A Study of Heavy Precipitation Events in Taiwan during 10-13 August, 1994: Mesoscale Model Simulations

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1. Introduction

Heavy rainfall occurred over the western side of Taiwan's complex terrain from August 10 to 13, 1994 after Typhoon Doug moved northward from the East China Sea into Taiwan and on towards the Yellow Sea. On August 10, most of the rainfall fell over sloped areas. The heaviest daily rainfall totals were in excess of 200 mm over southwestern as well as central Taiwan. However, not much rainfall occurred over northern Taiwan. The lack of rainfall over northern Taiwan also occurred on August 11, 12 and 13. The larger rainfall amounts shifted westward from the sloped areas on August 10 toward lower terrain on August 11. On August 12 and 13, most of the higher rainfall amounts were found over the coastal area in southwestern Taiwan. Notably, about 300 to 400 mm per day fell over the coastal area in southwest Taiwan on August 12 and 13. The distribution of rainfall amount was different on August 10 and 11 (termed as Case 1) compared to August 12 and 13 (termed as Case 2). The environmental situation and precipitation characteristics are analyzed using EC/TOGA data, ground-based radar data, surface rainfall patterns, surface wind data, and upper air soundings (see Chen *et al.* 2001). Chen *at al.* (2001) also categorized the precipitation pattern into two types, propagating and quasi-stationary. For the propagating type of precipitation, rainrates increased or remained the same as systems went from the plains to mountainous regions. With the quasi-stationary type of precipitation, however, rainrates decreased as precipitation propagated across the plains and into the mountains.

The focus of this study is to understand what causes the higher amounts of rainfall over Taiwan, and what factors influence where the higher amounts of rainfall will occur, over sloped areas or over coastal areas.

2. Model

The regional-scale model used in this study is the fifth-generation of the Penn State/NCAR mesoscale model MM5 V2.7. The model was initialized from NOAA/NCEP analyses (2.5° by 2.5°). Time-varying lateral boundary conditions were provided at 12-h intervals. The model was integrated, respectively, from 1200 UTC 9 August to 1800 UTC 11 August 1994 (for Case 1) and from 1200 UTC 11 August to 1800 UTC 13 August 1994 (for Case 2).

Multiple nested domains were constructed with grid resolutions of 45, 15 and 5 km, respectively; the corresponding numbers of grid points are 59 x 60 x 27, 58 x 79 x 27 and 82 x 73 x 27. The model top is located at the 50 hPa level. Time steps of 120, 40 and 13.33 s were used in these nested grids, respectively. The largest domain covers the area from southern Japan to the northern Philippines (35 - 15 N), and from central China to the west Pacific (104 - 134 E). The finest domain covers the entire island of Taiwan and the immediate vicinity.

3. Experiment design

The experiment design is summarized in Table 1. A total of twelve experiments are performed. There are seven runs simulating Case 1 and five runs for Case 2. In Run 1, the standard MM5 options for the physical processes (two-class ice scheme, simple radiation scheme, SLAB surface scheme) are chosen. The Goddard three-class ice scheme is used in Run 2 for comparison with the two-class ice scheme in Run 1. The difference between Run 1 and Run 3 is that the Goddard radiation scheme is used in Run 3 instead of the simple Dudhia radiation scheme. The PLACE land scheme is used in Run 4. In Run 5, all of the new modifications, the Goddard microphysics, PLACE and radiation scheme, are used. Run 6 is the same as Run 5 except that total (solar and longwave) radiation is turned off. The aim of this sensitivity test is to examine the effect of the land-sea breeze and PBL processes on precipitation over Taiwan. Run 7 is the same as Run 5 except the complex terrain is removed. The role of topographic lifting on the precipitation processes will be quantified in this sensitivity test.

Runs 8, 9, 10, 11 and 12 follow the model set-ups for Runs 1, 2, 5, 6 and 7, respectively, except for Case 2 (August 12 and 13).

Run	Land Processes	Microphysics	Radiation	Terrain	Case
1	Blackadar	2-Ice	Dudhia	Yes	1
2	Blackadar	3-Ice	Dudhia	Yes	1
3	Blackadar	2-Ice	Goddard	Yes	1
4	PLACE	2-Ice	Dudhia	Yes	1
5	PLACE	3-Ice	Goddard	Yes	1
6	PLACE	3-Ice	No	Yes	1
7	PLACE	3-Ice	Goddard	No	1
8	Blackadar	2-Ice	Dudhia	Yes	2
9	Blackadar	3-Ice	Dudhia	Yes	2
10	PLACE	3-Ice	Goddard	Yes	2
11	PLACE	3-Ice	No	Yes	2
12	PLACE	3-Ice	Goddard	No	2

Table 1 Summary of numerical experiments.

4. Results

In general, the model results showed that the location of precipitation was well simulated. But the timing and duration of heavy precipitation were not well simulated for both cases. The model using the standard MM5 options (2ICE scheme, simple radiation and SLAB surface model) simulated less rainfall compared to observations (see Tables 2 and 3). The model results indicated that the cloud physics, land surface and radiation processes do not generally change the location (horizontal distribution) of heavy precipitation.

The Goddard 3-class ice scheme produced more rainfall than the 2-class scheme in both cases. The third class of ice, graupel, with a faster fall speed, can fall into the melting layer and enhance the surface precipitation. However, the 3ICE scheme had much more of an impact on rainfall in Case 2 (August 12-13) than in Case 1 (August 10-11). These results are in agreement with previous MM5 studies (Kuo *et al.* 1996; Liu *et al.* 1999; Yang *et al.* 2000).

