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Evaluation of Multi-Satellite TRMM Derived Rainfall Estimates over a Western State of India

Sushma NAIR

Regional Meteorological Centre, Mumbai, India

Govindrajan SRINIVASAN

India Meteorological Department, Delhi, India

and

Ramkrishna NEMANI

NASA Ames Research Center, Moffett Field, California, USA

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Abstract

The Tropical Rainfall Measuring Mission (TRMM) blended rainfall product (3B42-V6 data set) has been used for inter-comparison with observations from a high density rain-gauge network over the western state of Maharashtra, India. The state of Maharashtra was chosen for the inter-comparison exercise primarily because of its diverse rainfall regime. The rain distribution over Maharashtra, characterized by a pronounced longitudinal gradient is closely linked to the north-south oriented orography of the region known as the Western Ghats. The validation exercise was carried out for 7 monsoon seasons from June to September from 1998 to 2004 at various space and time scales. The results are consistent at daily, monthly and seasonal timescales. The comparisons among stations and over geographically similar climatic zones demonstrated that the performance of 3B42-V6 product varies over the different climatic regimes. In terms of spatial reproductivity, the existence of the west-east rainfall gradient along the west coast is captured by the satellite product, but the orographic effect (rainfall maxima is over the Western Ghats as captured by the rain-gauge) is not reflected by 3B42-V6 product. The 3B42-V6 product shows rainfall maxima at the coast. The satellite estimates of rainfall amounts over the state were found to be most accurate over regions of moderate rainfall and mainly inaccurate in regions of sharp rainfall gradient. In terms of magnitude of the rainfall amounts, over the windward side of the Western Ghats the 3B42-V6 product was unable to resolve the heavy orographic rainfall amounts and over the leeward side the rainfall amounts in the immediate rain-shadow region were overestimated. One of the key results obtained from the daily rainfall intercomparison exercise is the ability of the 3B42-V6 estimates to detect the wet and dry phases of monsoon over most parts of the state (except the leeward side). Though the rainfall amounts estimated by the satellite product were sometimes under/over estimated, the timing of the rain events as estimated by the satellite product was generally coincident with the gauge observations over most of the regions except in the immediate rain-shadow region of the state. The TRMM 3B42-V6 estimates therefore could have tremendous potential to be used for intraseasonal studies over most regions of the state.

Corresponding author: Sushma Nair, Regional Meteorological Centre, Colaba, Mumbai 400005, India.
E-mail: nairsusha@gmail.com
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1. Introduction

Accurate estimates of precipitation on varying space and time scales are important to not just the

weather forecaster or climate scientists, but also to a wide range of decision makers dealing with sectors such as water resources and agriculture. However, measurement of rainfall over the globe is a challenging task. Precipitation observations are limited to land areas where rain-gauges can be deployed. Most of the oceans remain devoid of any direct rainfall measurements. Currently, satellite remote sensing is the only means for circumventing these difficulties encountered with conventional ground-based rainfall measurements. With a number of meteorological satellites in orbit and advanced computer processing of digital data, rainfall estimates can be derived at finer spatial and temporal resolutions for larger areas. Satellite-based precipitation products can give high temporal (3 hourly) and spatial (0.25×0.25) resolutions. Satellites have biases and random errors that are caused by various factors like sampling frequency, non-uniform field-of-view of the sensors, and uncertainties in the rainfall retrieval algorithms. It is therefore essential to validate the satellite derived products with more conventional rain estimates to quantify the direct usability of the products.

The Tropical Rainfall Monitoring Mission (TRMM), dedicated exclusively to monitor tropical and sub-tropical rainfall was launched in November 1997. TRMM is a joint US-Japanese satellite mission. TRMM operates in a circular and non-sun-synchronous orbit. TRMM's non-sun-synchronous orbit allows each location to be covered at different local times each day thereby allowing a particular location to be sampled at all local times over a few weeks. TRMM at 35° inclination to the equator is a low frequency (orbit period of 92.5 minutes), low altitude (350 km originally, orbit boosted to 403 km in August 2001) satellite. The low altitude of TRMM makes possible the resolution of cloud radiances over small areas, which permits a more accurate estimation of precipitation. With TRMM it is possible to obtain physically direct measurements of rainfall and its vertical structure on asynoptic hours of the day, thereby allowing study of rainfall variability at shorter timescales. This makes TRMM one of the best available remotely sensed rainfall estimates for the tropics.

There have been numerous attempts to validate TRMM retrievals with ground-based estimates like gauge and radar data in the tropics and the mid-latitudes. There have also been efforts to validate TRMM rainfall products over Asia as well as over the Indian sub-continent as a whole. There have been no TRMM inter-comparison exercises carried out for specific regions over India. It will be interesting to validate the TRMM products at a regional level. The availability of high-resolution gauge data for Maharashtra and Maharashtra's diverse climate regime is one of the main motivations for attempting an inter-comparison exercise over Maharashtra, a state in western India.

Section 2 gives a brief discussion of the other validation exercises. Section 3 discusses the data and methodology used for the present study. Results of the validation exercise at varying spatial and temporal scales are discussed in Sections 4, 5, and Section 6 presents the conclusions of the inter-comparison exercise.

2. Review of the other validation studies

Comparisons by Chiu et al. (2006) of TRMM retrievals (TRMM Precipitation Radar (PR), 2A25, TRMM Microwave Imager (TMI) 2A12, TRMM Combined Instrument (TCI) 2B31, TRMM 3B42, V5 & V6, TRMM, 3B43, V5 & V6) with Water District (WD) Rain-Gauge rates over New Mexico showed high biases for satellite-only algorithms. Merged satellite-gauge products (3B43 or 3B42) were found to be better correlated with WD gauge data. Bowman (2004) has used TRMM TMI and PR data retrievals for comparison with 25 rain gauges on the ocean buoy in the tropical Pacific. Agreement of gauge data with TRMM TMI was found to be better than with TRMM PR. Adeyewa and Nakamura (2003) have validated the TRMM PR and 3B43 rainfall products with the Global Precipitation Climatology Center (GPCC) global precipitation analysis rain gauge data over the major climatic regions of Africa. Significant seasonal and regional differences were observed. One major conclusion drawn from their assessment is that TRMM PR data does not appear to be adequate enough to serve as a stand alone satellite product. The best agreements were achieved with the TRMM 3B43 data. Similar results were obtained by Nicholson et al. (2003) who have used gauge data from a network of 920 stations over West Africa to evaluate TRMM (PR, TMI, 3B43) rainfall products for the year 1998. While TRMM PR and TMI products showed a net tendency to overestimate gauge measurements, 3B43 merged product showed excellent agreement with gauge measurements on monthly to seasonal timescales.

