A Sensitivity Study of Integration Time-Step in Heavy Rainfall Simulation

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1. Introduction

In the integration of a non-hydrostatic system, computational efficiency and accuracy are significantly dependent on integration time-step. In spite of low integration efficiency, a short time step should be used for numerical stability condition. Therefore, in general, most numerical models have used time splitting method for computational efficiency. A time splitting method usually uses smaller time step for a high frequency mode and longer time step for a low frequency mode (Marchuk, 1974). The method is also applied to the Weather and Research Forecast (WRF) model (Klemp et al., 2000). In particular, the third-order Runge-Kutta scheme for time integration and a high order spatial discrete scheme for the advection term are used in the time splitting method of the WRF model. The Runge-Kutta scheme results in good computational efficiency and high accuracy in solution with high order spatial differentiation, as shown by Wicker and Skamarock (2002).

In heavy rainfall simulations, rainfall amount and location highly depend on a number of factors such as initial and boundary condition, model resolution, and physical processes parameterizations (Lee, 2004). Because the integration time-step is also an important factor in predicting heavy rainfall, we investigate the sensitivity of heavy rainfall simulation over East Asia to integration time-step and an optimal range of integration time-steps between accuracy and efficiency.

2. Method

Experiments are performed using time steps 90, 120, 150, and 180 seconds on the model domain (197 × 171 grid points) with 30 km horizontal grid spacing and 34 vertical layers between the 50 hPa model top and the surface in the WRF model (Version V2.0.3.1). Assuming constant flow having 100 m/s for the 30 km horizontal resolution, the four time steps correspond to 0.3, 0.4, 0.5, and 0.6 CFL conditions($=U\Delta t/\Delta x$), respectively. Model initial and lateral boundary conditions are obtained from the NCEP global final (FNL) analyses with 1 degree horizontal resolution. For the parameterization of physical processes, the Kain-Fritsch (New Eta) cumulus parameterization scheme, the Lin et al. cloud microphysics scheme, the YSU PBL schemes, and the NOAH land surface scheme are used. The experiments are run for two heavy rainfall cases over the Korean Peninsular. Experiments are also performed on a nested domain (220 × 193) with 10 km horizontal grid spacing using integration time-steps 30, 40, 50 and 60 seconds.

3. Results

3-1. Case 1 (23-25 August 2003)

A heavy rainfall event occurred over the Korean Peninsular with 24-hour rainfall of 176.5 mm and hourly rainfall of 64.5 mm in Seoul during 23-25 August 2003. In this case, most simulated rainfall amount results from grid-resolvable (non-convective) rain. Figure 1 shows the 24 hour accumulated rainfall distribution and maximum rainfall points of observation and the simulated results with the initial time at 00 UTC 23 August. The simulated precipitation distribution over central region of the Korean Peninsular is similar between experiments. In particular, two maximum rainfall points are well captured in all experiments. However, there are obvious differences in rainfall amount and location between the experiments (Figure 1). The 24-hour accumulated maximum rainfall for the initial time at 12 UTC 23 August is shown in Table 1. With the initial time, the model simulates much overestimated rainfall. There are also pronounced difference in 24-hour accumulated rainfall amount between the experiments. Precipitation amount is about 40 % overestimated in EX90 and about 80 % overestimated in EX180. Hourly maximum rainfall amount is also different between experiments depending upon model initial time and time step. The simulated rainfall peak is about

Table 1. Observed and simulated 24-hour (00 UTC 24 – 00 UTC 25) accumulated rainfall (mm) at the maximum rainfall points, Seoul and Hongcheon, using the method initial time at 12 UTC 23 August for Case 1.

