A numerical study of mesoscale precipitating system along Meiyu Front observed during GAME-HUBEX 1998

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Abstract

In order to improve our understanding of the mesoscale organization process, we performed a numerical experiment of the disturbance observed near Fuyuang radar site (115.83 E, 32.93 N) on 2 July 1998, during GAME/HUBEX 98. The model used in this study is Non Hydrostatic Model (NHM) developed by MRI/JMA. We performed two runs using two datasets, i.e., GAME-Reanalysis dataset and ECMWF dataset, for initial and boundary conditions, and we investigate the organizing process by comparing the results of two runs. In both runs, the model successfully reproduced the development of the large-scale horizontal shear, convergence, and the precipitation along the Mei-yu front. However, the disturbance of the GAME-Reanalysis run was too strong and moved too fast to the northeastward, and after its movement, there is no intense convection. On the other hand, in the ECMWF run, there occurred many convection systems along the front region and properly reproduced the persistent heavy rainfall area. We preformed several experiments (the wetness parameter w=0.1 and w=1.0) to investigate the effect of the surface conditions. It is shown that although the effect of the wetness parameter on the boundary layer structure is large, its effect on the convective activity seems to be small.

Keyword: mesoscale convection, heavy rainfall

1. Introduction

One of the most important research subjects of the GAME-HUBEX Project is to understand and to model the mesoscale organization process of the cloud and precipitation system along the Meiyu front, because precipitation does not occur homogeneously but occurs in some mesoscale organized convection system along the front. There are several processes which are considered to be important for the development of the mesoscale disturbances, such as, large-scale convergence and northward moisture flux in the lower layer, southward flow of cold dry air in the middle layer, upper layer disturbance along the jet stream, and sensible and latent heat flux from the surface. In order to improve our understanding of the development process of mesoscale disturbance, we must investigate what is important in these processes for each event.

There occurred several heavy precipitations during the Intensive Observation Period (IOP) of the GAME/HUBEX experiment. In this paper, some results of the simulation of the mesoscale disturbances occurred on 2 July during GAME/HUBEX IOP 98 are reported. It is shown that the precipitation occurred in the two successive mesoscale disturbances, which moved along the Meiyu Front. Therefore, it is important to simulate the successive development of the mesoscale system in order to simulate the heavy rainfall. We will simulate the heavy rainfall using several analysis datasets. By comparing the results of the runs of the different datasets, we will examine the development process of the disturbances.

2. The precipitation system observed on 2 July 1998

The rainfall we simulated in this study is the one observed near Fuyuang radar site (115.83 E, 32.93 N) on 2 July 1998. This is one of the several heavy rainfalls during the HUBEX Intensive Observation Period 1998, as is investigated by many authors (e.g., Xu and Xu, 1999; Fujiyoshi et al, 2000; Uyeda, 2000; Maesaka and Uyeda, 2000). During this period, Meiyu front was located along the southwest-northeast direction, and several mesoscale precipitation systems moved along the Meiyu front one after another. The precipitation systems brought about a heavy rainfall along the Meiyu front as is shown in Fig. 1. The Fuyuang radar (115.83 E, 32.93 N) is located in the heavy rain band region. We used two analysis data sets for the initial and boundary conditions. The two data sets are GAME-Reanalysis dataset, and ECMWF dataset. Fig. 1 shows the analyzed data of daily precipitation of ECMWF dataset integrated for 24 hours from 07/01/00 UTC (Universal Time Coordinated), i.e., 07/01/08 BST (Beijing Standard Time), to 07/02/00 UTC, i.e., 07/02/08 BST.

