# ESTIMATION OF SPECIFIC RAIN ATTENUATION FROM RAIN RATE USING TRMM DATA FOR DIFFERENT REGIONS OF INDIA

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## ABSTRACT
Attenuation diminishes signal strength, causing degradation of the signal-to-noise ratio (SNR) and system performance. Therefore, a comprehensive examination of attenuation plays a crucial role. Specific attenuation for predicting rain attenuation and subsequently designing prediction models has utilized rainfall data retrieved from the Tropical Rainfall Measuring Mission (TRMM) satellites. TRMM satellites, in conjunction with other satellites within NASA's Earth observing system, provide vital precipitation information, enhancing our understanding of Earth's climate dynamics by analyzing the interplay between water vapor, clouds, and precipitation. As frequency of operation is higher than 10 GHz there exists a significant risk of attenuation due to scattering and absorption by raindrops resulting in need of fade mitigation technique (FMT) design. The study was conducted at Ahmedabad and Kolkata, spanning two decades (2000-2019), and we observed discrepancies between TRMM-estimated specific attenuation and the ITU-R model. The analysis revealed that specific attenuation values, as estimated by TRMM, either exceeded or fell short of the ITU-R model predictions and also the relationship between rainfall rate and rain-induced specific attenuation does not consistently adhere to a power law relation, contrary to the global consensus. Instead, the specific attenuation varies with rainfall rate fluctuations, influenced by India's tropical climate and geographical diversity.

**Keywords**: specific attenuation, rain fall, TRMM, tropical country, prediction model

## Introduction
During communication, signal has to propagate long distance through guided medium or without any guiding medium that means in wireless way. Air is generally used as channel for wireless communication. For satellite signal propagation, high frequency is a good choice as it can easily penetrate ionosphere and can reach from one end to another on Earth. But it is very common that intended signal can easily be affected or interfered by the unwanted signal called noise, generated from different sources in the environment or losing its energy by different components of environment viz. rain, snow, water vapor and atmospheric gases etc. while propagating through air in unguided way [1]. Due to the interference of this unwanted signal or affected by the components, intended signal get attenuated easily which is an unwanted but inevitable phenomenon. Rain is the most serious cause of attenuation of all these components. Above 10 GHz, the attenuation due to rain is so severe that it causes a significant signal loss. So, estimation of attenuation due to rain plays a vital role specifically in wireless communication field. In the existing literature rain fall rate and rain induced attenuation has a power law relation among them [2]. Though it is not always true. Because depending on different parameters like -rain drop size, rain distribution dynamics over different locations and climatology condition this relation varies [2]. The main aim of this paper is to verify relation between rain fall rate and rain induced specific attenuation and whether specific attenuation follows the universal relation i.e. power relation with frequency or not. Another aim is to verify whether the measured value of specific attenuation will be same as ITU-R 618-13 [3] recommended values or there exists any deviation and depending on the result, a new model will be proposed to mitigate this deviation so that FMT can be adjusted in a proper way by the SATCOM link design engineer. Various experimental

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studies have been done for tropical climate for understanding rain associated fade dynamics [4] and for finding suitable model to achieve best quality of service. An investigation has been reported at Madrid, Spain [5] with 50 GHz signal with 40-degree elevation angle and result shows short duration of inter fades follow power law distribution while the long duration of inter fades follow the log-normal distribution. Due to unavailability of measured rain-fall data of LPM, TRMM [6] data has been collected for two tropical regions in India. One is Kolkata, a coastal area and another is Ahmedabad, a land area as per the geography. The change in climate over the past decades specially in these regions have forced us to choose such areas and presence of seasonal variation, an efficient Radio Communication link is needed to be designed to achieve best reliability.

