A Numerical Study on the Pre-front Convective Systems over Taiwan Area

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Abstract

The PSU/NCAR MM5 was used to investigate the orographic effects on the characteristics of mesoscale precipitation systems over Taiwan. For the particular shape of Central Mountain Range (CMR) which located with NNE-SSW direction along the island and with maximum height over 3000m, the passage of environment flow will be modified by CMR tremendously. It is also found that the rainfall was concentrated on some special locations during the Mei-Yu season. The most interesting point on this study is to discuss the terrain effect on the special precipitation pattern using simulation results.

A Mei-Yu front penetrated over Taiwan on 7-8 June 1987 (TAMEX IOP8) was presented. The observation indicated that before the front passage (20 hour earlier, 7 June) there were heavier rainfall accumulations occurred in the slope of CMR, and concentrated on northern, central and southern of Taiwan. While rainfall amount exceeded over 150mm during only few hours in the afternoon and there were 2 or 3 peaks found on the rainfall time-series record. On 7 June, the environment was suitable for the development of convetion systems with the unstable atmosphere of high CAPE value (~2000) and low Froude number (Fr, ~0.3), synoptic flow was from south (southwest). Flow split around the CMR while interacted with the diurnal thermal circulations during the daytime, there were three convergent area formed on the northern, central, and southern parts of the western slope of CMR. These convergence areas triggered the convective system and made abundant rainfall. Modeling studies shown the evidence of convection is at first triggered on the slope of Central Mountain Range (CMR) by the local convergence which formed by the synoptic flow with the thermal induced circulation. The sensitivity tests also indicate that the land-sea breeze, latent heat releasing and the surface fluxes support the dominant lifting part on the generation of the convection systems.

1. Introduction

During the transition period of spring and summer seasons there are many flash flood episodes occurred in Taiwan Area. While the winter continental cold air-mass weaken and the south summer monsoon become stronger gradually, synoptic unstable zones usually occupied on the southeast Asia, this is so called the Mei-yu front in China. Most of these heavy rainfall events occurred in Taiwan are associated with the stationary Mei-yu front, which stayed over the island region for a long time and made a lot of precipitation. Meanwhile, not only the frontal precipitation system brought abundant rainfall amount to Taiwan in May and June, but there is also tremendous rainfall occasionally happen in the afternoon on weak synoptic forcing days during the Mei-yu season. This made the rainfall mechanism more complex in this season.

The special topography on this subtropical island is a high mountain (top to 4000m), Central Mountain Range (CMR), which locates on the center part of Taiwan with NNE to SSW orientation. The steep slope on both side of CMR will affect the coming flow tremendous and also will induced deep convection system in suitable thermal environment by the terrain forcing.

For the studies of the pre-frontal convection cells, Johnson and Bresch(1991) studied the diurnal circulation when the afternoon thunderstorms occurred during 24 to 26 May 1987 and their analysis illustrate that the diurnal cycle is a prominent feature of precipitation on Taiwan. The characteristics of the afternoon thunderstorms found by them are: 1). located between 100-500 meters elevations of the foothills of CMR, 2). sea breeze touch at the interior mountain about

1000Z LST, 3). well mixed layers development along the west coast plain as the sea breeze penetrated inland. They also concern the effect of drainage flow, evaporation cooling and evening cloud systems are the mechanism of formation of deep convection. Lin and Sheng (1990) analyzed the thermal induced circulation during TAMEX and found that the land-sea breeze and valley wind is very announcement in the Mei-yu season. Since the particular distribution of the local rainfall maximum areas, celled like and very closed to the topography. The role of orography on the pre-front precipitation seems very important. Chen et al (1991) used 2-D cloud model to study the pre-frontal convection system of TAMEX IOP8. The simulation results denote terrain lifting is the most important forcing on the formation of the connection cells, they also remind the consideration of large scale forcing and 3D simulation are necessary.