Chokngamwong and Chiu (2005) have compared gauge data from more than 100 rain gauges over

Thailand with the TRMM level 3 rainfall products (TRMM 3B42, 3B43 for V5 and V6). Their results show that 3B42-V6 data correlates best with the gauge data. Wann-Jin Chen et al. (ams.confex.com/ams/pdfpapers/79068.pdf) have used the TRMM PR data to study the characteristics of typhoon rainfall over Taiwan and also compared the rainrates generated from TRMM PR with ground-based gauge observations at sub-daily timescales. The best correlations between TRMM PR and rain-gauge rates were found to be for 30-minute accumulations than for other time intervals. Kishtiwal and Krishnamurti (2001) have used TRMM TMI and PR observations to study the diurnal characteristics of Taiwan Summer Rainfall. They have concluded that though in most cases TRMM satellite can detect diurnal cycle of rainfall using one month of observations, it should be used in combination with other satellite data for more robust results. Bookhagen and Burbank (2006) have used TRMM (PR and TMI) rainfall data to investigate the characteristics of Himalayan rainfall. The new high resolution TRMM data also revealed some striking features of Himalayan rainfall. It revealed a more continuous band of heavy rainfall along the southern edge of Lesser Himalaya near their junction with the Indo-Gangetic foreland basin. The TRMM (PR and TMI) satellite estimates were also validated with 30-minute rainfall measurements from a gauge network over central Nepalese Himalaya for the monsoon season. The data sets, TRMM-derived estimates and point estimates from the gauge network agreed well inspite of the difference in spatial resolutions.

Validation of TRMM merged rainfall products (level 3) with gauge data have also been done over Indian subcontinent. Narayanan et al. (2005) have validated 3B42-V5 data with India Meteorological Department (IMD) rain gauge data. Their main finding is that the satellite algorithm does not pick up very high and very low daily average rainfalls. Rahman and Sengupta (2007) have compared the Global Precipitation Climate Project (GPCP), 3B42-V5 and 3B42-V6 rainfall products with the IMD gridded daily rainfall at grid resolution of $1^\circ \times 1^\circ$ for the monsoon season (June–September). Their results show that GPCP and 3B42-V5 reproduces only the broadest features of the monsoon rainfall. But spatial patterns of 3B42-V6 data shows closest agreement with observed patterns of IMD gauge data except over certain places like Gangetic plains, Himalayan foothills and parts of east central India. The TRMM products were also compared over oceanic areas for four representative boxes. Over the oceanic areas, GPCP estimates were much lower than 3B42-V6. So from their results the 3B42-V6 TRMM product appears to have great potential in reproducing the climatology and studying rainfall variability at the all India scale. It will be interesting to examine the TRMM estimates over smaller regions.

3. Data and methodology

The sampling of TRMM satellite is limited to 2 overpasses per day. So when TRMM overpass data is blended with estimates from other spaceborne sensors it greatly improves the temporal sampling. The present study uses the 3B42-V6 a blended TRMM rain product, based on TRMM calibrated multiple satellite microwave and infrared measurements, with a global coverage of precipitation over 50°S–50°N latitude belt at $0.25^\circ \times 0.25^\circ$ spatial and 3-hourly temporal resolutions (Huffman et al. 2007). 3B42 rain products are based on first using the PR/TMI combined rain rates to calibrate rain estimates from other microwave and Infrared (IR) measurements, then adjusting their rain rates with the surface rain gauge measurements at monthly time scales. The detailed 3B42-V6 product description can be found at http://trmm.gsfc.nasa.gov.

For the present study, TRMM 3B42-V6 data is extracted between latitude 15.75°N–21.75°N and longitude 72.75°E–80.25°E (775 grids) to cover Maharashtra region. The TRMM data set used covers a span of 7 years from 1998–2004 with no missing data for the years 1999, 2000, 2001 and 2002. The validation data set is the daily rainfall data for the summer monsoon months of June to September generated by a high density rain gauge network of 229 reporting stations over Maharashtra. The reporting stations were binned into $0.25^\circ \times 0.25^\circ$ latitude/longitude grids. There were 200 grid-boxes, with rain-gauge stations, out of which, 170 grids have one station each, 28 having two stations per grid and 2 with three stations per grid. For grid cells with more than one observing station the rainfall average of stations in the grid was used while generating the time series of actual observed rainfall. Figure 1 displays the grid points with observing stations. The validation gauge rainfall observations are 24-hr accumulations observed at 03 UTC from a network of about 229 stations reporting on near real time basis. The pres-

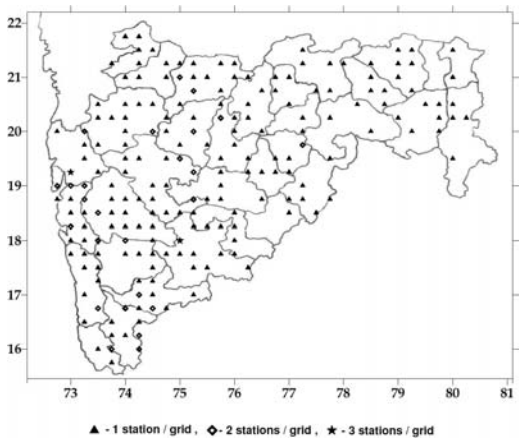

Fig. 1. Distribution of TRMM grid-boxes with at least one rain-gauge station

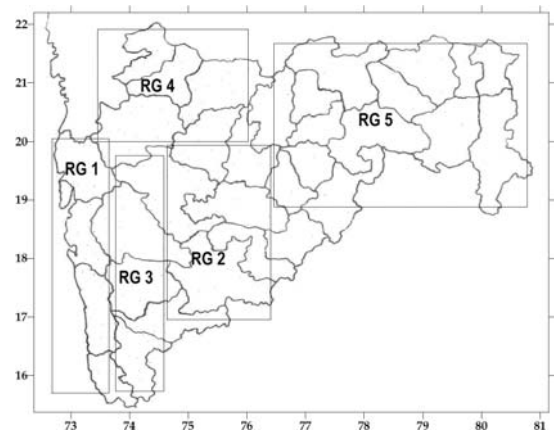

Fig. 2. Locator map of the homogenous rainfall zones

ent study utilizes gauge data that is not gridded. The sub-daily 3-hourly TRMM accumulations were summed from 06 UTC of previous day to 03 UTC of next day to correspond to the time scale of the verification data. Since the three hourly TRMM data are centered at the three hourly observation time, the gauge data lags by 1.5 hrs from the satellite data. An overall daily correlation of 0.52 exists between the time series of the gauge and satellite data. Since 90% of the rains over the state occur in the monsoon months from June to September the analysis is restricted to the monsoon season.

