CHAPTER VII

COMPARISON OF SATELLITE (TRMM) PRECIPITATION DATA WITH GROUND-BASED DATA
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7.1. INTRODUCTION

Most of the earth’s rain falls over the oceans, especially in the tropics. Therefore, emphasis should be given to rainfall measurements over oceans, to understand the global hydrologic cycle. But, since the in-situ measurements are very difficult over oceans, we need to depend on satellite measurements that are validated sensibly. Tropical Rainfall Measuring Mission (TRMM) is the first satellite mission of National Aeronautics and Space Administration's (NASA), United States of America, launched in November 1997, dedicated for observing and understanding tropical precipitation and its relation with global climate. TRMM Merged High Quality/Infrared Precipitation estimates obtained from the TRMM ‘3B42’ algorithm provide high resolution satellite-based rainfall estimates. To understand these measurements and to use the derived data products, it would be needed to compare/validate with ground-based measurements and also be aware of the seasonal and coastal dependence of the satellite measurements. This chapter presents such a comparison carried out for different monsoon seasons for all the stations out of which two coastal stations are on the west coast of India which experiences intense precipitation during the Indian summer monsoon (Xie et al., 2006), one high altitude station on the Western Ghats and one station on the east coast. The methodology and analysis followed here will eventually help in validating the precipitation data from the Indo-French upcoming satellite mission Megha-Tropiqes.

TRMM provides a unique platform for measuring rainfall from space using a passive sensor TRMM Microwave Imager (TMI; Kummerow et al., 1998), an active Precipitation Radar (PR) operating at 13.6 GHz, and a visible and infrared scanner (VIRS) radiometer. Precipitation Radar is the first satellite-based radar (active sensor) to measure rain parameters. TMI is a multi-channel/dual polarized (except in 22 GHz) microwave radiometer (10, 18, 22, 37 and 85 GHz), which provides rain rates over the tropical oceans besides sea surface temperature (SST).
sea surface wind speed (SSW), total water vapor (TWV) and cloud liquid water content (CLW). Passive estimates from the TMI are a less direct rainfall estimate since the radiometer responds to integrated liquid water, not just to raindrops. But by comparison, the more direct measurement of hydrometeors by the TRMM PR would seem to have less uncertainty; however, the PR operates at a single frequency (13.8 GHz) so that microphysical assumptions regarding drop size distributions come into play in the process of correcting the measured reflectivity for attenuation and relating reflectivity structure to rainfall rate (Franklin et al., 2003). Since the PR is a single-frequency, single-polarization, and non-Doppler one, the retrieval of rain intensity from the echo intensity data requires careful interpretation based on sophisticated algorithms which incorporate with peripheral ground validation data (Koru et al., 1996). Since, 13.6-GHz radar will only be sensitive to reflectivities higher than about 17 dB, there is disagreement between PR and TMI (Berg et al., 2006). Any way, the upcoming Global Precipitation measurement (GPM) mission will improve upon TRMM by employing a dual-frequency precipitation radar. The 13.6-GHz radar will only be sensitive to reflectivities higher than about 17 dB, whereas at 35 GHz, the minimum sensitivity will be 12 dB, according to recent design specification (Iguchi et al., 2003).

TRMM algorithm 3B42 provides adjusted 3-hour cumulative estimates of rain using merged microwave and infrared (IR) precipitation information (Adler et al., 2000). The TRMM adjusted Geostationary Observational Environmental Satellite (GOES) precipitation index (GPI) (AGPI) is produced by using cases of (nearly) coincident TRMM combined instrument (TCI) using the combined TMI and PR algorithm (Haddad et al., 1997) and VIRS IR data to compute a time and space varying IR-rain rate relationship that matches the TCI IR rain rate. This relation is used to calibrate IR estimates from geosynchronous satellite IR data to form the 3B42 product. Global estimates are made by adjusting the geosynchronous satellite Precipitation Index (GPI) to the TRMM estimates. The monthly TRMM and merged estimate is produced by merging the AGPI with information from rain gauges. The gauge analysis used in this procedure is from the GPCP (Rudolf, 1993). The merger is computed following Human et al. (1997). The 3B42 algorithm
provides daily precipitation and root mean square (RMS) error estimates at 1° x 1° latitude/longitude grids in the TRMM domain 40° N to 40° S (Human et al., 2001) for 3B42-V5 and in 3-hourly at 0.25° x 0.25° latitude/longitude grids over 50° N to 50° S for 3B42-V6.

