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Rainfall Observation from Tropical Rainfall Measuring Mission (TRMM) Satellite

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***Abstract*:** National Space Development Agency of Japan (NASDA) successfully launched the Tropical Rainfall Measuring Mission (TRMM) observatory at 06:27 (JST) on Nov. 28, 1997. The TRMM satellite carries the first spaceborne Precipitation Radar (PR) which was developed by NASDA and Communications Research Laboratory. The PR can measure the horizontal and vertical structure of rain day and night, and over ocean and land. This capability allows scientists for the first time ever to grasp the three-dimensional structure of rain in the tropics and sub-tropics around the globe. In addition to the PR, the satellite carries four more sensors which were developed by National Astronautics and Space Administration (NASA): the TRMM Microwave Imager (TMI), the Visible Infrared Scanner (VIRS), and the Cloud and the Earth's Radiant Energy System (CERES), the Lightning Imaging Sensor (LIS). Preliminary results and images from these sensors are shown in this paper.

***Keywords*:** Tropical Rainfall Measuring Mission (TRMM), Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Clouds and the Earth's Radiant Energy System (CERES), Lightning Imaging Sensor (LIS), El Niño, tropical cyclone, heavy rain.

1. Introduction

The National Space Development Agency of Japan (NASDA) successfully launched the Tropical Rainfall Measuring Mission (TRMM) and ETS-Ⅶ on H-Ⅱ Launch Vehicle Flight No. 6 at 6:27 a.m. (JST) on November 28, 1997. The TRMM launch culminated a joint venture between Japan and the US which has been continuing over 10 years. This mission carries the Precipitation Radar (PR) which was developed by NASDA in cooperation with the Communication Research Laboratory (CRL). The other TRMM rain observation sensors are the TRMM Microwave Imager (TMI) and the Visible Infrared Scanner (VIRS), but TRMM also carries the Cloud and Earth's Radiant Energy System (CERES) and Lightening Imaging Sensors (LIS). Each sensor has completed its initial validation and has begun observation, and data have been released to public users.

Table 1.

Radar Type	Active Phased-array Radar
Frequency	13.796 GHz and 13.802 GHz
Swath Width	215 km
Observable Range	From surface to a height ≥ 15km
Range Resolution	250 m
Horizontal Resolution	4.3 km (at nadia)
Sensitivity	S/N per pulse ≥ 0 dB for 0.7 mm/h rain at rain top

2. Outline of TRMM Satellite

TRMM was designed as a non-sun-synchronous satellite with a 350 km circular orbit and a 35 degree inclination angle, to observe the diurnal variation of the tropics.

The PR on board TRMM is the first spaceborne rain radar in the world and was developed by NASDA in cooperation with the Communications Research Laboratory (CRL). Table 1 shows the PR's major parameters. The major objectives of PR are to provide three-dimensional rainfall structure, to achieve quantitative rainfall measurement over land as well as over oceans, and to improve the accuracy of TRMM Microwave Imager (TMI) measurements by providing rain structure information.

TMI is a multichannel, dual-polarized microwave radiometer which will provide data related to rainfall rates over the oceans; it was developed by Goddard Space Flight Center (GSFC). The TMI data together with PR data will be the primary data set for precipitation measurement. The TMI data combined with the data from the PR and VIRS will also be utilized for deriving precipitation profiles.

VIRS is a passive, cross-track scanning radiometer which measures scene radiance in five spectral bands operating in the visible through the infrared spectral regions and was developed by GSFC. Comparing microwave, visible and infrared data is expected to enable more precise precipitation estimates than are possible with visible and infrared data alone.

CERES was developed by NASA Langley Research Center. It is a passive broadband scanning radiometer which has three spectral bands in the visible through the infrared spectral regions. CERES measures the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface of the Earth. CERES will be operated in either a cross-track scan mode or a biaxial scan mode. The primary mode will be the cross-track scan mode.

LIS was developed by Marshall Space Flight Center (MSFC). It is an optical staring telescope and filter imaging system which will acquire and investigate the distribution and variability of both intracloud and cloud-to-ground lightning over the Earth. The LIS data will also be used with PR, TMI and VIRS data to investigate the correlation of the global incidence of lightning with rainfall and other storm properties.