## Data analysis and methodology

### *Data Collection*

The rainfall data used in this study were collected from Giovanni, a Web-based application developed by the Goddard Earth Sciences Data and Information Services Center (GES DISC) that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data, particularly from Satellites, without having to download the data (although data downloads are also supported).Giovanni is an acronym for the Geo spatial Interactive Online Visualization and analysis Infrastructure(https://gpm.nasa.gov/).Area-averaged of precipitation-3-hourly-TRMM data spanning two decades (2000-2019) were filtered and processed for the locations under study. TRMM was a research satellite in operation from 1997 to 2015, designed to improve our understanding of the distribution and variability of precipitation within the tropics. TRMM is a joint space mission between NASA and Japan's National Space Development Agency designed to monitor and study tropical and subtropical precipitation and the associated release of energy shown in Fig. 1 (www.slideplayer.com). Flying at a low orbital altitude of 240 miles (400 kilometers) with the orbital inclination at 35 degrees, iinjected by H-II rocket in this orbit, TRMM rotates the earth once for approximately 90 minutes, and 16 orbits a day. The mission uses five instruments: Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Clouds and Earths Radiant Energy System (CERES), and Lightning Imaging Sensor (LIS) [7]. The TMI (Passive Sensor) and PR (active sensor) are the main instruments used for precipitation. Fig. 2(a) is the outline sketch of physical outlook of TRMM satellite and Fig. 2(b) is the physical outlook of different instruments of the satellite while Fig. 2(c) represents main instruments used by this satellite (Source: GES DISC ,2014). TRMM [6-8]Rain Sensing Instruments TRMM - PR, TMI, and VIRS are used for rainfall remote sensing. The PR is an active instrument whereas TMI and VIRS are passive. Complex algorithms are involved in determining rainfall intensity, amount, and extent from each instrument. TRMM is first space borne instrument to provide three-dimensional maps of storm structure and provide a quantitative rainfall measurement over ocean and land (frequency 13.8 GHz) 247 km swath width x 5 km instantaneous field of view Can provide vertical profiles of rain and snow from the surface to 20 km Can detect rain as little as 0.7 mm per hour [8].A radar frequency about three times higher than that of ground radar provides good resolution and higher quality images TRMM PR Reflectivity Hurricane Irene Vertical profiles [8] shown in Fig. 3.

Figure 1: NASA Earth observing satellite


Figure 2: (a) Outline sketch of physical outlook of TRMM (File: TRMM INST.


Figure 2: (b) Physical outlook of different instruments of the satellite

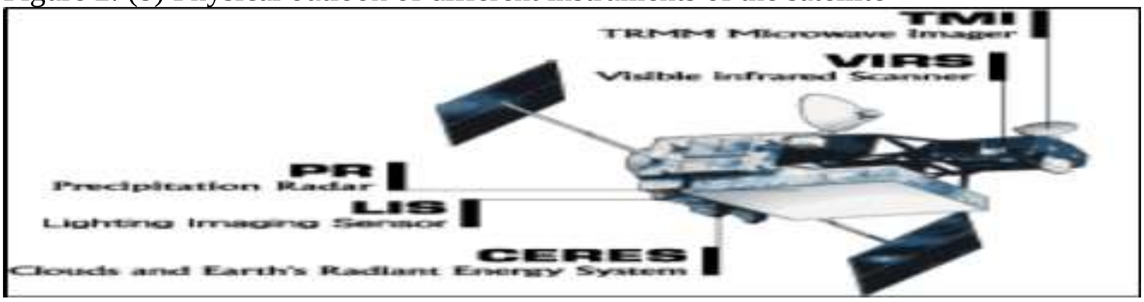

Figure 2: (c) Main instruments used by this satellite

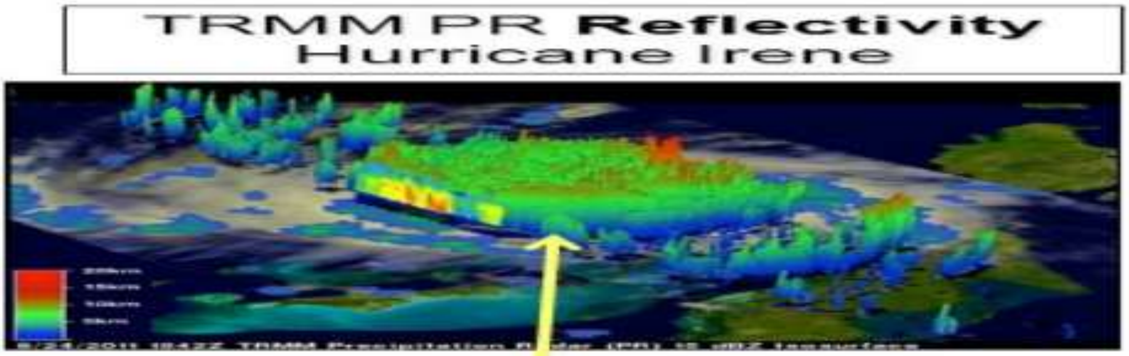

Figure 3: TRMM PR reflectivity Hurricane Irene Vertical Profiles.

