Study of 1998 Heavy Rainfall over the Yangtze River Basin Using TRMM Data①

Cheng Minghu (程明虎), He Huizhong (何会中), Mao Dongyan (毛冬艳),
Qi Yanjun (齐艳军) and Cui Zhehu (崔哲虎)
Chinese Academy of Meteorological Sciences, Beijing 100081
Zhou Fengxian (周凤仙)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029

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ABSTRACT

TRMM (Tropical Rainfall Measuring Mission) data have been made available to the public users since June 1998. In this paper, some preliminary research is reported for the case study of heavy rainfall over the Yangtze River Basin using TRMM data at 2140 UTC 20 July 1998. TRMM derived precipitation products are also compared with rain gauge observation, ground radar data and numerical model simulation results. It is shown that TRMM data can be easily used to monitor the heavy rainfall and have many applications.

Key words: Heavy rainfall, TRMM data, Precipitation structure

1. Introduction

Heavy rainfall and / or floods brought by it have already caused the damage of property and the loss of human life (Cheng, 1994; Qi et al., 2000). On the other hand, heavy rainfall is the water resource especially for dry regions. In addition, rainfall is a key component of the Earth climate system, which may strongly affect the atmospheric circulation through the associated latent heat releases (Browning, 1990). The study of heavy rainfall can be traced for a long history with many techniques. Recently there have been several projects involving in the study of heavy rainfall. For example, the European Union supported STORM project from 1993−1995 (Barrett and Cheng, 1996). Taiwan Province funded TAMEX from 1983 to 1993. Ministry of Science and Technology of China is funding a national key project entitled Heavy Rainfall Experiment over South China Areas (1998−2000) and a national fundamental research project entitled Mechanism and Prediction Theory of Hazard Climate and Weather (1999−2003). Currently, besides the numerical meteorological model which is often used to study the heavy rainfall, there are three major techniques for the observation of heavy rainfall, i.e. direct measurement using rain−gauge, active remote sensing using radar (Collier, 1989; Cheng and Collier, 1993), and passive remote sensing using radiometer (Cheng et al., 1993; Cheng and Brown, 1995). Normally the radar is based on the Earth surface, and the radiometer is loaded onto satellite. The TRMM is the first meteorological satellite loading

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Precipitation Radar (PR). The PR together with on board Visible and InfraRed Scanner (VIRS) and TRMM Microwave Imager (TMI) form the most powerful capability to observe heavy rainfall from satellite. Therefore, some preliminary research has been carried out for the case study of heavy rainfall over the Yangtze River Basin using TRMM data at 2140 UTC 20 July 1998 (or 0540 BST 21 July 1998), which is described in this paper. TRMM derived precipitation products are also compared with rain gauge observation, ground radar data and mesoscale numerical model simulation results.

2. TRMM instruments

TRMM is a joint effort by National Aeronautic and Space Administration (NASA) and National Space Development Agency of Japan (NASDA). One of the mission objectives is to test, evaluate and improve the performance of satellite rainfall measurements and estimate techniques. The satellite was launched on 27 November 1997 from Tanegashima, Japan. It has a circular orbit with altitude 350 km ranging between 35 degrees north and 35 degrees south of equator. Aboard the TRMM there are five instruments. Among them the PR, TMI and VIRS are the three primary instruments which constitute a rainfall measurement package. They work in a complementary manner.

The PR is the first space–borne meteorological instrument designed by NASDA to provide three–dimensional maps of precipitation structure. The measurements should yield invaluable information on the intensity and distribution of the precipitation, on the precipitation type, on the storm depth and on the height at which the snow melts into rain. The PR has a horizontal resolution at the ground of 4.3 kilometers and a swath width of 220 kilometers. It is operated at 13.8 GHz with horizontal polarization. One of its most important features is its ability to provide vertical profiles of precipitation from the earth surface up to a height of 20 km.