Fig. 2 shows the hourly rainfall estimated from Fuyuang radar observation. From 20 BST (12 UTC) to 04 BST (20 UTC), a rain band along from the west-southwest to the east-northeast moved over Fuyuang radar site. Another rain system developed

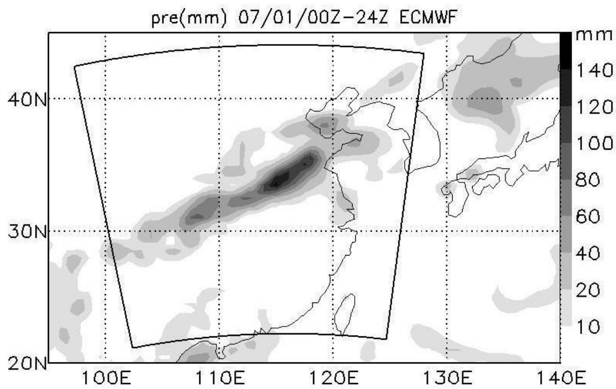

Fig. 1: Analyzed daily precipitation on 1 July 1998 in ECMWF analysis data. The model domain of the numerical simulation is indicated in the figure.

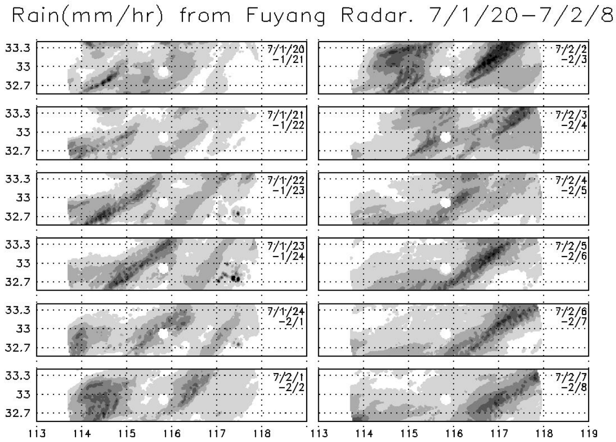

Fig. 2: Hourly rainfall estimated from Fuyuang radar observation from 20 BST (12 UTC) 1 July to 08 BST (00 UTC) 2 July.

about 00 BST (16 UTC) at 114E and moved after the previous system. The time sequence of TBB (equivalent blackbody temperature) observed by GMS shows two cold region corresponding each precipitation system (Figure is not shown.).

It indicates that the precipitation does not occur continuously, but occurs in the mesoscale organized precipitation systems which continually occur one after another. As is shown in these figures, it is important to simulate the subsequent occurrence of the mesoscale disturbances in order to simulate the heavy precipitation occurred on 2 July 1998. In the simulation of the subsequent occurrence of the mesoscale disturbances, we can investigate the mechanism of the organization of the convection.

3. Model

The model used for the simulation in this study is the NHM (Non-Hydrostatic Model) developed by MRI (Meteorological Research Institute) / JMA (Japan Meteorological Agency). The details of the model are shown in http://www.mri-jma.go.jp/Dep/fo/mrinpd/INDEXE.htm. The domain of the model is shown in Fig. 1. It is a square about 2500km×2500km wide in order to include the whole lifetime of the mesoscale systems, and its center is located about at (113E, 33N) near to the Fuyuang radar. The horizontal grid interval is 13.5 km, and there are 38 layers in the vertical. We used the convective adjustment scheme for cumulus parameterization. There are four soil layers and the land surface temperature is predicted by the heat balance equation with wetness parameter denoted by w. In the control runs, we set w=0.1 for land surface and w=1.0 for sea surface.

In this study, we used two data sets in order to make initial and boundary conditions. One is GAME-Reanalysis data sets made by JMA, and the other is the analysis data by ECMWF. The horizontal resolution of the two data sets is 0.5 deg, and their time interval is 6 hours. We used the data at 06 UTC, i.e., 14 BST on 1 July for the initial conditions and the model was integrated for 18 hours.

Fig. 3 shows horizontal vorticity and wind at 700hPa at 06 UTC 1 July in the two analysis data. In both data,

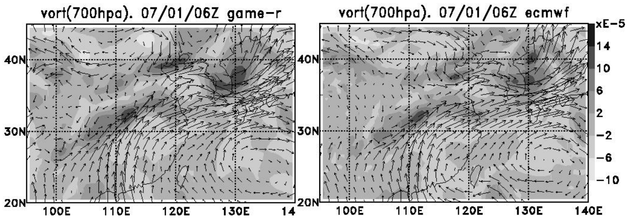

Fig. 3: Two analyzed data of 700 hPa wind and vertical vorticity, 06UTC 1 July. GAME –Reanalysis (left) and ECMWF (right) data.