### *Study Site/Locations*

Two cities in India one is of urban characteristic, referred as coastal city and another is of urban characteristic but not a coastal city was taken into consideration in this study namely Kolkata, capital of West-Bengal and Ahmadabad, capital of Gujarat. Table I presents the characteristics of the study locations.

TABLE I. CHARACTERISTIC OF STUDY LOCATIONS

| Station | Latitude | Longitude | StationHeight (meter) | Geography |
|---|---|---|---|---|
| Kolkata | 22.5726° N | 88.3639° E | 9.14 | Coast |
| Ahmedabad | 23.0225° N | 72.5714° E | 53 | Land |

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### *ITU-R Rain Attenuation Model description*

ITU-R P.618-13[3] is a recommendation published by the International Telecommunication Union Radio Communication Sector (ITU-R) that provides a standardized method for predicting the attenuation caused by rain in radio communication links. ITU-R P.618-13 model [3] enacts a significant role in the field of designing and configuring satellite communication systems which basically operating in heavy rainfall areas or designed to use the frequency band which are more prone to rain-induced attenuation. This model is widely accepted in research areas associated with determining specific attenuation due to rain considering different parameters like frequency of operation, the elevation angle of the path, the path length, and most importantly the rain rate having unit millimeters per hour (mm/H). Conversion of rainfall into rain rate is possible with this model for wide range of operating frequencies, from a few hundred Megahertz to the millimeter-wave bands.

Data Analysis method

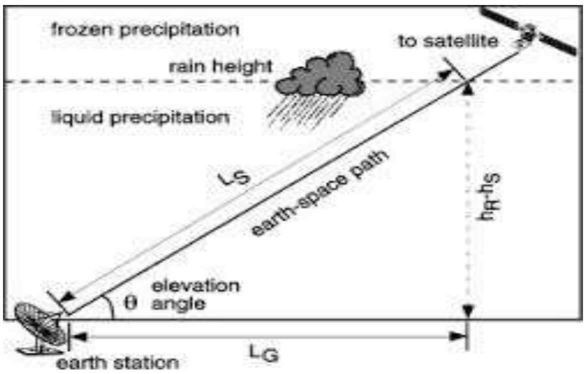


Figure 4: Slant path through Rain[1].

From Fig. 4 we observe the slant path through rain and the parameters used in the corresponding chronological procedure for design of the model. TRMM satellite [2] provides the Path Integration Attenuation (PIA) i.e. the attenuation along the slant path from the TRMM satellite to the receiver on ground. The TRMM satellite passes across a station only once or twice per day which causes missing of many rain events by the TRMM satellite [2]. As per the recommendation of the ITU-R P.618-13 model [3], PIA and specific attenuation have been calculated and compared using ITU-R P.618-13 model [3] by considering TRMM-retrieved rain fall values as input over the selected location. The figures from the calculated values of specific attenuation were generated using MATLAB program taking signal operating frequency (10-50 GHz) as input for horizontal polarization as well as for vertical polarization for the cities mentioned in Table I and compared with the nature of variation recommended by ITU-R P.618-13[3]. Graphs for slant path length (Ls) have also been made taking elevation angle (θ) as input for these two cities mentioned in table I. In order to compute slant path rain attenuation using rain fall rate, the following input parameters are required:

$R_{0.01}$ : Point rainfall rate for the location for 0.01% of an average year(mm/h)
$h_s$ : Height above mean sea level of the earth station (km)
$\theta$: Elevation angle (degrees)
f: Frequency of operation (GHz)
$R_e$: Effective radius of the Earth (8500 km).

