A Multiscale Study of the Landfalling Typhoon Nari (2001): Control Simulation and Observation verification

Ming-Jen Yang* 楊明仁
Institute of Hydrological Sciences, National Central University
Shiao-Ling Huang 黃小玲
Institute of Geography, Chinese Culture University

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 responsible for heavy rainfalls of Typhoon Nari. The simulated Nari made landfall over Kee-Lung (30 hours after initialization), only 15-20 km off the actual landfalling position of I-Lan. The MM5 model with a 2-km grid size can simulate the maximum 24-h rainfall of 1183mm near I-Lan on September 17th, in close agreement with observed maximum of 1188mm. 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. More observation verifications of model simulation results are discussed in the paper.

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 54, 18, 6, and 2 km, respectively, and 31 sigma levels in the vertical. The simulation is integrated for 108h, starting from 120 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: the Grell (1993) cumulus parameterization scheme, the Reisner microphysics scheme with graupel (Reisner et al. 1998), the MRF PBL scheme (Hong and Pan 1996), and the atmospheric radiation scheme of Dudhia (1989). Note that no cumulus parameterization scheme is used on the 6 and 2-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 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

---

*Corresponding author address: Dr. Ming-Jen Yang, Institute of Hydrological Sciences, National Central University, Chung-Li, 320, Taiwan. E-mail: mingjen@cc.ncu.edu.tw

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) and Yang and Huang (2004), so we only present updated progress and ongoing work here. For the results reported here, we have redone the control simulation to have a slightly higher horizontal resolution. So the domain sizes for the four-nested grid are 54, 18, 6, and 2 km, respectively, instead of the 60-20-6.67-2.22-km configuration used in Yang (2003) and Yang and Huang (2004). We also moved the model top to 50 hPa, instead of 100 hPa used in Yang (2003) and Yang and Huang (2004). The model is now initialized at a synoptic time of 1200 UTC 15 September 2001, instead of a nonsynoptic time of 1800 UTC 15 September 2001 used in Yang (2003) and Yang and Huang (2004).

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 of 17 September (0000 UTC 17 September to 0000 UTC 18 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, and the simulated rainfall maximum of 1183 mm was very close to the observed maximum of 1188 mm. As the grid size is reduced to 6, 18, and 54 km, the simulated rainfall maximum over Mount Snow is further decreased (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.

Figure 2 further illustrates the comparison of simulated versus observed radar reflectivity field from the WuFeng Shan radar. Note that because of the landfall timing error (roughly eight hours earlier) of the simulated Nari, both radar reflectivity fields are adjusted in time so that both typhoon centers are at relatively the same position with respect to Taiwan's northern coast. Also note that both simulation and observation data are analyzed in the same horizontal resolution (6 km) and the same height (3 km AGL), and both are displayed in the same color scale. It is evident in Fig.2 that the heavy precipitation around the eyewall, a clear typhoon eye, and the spiral rainbands are well simulated by the MM5 model.

Figure 3 shows the comparison of simulated versus observed radar radial wind field from the WuFeng Shan radar. Again, both fields are adjusted in time so that both typhoon centers are at relatively the same position with respect to Taiwan's northern coast. Also both data are analyzed in the same horizontal resolution (6 km) and the same height (3 km AGL), and are displayed in the same color scale ("positive" red color is for wind away from the radar and "negative" blue color is for wind coming toward the radar). It is clear from Fig. 3 that the counterclockwise tangential wind circulation around Nari is well captured by the MM5 model, although the simulated wind (of maximum radar wind of 40 m/s) is slightly stronger than the observed wind (of the maximum radar wind of 35 m/s).

A horizontal pressure gradient of 7~8 hPa within 50 km near the inner core was simulated by the MM5 (not shown), in comparison with derived pressure gradient of 5~6 hPa from radar data using a thermodynamic retrieval method (Liou et a. 2003). Simulated vertical divergence profile also compares fairly with that estimated by radar observations using the VAD technique. The issue of precipitation efficiency associated with Typhoon Nari has been discussed in Sui et al. (2005). Our ongoing work is to conduct a series of numerical experiments 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 open ocean and mountain area are also performed to investigate the complex interaction between the microphysical and topographic processes. More simulation results will be presented in the conference.

