A Numerical Study on a Shallow Front Passage over Taiwan during TAMEX IOP8

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Abstract

A Mei-Yu front penetrated over Taiwan on 7-8 June 1987 (TAMEX IOP8) was presented and the numerical simulation results of PSU/NCAR MM5 was used to investigate the orographic effects on the characteristics of mesoscale precipitation systems over Taiwan. The precipitation pattern was quite different before and during the front passage, rainfall spread from coast to mountain area associated the passing front indicated the convection systems were moved from the Taiwan Strait. There also found that just prior the front the interaction between southwesterly and topography will trigger precipitation over southern Taiwan.

There were three types of precipitation systems found during the passage. The first one was formed prior the front on the southern area of Taiwan Strait, from the simulation experiment the prefrontal southwesterly near the island will decelerate by the topography of Taiwan then turn its direction. While confluent with the continuously southwesterly, a confluence zone just located offshore which triggered deep convection and moved into Taiwan Island. The second type of precipitation was embedded in the front zone, there were shallow convection occurred due to frontal up motion. The third type was pre-frontal weak precipitation, the orographic lifting occurred on the windward side slope and made vertical lifting near the top of CMR. Meanwhile, the retarding of CMR when the front arrived in the north tip of Taiwan enhanced temperature and moisture gradient, convective systems then be triggered and move to northeast by the prefrontal southwesterly. The modeling results showed the shallow front separated to two parts when penetrated in Taiwan, east part moved fast and west part slowed down. By the intending of low convergence in the west part of front zone, deep convection associated with front passage made heavy rainfall observed in the inland area of Taiwan (central), with the friction of land surface the convection weaken for a while but enhanced again by the lifting of CMR.

1. Introduction

Most of the heavy rainfall events occurred in Taiwan in May and June are associated with the stationary Mei-yu front, which stayed over the island region for a long time and made a lot of precipitation. During the Mei-yu front passage, there were many mesoscale weather system will occur or be modified. The most prominent forcing is the topography on Taiwan, the Central Mountain Range (CMR) which locates on the center part of Taiwan with NNE to SSW orientation. The steep terrain of CMR will affect the passing weather system and also will induced deep convection system. (Chen et al., 1989; Chen, 1993)

Trier et al. (1990) analyzed a shallow front passing Taiwan during 8 June 1987, TAMEX IOP8. Their study depicted that there were three types of precipitation during the front passage from sounding analysis and surface measurement. They also conclude the terrain forcing is important on these precipitation systems. Our interesting in this study is to realized how the orographic forcing act on the frontal passage. Using a realistic model to study the detail processes of this Mei-yu front passing Taiwan and focus our topics on the following issues: 1).What's the effect of terrain of Taiwan on the frontal convection systems, 2).How the front distortion during the passage? Analysis work will be presented on the second section; detail model introduction and sensitivity construction will be noted on the 3 section. At the 4 section, we will discuss the simulation results and diagnose the effects of terrain, latent heat releasing, surface fluxes on sensitivity test; summary and conclusion will be given in the last.

2. Weather patterns

At 0000Z 8 June a front was located just over the northern tip of Taiwan (Fig. 1a). This front accompanied a continental high pressure moved to southeast. Associated a deep trough in 850 hPa the pressure trough moved close to Taiwan and the southwesterly became more stronger (Fig. 1b). This front passed through Taiwan during the next 12 hours, Fig. 2 depicts the sounding data of Pan-Chiao station after the front passage. A strong cold air layer was found below 800 hPa with obvious wind shear; it showed the depth of this front was only 2 km. Since the average height of CMR is about 2.5 km, the orographic effects should play important role while front was passing.

The 24 hours accumulated rainfall amount showed that there were 3 types of rainfall regime during the front passage. The first one was prior the front, rain was heavy and concentrated; the second type of precipitation was embedded in the front zone; the third type was pre-frontal weak precipitation, this type occurred on the windward side slope (Fig. 3). Since the observation data is not good enough in spatial and temporal to find the trigger mechanism on these different types of precipitation, our study will use numerical model to realize the reason.

