Observation of Precipitation by the TRMM Precipitation Radar

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Abstract: The Tropical Rainfall Measuring Mission (TRMM) is an US-Japan joint space mission to observe tropical and subtropical rainfall. This satellite is equipped with the world's first precipitation radar that operates at 13.8 GHz. We introduce the TRMM precipitation radar (PR) system, along with the PR data processing and analysis algorithms, and some observation results obtained by the TRMM PR. It is concluded that the TRMM PR can give quite useful rainfall data for the understanding of global climate changes, meteorology, climatology, atmospheric science, and also for the studies of satellite communication.

Keywords: TRMM, Precipitation Radar, Rain, Spaceborne Microwave Remote Sensing.

1. Introduction

The Tropical Rainfall Measuring Mission (TRMM) is an US-Japan joint space mission to observe tropical and subtropical rainfall [1]. This satellite is equipped with the world's first precipitation radar that operates at 13.8 GHz. The TRMM was launched from the Tanegashima Space Center in Japan on November 28 in 1997 by the H-II Launch Vehicle Flight No. 6 of JAXA (Japan Aerospace Exploration Agency) on a three-year mission, and is still operating well even now. TRMM has become the first space mission dedicated to the measurements of the tropical rainfall that plays an important role in the global hydrologic cycle and in the global energy cycle.

The tropics account for over two-thirds of global rainfall. The rain releases the energy that helps to power the global atmospheric circulation, which causes the global climate changes, such as El Nino and Southern Oscillation. TRMM data can be of great use to understand tropical rain processes. The goals of TRMM project are mainly: (1) to enhance understanding of global energy and water cycle by providing distributions of tropical rainfall, (2) to improve the global circulation model with the understanding of the mechanism how the tropical rainfall affects the global atmospheric circulation, and (3) to evaluate the satellite system for rain measurement.

The orbit of TRMM takes the altitude of 350 km and is inclined 35 degrees, which leads to suitable sampling in tropics to study the diurnal cycle of tropical precipitation. The altitude was boosted up to 402.5 km in August 2001.

The primary mission product of TRMM is the monthly average rain rate data over 5° x 5° grid boxes between the latitude of 35° N and 35° S for six years.

Figure 1 shows the TRMM satellite with precipitation observation sensors and related sensors. TRMM has three kinds of rain sensors: a precipitation radar (PR), a multi-channel dual polarized microwave radiometer (TMI), and a visible and infrared cross-track scanning radiometer (VIRS).

TRMM also installs two other sensors, CERES (Clouds and Earth's Radiant Energy System) and LIS (Lightning Imaging Sensor). The former measures visible and infrared radiation from Earth surface and clouds, and the latter measures lightning activities over the globe.

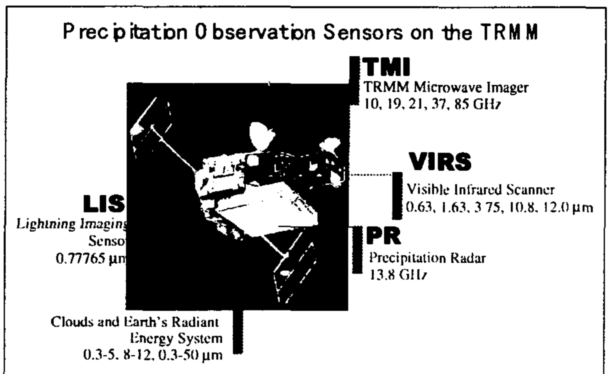

Fig. 1. TRMM satellite.

2. TRMM Precipitation Radar

TRMM PR was developed in Japan by JAXA in cooperation with National Institute of Information and Communications Technology (NICT) and is the first spaceborne rain radar, making TRMM a unique mission [2, 3]. What is special about TRMM PR is that it can provide three-dimensional structures of rain. Besides, it can show vertical distributions of rain rates directly, which is impossible by any method other than TRMM PR. TRMM PR estimates rain rates independently of the microwave emission properties of the background (land or ocean), and provides rain height information, which is useful for

Table 1. Major parameters of TRMM PR.