**Step 1:** Rain height for two Indian stations is calculated as given in Recommendation ITU -R P.839.4 model [9].

$$h_R = h_0 + 0.36\text{km} \quad (1)$$

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where, $h_R$- rain height in km and $h_0$ is the mean annual 0°C isotherm height. The values of $h_0$ are obtained from ITU-R P.839.4 model [9].

**Step 2**: Determination of the slant path length and the horizontal projection:
Slant path length Lsis computed from (2a).

$$Ls = \frac{(h_R - h_S)}{\sin\theta} \text{ Km} \quad \text{if } \theta \geq 5° \qquad (2a)$$

$$Ls = \frac{2\,(h_R - h_S)}{\left(\sin^2\theta + \frac{2\,(hr - hs)}{R_e}\right)^{0.5} + \sin\theta} \text{ Km} \quad \text{if } \theta < 5° \qquad (2b)$$

where, Lsis the slant path length, $h_R$is the rain height, $h_S$is the station height from mean sea level, θis the Earth station elevation angle, and $R_e$is the effective radius of Earth (8500 km).

**Step 3**: The horizontal projection ($L_G$) of Slant path is calculated from (3)

$$L_G = L_S \cos\theta \qquad (3)$$

where, $L_G$ is the horizontal projection.

**Step 4**: The rainfall rate $R_{0.01}$% is computed from (4)

$$R_{0.01} = aR_{5H} \qquad (4)$$

where, $R_{5H}$is the mean of first five largest values during 2000- 2019. The value of $a$ is 2.3 for locations in India.

**Step 5**: Obtain the specific attenuation, $\gamma_R$, using the frequency-dependent co-efficient and the rainfall rate,$R_{0.01}$, The relationship between rain rate R (mm/hr), and specific attenuation γ (dB/km) is given as:

$$\gamma_R = k(R_{0.01})^{\alpha} \text{ dB/km} \qquad (5)$$

where, $\gamma_R$is the specific attenuation and the constant value $k$ and $\alpha$ are based on ITU R P.838-3model [10].