The TMI and VIRS were developed by Goddard Space Flight Center(GSFC), NASA. TMI is similar to Special Sensor Microwave / Imager (SSM / I) on board the Defense Meteorological Satellite Program (DMSP). Instead of 4 frequencies, TMI has 5 frequencies (10.65 GHz, 19.35 GHz, 21.3 GHz, 37.0 GHz and 85.5 GHz) with dual polarization except 21.3 GHz. The additional 10.7 GHz is designed to provide a more–linear response for high rainfall rates common in tropical regions. The horizontal resolution of the TMI changes from 5 km at 85.5 GHz to 45 km at 10.65 GHz. A conical scan angle of 65 degrees provides a swath width of 760 km with the same resolution. The VIRS has 5 channels (0.63, 1.6, 3.75, 10.80 and 12.0 microns) with a swath width of 720 km and horizontal resolution of 2 km at nadir. The channels selected are similar to NOAA / AVHRR and GMS / VISSR. Thus the VIRS provides a link between measurements made by TRMM rain package and those made simultaneously by the visible and infrared radiometers on operational polar and geostationary satellites. The primary sensors PR, TMI and VIRS in combination constitute TRMM as a 'flying rain gauge' to correct or calibrate the rain estimates made by other instruments such as GMS / VISSR, NOAA / AVHRR etc. The detailed description of TRMM sensor package is given by Kummerow et al.(1998).

3. Data

The data used in this investigation are TRMM products, ground radar image, rain gauge observation, and Mesoscale Model MM5 simulated results. They are described as follws.

3.1 *TRMM data*

Since there are only 2–3 TRMM orbits across China area per day and there are gaps between orbits, all rain situations cannot be caught by TRMM. The case chosen here is the orbit #3706 on 21 July 1998 because of availability of ground radar data at Wuhan City. The time for the TRMM satellite overpassing Wuhan areas was at about 0540 BST 21 July 1998. Data used here are the second level products of precipitation derived from PR data and from the combination of PR and TMI data. These data are provided by the Distributed Active Archive Center (DAAC), NASA. The PR coverage is shown in Fig. 1 by gray band.

3.2 *Ground radar data*

The radar data used were obtained from the Wuhan Central Meteorological Service for the Wuhan radar image only. The radar was located at Wuhan City with the latitude of 30.52°N and the longitude of 114.39°E. The radar was operated every ten minutes for this case with volume scanning. For some reasons, the archived radar data are column maximum image with 7 grades and 4 km resolution only. The column maximum is defined by choice of maximum value of every column from the volume scanning data. The seven grads are 0.3, 2.5, 5.2, 10.7, 22.0, 45.2, 107.3 mm/h. The radar image chosen is at 0540 BST 21 July 1998, which is consistent with TRMM observation. The radar covered area is illustrated by a circle with the radius of 150 km in Fig. 1.

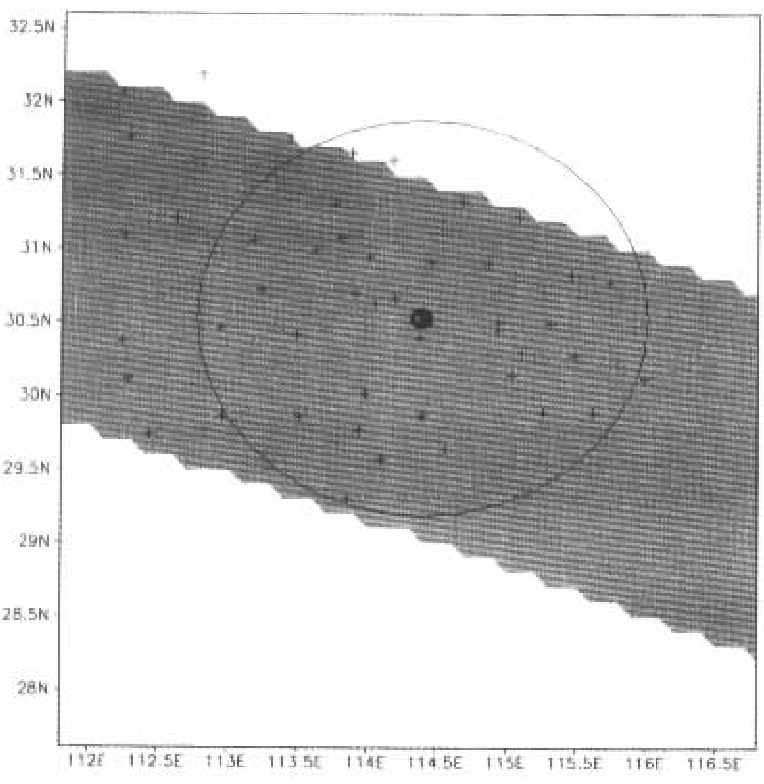

Fig. 1. The PR coverage (shaded area) with radar range (the circle with radius of 150 km) and rain gauge positions (cross +) overlaid.