Our studied will continue the work of Chen et al.(1991) and focus on the following issues: 1).What's the effect of large-scale environment on the prefrontal convection systems, 2).Why the heavier precipitation locates on the particular positions? 3). What are the mechanisms induced the heavy rainfall? 4).How the convection cells initiated and maintains their life cycle? A simulation study will be helpful to understand the topics, case analysis 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 land/sea contraction, latent heat releasing, surface fluxes on sensitivity test; summary and conclusion will be given in the last.

2. Weather patterns

At 0000Z 7 June a shallow front was located over the coast of southern Mainland China by about 500 km far away from Taiwan (Fig. 1a). This association the Pacific High ridge moved to east away from Taiwan. It is practical to investigate if there any impact from Mei-yu front to the pre-frontal heavy rainfall case, the Rossby deformation radius was used to estimate the influence of the front with CMR. By the comparison parameter of wind speed and characteristic scale of terrain, Rd could used to estimate the distance the system or topography affect. Since the potential temperature deviation is 6 K and averaged is 300 K, the averaged Mountain height is about 2000m, the Rossby deformation radius is about 200 Km from the axis center of CMR, and the deformation radius of the front is about 250 Km (Theta ~300, delta theta~10K, cold layer height~1.5km), it seems there is no strong direct interaction between the front and the topography of Taiwan in this time. This also implied that the thermal induced circulation dominated the weather pattern under the weak synoptic force condition. At 850 hPa the pressure trough moved close to Taiwan and the southwesterly became stronger and stronger, there was a low-level jet form along the coast of southern China (Fig. 1b).

Fig. 2 depicts the sounding data in the flow upstream (RCJH, ship), it showed the high CAPE value environment atmosphere. Also the wind veered from low level to the top of troposphere indicated the deep warm advection during the period. Wind speed below 700 hPa was weak to moderate, Fr approached 0.3 means the environmental flow is in low Froude number regime (Smith, 1989) and would split around the obstacle.

Since the synoptic scale system presented in the previous section shown the weak surface pressure gradient over Taiwan during 7 June, the thermal induced circulation becomes pronouncedly by this time. At 2100Z 6 June, the surface observation of island stations shown the weak off-shore flow. After the sun raised and temperature heat up, the surface wind turned to on-shore all around the island at 0300Z (Fig. 3).

Fig. 4 shows the distribution of 24 hours accumulated rainfall amount over Taiwan Island . There are three local maximum areas, the northwestern, central and southwester slope of CMR. The three maximum rainfall areas all lied on the western slope of CMR over 100m height to the top of mountain. It is also interesting that there is no rainfall occurred in the plant areas. The characters of the prefrontal precipitation patterns were found around the three local maximum areas. At first, precipitation was observed on the stations such as a41, a44, c46, e06, h54, o77 and o79, which were situated on the western slope higher than 100 meters. The amounts of rainfall were very large but the lasting time period of rainfall were only 3 to 4 hours. Second, there are 2 or 3 peaks on the time series of rainfall record, rain station a41, a44, c46, e06, h54, o79, it shown the convection system is not only one cell, there were 2 or more cells in this event. It is important to understand the trigger mechanism in the new cell formation.

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 6 June 1987 as the first guess and integrated for 36 hours (up to 0000Z UTC 8 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 land/sea contrast, experiment 2 (NS) replaced the sea to land in the finest domain but keep the other parameterization physics with respect to control run. Experiment 3 (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, experiment 4 (NA) ignored the latent heating, surface fluxes, land/sea contrast in integrating but keep the other processes as CN run.

TABLE 1. The experimental design of the model simulation

Experiment name	Sea/ Land contrast	Latent Heat	Surface Fluxes
Experiment 1: CN	●	●	●
Experiment 2: NS	×	●	●
Experiment 3: NL	●	×	●
Experiment 4: NA	×	×	×

4. Model results and discussion

a. Results of control run

The resulting of 24 hours accumulated precipitation of 7 June was shown in Fig. 5. It shows there are three rainfall maximum areas around west slope of CMR, the northern, central and southern parts. This pattern is in good agreement with the surface and radar observation. Not only the total daily accumulated rainfall pattern, but also the hourly evolution of precipitation results, MM5 simulated a very close run both in the temporal and spatial patterns that could be very helpful to understand the prefrontal case..