Results And Discussion

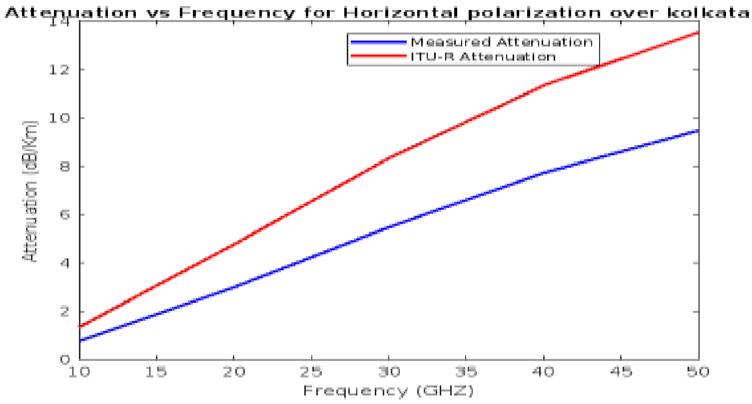


Figure 5: Variation of specific rain attenuation for horizontal polarization

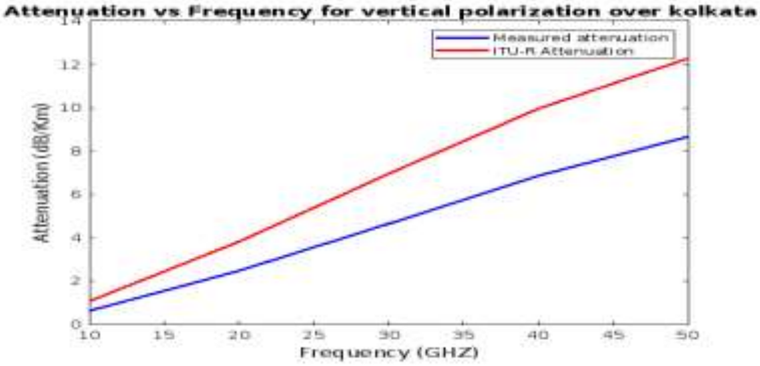


Figure 6: Variation of specific rain attenuation for vertical polarization

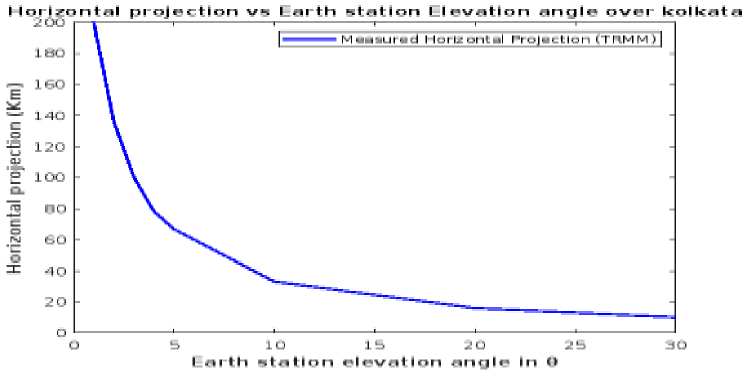


Figure 7: Variation of slant path length (Ls) at different elevation angle

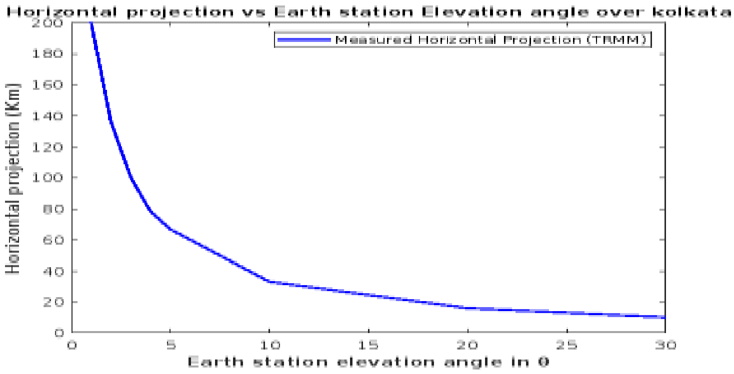


Figure 8: Variation of horizontal projection (LG) at different elevation angle

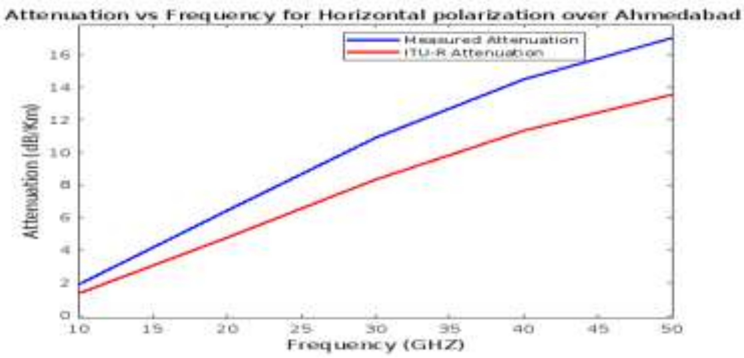


Figure 9: Variation of rain attenuation for horizontal polarization depending on frequency