Meanwhile, the infrared satellite image at 0300Z 8 June showed the broad frontal cloud was spread from South Korea to South China (Fig. 4). But as in the surface observation, the surface front was not penetrated over Taiwan. It seemed that there was another frontal zone in the south of Taiwan Strait. Figure 5 showed the time-height series of wind and equivalent potential temperature (θe) observed in Ma-Kung (46734) and Navy ship (RCJH), the greatest θe gradient appeared in both stations was showed in the same time. There was no obviously change in the wind direction in RCJH, but the front structure was seen in the satellite picture and θe gradient. It is interesting to discuss this front more detail, and we will present it on the simulation result.

3. Experiments design

PSU-NCAR MM5 was used in this study, four experiments were conducted (Table 1). 45, 15, and 5 km are the grid resolutions for each domain from coarse to finest. Grid points are 56X56, 76X76 and 112X100. The initial condition input in all runs adapted ECMWF 2.5X2.5 data at 1200Z 7 June 1987 as the first guess and integrated for 36 hours (up to 0000Z UTC 9 June 1987), which covers the life time of the precipitation event and diurnal circulation. Control run (CN) experiment included all physical processes discussed in the previous section. For discussion of the effects of terrain of Taiwan, Experiment 2 (HA) reduced the terrain height to half and Experiment 3 (NT) reduced the terrain height to 0. Experiment 4 (NL) keep the same with CN run expect the latent heat releasing, this run could examine the latent heat warm-up function. The final sensitivity test is to examine the effect of flow dynamic.

TABLE 1. The experimental design of the model simulation

Experiment name	Terrain	Latent Heat	Surface Fluxes
Experiment 1: CN	●	●	●
Experiment 2: HA	Half height	●	●
Experiment 3: NT	×	●	●
Experiment 4: NL	●	×	●

4. Model results and discussion

a. Precipitation types

The result of 24 hours accumulated precipitation of 8 June for CN run was shown in Fig. 6. It shows a good agreement with the observation (Fig. 3). The local maximum of simulated result on the mountain was 130mm, only 7 mm difference with the observation. Not only the amount of precipitation, but also the position were also close to observation. MM5 simulated a very good run both in the temporal and spatial patterns that could be very helpful to understand the prefrontal case.

Figure 7 shown the longitude-time variation of horizontal wind, vertical velocity, and hourly rainfall of 24.15 N. From 1500Z 7 to 0000Z 8 June, the southwesterly flow was passing by the CMR, the lower boundary flow retarded by mountain then turn the direction reverse. But the upper flow passed over and formed up-motion on the higher mountain area; then there was light rain occurred in the mountain area. The orographic lifting induced this type of precipitation; when the pre-front southwesterly passed through Taiwan under unstable environment.

The front approached at 0000Z 8 June, while the movement of front in Taiwan Strait was faster than in the Taiwan area, especially the wind below 1800 m was not southwesterly but northwesterly. This implied that the pre-front southwesterly was retarded by CMR then split, and the split flow confluent with the southwesterly then formed the up-motion. From the simulation result, we found that the convection system was triggered in the confluence zone just prior the surface front. This was the second kind of precipitation. After the initialization, the convection system moved to northeast by the strong southwesterly prior the deep low level trough. When it moved into Taiwan, the convection system was enhanced by the orogaphic lifting and precipitated on the slope of windward side.

The front passed through 24.15 N at about 0600Z 8, there were weak precipitation found along the post frontal northeasterly. Examine this type of precipitation on the N-S cross-section found that it is the shallow convection formed by the frontal lifting (not shown). We also found that that northeasterly was only appeared higher than 1500 m, this is descript by Trier et al. (1990) that the shallow front never touched the higher region of Taiwan. From CN simulation, we found rainfall occurred in Taiwan was influenced by CMR tremendously.

b. Southern front zone

As depicted in Fig. 3, it seems there was a front zone form in south Taiwan Strait, which is different with the northern one, came from southwest. Frontogenesis is calculated to examine this finding, Fig. 8 shown that there was really a frontogenesis formed in the southern part of Taiwan Strait. It is interesting to investigate the trigger mechanism of this front, for the convection systems embedded in it would advect to Taiwan and precipitate a lot. The Lagrangian trajectory method was used to illustrate the air parcel motion.

