# 10A.3 Mesoscale Features of Tropical Cyclone Formations Associated with the Trade Wind Surges in the Western North Pacific

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## 1. INTRODUCTION

Ritchie and Holland (1999) classified the large scale circulations during tropical cyclone (TC) formation in the western North Pacific (WNP) into five patterns: easterly waves, monsoon trough, monsoon gyre, monsoon shear and Rossby wave dispersion. They also pointed out that mesoscale convective systems (MCSs) play an important role during TC formation. The interactions between the large scale environment and the evolution of MCSs during TC formation remain as an interesting subject to explore. Besides, the vertical development of initial disturbances is also an important issue. Whether the vertical development is a top-down process (Simpson et al. 1997, Bister and Emanuel 1997) or a bottom-up process (Möller and Montgomery 2000, Enagonio and Montgomery 2001) is worth of great attention.

In this study, we focus on the tropical cyclone formation accompanied with the low level trade wind surges (Lee 1986, Lee and Lee 2002). The evolution of MCSs during the formation stage is investigated by using high spatial resolution satellite data, including QuikSCAT 10 m wind and TMI/TRMM rainwater distribution. To study the interaction between the environmental low-level forcing and the evolution of MCSs, Weather Research and Forecasting model version 2.2 (WRF) is used to simulate the formation process of Bolaven (2005). Model simulations are used to identify the possible role that the MCSs and the low level environmental forcing might have played during the formation of Bolaven.

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## 2. DATA ANALYSIS

It has to be noted that the tropical cyclone formation is a continuous process (Ooyama 1982), and there is no specific formation point. However, for the convenience of discussion, we used tropical cyclone formation alert (TCFA) issued by the Joint Typhoon Warning Center (JTWC) as the formation reference point. The system should have been undergoing the formation process when JTWC issued the TCFA.

The TCFA for Bolaven (2005) was issued at 1200 UTC 13 Nov 2005. During the formation period of Bolaven, the trade wind surges with maxinum wind speed over 12 $ms^{-1}$ were observed over a large domain to the north of the disturbance center at 850 ~ 925 hPa since 48 hours before TCFA. From the three hourly enhanced IR images (Fig. 1), a strong east-west oriented convection belt is observed at 132° ~ 134°E, 7° ~ 9°N at 1125 UTC 11 Nov or 48.5 hours before TCFA. The IR images also show that some strong convective cells are embeded in the convection belt. The convection belt extends southwestward at 17 ~ 20 UTC 11 Nov. Fig. 2a shows the QuikSCAT 10 m wind at 1528 UTC 11 Nov (45 hours before TCFA). The trade wind is located to the north of a broad area with cyclonic circulation. The TMI/TRMM rainwater distribution (Fig. 2b) at 1302 UTC 13 Nov (1 hour after TCFA) shows that a belt structure of rainwater extends from the northwest of the disturbance center to the northeast of the disturbance center. Several mesoscale convective cells are observed to be embaded inside this belt. Bolaven intensifies greatly after reaching TS intensity. The incipient disturbance intensifies to TS intensity at 0600 UTC 14 Nov only 18 hours after TCFA. JMA surface weather maps show that at latitude about 25° to the north of the incipient disturbance, there is a high pressure system moving eastward during the formation period (0000 UTC 13 Nov ~ 1200 UTC 14 Nov) as illustrated in Fig. 3.

All TC formations accompanied with trade wind surges in 2000 ~ 2005 are investigated using same satellite data set and JMA surface weather maps. Results show that 70 % of all TC formations accompanied with the trade wind surges occur in the late season (Oct. ~ Dec.) and most of trade wind surges are related to a eastward moving high pressure system. After examining all trade wind surge TC formations, a conceptual model is proposed to describe the contributions of synoptic environment and MCSs in this kind of TC formation process (Fig. 4). At the first stage (48 ~ 24 hours before TCFA, Fig. 4a), a strong vorticity belt which is located to the south edge of the strong trade winds and north of the disturbance center, extends southwestward to the northwest quadrant of a broad, weak cyclonic circulation area. Through the convergence effect of flow pattern and the advection effect from the vorticity belt, a disturbance with smaller spacial scale but stronger circulation starts to form at the northwestern part of the weak cyclonic circulation area at this stage. At the second stage (24 hours before TCFA to TCFA, Fig. 4b), the increased southerly flow associated with the developing incipient vortex merges with the strong trade winds to form a convergence zone and a sharp vorticity belt with MCSs. The vorticity patches associated with MCS's are then wrapped around following the cyclonic circulation to merge into the vortex center, resulting in the further developing of the incipient vortex and the formation of TC (after TCFA, Fig. 4c).

