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Rainrate and rain attenuation statistics for different homogeneous regions of India

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Rain rate and rain attenuation predictions are one of the most important steps to be considered when analyzing satellite communication links at the Ku and Ka bands. Rain rate distributions are calculated from the global data sets of Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Climatology Project (GPCP) for six rainfall homogeneous regions of India. The rain rate distributions are estimated from the monthly accumulations of TRMM and GPCP for the years 1998-2010. The estimated rain rate distributions are compared with the standard ITU-R P.837-5 (International Telecommunication Union - for Radio wave propagation) and observed relative errors are presented. The specific rain attenuation calculated at 0.01% and 0.001% probabilities of exceedance in an average year for different frequencies are also presented for the six homogeneous regions of India. Observations indicate maximum specific attenuation in the NE region over Cheerapunji at 0.001% of the time, and minimum attenuation of 21.988 dB km^{-1} in Bikaner at 0.01% for 50 GHz frequency in the NW region. Rain attenuation and rain rate distribution are found to exhibit similar characteristics over six homogeneous regions of India.

Keywords: Rain rate, Rain attenuation, Relative Error

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1 Introduction

The reliability of high speed, high data rate satellite communication link is impaired by the precipitation. In tropical countries, the effect of rain is important as other hydrometeors are very rare. The prediction of rain attenuation is in its premature state and especially the experiments conducted over operation links are very limited. Rain attenuation is the primary impairment for radio communications above 10 GHz frequencies[1]. In order to obtain suitable rain attenuation models, significant rainfall database is required, and rain rate statistics has to be developed. Rain rate distribution is one of the important parameters for calculating the rain attenuation at a specific location[2,3].

Rainfall is one of the most discontinuous atmospheric phenomena with significant spatial and temporal variability. Indian region has heavy rainfall spells in all the seasons due to both tropical and extra-tropical weather systems. Based on the precipitation studies over the Indian region, homogeneous monsoon regions are proposed by Indian Institute of Tropical Meteorology (IITM). In the homogeneous regions of India, Kranthi *et al.*[4] found that the convective rain dominates in the northwestern parts of India (near the foothills of the Himalayas) and in the southeastern peninsular India; while the stratiform rain dominates (50–60%) in central India. Rajeevan *et al.*[5] found the spatial distribution of the seasonal mean rainfall using the India Meteorological Department (IMD) gridded rainfall data set for the period 1951-2003. The maximum rainfall is observed in the west coast of India and North-East (NE) India, and rainfall is minimum in North-West (NW) India. Konwar *et al.*[6] studied two years data using different instruments and they observed that the convective rain dominates in the peninsular region. Roy *et al.*[7] observed two years rainfall data and they found the rainfall is minimum in the west coast of India and the foothills of the Himalayas. Adler *et al.*[8] compared TRMM merged rainfall data with GPCP data for one year over the globe. He reported that TRMM merged data shows the higher rainfall values over ocean than the land areas. The average precipitation over the land area of 3b43 v7 is 3.19 mm per day and GPCP v2.2 is 3.16 mm per day. TRMM and GPCP rain estimations are mostly identical. Similar results are reported by Huffman & Bolvin[9] while comparing the land values for 3b43 v7 and GPCP SG v2.2.

These values are very close to each other because they use the same GPCC gauge analysis and the gauge tends to dominate the land bias in most places by construction.

Rainfall rate distributions estimated from satellite data sets is reported for some regions. Similar work is not reported in India, however, considerable work has been reported elsewhere. There are different rainfall rate and rain attenuation models that are developed by many researchers worldwide. The works performed on precipitation, attenuation studies using the satellite datasets only are presented. Omotosho *et al.*[10] analyzed the TRMM 3b43 v7 data of nine years in Nigeria and reported that the highest rainfall rate is observed in the south-east region. The lowest rain rate values are reported in north-west region. In the southwest region of Nigeria, in Ogbomosho, Semire *et al.*[11] analyzed two years (2009-2010) rainfall rate data at different integration times and observed that the highest 1-min rain rate value is 150 mm h^{-1} for 0.001% of the time. Semire *et al.*[12] using the 2009 year rainfall data observed the 1-min rain rate distribution at different integration times in Ogbomosho station. In southwestern Nigeria, Federal University of Technology in Akure. Ojo *et al.*[13] studied the 1-min rain rate distribution and observed that ITU-R model overestimates the rain rate distributions. They have also reported the attenuation values at Ku and Ka band frequencies using the NIGCOMSAT-1 for different probabilities. Omotosho *et al.*[14] observed the rainfall accumulation in the TRMM 3b43 satellite data and compared the ITU-RP Study Group3 database in 57 stations in Malaysia, and reported that the rain rate values are lowest in western Malaysia and highest in eastern Malaysia at 0.01% of exceedance.

Mandeep & Hassan[15] observed the 1-min rain rate distribution for seven southeast Asian countries identified by P and N climatic regions (where the 1-min rainfall rates exceeded 0.01% of time are 120 and 100 mm h^{-1}) based on ITU-Recommendations. They observed that Bukit Timah station shows the maximum rain rate (approximately 220 mm h^{-1}) and Suva shows the minimum rain rate values (approximately 146 mm h^{-1}) at 0.001% of probability. Mandeep & Allnutt[16] studied the rainfall characteristics of the four southeast Asian countries and observed that the Universiti Sains Malaysia (USM) has 181 mm h^{-1} rain rate, Ateneo De Manila University (ADMU) has rain rate of 140 mm h^{-1} at 0.001% of probability. The University of South Pacific (USP) shows the lowest rain rate values for all percentages of time.