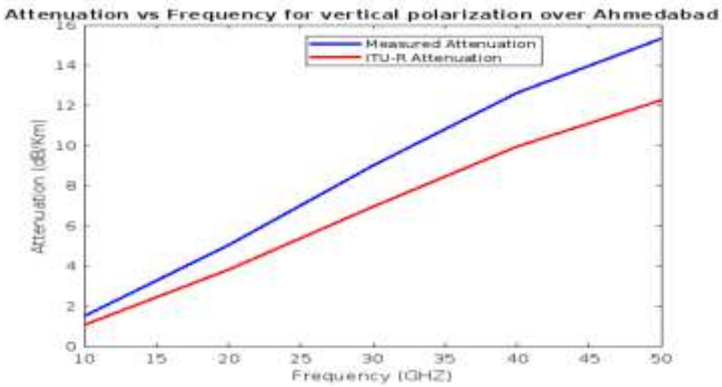


Figure 10: Variation of rain attenuation for vertical polarization depending

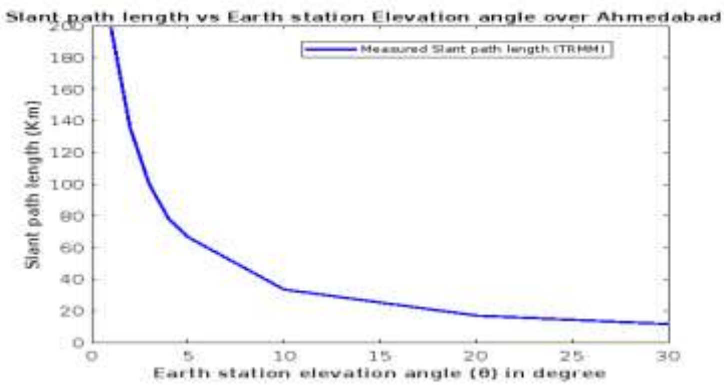


Figure 11: Variation of slant path length (Ls) at different elevation angle

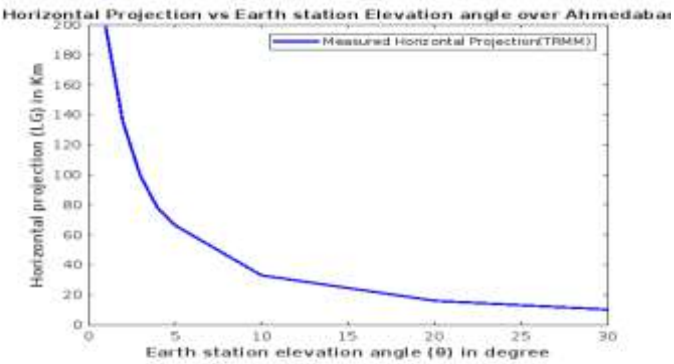


Figure 12: Variation of horizontal projection (LG) at different elevation angle

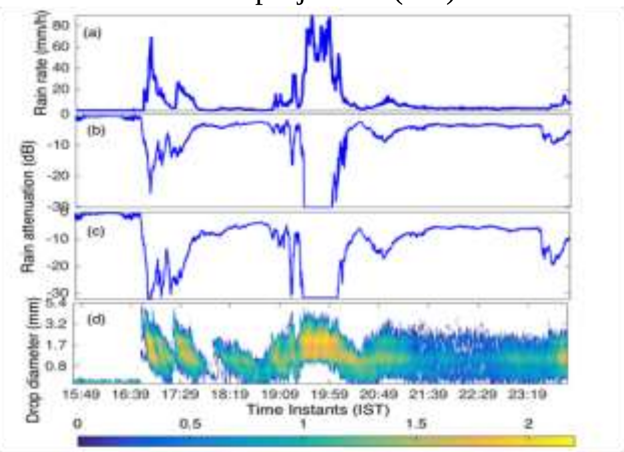


Figure 13 An example of the rain attenuation over Ahmedabad. (a) rain rate, (b) fade at 20GHz, (c) fade at 30 GHz, and (d) corresponding DSD. The DSD concentration is in log scale.