## 3. MODEL SIMULATION AND ANALYSIS

The WRF model is used to simulate Bolaven (2005) which is accompanied with trade wind surges. The model uses high grid spacial with 60, 20 and 4 km resolution. In the vertical layers, there are 31 σ levels. The model initial time is 48 hrs before TCFA (1200 UTC 11 Nov 2005). Results show that model can simulate the track and intensity of Bolaven during formation period well as shown in Fig. 5. The trade wind surges in this case is also well-simulated as shown in Fig. 6. The strong trade wind ( > 16 $ms^{-1}$) is located at 850 ~ 900 hPa and extends 10 degrees to north of the disturbance center at 36 model hours (12 hours before TCFA).

To illustrate the meso-scale evolution, Fig. 7 shows the potential vorticity (PV) and wind field at 500, 700 and 850 hPa at a 6° X 6° area around the low level disturbance center at 18 ~ 24 model hours (30 ~ 24 hours before TCFA). During this period, a east-west oriented PV belt is located to the cyclonic shear side (south side) of trade winds and to the north of a weak cyclonic circulation area. Several mesoscale high PV patches form in this PV belt at 850 hPa and move into the center region of the disturbance following the cyclonic circulation. During these 6 hours, the western edge of the PV belt starts to bend southward resulting in a southwestward extension of the PV belt. The cyclonic circulation also contract from a broad structure to a smaller but stronger disturbance located at the northwest part of the circulation during this period. The center of the disturbance tilts toward the west vertically but the tilting presents only below 500 hPa. At 40 ~ 42 model hours (Fig. 8) the PV and cyclonic circulation of the disturbance appear to be stronger than those shown in Fig. 7. During this period, the cyclonic circulation at 700 hPa have also intensified. At 850 hPa, some strong PV patches form near the circulation center. These PV patches then rotate, coil, lengthen and merge to form a stronger PV patch. Through the merging process, the low level PV of the whole system intensifies. Stronger PV indicates that the vertical penetration depth of the system also increases. In the current situation, the shag PV associated with the system increases initially at the low levels and then extends to upper levels at late stage. The cyclonic circulation at 500 hPa does not set up until after 60 ~ 72 model hours ( 12 ~ 24 hours after TCFA, Fig. 9 ) . The vertical structure also become more vertically during this 12 hours.

The merging process of MCSs can also be observed from the enhanced IR images. Figure 10 shows one-hourly enhanced IR images from 9.5 to 4.5 hours before TCFA. At 9.5 hours before TCFA, there are some MCSs formed around 130°E, 7°N (bright red area). The horizontal scale of these MCSs is about 1°~ 4°. There are also some extreme convective cells with 10~50 km horizontal scale (black area) embed in these MCSs. These MCSs and extreme convective cells then merging to form stronger MCSs. The convection significantly intensifies after the merging process.

The average of surface heat flux at a 3° X 3° area around the low level disturbance center (Fig. 11) shows that the surface heat flux remains small in the first 60 model hours of model simulation. The surface heat flux increase significantly after 60 model hours when the cyclonic circulation of the vortex become stronger.

## 4. CONCLUSION AND DISCUSSION

This study investigates the contribution of mesoscale convective systems (MCSs) to the intensification of the low-level vorticity of the incipient disturbance during formation under trade wind surges. High spatial resolution satellite data and WRF model are used to clarify the interaction between the large-scale environment and MCSs, and the role played by MCSs during TC formation.

