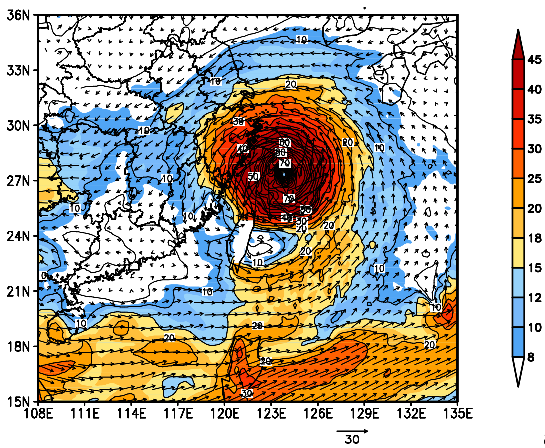
Modeling); b: Intensity (◆:Business Intensity; ■:Intensity of Numerical Modeling, Time in Figure Refer to GMT)

2.2.2 Increasing of transfer of water vapor

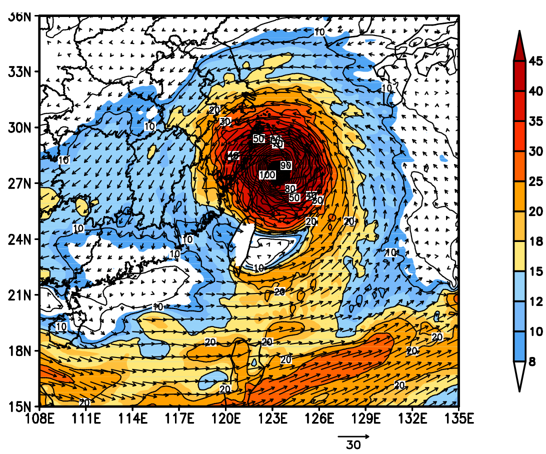
As the water vapor flux and wind vector at 850hPa show that horizontal distribution of Haikui is almost symmetry and the water comes mainly from the south (Figure 3a). There was a conveyer belt as wide strip in south conveyed water vapor to the circulation of Haikui at 0000 UTC, Aug7th(Figure 3b) and at 0600 UTC the input channel connected the circulation completely, as a result, the water in south could fully reach the internal of Haikui through the path (Figure 3a). Although the input channel kept connected the peripheral circulation of Haikui since 1200 UTC, the intensity of water vapor transportation decreased rapidly (Figure 3d). Since 1800 UTC, Aug7th the channel was broken (figure not shown). Water vapor input impacted the variation of intensity of TC directly: from 0000 UTC to 0600 UTC, Aug7th the input increased rapidly, thus provided conditions for rapid strengthening of Haikui.



