Indian Journal of Radio & Space Physics
Vol 42, February 2013, pp 34-41

Diurnal variation of slant path Ka-band rain attenuation at four tropical locations in India

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Received 3 October 2012; revised received and accepted 11 January 2013

Rain attenuation is very severe at Ka and higher frequencies especially in tropical regions. The conventional fade mitigation techniques are not be able to mitigate this severe fade and hence, suitable diversity technique is required for this purpose. In this paper, rain characteristics and slant path rain attenuation at 30 GHz using synthetic storm technique has been presented. Three years of high resolution rain rate data obtained from disdrometer at four tropical and equatorial locations in India have been utilized. The results indicate that the fade margin requirement is very high (above 50 dB at 30 GHz) for 99.99% link availability for these locations. However, the diurnal analysis shows that in most of the places, the rain occurrence is much less in morning/early-morning hours and therefore, the fade margin requirement will be considerably lower (around 30 dB at 30 GHz) in the morning hours compared to the afternoon hours. The result indicates the suitability of using selective time period for high link availability data communication over the locations studied.

Keywords: Data Communication link, Fade mitigation technique, Rain attenuation, Rain rate exceedance, Synthetic storm technique

PACS Nos: *92.40.eg*; 84.40.Ua

1 Introduction

The use of the Ka or higher band frequencies (>18 GHz) in satellite communication is limited due to the severe attenuation caused by atmospheric elements. Major contribution is due to the rain in terms of fading and depolarization[1]. In order to implement the fade mitigation techniques for Ku/Ka and V band satellite systems, the knowledge of propagation impairments are essential[2-7]. This is more problematic in tropical region as heavy convective rain dominates with substantial rainfall over this region. Further, countermeasure of these heavy fades is not possible using conventional methods and dynamic fade counter measures are of practical importance. However, performance evaluations of different fade mitigation techniques (FMT) are very limited over Indian region due to very scattered measurement of satellite signal at these frequency bands. With the limited experimental signal fade measurements, rain attenuation statistics is normally generated using meteorological parameters, like rain rate and rain cell size.

To devise suitable FMT, time series of attenuation value is required with the long term statistics. Synthetic storm technique (SST)[8,9] is one of the most popular techniques for attenuation time series generation from rain rate time series, applicable to both terrestrial and satellite links. The dynamic characteristics of rain attenuation derived from rain rate database can, thus, be used effectively for regions where direct signal measurements are not possible. The validity of SST is studied by various researchers over the globe[10-14]. The performance of the SST is also studied over Indian region and found to be performing well when compared with radiometer observations[15,16].

The rain is very inhomogeneous both in time and space. The tropical rain is dominated by convective rain, which occurs in short time spell over shorter region. The tropical rain also have distinct diurnal and seasonal pattern. It was reported that the rainfall is maximum in late-evening and early-morning hours over ocean, while maximum occurs in the mid to late-afternoon over land[17]. There are number of reasons behind this diurnal behaviour. Temperature variation and aerosol are considered two major reasons behind the diurnal variation of the rainfall over Indian region[18].

In this paper, the variability of rain is studied for four locations in India, namely Shillong (25°34'N, 91°53'E), Trivandrum (08°29'N, 76°57'E), Ahmedabad (23°04'N, 72°38'E) and Hassan (13°00'N, 76°09'E), having different rain climatology. Attenuation time series are generated using rain rate data measured by disdrometer with 30 second integration time over 3 years experimental period (2005-2007). The annual and diurnal attenuation statistics is then studied to understand the probable rain attenuation encountered at these locations and the possibility of using selective time period for better link availability over the region of study. This study is particularly important in view of future satellite communication systems in Ka band for tropical region where conventional fade mitigation techniques are not sufficient to overcome the fade[10,19-21].