Simulation results show that WRF model can simulate the evolution of MCSs and the formation process of this kind of TC well. Under this strong low level external forcing [trade wind surge, maximum in 850 ~ 900 hPa], a vorticity belt is formed in the cyclonic shear side (south edge) of the strong trade wind. Some short lifetime (~ 5 hours) mesoscale cells are generated and embedded in the vorticity belt. When the vorticity belt bending and moving toward southwestward to the northwest quadrant of a weak cyclonic circulation region. A stronger disturbance may form in this area. Without too much negative effect, the disturbance intensifies continually and generates lots of MCSs in the center area of disturbance. Those MCSs then coil, lengthen, and merge to each other. Through these processes, MCSs concentrate background vorticity to the disturbance. The low level PV of disturbance increased and begin to penetrate toward upper level. The mid-level vortex then be generated and the vertical structure of TC become vertically. Those results consistent with the bottom-up theory (Möller and Montgomery 2000, Enagonio and Montgomery 2001) and vortical hot tower (VHT) phenomenon in Montgomery et al. (2006).

The average of surface heat flux shows that the process of merging of MCSs stays in stochastic stage, which means the time and location of MCSs' generation occurs randomly. However, the formations of this kind TCs are triggered by a unique synoptic low level forcing. Under this forcing, TC tends to formation in a particular area and with particular mesoscale features. Therefore, quasi deterministic stage can be established to define this phenomenon: when large synoptic forcing is build up, tropical cyclone stands a good chance to be formatted with typical MCSs features. Detail investigate of non-formation TCs is required to help understanding the mechanism and criteria of this kind of TC formation.

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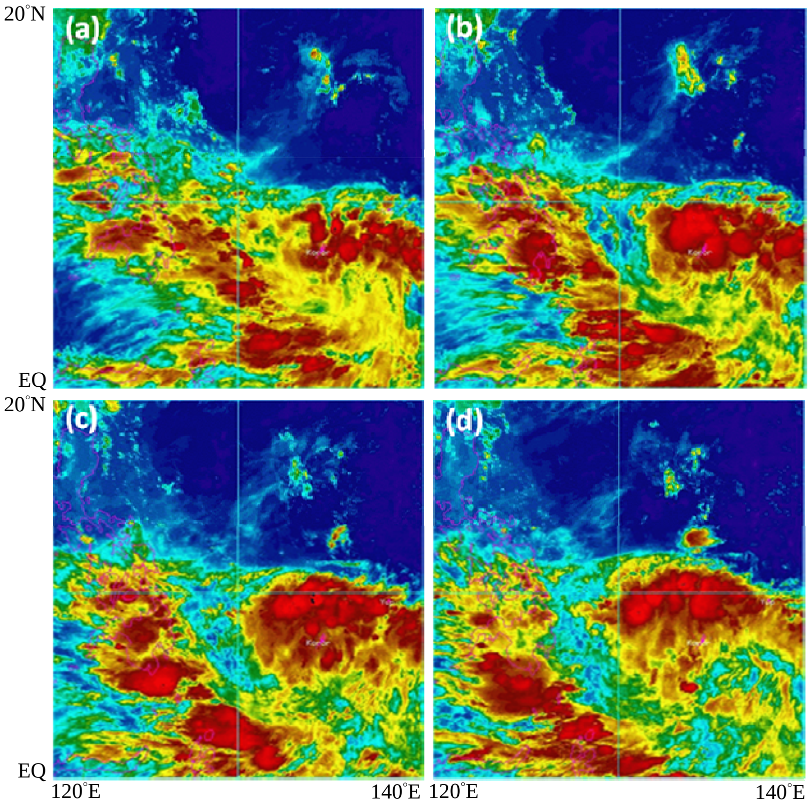


FIGURE 1 Three-hourly GOES-9 enhanced IR images, over the domain 120°E~140°E, 0°N~ 20°N at (a) 1125 UTC (48.5 hours before TCFA), (b) 1425 UTC, (c) 1725 UTC and (d) 2025 UTC 11 Nov 2005.