3.3 *Rain gauge data*

In this study, 24–hour accumulated rain gauge data were obtained from Chinese National Meteorological Center. The hourly rain gauge data were provided by the Hubei Meteorological Bureau and recorded from 77 rain gauges scattered in Hubei Province. The 77 rain gauge positions are plotted by crosses in Fig. 1.

3.4 *MM5 simulated data*

A two–way nested non–hydrostatic mesoscale numerical model named MM5 (Grell et al., 1994) was used to simulate the heavy rainfall event occurred near Wuhan during 20–21 July 1998. In the model process, grid numbers of coarse and fine nest are both 61 × 61 with the grid distances of 60 km and 20 km respectively, and initial data are just conventional observation (for detail, see Qi et al., 2000).

4. Heavy rainfall case

4.1 *The brief description of the case*

On 20–22 July 1998, there occurred a continual heavy rainfall over the south of Hubei Province. On 20 July the heavy rain was mainly located over Sichuan Province then moved eastward and southward. The rain continued eastward on 22 July and reached the coast area on 23 July 1998. By analyzing reported rainfall data, it is found that the rainfall intensity on 21 July reached the peak. Figure 2 shows the daily rainfall distribution of 21 July 1998 from rain guage observation. The rainfall amount reported by Wuhan weather station on 21 July is 285.7 mm within 24 hours. The peak period for this heavy rainfall was from 0200 to 1500 BST 21 July 1998. The observed rainfall rate of 88.4 mm / h for the period of 0600 to 0700 BST 21 July was reported by Wuhan Weather Station. It is just after the TRMM overpassed Wuhan region.

4.2 *3–D Structure of precipitation*

The unique feature of PR is providing 3–D volume data of precipitation. The file name is identified as 2A25 in the TRMM product provided by DAAC. It is a level–2 product. They are divided into 80 levels with the vertical resolution of 250 m and sub–satellite horizontal resolution of 4.3 km. Figure 3a shows PR derived 3–D structure of precipitation with the iso–surface value of 1.0 mm / h at 0540 BST 21 July 1998, which is viewed at an elevation of 60 degree. From the figure, it is seen that the precipitation system consists of many precipitation towers which form rain bands. These precipitation towers may be connected together in the lower layer but are separated in the higher layer. Horizontal sizes of these precipitation towers are from about ten to several ten kilometers, which illustrate that the heavy rainfall was produced from mesoscale convective system (MCS). The MCS was formed by many convective cells in the mesoscale scale of β (even γ). Figure 3b shows PR derived precipitation map for the horizontal layer at the height of 4 km. From Figs. 3a and 3b, it is found that generally speaking, there is correlation between the rain rate at the layer of the height of 4 km and the height of precipitation tower. Figure 3c is the vertical cross–section of the PR derived rain rate distribution across the track where the heavy rainfall near Wuhan is located. The cutting line is shown by a solid line in Fig. 3b. From these figures, it can be seen that the precipitation tower reaches up to 14 km with maximum rain intensity occurred at the centers of

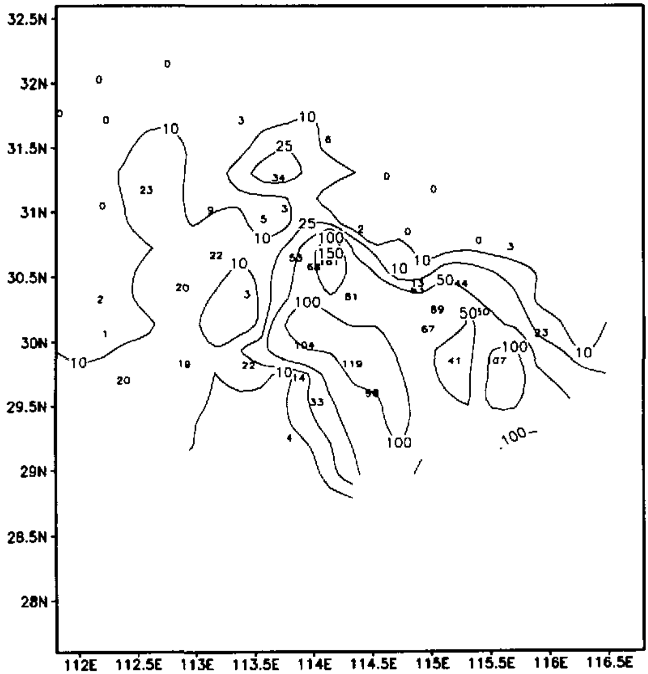

Fig. 2. The daily rainfall distribution on 21 July 1998.

the tower for the horizontal direction and between the heights of 2–5 km for the vertical direction for this case.

