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NUMERICAL SIMULATION OF HEAVY RAINFALLS IN THE BAIU FRONT BY THE WRF AND MM5

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1. INTRODUCTION

In recent years, natural disasters, such as strong winds and heavy rainfall, occur frequently, and have done serious damage to life. The MM5 has been widely used for the prediction of natural disasters. The WRF model is a next-generation numerical weather prediction model with advanced dynamics, physics, and numerical schemes, and thus it is expected that the WRF is more useful than the MM5 in the analysis and prediction of the natural disaster. However, verification of the simulation of heavy rain which causes a natural disaster, particularly the simulation of heavy rain under the Baiu front with a different mechanism from the squall line in the U.S. has hardly been performed yet. Thus, in this study, we conduct a simulation of the heavy rain under the Baiu (Meiu) front which caused the natural disaster to kill 15 people, and investigate the performance of the WRF model. Furthermore, the usefulness of the WRF model is evaluated by comparing with the result of the MM5 model.

2. HEAVY RAINFALLS IN THE BAIU FRONT

The Baiu front extended from the Sea of Japan to the southern Tohoku district occurred from July 12th to 13th, 2004, and it caused record heavy rain in the Niigata-Fukushima areas (Figure 1).

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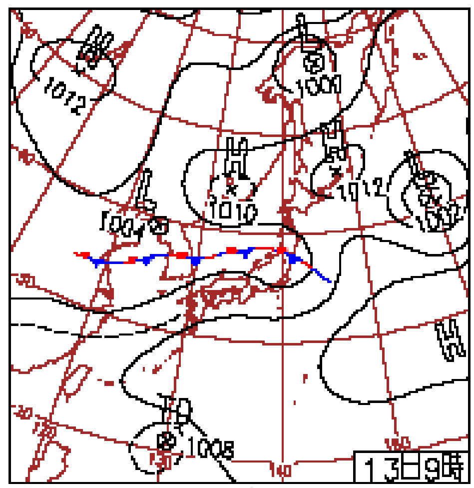

Figure 1: Surface Weather Chart on 0900 JST July 13th 2004.

The 3-hourly precipitation is shown in Figure 2. At 0600 JST July 13th 2004, rainfall exceeding 20 mm per three hours was widely observed over the Niigata area (Figure 2a). Two convective lines extended around the Noto Peninsula. Afterward, the convective line was well developed and made a band-shaped rainfalls exceeding 100 mm per three hours from north of the Noto Peninsula to the inland area of Niigata area (Figure 2b). The band-shaped rainfalls lasted for 6 hours, and gradually dissipated at around 1500 JST July 13th. At Sanjo station in the Niigata area, an hourly precipitation of 43 mm was recorded on 0700 JST July 13th, and the 24-hourly precipitation on 2100 JST July 13th was 208 mm.

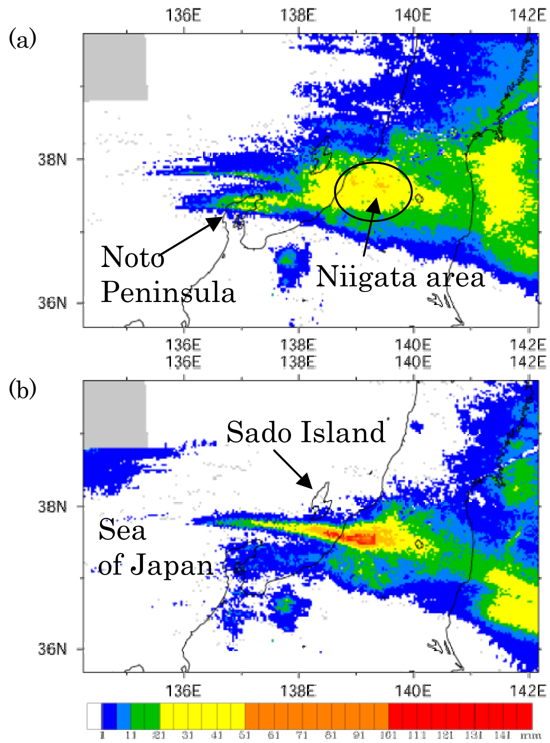

Figure 2: 3-hourly precipitation from Radar AMeDAS. (a) 0600 and (b) 0900 JST July 13th 2004.

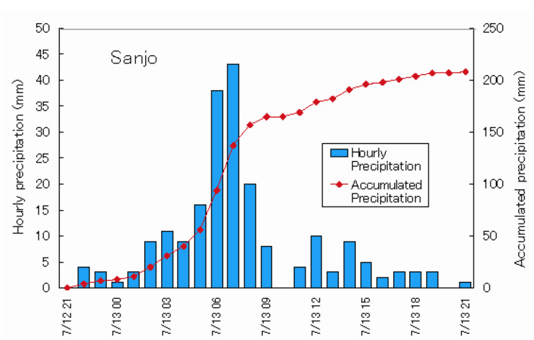

Figure 3: Time series of hourly precipitation and accumulated precipitation at Sanjo station.