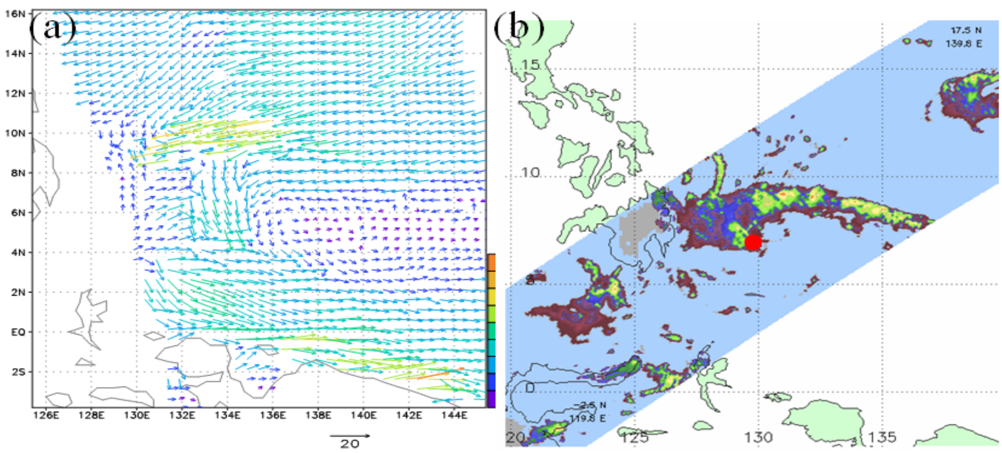


FIGURE 2 (a)QuikSCAT 10 m wind field at 1528 UTC 11 Nov 2005. (b) TMI/TRMM rainwater distribution at 1302 UTC 13 Nov 2005. Red dot represents the JTWC best track location.

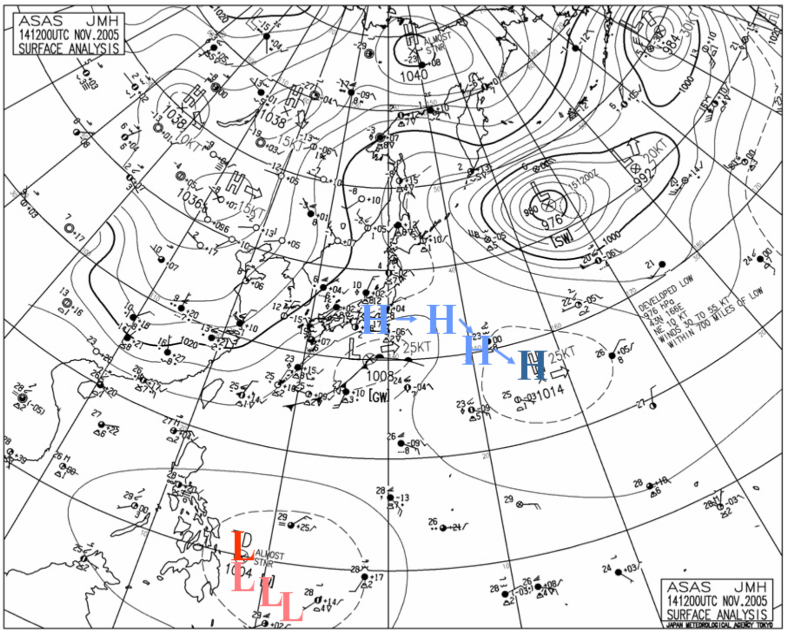


FIGURE 3 JMA surface weather map at 1200 UTC 14 Nov 2005. Dark mark indicated high and low pressure system at this time. Lighter mark indicated the location of high and low pressure system 12, 24 and 36 hours before.