Observation	EX90	EX120	EX150	EX180
Seoul / Hongcheon : 176.5 / 161.5	297.4	287.0	253.0	323.8

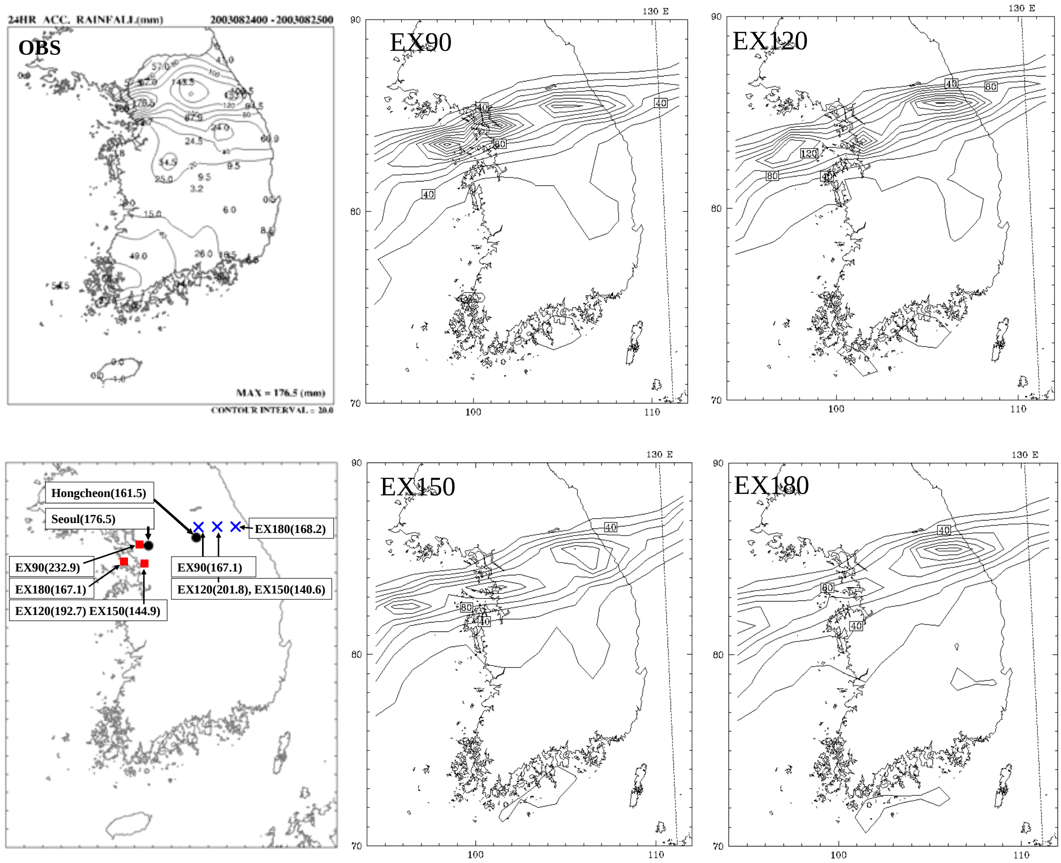

Figure 1. The 24 hour (00 UTC 24 – 00 UTC 25) accumulated rainfall and its maximum points (lower left panel) of observation and simulation with the initial time at 00 UTC 23 August. EX90, EX120, EX150, and EX180 indicate the experiments in which time-steps are 90, 120, 150, and 180 second, respectively.

Table 2. Hourly maximum rainfall (mm) for Case 1.

Model initial time	Observation	EX90	EX120	EX150	EX180
00UTC 23 August	64.5	68.8	51.5	43.8	17.9
12UTC 23 August	64.5	72.3	85.0	64.6	84.5

10 hours delayed in the experiment using the initial time of 00 UTC 23 (Figure 2), and about 5 hours for 12 UTC. For this heavy rainfall case the time steps 90, 120 and 150 seconds for model integration would be acceptable in terms of comparison with observation.

3-2. Case 2 (24-25 July 2003)

This is a rapidly developing heavy rainfall case with 30.5 mm/hour over Chungju at 18 UTC 24 July, 27.5 mm/hour over Sangju at 00 UTC 25, and 85 mm/hour over Jeonju at 02 UTC 25. In this case, simulated total rainfall amount results mostly from convective rain by the cumulus parameterization scheme. The 24-hour maximum rainfall amount is shown in Table 3. The model does not simulate the observed hourly rain peak of 85.0 mm, but the total amount is close to observation. The rainfall amount differences between time steps in this case are relatively small compared to those in Case 1. Figure 3 shows the simulated secondary rainfall maximum at Chungju and Sangju. There is not much difference in total rainfall between the integration time-steps. All four time steps used for the experiments could be feasible for simulation of this heavy rainfall case.