4.3 *Comparison with ground truth*

Figures 4a and 4b show column maximum precipitation maps of the Wuhan radar and TRMM PR respectively at 0540 BST 21 July 1998. The reason to use the column maximum precipitation map of Wuhan radar here is that only this radar derived product is available although this product cannot represent precipitation at any specific height. In order to compare PR product with ground radar data, the TRMM PR derived column maximum precipitation map is presented in Fig. 4b. Comparing two figures, it is found that for the case, the patterns of precipitation are quite close, but the intensity may be much different. The precipitation intensity derived from the PR is generally smaller than that derived from the Wuhan radar. More comparison will be conducted in further study. The rain guage reported hourly rainfall at 0500–0600 BST 21 July 1998 is plotted in Fig. 5a with contours overlaid. The current rain gauge network may not catch rain system well especially for the mesoscale convective cases. But the rain gauge reported hourly precipitation is the only ground truth available. Fig. 5b presents the surface rain rate from TMI and PR combination product. From Fig. 5a, it can be seen that the rain gauge reported hourly rainfall distribution has a band shape with northwest to southeast direction. Within this band, there are three major centers with rain rates of 52, 31 and 26 mm / h respectively. Comparing Fig. 5a to Fig. 5b, it is seen that the general patterns of two rainfall maps are quite coherent. For example, the hourly rainfall distribution has

