# RADAR ANALYSIS OF PRECIPITATION STRUCTURE OF LANDFALLING TYPHOONS: A CASE STUDY

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#### ABSTRACT

In this study, the precipitation structure of Typhoon Nari (0116) before and after landfall is examined using the reflectivity data collected by the NEXRAD radar located at northern Taiwan. It is shown that the inner core precipitation of the storm increased more than 50% during its landfalling period. It can be identified that, with the help of TRMM TMI and PR data, enhanced convective activity after landfall was observed. The extremely low brightness temperature outside the eyewall by TRMM 85GHz microwave imager suggests the existence of severe thunderstorms. The asymmetrical characteristic of the precipitation during landfall is also studied.

### **1. INTRODUCTION**

Heavy rainfall and flash flood produced by landfall typhoons is one of the biggest natural disasters in Taiwan. Not only human lives and personal property were severely demolished, but also the societal stability and sustainability were greatly threatened. To understand and predict heavy rainfall and flash flood caused by landfalling typhoons has become the most urgent challenge the meteorological community in Taiwan to face. The island wide Doppler radar network has been completed in 2001 and four NEXRAD type S-band Doppler radars are in operation since then. This set of data provides an unprecedented opportunity to study the detailed wind and rainfall structure of landfalling typhoons over the Taiwan area. In this study, the precipitation structure of Typhoon Nari (0116) before and after landfall is examined using the reflectivity data collected by Wu-Feng-Shan radar (northern Taiwan). Typhoon Nari made landfall at northern Taiwan on Sept. 16, 2001. Its slow movement and associated heavy rainfall and flash flood caused many fatalities and more than 3B US\$ property damages. Preliminary study of radar reflectivity showed the abrupt intensification of precipitation in the inner core of the storm during its landfall period. In addition to NEXRAD data, TRMM TMI and PR data is also used to identify the enhanced convective activity after landfall. The extremely low brightness temperature observed outside the eyewall by TRMM

85GHz microwave imager suggests the development of severe thunderstorms. This enhancement of thunderstorm activity seems to explain the intensification of precipitation after landfall.

# 2. AZIMUTH-MEAN REFLECTIVITY DISPLAY

The space and time variations of precipitation of Nari are examined by restructuring the reflectivity data with radar site as origin into cylindrical coordinate with storm center as origin. In Fig.1, the Hovmoller diagram, total 18 hours, 13 hours before landfall and 5 hours data after landfall, of azimuthally-mean 4 km height reflectivity field is given. Each bin (1 km resolution) of reflectivity was calculated by averaging data azimuthally and the time interval of observation was 6 minutes. The figure shows the precipitation area of typhoon Nari extended 200 km in radius. The eye region with echo less than 10dBZ was about 20 km wide. Significant precipitation occupied region from 20 km to 110 km with mean reflectivity value larger than 30 dBZ. No distinguished echo peak was observed when the storm was still far away from the island. Reflectivity larger than 35 dBZ scattered between 40-110 km range in an earlier time and became to concentrate into eye wall region, i.e., 30-60 km range, however, when the storm moved closer to the island. The near center precipitation intensified significantly during landfall period. The eye contracted and filled with precipitation after the storm made landfall.

For a crude quantitative analysis, we divided the precipitation distribution of Nari into three annular rings (e.g., r<100km, ring A, the inner core region; 100km<r<200km, ring B, the outer region 1; and r>200km, ring C, the outer region 2; respectively), the area-weighted precipitation (using Z=300R<sup>1.4</sup> to convert mean reflectivity into rainfall rate) can be estimated respectively. The area-weighted precipitation total in the inner core region was almost the same as that in the outer region while the storm was still 12 hours before landfall. It was observed that the precipitation total of the inner core increased gradually and the outer core decreased at about the same rate while the storm approached to the island. At landfall, the area-weighted precipitation total in the inner core possessed more than 75% of rainfall for the whole storm system. Concentration of precipitation into the inner core precipitation total in this period. However, it is interesting to note that at about one hour before landfall, the inner core precipitation into the inner core of the storm is an indicator for an intensifying storm (Rodgers et al. 1994) and this is the case Nari was experienced in this period. However, it is interesting to note that at about one hour before landfall, the inner core precipitation in the inner core of the storm seems to suggest the pronounced influence of topography on enhancing the precipitation of landfall typhoons.

## 3. ASYMMETRICAL STRUCTURE OF PRECIPITATION

The asymmetrical structure of precipitation of typhoon Nari at landfall is examined. In Fig.2, the quadrant-averaged rainfall rates divided according to vertical wind shear vector is calculated. At about 13 hours before landfall, the mean (200 -850 hPa) vertical wind shear was directed to NE and the storm moved SW, the maximum rainfall rate occurred at upshear left and right front of



**Figure 1.** Hovmoller diagram of 4 km height azimuth mean reflectivity (in dBZ) of typhoon Nari. The abscissa is distance in km from the storm center and the vertical coordinate is time in hours before (-) and after (+) the storm made landfall (left). The azimuthally-mean reflectivity profiles 4-7 hours before landfall, 0-4 hours before landfall, and 12 hours after landfall, respectively. Typhoon Nari made landfall in northern Taiwan on 1340UTC September 16, 2001 (right).