One of the main objectives of the study is to evaluate how closely TRMM is able to reproduce the general climatology of the region. The analysis to validate TRMM retrievals with gauge data was done point-to-point for all the meteorological stations for seasonal and monthly series. Maps are used to illustrate the spatial distribution of bias at seasonal and monthly resolutions. Scattergrams are used to illustrate the bias over the range of rain rates.

Based on the precipitation characteristics, Maharashtra is divided into five distinct climate regimes by a common factor analysis. The boxes in Fig. 2 roughly demarcate the homogenous rainfall zones. Region 1 comprises of the coastal regions and regions on the windward side of the Western Ghats. Region 2 includes parts of Madhya Maharashtra and Marathwada, in central parts of the state. Region 3 lies on the immediate leeward side of the hill range. A homogenous zone of smaller geographical extent was noticed to the north of the state and demarcated as Region 4. Region 5 includes the entire subdivision of Vidharbha and parts of Marathwada, eastern parts of the state. The daily rainfall value of the stations belonging to each distinct rain regime is aggregated to obtain the aggregated regional rainfall series. Concurrent satellite estimates are also aggregated to produce the area averaged satellite estimates. Times series plots, column bar graphs and scattergrams are used to assess and quantify the performance of TRMM retrievals over each region.

4. Station-level analysis

Figure 3 illustrates how closely TRMM 3B42-V6 is able to reproduce the general climatology of the state by depicting the spatial distribution of the 7-year seasonal (June–September) mean rainrates for Maharashtra derived from observed and TRMM rain estimates. The rain distribution over Maharashtra, a steep west-east longitudinal gradient is closely linked to the orography of the region, the north-south oriented hill ranges known as the Western Ghats. Observed rainfall increases as one goes from the coast towards the Ghats with a steep gradient on the leeward side of the Ghats (Fig. 3a). The maximum mean observed seasonal rainfall ($>= 20$ mm/day) is seen as two maxima in the box between 16.00°N and 19.75°N and 73.00°E and 74.00°E. The satellite analysis of the mean rainfall field (Fig. 3b) at the seasonal scale captures the strong west-east longitudinal gradient, but the rainfall maximum is displaced and the intensity is underestimated. The satellite mean rainfall field

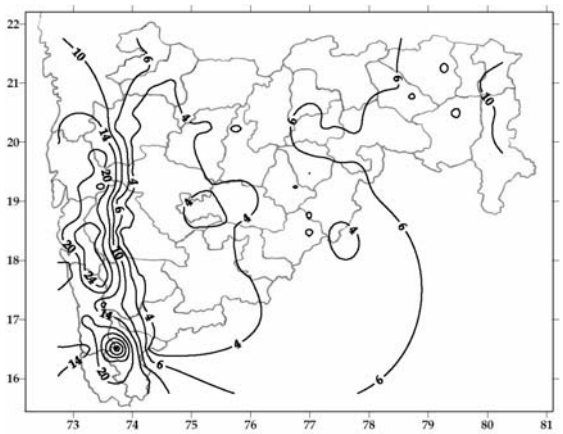

Fig. 3a

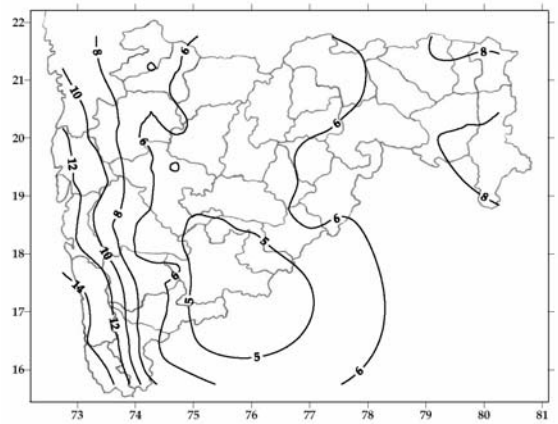

Fig. 3b

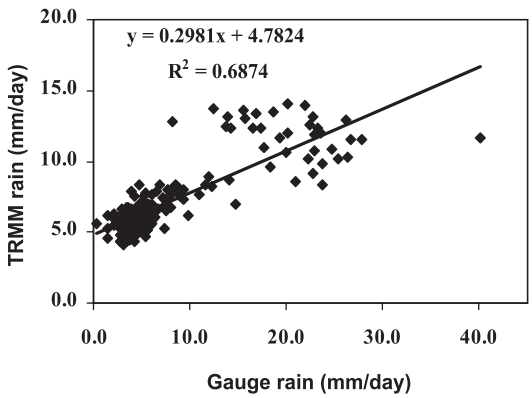

Fig. 3c

Fig. 3. Observed and TRMM rainfall climatologies (a) mean observed seasonal JJAS rainfall (mm/day) (b) mean (JJAS) TRMM 3B42-V6 estimates (c) Scatter plot of JJAS mean observed vs TRMM 3B42-V6 product.

shows a maximum at the coast (around 15 mm/day) with the rainfall reducing towards the Ghats which is different from the topographic features that produce the maximum in the observed rainfall field. The general rainfall climatology of Maharashtra shows a minimum over the Deccan tract, on the leeward side of the hill ranges, with rainfall increasing marginally eastwards. Both the observed and satellite estimated rainfall fields depict this feature, but the rainfall minimum is latitudinally more continuous over the leeward side of the Western Ghats in the observed rainfall field. The satellite derived field shows more localized rainfall minima.

Scatterplots of gauge versus TRMM 3B42-V6 estimates (Fig. 3c) are used to illustrate the bias over the range of rain rates. There is an overall good correlation (0.7) between the gauge and TRMM estimates at the seasonal level. The large intercept value suggests that there is a net tendency for the lower observed rainfalls to be overestimated by the satellite, whereas the low slope value suggests the higher rainfall values are underestimated. The scatter is more for observed values greater than > 15 mm/day.