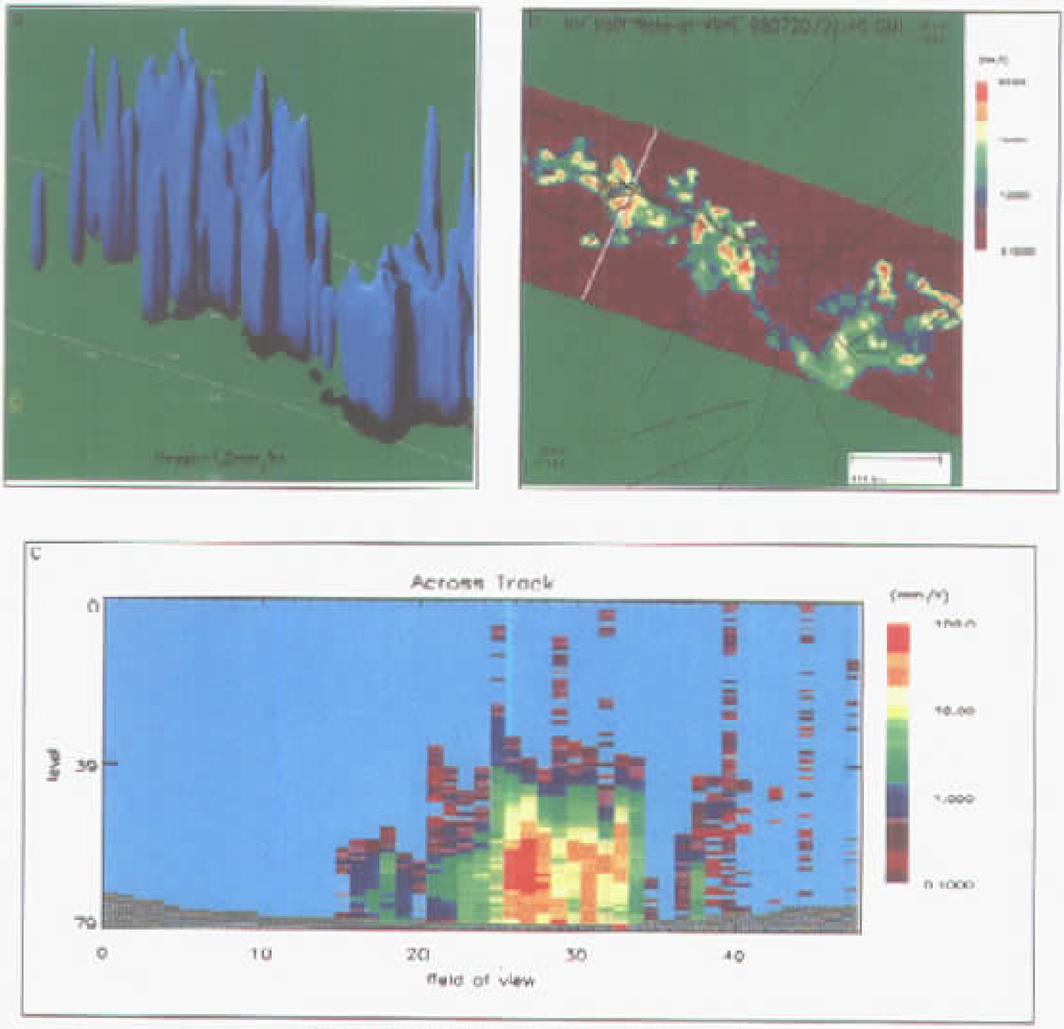

Fig. 3. TRMM PR derived precipitation products.

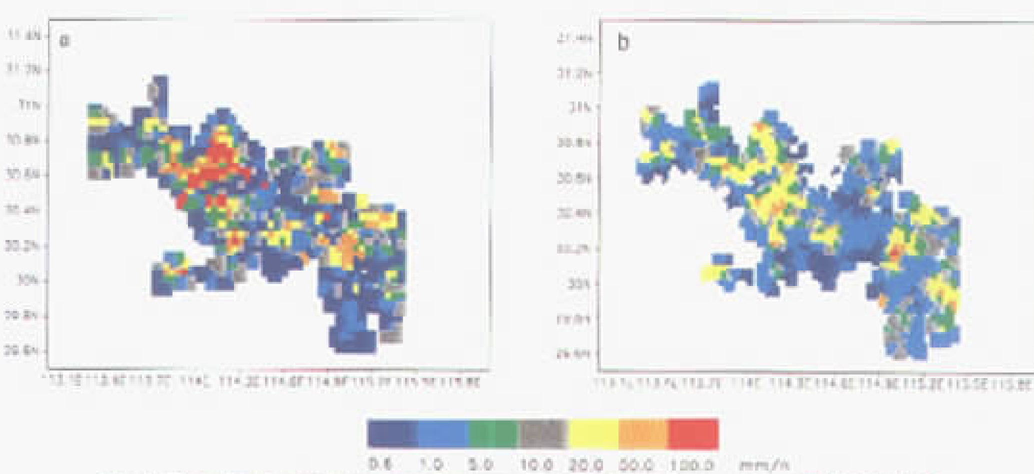

Fig. 4. The column maximum precipitation maps for Wuhan Radar (a) and TRMM PR (b).