Acknowledgements

This research is supported by the National Science Council in Taiwan, ROC, under Grants NSC 94-2111-M-008-015-AP1 and NSC 94-2625-Z-008-005. The authors thanks Profs. Yu-Chieng Liou, Tai-Chi Chen, and Dr. Jen-Hsin Teng for providing us the radar data and RASTA radar data analysis software.

Reference

Davis, C. and S. Low-Nam, 2001: The NCAR-AFWA tropical cyclone bogussing scheme. *A report prepared for the Air Force Weather Agency (AFWA)*. National Center for Atmospheric Research, Boulder, Colorado. (Available from the MM5 web site at http://www.mmm.ucar.edu/mm5)

Dudhia, J. 1989: Numerical simulation of convection observed during the Winter Monsoon Experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.*, **46**, 3077-3107.

Grell, G. A., 1993: Prognostic evaluation of assumptions used by cumulus parameterizations. *Mon. Wea. Rev.*, **121**, 764-787.

Grell, G. A., J. Dudhia, and D.R.Stauffer,1995: A description of the fifth-generation Penn State/NCAR Mesoscale Model. NCAR Technical Note,122 pp.

Hong, S.-Y., and H.-L. Pan, 1996: Nocturnal boundary layer vertical diffusion in a medium-range forecast model. Mon. Wea. Rev., 124, 2322-2339.

Liou, Y.-C., T.-C. C. Wang, and K.-S. Chung, 2003: A three-dimensional variational approach for deriving the thermodynamic structure using Doppler wind observations—An application to a subtropical squall line. J. Appl. Meteor., 42, 1443-1454.

Reisner, J., R. J. Rasmussen, and R. T. Bruitjes, 1998: Explicit forecasting of supercooled liquid water in winter storms using the MM5 mesoscaled model. *Quart. J. Roy. Meteor. Soc.*, **124**, 1071-1107.

Sui, C.-H., and Coauthors, 2002: Meteorology-hydrology study targets Typhoon Nari and Taipei flood.. *Eos*, Transctions, AGU, **83**, 265, 268-270.

Sui, C.-H., X. Li, M.-J. Yang, and H.-L. Huang**,** 2005: Estimation of oceanic precipitation efficiency in cloud models. *J. Atmos. Sci.*, in press.

Wu, C.-C., T.-H. Yen, Y.-H. Kuo, and W. Wang, 2002: Rainfall simulation associated with Typhoon Herb (1996) near Taiwan. Part I: The topographic effect. *Wea. Forecasting*, **17**, 1001-1015.

Yang, 2003: Precipitation structure and processes of Typhoon Nari (2001): A modeling prospective, 第五屆雷達氣象近期研究研討會，桃園中壢市，2003 年 3 月 17-18 日，中央大學主辦，7-13。

Yang, M.-J., and H.-L. Huang, 2004: Precipitation processes associated with the landfalling Typhoon Nari (2001). *Preprints. The 26th Conference on Hurricanes and Tropical Meteorology*, Miami, 3-7 May 2004, Amer. Meteor. Soc., 134-135.