The Goddard multiple broad-band radiative transfer model reduced the amount of precipitation compared to a single broad band (emissivity) radiation model. The emissivity radiation model's longwave radiative cooling is over -6 C compared to -4 C in the Goddard radiation scheme near the surface for the cloud-free region. The stronger lower tropospheric cooling can further increase the relative humidity and consequently provide a more favorable thermodynamic condition for cloud to form. The Goddard radiation scheme also produces stronger day time radiative heating compared to the simple radiation model. Both factors could explain the reason why more rainfall is produced in the run using the simple radiation model.

The Goddard land-soil-vegetation surface model also reduced the rainfall compared to a simple surface model in which the surface temperature is computed from a surface energy budget following the "force-restore" method (SLAB surface model). Diurnal variation is clearly evident in the surface temperature and surface fluxes in both surface models. Weaker diurnal variation isfound in the run using the PLACE because the PLACE allows for precipitation feedback and vegetation-wetness. In addition, the PLACE model produces more latent heat fluxes than the SLAB model on the second day of model integration. This is caused by the moistening of the soil by the previous day's precipitation. The results also indicated that the run using the PLACE model allows for a stronger land-sea temperature gradient. The stronger land-sea temperature gradient simulated by the PLACE model run also does not enhance precipitation. Stronger latent heat fluxes were simulated in PLACE, but they did not enhance rainfall. Dynamic processes (i.e., moisture convergence and topographic lifting) may have played a major role in determining the rainfall amount.

The results (particularly for the second day of integration) from the model runs including all Goddard physical processes are in better agreement with observations than the runs using standard MM5 options. The Goddard physics runs produced significant precipitation for both cases in better agreement with observations. Hourly rainfall rates for areas over the coast, plains, slopes and mountains are also better simulated in these runs. The run with all Goddard physics, however, produced significant rainfall over the northern Taiwan Strait. This feature was not observed. Note that the PLACE and Goddard radiation scheme each reduce the rainfall amount compared to the Slab model and simple radiation scheme, respectively. Only inclusion of the Goddard 3ICE scheme should produce (slightly) more rainfall compared with the 2ICE scheme. The results suggest that there are non-linear interactive processes between precipitation, radiation and the surface. For example, different microphysical schemes can either enhance or reduce the cloudiness. Cloudiness can modulate atmospheric radiational cooling and heating profiles that can also effect the surface radiation budget. And, rainfall can modify the surface fluxes.

No offshore flow was simulated when the radiation processes were turned off. Heavy precipitation was mainly located along areas of 900-1200 m of elevation. The sensitivity tests suggest that diurnal variation of land surface temperature may be needed for the "propagating" type of precipitation that occurred in the morning on August 10. The interaction of the oncoming prevailing wind and offshore flow is important for developing the "quasi-stationary" type of precipitation on the late evening of August 12. However, without radiation, the simulated maximum precipitation in southwestern Taiwan was located inland in contrast to the coastal maximum observed. Furthermore, the model is not completely able to simulate the surface wind correctly. The conclusions from these runs need to be taken cautiously, therefore. Radiation also enhances the precipitation for both cases (two-day totals).

The Taiwan terrain can modify the characteristics of the precipitation in terms of location and timing. For example, precipitation is more organized in the run with terrain compared to the run without. Terrain increased the rainfall amount for Case 1 which had strong westerly winds in the lower and middle troposphere. The rainfall, however, was only slightly modified for August 10. This result implies that topographic lifting played a secondary role on August 10. In contrast, terrain effects reduced the total precipitation by about 7% for August 12. The larger scale (or meso-Alfa-scale) probably played the most important role in providing moisture for Case 2, and it dominated the rainfall processes.

Note that the performance of the Goddard physical processes was only based on comparisons against to the simplest ones available in the MM5. It is planned to compare the Goddard physical schemes against more sophisticated schemes for various heavy precipitation cases that developed in different geographic locations in the near future.

No matter how sophisticated the model physics, the synoptic initialization dominates the first 24 hours of simulation. The sensitivity of the model physics becomes more apparent between 24 and 48 hours of simulation time. Possible reasons for some of the poor simulations (i.e., timing and exact location of precipitation, surface wind over mountainous areas) are:

(1) The model was initialized with a very coarse resolution (2.5 by 2.5 degree) for both atmospheric thermodynamic, dynamic and soil vegetation land data sets. In addition, the SST was kept constant neglecting the impact of radiation, precipitation and winds.

(2) The model's horizontal resolution was 5 km. Consequently, the resolution may not have been accurate enough to simulate detailed convective cells that produce heavy precipitation.

(3) The model was initialized with poor terrain resolution. Figure 28 shows the real and model terrain. The deficiency in terrain resolution may lead to the poor simulation of surface winds.

(4) The model's physical processes may need more improvement. Observations are needed to assess the performance of the different physical processes.

Future model studies will be needed to resolve these issues.

Run	August 10/11
1	41.44/18.24
2	47.19/16.00
3	30.58/13.32
4	39.93/11.80
5	62.36/48.18
6	47.53/23.01
7	55.89/38.69
Observation*	60.00/54.00

Table 2 Daily accumulated rainfall in mm for Case 1 (August 10 and 11) and Case 2 (August 12 and 13). Observational rainfall is summed from 237 ground stations

Run	August 12/13
8	7.69/13.92
9	28.31/38.55
10	33.79/46.00
11	44.49/22.09
12	36.11/45.63
Observation*	51.00/24.00

Table 3 Same as Table 2 except for Case 2 (August 12 and 13).

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