3. PR Image

3.1 Concentrated Heavy Rain over Korea

Figure 1 shows concentrated heavy rain over Korea observed by the TRMM Precipitation Radar (PR) on July 31, 1998 from 10:12 p.m. to 10:16 p.m. (JST). The heavy rain front in middle and eastern China moved to the east without weakening, bringing great damage, landslide casualties, and muddy streams to the southern part of Korea.

According to the newspaper, the highest recorded precipitation was 226 mm in Soon Cheon, Cheon Ra Nam-Do. However, 202 mm of precipitation also occurred in San Cheong, Kyung Sang Nam-Do, and 103 mm, in Hae Nam, Cheon Ra Nam-Do. These precipitation estimates are for the night of July 31 up to 7 p.m. on August 1. A record Korean precipitation rate of 128 mm/hour was also observed in Soon Cheon, Cheon Ra Nam-Do.

The upper image shows the horizontal distribution of rain at an altitude of 2.0 km. TRMM PR observations indicate the precipitation system produced rainfall at a rate exceeding 30 mm/hour. The image also identifies occurrences of heavy rain in the area. The lower image shows the vertical cross section of rain along the line AB. This example highlights the fact that TRMM PR is able to observe rain rates at different heights in precipitation systems. In this case, the image presents rain rate information for different heights along a 14 km vertical column.

In Japan, the end of the rainy season is usually announced on an annual basis. However, this did not occur this year in the Tohoku and Hokuriku regions in Japan because of abnormal weather. Other examples of abnormal weather such as heavy rains in Niigata, Japan, and a flood in Chang Jiang, China might have been caused by the presence of a historically anomalous El Niño. TRMM data are expected to be useful for investigating of these abnormal weather phenomena.

3.2 Evolution of a Tropical Cyclone

TRMM can detect various evolution stages of tropical cyclones. It is especially difficult to observe cyclone generation and developing stages over tropical oceans where surface radars are not available. TRMM clearly shows the internal structure of the cyclone in detail over such oceans. Figure 2 shows the various evolution stages of the cyclone by horizontal cross section of the Precipitation Radar (PR) rain maps at an altitude of 2.0 km superposed on cloud maps from meteorological satellites.

(a) Formation and Developing Stage

These images show a tropical cyclone that formed southwest of Taiwan on 8 July 1998. Light rain is indicated in blue, broadly north and east of the eye (left image). It then gathers and develops after 16 hours (right image). It has some heavy rain parts indicated in red. In 10 hours, this cyclone grew to become Typhoon No. 1 in 1998.