they analyzed a subtropical high to the south of Japan, and strong southerly wind in the southern part of China, which went to the large shear zone at the Meiyu front. In the lower atmosphere, the wind transports a large amount of humidity toward the Meiyu front zone. Around the Korean peninsula, there is a low pressure, which brought about the heavy rain on 29-30 June. After the passage of the low pressure, there occurred northerly flow in the northern part of China. Therefore, the Meiyu front zone is also a convergence zone between the southerly and northerly flows. The difference in the wind and vorticity fields between the two data sets does not seem to be so large to make large difference in the development of the disturbances. The horizontal convergence in the lower layer is about $5x10^{-5}$ at its maximum in ECMWF data and it is a little larger than in GAME-Reanalysis data. On the other hand, the vertical vorticity in the lower layer is about $1.5x10^{-4}$ at its maximum in both GAME-Reanalysis data and ECMWF data.

There is a large difference between the two data in the surface air temperature at 06 UTC. It is much warmer in the southern part of China in GAME Reanalysis data than in ECMWF data. It seems to produce active convection that might enhance the moisture transport to the front area. However, the specific humidity in the region is smaller in GAME Reanalysis data than in ECMWF data. So, although the activity of the convection in the lowermost layer is active in the results using GAME Reanalysis data, the convection does not penetrate to the upper level to produce active condensation.

4. Results and discussions

As a whole, the model successfully reproduced the development of the large-scale horizontal shear, convergence, and the precipitation along the Meiyu front. In both runs, there occurred convective rain around the Fuyuang radar area at t=8-9UTC, i.e., 2-3 hours after the initial time. (Figure is not shown.) However, the disturbance of the GAME-Reanalysis run moved to the northeastward, and after its movement there was no intense convection around the region, because the convection, which occurs at the convergence zone between the outflow from the previous convection and the southerly flow in the southerly region of the previous convection, also moved toward the northeastward along the flow. On the other hand, in the ECMWF run, although the disturbance first developed around the Fuyuang radar moved to the northeastward, there developed several disturbances one after another along the Meiyu front, and the rainfall lasted after the first

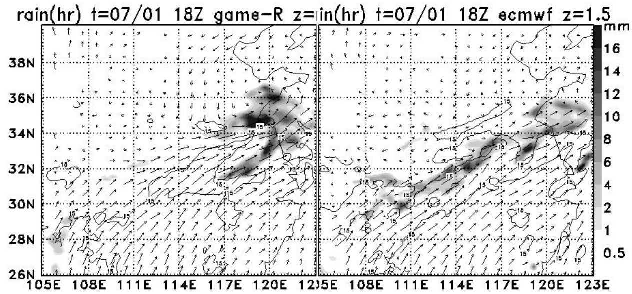

Fig. 4: Simulated precipitation from 17 UTC to 18 UTC 1 July. Arrows indicate horizontal wind, and contour lines indicate specific humidity at 18UTC, z=1.5km. GAME-Reanalysis (left), ECMWF (right)

convection moved eastward.

The convection in the GAME-Reanalysis run moved toward northeastward, and the velocity of the movement is only a little smaller than the wind velocity. Therefore, the relative wind to the convective motion, which indicates the inflow to the convection, is from north and the convection at the point can be maintained only for few hours. On the other hand, in the ECMWF run, the speed of movement of the convection is much slower than the wind speed. The relative wind is from the south, and the downdraft makes the cold pool, over which the southerly wind goes upward. The southerly air is very moist and the convection is maintained more than a few hours at the same position.

Fig. 4 shows the one-hour rainfall from 17 UTC to 18 UTC, i.e., from 11 hours to 12 hours after the initial time, and horizontal wind at z = 1.5 km at the time of 18 UTC. Although there is a large southerly wind and large convergence along the front area, there is no intense rainfall at the southwestern region of this figure in the GAME-Reanalysis run (left figure). On the other hand, in the ECMWF run, there occurred many convection systems along the front region and they moved along the front region. Therefore, in the ECMWF run, the "heavy rainfall area" is well simulated, as is shown in Fig. 4 (right).