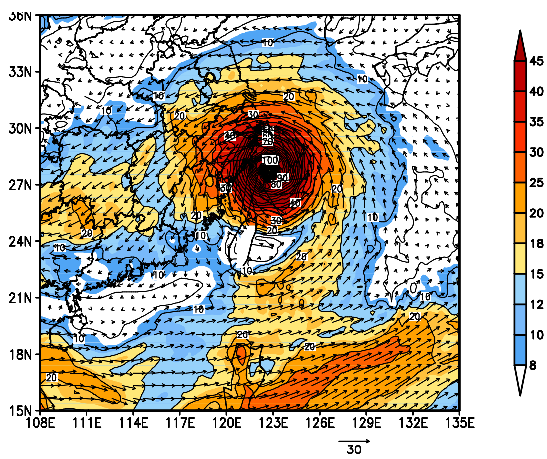
a: 1800 UTC 6 August



b: 0000 UTC 7 Augus



c: 0600 UTC 7 August

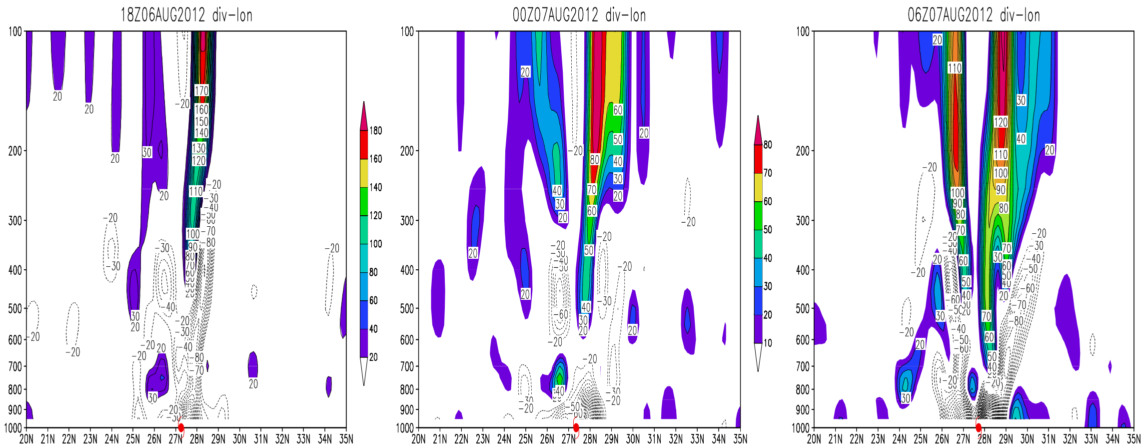


d: 1200 UTC 7 August

Fig3:Water Vapor Flux at 850hPa (Contours and Shadow, $gcm^{-1}hPa^{-1}s^{-1}$) and Wind Vector Changed over Time

2.2.3 Variation of Divergence aloft and Low Altitude

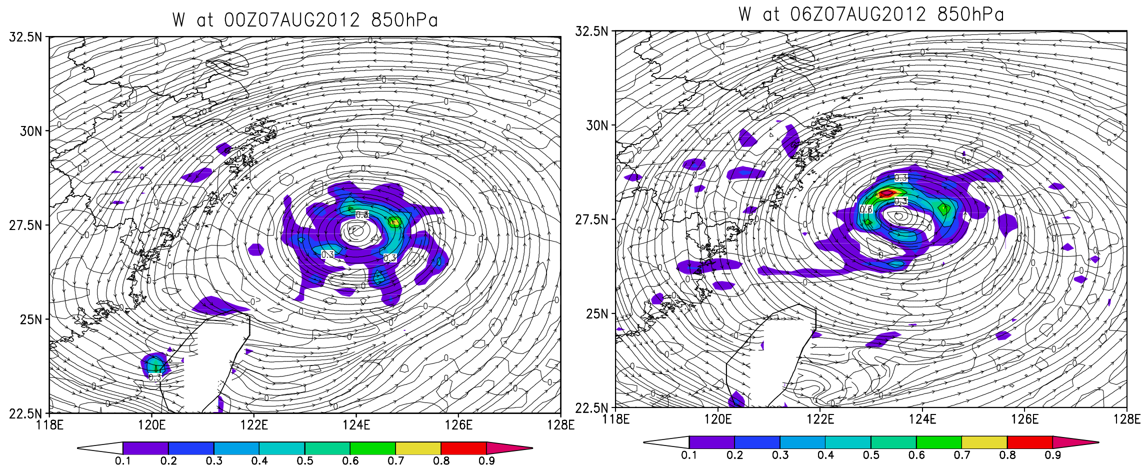
Analyze the time variation of vertical cross section of divergence, which passed the typhoon center and along the longitude, strengthening of Haikui can be seen clearly from variation of upper divergence and lower convergence. Besides, the upper divergence center increased rapidly and moved to the lower, as a result, the intensity of divergence upper and middle increased (Figure 4a、b). The intensity of Haikui continuing strengthened; with wind and upper divergence tended to be symmetric changing over time (Figure 4c). All the variation of large-scale environment was benefit to the strength of Haikui's intensity.



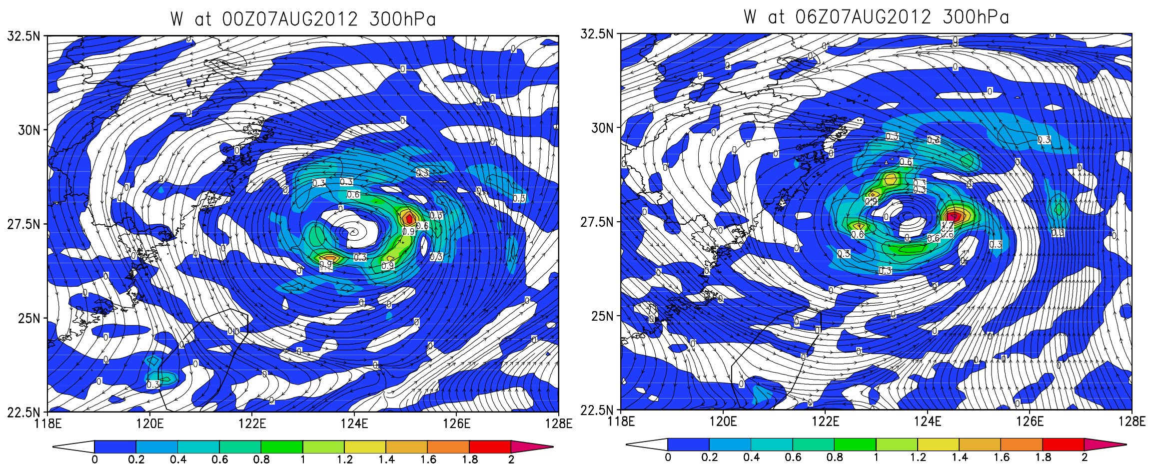
a: 1800 UTC 6 August b: 0000 UTC 7 August c: 0600 UTC 7 August