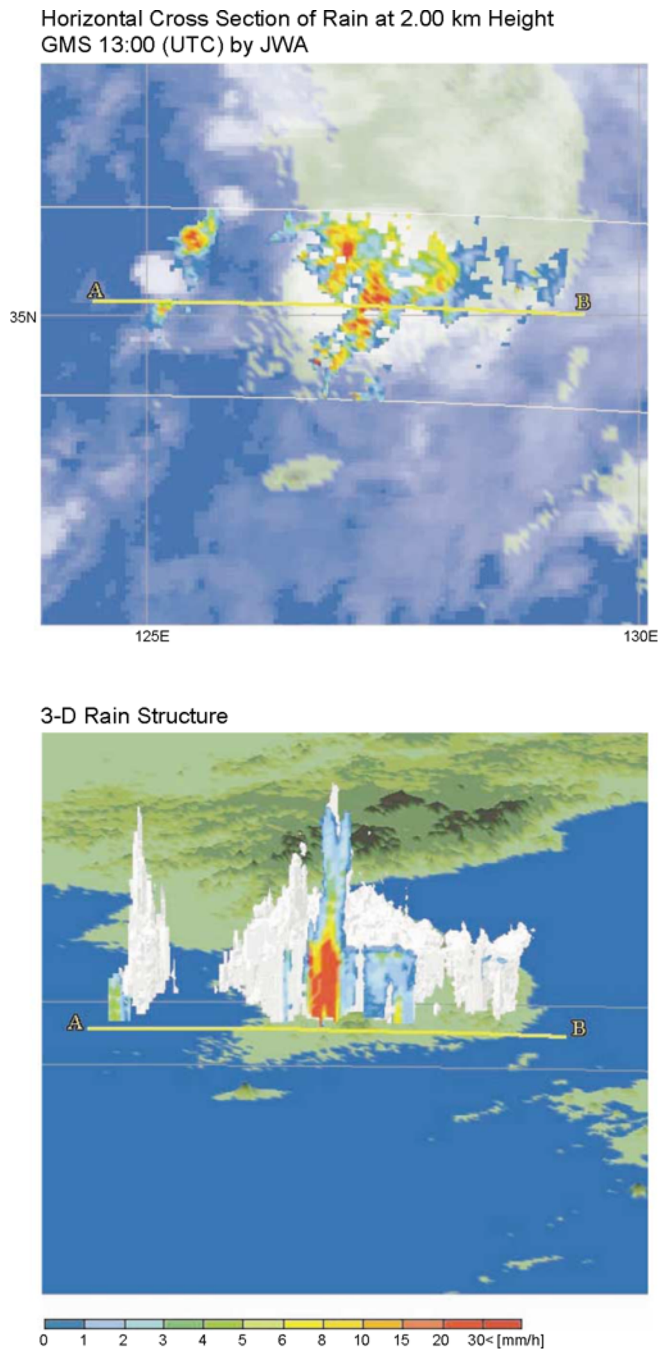

Fig. 1. Horizontal Cross Section of Rain at 2.00 km Height GMS 13:00 (UTC) by JWA and its 3-D Rain Structure (NASDA/CRL/NASA).

(b) Mature Stage

The left image shows a strong tropical cyclone in the west of the Indian Peninsula. The structure of rain is similar to that in Typhoon PAKA. This indicates that the structure is typical for mature tropical cyclones. The cloud image is not clear because this area is located at the edge of the meteorogical satellite observation area. The right image shows typhoon PAKA that inflicted great damage on Guam Island in December 1997. There is no rain in the eye of this cylone. The cloud was round, and rain existed only on the eastside of the eye. There were several strong linear rain areas, called "rain bands," around the eye and in the rain area on the east side of the eye.

(c) Decaying Stage

This image shows the cyclone PAM observed in the December 1997. This cyclone had a clockwise spiral because it was located in the Southern Hemisphere. This tropical cyclone had some rain bands in the eastern rain area like a mature cyclone. However, neither the eye nor strong rain around the eye could be detected.