As mentioned earlier, there exist several methodologies for the prediction of rain-rate. Here, an overview of some of the important models and their results are considered in the Indian region. Das *et al.*[1] has measured the specific attenuation values and compared with the ITU-R model for different rain rates in the frequency range 10-100 GHz. They have shown that the specific attenuation values for Ahmedabad and Thiruvananthapuram stations are found to be underestimated compared to ITU-R predicted values in the frequency range 40-80 GHz. Vidyarthi *et al.*[17] has confirmed the $R_{0.01}$ (Rainfall rate at 0.01 percentage of exceedance) of Ahmedabad station as 75 mm h^{-1} using two-years rainfall data. Observation of individual years in Thiruvananthapuram shows the lowest (64 mm h^{-1}) rain rate for the year 2004, 82 mm h^{-1} rain rate for the year 2006 at 0.001% of time. Das *et al.*[1] also observed for Thiruvananthapuram station, which shows 67 mm h^{-1} rain rate at 0.01% of time. Maitra *et al.*[18] also found rain rate of 79 mm h^{-1} at 0.01% of time and 120 mm h^{-1} at 0.001% of time at Ahmedabad station.

Baldotra[19] studied the rain rate distribution of Amritsar at different probabilities and compared with the ITU-R model; the ITU-R predictions are observed to underestimate the measured rain rate and rain attenuation statistics. Sharma *et al.*[20] conducted rain attenuation measurements at 28.75 GHz over a terrestrial path link in Amritsar, India. They made a comparison of the measured data against ITU-R model and found that the model underestimates the attenuation at lower rain rates and overestimates at higher rain rate. Sharma[21] measured the rain rate and rain attenuation values for two years data (2004-2005) using the tipping bucket rain gauge and he observed that measured rain rate and rain attenuation values are underestimated when compared to the ITU-R model.

Adhikari *et al.*[22] considered rain attenuation studies in Kolkata using different models. They noted the SAM and ITU-R model gives better estimation compared to other models. Madgum & Sutar[23], using the ITU-DAH model, observed the specific attenuation at 30 GHz frequencies in all Indian regions; north west (NW) and hilly regions (HR) show less than 5 dB km^{-1}; North East (NE), Central

North East (CNE), Peninsular (PS), West Central (WC) regions show 5 to 10 dB km^{-1}. Therefore, ITU-R model is considered in the present study.

In this study, using the satellite data, rain rate distributions are presented for the first time over homogeneous monsoon regions of India. Comparison is made between TRMM (Tropical Rainfall Measuring Mission) and GPCP (Global Precipitation Climatology Project) data sets over the Indian region, TRMM is considered as standard observation and GPCP as the forecast observation. This work using satellite data for propagation studies is the first of its kind in India.

2 Data and Methodology

The monthly TRMM (3b43 v7) data set and GPCP v2.2 (monthly global precipitation) data sets constitute the database for this study. These data products are distributed by the Goddard Earth Sciences Data and Information Services Centre (GESDISC), and it was developed by the TRMM Online Visualization and Analysis System (TOVAS). TOVAS is a powerful tool that allows users to explore data entirely. TOVAS makes TRMM and other gridded precipitation data available in a format that anyone can learn to use in research or applications. GESDISC provides a web-based resource for accessing '3b42/43' and GPCP data sets in ASCII format (American Standard Code for Information Interchange)[9,24-29].

The Tropical Rainfall Measuring Mission (TRMM) is a joint US-Japan satellite mission. The objectives of TRMM are to measure rainfall and energy exchange of tropical and subtropical regions of the world. It was launched on 27 November 1997 and it also acts as a "flying rain gauge" in connection between TRMM and operational geostationary platforms[27,30,31]. It gives a standard rainfall estimation compared to other satellites, and the accurate global rain maps[32].

The TRMM 3b43 v7 is the TRMM Multi-Satellite Precipitation Analysis (TMPA) that combines the CAMS global gridded rain gauge data and global rain gauge product produced by GPCC. The spatial resolution is 0.25° latitude by 0.25° longitude.

The Global Precipitation Climatology Project (GPCP) is the World Climate Research Programme (WCRP) and its key Global Energy and Water Exchanges (GEWEX) project to produce the community analysis of global precipitation. It is a global merged rainfall analysis for research applications. GPCP provides a long time series of monthly and finer time resolution precipitation analysis on a global scale of 2.5° latitude × 2.5° longitude grid for the period 1979 to present[33]. The spatial resolution of TRMM 3b43 v7 is 0.25° × 0.25° and GPCP v2.2 is 2.5° × 2.5°. Bi linear interpolation method interpolates these two data sets.

The data analysis in this work includes 13 years of rainfall data collected over 32 stations (Fig. 1) in India. The country has been divided into six distinct areas based on homogeneous monsoon regions (maps of regions used for IITM regional rainfall data sets), namely Northwest (NW), Central Northeast (CNE), North East (NE), West Central (WC), Peninsular (PS) and Hilly Regions (HR). Rain rate distributions are estimated using the Ito & Hosono[34] method.

2.1 Prediction method for 1-minute rain rate distribution

Cumulative distribution functions (CDF) for one minute rain rate values are estimated by using the method developed by Chieko & Yoshio[34], and this model gives the best prediction accuracy, especially for a small percentages of the time (0.001-1%). Cumulative distributions of the 1-minute rain rates for arbitrary percentages of time p (%) are calculated using the average annual total rainfall accumulation *(M)*, the thunderstorm ratio *(β)*, as given in Eqs (1-4). The coefficients a_p b_p c_p with $x = log\ (p)$ are determined by multiple regression analysis.

$$R_p = a_p M^{bp} \quad {}^{cp} \qquad \ldots(1)$$

$$Log(a_p) = 0.1574155X^4 + 1.348171X^3 + 3.528175X^2 + 1.479566X - 2.302276 \qquad \ldots(2)$$

$$b_p = -4.583266 \times 10^{-2}X^4 - 0.409816X^3 - 1.162387X^2 - 0.8261178X + 0.911857 \qquad \ldots(3)$$

$$c_p = 2.574688 \times 10^{-2}X^4 + 0.1549031X^3 + 0.1747827X^2 - 0.2846313X + 1.255081 \times 10^{-2} \qquad \ldots(4)$$