Item	Specification
Frequency	13.796, 13.802GHz
Sensitivity	0.5mm/h
Swath width	220km
Observable range	Surface to 15km altitude
Horizontal resolution	4.3km (nadir)
Vertical resolution	0.25km (nadir)
Antenna	
Type	128-element WG Planar array
Gain	47.4 dB
Beam width	0.71° x 0.71°
Aperture	2.1m x 2.1m
Scan angle	±17° (Cross track scan)
Transmitter/receiver	
Type	SSPA & LNA (128 channels.)
Peak power	616w
Pulse width	1.6μs x 2ch (Transmitted pulse)
PRF	2776Hz
Dynamic range	79dB
Number of indep. samples	64
Data rate	93.4kbps
Mass	465kg
Power	217w

the TMI. Figure 2 is a block diagram of TRMM PR. Table 1 shows major parameters of TRMM PR. The footprint size of TRMM PR is 4-5 km square, which is much smaller than that of low frequency channels of TMI.

TRMM PR is a 128-element active phased array system, operating at 13.8 GHz. The transmitter/receiver consists of 128 solid-state power amplifiers (SSPA), low noise amplifiers (LNA) and PIN-diode phase shifters. Each T/R element is connected to a 2-m slotted waveguide antenna, with which a 2-m x 2-m planar array is constructed.

3. TRMM Precipitation Radar Algorithm

The international TRMM PR team also developed the standard data processing and analysis algorithms of

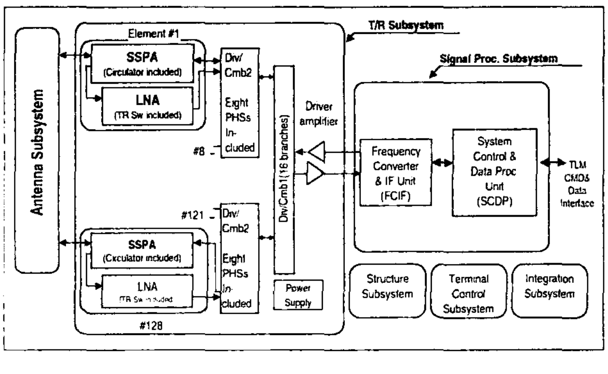

Fig. 2. Block diagram of TRMM PR.

TRMM PR [1, 4]. The standard algorithms are classified into Level 1, Level 2 and Level 3. Level 1 and Level 2 products are the data in the instantaneous field of view (IFOV) which is determined by the antenna beam width of 0. 71°. Level 3 data give the monthly statistical values of rain parameters in the 5° x 5° grid boxes. Table 2 shows major products of each algorithm.

The algorithm 1B21 involves converting of the count values of radar echoes (signal + noise) and noise levels into their engineering values. By comparing the received power with a threshold level, it decides whether or not there exists rain in the IFOV. The algorithm 1C21 gives the radar reflectivity factor Z including rain attenuation effects only when it rains in the IFOV. When it is raining in the IFOV, the algorithm 2A21 estimates the path-integrated attenuation by rain and its reliability considering the surface as a reference target. When it is not raining in the IFOV, it also computes the statistics of the surface scattering coefficient σ^0 over the ocean or the land. Algorithm 2A23 checks whether a bright band exists in the rain echoes and determines its height when it exists. The rain is classified into any of the stratiform type, the convective type or the others. The algorithm 2A25 retrieves rain rate profiles for each angle-bin direction. As the 13.8 GHz frequency band is used for the TRMM PR, compensation of the rain attenuation becomes the major problem to be solved in the rainfall rate retrieval algorithms. The algorithm 3A25 gives the space-time averages of accumulations of 1C21, 2A21, 2A23 and 2A25 products. The most important output products are the monthly rainfall accumulations and the monthly average rain rate over 5° x 5° grid boxes at the altitudes of 2 km and 4 km. The algorithm 3A26 gives the monthly rain accumulations and the monthly average of rain rate over the 5° x 5° grid boxes using the multiple threshold method.

Table 2. TRMM PR standard algorithms.