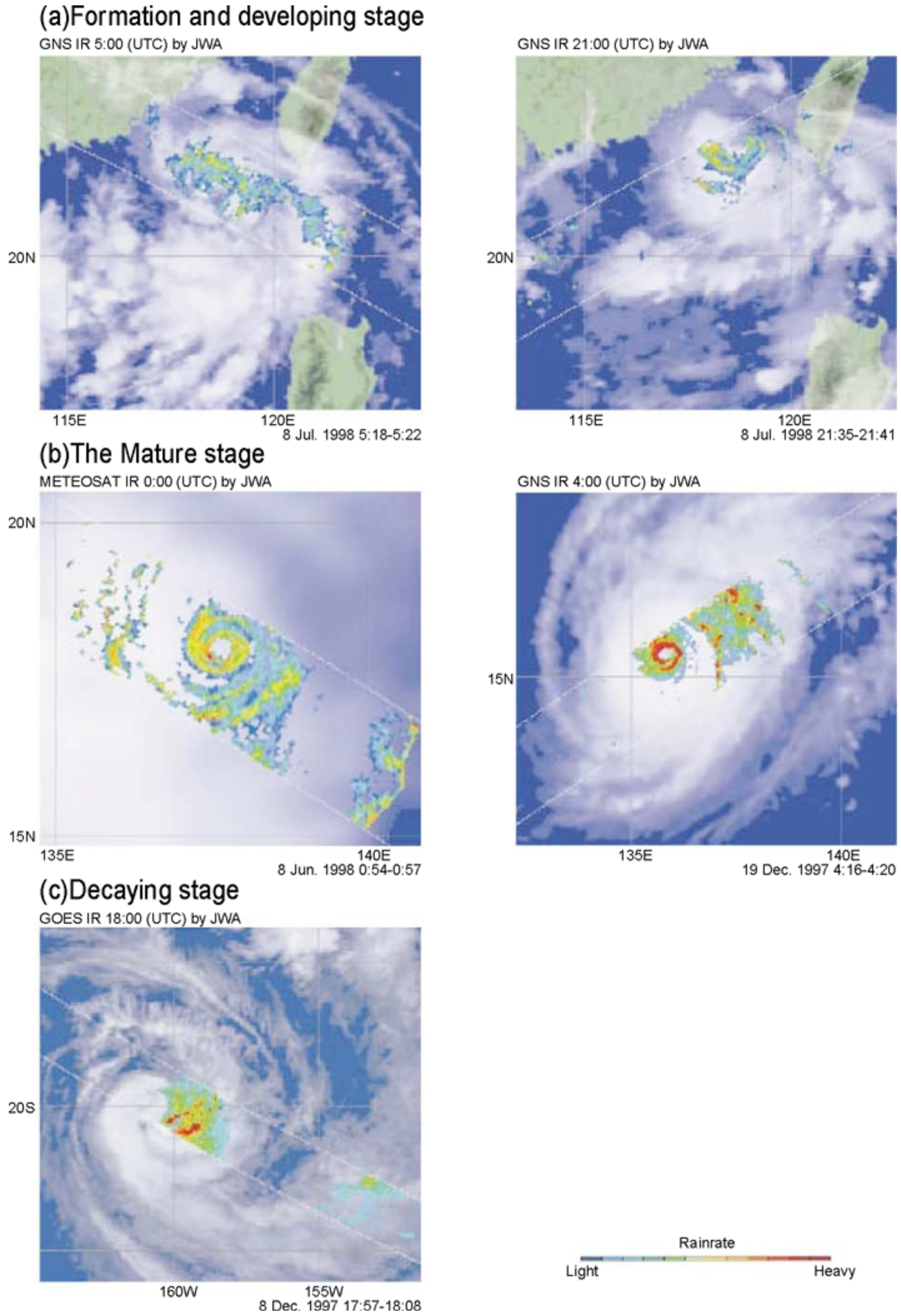

Fig. 2. Stages of a Tropical Cyclone (NASDA/CRL/NASA).

3.3 El Niño Warm Episode Observed by TRMM

Figure 3 indicates the variation Sea-Surface Temperature (SST) related to an El Niño warm episode and corresponding rainfall distribution in February 1998.

The upper panel shows the estimated accumulated monthly rainfall at 2.0 km derived from the Precipitation Radar (PR). Heavy rainfall regions were observed in the Southern Hemisphere, which was in the summer season in this figure. Zonal heavy rainfall regions along the equator correspond to the Intertropical Convergence Zone (ITCZ). In a normal year, heavy rainfall regions are located around the western tropical Pacific, but in February 1998, the maximum rainfall region over the equatorial Pacific to the moved to the east of the date line, around 150° W at the equator. The El Niño warm episode is thought to have influenced this shift. Also, there were no rain observations in the Tibetan Plateau, the Rocky Mountains, or the Andes because those regions are highlands where the altitude exceeds 2.0 km.

The middle panel shows the monthly mean SST retrieved from the TRMM Microwave Imager (TMI) and its deviation from the climatological monthly mean compiled by the Japan Meteorological Agency. Yellow and red areas indicate higher SST than in normal years. In the middle panel, higher SST regions in the tropics correspond well to heavy rainfall regions in the upper panel. Since the El Niño warm episode continued in February 1998, there are higher than normal SSTs in the Eastern equatorial Pacific and lower than normal SSTs in the western tropical Pacific. Related to those positive and negative SST abnomalities, the heavy rainfall region extending over the equatorial Pacific shown in the upper panel shifted its maximum area further eastward than in normal years and less rainfall was observed in the western tropical Pacific. Such a shift of the maximum rainfall region in the tropics linked to convective activity variations should significantly affect world weather.