The thunderstorm ratio β is estimated from Dutton-Dougherty model specified in Eq. (5). These parameters may be calculated from the local long-term average annual precipitation accumulation (M), the number of thunderstorm days (D_{th}), and the maximum monthly precipitation (M_m) in 30 years.

$$= [0.03 + 0.97\ exp\ \{-5\ exp(-0.004M_m)\}]^* [0.25 + 2\ exp\{-0.35(1 + 0.125M) \mid D_{th}\}] \qquad \ldots(5)$$

where, M (mm) = average annual total rainfall;
D_{th} (day) = the average annual no of thunderstorm days;

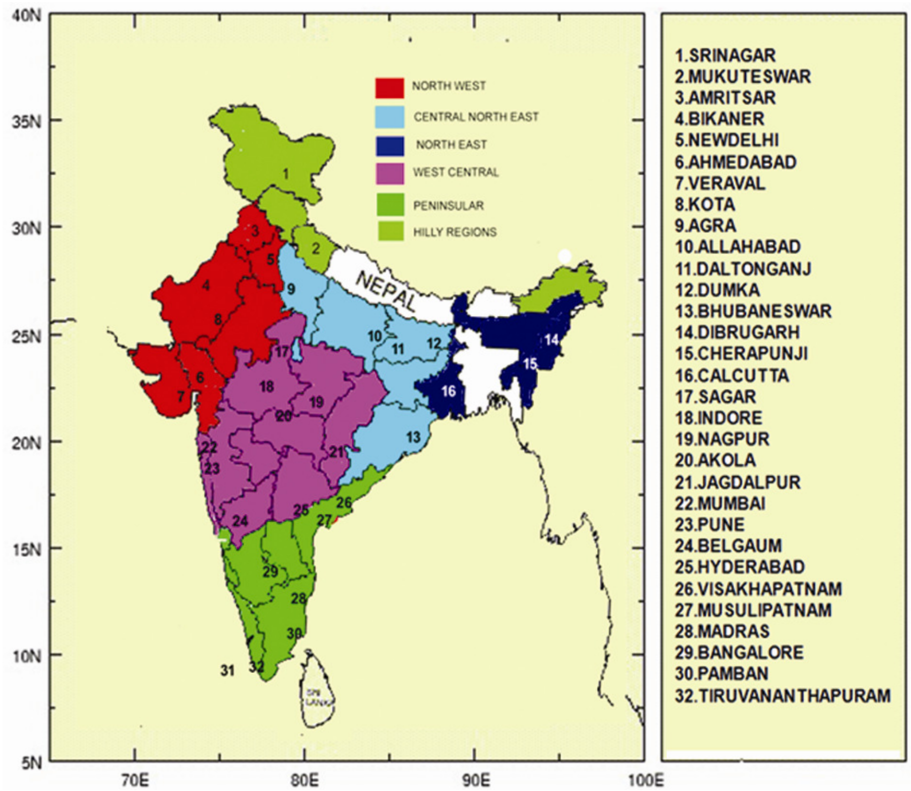

Fig. 1 — 32 Homogeneous monsoon regions of India

M_m (mm) = the highest monthly precipitation observed over 30 consecutive years [statistic distribution 1961 to 1990].

The D_{th} values were considered from IS2309:1989 (Ref. 35). The cumulative distribution of rainfall rates is estimated for the 32 stations over Indian sub-continent using the regional climate parameter thunderstorm ratio ( ), and M.

2.2 Prediction of specific rain attenuation

Rain attenuation is a major limiting factor above 10 GHz frequencies for satellite communications. Rain attenuation can be estimated from specific attenuation and effective path length of the communication channel.

Specific rain attenuation is an important parameter for planning communication links. In order to predict reliable rain attenuation for a given location, an appropriate distribution of rainfall rate for the site is required. The distribution must be based on long-term (typically more than ten years) measured data with 1-minute integration time. An equation useful to estimate the direct relationship between rainfall rate and the rain attenuation is given in Eq. (6). A power-law relationship of the following form has been considered to determine specific rain attenuation using the rain rate from different locations in the tropical Indian region. ITU-R has proposed the following formula:

$$= KR^{\alpha} \quad \ldots(6)$$

where, R, is the rain rate value; constants K and α, are polarization and frequency dependent coefficients, which give better accuracy of the calculation of a specific attenuation at any frequency and rain rate[36,37].

3 Results and Discussion

3.1 Cumulative distributions of rainfall rates in the six regions

The cumulative rain rate distribution for the six regions using the three data sets is shown in Fig. 2. The rain rate values are plotted for different percentage time of probabilities, from 0.001 to 1%, which corresponds to 5.26 minutes to 8.76 hours.

ITU-Recommendation P837-5 shows the rain rate distribution over different regions of India at 0.01% of the time. It can be observed that the NW has 60 mm h^{-1}, PS and NE regions show 80 mm h^{-1}, CNE shows 70 mm h^{-1}, WC region shows 50-60 mm h^{-1} rain rate values. ITU-R P838 divide the globe into

