Precipitation Processes Associated with Typhoon Nari (2001)

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Abstract

Typhoon Nari struck Taiwan on 16 September 2001. Its record-breaking 24-48 hour accumulated rainfalls more than 2000 mm in some parts of Taiwan caused widespread flooding, resulted in severe economical and societal damage. The PSU-NCAR MM5 model is used in this study to investigate the key precipitation processes responsible for heavy rainfalls of Typhoon Nari. Numerical simulations with different horizontal resolutions show that the ability of the model to successfully predict the observed rainfall maximum is increased with the refinement of grid resolution. The MM5 model with a 2.2-km grid size can successfully simulate the observed maximum 24-h rainfall of 540 mm at Mount Snow. When Nari made landfall, Taiwan's topography induced an asymmetric structure, and lowered the level of maximum heating over the mountain area. Most of outer spiral rainbands were associated with precipitating ice clouds, and rainfalls within the inner core or eyewall were mainly associated with raindrops, melting snowflakes, and graupels. Evaporative cooling of rainwater reduced the strength of warm core within Nari's eye and fastened its moving speed, although Nari's track was primarily determined by the interaction between the synoptic-scale steering flow and Taiwan topography.

1. Introduction

Typhoon Nari struck Taiwan on September 16, 2001; it brought heavy rainfall, fresh flood, and caused severe economical and societal damage, including 92 human lives. The record-breaking 24-48 hour accumulated rainfalls more than 2000 mm in some parts of Taiwan caused widespread flooding, and a great loss of human life and property damage. Analysis revealed that Nari's heavy rains were due to warm sea surface temperature, Nari's unique track and very slow moving speed, and the steep terrain of Taiwan (Sui et al. 2002). The objective of this study is to investigate the key precipitation processes responsible for heavy rainfalls of Typhoon Nari (2001).

2. Methodology

The PSU-NCAR MM5 model (Grell et al. 1995) is used to investigate the precipitation structure and processes associated with Typhoon Nari (2001). The MM5 model configuration includes four nested grids with horizontal grid size of 60, 20, 6.67, and 2.22-km, respectively, and 31 sigma levels in the vertical. The simulation is integrated for 102 h, starting from 1800 UTC 15 September 2001. The initial and boundary conditions are taken from the ECMWF advanced global analysis with 1.125° x 1.125° horizontal resolution. Sea surface temperature is kept constant during the period of integration. The full-physics control simulation uses the following physics options: 1) the Grell (1993) cumulus parameterization scheme, 2) the Reisner microphysics scheme with graupel (Reisner et al. 1998), 3) the MRF PBL scheme (Hong and Pan 1996), and 4) the atmospheric radiation scheme of Dudhia (1989). Note that no cumulus parameterization scheme is used on the 6.67 and 2.22-km grids.

Because the vortex contained in the large-scale ECMWF analysis is too weak and too broad, some method of typhoon initialization (or tropical cyclone bogussing) is required in order to improve the track and intensity forecast. We follows the method of Davis and Low-Nam (2001) to perform typhoon initialization. First the erroneously large vortex in

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the large-scale analysis is removed. Then an axis-symmetric Rankine vortex is inserted into the wind field, with the storm characteristics estimated from the JTWC best-track analysis. When constructing the three-dimensional bogus wind, the axis-symmetric wind is vertically weighted. The vertical weighting function is specified to be unity from the surface through 850 hPa, 0.95 at 700 hPa, 0.9 at 500 hPa, 0.7 at 300 hPa, 0.6 at 200 hPa and 0.1 at 100 hPa. Then the nonlinear balance equation is used to solve the corresponding geopotential height perturbation, and the hydrostatic equation is used to obtain the temperature perturbation. Moisture is assumed to be saturated within the typhoon vortex.

3. Results

Some results were already shown in Yang (2003), so we only present updated progress and ongoing work here. One of the reasons for Typhoon Nari to cause such a severe damage is its record-breaking 24-48 hour cumulated rainfall in many parts of Taiwan, it is interesting to examine the ability of the MM5 to predict the detailed precipitation distribution and amount. The observed and simulated 24-h rainfalls during the initial landfall stage (0000 LST 16 September to 0000 LST 17 September) of Typhoon Nari are shown in Fig.1. This is the period when Nari's rains overwhelmed existing flood protection capacities downstream of the Chi-Lung River in a part of Taipei that had no regulatory reservoirs, resulting in major flooding in the northern Taiwan (Sui et al. 2002). Basically the precipitation distribution was well simulated by the MM5. When the grid size is as fine as 2.22 km, the model can successfully simulate rainfall maximum (552.6 mm) in close agreement with the observation (540.5 mm). As the grid size is reduced to 6.67, 20, and 60 km, the simulated rainfall maximum over Mount Snow is decreased to 425, 252, and 130 mm, respectively (figures not shown). Hence it is consistent with Wu et al. (2002) that the ability of the MM5 model to successfully predict the observed rainfall maximum is increased with the refinement of grid resolution.