The spatial patterns of the satellite-gauge difference fields for all the monsoon months show a negative to positive bias from west to east. Figure 4a to 4d show the satellite-gauge difference fields for the individual monsoon months. Over the months the magnitude of these differences differs, with the differences being greatest in the wettest month of July and the least in the month of September. As noticed in the seasonal analysis, the stations with largest biases ($>= 20$ mm/day) are along the Ghats. The

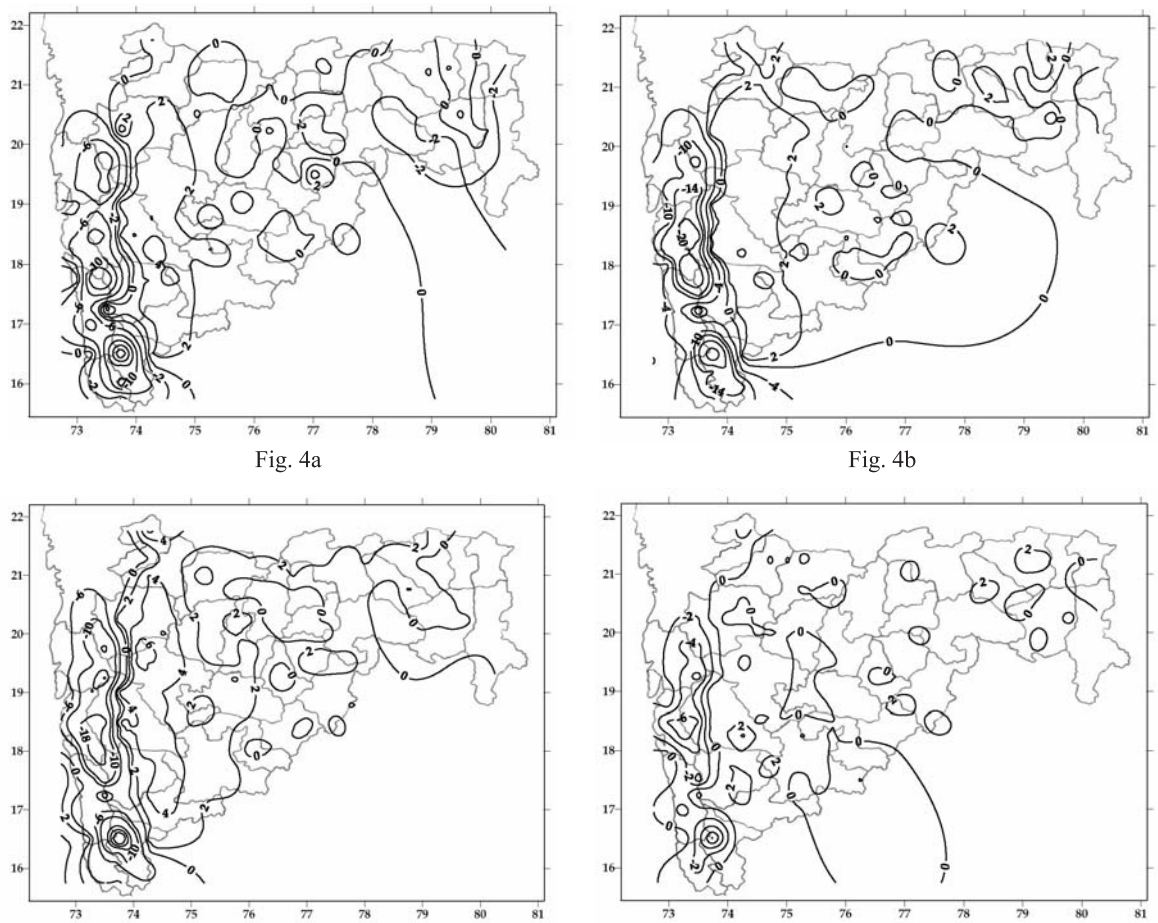

Fig. 4. Mean monthly difference fields (mm/day) between Gauge data and TRMM 3B42-V6 data for (a) June (b) July (c) August (d) September

coastal regions show a relatively less negative bias in all the individual monsoon months. The agreement between mean monthly gauge and satellite analysis is reasonably good over the other regions of the state with a small positive bias (2 mm/day at most places). The overestimation of rainfall on the leeward side of the Western Ghats is latitudinally more continuous in the months from June to August though the positive bias on the leeward side is slightly more in terms of spatial extent in the month of August. The magnitude of the difference fields is the least and more random in the month of September, perhaps because by September rainfall over the entire state reduces as the withdrawal phase of monsoon sets in.

The scatter plots of gauge data versus TRMM 3B42-V6 data (Figs. 5a–d) show a positive correlation though the correlation drops through the months from a strong correlation (nearly 0.7) in June to a weaker correlation (0.3) in September. The scatter for July closely resembles the seasonal scatter. The scatter plots for June, July and August show a larger scatter when observed rainfall values are greater than 20 mm/day. The large positive y-intercept values through all the individual months show that low rainfall is overestimated. The low slope values also indicate that the higher rainfalls are underestimated. The best scatter is for June and the worst scatter is for the month of September. The range of rain rate being lower in September results in an almost horizontal scatter for the month.

To further judge the utility of the satellite product, in the next section is a review of the perfor-