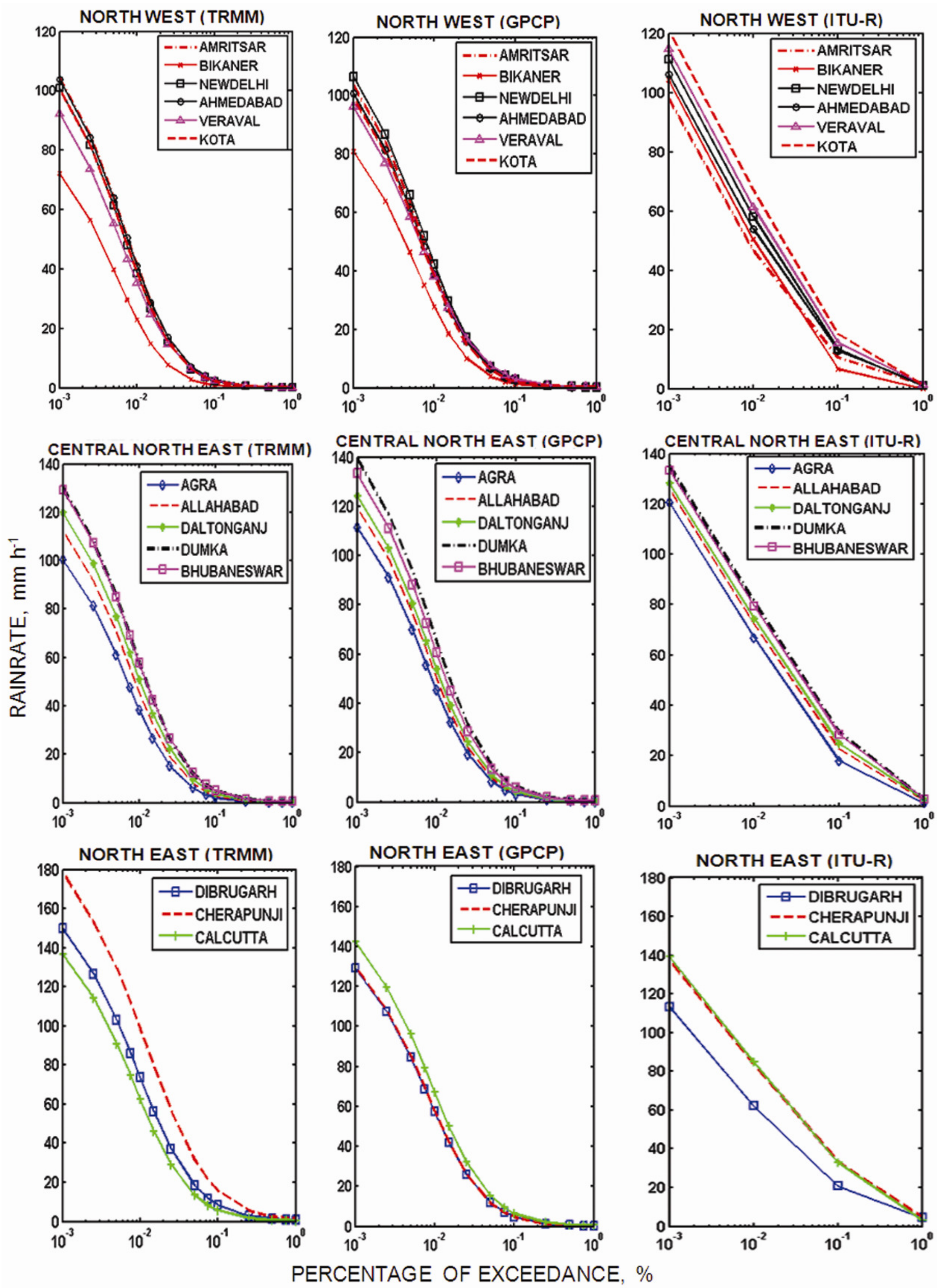

Fig. 2 — Cumulative rain rate distribution for over all six regions of India (Contd.)