**Figure 2**. Displays of annular-quadrant mean rainfall rates (unit in mm h<sup>-1</sup>) of typhoon Nari before (left) and after (right) landfall. The long arrow indicates the movement of the storm and the short arrow indicates the 200-850 hPa mean vertical wind shear direction.

vertical shear calculated based on Hanley et al. (2001) was very weak and smaller than 1 m/s for movement. The maximum rainfall rate moved to the forefront region during landfall. 5 hours after landfall, the maximum rainfall rate occurred at the right rear quadrant of movement. The pronounced effect of vertical wind shear on the asymmetrical structure of precipitation of tropical cyclone has been recognized (Corbosiero and Molinari 2002). In Nari case, the 200-850hPa mean the whole period, and the effect should be minimal. On the other hand, the moving speed of Nari was less than 3 m/s in average during landfall period, thus, should not alter the precipitation structure significantly. Under this weak vertical shear situation, the shift of the maximum rainfall rate from motion right front quadrant to motion forefront is consistent with that simulated by numerical model (Chen and Yau 2003). The model results suggested the shift of maximum rainfall was due to the large difference of surface roughness length between ocean and land. The enhanced low level convergence produced by differential friction between ocean and land seems to play an important role of enhancing precipitation of a landfalling typhoon. After landfall, the maximum rainfall shifted



**Figure 3.** TRMM PR 3 km height reflectivity images (left panel) and vertical profiles of reflectivity of convective precipitation in motion right front quadrant (right panel, dBZ vs height in km) of Typhoon Nari (a) before landfall, upper panel 2001/9/15/0028UTC, and (b) after landfall, lower panel 2001/9/16/1739UTC.

to the motion rear right quadrant in this case. This is because the enhanced precipitation induced

by Taiwan topography was stationary with respect to storm movement. It is difficult to distinguish between the effect of terrain slope uplifting and the enhanced convergence by differential friction through radar data only.

## 4. TRMM OBSERVATIONS

During the landfall period of Nari, TRMM satellite made several overpasses. Fig.3 shows the reflectivity images of TRMM precipitation radar observations before and after landfall. It can be seen that while the storm was still in the open ocean, the maximum reflectivity occurred in motion right front quadrant and shifted to the motion right rear quadrant after it made landfall. It is worth to note that, however, the convective activity overall intensified significantly. In Fig.3, it also shows the vertical profiles of reflectivity of convective precipitation in the inner core (<100km) motion right front quadrant before and after landfall. The separation of convective and stratiform precipitation followed the technique developed by Steiner et al. (1995). There were 42 pixels satisfy the criteria before landfall and 75 pixels after landfall. The reflectivity profiles show large differences in intensity, before landfall the largest value is 42 dBZ and after landfall was 50 dBZ. Convert these reflectivity values to rainfall rates using  $Z=300R^{1.4}$ , they are 14.5 and 63.4 mmh<sup>-1</sup>, respectively, a dramatic rainfall intensity change. This observation was consistent with what was observed by NEXRAD discussed in the previous section.

It is interesting to point out that extreme low brightness temperature also detected by TRMM 85GHz TMI sensor. Before landfall, the lowest polarization corrected temperature (PCT, defined by Spencer et al. 1989) was 220K, however, after landfall, PCT less than 180K was detected (figure not shown). According to Mohr and Zipser (1996), when PCT is less than 200K, it means there are large amount of precipitation- size ice particles existed in the cloud and significant lightning activity is anticipated. From both the ground surface station observation record and TRMM lightning mapper, all these observations confirmed the existence of lightning and indicated the occurrence of deep thunderstorms during the landfall period of typhoon Nari. Deep convection development in a landfall tropical cyclone was recently documented by Geerts et al. (2000) when hurricane Georges (1998) made landfall in the Dominican Republic. The severe thunderstorm developed within the eye while the storm encountered the high mountain Cordillera Central. In Typhoon Nari case, the thunderstorm developed along the coastal region instead of the high mountain and was outside the eye wall region. These differences suggest possibly different triggering mechanisms were operated and deserve further investigation.

## 4. SUMMARY

In this study, the precipitation structure of Typhoon Nari (0116) before and after landfall is examined using the reflectivity and brightness temperature data collected by NEXRAD in northern Taiwan and TRMM TMI and PR. Pronounced precipitation structure changes were identified. The contraction of the eye and the associated intensification of precipitation in the inner core region were observed and this phenomenon can be traced back 4-5 hours before the storm made landfall. The final hour enhancement of precipitation (about 50% increases) before landfall suggests the strengthening low level convergence induced by the differential friction may play important role. Since the mean vertical shear was rather weak for the whole period, the asymmetrical distribution of precipitation of the storm in the open ocean was consistent with that expected from asymmetric boundary layer flow under a translating storm (Shapiro 1983). The change of the asymmetry during landfall can be crudely attributed to the effect of Taiwan topography. From TRMM observations, the detection of very low brightness temperature by 85GHz TMI and significant intensification of radar reflectivity by PR all suggest the existence of severe convective activity. The formation mechanism of these convective activities is possibly related to terrain effect and needs further investigation. High resolution mesoscale numerical simulation will be conducted to confirm this hypothesis. In addition, analyzing hurricanes approaching US continent is also helpful to distinguish the differences of a landfall tropical cyclone in an environment with complex terrain and an environment with flat land.

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