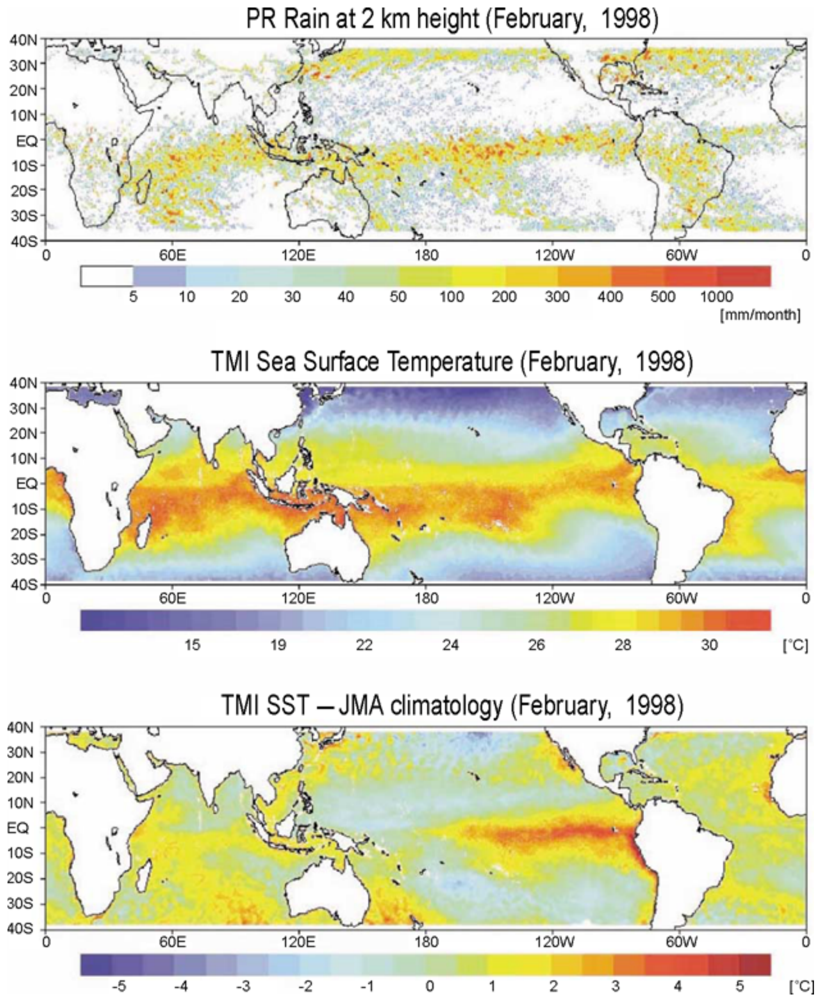

Fig. 3. El Niño Warm Episodes (NASDA/CRL/NASA).

3.4 Rain over Argentina (VIRS, TMI, PR)

Figure 4 shows simultaneous images of rain over northern Argentina and Uruguay from the Visible Infrared Scanner (VIRS), TRMM Microwave Imager (TMI), and Precipitation Radar (PR) from 10:40 to 10:48 on Dec. 21, 1997 (UT). Image 1 is a color-composite RGB image of channels 1 (visible), 2 (near infrared) and 4 (infrared) (for red, green and blue respectively) observed by VIRS. Image 2 shows the 85 GHz, vertically polarized brightness temperature observed by TMI. Image 3 shows the horizontal cross section of rain at 2.0 km. Image 4 shows the vertical cross section of rain along the line AB in Image 3.

Optically thicker clouds in the upper layers are reddish in Image 1 because of the high reflectivity of ch1 and their low temperature. Image 3 shows rainfall observed in these areas. It is clear in Image 4 that the heavy rain developed in the layers above the heavy rain which was in the lower layers. Generally, there were ice crystals over the rain which developed at high altitudes. The brightness temperature in Image 2 decreased due to microwave scattering caused by these ice crystals.