2 Experimental details and Data analysis

2.1 Site selection

In Fig. 1, the locations of the experimental sites are shown. The different locations are associated with different rain climatology. Shillong (25°34'N, 91°53'E) is located in the hilly region of Himalaya and governed by the S-W and N-E monsoon rain, whereas Trivandrum (08°29'N, 76°57'E) is on coastal plane and governed by the same S-W and N-E monsoon. Ahmedabad (23°04'N, 72°38'E) and Hassan (13°00'N, 76°09'E) both are in plane and rain occur mostly by S-W monsoon. Shillong receives maximum rainfall (~2415 mm per year) and Ahmedabad receives lowest rainfall (803 mm per year). More details about these locations are given in Refs (22 and 23).

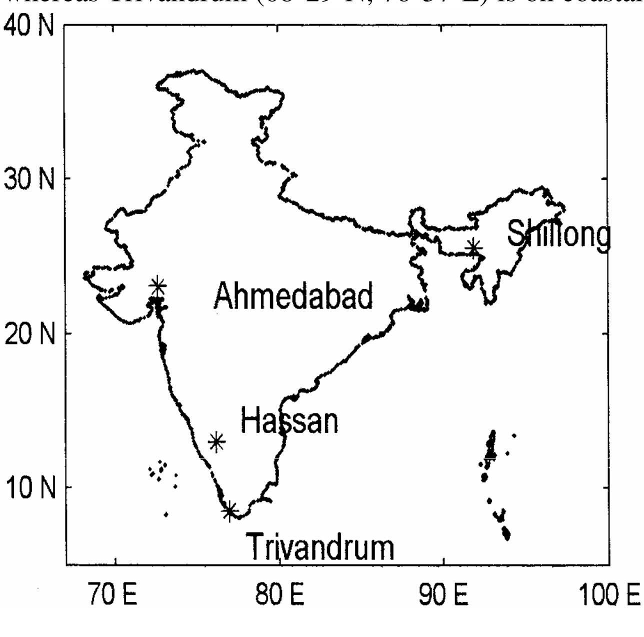

Fig.1 — Location of the sites

2.2 Rain measurement

The Joss-Waldvogel disdrometer (RD-80) is employed to measure the rainfall at all the locations. It measures the drop size distribution (DSD) by transforming the momentum of the falling drops into electrical signal which is a function of drop diameter. It measures the drops of diameters in 20 bins varying from 0.03 mm to 5.3 mm. Rain rate is obtained from the measured drop size distribution. Disdrometer was operated with 30 second integration time for the years 2005-2007.

The instrument was regularly cleaned and the sensitive surface was changed, whenever necessary. Errors due to acoustic noises and splashing of rain drops were minimized by proper installation of the instrument. Another error source in disdrometer is due to the insensitivity for a time period after a bigger drop strikes. This 'dead time' leads to underestimation of the smaller drops that fall within this period. But, the smaller drops have less effect on rain rate and attenuation value and are usually within 5% error limit[24]. Therefore, in this present paper, these dead time effects are ignored.

The validity of rain rate estimation by disdrometer is studied earlier using a collocated tipping bucket rain gauge[25]. The observation shows that the disdrometer is very sensitive in measuring the fast variation of rain rate in comparison to the tipping bucket rain gauge. Also, low rain rate is usually under estimated in tipping bucket measurement.

The measurements at different locations could not be made for ~2-3% of total time due to technical problems during the observation period. However, since the outage is random, the statistical picture should not change significantly for such a long measurement period.

2.3 Attenuation time series generation

The rain attenuation is calculated from rain rate using SST, originally developed by Drufuca[8] and extended by Matricciani[9] for both terrestrial and satellite links. It calculates the rain attenuation due to rain layer and melting layer separately. This also incorporates the local parameter such as position of receiver, elevation angle and rain cell speed, therefore, provides a better estimation of rain attenuation for the location and is in good agreement with instantaneous fade measurements. The applicability of SST depends on the validity of the assumptions taken in the formulation. It is assumed that the advection velocity of rain cell is constant and in direction of the projection of the link on ground. Similarly, the attenuation due to the melting region is simplified by taking apparent rain rate value estimated from the actual rain rate at ground. Though, this is not always true for any location, it is, however, reported that the SST is highly suitable for converting rain to attenuation time series for both tropical and temperate regions[10,13].