3. NUMERICAL SIMULATIONS BY THE WRF AND MM5

(1) Model Setup

Control simulations of the WRF and MM5 are designed as follows. The 1st domain is 3600km in the horizontal direction and includes Japan, Taiwan, and Kamchatka peninsula. The 2nd domain is 1320km in the horizontal direction. The horizontal grid spacing for the 1st and 2nd domains is 12km and 4km, respectively. The 31 sigma levels are set up in the vertical both of the 1st and 2nd domains. The numerical integration starts at 2100 JST July 12th 2004 and runs 24 hours. NCEP-FNL data is used for creating the initial and boundary conditions. Physics schemes are also basically same between the WRF and MM5, which includes Dudhia short wave radiation, RRTM long wave radiation, Kain-Fritsch cumulus parameterization (only for the 1st domain), Lin (WRF) and Goddard (MM5) cloud microphysics, MRF-PBL, and Noah-LSM. However, the dynamics and numerical schemes are different between the WRF and MM5; the 3rd order Runge-Kutta (WRF) and Leap-Frog (MM5) for the time scheme, Arakawa-C (WRF) and Arakawa-B (MM5) for the grid arrangement, 5th order upwind (WRF) and 2nd order centered (MM5) for the horizontal advection scheme, Smagorinsky model (WRF) and constant (MM5) for the horizontal diffusion coefficient, for instance.

(2) MM5

Figure 4 shows the distribution of the 3-hourly accumulated rainfall simulated by the MM5. At 0600 JST, the simulated rainfall areas agree with the observations well, except the area located at northwest of the Sado Island. The MM5 predicts the band-shaped heavy rainfalls around the Niigata area. However, the rainfalls exceeding 100 mm per three hours appear earlier than the observation. Additionally, the most intensive rainfall from the MM5 appears west of the coast, although the observation is over Niigata area.

(3) WRF

a) Control Case

Figure 5 shows the distribution of the 3-hourly accumulated rainfall simulated by the WRF. Like the MM5, the WRF represents the rainfall areas well, and predicts the band-shaped heavy rainfall over the Niigata area. That is, the WRF predicts the position of the most intensive rainfall better than the MM5. However, the rainfalls exceeding 100 mm per three hours appear and disappear earlier than the observation.

(a)

(b)

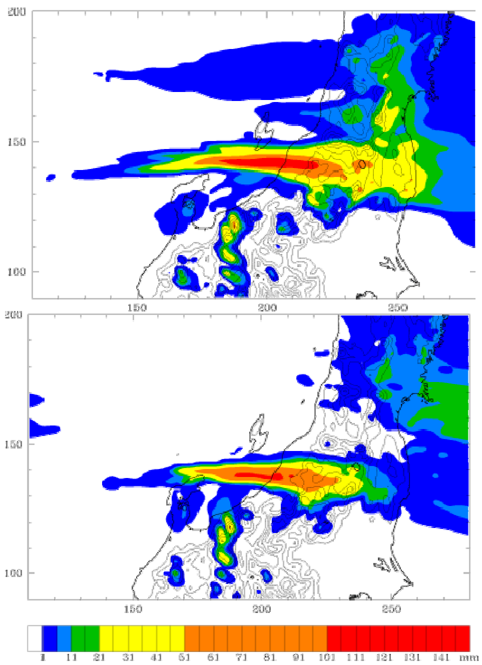

Figure 4: Figure 2: 3-hourly precipitation from the MM5. (a) 0600 and (b) 0900 JST July 13th 2004.

(a)

(b)

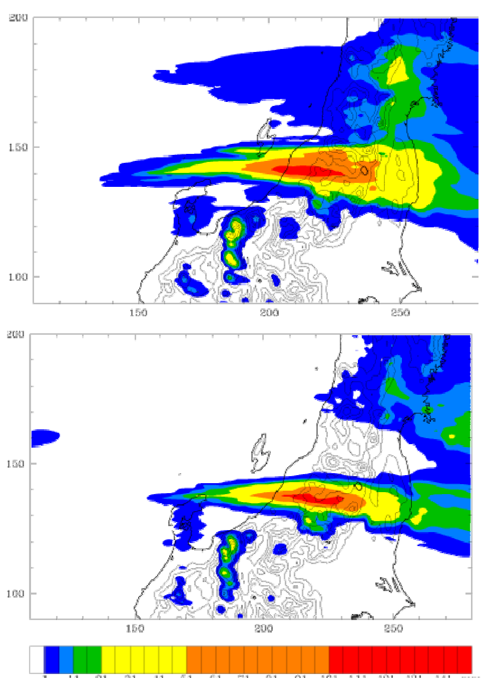

Figure 5: Same as Figure 4, except for the WRF.

b) Experimental Cases

Two sets of numerical experiments were conducted by the WRF in order to find the impact of differences between the WRF and MM5. We first run the WRF with 2nd order accurate centered differencing scheme and constant horizontal diffusion coefficient, which is the same as horizontal grid spacing. These schemes are closer to those in the MM5. Figure 6 shows the distribution of the 3-hourly accumulated rainfall from the experiment. Comparing them with Figure 5, the results from the experimental case are similar to those from the control case. Additionally, the position of the most intensive rainfall is similar to that of the control case. However, the 2nd order centered scheme with constant diffusion coefficient gives more smoothed forecast of the precipitation than the 5th order upwind scheme with Smagorinsky, and thus the experiment case makes band-shaped heavy rain disappear earlier than the control case.

