The mechanisms of the evolution of a Mei-Yu frontal rain band revealed from multiple Doppler/Polarimetric radar observation in the torrential rain event on June 11, 2012

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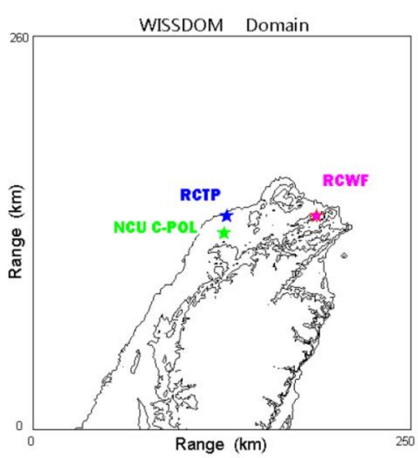
1. Introduction

This article studies the Mei-Yu front in time from 2000 LST to 2400 LST on 11 June 2012. The system brought about 500 mm rainfall to northern Taiwan in 10 hours. The numerical weather predictions were not able to forecast the movement of the rain band and the extreme rainfall. The rainband moved fast from the south of China to northern Taiwan, but the movement of system was almost stationary and brought the most intense rainfall after landing. The system was divided and examined in three different stages. Through a variational multiple Doppler wind synthesis algorithm by Liou et al. (2012), three dimensional winds at different time are retrieved. The wind fields were further applied to retrieve the perturbation of pressure and temperature fields. The changes of the vertical motion and the new cell propagation were investigated in detail. The interactions between the low level jet, the Mei-Yu front and the high terrain was also discussed.

2. Introduction of method and data resource

The technique of Wind Synthesis System of Doppler Method (WISSDOM) from Liou et al. (2012) is used in the study. WISSDOM allows to include multiple radar radial wind by variational algorithm. By satisfying a series of constraints as weak constraint, the 3-D wind fields are retrieved. The method include the immersed boundary method (Tseng and Ferziger 2003) to incorporate to take into account the topographic forcing, so the wind fields can be synthesized over complex terrain. After obtaining 3-D wind components, thermodynamic fields are retrieved based on GC78.

We use three radar data at northern Taiwan that are S-band RCWF, C-band RCTP and NCU C-POL from 2000 LST to 2400 LST on 11th June 2012 (Figure1). Radar data quality control is used by RAKIT system developed by NCU radar lab.



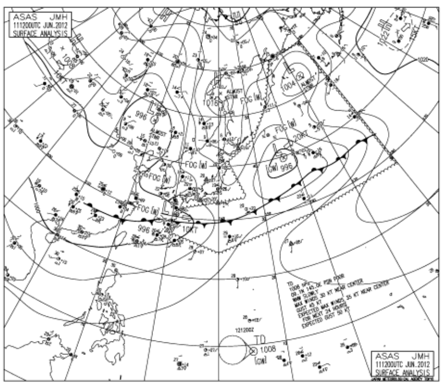
Domain：	250km*260km (1km*1km)
Vertical：	0.5km~14.5km (0.5km)
Data：	RCWF、RCTP、NCU-CPOL
Time：	2012.06.11. 2000LST ~2012.06.11. 2400LST (30min)

Figure 1. Domain for WISSDOM in the study (Left).
The list is data domain setting, data resource and time of the study. (Right)

3. Overview of the torrential rain event and environmental of the mei-yu front

The JMA weather surface map (Figure 2a) is showed at 1200 UTC (2000 LST) June 11. Mei-Yu front was very close to the northern Taiwan. The satellite image (Figure 2b) shows that the front system covers from south of China to Japan at June 11 1200 UTC (2000 LST). This indicates that the environment condition is unstable, and it has a better chance for the development of convection. There was a mesoscale convective system at northern Taiwan that was the main system for the torrential rainfall. As the frontal system on the 11 June near the northern Taiwan, the environment is very suitable for development, and there is a strong flux of water vapor environment, continuous heavy rain caused flooding throughout the disaster in northern Taiwan.