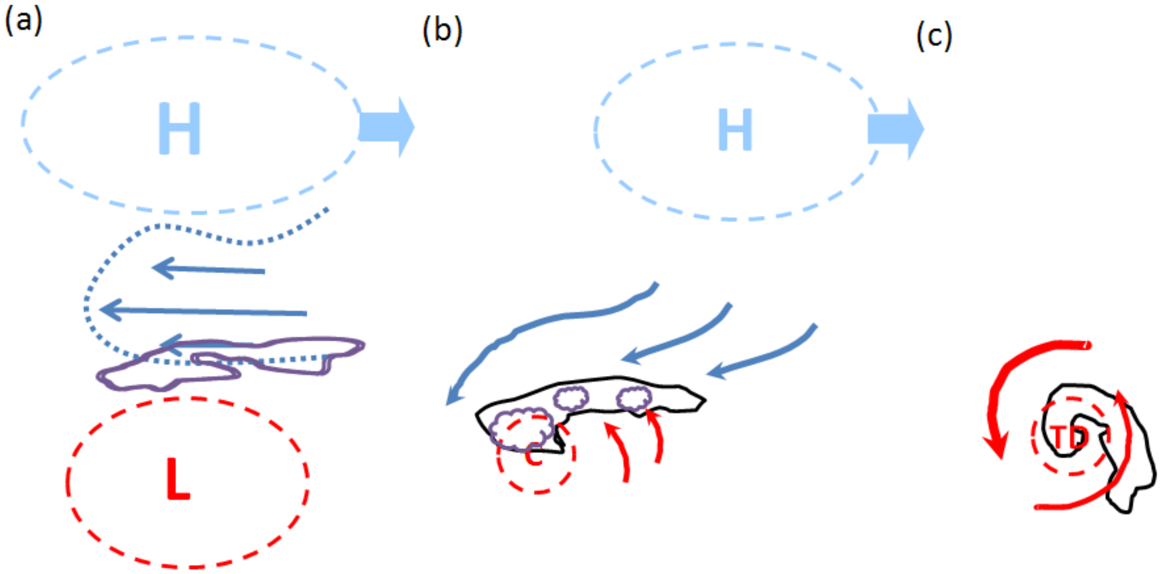


FIGURE 4 Conceptual model of tropical cyclone formation process accompanied with trade wind surges. Dash line indicates the high and low pressure system. Dot line represents the strong trade wind area. Solid ling indicates the vorticity (rainwater) distribution. Arrows represent the flow patterns.

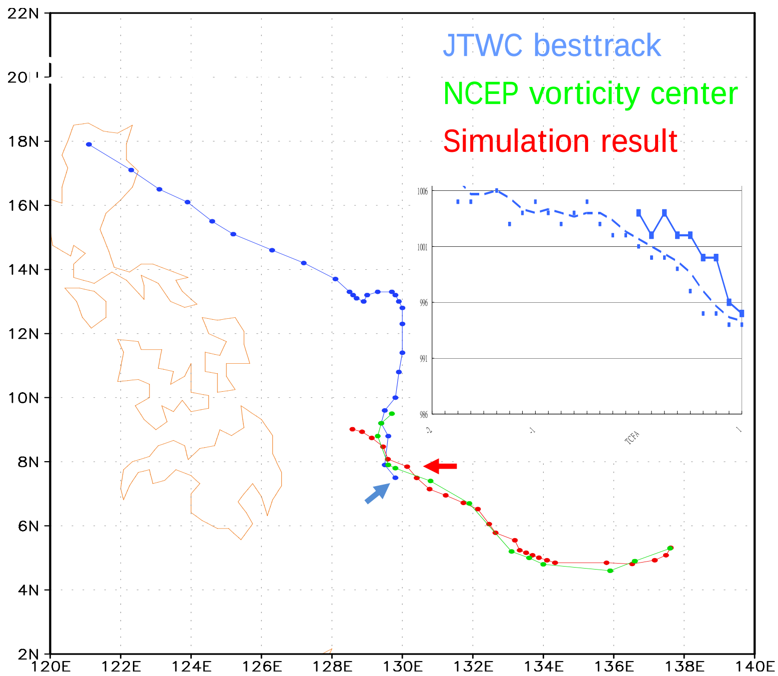


FIGURE 5 WRF simulation results of Bolaven (2005). Arrows represent the TCFA location.

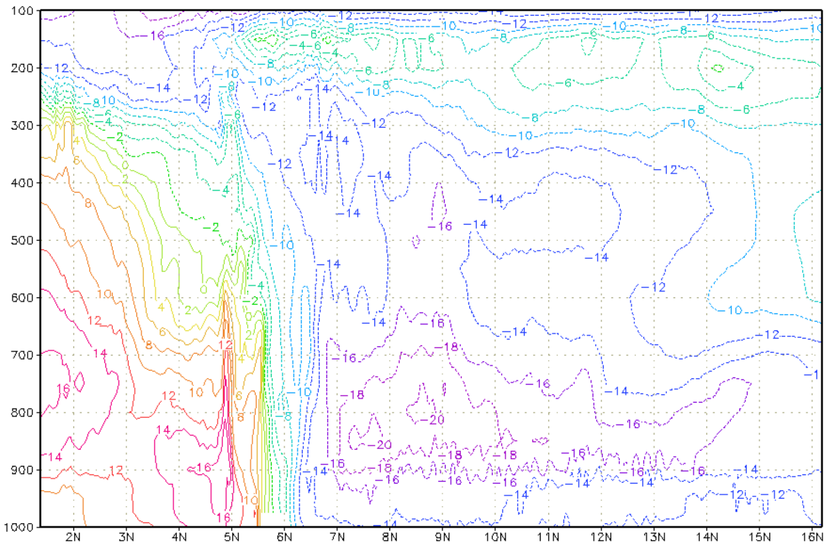


FIGURE 6 North-south vertical cross-section of zonal wind component at 132.5°E (disturbance center) at 36 model hours. (unit= $ms^{-1}$)