Different parcels near the surface (σ=0.99) were released at 0500Z using backward and forward trajectory to trace the front motion. Fig. 9 denotes the 3D pathway of these parcels; it was obviously that these parcels were came together in two ways, one from northwest and the other southwest. That means the front was confluent by the flow from the west side of Hwa-Nan topography and the southwesterly. This modeling result shown that the Hwa-Nan topography would distort the Mei-yu front, and the south part will move faster then the north part.

c. Sensitivity studies

From CN run result, we learn that the topography of Taiwan was one of the main reasons of the local precipitation. In HA and NT runs, the topography was reduced to the half height and none to examine the effect of CMR. Fig. 10a,b shown that the distribution of precipitation was located on east side of terrain in HA run, and was on the ocean in NT run. These results shown that the CMR would retard the movement of these convection systems.

The effect of latent heat release on mesoscale convection systems in the transition season was also examined. The experiment NL turned the latent heat release function off to obtain the impact of latent heating. Fig. 10c shown the 24 hours accumulated rainfall simulated by NL run, there was fewer to none rainfall be simulated on finest domain. This implied that without the updraft motion generated by latent heating, the convection cells would not be triggered even there were strong synoptic weather system or topography.

5. Summary

On 8 June 1987, a shallow Mei-yu front passed through Taiwan, precipitation was associated during the passage. A realistic model (PSU-NCAR MM5) was used to study the forming mechanisms of these convection systems. There were three types of precipitation: 1. The orographic lifting induced the light mountain area precipitation when the pre-front southwesterly passed through Taiwan under unstable environment. 2. The second kind of precipitation was triggered in the confluence zone just prior the surface front. The confluence was initialized by environmental flow and CMR. 3. Weak precipitation along the post frontal by the frontal lifting..

This study also found that the south part of the front moved faster than the north part. The south part of front was confluent by the flow from the west side of Hwa-Nan topography and the southwesterly. It shown that the Hwa-Nan topography would distort the Mei-yu front tremendously.

References

Chen, Y. -L., Y. –X. Zhang, and N. B. –F. Hui,1989: Analysis of a surface front during the early summer rainy season in Taiwan. *Mon. Wea. Rev.*, **117**, 909-931.

Chen, Y. -L., 1993: Some synoptic scale aspects of the surface fronts over southern China during TAMEX. *Mon. Wea. Rev.*, **121**, 50-64.

Trier, S. B., D. B. Parsons, and T. J. Matejka, 1990: Observations of a subtropical cold front in a region of complex terrain. *Mon. Wea. Rev.*, **118**, 2449-2470.