Fig 4:Time Variation of Vertical Cross Section of Divergence Which Passed the Typhoon Center along the Longitude

2.2.4 Summarization of the Vertical Motion



a: 0000 UTC 7 August at 850hPa b: 0600 UTC 7 August at 850hPa



c: 0000 UTC 7 August at 300hPa d: 0600 UTC 7 August at 300hPa

Fig 5:Vertical Velocity at High and Low Level in the Process of Rapid Strengthening of Intensity

Further we analyze the vertical ascending motion upper and lower. Figure 5 shows the variation of structure of vertical motion before and after the abrupt change of Haikui. There was severe mesoscale convection near the center of the typhoon at 850hPabefore the abrupt change although the destruction was dispersed. The severe vertical ascending motion was mainly in the northeast quadrant (Figure 5a). With the rapid strengthening of the intensity of Haikui, center of the severe convective motion tended to be distributed evenly at 850hPa at 0600 UTC, Aug 7^{th}(Figure 5b). As the time variations of vertical motion at 300hPa clearly show, the severe vertical ascending motions was chiefly in east quadrant before the abrupt change (Figure 5c). With the intensity of Haikui strengthening, severe convective center near the center of the typhoondistributed evenly in the four quadrants near the center of Haikui (Figure 5d). Therefore distribution of severe convective center near the center of the typhoon became uniform from non-uniform was also one of the reasons why the intensity of typhoon rapidly strengthened.

3 DIAGNOSTIC ANALYSIS OF THE HEAVY PRECIPITATION HAIKUI CAUSED

There were two precipitation processes in Zhejiang Province with the influence of Haikui. Take Shipu station near the landfall for example (figure not shown): The former periodof the precipitation from 0000 UTC to 1800 UTC 7 August was heavier and the latter from 2100 UTC 7 to 0600 UTC 8 was relatively weaker. As the path and the precipitation caused by Haikui shows (Figure 6), the rain belt appeared in the northwest-southeast direction, which was consistent with the motion trend of Haikui before and after its landfall. The most severe precipitation area occurred on the right side of its motion direction. The whole precipitation amount was above 100mm generally, the eastern coastal regions within it, especially, about 200mm. The regions impacted by Haikui had a large area rainfall.