Even though we have been using data from TRMM satellite for more than 10 years, the effect of coastal dependence and seasonal dependence on data products at each location is still a dilemma. Validation of TRMM 3B42-V5 data has been done using IMD rain gauge data by Narayanan et al. (2005) over Indian land. They found out that 3B42-V5 does not pick up small (< 1mm) and very high (> 80 mm per day) daily average rainfall. Thus, the daily variance (day-to-day variations within the season) estimated by 3B42-V5 is poor compared to the gauge data. The reasons may be related to deficiencies in the IR estimates. However, at pentad (five-day) time scale the correspondence between the two datasets improves and intraseasonal and interannual variations are reasonable. The correlation coefficient over all of India on the monthly scale is high (r²=0.92) in comparison to 5-day (r²=0.89) and daily (r²=0.79) time scale. Chokngamwong and Chiu (2005) have validated 3B42 data using rain gauge data from more than one hundred gauges over Thailand. Their results show that 5-year (1998-2002) daily average rainfall for gauge, 3B42-V5 and 3B42-V6 are 4.73, 5.62 and 4.58 mm/day respectively. The bias and root mean square deviation (RMSD) for V5 are 0.88 mm and 9.71 mm whereas for V6 it is 0.15 mm and 9.60 mm respectively. Scatter plots of daily gauge data versus 3B42 data show that 3B42-V6 correlates better with gauge (r²=0.44) than V5 (r²=0.37). The distribution of daily 3B42-V6 rain rate is quite similar to gauge while 3B42-V5 has more rain in the range 5-20 mm/day. The 3B42-V6 TRMM algorithm shows improvement over 3B42-V5 in terms of the bias, RMS difference, and mean absolute difference. Long-term mean rainfall rates from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and Precipitation Radar (PR) are compared with in-situ measurements by rain gauges on the NOAA TAO/TRITON buoy array in the tropical Pacific by Kenneth et al (2003) [12]. The buoy rain gauges have an advantage over most of the available ground truth data in that the local meteorological effects do not influence them.
The TRMM 3B42-V5 and 3B42-V6 daily rainfall data has been compared both with GPCP as well as IMD Indian gauge data for the duration 1998 to 2003 by Rahman and Gupta (2007). They have compared the all India seasonal (JJAS) total rainfall derived from IMD data with GPCP and 3B42-V6. In all the years the former is having more difference from the later two. Among known sources of errors in the rain retrieval, Toru et al. (1996) studied the vertical variability of the DSD and examined the partial beam-filling effect in terms of their significance with numerical simulations based on the MU radar data. Here, they examined the effect of the height variations of DSD using the MU radar data as realistic examples of the given ‘truth’ in the simulation. An accurate mean of the ground truth for the TRMM precipitation radar has been developed with the MU radar. Adeyewa and Nakamura (2003) have shown that TRMM PR data overestimates rain in the tropical rain forest region of Africa when compared with Global Precipitation Climatology Centre (GPCC) rain gauge data (Rudolf, 1993). The 3B43 product, which is the TRMM merged analysis on monthly scale, has the closest agreement with rain gauge data. Nicholson et al. (2003a), using rain gauge data from 515 stations over North Africa shows 3-4% bias for GPCC or GPCP with reference to seasonal rainfall fields (1988-1994). Nicholson et al. (2003b) and excellent agreement of TRMM-adjusted GOES precipitation Index (AGPI) and TRMM merged rainfall analysis with high density (920 stations) gauge data over West Africa on monthly to seasonal time scale. The RMSD of both satellite-derived products is 0.6 mm/day at seasonal scale and 1 mm/day at monthly resolution. The bias of AGPI is only 0.2 mm/day whereas the TRMM-merged product shows no bias over West Africa. The 1ºx1º latitude/longitude product also shows excellent agreement at the seasonal scale and good agreement at monthly scale. In the present study, the comparison of TRMM and disdrometer data from four stations has been done. The details are explained below.