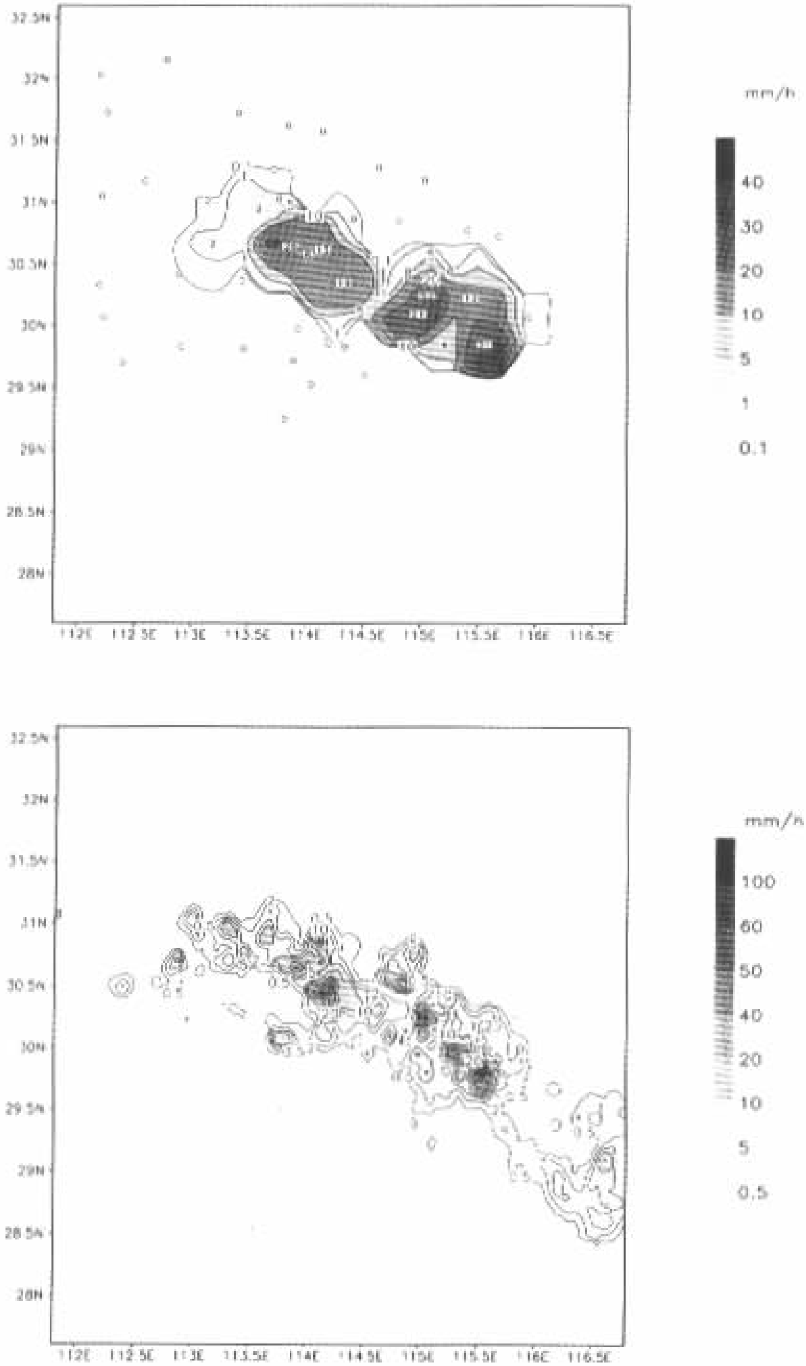

Fig. 5 (a) The rain guage reported hourly rainfall of 0500–0600 BST 21 July 1998, and (b) the surface rain rate given by TMI and PR combination product at 0540 BST 21 July 1998.

nearly the same band shape as that given by PR and TMI combined product and the locations of three major centers are close. However, the rain guage network cannot delineate the fine structure because of its coarse spatial resolution and the TRMM products can show more details of rain structure. The difference of intensity on two maps is due to that the TRMM product is instantaneous at 0540 BST and rain guage data are one hour average from 0500 to 0600 BST or due to that TRMM gives less rain.

4.4 *Comparison with numerical simulation*

Figure 6 shows precipitation maps derived from MM5 simulated results using the fine nest between 0500–0600 BST 21 July 1998. The simulated results give rain band but with different patterns and intensity. The simulation has larger precipitation areas than that derived from the observations and the simulated precipitation intensities are much smaller than those from observations. For example, the simulated top rainfall is only 13 mm / h near Wuhan, while rain gauge reported peak rainfall reaches 52 mm / h.

5. Potential research

Based upon the preliminary research, the TRMM data have displayed powerful capability to observe heavy rainfall and to estimate precipitation, although the current PR derived

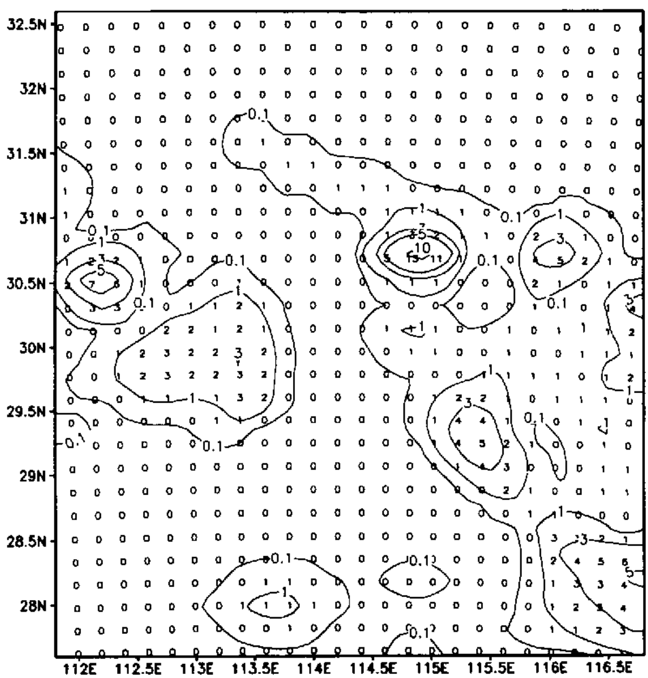

Fig. 6. The precipitation map derived from MM5 simulated results using the fine nest model for 0500–0600 BST 21 July 1998.