(a)

(b)

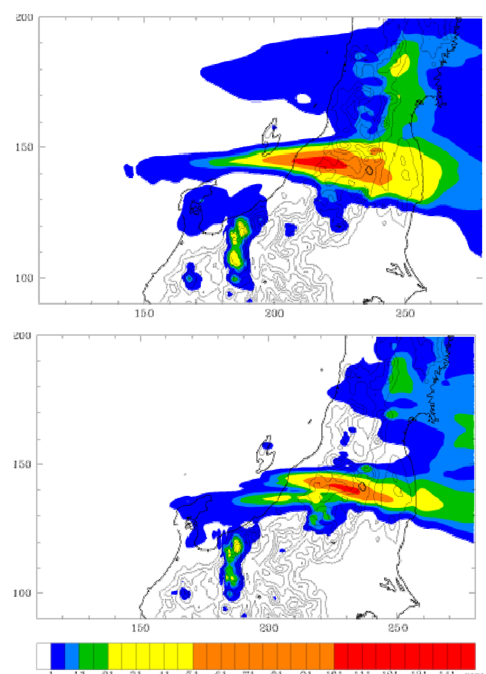

Figure 6: Same as Figure 5, except for the WRF with 2nd order centered scheme and constant diffusion coefficient.

Second, we run the WRF with simpler cloud microphysics, WSM3 in order to find the impact of the small difference in the microphysics between the WRF and MM5. The simulated results roughly agree with those of the control case, except precipitation amount (Figure 7). This indicates that the small difference in the cloud physics between the WRF and MM5 has a little impact on the position of the heavy rain in the present case.

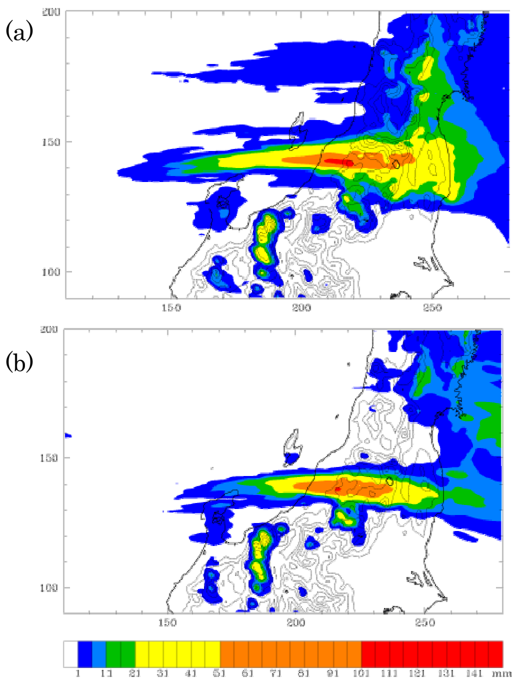

Figure 7: Same as Figure 5, except for the WRF with WSM3.

4. DISCUSSION

Some may think that the difference in the position of the most intensive rainfall between the WRF and MM5 is due to one of the well-known features of the Leap-Frog scheme, which has lagging phase error. However we consider that the impact of the time scheme is not so large, except in ensuring numerical stability. The behind idea is that the atmospheric phenomenon is not so rapidly changed as the other fluid ones, particularly in the present case. From these, we consider that the difference in the position should be due to the differences in the systematic error and/or the other numerical schemes such as the grid arrangement, which affects the accuracy of the wind convergence and pressure term, for instance.

When the simulation is conducted by the WRF with even-number order centered scheme and Smagorinky model, the numerical instability appeared due to the behavior of the truncation error (Figure 8). This indicates another advantage of the WRF, which has 3rd and 5th order upwind schemes with the implicit numerical filter to suppress the computational noise.

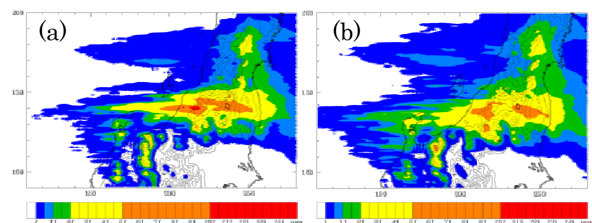

Figure 8: Same as Figure 5a, except for the WRF with (a) 2nd order and (b) 6th order centered scheme and Smagorinsky model.

5. SUMMARY

We conducted the numerical simulation of the band-shaped heavy rainfall in the Baiu front using the WRF and MM5, and found differences in the features between the two models. The simulated results showed that the WRF model reproduced the position of the band-shaped heavy rainfall better than the MM5. The results from the sensitivity experiments indicated that the difference was not due to the horizontal advection and diffusion schemes but the systematic error of the MM5 and/or the differences in the other numerical schemes. Furthermore, the simulation showed the advantage of the high order upwind schemes.