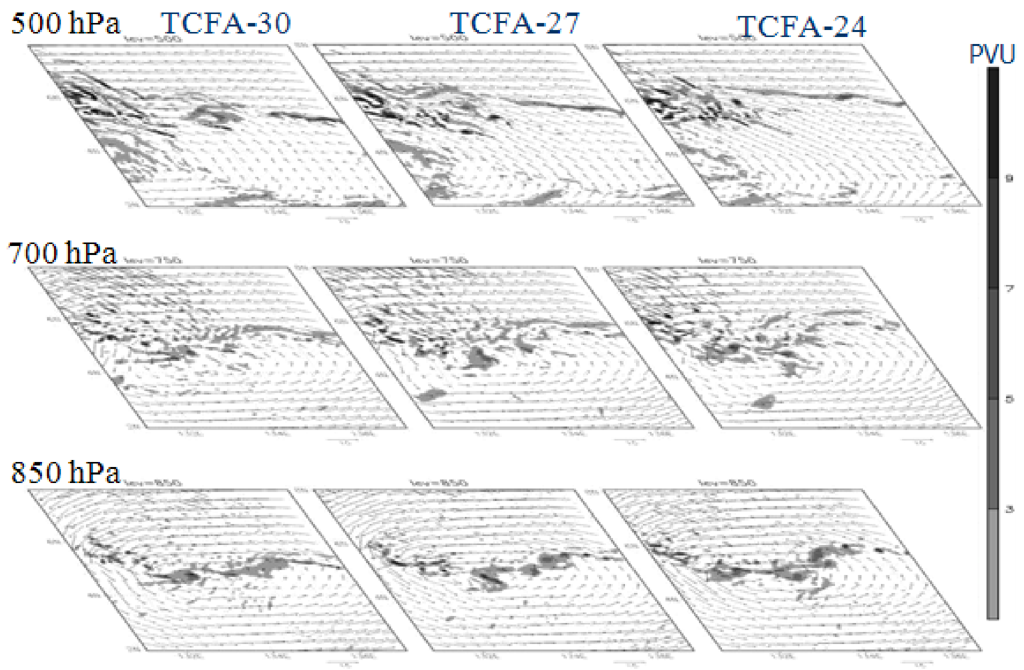


FIGURE 7 PV and wind field at 6°  x 6°  area around low level disturbance center, from bottom to top are level 500, 700 and 850 hPa, form left to right are TCFA-30hr, TCFA-27hr and TCFA-24hr. (shaded: PV, unit= PVU).

