STRUCTURE OF THE REGIONAL HEAVY RAINFALL SYSTEM THAT OCCURRED IN MUMBAI, INDIA, ON 26 JULY 2005

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1.Introduction

The heavy rainfall that occurred in Mumbai on 26 July 2005 produced the 24 hour rainfall amount exceeding 944.2 mm (Bohra et al, 2005). The rainfall at Santa Cruz, a suburb of Mumbai, started at 0600 UTC (11.5 India Standard Time (IST)) on 26 July 2005, and continued for 18 hours. The rainfall region observed by the TRMM satellite revealed that the horizontal scale of this rainfall event was several tens of kilometers. The airflow structure was investigated with the outputs of the Non-hydrostatic model with the horizontal grid interval of 1 km.

2. Design of experiment

This study used NHM with triple-nested grids (20 km, 5 km and 1 km). Initial and boundary conditions of 20km-NHM were obtained from the global analysis data of JMA. First, the analysis data at 11.5 IST (0600 UTC), 25 July were tested, but the heavy rainfall was not reproduced. Alternatively, the global analysis data at 5.5 IST (0000 UTC) 25 July were used as the initial condition of 20km-NHM. When this analysis was used as the initial data, an intense rainfall system was reproduced near Mumbai, though its generation time was 18 hours earlier than the observed one. In the satellite images of SSM/I, similarly developed convective systems existed on the western coast of India on 25 July, though their intensities were weaker than that of the heavy rainfall. Thus, we believe that the rainfall system simulated from this initial time had the information of the heavy rainfall. Outputs of 20km-NHM and 5km-NHM provided the initial and boundary conditions of 5km-NHM and 1km-NHM. The initial data of 5km-NHM and 1km-NHM were given by the outputs at the forecast time (FT) of 6 hours.

3. Evolution and structure of the simulated heavy rainfall

3.1 Evolution of the regional heavy rainfall (from FT=3-27 hours of 5km-NHM)

Evolution of the heavy rainfall was explained by the outputs of 5km-NHM. The rainfall regions were generated along the mountain range near the western coast of India by FT=3 (14.5 IST). An intense rainfall system was organized near Mumbai by FT=6 (17.5 IST). The system began to split into several rainfall cells along the mountain range at FT=18 (5.5 IST, 26 July), and then the intense rainfall was terminated at FT=23 (10.5 IST, 26 July). The rainfall amount in 17 hours from FT=6 to FT=23 caused by the system reached 1,149 mm. The rainfall amount and duration indicated that the heavy rainfall was quantitatively well-simulated.

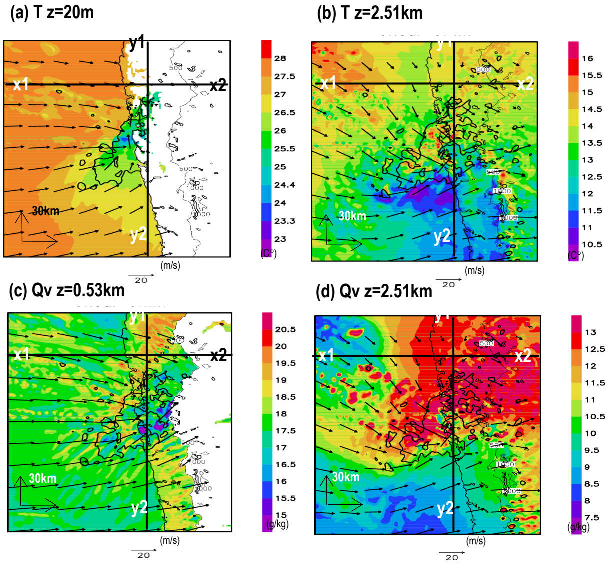

(a) T z=20m (b) T z=2.51km (c) Qv z=0.53km (d) Qv z=2.51km

Fig. 1. Horizontal distribution of temperature (T) and water vapor mixing ratio (Qv) at FT=6 (23.5 IST) reproduced by 1km-NHM. Black contours indicate rainwater mixing ratio of 1 g/kg. Large arrows indicate the horizontal scale of 30 km.

3.2 Structure of the heavy rainfall system (at FT=6 hours of 1km-NHM)

Figure 1b depicts the rainwater mixing ratio of the regional rainfall system reproduced by 1km-NHM. The intense rainfall system had already been organized by FT=6 (23.5 IST) 100 km south of Mumbai. The horizontal scale of regional heavy rainfall was several tens of kilometers.

