Hydrometeor Trajectories and Precipitation Processes of Typhoon Nari (2001)

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ABSTRACT

The record-breaking 48 hour accumulated rainfalls more than 2000 mm in some parts of Taiwan for Typhoon Nari (2001) 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 associated with Nari's heavy rainfalls. The simulated Nari made landfall over Kee-Lung (24 hours after initialization), only 15-20 km off the actual landfalling position of I-Lan. Numerical simulations with different horizontal grid sizes show that the ability of the model to successfully predict the observed rainfall maximum is increased with the refinement of grid size. As Nari made landfall, Taiwan's terrain 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 produced by raindrops, and melting snowflakes/graupels. Analyses of air-parcel and hydrometeor trajectories over the ocean and mountain area are conducted to examine the interactions between the microphysical and topographic processes.

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 tremendous 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 and severe flooding 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. 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.

We followed the method of Davis and Low-Nam (2001) to perform typhoon initialization. First the erroneously large vortex in 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

The simulated Nari makes landfall over Kee-Lung (1400 LST 16 September), only 15-20 km off the actual landfalling position of I-Lan, and the central pressure intensity enhances with horizontal resolutions increases (Fig. 1). Numerical simulations with different horizontal grid sizes show that the ability of the model to successfully predict the observed rainfall maximum is increased with the refinement of grid size, consistent with Wu et al. (2002). The MM5 model with a 2.2-km grid size can simulate the maximum 24-h (0000 LST 17 September to 0000 LST 18 September) rainfall of 855 mm near Mount Snow on September 17th, in close agreement with observed maximum of 940 mm (Fig. 2). As the grid size is reduced to 6.67, 20, and 60 km, the simulated rainfall maximum over Mount Snow is decreased to 709, 426, and 184 mm, respectively. The hydrometeor trajectories in the eyewall are mainly from ocean and lifted by the strong updraft, and almost stay at upper troposphere (150 hPa). When the hydrometeor has a size big enough to counteract the buoyancy, it will precipitate rapidly to ground within 3-4 hours (Fig. 3).

When Nari was still in the ocean, its precipitation and circulation structures were quite axis-symmetric, and the maximum condensational heating level 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.

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, shows 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, there was less ice-phase hydrometeors, compared to the more liquid-phase hydrometeors as indicated by the liquid-water path. These ice-phase hydrometeors (ice crystals and snow flakes) occurred mainly over the top of eyewall near northern Taiwan, not over the windward slopes of Central Mountain Range.

A horizontal pressure gradient of 7-8 hPa within 50 km was simulated near the inner core, in comparison with derived pressure gradient of 5-6 hPa from radar data using a thermodynamic retrieval method (Liou et al. 2003). Simulated vertical divergence profile also compares fairly with that estimated by radar observations using the VAD technique. A series of numerical experiments are conducted to examine the sensitivity of simulated typhoon intensity, track, rainfall amount and precipitation structure to the choice and details of microphysics parameterizations used in the model. Analyses of air-parcel and hydrometeor trajectories over the ocean and mountain area are performed to investigate the complex interaction between the microphysical and topographic processes.

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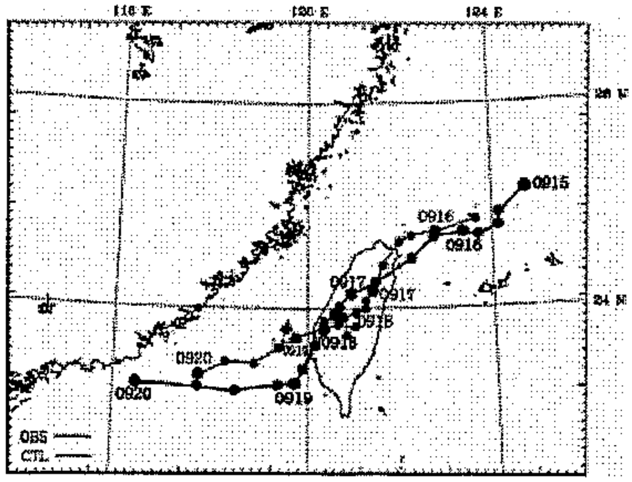
(a)



(b)

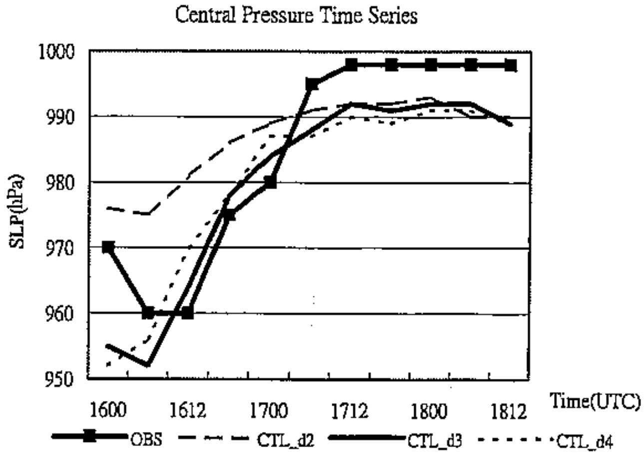


Figure 1. (a) The tracks of Typhoon Nari. The black line is the best track provided by the Central Weather Bureau (OBS) and the gray line is MM5-predicted track; a dot along the line represents the position of typhoon center every 6 h. (b) The central pressure of time series of Typhoon Nari.