(a)



(b)

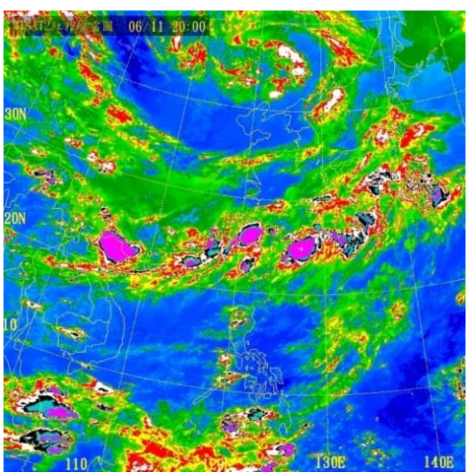
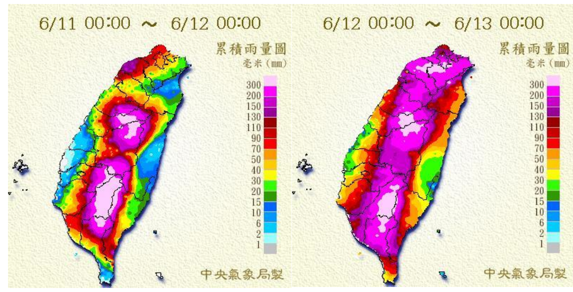


Figure 2.(a) The surface map at 1200 UTC June 11, 2012, before the heavy rainfall. (b) The infrared image at 2000 LST (1200UTC)

From June 11 to June 12, there was more than rainfall 300 mm per day in Taiwan (Figure 3). The rainfall in 10 hours displays the maximum rainfall center at north Taiwan. The hourly rainfall in Yangmei station shows 123 mm hr^{-1} at that night, and the heavy rain keeps for 10 hours.

(a)



(b)

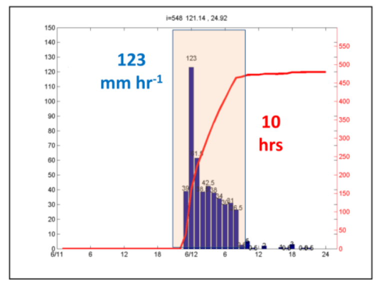


Figure 3. (a) The accumulated rainfall from June 11 to June 12. (b) The hourly rainfall at Yangmei station.

4. Different structure of the mei-yu front in three stages

During the Mei-Yu front passed through north of Taiwan, there were three stage that represent different states of rain band (Figure 4). According to the system moving speed, three different stages were defined. In this study, nine results of wind synthesis is obtained from 2000LST to 2400LST 11th June 2012 in figure 1. The first stage is the rain band which has high speed from south of China to north of Taiwan about 15km hr^{-1}. Next stage is from 2100 LST to 2200 LST, and the system was going to landing on Taiwan. The system is stronger than first stage and then landing at the third stage. That is stationary movement in stage three. It is an important stage of the rain band, which was strong and stayed at the north of Taiwan. That is why the torrential rainfall concentrated at north of Taiwan.

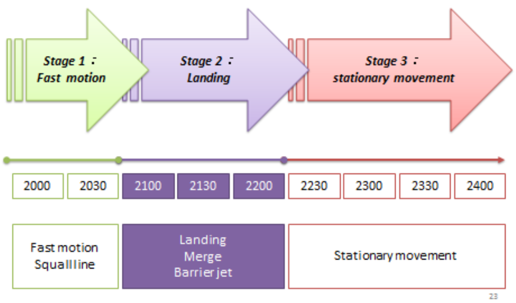


Figure 4.Three stage with 9 times in the heavy rainfall event.

4.1 ***The first stage: Fast motion***

At 2000 LST, the system approached to the coast of the northern Taiwan, the wind field has an environmental convergence with northwest wind and southwest wind at the north of Taiwan. It existed a barrier jet for over 20 m s^{-1}, which appeared at the height of 1 km, and consistent with TAMEX observation experiment in Li and Chen (1997). After half an hour (at 2030 LST), when the system was even closer to Taiwan, a barrier jet over the northern coast of Taiwan becomes wider. In addition, the wind speed is greater than 20 m s^{-1} at high level. The southwest side of the wind component climb up to the upper level, and the kinetic energy is transited from low level, resulting in the wind speed exceeds 20 m s^{-1} in strong wind areas.

By the cross-sectional structure, the system is similar as a squall line in mid-latitude. Figure 5 shows the rainband have leading convective region that is 30 dBZ reflectively higher than 10 km and stratiform region. The wind field stream lines have rear-to-front with downdraft at low level and front-to-rear with updraft at midlevel in leading convective region. The maximum vertical velocity is about 5 m s^{-1} at 7 km. The cross section of thermodynamic retrieval in the rainband was showed in figure 5e and 5f. Figure 5 (e) has low pressure at mid-level about high of 2 km; figure 5 (f) illustrates a cold pool under the leading convective region. The structure of the system represent the squall line feature at this stage.