One important point pointed out in Yang (2003) is that when Nari was still in the open ocean, its precipitation and circulation structures were quite axis-symmetric, and the level of maximum condensational heating within the eyewall was located in the middle-to-upper troposphere. As Nari made landfall, Taiwan's topography induced an asymmetric structure on precipitation and circulation, and the level of maximum condensational heating was located in lower troposphere over Mount Snow. Similar result was also found by Wu et al. (2002) for Supertyphoon Herb (1996) over Mount A-Li.

Figure 2 further illustrates the simulated liquid-water path and ice-water path of Typhoon Nari at 1800 UTC 16 September (0200 LST 17 September) when severe flooding occurred over northern Taiwan. It is evident in Fig. 2a that there were lots of raindrops, melting snow flakes and cloud drops within the eyewall in northern Taiwan and along the western (windward) slopes of Central Mountain Range. On the other hand, Fig. 2b shows that there was less ice-phase hydrometeors, compared to the more liquid-phase hydrometeors as indicated by the liquid-water path (Fig. 2a). These ice-phase hydrometeors (ice crystals and snow flaskes) occurred mainly over the top of eyewall near northern Taiwan, not over the windward slopes of Central Mountain Range.

Figure 3a displays the southwest-northeast vertical cross section of equivalent potential temperature at 0900 UTC 16 September when the simulated Nari was about to make landfall over Kee-Lung. The warm core in Nari's eye was indicated by a maximum of equivalent potential temperature of 365.6 K. The slope of the surface of equivalent potential temperature was vertically upright along the eyewall. A sensitivity experiment is conducted with evaporative cooling by raindrops turned off; the physical parameterizations and model setting are otherwise the same as those in the control simulation. In the absence of rainwater's evaporative cooling, the simulated Nari's eye is warmer by 3.5 K (the maximum of equivalent potential temperature is 369.1 K). The typhoon track is almost identical to that of the control storm, and its moving speed is slightly slower than the full-physics control run.

4. Ongoing work

This modeling study of Typhoon Nari (2001) is still in progress, and a series of numerical experiments are planned to conduct in order to examine the sensitivity of simulated typhoon intensity, detailed precipitation structure, and rainfall amount to the choice and details of microphysics parameterization used in the model. Wang (2002) showed in his idealized tropical-cyclone simulation that cloud structures of the simulated tropical cyclone could be quite different with various microphysics schemes, but intensification rate and final rate were not very sensitive to the details of the cloud microphysics parameterizations. Our study would be an extension of Wang's idealized work to a real case, namely, the landfalling Typhoon Nari. Another issue planned to explore is the interaction between the microphysics and topographic processes. When Nari made landfall, Mount Snow induced an asymmetric structure on Nari; the level of maximum heating was located in lower atmosphere and tremendous rainfalls was dumped over the mountain area. What is the relationship between the vertical level of maximum heating and the precipitation efficiency? In other words, how does Mount Snow enhance the precipitation efficiency associated with Typhoon Nari? Analyses of air-parcel trajectories and hydrometeor trajectories over the open ocean and near Mount Snow are planned to conduct in order to answer the above questions. These issues are our future research directions in this modeling study of Typhoon Nari (2001).