The difference between the two runs is well indicated in Fig. 5, which shows the 18-hour integrated precipitation in the two runs. In the ECMWF run (center), there occurred many rain systems frequently along the Meiyu front and the total amount becomes as much as was observed. However, in the GAME-Reanalysis run (left), the total rain is large only in the eastern region in the figure, and it is smaller than the observed in the western part along the Meiyu front. (The right figure in Fig. 5 is the result of the modified GAME-Reanalysis data run, and will be discussed later.)

It is often said that such meso scale cloud system is often associated with a large vorticity on the right forward (moving direction) region of the precipitation area. In this case, the right forward region is the southeast region, where intense vorticity was observed, and the relation between the precipitation and vorticity agrees well with the usual cases. This simultaneous occurrence of the precipitation and vorticity is well indicated in Fig. 6, which shows the longitude-time section of the maximum values of vertical vorticity below z<4.2km and rain intensity between latitudes of 31N and 33.5N. In both runs (upper and middle), the heavy rain system which appeared around 115E at 09 UTC moved eastward at the velocity of about 100km/hour. The system was associated with the large vorticity. The maximum value is about $7x10^{-4}$ s^{-1} in both runs. After the movement of the first system toward to the east, the vorticity around 110E-115E became small in the GAME-Reanalysis run, while it remained a large value in the ECMWF run. It seems that the vorticity is important for the successive occurrence of the many convective systems along the Meiyu front, while the vorticity is produced by the large heating due to the convection. This kind of interaction between the convection and the vorticity is important for the heavy precipitation that is brought about by the several mesoscale disturbances occurring one after another.

There are several processes which are considered to be important for the mesoscale organization process of the convective systems. One of them is condensational heating and its effect on the producing depression. The heating is brought about from the surface sensible and latent heating, and/or moisture supply by the large-scale southerly wind. And another process is the effect of upper layer trough, which brings about the large-scale upward motion and enhances the convective activity. We performed several sensitivity runs in which surface and lower moisture conditions are changed.

At first, we discuss the results of the runs performed to investigate the effect of the wetness parameter w in the NHM. In NHM, the land surface condition is represented by the wetness parameter, w. The latent heat flux at the

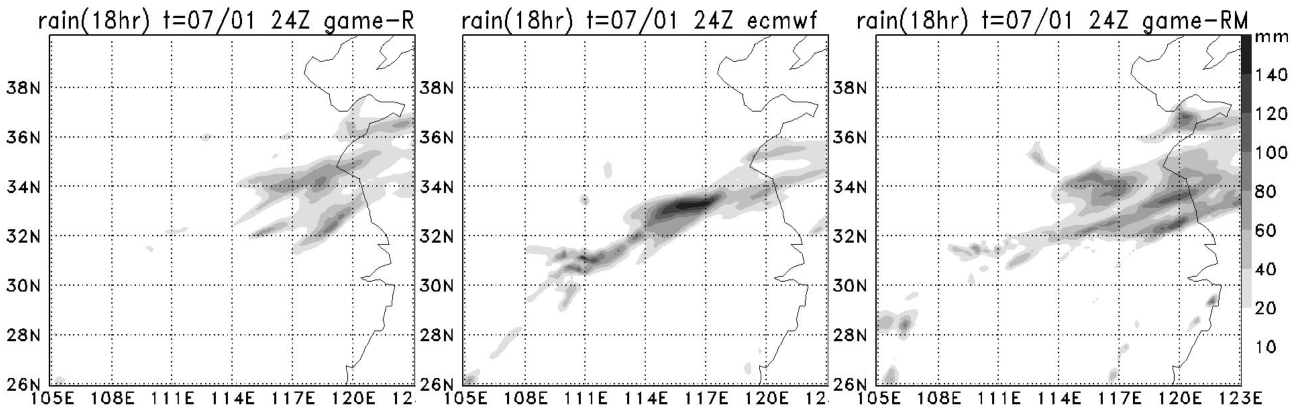

Fig. 5: Simulated precipitation integrated during 18-hour from 06 UTC 1 July to 00 UTC 2 July. GAME-Reanalysis(left), ECMWF(center), and modified GAME-Reanalysis(right) runs.