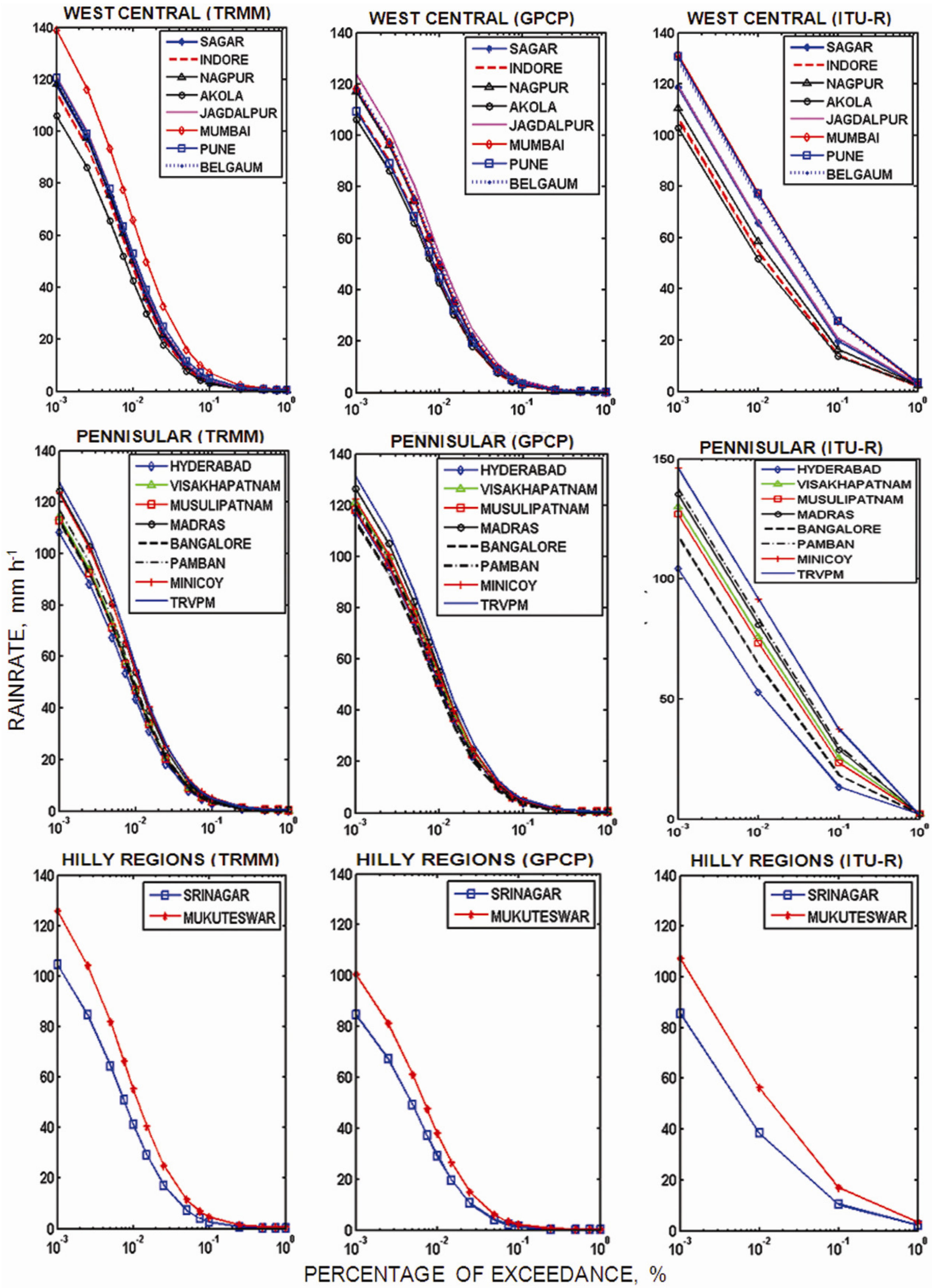

Fig. 2 (Contd.)— Cumulative rain rate distribution for over all six regions of India

15 rainfall zones based on rain rate distribution at 1-0.001% probabilities. The Indian region comes under the K and N rain zones. Here, peninsular and west central regions are N zone and remaining all regions are in K zone. At 0.01 and 0.001% probabilities, the TRMM and GPCP rain rate values mostly coincided with the ITU-R P838[37,38].

Figure 2 shows cumulative rain rate distributions over all India. The highest rain rate values are seen over the NE region (180 mm h^{-1}). In TRMM data set, Cheerapunji has the highest rain rate (178.56 mm h^{-1}) and Calcutta has the lowest rain rate (136.66 mm h^{-1}); but in GPCP data set, Calcutta has the highest rain rate (142.43 mm h^{-1}) and Cheerapunji, Dibrugarh stations have the same rain rate (130 mm h^{-1}) at 0.001% of the time.

The NW region shows the minimum rain rate values at all percentages of time. In TRMM and GPCP data set, Bikaner shows the lowest rain rate (72.147 mm h^{-1}, 80.957 mm h^{-1}). In TRMM, Amritsar has the highest rain rate (104.53 mm h^{-1}), New Delhi and Kota stations have almost the same rain rate values. In GPCP data set, New Delhi has the highest rain rate (106.52 mm h^{-1}), and all stations have negligible rain rate values at 1% of the time.

In CNE region, Dumka station has the highest rain rate (129.83 mm h^{-1}, 139.49 mm h^{-1}) and Agra has the low rain rate (100.41 mm h^{-1}, 111.53 mm h^{-1}) and there is a small difference in TRMM and GPCP data sets at the 0.001% of probability. In TRMM, Dumka and Bhubaneswar stations show almost same rain rate values at 0.001 - 1% of the time.

In WC region, Mumbai shows maximum rain rate (139.02 mm h^{-1}) and Belgaum, Sagar, Nagpur stations show the same rain rate values in TRMM data set. In GPCP data set, Sagar, Nagpur, Mumbai, and Belgaum stations show almost same rain rate distribution at all probabilities. Akola has the low rain rate value and Sagar, Nagpur, Jagdalpur, Akola and Belgaum stations show small rain rate difference at all probabilities of time in both the data sets.

In PS region, Thiruvananthapuram shows the highest rain rate value in TRMM and GPCP data sets. In GPCP, Bangalore shows the minimum rain rate (113.61 mm h^{-1}), but in TRMM data set Hyderabad shows minimum rain rate (108.12 mm h^{-1}) at 0.001% of the time. Madras, Bangalore, Pamban and Minicoy stations show a small rain rate difference in both the data sets.

Srinagar is observed to exhibit minimum rain rate value and Mukuteswar the maximum rain rate value in TRMM and GPCP data sets over Hilly regions. Compared to the ITU-R P837.5 Rainfall zones, Srinagar is underestimated in GPCP dataset, Mukuteswar is over estimated in the TRMM dataset at 0.001% of the time. Comparison of the estimated rain rate distributions with the standard ITU-R P837-5 distributions is performed using the relative error as the criteria.

3.2 Relative error

The relative error is the ratio of an error in a measured or calculated quantity to the magnitude of that quantity. In a widely used error evaluation method, it is given by:

$$\textit{Relative Error} = (R_P - R_M) / R_M \qquad \ldots(7)$$

where, R_P, is predicted rain rate (mm h^{-1}); and R_M, measured rain rate (mm h^{-1}).

One commonly distinguishes between the relative error and the absolute error. The absolute error is the magnitude of the difference between the exact value and the approximation. The relative error is the absolute error divided by the magnitude of the exact value.

The TRMM and GPCP rain rate values are considered as predicted rain rates and ITU-R P837-5 rain rate values as measured. The TRMM and GPCP rain rate values predicted for the six regions are compared with the corresponding region rain rate values of ITU-R P837-5. GPCP gives the good rain rate estimation in CNE, NE and PS regions. In the West Central region, TRMM gives the good rain rate estimation.

Based on the relative error in overall six regions and 32 stations of India (Table 1), Amritsar in NW region; Dibrugarh in NE region; Hyderabad station in Peninsular region; Indore, Nagpur, Akola, Jagdalpur stations in WC region, show the positive relative error in TRMM and GPCP data sets at 0.001% of exceedance. Two stations in Hilly region and Mumbai stations in WC region show the positive error at 0.001% of the time in TRMM only.