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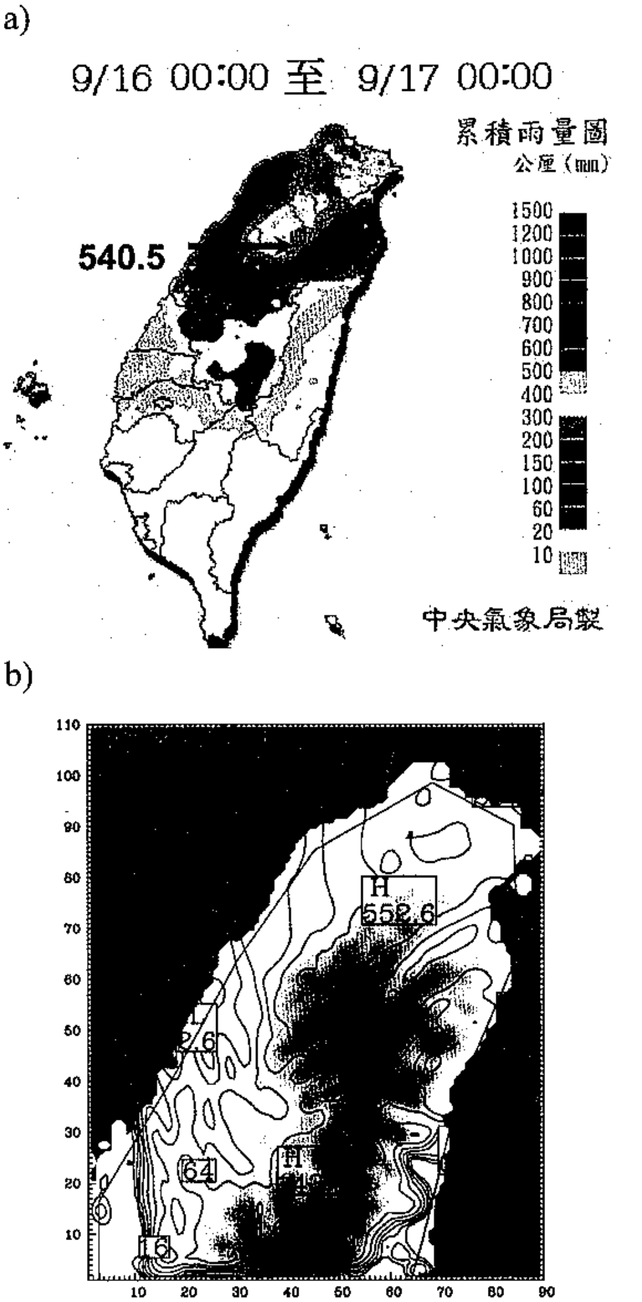

Figure 1: (a) The observed 24-h rainfall (0000 LST 16 September to 0000 LST 17 September) and (b) the corresponding simulated 24-h rainfall (in units of mm) on the 2.22-km MM5 gird.

a)

b)