Acknowledgements

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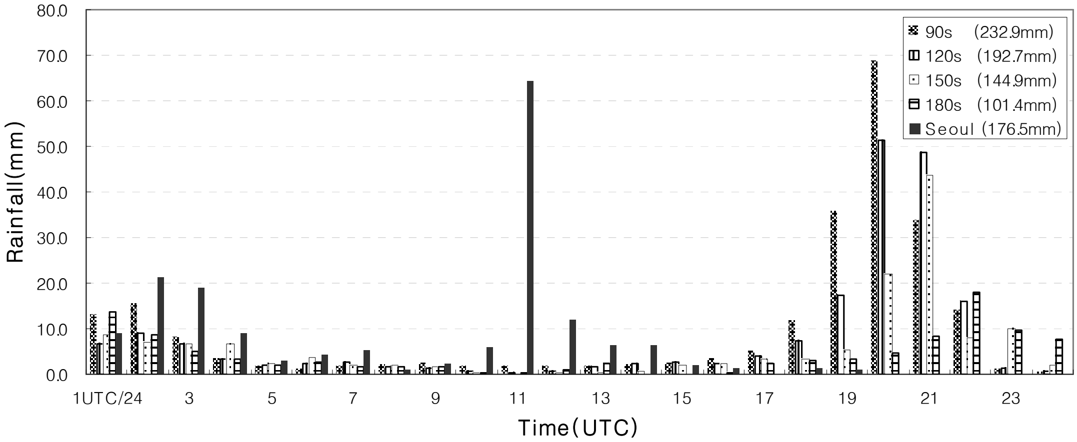

Figure 2. Time series at 24-hour maximum rainfall point using the initial time at 00 UTC 23 August for Case 1.

Table 3. Observed and simulated 24 hour (12 UTC 24 – 12 UTC 25) accumulated rainfall (mm) at the maximum rainfall points, Jeonju and Chungju, for Case 2.

Initial time: 00UTC 24 July	Observation	EX90	EX120	EX150	EX180
Jeonju	97.5	68.4	71.0	77.4	71.3
Chungju	84.5	61.0	63.5	65.4	75.4

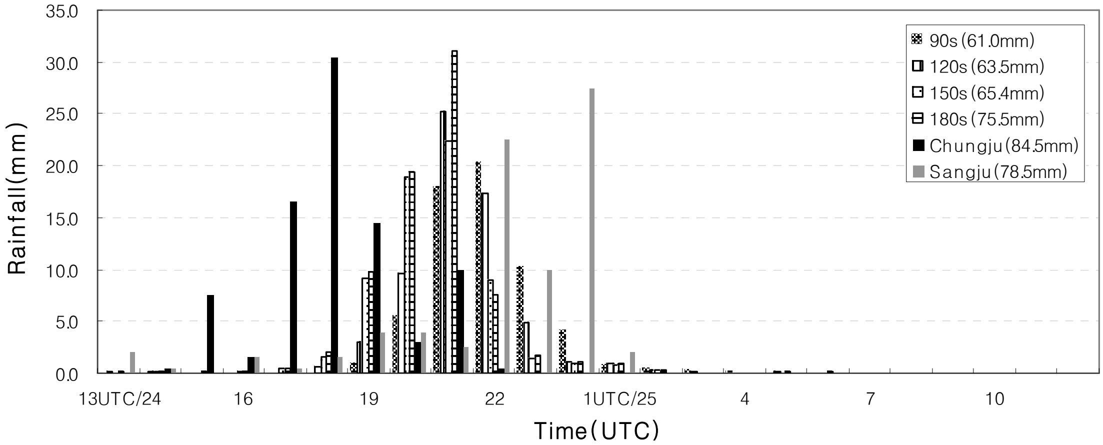

Figure 3. Time series at 24-hour maximum rainfall point using the initial time at 00UTC 24 July for Case 2.

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