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Fig.5 and Fig. 6 show the variation of specific rain attenuation for Kolkata at 10GHz, 20GHz, 30 GHz,40 GHz and 50 GHz for horizontal &vertical polarization. The specific attenuation (dB/Km) obtained for a frequency of 10 GHz, 20GHz, 30 GHz, 40GHz and 50 GHz are found to be 0.766,2.9813,5.4713, 7.7204 and 9.471 dB/Km respectively for horizontal polarization and 0.6198 ,2.4655 ,4.6389,6.8535 and 8.6578 dB/Km for vertical polarization. It can be observed from Figure 5 and 6 that for Kolkata, specific attenuation increases with increasing frequency. The nature of variation of measured specific attenuation from TRMM data is also being compared with a standard ITU-R model [3] and it is clearly visible that the deviation between data derived from TRMM and ITU-R [3] increases with increasing frequency. Also, the specific attenuation for the same place is different for each of the polarization. For example at 50 GHZ the specific attenuation is 9.471 dB/km in horizontal polarization while for vertical polarization the value is 8.6578 dB/km. Fig. 7 shows the variation of Slant path length (Ls) for Kolkata at different values of elevation angle (θ) which varies from 0° to 30°°.It is clearly seen from the figure that Slant path length decreases with increasing elevation angle .With high value of elevation angle (θ) ,Slant path length value reduces means signal has to propagate through atmosphere for shorter period thus attenuation get reduced .Fig. 8 represents how the length of Horizontal projection ($L_G$) varies with Elevation angle(θ) for Kolkata. The nature of variation is same as Figure 6 as $L_G$ directly proportional with Ls.Fig.9 and Fig. 10 show the variation of specific rain attenuation for Ahmedabad at 10GHz, 20GHz, 30 GHz, 40 GHz and 50 GHz for horizontal &vertical polarization. The specific attenuation (dB/Km) obtained for a frequency of 10 GHz, 20GHz , 30 GHz,40 GHz and 50 GHz are found to be 1.8802 ,6.4177 ,10.8879,14.484 and 17.0257 dB respectively for horizontal polarization and 1.4971 ,5.0369 ,8.9961 ,12.6252 and 15.3252 dB for vertical polarization .It can be observed from Fig 9 and Fig 10 that for Ahmedabad , specific attenuation increases with increasing frequency .The nature of variation of measured specific attenuation is also being compared with a standard ITU-R model [3] and it is clearly visible that the measured attenuation characteristic does not follow the ITU-R characteristic [3] in exact way. There is some deviation between them and it also increases with increasing frequency. In both case, measured attenuation overestimates the calculated attenuation based on ITU-R [3] which is exactly the opposite in nature that we have observed in Fig. 5 and 6.Fig. 11 shows the variation of slant path length (Ls) for Ahmedabad at different values of elevation angle (θ) which varies from 0 to 30 degree .It is clearly seen from the figure that slant path length decreases with increasing elevation angle (θ) same as Kolkata from Figure 7, concluding the same. Fig. 12 represents how the length of horizontal projection ($L_G$) varies with Elevation angle(θ) for Ahmedabad. The nature of variation is same as Fig.8 as $L_G$ is directly. Fig. 13 is depicting GSAT 14 satellite data at 20 and 30 GHZ for Ahmedabad along with rain rate and drop size distribution at an instance of the severe rain attenuation observed over Ahmedabad on 17 July 2014. The corresponding rain rate and rain drop size distribution are shown in the same figure. Large drops are evident during heavy rain spell and associated rain attenuation is also very large. In fact, the fade was more than 30 dB and signal were lost for a significant time with rain rate >60mm/hr. in both frequencies. This figure shows the real picture of attenuation due to rain both for Ka band at the same place that was investigated here using TRMM data.

**Conclusion**

This paper has presented the evaluation of specific rain attenuation estimated for Kolkata and Ahmedabad cities in India and also presented real date presentation of GSAT 14 for Ka band signal. Rrainfall data or rain rate data recorded by TRMM for two decades (2000-2019) were collected from GIOVANNI,processed and implemented using both ITU-R P 618-13 and ITU-R P 838-3 models [10].These internationally established models were used to evaluate rain attenuation at 10, 20 ,30 ,40 and 50 GHz frequencies. The calculated result shows that higher frequencies variations cause higher attenuation in both locations and the deviations from ITU-R are different for different location. In case of Kolkata, the rate of increment of attenuation value with frequency is comparatively lesser than the rate of increment of attenuation based on ITU-R value for both polarizations while in case of

Ahmedabad the scenario is totally reverse. For both cities, the length of Horizontal projection ($L_G$) and slant path length (Ls) decrease with increasing elevation angle (θ). Though the values are different. One example of real GSAT 14 data shows the real picture at Ka band at the time of heavy rain and larger DSD. So, it can be concluded that a single value for validation in the country like India will not be enough for calculation specific attenuation or attenuation in future. And also, if the real rain data is missing due to unavailability of instrument, TRMM data can be used for predicting nature of attenuation for proper design of FMT for system engineers.

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