Fig. 6 shown the surface flow at 0800 and 1100 LST before the precipitation occurred. During midnight, the surface cooling on both side of the slope of CMR and coast induced the down-slope wind and land breeze; the surface upstream flow from southeast/south passed CMR and split to two parts, east and west. Confluent with the split large scale flow and nighttime circulation, there were convergence lines found in the Taiwan Strait and the Pacific Ocean near by east of Taiwan. After sun raise, these convergence line moved inland since the thermal induced circulation flow turned the wind direction opposite, that were sea breeze and up-slope wind . While the surface heating became more enhanced the convergence lines changed their position more complex for the complex shape of CMR. Diagnose with the position where heavy precipitation occurred a few hours later, we found strong confluence (or convergence) over these position. At 1400 LST, convection system became developing and rainfall occurring, the downdraft outflow by precipitation presented.

The Lagrangian trajectory method was also used to illustrate the air parcel motion. Different points near the surface (σ=0.99) around the three maximum precipitation areas were released at 1400 LST using backward trajectory to trace the motion. Fig. 7 denotes the 3D pathway of these parcel around the precipitation area of northwester, central, southern Taiwan. There are some significant features on the path of air parcel. At north part, the parcel on the west side of precipitation area were come from Taiwan Strait, the way from environment southwesterly then turned in the daytime when the sea breeze circulation was established ; the parcel released on the east side of precipitation area were come from the southward along CMR, that is the path followed by the slope terrain of CMR.

Trajectory on central part was different with the north part, precipitation parcels were came from the shore and the higher position of the mountain. As at south part, parcels were confluent by the sea breeze and the flow split by the south tip of CMR. The trajectory analysis shows that the thermal induced mesoscale circulation will greatly affect the motion of air parcels on this study.

b. Sensitivity study

In NS run, the sea characters (the albedo, heat specify) on the sea coverage was replaced by the landuse of Taiwan Island, then the effect of land/sea contrast will be reduced to minimum. From the 24 hours accumulated rainfall pattern in Fig. 8, it shown that the pattern was much different to the results of control run (CN). The rainfall were concentrated on the off shore, there were fewer amount on the western slope of CMR.

Fig. 9 shown the simulated cross horizontal wind field of NS run compared with CN run. Without the different heating on the coastline, the horizontal wind speed is much weaker on the windward slope than the CN run. The sea breeze will couple with up-slope wind and formed a "large" local circulation after it penetrated in the mountain slope. At 1200 LST the stronger in-land wind will converge with the deceleration up-slope wind formed by the condensation of deep convection, and then a new convection cell was triggered. It is the same on the other locations which observed heavy precipitation, this means that the humid sea breeze penetration provide the main trigger forcing on the new cells' formation.

It is very important to estimate the effect of latent heat release on the transition season. The experiment NL turned the latent heat release function off to obtain the impact of latent heating. Fig. 10 shown the 24 hours accumulated rainfall simulated by NL run, there was no rainfall be simulated on Taiwan Island expect a very few rainfall occurred on the east slope of CMR. Even in the Pacific Ocean with warm, humid and conditional unstable environment over it, there was no convection occurred. Without the updraft motion generated by latent heating, the convection cells would not be triggered even there were sea breeze penetration and terrain lifting.

To investigate the orographic effect of CMR, we designed the sensitivity test run named NA, which turned the PBL processes and latent heat releasing off, to reduced the thermal forcing to minimum. This run also replaced the sea/land contrast by all land landuse to drop the effect of local circulation down. All the design is to examine the dynamic effect of flow passing through CMR in this case. There was no precipitation occurred as in observation (Fig. 11).

On NA result, there was almost no rainfall occurred on the western slope of CMR. We examined the air motion as done in CN run, there were trajectories released in the heavy precipitation areas on low-level (σ=0.99) at 1400 LST 7 June. Fig. 12 shown the pathway of these trajectories of NA Run. The terrain-shape following horizontal path depicts that the moderated environment flow move around the CMR, and there were no confluent found in these areas.