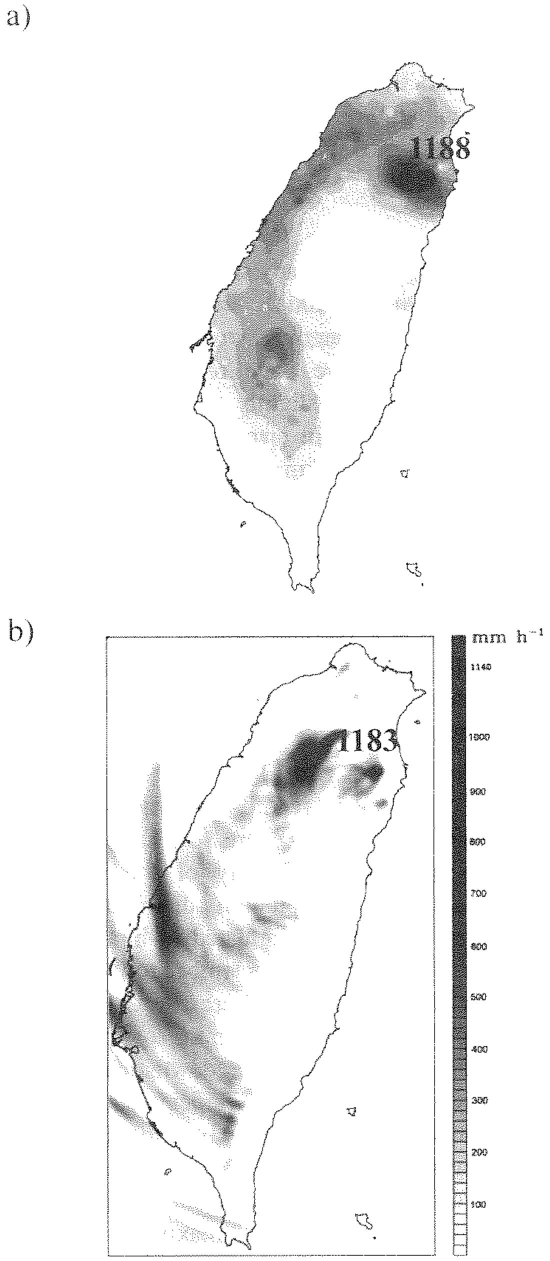

Figure 1: (a) The observed 24-h rainfall (0000 LST 17 September to 0000 LST 18 September) and (b) the corresponding simulated 24-h rainfall (in units of mm) on the 2-km MM5 gird.