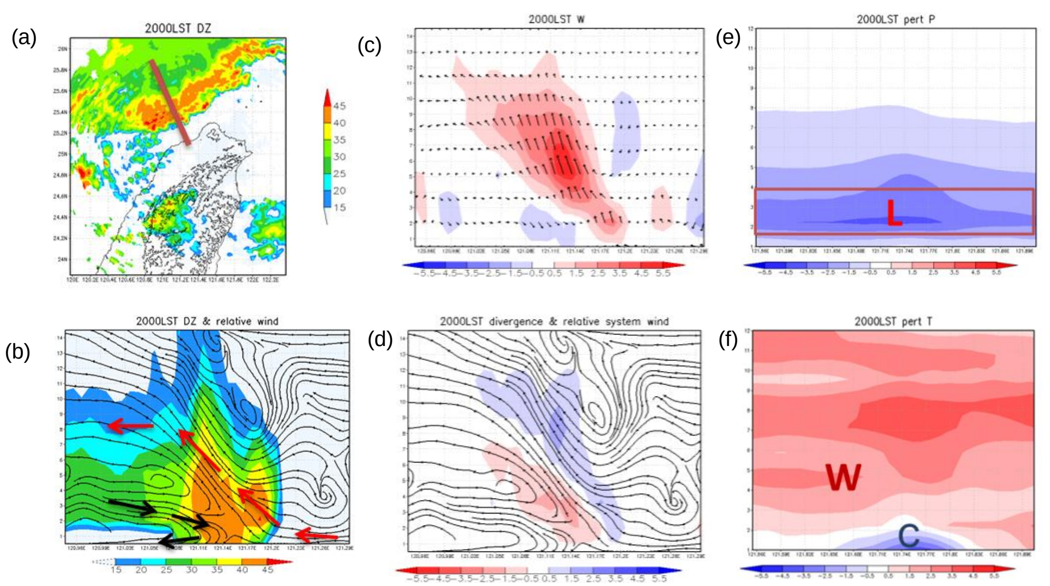


Figure 5.At 2000LST, (a) The line display the cross section of (b), (c), (d), (e), (f). (b)Radar reflectivity(shaded) and wind field(stream line), (c) vertical velocity(shaded) and wind field(vector), (d) divergence(shaded), (e) thermal retrived perssure pertabation, (f) thermal retrived temperature pertabation.

4.2 *The second stage: Landing*

The second stage is the landing stage, and the squall line had some difference features from the first stage. Before landing, the squall line is closer to north of Taiwan and there is a cell at southwest of the leading convective rainband. Figure 6 shows the cell (black circle) grew up and moved to the northeast, and then merged with the rainband from 2100 LST to 2200 LST. From the analysis of wind direction and vertical velocity, it can be found that in this period, the feature has become a stronger reflectivity than before cell merging at 2200 LST.

The vertical cross sections (Figure 7) demonstrate the process of the cell merging that vertical velocity from WISSDOM is about 4 m s^{-1} at 2200 LST. It means the squall line strengthen by the cell merging process before landing. That is one of the reason that heavy rain fall happened in north of Taiwan.

4.3 *The third stage: Stationary movement*

After second stage, the merging system landed on north of Taiwan and the heavy rainfall started. The radar reflectivity (Figure 8) of over 30 dBZ still stays near Taoyuan, Hsinchu and Taipei for more 2 hours. In figure 8, the reflectivity shows that the system stays in north of Taiwan. Reflectivity are weaker at 2300 LST and 2400 LST than others times. The environmental southwest wind converged to the system and triggered new convective cell at south edge of system from positive vertical velocity pattern in figure 9. The horizontal wind field has a maximum wind speed about 25 m s^{-1} at 2 km height. The intensity and the location of the barrier jet (figure 10) is similar to the case study in Li and Chen (1998).