Compared to the ITU-R recommendations, the CNE region shows underestimation in the TRMM and GPCP data sets. Except Amritsar in the NW region, Dibrugarh in NE region, and Hyderabad stations in Peninsular region, remaining all stations in the NW, NE and Peninsular regions are underestimated in the

Table 1 — Relative error in TRMM and GPCP data sets

Region	Station	Relative error of TRMM, mm h^{-1}				Relative error of GPCP, mm h^{-1}			
		0.001	0.01	0.1	1	0.001	0.01	0.1	1
North West (NW)	Amritsar	0.0686	-0.1240	-0.7571	-0.8321	0.0582	-0.1349	-0.7634	-0.8364
	Bikaner	-0.3074	-0.5468	-0.8695	0.0000	-0.2228	-0.4502	-0.8011	0.0000
	New Delhi	-0.0933	-0.3349	-0.8315	-0.8034	-0.0429	-0.2725	-0.7961	-0.7623
	Ahmedabad	-0.0223	-0.2390	-0.7860	-0.8257	-0.0512	-0.2771	-0.8098	-0.8457
	Kota	-0.1934	-0.4247	-0.9516	-0.8084	-0.1599	-0.3774	-0.7972	-0.7514
	Veraval	-0.1683	-0.4264	-0.8778	-0.8510	-0.1790	-0.4386	-0.8833	-0.8576
Central North East (CNE)	Agra	-0.1676	-0.4263	-0.8770	-0.8335	-0.0754	-0.3164	-0.8204	-0.7569
	Allahabad	-0.1088	-0.3683	-0.8672	-0.8771	-0.0516	-0.2998	-0.8350	-0.8478
	Dalton Ganj	-0.0652	-0.3167	-0.8456	-0.8721	-0.0303	-0.2741	-0.8247	-0.8550
	Dumka	-0.0387	-0.2840	-0.8306	-0.8384	0.0328	-0.1934	-0.7816	-0.7920
	Bhuvaneswar	-0.0294	-0.2718	-0.8236	-0.8500	-0.0002	-0.2349	-0.8038	-0.8331
North East (NE)	Dibrugarah	0.3223	0.1848	-0.6019	-0.8432	0.1378	-0.0770	-0.7664	-0.9077
	Chirapunji	0.2987	0.1778	-0.5277	-0.7270	-0.0543	-0.3110	-0.8567	-0.9187
	Kolkata	-0.0189	-0.2643	-0.8294	-0.8433	0.0225	-0.2121	-0.8027	-0.8190
West Central (WC)	Sagar	-0.0066	-0.2490	-0.8209	-0.8801	-0.0121	-0.2558	-0.8243	-0.8824
	Indore	0.0774	-0.1324	-0.7665	-0.8575	0.0314	-0.1930	-0.7998	-0.8776
	Nagpur	0.0706	-0.1407	-0.7633	-0.8651	0.0585	-0.1568	-0.7726	-0.8704
	Akola	0.0296	-0.1796	-0.7843	-0.8804	0.0333	-0.1747	-0.7814	-0.8788
	Jagdalpur	0.0152	-0.2165	-0.7998	-0.8795	0.0374	-0.0374	-0.7835	-0.8697
	Mumbai	0.0577	-0.1508	-0.7399	-0.7868	-0.1008	-0.3579	-0.8642	-0.8913
	Pune	-0.0776	-0.3119	-0.8192	-0.8661	-0.1622	-0.4165	-0.8762	-0.9094
	Belgum	-0.076	-0.3227	-0.8421	-0.8921	-0.0845	-0.3332	-0.8474	-0.8958
Peninsular (PS)	Hyderabad	0.0362	-0.1725	-0.7749	-0.8611	0.1226	-0.0535	-0.6980	-0.8133
	Visakhapatnam	-0.1211	-0.3711	-0.8553	-0.8507	-0.0673	-0.3039	-0.8176	-0.8105
	Musulipatnam	-0.1097	-0.3570	-0.8464	-0.8428	-0.0698	-0.3070	-0.8179	-0.8129
	Madras	-0.0802	-0.3355	-0.8552	-0.8198	-0.0636	-0.3155	-0.8458	-0.8082
	Bangalore	-0.0417	-0.2795	-0.8166	-0.8517	-0.0347	-0.2708	-0.8118	-0.8479
	Pamban	-0.1489	-0.4109	-0.8829	-0.7873	-0.1328	-0.3923	-0.8750	-0.7731
	Minicoy	-0.1554	-0.4015	-0.8640	-0.6822	-0.1637	-0.4117	-0.8694	-0.6920
	Thiruvanthapuram	-0.1338	-0.3931	-0.8808	-0.8562	-0.1094	-0.3643	-0.8684	-0.8413
Hilly region (HR)	Srinagar	0.2204	0.0770	-0.7355	-0.8852	-0.0109	-0.2380	-0.8714	-0.9418
	Mukuteswar	0.1724	-0.0176	-0.7275	-0.8815	-0.0630	-0.3216	-0.8749	-0.9365

TRMM and GPCP data set. All six regions are underestimated in two data sets at 0.01-1% probabilities. In NE region, Dibrugarh and Cheerapunji stations show positive relative error in TRMM at 0.001 and 0.01% of the time, whereas Calcutta station shows the lowest relative error in two data sets at 0.001% of the time.

3.3 Specific attenuation values for all the homogeneous regions

Using the Eq. (6), specific attenuation is estimated for 10-50 GHz frequencies and are shown in the Figs 3 and 4 over all six regions of India. The TRMM and GPCP data rain rate values at 0.001 and 0.01% probabilities are used for the calculation of specific rain attenuation. The NE region shows the maximum attenuation values and minimum attenuation values are observed in the NW region.

In all six homogeneous regions of India, the TRMM gives the proper attenuation values in the CNE, PS and NE regions. The GPCP give the good attenuation values in WC and over HR regions. In the NW region, TRMM and GPCP data sets give the almost the same attenuation values in this study, because Amritsar, Kota, Ahmedabad, Veraval and New Delhi stations show small differences in the attenuation values in TRMM and GPCP data sets for 10-50 GHz frequencies.