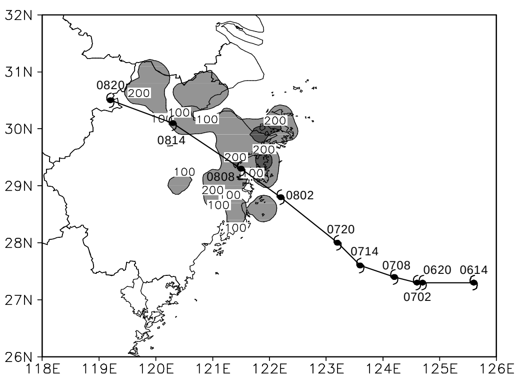


Fig 6:Distribution of Precipitation (mm) and Path

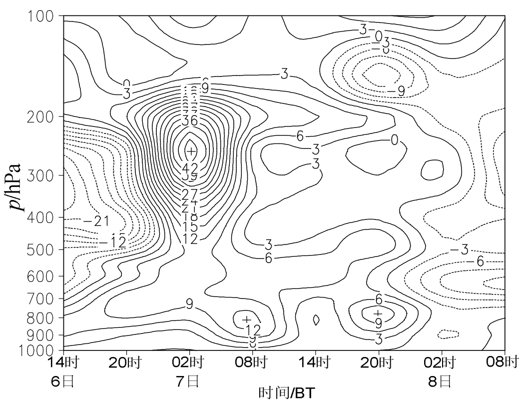


Fig 7:Altitude-Time Profile of Horizontal Spiral over Shipu

3.1 Diagnosis of the Typhoon Rainstorm

The precipitation process caused by Haikui was mainly divided into two sections: the former from 0000 UTC to 1800 UTC 7 August was heavier, the maximum one hour rainfall exceeded 20mm from 0900 UTC to 1200 UTC on Aug7^{th}, especially; while the latter from 2100 UTC 7 to 0600 UTC 8 was relatively weaker, when the heaviest within it occurred at 0000 UTC 7 August. The formation of the heavy rainfall had a close contract with the cyclostrophic wind of the flow. As Figure 7 shows.9 hours before the heavy rainstorms (0000 UTC and 1200 UTC Aug7^{th}),value of the horizontal spiral at 850hPa increased to $12\times10^{-5}hPas^{-2}$and $9\times10^{-5}hPas^{-2}$ respectively with the energy downward from 250hPa. The result show that the energy from upper can make the circulation increased, and then make the intensity of the influx of the storm increase, which is benefit to the development of the upper flow at low altitude and transporting water vapor into the internal of the circulation of Haikui, at last the rainstorm occurred for the benefit of the sufficient energy. Differ in intensity can reflect the differences of rainfall intensity and duration before and after the landfall to some extent. Besides, about 12 hours before the intermittence period of the precipitation, the lower horizontal spiral reduced to zero rapidly. It reflected the positive feedback mechanism between the precipitation and cyclone, in other words, drag of the raindrop and evaporative cooling broke the transportation of the water vapor to the fluid gradually. Therefore, there was an intermittence period of the precipitation during the landfall and it had a response time about 12 hours (at 0600 UTC 7)to the period the horizontal spiral at 850hPa reduced to zero.

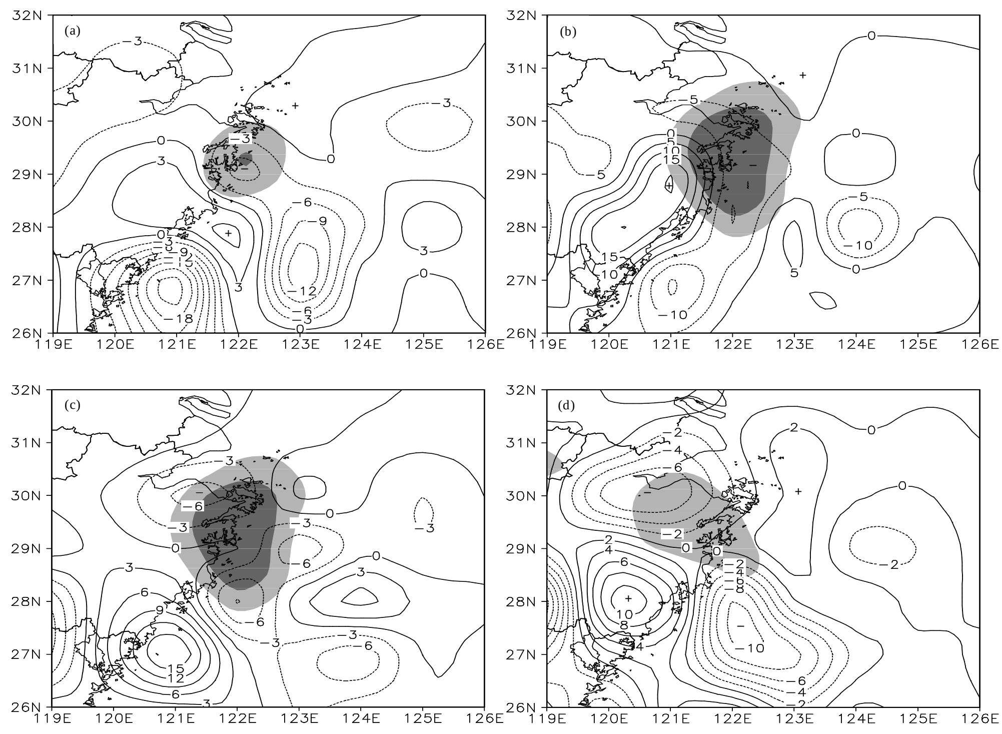


Fig 8:Physical Quantities at 850hPa and Rain Belt 6 Hours Later, Dark and Light Shadow Refer to Precipitation>50、35mm Respectively(a、b:MPV2，PVU；c、d:Wet Q Vector，$10^{-15}hPas^{-3}$ (a: 1800 UTC 6；b、c:0000 UTC 7；d:1800 UTC 7)

3.2 Distribution of the Rain Belt during Landfall

Researches show that the distribution of rain belt can be forecasted by using MPV and wet Q vector. They can be used in this case, too.

As Figure 8 shows, the rain belt mainly distributed in east Zhejiang before the typhoon landfall. The center of the belt was from south Ningbo to north Taizhou near the landing, where the maximum precipitation could exceed 100mm. After the landfall, however, the precipitation region moved towards north, the center to northern Ningbo, as a result, the precipitation decreased to tens of millimeters.