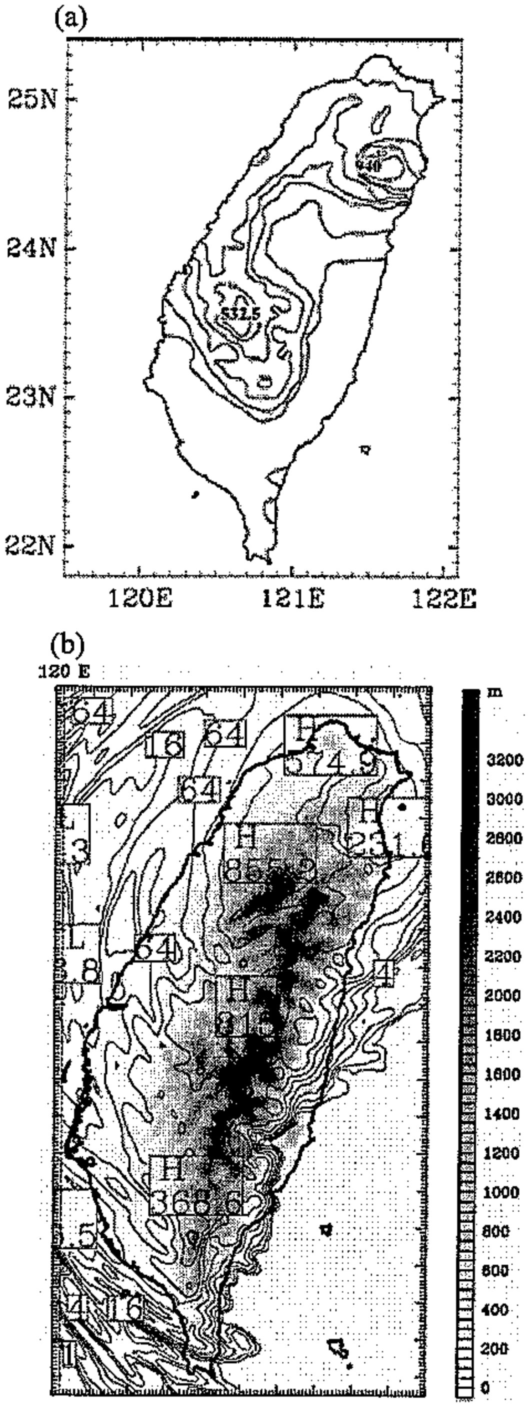


Figure 2: (a) The observed 24-h rainfall (0000 LST17 September to 0000 LST 18 September) and (b) the corresponding simulated 24-h rainfall (mm) on the 2.22-km MM5 gird. Shaded is terrain height.

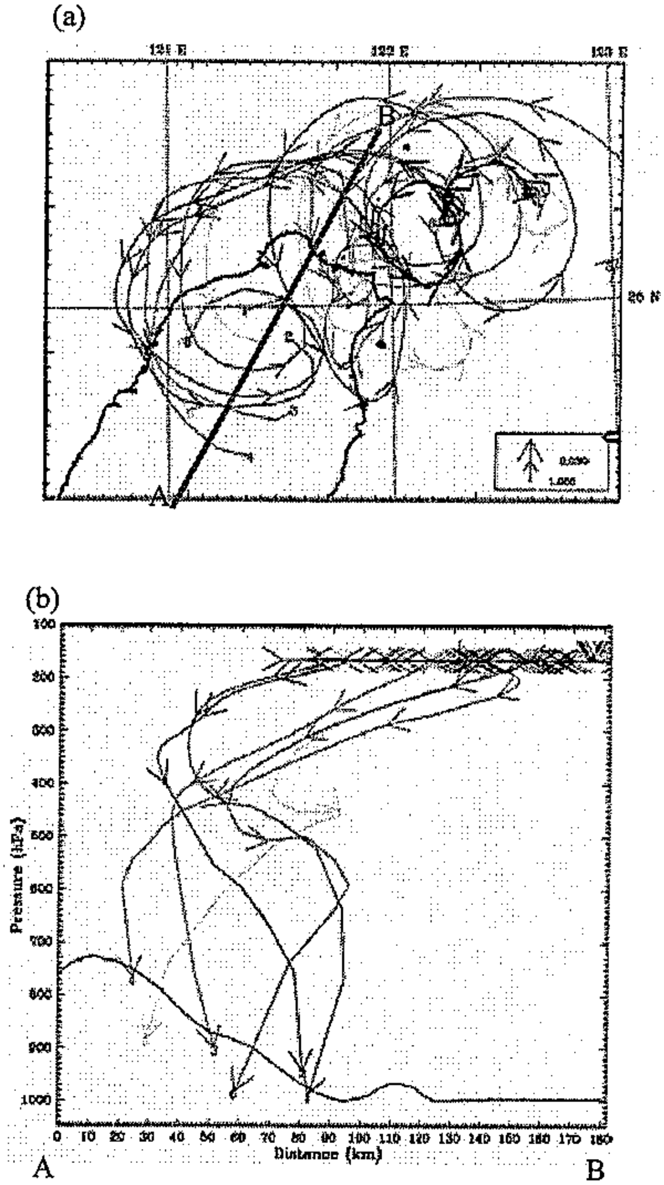


Figure 3: (a) The horizontal and (b) vertical cross section showing the simulated hydrometeor trajectories. Line AB in (a) is the horizontal position of the vertical cross section in (b).