Algorithm	Products
[1B21] PR Calibration	Total received power, Noise Level, Rain/No rain flag, Storm height, Clutter contamination flag
[1C21] Radar Reflectivity	Radar reflectivity factor Zm including rain attenuation
[2A21] Surface Scattering Coefficient (σ^0)	Path integrated attenuation (PIA), σ^0 value (ocean/land) in case of no rain
[2A23] Rain Type Classification	Bright band (presence or no), Bright band height, Rain type classification
[2A25] Rainfall Rate Profiles	Profiles of rainfall rate and radar reflectivity factor Ze with the correctio nof rain attenuation
[3A25] Monthly Statistics of PR Products	Monthly statistical values of 1C21, 2A21, 2A23, 2A25 products
[3A26] Monthly average of Rainfall Rate by Statistical Method	Monthly average rainfall rate over 5° x 5° boxes using a statistical method

4. Examples of observations by TRMM PR

1) Typhoons

TRMM PR has been successful in providing the three dimensional structure of tropical cyclones very clearly and in observing the rainfall rate distribution inside of the tropical cyclones, which the conventional visible and IR sensors on the geostationary meteorological satellite cannot observe. Figure 3 shows an example. TRMM overflew both of the typhoons T0407 and T0408 on 28 June 2004 that were south of Japan. The Precipitation Radar saw the eye region of both typhoons. At the time of the overflight, Typhoon Mindulle (T0407) had just finished intensifying to category 4. The cloud top data (TRMM VIRS 11 micron infrared brightness temperature) shows that T0407 had a well-defined eye. The precipitation radar (lower left) shows that the eyewall of T0407 was nearly vertical, which is consistent with the storm being well organized and intense. The three dimensional surface is defined by the 1 mm/hr rain estimate of the precipitation radar. Only the precipitation radar can tell the shape of the rain volume inside of the typhoon's clouds.

In the previous orbit, TRMM saw Typhoon Tingting (T0408) when it had just finished strengthening to become a full-fledged typhoon. The precipitation radar shows (lower right) that T0408 had rain that reached higher than T0407, even though T0408 was a weaker typhoon. The tallest location of 1 mm/hr rain was 16.75 km above the ocean, just north of the center of T0408. A very tall rain cell is often a sign that a weak storm is becoming more intense. Only the precipitation radar can tell the exact height of rain inside the heart of a typhoon.

2) Bright-band height

A bright-band is a melting layer of snow and ice that usually lies above the stratiform type of rain [5]. On the meteorological radar a bright-band can be seen as a nearly horizontal thin bright echo layer with a large radar reflectivity factor Z. The bright-band height gives an important indication in estimating the height of the stratiform type of rain and the 0°C isotherm height, i.e. the freezing height. The rain height is one of the important parameters to retrieve the rainfall rate from the brightness temperature data obtained by the microwave radiometer.

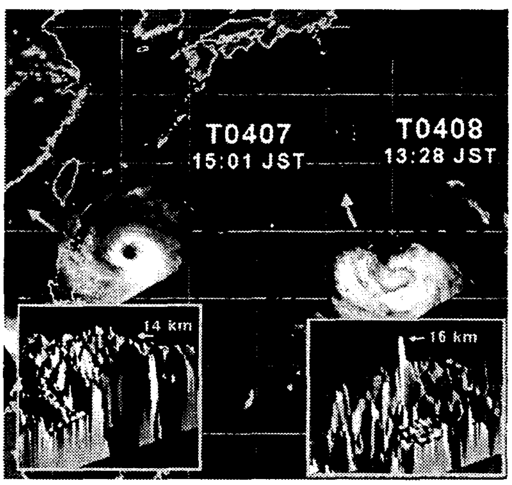

Fig. 3. T0407 and T0408 observed by TRMM VIR and PR.

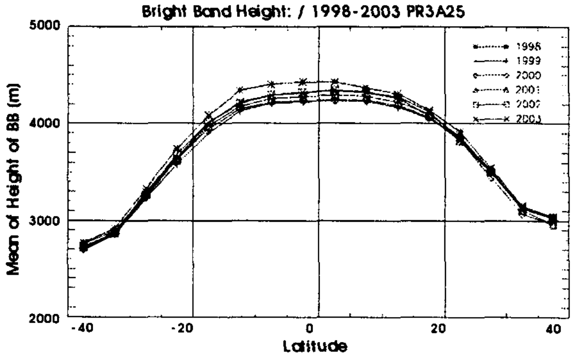

Fig. 4. Zonal average of bright-band height (1998-2003).

In the design of the satellite communication link of the microwave and millimeter radio waves, the rain height is also considered to be an indispensable parameter to evaluate the effect of rain attenuation, which is a main factor of deterioration of the communication link.