So in this stage, the strong southwestern wind and rain band movement are different direction and trigger new cell at south of rain band. In addition, a mountain exists at the east of rain band and prevents the system to pass through it. In the result, the systems keep at the north of Taiwan then to have heavy rainfall in the stage. (Figure 11)

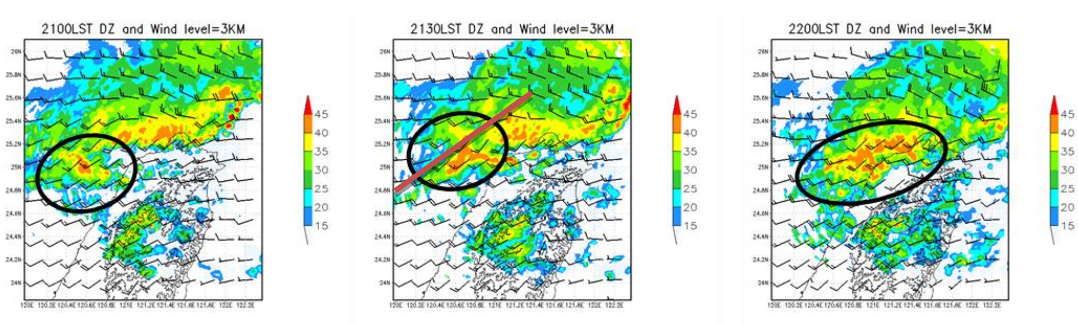


Figure 6. The convective cell moved toward northeastern to the rain band, and merged at 2200 LST.

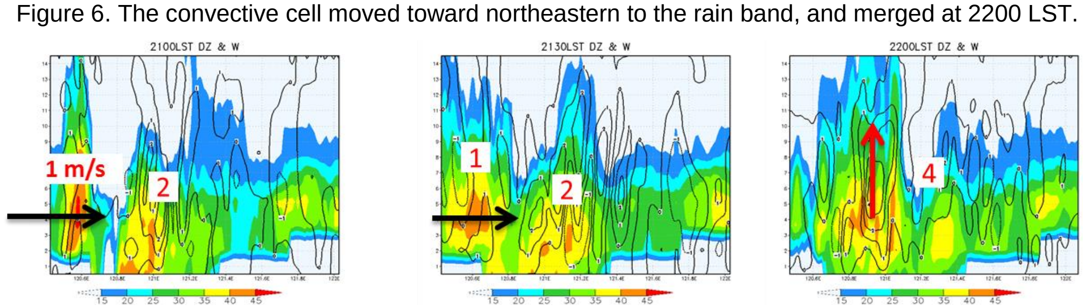


Figure 7. Three cross sections display the convective cell merging to rain band. The vertical velocity was faster after merging.

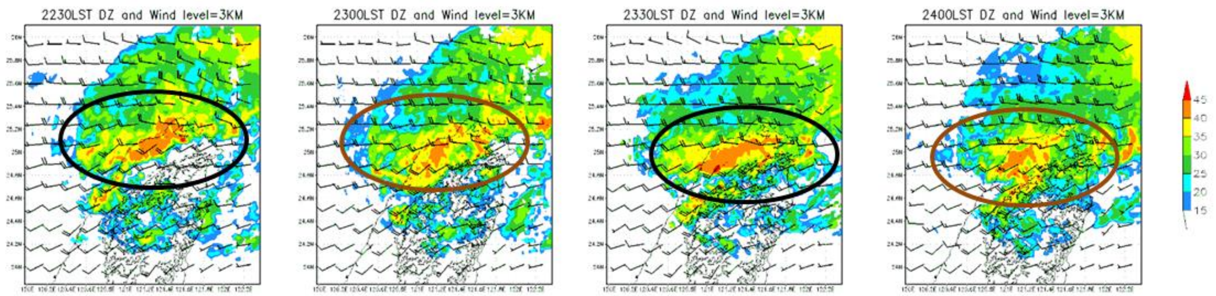


Figure 8.Radar reflectivity are from 2230 LST to 2400 LST in the third stage.