In this way, the rainfall process in the clouds and the characteristics of rainfall will be revealed by simultaneous measurements from these three sensors.

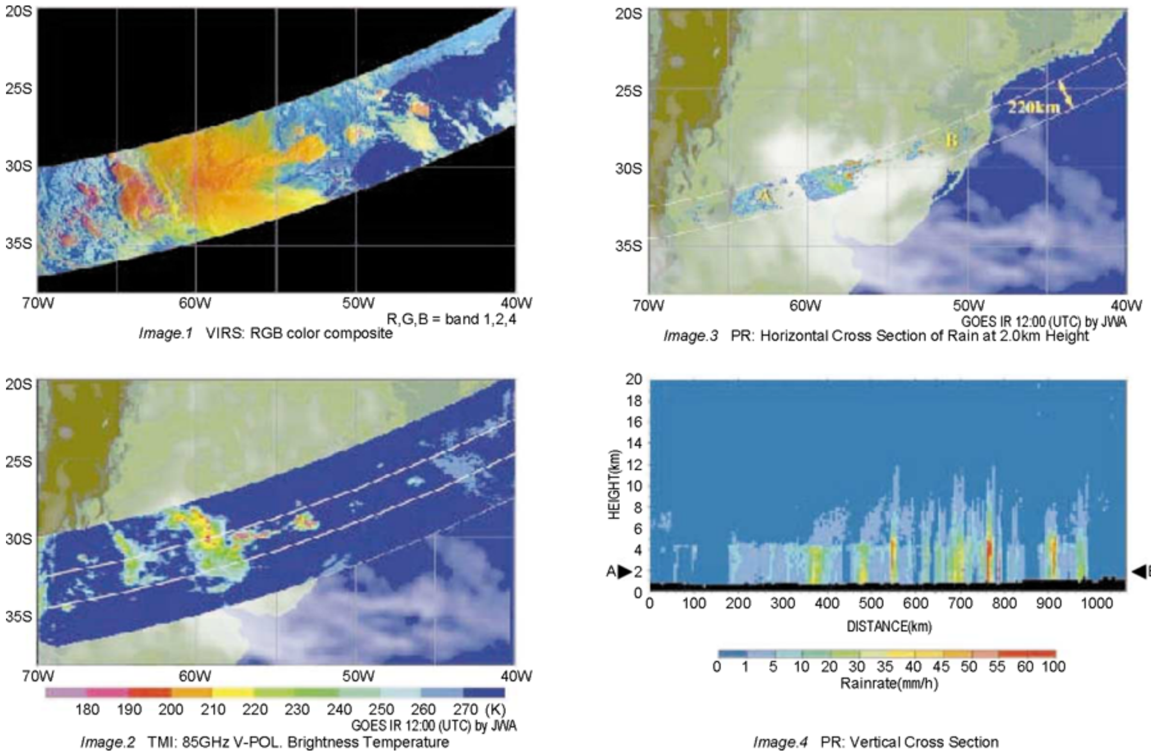

Fig. 4.

4. Conclusion

Global rain distribution in tropical and subtropical zones may be understood more accurately by using TRMM observation data. TRMM also provides us the three-dimensional heat distribution influence on the atmosphere with the convection activities in tropical zone which is the driving force of global weather. TRMM data is valuable for understanding and predicting global climate change mechanisms such as "El Niño." The data have been released to the public since September 1, 1998 and are available to users for free.

For TRMM information, including how to obtain the data, visit the internet URL below. The information on PR is primarily provided at Japan's site (http://www.eorc.nasda.go.jp/TRMM/), and information on other sensors is primarily provided at NASA's site (http://trmm.gsfc.nasa.gov/).

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Author's Profile

Kazuhiro Hiroshima: He received his Master degree in electrical engineering in 1983 from Waseda University. After that he worked in Space Development Division of Toshiba Corporation. He worked as a researcher and engineer in space data processing and image processing region. Now he is in NASDA (National Space Development Agency of Japan) and in charge of TRMM (Tropical Rainfall Measuring Mission) Program Coordinator.