The structure of heavy rainfall is revealed by the illustration of airflow (Fig. 2), and the distributions of temperature, water vapor and equivalent potential temperature (Figs. 1 and 3). The intense rainfall region extended southwestward from the mountain range near Mumbai. A cold pool developed between the intense rainfall region and the mountain range (Fig 1a, cold pool in Fig. 2). A westerly flow near the surface (Figs. 1a and 1c, A in Fig. 2) intruded the intense rainfall region from the west of the rainfall system, changing its moving direction to southeastward. This flow overrode the cold pool along the western side of the intense rainfall region (Fig. 1a). The westerly flow on the southern side of the system (Fig. 1a, E in Fig. 2) changed its moving direction to northeastward, and then passed the southern side of the system.

At the height of 0.53 km, the westerly flow from the west of the heavy rainfall (A in Fig. 2) was warmer and more humid than that in the westerly flow on the south of the system (E in Fig. 2). This warm humid westerly flow (A in Fig. 2) overrode the cold pool, and then produced an intense updraft at over 5 m/s at a height of 1.69 km (not shown). On the southern side of the intense rainfall region, a dry southwesterly flow occurred (Fig. 1c, head part of D in Fig.2). Figure 3a presents the vertical cross section of the equivalent potential temperature (θ_e) that crossed this dry flow region. The downdraft of low θ_e air, (dry airflow in Fig. 1c, head part of D in Fig. 2) occurred on the southern side of the system. This region extended northward as it descended, and then reached the lower layer (Fig. 3a). It was inferred that this descending dry airflow evaporated rain droplets and produced the cold downdraft.

At a height of 2.51 km, two key airflows were observed. The first one was a moist airflow that entered the rainfall system from the north (Fig. 2d, C in Fig. 2). This flow was expected to increase the rainfall amount because it provided water vapor to the rainfall system. Figure 3b depicts a vertical cross section of water vapor and vertical flux of water vapor along line x1-x2 in Fig. 1 where the humid westerly flow (B in Fig. 2) existed near the surface (Fig. 1c). Regions of upward water vapor flux exceeding 2×10^{-3} kgm^{-2}s^{-1}, whose top reached a height of 3 km, occurred over the western slope and on the western side of the mountain range. This distribution indicated that the thick humid layer originated from the low-level humid airflow (B in Fig. 2) stagnated by the topography effect of the mountain range. The second key airflow was the relatively dry westerly flow that intruded into the southern side of the rainfall system (D in Fig. 2), where the downdraft was dominant. This dry airflow was cooled by the evaporation of the rain droplets, and then became the downdraft in the southern side of the rainfall system. This cold airflow enhanced the convective instability and produced the cold pool. Both airflows (C and D in Fig. 2) were favorable for maintaining the heavy rainfall.

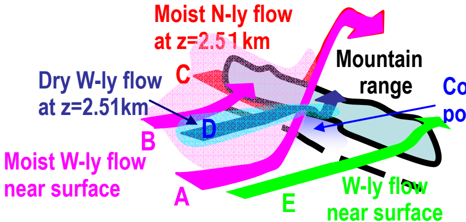
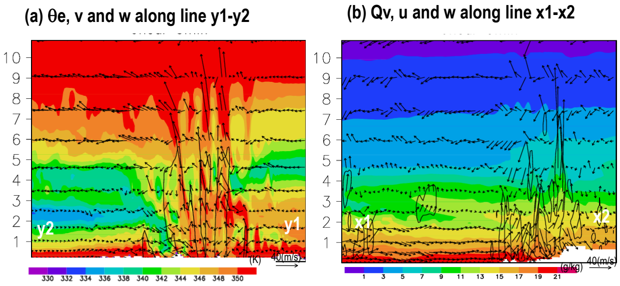


Fig. 2. Schematic illustration of the heavy rainfall.


(a) θe, v and w along line y1-y2

(b) Qv, u and w along line x1-x2

Fig. 3. Vertical cross sections of (a) equivalent potential temperature (θ_e) and (b) water vapor mixing ratio (Qv) at FT=6 (23.5 IST) along the lines in Fig. 1. Vertical velocities in (a) and (b) are multiplied by 10 and 50, respectively. Contours in (a) and (b) show the region where rainwater mixing ratio exceeds 1 g/kg and where vertical flux of water vapor exceeds 2.0×10^{-3} kgm^{-2}s^{-1}, respectively.

References

Bohra, A. K., S. Basu, E. N. Rajagopal, G. R. Iyengar, M. D. Gupta,R. Ashrit, and B. Athiyaman, 2005: Heavy rainfall episode over Mumbai on 26th July 2005: Assessment of NWP Guidance, Report of NCMRWF, 25 pp.