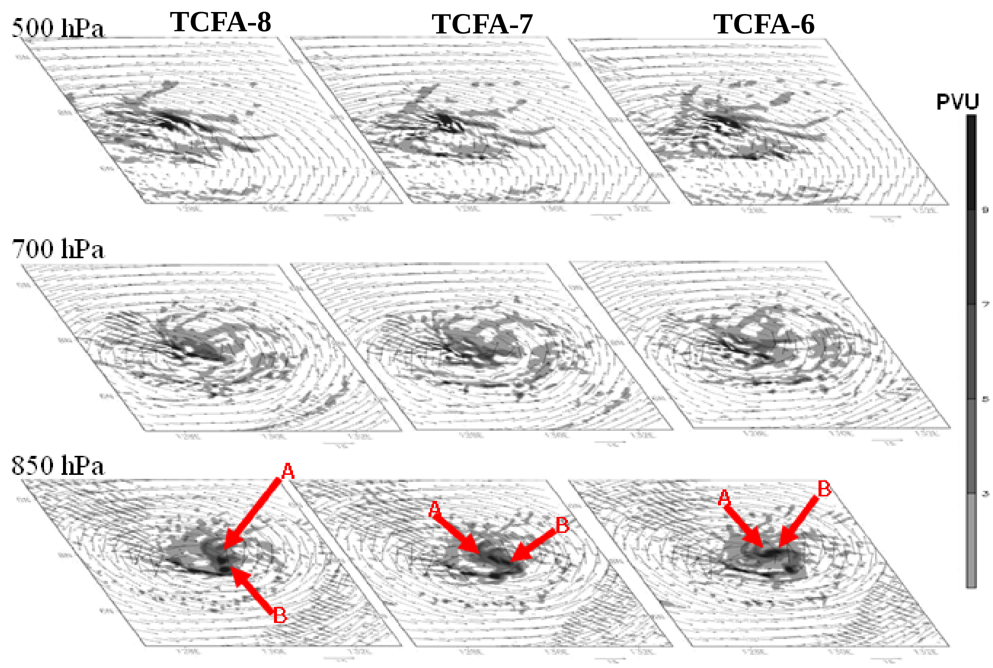


FIGURE 8 Same as figure 6, except at TCFA-8hr, TCFA-7hr and TCFA-6hr. (shaded: PV, unit= PVU), A, B indicated single PV maximum cell.

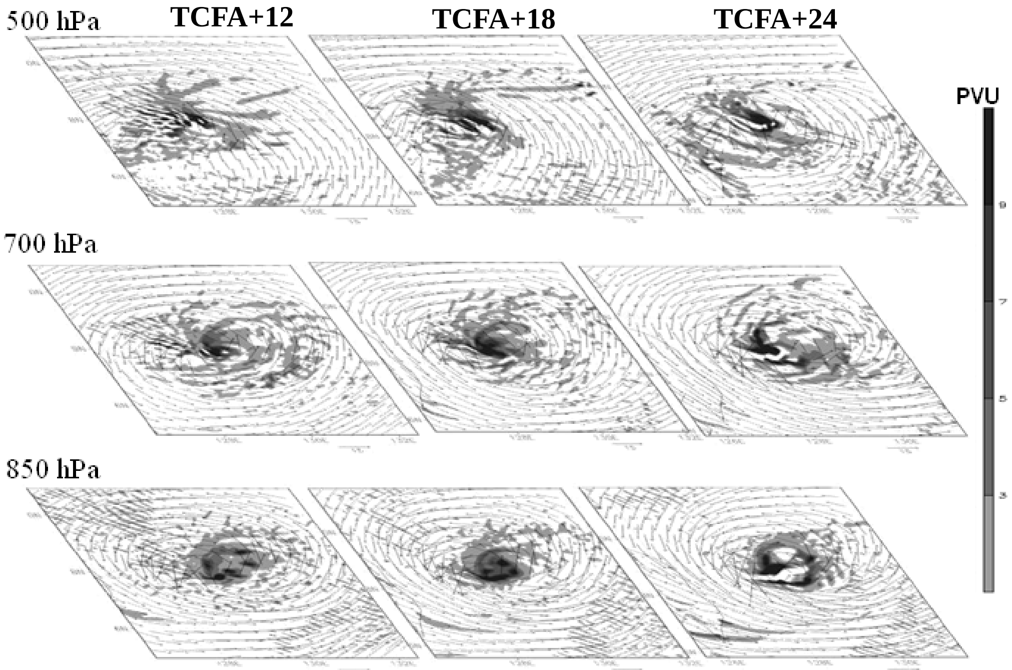


FIGURE 9 Same as figure 6, except at TCFA+12hr, TCFA+18hr and TCFA+24hr. (shaded: PV, unit= PVU).