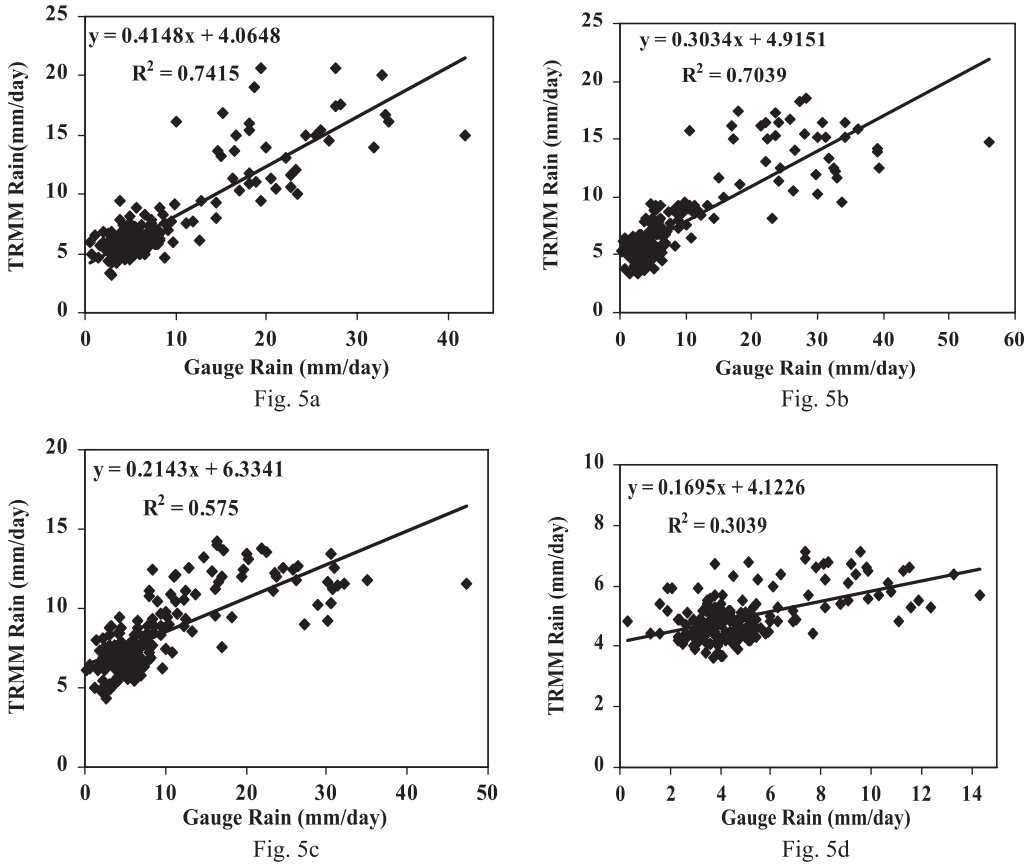

Fig. 5. Scatterplots of mean monthly gauge rainfall vs TRMM 3B42-V6 satellite product for (a) June (b) July (c) August (d) September

mance of TRMM 3B42-V6 product over the homogenous rainfall zones of the state at varying time resolutions stepping up from daily-monthly-seasonal-interannual time scales. The utility of the satellite product for intraseasonal studies over the homogeneous zones is also evaluated.

5. TRMM 3B42-V6 evaluations over homogenous rainfall zones of the state

5.1 Daily

Daily rainfall values for the entire period (1998–2004, June to September months of each year) are plotted. The TRMM 3B42-V6 reproductions are significantly better over the homogenous regions. The scatterplots show a positive and strong correlation between the two rainfall values over all the homogenous zones. The regional differences are discussed below.

Region 1 is the wettest region over the state and observed values in the given period exceed 150 mm on some days (Fig. 6a). The daily values show a correlation of 0.6 with some extreme outliers which points to rainfall being grossly underestimated (for some observed values exceeding 100 mm/day, the satellite estimates fail to reproduce even 50% of the rain). A negative intercept, with a slope value < 1 means that the rainfall is generally underestimated by the satellite over this region. This is in concurrence with the station level analysis. The scatter is lesser over Region 2 (Fig. 6b) where the observed rainfall values do not exceed 60 mm/day. However TRMM 3B42-V6 appears to overestimate rain in this region with satellite values exceeding 60 mm/day on some occasions. This is also evident from the regression equation with a low negative intercept and a slope value > 1. TRMM 3B42-V6 shows a net tendency to slightly overestimate rainfall in this region.

Region 3 mainly includes parts of the state which lies in the immediate rain shadow region of the

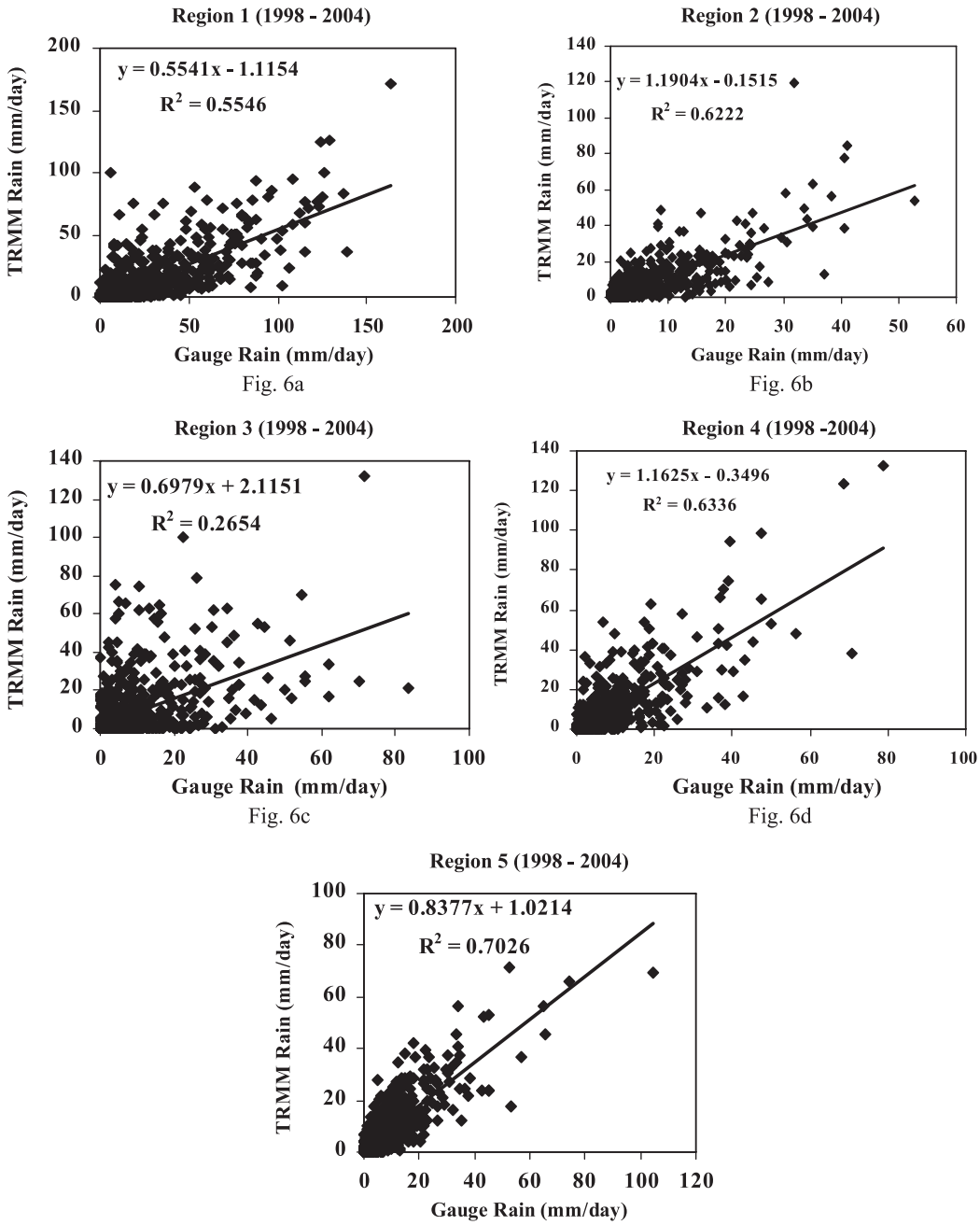

Fig. 6. Scatterplots of Gauge Rain vs TRMM 3B42-V6 product for the different rainfall zones