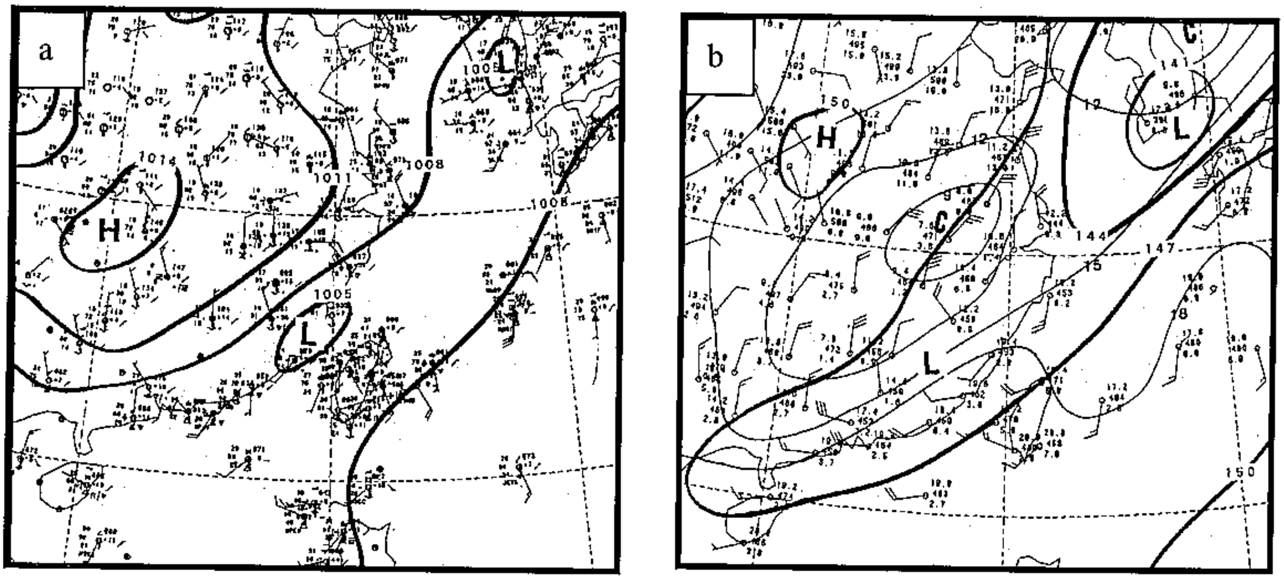


Fig. 1. The (a) surface and (b) 850 hPa weather map of 00Z 8 June 1987.

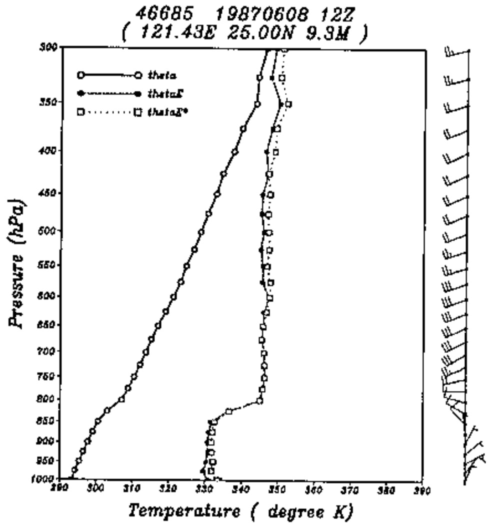
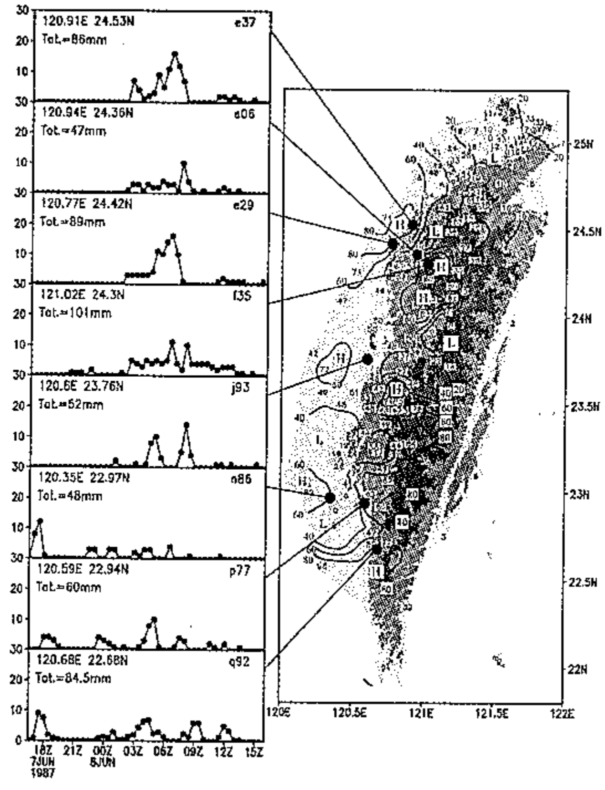


Fig. 2 The potential temperature, equivalent potential temperature and saturated equivalent potential temperature observed by Pan-Chaio sounding at 12Z 8 June 1987.



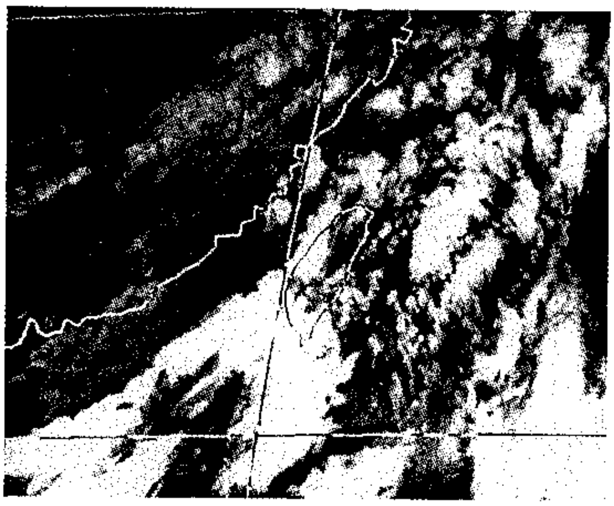


Fig. 4 The infrared satellite image at 0300Z 8 June 1987.

