Cloud-Resolving Simulated Cloud-Precipitation Processes of a Landfall Tropical Storm

Donghai Wang[1,2], Wei-Kuo Tao[2], Ying Liu[1], Haiguang Zhou[1], and Xiaofan Li[3]
[1]State Key Laboratory of Severe Weather ,Chinese Academy of Meteorological Sciences, Beijing, China
[2]NASA/Goddard Space Flight Center, Greenbelt, MD, USA
[3]NOAA/NESDIS/Office of Research and Applications, Camp Springs, MD, USA

1. INTRODUCTION

The landfall of typhoons causes major floors and associated socio-economic losses over southeast coast of China. The understanding of the surface rainfall processes associated with typhoon-induced torrential rainfall events relies on numerical modeling. The cloud-resolving models have been used to study convective systems and associated precipitation. The simulations have been validated with observations in terms of atmospheric thermodynamic states and cloud microphysical and rainfall properties.

In this study, a cloud-resolving simulation of a torrential rainfall event associated with the landfall of Typhoon Bilis (2006) is carried out using a large-scale forcing from National Centers for Environmental Prediction (NCEP)/Global Data Assimilation System (GDAS) data. The questions to be addressed in this study are: How good are the cloud-resolving typhoon simulations compared to the observations? Which processes play important roles in determining the cloud and rainfall development? The model, data, and experiment are briefly described in the next section. In section 3, the simulation will be compared with observations of rain gauge and radar. In section 4, the surface rainfall and cloud microphysical budgets will be analyzed using the simulation data. A summary is given in section 5.

2. MODEL, DATA, AND EXPERIMENT

The cloud-resolving model (Soong and Ogura 1980; Soong and Tao 1980; Tao and Simpson 1993) used in this study is the two-dimensional version (Sui et al. 1994, 1998) modified by Li et al. (1999). The model uses cyclic leteral boundary conditions, a horizontal domain of 768 km, a horizontal grid resolution of 1.5 km, and a time step of 12 s. The top model level is 42 mb. The vertical grid resolution ranges from about 200 m near the surface to about 1 km near 100 mb.

The reanalysis data from NCEP/GDAS that have a horizontal resolution of 0.5^o x 0.5^o and a temporal resolution of 4 times per day are used to construct time-varied zonally-uniform vertical velocity, zonal wind, and horizontal temperature and vapor advection. The forcing data are interpolated to be imposed in the model at each time step. The model is integrated from 0800 LST 14 July to 0800 LST 20 July 2006 (a total of 6 days) with the forcing averaged in a rectangular box of 108-116E, 23-24N.

3. COMPARISON OF SIMULATIONS WITH OBSERVATIONS

The brightness temperature measured from satellite Fengyun II shows that the negative brightness temperature (<-30 oC) occurs from 14 July to 18 July 2006, which coincides with upward motion. The large negative brightness temperature (<-60 oC) appears during the period of 15-16 July 2006 when imposed upward motion is strong. The negative brightness temperature (<-30 oC) shows westward propagations as the westerly winds prevail. Time-longitude distribution of observed surface rain rate calculated from rain gauge data mainly displays rainfall during the period of 14-18 July 2006, and westward propagation, which is consistent with the analysis of satellite brightness temperature.

Figures display time-zonal distribution of simulated surface rain rate during 6-day integration. The comparison shows similarities in surface rain rate in the areas of X=400-768 km from the simulation and 113-116oE from the observation on 15 July 2006 and in the areas of X=0-400 km from the simulation and 108-112oE from the observation on 16 July 2006, although the simulated surface rain rate is larger than the observed surface rain rate. The westward propagation of simulated rainbands is similar to that of observed rainbands. However, the observed surface rainfall appears between 112-116oE whereas the simulated surface rainfall is absent between X=400 and X=768 on 16 July 2006. The observed surface rainfall continues to cover most of the area whereas the simulated surface rainfall only is present over the small portion of area on 17 July 2006.

The time series of domain-mean simulated surface rain rate is compared with that of observed surface rain rate in Fig. 1. The observed surface rain rate is calculated using the rain gauge data in a rectangular box of 108-116oE, 23-24oN, which is the simulation domain. The simulated and observed surface rain rates show a similarity, in particular, during the period of 16-17 July 2006. The differences include the following: (1) the simulated surface rain rate leads the observed surface rain rate by 3-5 hours; (2) the simulated surface rain rate is generally larger than the observed surface rain rate, in particular, in late afternoon of 16 July and early morning of 17 July 2006; (3) the simulation does not produce the small surface rain rate on 18 July 2006; (4) unlike the observation, the model generates the moderate surface rain rate on late19 and 20 July 2006. The differences may be partially due to the inconsistent calculations of phase and magnitude of the imposed vertical velocity from the 6-hourly NCEP/GDAS data and partially due to the sampling and accuracy of observed rain gauge data.