5. Summary and remarks

A realistic model (PSU-NCAR MM5) was used to study the forming mechanism of afternoon deep convection during the Mei-yu season. There were three local rainfall maximum areas occurred during the pre-front period of TAMEX IOP8, 7 June 1987. This precipitation episode was an obvious noontime convection event and supplied a good chance to study.

On 7 June, the environment was suitable for the development of convetion systems with the unstable atmosphere of high CAPE value (~2000) and low Froude number (Fr, ~0.3), synoptic flow was from south (southwest). Flow split around the CMR while interacted with the diurnal thermal circulations during the daytime, there were three convergent area formed on the northern, central, and southern parts of the western slope of CMR. These convergence areas triggered the convective system and made abundant rainfall. Modeling studies shown the evidence of convection is at first triggered on the slope of Central Mountain Range (CMR) by the local convergence which formed by the synoptic flow with the thermal induced circulation. The sensitivity tests also indicate that the land-sea breeze, latent heat releasing and the surface fluxes support the dominant lifting part on the generation of the convection systems.

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Smith, R. B., 1989: The differential advection model of orographic rain. *Mon. Wea. Rev.*, **110**, 306-309.

(a)

(b)

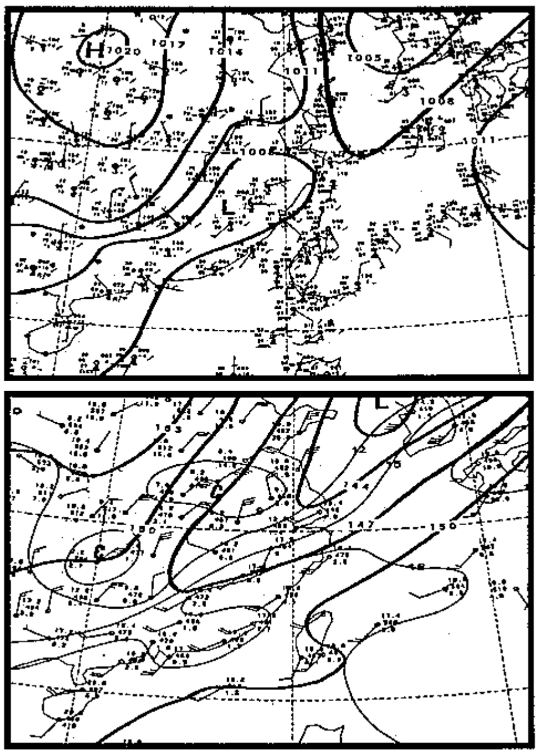

Fig. 1. The (a) surface and (b) 850 hPa weather map of 00Z 7 June 1987.

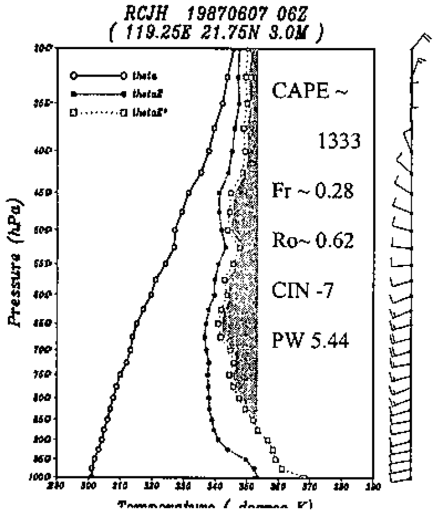

Fig. 2 The potential temperature, equivalent potential temperature and saturated equivalent potential temperature observed by RCHY sounding at 06Z 7 June 1987.