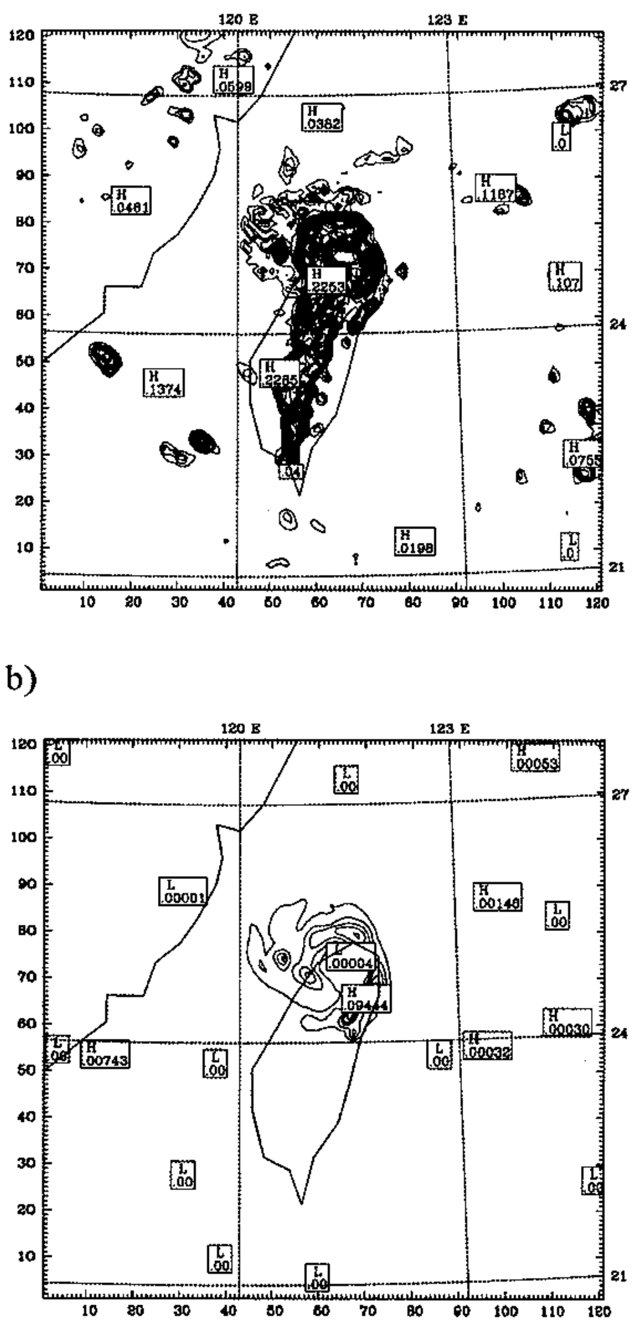

Figure 2: (a) The simulated liquid-water path and (b) ice-water path (both in units of kg m^{-2}) of Typhoon Nari at 1800 UTC 16 September (0200 LST 17 September) 2001. Contour interval is 0.01 kg m^{-2}.

a)

b)

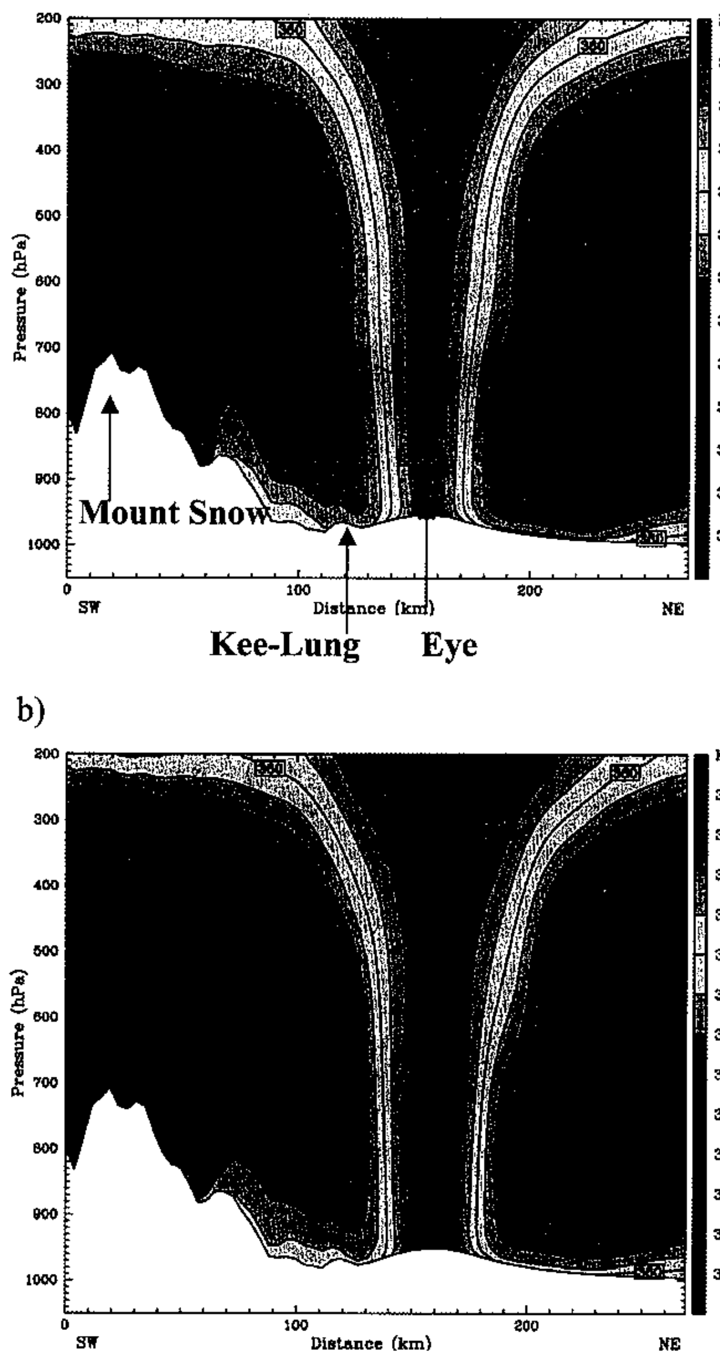

Figure 3: Vertical cross sections of equivalent potential temperature (in degree K) at 0900 UTC 16 Sepember for (a) the full-physics control simulation and (b) the No-Evaporative-Cooling simulation. Contour interval is 2 °K.