Western Ghats and where some of the lowest rainfalls are observed. As illustrated in the scatter plots (Fig. 6c), observed daily rainfall at the lower ends (<= 30 mm/day) are overestimated by the TRMM 3B42-V6 product by a sizeable amount. The magnitude of overestimation of rainfall by satellite is more in this region as compared to Region 2 and Region 4. This is also reflected in the regression equation with a positive intercept value (largest intercept value is for this region). This is in agreement with the station level analysis wherein stations in this region had shown maximum overestimation

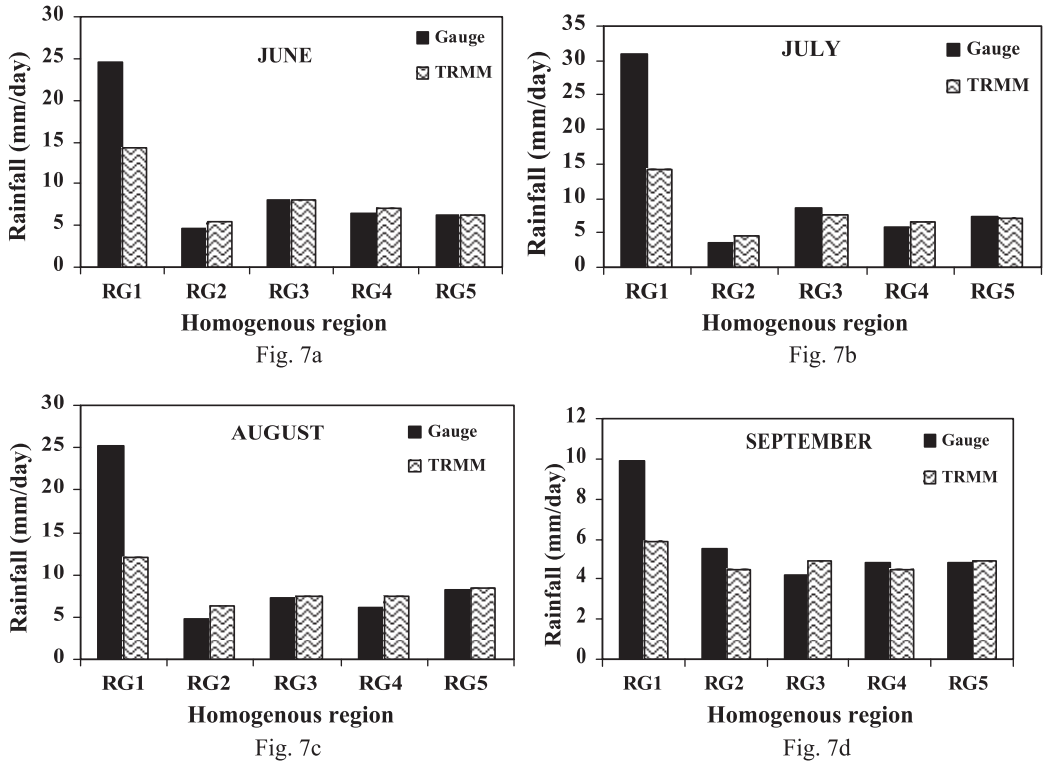

Fig. 7. Intercomparison of mean monthly gauge data with TRMM 3B42-V6

of rainfall by TRMM 3B42-V6. The correlation for this region is also the poorest. Region 4 comprises parts of North Madhya Maharashtra where the observed rainfall generally does not exceed 60 mm/day as in Region 2 (Fig. 6d). The rainfall is generally overestimated by TRMM 3B42-V6 in this region with some daily estimates as high as 130 mm when the actual gauge estimate is just about 80 mm. This is also evident from the negative intercept and the slope value > 1. However the scatter is more in this region as compared to Region 2 as this region is climatologically more wetter than Region 2.

Region 5 includes Vidharbha and parts of Marathwada. Observed daily rainfall totals are moderate in this region. Scatter plot (Fig. 6e) demonstrates that some of the best TRMM 3B42-V6 estimates are over this region. A low positive intercept with a slope value close to 1 though pointing to the rainfall being overestimated by TRMM also indicates that the biases between observed and estimated values are the lowest in these regions. This region also shows the best correlation between observed and estimated values.

5.2 *Mean monthly TRMM estimates*

Mean monthly estimates of rainfall (mm/day) for JJAS observed by the high density validating network and estimated by TRMM 3B42-V6 for the 7 year period from 1998–2004 are calculated for the homogenous regions (Figs. 7a–d). As noticed at the other spatial and temporal resolutions, the TRMM 3B42-V6 estimates over Region 1 are grossly underestimated. The picture remains unchanged through all the individual months from June to September, where the estimated rainfall is at least 50% less than that observed by the gauge. Once again concurrent with station level analysis and the daily regional analysis, Region 5 shows excellent agreement of observed rainfall with the TRMM 3B42-V6 blended product. The near zero bias is consistent throughout the monsoon months (JJAS) though it is negative in July and positive in the other months.

Region 2 and Region 4 show a similar pattern, with slight overestimation from June to August. However the picture in September is different over these regions. The satellite product is underestimated in both the regions, with the negative bias

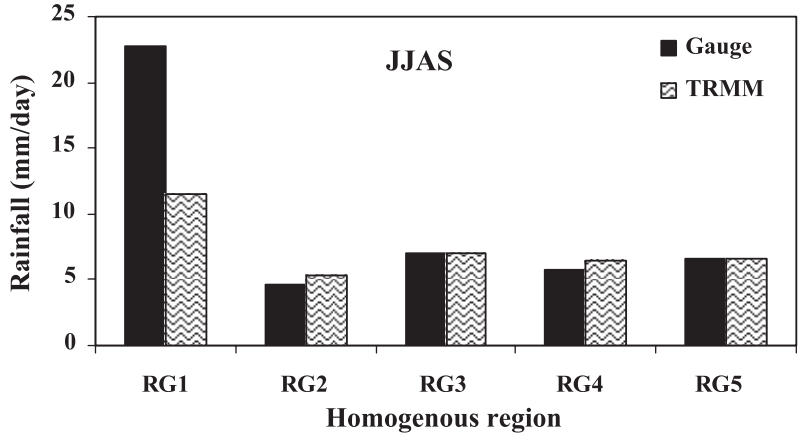

Fig. 8. Intercomparison of mean JJAS rainfall over the homogenous zones

slightly more in Region 2 for the month of September. Though the station level analysis and the daily regional analysis points to a consistent overestimation of satellite rainfall in Region 3, the aggregated mean monthly representation is different in the monsoon month of July where there is a slight negative bias ($\sim$ 10%). The estimations in the months of June, August and September are excellent with a near zero positive bias.