Damodaram *et al.*[23] predicted the specific attenuation in all homogeneous regions of India at 30 GHz frequency. They observed that specific

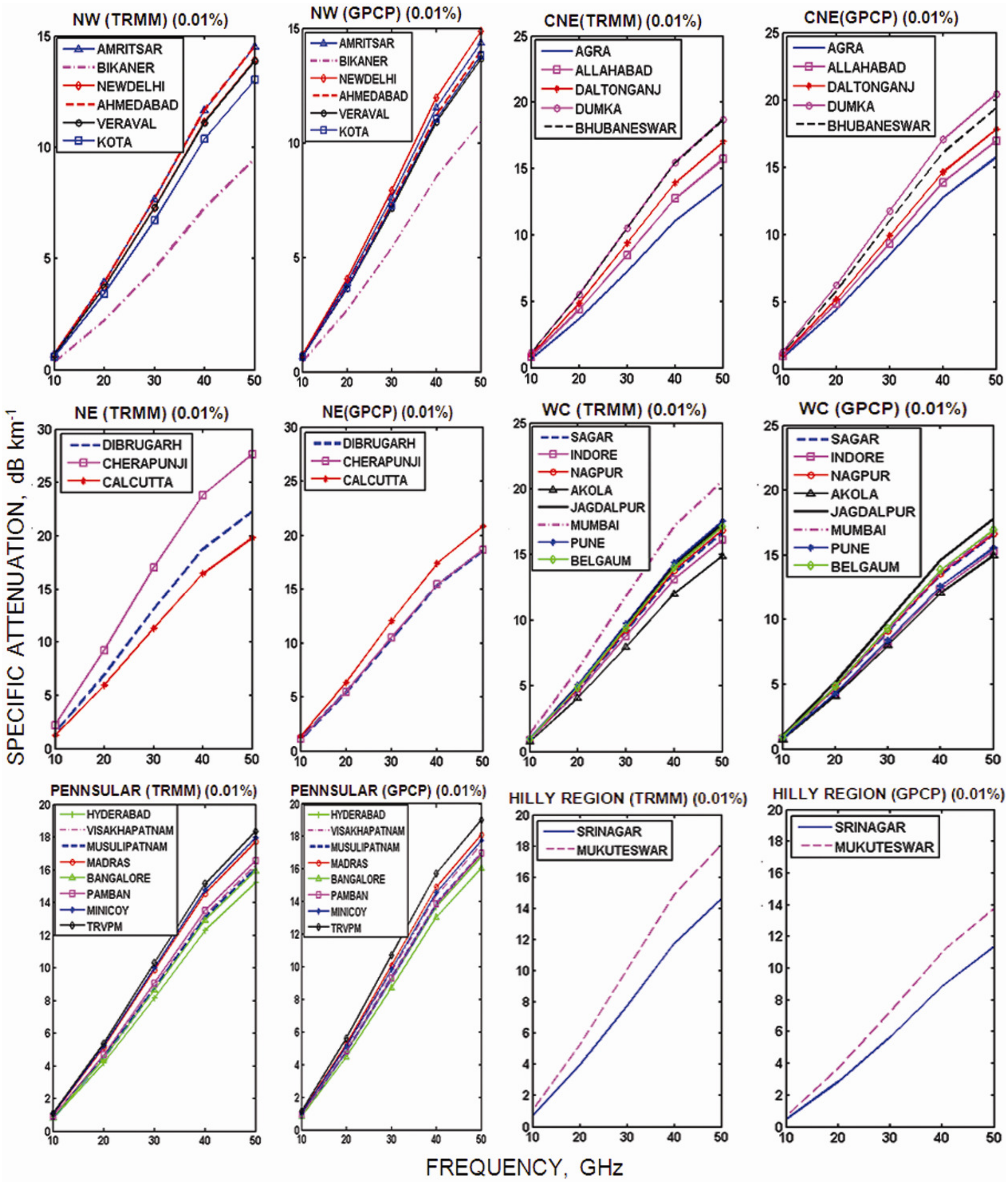

Fig. 3 — Specific attenuation for over all six regions at 0.01% of exceedance

attenuation values are similar to the present observed values using those two satellite data sets.

In TRMM data set, NE region Cheerapunji shows the maximum attenuation of (27.645 dB km^{-1}) and (42.657 dB km^{-1}) at 0.01 and 0.001% of time for the 50 GHz frequency. In GPCP data set, Calcutta shows the maximum attenuation values of (20.831 dB km^{-1}) and (36.157 dB km^{-1}), respectively. Here, the specific attenuation compared to the TRMM, Dibrugarh and Cheerapunji stations, are underestimated, whereas Calcutta is overestimated.