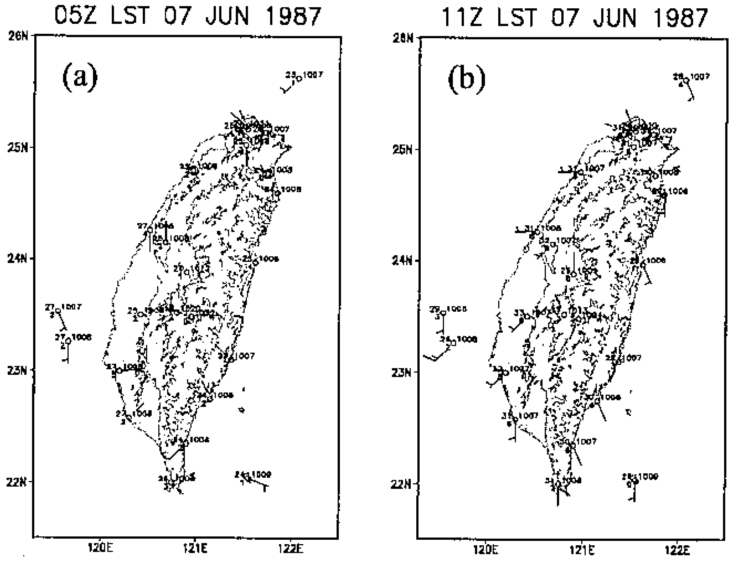

Fig. 3 The surface observation plotting of (a) 0500LST and (b) 1100LST of 7 June 1987.

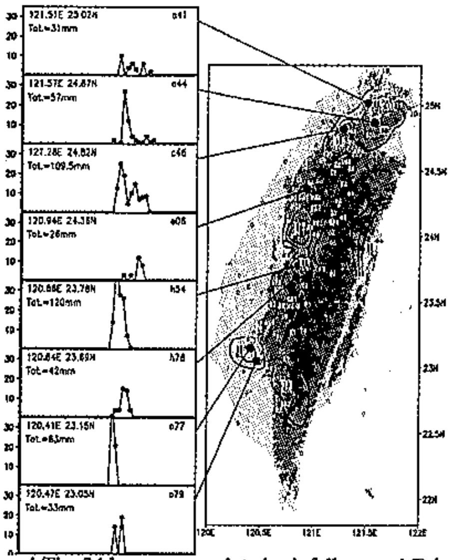

Fig. 4 The 24 hour accumulated rainfall around Taiwan and time series record of rainfall intensity in local maximum areas during 7 June 1987.

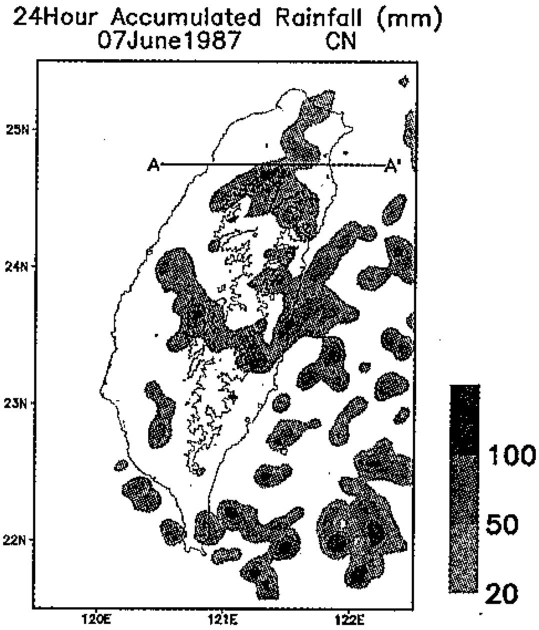

Fig. 5 The 24 hour accumulated rainfall around Taiwan during 7 June 1987 of CN run.

(a) (b)