Figure 8a, b show the distribution of the horizontal MPV. It can be seen that the extraordinary rainstorm region was near the zero line of MPV2, where the contours dense and close to the negative region. Energy could be accumulated in this region for the vertical shear of wind here was weaker. The negative region above Shipu at 0600 UTC 7 was consistent with the heavy rainfall belt 6 hours later. That is to say the slantwise isentropic surface and reduce ofthe vertical shear of wind can lead to the rapid strengthening of Haikuiand cause the unstable energy released, which presented as the heavy rainfall finally. At12am, 7th dense of the contours increased near 122°E and the center value of MPV2 increased from 3 to 5 PVU (absolute value), which reflected the wet barocline enhancing as the typhoon moved towards north and combined with the wester lies gradually. Lai Shaojun et al believe the negative value can be seen as the tracing of warm wet air current or activity of vortex and In this case it represents the warm wet air current constantly added to the typhoon as the energy released. As a result, the precipitation continued and increased as the range of the rain belt expanded.

Similarly, value of the wet Q vector along the direction of Haikui was negative, too (Figure 8c), which reflected that the ascending motion was intensive. On left and right side of Haikui the value was positive, which reflected the downdraft. So the positive-negative-positive interphase distribution presented as northeast-southwest direction. This spatial structure was benefit of formation of vertical circulation and led to the development of the convective motion and finally caused the precipitation increased. Besides, compare Figure 8b to c we can see the center of the wet Q vector is northern to the center of the precipitation region, that is to say the effect of its representation is weak. However, the negative region of it was consistent with the range of the rain belt.

MPV and wet Q vector can both be used to forecast precipitation before the landfall, but only the latter can be used to reflect the rainfall after it (Figure 8d). There presented two positive and negative regions around the center of Haikui on 1800 UTC 7 August and the structure was clearer than it was 6 hours before. Research shows the interaction between wet Q vector and topography was tend to inspire the development of mesoscale surface system and the formation of the secondary circulation. Therefore the constant of the banded structure of the wet Q vector forecasted the precipitation after the landfall. Besides, comparing Figure 8C to d we can see that although the wet Q vector can reflect the range of the rainstorm clearly, it can't represent the differences of intensity between the precipitations before and after the landfall respectively.

4. Summary

4.1 Haikui(1211) is an intensified Typhoon, but the remarkable difference of its intensity determination between CMA, and RSMC Tokyo as well as JTWC is presented. The long lasting strong wind is also detected from the data derived from the stations along strip coast, including both the automatic stations and inner island stations. The gust with the intensity above 13 grade has been lasting for 26 hours during the period. The maximum wind is 46.9 ms-1, and 39.4 ms-1 as well as 36.8 ms^{-1} respectively at Dongji station, and Dachen station as well as Shippu station. Haikui has matched the standard of the strong typhoon due to the observed data, and the intensity determination by CMA is reliable accordingly. The result indicates that the determination of typhoon grade is not enough to depend on the using the Dvorak technique and the detective data from stations should be referred more.

4.2 The non-hydrostatic WRF (Weather Research and Forecast) model was used to study the rapid intensification of Typhoon Haikui (1211) over the offshore of China. After the well simulation on the intensity change and track, the model output was further analyzed to detect the mechanism for the rapid intensity change Typhoon Haikui. The results indicated, the remarkable increase of low-level moisture transportation towards inner core, the favorable large-scale background field with low-level convergence and high-level divergence play a key role for the rapid intensification of Typhoon Haikui, and the later can be an indicator for the rapid intensity change of Typhoon Haikui with about 6 hour advance.

4.3 Under the condition of unstable stratification, development of typhoon conducive to the energy accumulation near the center, prompting the lower airflow enhancement and carrying rich water vapor transported to eastern Zhejiang coastal, formed the rainstorm before landfall, and maintaining of part of the water vapor cased the heavy rain after it. The evolution of the top level spiral degrees in strong wind zone of typhoon prompting changes of low level horizontal spiral degrees by influencing the typhoon intensity, the process of increasing of 850hPa and decreasing to zero give us a signal of the formation and weaken of the heavy rain, with a 9 to 12 hours period in advance. And the center threshold showed the differences of precipitation intensity and duration to a certain extent. Horizontal component of Moist Potential Vorticity (MPV) and wet vector can predict the distribution of rain-band before landfall and the effect of the former is better as the center of the latter northern to the center of the precipitation region. Wet Q vector can be used to reflect the rainfall after the landfall and reflect the range of the rainstorm clearly, but it can’t represent the differences of intensity of the precipitations before and after the landfall respectively.

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