5.3 *Seasonal*

Figure 8 illustrates the mean seasonal rainfall over the different rainfall zones for the monsoon months (June to September). Once again Region 5 shows a near zero bias with Region 1 showing a 50% negative bias (satellite–gauge difference). Region 2, Region 3 and Region 4 show a slight positive bias for the seasonal as a whole. The seasonal picture is close to that derived for the monsoon month of June.

5.4 *Interannual variability of seasonal estimates*

Actual observed rainfall generally shows a significant variability on inter annual timescales. Figures 9a–e compares the inter-annual variability of the seasonal rainfall obtained from the gauge analysis with that of the TRMM 3B42-V6 estimates over the spatially coherent rainfall zones.

Over Region 1 (Fig. 9a) the inter-annual variability of observed rainfall has the right phase with the satellite estimates though the amplitudes are consistently underestimated by a factor of 40% to 50%. Over Region 5 (Fig. 9e) the rainfall variations are not just in phase (except for year 2000), but the amounts estimated are also in excellent agreement though there is an occasional tendency to slightly overestimate the amplitude. Variations on the inter-annual scale over the other regions (Region 2, Region 3 and Region 4, and Fig. 9b, Fig. 9c, Fig. 9d respectively) are not consistent in phase, though the amplitude of variation is small.

5.5 *Intra-seasonal inter-comparison of gauge and satellite estimates*

Rainfall occurs in wet and dry spells coinciding with the active and weak phases of monsoon. The wet spells can be multi-day spells or isolated heavy rainfall occasions depending on the synoptic systems that influence a particular region or the oscillation of the monsoon trough or even the offshore trough. An attempt has been made to investigate whether the daily satellite estimates can capture the timing of these wet and dry phases of monsoon as observed by the gauge network. To reduce the noise in daily series and since the precipitation generating mechanisms over the region under consideration have a temporal scale of a few days (3–5 days) for precipitation associated with synoptic systems over the region, a 5-day running means of the 122 daily rainfall totals (JJAS) are used to generate time series for comparison region-wise from the in-situ gauge observations and the corresponding TRMM estimates for each year from 1998–2004.

Figures 10a–e illustrates the comparison between gauge observation and TRMM 3B42-V6 estimates for the 5-day running means. The times series of Gauge and TRMM estimates for Region 1 (Fig. 10a) also suggests a consistent underestimation of