7.2. THE STATIONS AND THEIR CORRESPONDING TRMM GRIDS

The stations, duration for which data being compared and the corresponding TRMM grid that is chosen for comparison for each station are given in the Table VII.I. Thiruvananthapuram is a coastal station and about 25% of the
TRMM grid falls over the ocean. Kochi is also a coastal station with the same type of grid. Munnar is a high altitude station and an entire grid falls over the land. SHAR is a coastal station on the eastern coast and about 40% of the grid could be over the oceans. The stations along with the corresponding TRMM grids are shown in a physiographical map shown in figure 7.1. The percentage of background that ocean or land occupies each of the grids can also be seen in the figure.

7.3. DATA AND DATA ANALYSIS

**Satellite data**

Algorithm 3B-42 produces Tropical Rainfall Measuring Mission (TRMM) merged high quality (HQ)/infrared (IR) precipitation and root-mean-square (RMS) precipitation-error estimates. These gridded estimates are on a 3-hour temporal resolution and a 0.25-degree by 0.25-degree spatial resolution in a global belt extending from 50 degrees south to 50 degrees north latitude. The main difference between TRMM 3B42-V5 and 3B42-V6 is that the resolution of 3B42-V5 is on a 1º x 1º grid and covers the global tropics (40º S-40º N latitude), whereas the 3B42-V6 product is in 3-hourly on a 0.25º x 0.25º grid and covers 50º S-50º N latitude. The 3B-42 estimates are produced in four stages, (1) the microwave estimates precipitation are calibrated and combined, (2) infrared precipitation estimates are created using the calibrated microwave precipitation, (3) the microwave and IR estimates are combined, and (4) rescaling to monthly data is applied. Each precipitation field is best interpreted as the precipitation rate effective at the nominal observation time.

The data has been downloaded from the web portal of NASA through anonymous FTP. The binary data obtained is converted into ASCII format. The data has a temporal resolution of 3 hours and corresponding to an area averaged over 0.25 x 0.25 degrees latitude-longitude grid. The program written in FORTRAN, derives the needed data corresponding to the grid where each station lies. The 3-hourly accumulated rainfall has then been derived from the 3-hourly rain rate for the comparison with the disdrometer data. The daily rainfall data has been compared by Rahman and Sengupta (2007). But in the current analysis, we have compared 3-hourly accumulated rainfall that is the maximum
temporal resolution of the rainfall data available from TRMM 3B42-V6 also apart from daily and monthly accumulation data.

<table>
<thead>
<tr>
<th>No.</th>
<th>Station</th>
<th>From</th>
<th>To</th>
<th>TRMM Grid box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thiruvananthapuram</td>
<td>March 2006</td>
<td>November 2006</td>
<td>8.375° N to 8.625° N; 76.875° E to 77.125° E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) July 2003</td>
<td>August 2003</td>
<td>76.125° E to 76.375° E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) May 2004</td>
<td>July 2004*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Munnar</td>
<td>July 2004*</td>
<td>October 2004</td>
<td>9.875° N to 10.125° N; 76.875° E to 77.125° E</td>
</tr>
<tr>
<td>4</td>
<td>Sriharikota (SHAR)</td>
<td>August 2003</td>
<td>October 2003</td>
<td>13.375° N to 13.625 °N; 80.125 °E to 80.375° E</td>
</tr>
</tbody>
</table>

Table VIII. The stations, duration for which data being compared and the corresponding TRMM grid that is chosen for comparison for each station.