4. ANALYSIS OF SURFACE RAINFALL AND CLOUD MICROPHYSICAL BUDGETS (NOT SHOWN HERE)

5. SUMMARY

A torrential rainfall event associated with a landfall of Typhoon Bilis (2006) is investigated using a two-dimensional cloud-resolving model. The model is integrated for 6 days with imposed zonally-uniform vertical velocity, zonal wind, horizontal temperature and vapor advection from NCEP/GDAS data. The comparison study in surface rain rate and reflectivity between simulations and observations is carried out. The simulation captures major rainbands in 15-16 July 2006. The comparison in rain gauge and radar reflectivity data between the simulations and observations shows general agreement.

The rainfall distribution shows that stratiform rainfall covers most of the simulation domain on 15 July 2006 whereas convective rainfall is significantly seen on 16 July 2006. Thus, the cloud properties and rainfall processes in the two days are analyzed and compared. The similarities in cloud and rainfall processes between the two days include the following: (1) vapor convergence mainly accounts for surface rainfall in domain-mean and convective rainfall budgets; (2) domain-mean ice water path is smaller than domain-mean liquid water path. The differences include the following: (1) the change of local vapor from the gain on 15 July to the loss on 16 July accounts for the increase of domain-mean surface rain rate from 15 to 16 July 2006; (2) raining stratiform rainfall covers 88.8 % of simulation domain on 15 July 2006 whereas it only covers 46.0 % on 16 July; (3) fractional convective and non-raining stratiform coverage and clear-sky coverage significantly increases on 16 July; (4) domain-mean surface rainfall and cloud hydrometeors come from stratiform regions on 15 July and by convective regions in 16 July; (5) vapor convergence is a major stratiform rain source on 15 July whereas about half of stratiform rainfall comes from local vapor loss and another half is from local hydrometeor loss/hydrometeor convergence and vapor convergence on 16 July; (6) in non-raining stratiform regions, the vapor convergence yields atmospheric moistening on 15 July whereas the vapor divergence causes atmospheric drying on 16 July.

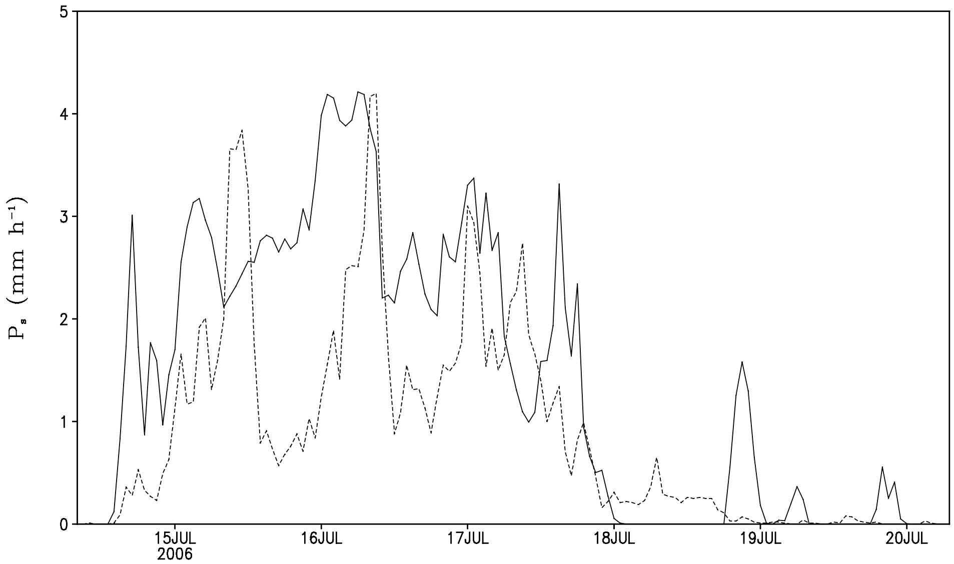

FIG. 1 Time series of domain-mean simulated (solid). The dashed line denotes observed calculated in a rectangular box of 108-116E, 23-24N. Unit is mm h^{-1}.