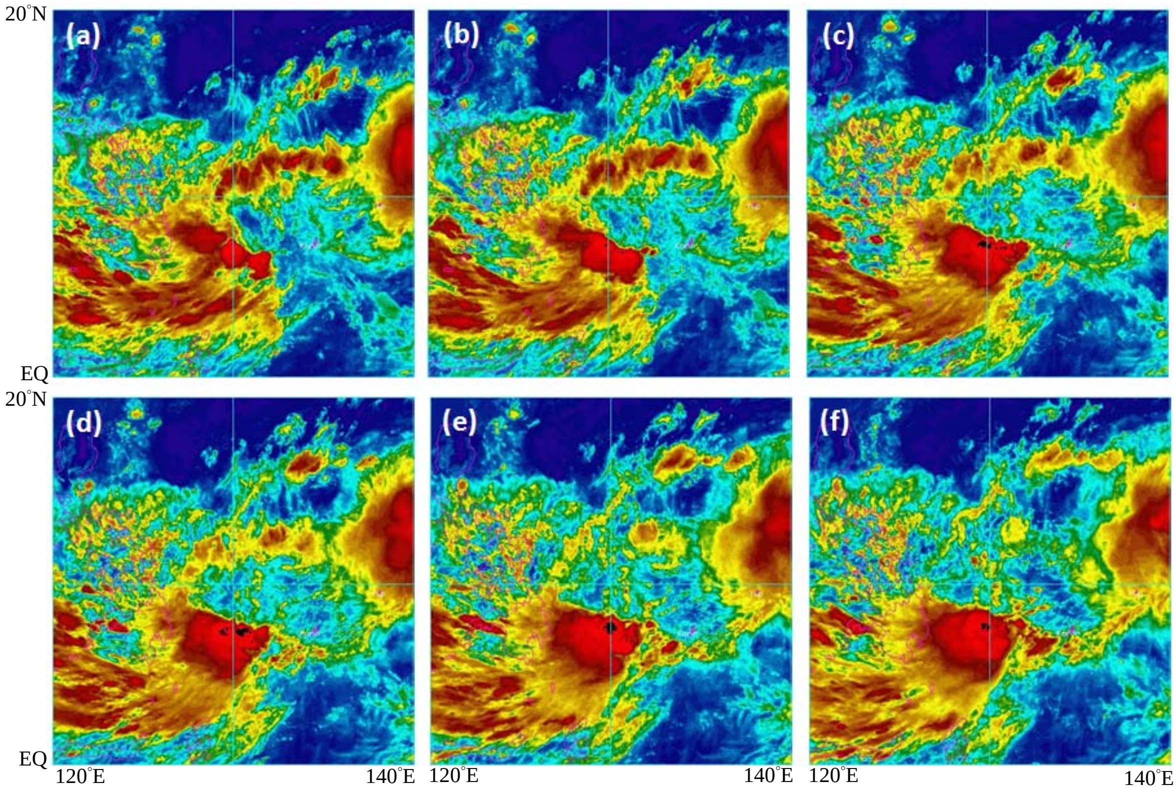


FIGURE 10 Hourly GOES-9 enhanced IR image, over the domain 120°E~140°E, 0°N~ 20°N at (a) 0225 UTC 13 Nov 2005 (9.5 hours before TCFA), (b) 0325 UTC 13 Nov 2005, (c) 0449 UTC 13 Nov 2005, (d) 0525 UTC 13 Nov 2005, (e) 0225 UTC 13 Nov 2005 and (f) 0625 UTC 13 Nov 2005.

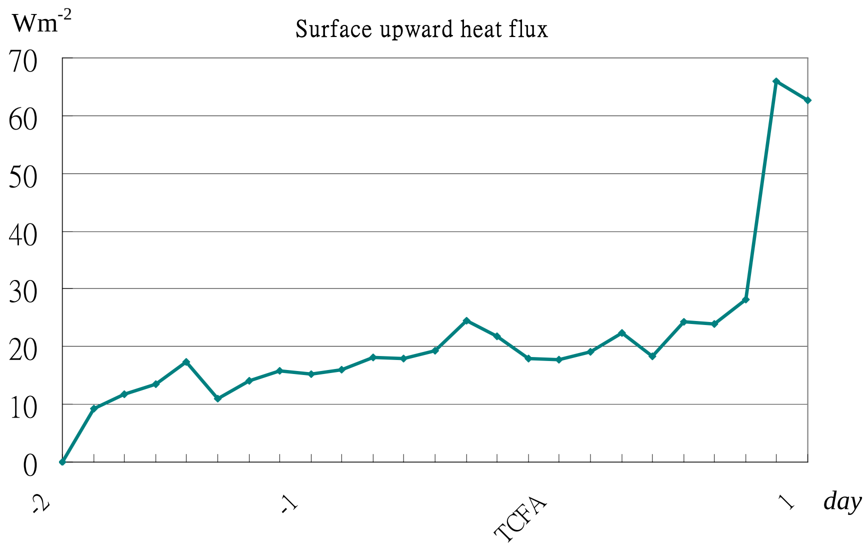


FIGURE 11 Area average of surface heat exchange at 3° x 3° area around the tropical disturbance center. (Unit= $Wm^{-2}$).