Figure 7.1. The Geographical locations of the 4 stations along with corresponding TRMM grid box shown in a physiographical map.
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Ground-based data

At all the four stations disdrometer was operated for differing periods. Therefore, the disdrometer data can be compared with the corresponding TRMM grid data. At Thiruvananthapuram, apart from the disdrometer Micro Rain Radar (MRR) and manual raingauge are also operational. Hence, at Thiruvananthapuram data from all these instruments have compared with the satellite data.

The disdrometer and MRR data obtained at one-minute interval were used to get the accumulated rainfall over 3 hour interval, over a day and for a month. Daily and monthly observations were obtained from the manual raingauge.

The analysis consisted of two parts. Firstly, the simultaneous detection of rain events by both ground-based and satellite measurements was found out. Then the correlation of the magnitude of the accumulated rain was done for only those events which were detected simultaneously.

The correlations for 3-hourly, daily and monthly precipitation data obtained from ground based and TRMM data have been evaluated.

7.4. RESULTS AND DISCUSSION

7.4.1. Simultaneous detection of rain

Before, correlating the measurements, the detection of daily rain events by these instruments simultaneously was evaluated as said earlier. The results for Thiruvananthapuram are shown as a pie diagram in figure 7.2. Both TRMM and ground-based instruments detected rain simultaneously for 35% time while 42% of time “no rain” was detected by both the instruments. Therefore for 77% time simultaneous detection of rain/no rain is seen. For the other 23% time only either one of the instruments has detected rain. This is not taken for the analysis. The 35% time when both detected is only used for analysis.

In the following sections, first the simultaneous detectability is shown by plotting the actual measurements from satellite and ground-based instruments. Then their magnitude was compared by doing a correlation analysis. By this way, the detectability and the efficiency of detection of rain events by all these instruments can be understood.
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7.4.2. Three-hourly rainfall

TRMM 3B42-V6, 3-hourly data has been compared with ground-based data. TRMM data is found to be matching with the ground-based measurements in the simultaneous sensing of rain. Munnar has a better correlation compared to other stations. Munnar is a high altitude station where the TRMM grid is wholly lying on the ground. That may cause the reduction in erroneous measurement for the microwave passive imager measurement when compared to other stations. Typical comparison for all the stations for each month is shown in the figure 7.3.
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Figure 7.3. Comparison of TRMM 3-hourly rainfall data with Ground-based observations. [Disdrometer data is not available from 20th to 22nd and MRR data is also not available on 20th at Thiruvananthapuram (TVPM; panel 1)].
The next step of the analysis is to compare the magnitude of rainfall seen by ground-based and satellite measurements.

All the 3-hourly rainfall data points measured by disdrometer and TRMM at Thiruvananthapuram during the year 2006 have been plotted to find out the correlation (figure 7.4). The total number of data points is 132. The correlation coefficient obtained is only 0.4. Since the satellite gives an area averaged rainfall, the magnitude of the rainfall shown will be averaged for that particular grid. So, the magnitude appears to be underestimated. We are assuming that the rainfall over an area that is as small as a satellite grid got homogeneous clouds and thus homogeneous precipitation. But even for this much small area, it is seen that rainfall may not be homogeneous. Here the magnitude of the satellite rainfall measurement is seen to be on average about 50% of ground based measurement.

![Figure 7.4. 3-hourly rainfall data measured by disdrometer and TRMM (number of data points=132).](image)

To understand the seasonal dependence on the satellite measurements of rainfall, Thiruvananthapuram 2006 data has been grouped for that of pre-monsoon, southwest monsoon and that of north-east monsoon. Then each set of data obtained from the disdrometer and TRMM has been put together and plotted and fitted to study the correlation in each season (figure 7.5). The correlation was 0.48 for premonsoon, 0.44 for southwest monsoon and 0.3 for northeast monsoon season.
Figure 7.5. 3-hourly rainfall obtained from disdrometer and TRMM for (1) Pre-monsoon (top panel) (2) southwest monsoon (middle panel) and (3) northeast monsoon (bottom panel).
7.4.3. Daily rainfall accumulation