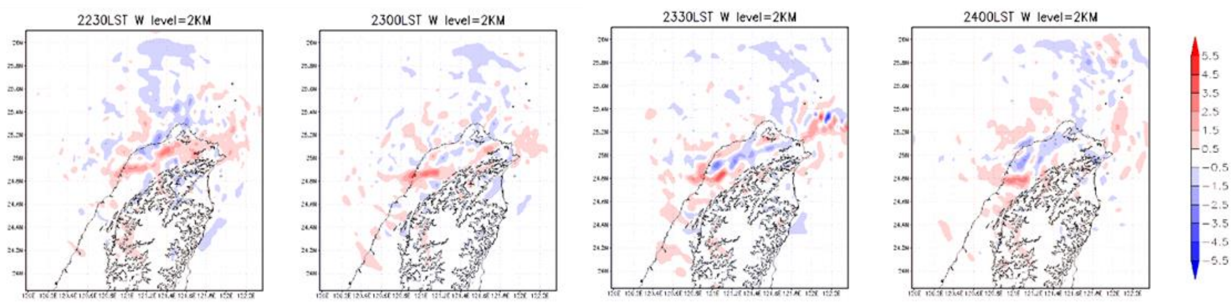


Figure 9. Vertical velocity

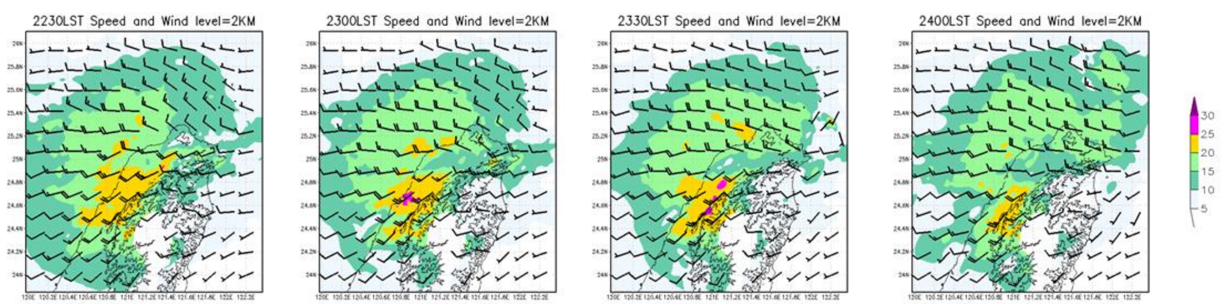


Figure 10.wind speed(shaded), barrier jet speed is about 25 m s^{-1} at north of Taiwan.

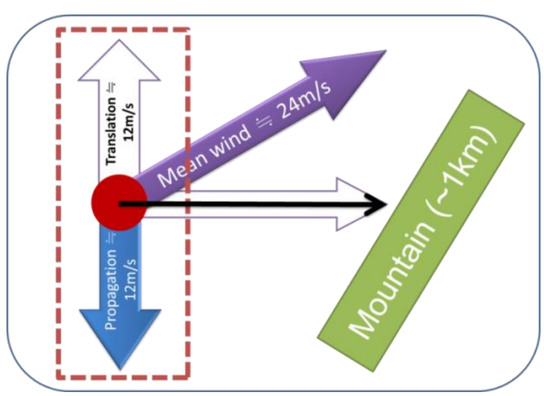


Figure 11. The picture demonstrate a cell have balance in north-south direction at stationary stage. Red circle means a cell in the stationary stage at north of Taiwan. Violet vector is mean wind about 24 m s^{-1}. Blue vector is propagation toward south about 12 m s^{-1}. Green block is the mountain at north of Taiwan.

5. Summary

In this study, structural of a squall line that occurred on 11 June 2012 from southern of China, were investigated by using Doppler radar observations. A band-shape precipitation system produced heavy rainfall over the north of Taiwan, which received about 500 mm h^{-1} of rainfall in 10 hours. We produced three-dimensional wind field data using the WISSDOM by Liou et al (2012a) and retrieved kinematic structures.

There are three stages by system different figure. The first stage is fast motion of leading edge the cold pool dynamics of the Mei-Yu front and the stronger convergence from the southwest Low level barrier Jet promoted the convection of the central part of the leading edge. The second stage was when a convective cell merged to the leading convective edge, and then the system was too stronger to cause the heavy rain fall. The third stage is stationary movement of system on land: The propagation speed toward south was balanced by the southwest barrier jet. Hence the newly formed convection was pushed back to northeast and joined the old system.

The changes of the vertical motion and the new cell propagation were studied in detail. The interactions between the low level jet, the Mei-Yu front and the high terrain was also discussed. The interaction between the front, the terrain and the jet was clearly shown by the radar analyses. It can explain the movement and evolution of different stages of this system. There are many interesting meso-scale phenomena need to be further studied, including the kinetic energy transport, the weak evolution of the stationary system, microphysical characteristics and so on.

6. Reference

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