Fig. 3 The 24 hour accumulated rainfall around Taiwan and time series record of rainfall intensity in local maximum areas during 8 June 1987.

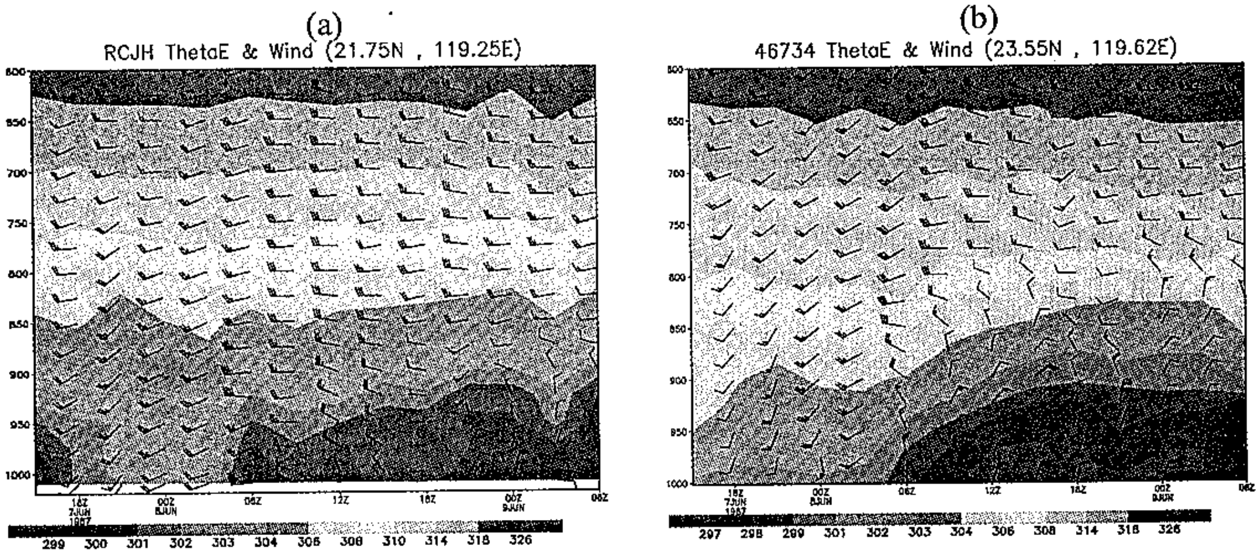


Fig. 5. The time-height cross-section of (a) RCJH and (b) 46734 sounding data. Wind shows by wind bar, full depicts 5 m/s and half is 2.5 m/s. Equivalent potential temperature is shown by shading, scale denotes under the pictures.

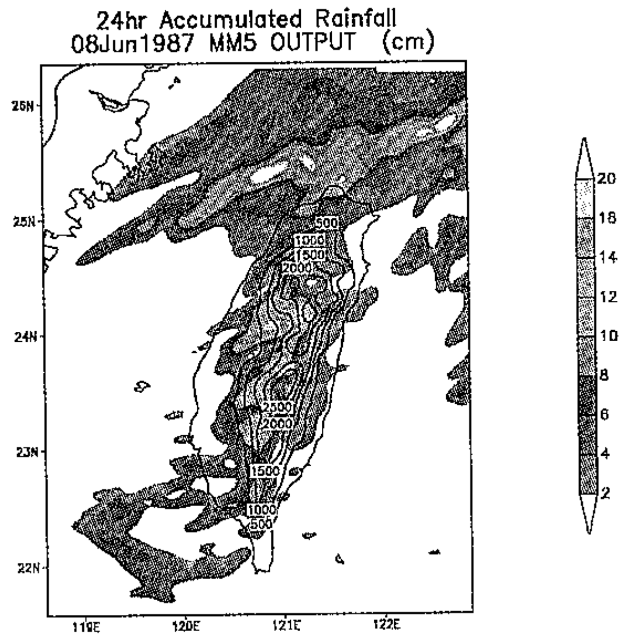


Fig. 6 The 24 hour accumulated rainfall on Domain3 of CN run during 8 June 1987.