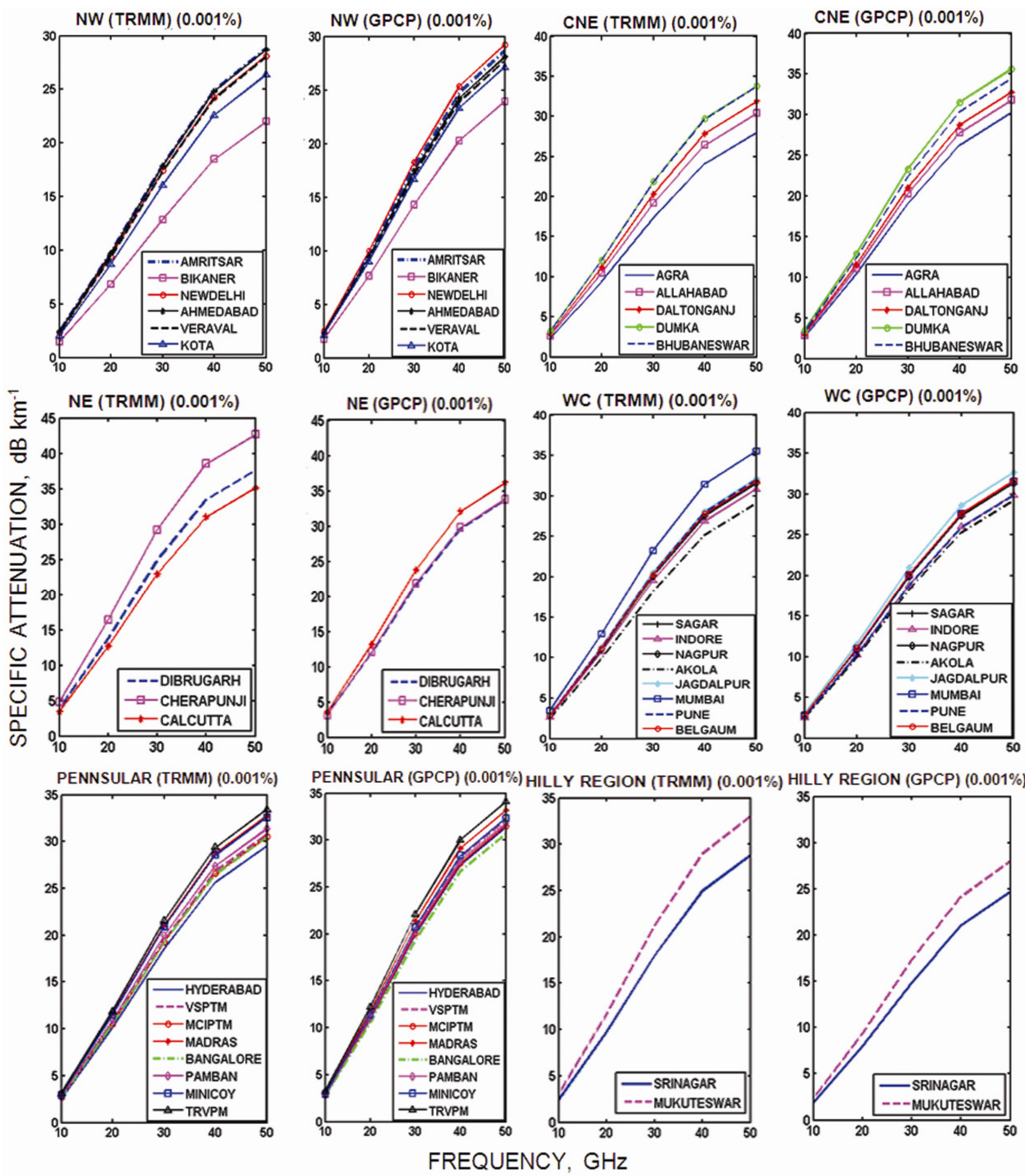

Fig. 4 — Specific attenuation for over all six regions at 0.001% of exceedance

In NW region, Bikaner shows the minimum attenuation at 0.01 and 0.001% of probabilities in TRMM and GPCP data sets for all frequencies. Ahmedabad shows the maximum attenuation (14.549 dB km^{-1} at 0.01%) and (28.707 dB km^{-1} at 0.001%) in TRMM data set. New Delhi shows the highest attenuation (14.8686 dB km^{-1} at 0.01%) and (29.237 dB km^{-1} at 0.001%) in GPCP data set.

In CNE region, at 0.01% Dumka station shows the maximum attenuation (18.732 dB km^{-1} and 20.4382 dB km^{-1}) value and Agra station shows the minimum attenuation (13.844 dB km^{-1} and 15.7374 dB km^{-1}) value in TRMM and GPCP data sets, respectively. Dumka and Bhubaneswar stations have the same attenuation values (18.7 dB km^{-1}) in TRMM at 0.01% of probability.

Daltonganj has 0.5 dB km^{-1} specific attenuation difference in two data sets at 0.01% of the time.

In WC region, Mumbai shows maximum attenuation (20.578 dB km^{-1} at 0. 01% and 35.522 dB km^{-1} at 0.001%) value in TRMM data set, but in GPCP data set, Jagdalpur shows maximum attenuation (17.794 dB km^{-1} at 0.01% and 32.636 dB km^{-1} at 0.001%) value at 50 GHz frequency. Akola shows the minimum attenuation value and approximately 14.9 dB km^{-1} and 29.1 dB km^{-1} specific attenuation values in TRMM and GPCP data sets for 50 GHz range frequency at 0.01 and 0.001% probabilities.

In PC region, Thiruvananthapuram shows the maximum attenuation (18.382 dB km^{-1} and 19.015 dB km^{-1} at 0.01%) value in TRMM and GPCP data sets. Hyderabad shows the minimum attenuation (15.212 dB km^{-1} at 0.01%) in TRMM data set. Bangalore shows the minimum attenuation (16.081 dB km^{-1} at 0.01%) in GPCP data set. Das *et al.*[1] observed that specific rain attenuation at 50 GHz frequency at Thiruvananthapuram and Ahmedabad stations is approximately 15 dB km^{-1}. In the HR, Srinagar shows the maximum attenuation value and Mukuteswar show the minimum attenuation value in TRMM and GPCP data sets for all frequency ranges at both probabilities.

4 Conclusions

The rain rate and rain attenuation parameters were measured at different locations of the tropical Indian region using 13 years data for TRMM 3b43v7 and GPCP v2.2 data sets. Cumulative distributions of rain rate values in six regions over India shows that the highest rain rate values are seen in the NE region and the minimum rain rate values in the NW region. Bikaner shows the lowest rain rate value in TRMM and GPCP data sets.

The evaluation of rain rate value is the first step for the prediction of specific rain attenuation. Using the power law relationship in ITU-R Model K, and α value are used for the determination of specific rain attenuation. The relative error in TRMM and GPCP data sets are compared to the ITU-R P837.5. It is observed that the GPCP gives good rain rate estimation in Central North East (CNE), North East (NE) and Peninsular regions (PS). TRMM gives the good rain rate estimation in West Central (WC) region.

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