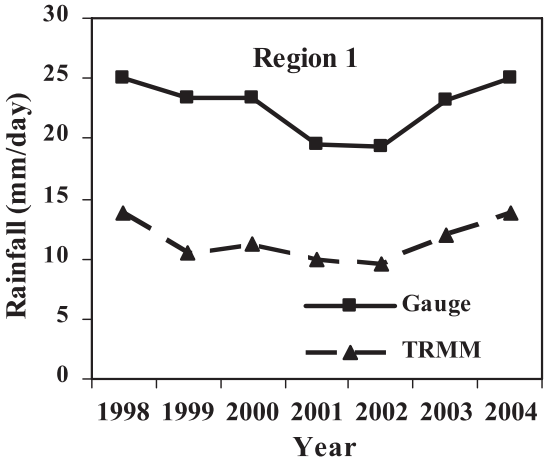

Fig. 9a

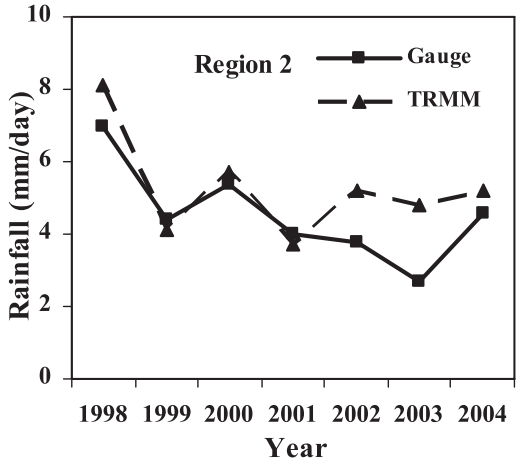

Fig. 9b

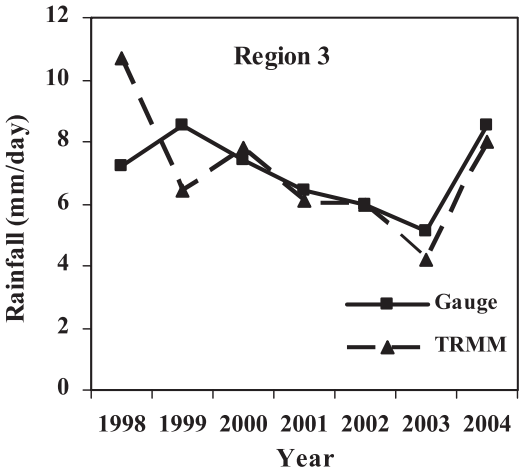

Fig. 9c

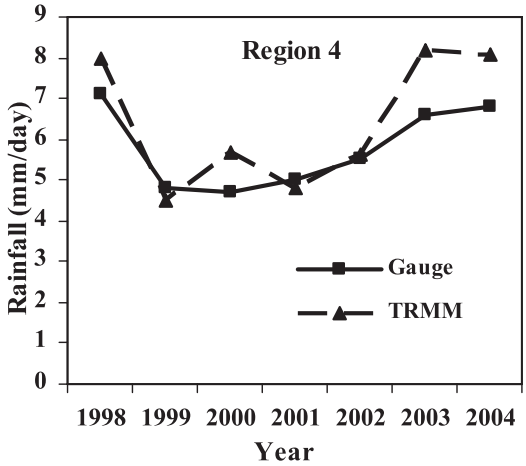

Fig. 9d

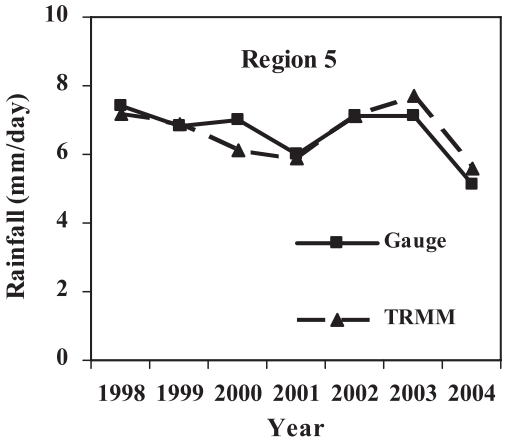

Fig. 9e

Fig. 9. Interannual variations over Homogenous zones

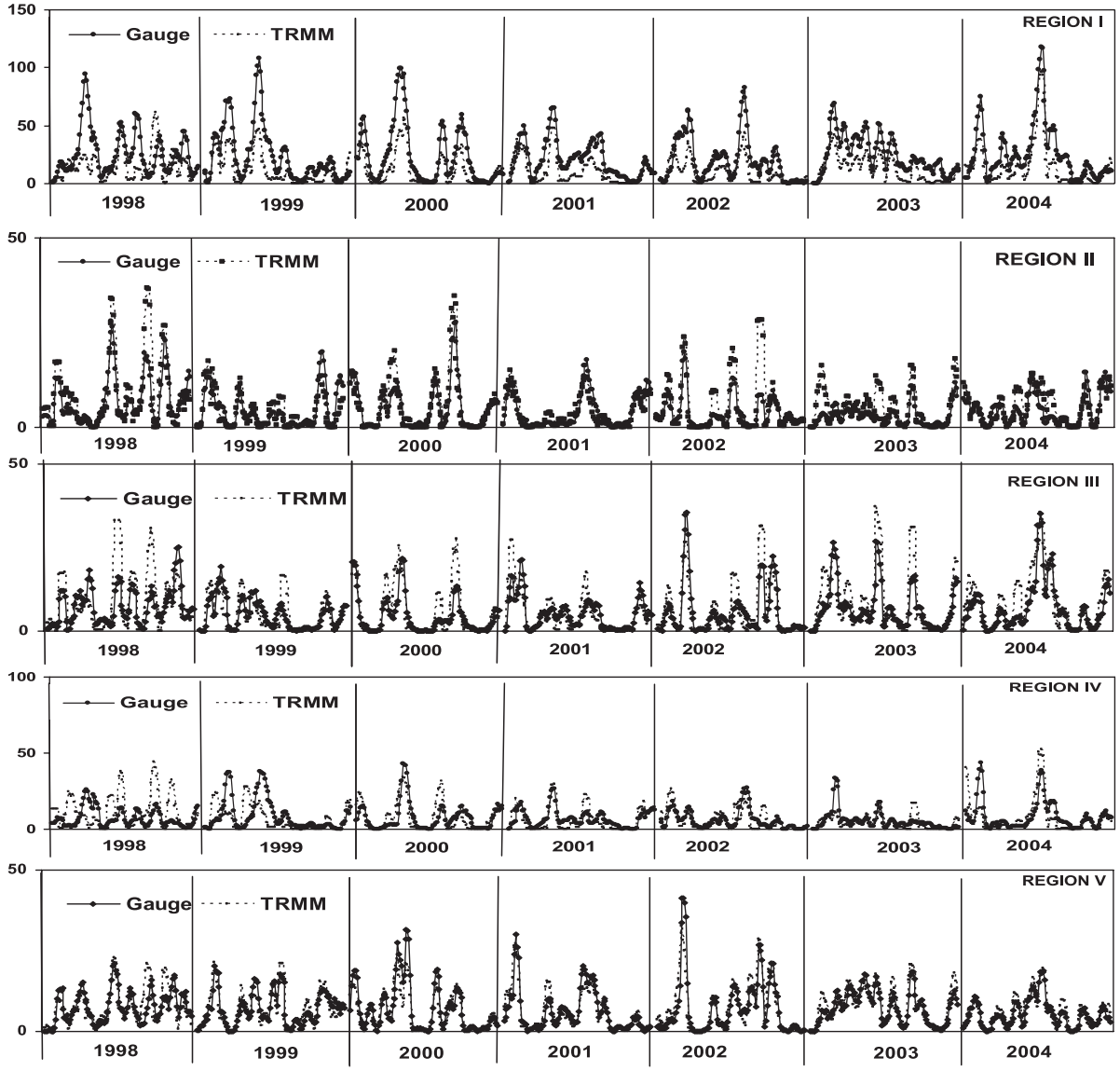

Fig. 10. Comparison of 5-day running means of Gauge and TRMM 3B42-V6 over the Homogeneous zones. (Rainfall in mms)

satellite rainfall. Though rainfall amounts estimated are lesser, the timing of the rain events is generally coincident with the corresponding gauge rainfalls. For Region 2 and Region 4 (Fig. 10b and Fig. 10d respectively) the time series for the gauge data is smoother than that of the satellite time series, which suggests that though there is a general tendency to overestimate rainfall, the satellite estimates resolved at a daily resolution for these regions are more variable as compared to the gauge data. The timing of the rain events estimated is also not always consistent with the gauge data. At larger timescales, Region 3 (Fig. 10c) shows a better agreement with gauge data, but at the daily time scale the results of the inter-comparison are highly inconsistent in terms of both the timing of events and the amounts estimated. Region 5 (Fig. 10e) shows consistent results with the best agreement at the daily timescale also. The timing of rain events and the amounts estimated are in excellent agreement with the area averaged gauge observed rainfall.

6. Conclusion

The performance of TRMM varies over the different climatic regimes depending on the topography and rainfall characteristics of the region, though the biases are consistent and systematic. In terms of spatial reproductivity, the existence of the sharp rainfall gradient along the west coast is captured but the orographic effect is not reflected. In terms of magnitudes also the rainfall estimated for the windward side was grossly underestimated (by almost 50%). Precipitation systems on the windward side particularly over the Ghats being highly convective in nature and short-lived could be missed by certain passes in the given 3-hr period, thereby affecting the average rain rate. In the immediate rain-shadow region rainfall is overestimated. Over most of Madhya Maharashtra (apart from the rain shadow region) and large parts of Marathwada the agreement with Gauge data is satisfactory. The satellite estimates of rainfall occurrence and amount are most accurate over Region 5 in regions of moderate rainfall, which includes Vidharhha and some parts of Marathwada. The rainfall over these regions is attributed to monsoon systems that have a longer life span as compared to the convective systems, so the probability of detecting these events by a satellite overpass is higher. One of the key results of the intercomparison exercise is the ability of these estimates to detect the wet and dry phases of monsoon over most parts of the state (except the leeward side). TRMM 3B42-V6 estimates could have tremendous potential to be used for intra-seasonal studies over most regions of the state.

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