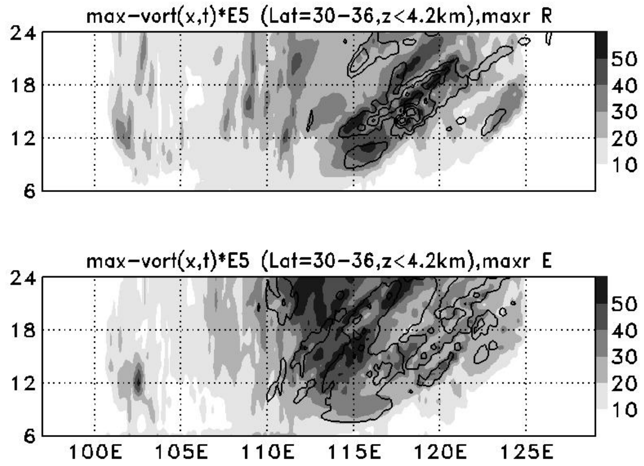

Fig. 6: Longitude-Time section of maximum vertical vorticity (shading) and maximum rain intensity (contour). The contour interval is 10 mm/hour. GAME-Reanalysis (upper), ECMWF (lower).

surface is calculated by the bulk formula using the "moisture difference between the air and saturation surface value" multiplied by w. We preformed several experiments to investigate the effect of the surface conditions.

Although the effect of the wetness parameter on the boundary layer structure is large, its effect on the convective activity appears to be small. When the surface wetness is large, the moisture becomes large in the boundary layer. However, the surface temperature does become lower because of the cooling due to the evaporation (latent heat flux). Because the effects of these two processes on the convective activity are opposite with each other, the convection does not becomes so active. As a result, the effect of the surface wetness parameter on the convective activity becomes small in the experiment.

The effect of the dryness in the boundary layer in GAME-Reanalysis data on the weak precipitation is examined by another sensitivity run, in which the artificial moisture is added to GAME-Reanalysis humidity data. The additional humidity is 2 g/kg below z*=1.2km, and it decreases to zero at z*=5km. The value of the 2 g/kg is the value of the humidity difference between GAME-Reanalysis and ECMWF datasets averaged over the whole domain.

The result partly shown in the right in Fig. 5 indicates that (1) there is a rain region along the front line, although the intensity is weak, (2) the total precipitation is much increased by the modification of the humidity profile, however, the rain is distributed in the wide area, and the generation of vorticity is not so enhanced, and (3) the maximum value of the precipitation at each point is not so increased as in the result in ECMWF run.

It is shown that although the total precipitation averaged over the whole domain becomes as large as in the result of the ECMWF run, the precipitation intensity does not become so large. It is because the convection is not so organized as in the run of the ECMWF run.

The results indicate that although the effect of the boundary layer humidity is important for the large precipitation, increasing humidity is not enough for the convection to be organized to bring about the large precipitation observed, because the increased humidity enhances the convective activity in the wide area of the south China region, and it does not lead to the enhancement of the mesoscale depression/vorticity along the Meiyu-front region which is important for the convections to be organized.

5. Summary

A numerical experiment of a mesoscale disturbance observed on 2 July 1998 along Meiyu front was performed using the two (GAME Reanalysis and ECMWF) datasets. The simulated mesoscale organization largely depends on the analysis data. In the ECMWF run, there occurred successive convection along the Meiyu-front region and the heavy rainfall is well simulated. However, in the GAME-Reanalysis run, the successive convection is not well simulated. The effect of the land surface condition seems to be small. The effect of the lower layer humidity on the precipitation amount is large, however, the increase of the humidity in the lower layer is not enough for the convection to be organized to bring about the heavy precipitation observed, because the increased humidity enhances the convective activity in the wide area of the south China region, and it does not lead to the enhancement of the depression/vorticity of the Meiyu-front region. The results indicate that the initialization including the meso-scale disturbance is important for the simulation of the heavy precipitation because the disturbance, including the spatial distribution of humidity, is important for the successive development of convection that brings about the heavy precipitation.

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