The daily accumulated rainfall data has been derived from the 3-hourly data. To understand the improvement in the correlation of the comparison when daily accumulations are taken, these daily TRMM data and ground-based data has been plotted in a bar-graph. Such comparisons for all the stations are shown in the figure 7.6. Since the manual rain gauge data was available at Thiruvananthapuram, data from it has also been incorporated in this analysis.
Figure 7.6. Comparison of TRMM rainfall/day data with Ground-based observations. [Disdrometer data is not available from 20th to 22nd and MRR data is also not available on 20th at Thiruvananthapuram (TVPM; panel 1)]

Exactly like the correlation study did for 3-hourly data, here also all the mm/day data points measured by disdrometer and TRMM has been plotted together to study the correlation between the measurements of the daily accumulations of rainfall (figure 7.7). Here the correlation coefficient has been improved from that at 3-hourly accumulation (0.4) to 0.6
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7.4.4. Monthly rainfall accumulation

Monthly accumulated rainfall data has been derived from the 3-hourly data from TRMM and from disdrometer. The daily manual raingauge data has been used to derive the monthly raingauge data. Root Mean Square Error (RMSE) in these comparisons has also been brought out and plotted along with the rainfall data. It is apparent from the figure that all the monthly accumulations obtained from the ground-based sensors compare well with the satellite detections.
Figure 7.8. Comparison of the rainfall/month at (1) Thiruvananthapuram (top panel), (2) Kochi (2nd panel), (3) Munnar (3rd panel) and SHAR (bottom panel). RMSE is given for measurements between disdrometer and satellite.
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Figure 7.9. Correlation of the monthly accumulations of rainfall between the disdrometer and satellite measurements.

Figure 7.10. Comparison of the RMSE obtained for the comparison for different accumulations at Thiruvananthapuram for the year 2006.
Here also, all the monthly accumulations obtained from the disdrometer have been put together and plotted with that obtained from the TRMM. Here, the correlation has improved from a value of 0.6 for daily data to a value of 0.9.

7.4.5. Evaluation of the correlation for accumulations

The RMSE obtained when the comparison has been done using 3-hourly data, daily data and monthly data is shown in the figure 7.10. If RMSE is less, then correlation between the data from disdrometer and TRMM is good. It is very clear from the figure that RMSE for 3-hourly is most, that of daily is more and that of monthly is less.

7.6. CONCLUSION

The major findings/conclusions from this study are given in brief below:

1. TRMM rainfall agrees well with the Manual rain gauge, Disdrometer and MRR rainfall, when monthly accumulation is taken (Correlation coefficient is > 0.9).

2. The same comparison for daily accumulated rainfall gives a correlation coefficient of around 0.6

3. For 3-hourly rainfall, the comparison gives a value of around 0.4

4. Magnitude of RMSE has no dependence on the magnitude of rainfall accumulation

5. RMSE varies from a low value for monthly accumulation to a high value for 3-hourly accumulation.

6. 79% of the total events could be detected together by the TRMM and disdrometer sensors.

7. Munnar shows a better correlation compared to other stations. This could be due the “coastal-grid effect”, as the other three stations are coastal stations. This could be due to the land and ocean back-ground emissivity within the same grid box in the scenario of satellite measurements.

8. To evaluate the ‘ground truth’ in a detailed way, it would be better to deploy more instruments within a single grid of 0.25º X 0.25º.

9. For rainfall events detected both by the satellite and ground based sensors, the TRMM rainfall appears to be under estimated in magnitude, on an
average, up to 50%. This could due to the fact that the satellite data is for an area averaged one over the 0.25° X 0.25° grid.

10. The number of events detected by single sensor only is being significant indicates that the rainfall may not be uniform even over a small grid size of 0.25X0.25 degrees. This also supports the need to have closely knit network of ground stations within the grid area.