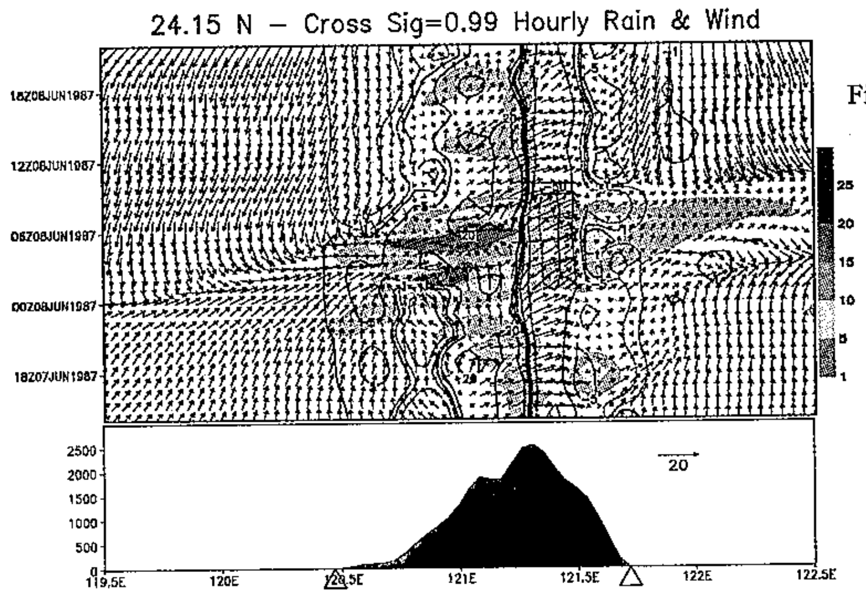


Fig. 7 The longitude –time cross-section of sigma level =0.99 on 24.15 N. Horizontal wind denotes by vector. vertical velocity shows by contour, solid line is up-motion and dash line is downward motion. Hourly rainfall shows by shading, scale depicts on right of the figure.

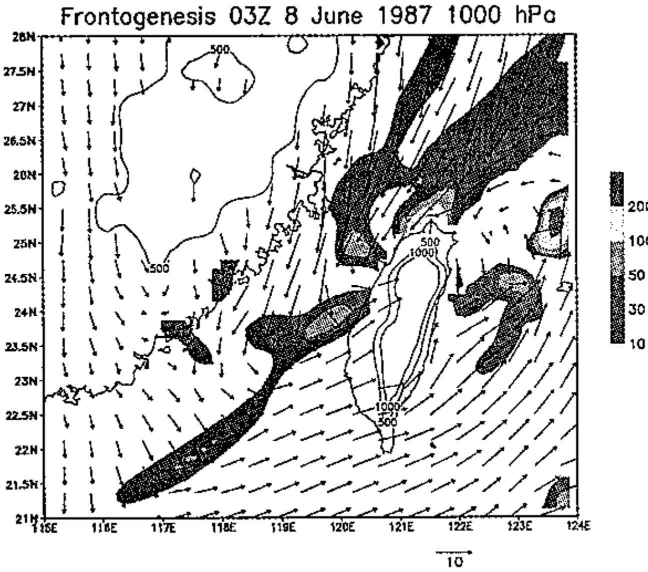


Fig. 8 Frontogenesis function on 1000 hPa at 03Z 8 June. The shading area is scaled by 10e-9, wind vector are also shown.