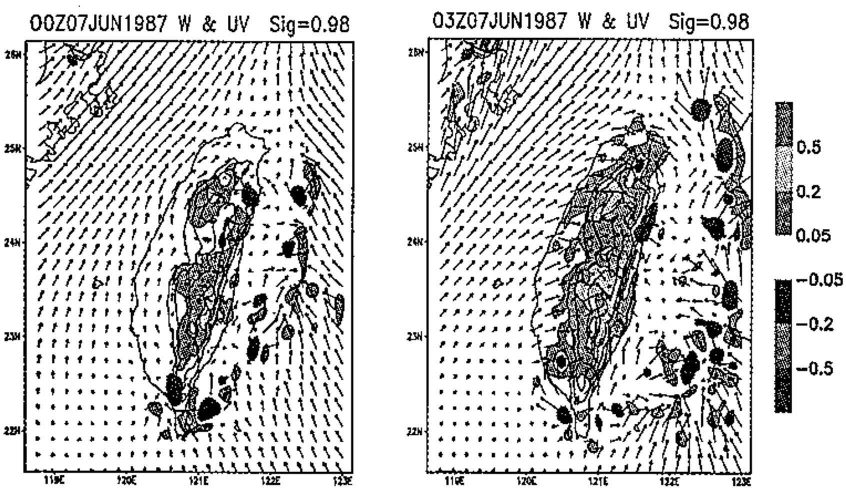

Fig. 6 The horizontal wind and vertical velocity on (a) 00Z , (b) 03Z 7 June 1987.

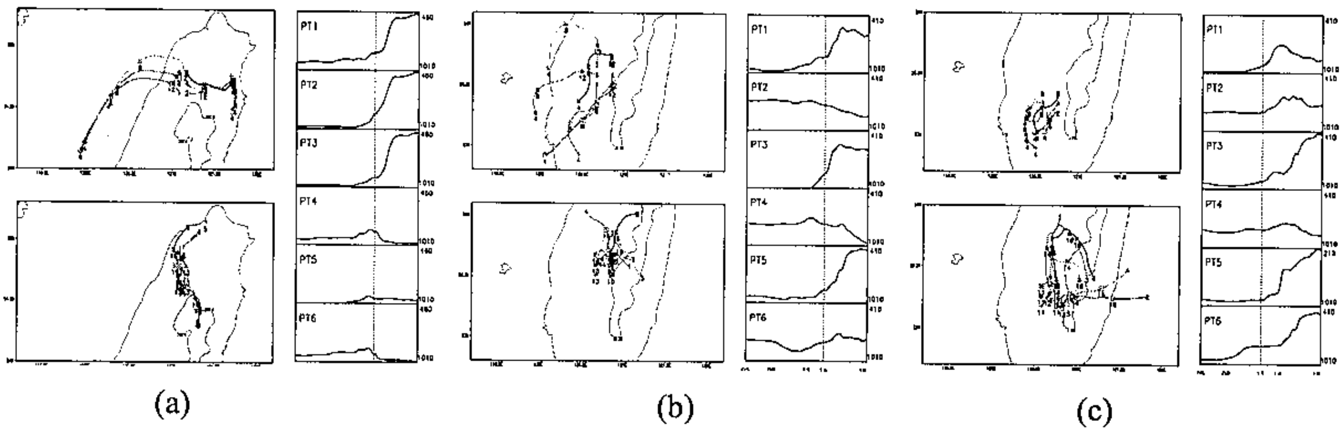

Fig. 7 The trajectoty analysis of CN run, parcels were released around the local rainfall maximum areas at the time convection system developed. (a) north part , (b) central part, (c) south part.

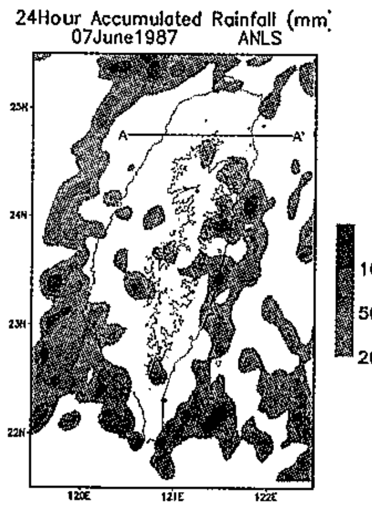

Fig. 8 The 24 hour accumulated rainfall around Taiwan during 7 June 1987 of NS run

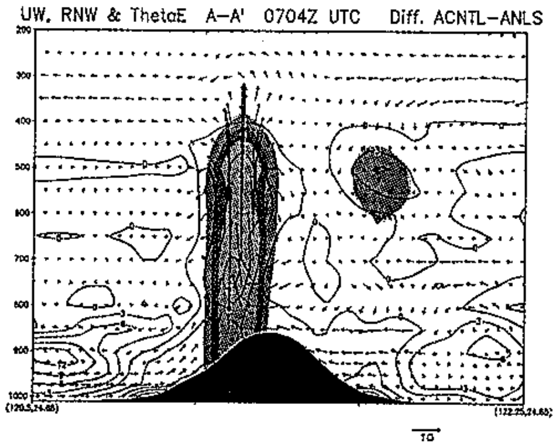

Fig. 9 The difference of wind, rain water (shading area) and equivalent potential temperature (contour) between CN and NS runs at 04Z 7 June 1987.