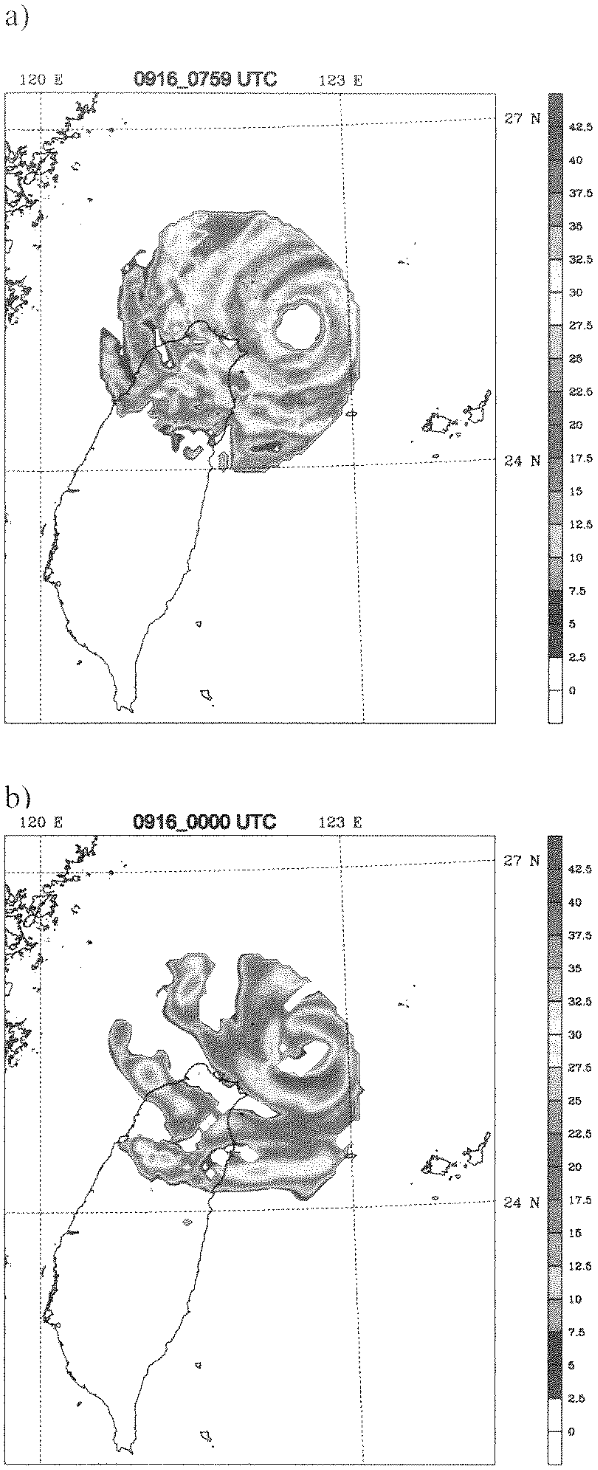

Figure 2: (a) The observed radar reflectivity field (in dBZ) of Typhoon Nari at 0759 UTC 16 September and (b) the simulated radar reflectivity at 0000 UTC 16 September 2001 at 3 km AGL

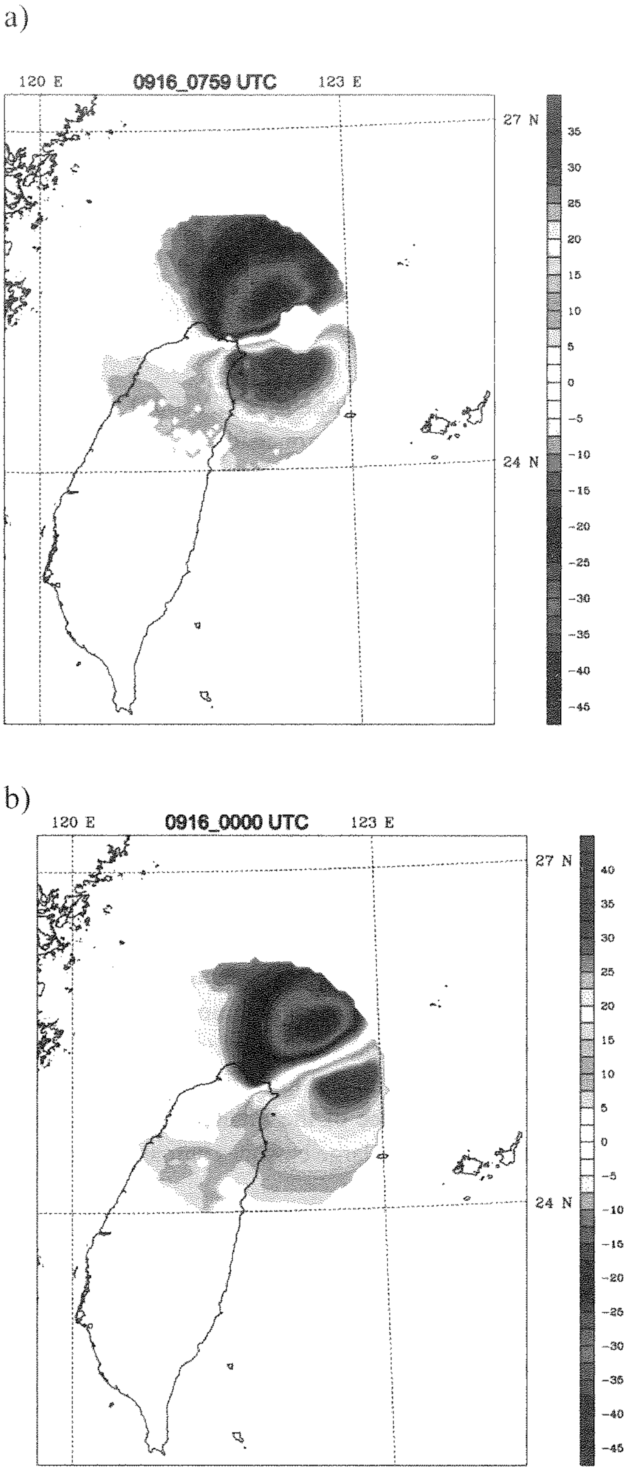

Figure 3: As in Fig,2 but for (a) the observed radial velocity and (b) the simulated radial velocity for the Wu Feng shan radar at 3 km AGL