precipitation products seem to underestimate the precipitation intensity. In order to fully benefit from the TRMM data, this research group has proposed following research subjects.

1) Studies of TRMM precipitation algorithms.

2) Validation of TRMM precipitation algorithms using more ground true data.

3) Retrieval of three-dimensional structures of cloud-precipitation system using combination of the TRMM PR, VIRS and TMI data. The principles have been pointed out by Cheng et al. (2000).

4) Estimation of precipitation using geostationary satellite data calibrated by the TRMM products for geostationary satellite has more temporal observing frequencies and spatial coverage. The principles are described by Lovejoy and Austin (1979), and Cheng and Brown (1995).

5) Calibration of Chinese radar network using TRMM PR data. It is frequently observed that much different signals may be obtained from different radars while observing the same target. Because of the relative stability of the PR signal, a radar network should be benefited by the calibration using TRMM PR data.

6) Mesoscale model initialization and assimilation using the TRMM data to improve the accuracy.

6. Conclusions

Heavy precipitation events occurred over the Yangtze River Basin on 20-23 July 1998. Mainly based upon the TRMM data provided by DAAC / NASA, plus ground radar data, rain gauge data and MM5 simulated data at 0540 BST 21 July 1998, some preliminary researches have been performed for this heavy rainfall event.

From TRMM precipitation radar derived 3-D precipitation map, it is found that the precipitation system consists of many precipitation towers which form rain bands. These precipitation towers may be connected together in the lower layer but are separated in the higher layer. Generally speaking, there is a correlation between the rain rate at the layer of the height of 4 km and the height of precipitation tower. The precipitation tower reaches up to 14 km with maximum rain intensity occurred near the centers of the tower for the horizontal direction and between the heights of 2-5 km for the vertical direction for this case.

Intercomparison between PR and Wuhan radar derived column maximum rain maps has shown that the patterns of precipitation are quite close, but the intensity may be much different. The precipitation intensity derived from the PR is generally smaller than that derived from the Wuhan radar.

By comparing the rain gauge reported hourly rainfall with PR and TMI combined product, it is found that two precipitation maps give a rain band with northwest to southeast direction containing three major centers. However, the fine structures of these precipitation maps and magnitudes of these precipitation intensity may be quite different. The rain gauges fail to give small scale precipitation cells and fine structures which can well be delineated by TRMM precipitation map. This is because the TRMM data have much higher spatial resolution than the current mesoscale observation network.

The MM5 simulated results give rain band but with different patterns and intensity. The simulation has larger precipitation areas than that derived from observations, and the simulated precipitation intensity is much smaller than those from observations. In addition, potential researches in this group have been presented, including studies of TRMM precipitation algorithms, validation of TRMM precipitation algorithms using more ground true data, retrieval of three–dimensional structures of cloud–precipitation system using combination of the TRMM PR, VIRS and TMI data, estimation of precipitation using geostationary satellite data calibrated by the TRMM products, calibration of Chinese radar network using TRMM PR data, and mesoscale model initialization and assimilation using the TRMM data.

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用 TRMM 资料研究 1998 年长江流域暴雨

程明虎　何会中　毛冬艳
齐艳军　崔哲虎　周凤仙

摘　要

热带测雨卫星 TRMM 资料于 1998 年 6 月起向公众用户开放。本文使用了 1998 年 7 月 20 日世界时 21: 40 分的 TRMM 资料对长江流域暴雨作了初步研究. TRMM 导出的降水产品亦与雨量计，地面雷达观测以及数值模拟结果进行了比较. 由此得出，TRMM 资料非常适合于暴雨监测研究. 此外，它们还有其他广泛得用途.

关键词: 暴雨，TRMM 资料，降水结构