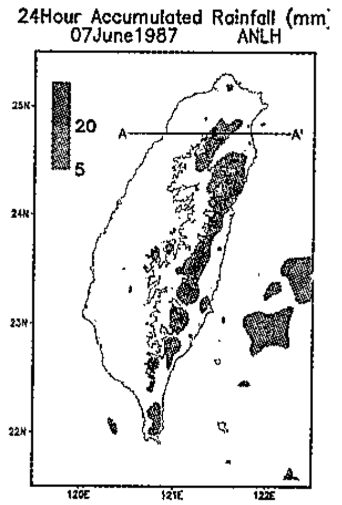

Fig. 10 The 24 hour accumulated rainfall around Taiwan during 7 June 1987 of NL run

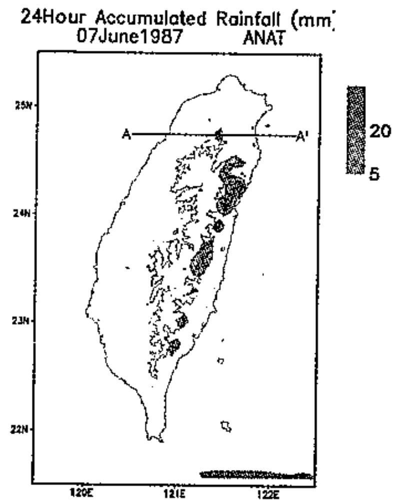

Fig. 11 The 24 hour accumulated rainfall around Taiwan during 7 June 1987 of NA run.

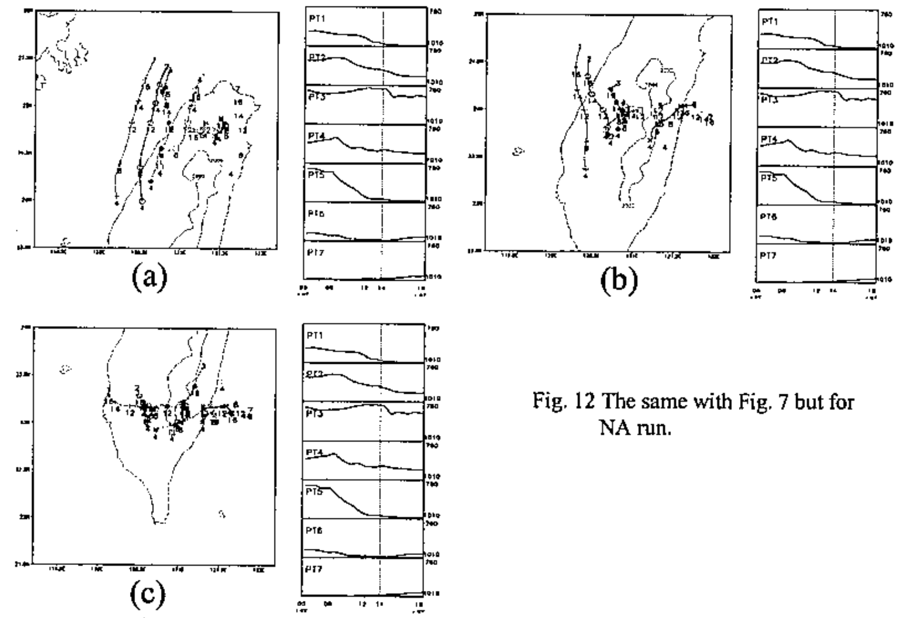

Fig. 12 The same with Fig. 7 but for NA run.