We have analyzed TRMM PR 3A25 six-year data (1998-2003) to obtain the monthly, yearly and seasonal variations of the bright-band heights over the ocean and the land within the latitude of +/– 40 degrees and have compared the mean values of the bright band heights of those five years with the ECMWF 0°C isotherm heights.

We have analyzed the six-year (1998-2003) annual mean variations of bright-band heights over the entire globe (at the fixed latitude and the longitude from 0 to 360 degrees). From the results of the analysis shown in Figure 4, we could learn the zonal averages of the bright-band height of 1998 are higher than those of the other five years around the regions from the equator to the latitude of approximately 20 degrees south. This can be considered the effects of the 1998 El Nino event, which was the largest in the 20th century.

We have also found that the yearly variations of the bright-band heights are smaller at the higher latitude in both hemispheres. Apart from the year of El Nino 1998, the bright-band heights shows almost the same figures and change in a similar way as a function of latitude in the other five years (1999-2003). However, if we look at the figures carefully, the height of bright-band is a little higher in 2002 than in the other years. This may be caused by the small El Nino, which was seen during March 2002 to March 2003. The bright-band heights are virtually constant at the low latitude (+/–10 degrees) and the figures decrease gradually as the latitudes goes higher in both hemispheres. These downward trends of

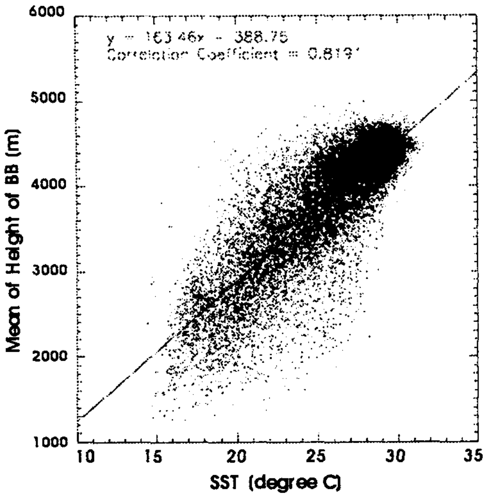

Fig. 5. TRMM/TMI derived SST versus TRMM/PR derived bright-band height (Jan. 1998-Jul. 2001).

the bright-band height in each hemisphere are, however, asymmetric, and the bright-band heights are slightly higher in the north hemisphere than in the south hemisphere. Each of the yearly variations of the ocean and the land shows the similar trend to that of the whole globe.

Figure 5 is a scatter diagram for every 5 degrees of latitude and longitude, of the monthly mean SST (Sea Surface Temperature) on the horizontal axis and monthly mean bright-band height on the vertical axis. The SST are retrieved from TMI and 5° x 5° grid data are obtained by averaging the original 0.25° x 0.25° grid data.

The correlation coefficient is 0.82 and good correlation can be seen from the scatter diagram. The bright-band height increases by about 1km every 6°C increase of the SST.

3) El Nino Event

The precipitation distribution over the tropical Pacific in the year of El Nino is obviously different from that in the year of La Nina. With these phenomena, it rains far more than usual where it hardly rains, or vice versa. During the period of 1997-1998, when we had the strongest record of El Nino, TRMM PR clearly observed the unusual distribution of rainfall rates over the tropical Pacific and contributed to clarifying the end of the El Nino.

4) Concentrated heavy rain over Korea

TRMM PR observed the concentrated heavy rain over Korea on 31 July 1998. The heavy rain front caused great damage, landslide casualties, and muddy streams in the southern part of Korea. The highest precipitation recorded was 226mm in Soon Cheon, Cheon Ra Nam-Do from the night of 31 July through 19:00 of 1 August. A precipitation rate of 128mm/hour was also recorded in Soon Cheon, Cheon Ra Nam-Do, Korea.

5. Conclusions

The TRMM satellite has brought us much better results than expected over the past six years and ten months. It can be concluded that TRMM PR gives quite useful rainfall data for the understanding of global climate changes, particularly El Nino and Southern Oscillation, and also for the studies of meteorology, climatology and atmospheric science. TRMM PR data also provide much information on the bright band height statistics, which is useful for the design of the satellite communication link.

The TRMM satellite is continuing its mission in very good condition as of September 2004, at the time of writing. We hope that NASA and JAXA will continue the operation of TRMM through 2005 and hopefully even longer.

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