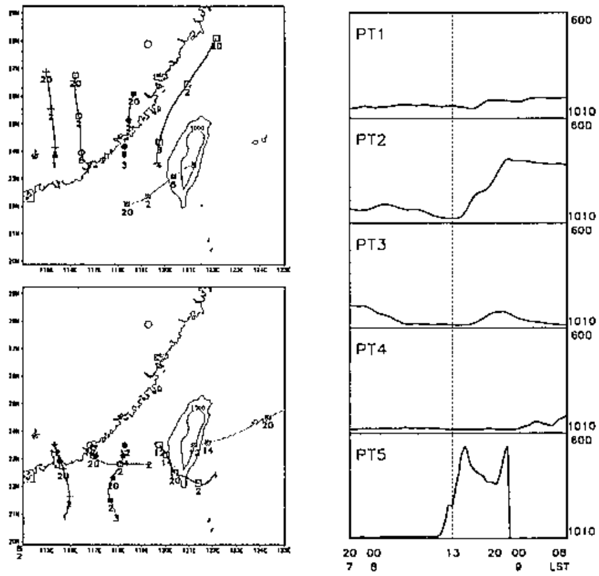


Fig. 9 The trajectory analysis of CN run, parcels were released at the south of Taiwan Strait at the time convection system developed. Left up panel shows the backward trajectory, left-down shows the forward trajectory. Vertical movement of air parcels are shown in right panel.

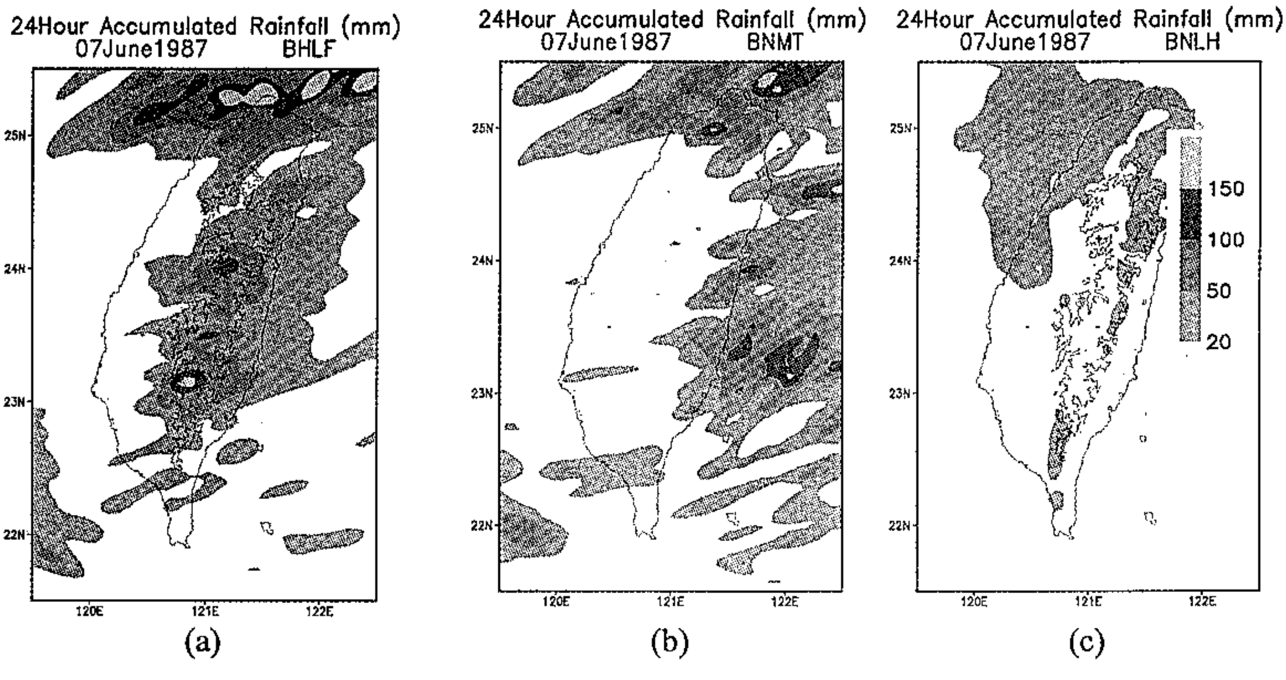


Fig. 6 The 24 hour accumulated rainfall on Domain3 of (a) HA run, (b) NT run , (c) NL run during 8 June 1987.