Using SST, the rain attenuation is calculated for satellite links (geostationary at 83°E) for all the locations at Ka band frequency (30 GHz). The mathematical details of the SST are discussed at length by Drufuca[8] and Matricciani[9] and therefore, not repeated here.

The average storm speed for all the locations are assumed to be 10 ms^{-1}, however, it is to be emphasized that the long term statistics are mostly independent of the storm speed[26]. The rain height is estimated from the ITU-R model P. 839-3 (Ref. 28) for these locations separately. It is assumed that the layers with liquid rain drops are at temperature 30°C and the region with melting ice are at temperature 0°C. The specific attenuation coefficients due to rain are calculated from the ground based DSD measurements at these locations[23] and given in Table 1. The specific attenuation of melting region is modeled from Maggori *et al.*[28] and the values for coefficients K and α of ice region are taken to be 0.1590 and 1.018, respectively. These coefficients are assumed to be same for all the locations, as no direct measurements of ice region are available. The K and α values are related with specific attenuation by the following equation[29]:

$$A = kR^{\alpha} \qquad \ldots(1)$$

Table 1 — Coefficients of attenuation estimation

Station name	K (30°C)	α (30°C)
Shillong	0.2932	0.8922
Ahmedabad	0.3241	0.8577
Trivandrum	0.3385	0.8492
Hassan	0.2625	0.9169

3 Results and Discussion

3.1 Annual rain attenuation statistics

Rain attenuation estimated by SST is found to be significantly high for different locations in India as shown in Fig. 2. The result indicates that Trivandrum shows the lowest rain attenuation, whereas Ahmedabad shows the highest rain attenuation probability. This means that at 30 GHz communication, at least 50 dB fade margin is required for 99.99% link availability, which is very high. Usual FMT can't be suitable to compensate these amounts of high fade. The only realistic solution is to use the diversity technique.

However, the site diversity or space diversity is relatively expensive method involving additional ground station or satellite system. The time diversity or frequency diversity are, on the other hand, relatively cheaper, but compromise with data capacity. The choice of the technique depends on the application and cost effectiveness. It has already been emphasized that the tropical rain have some distinct diurnal pattern and therefore, the performance of time diversity technique for these locations have been studied.

3.2 Diurnal variation of rain

The diurnal rain patterns of the experimental locations are shown in Fig. 3(a). The 24-hour period is first divided into 12 blocks of 2-hour duration. The total rain duration encountered over the full measurement period is then obtained from the database in each of these 12 blocks. Finally, it is

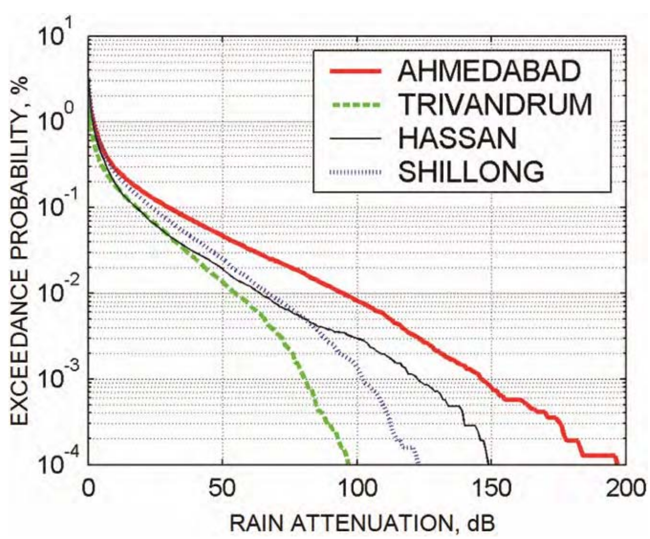

Fig. 2 — Rain attenuation exceedance probability for different locations

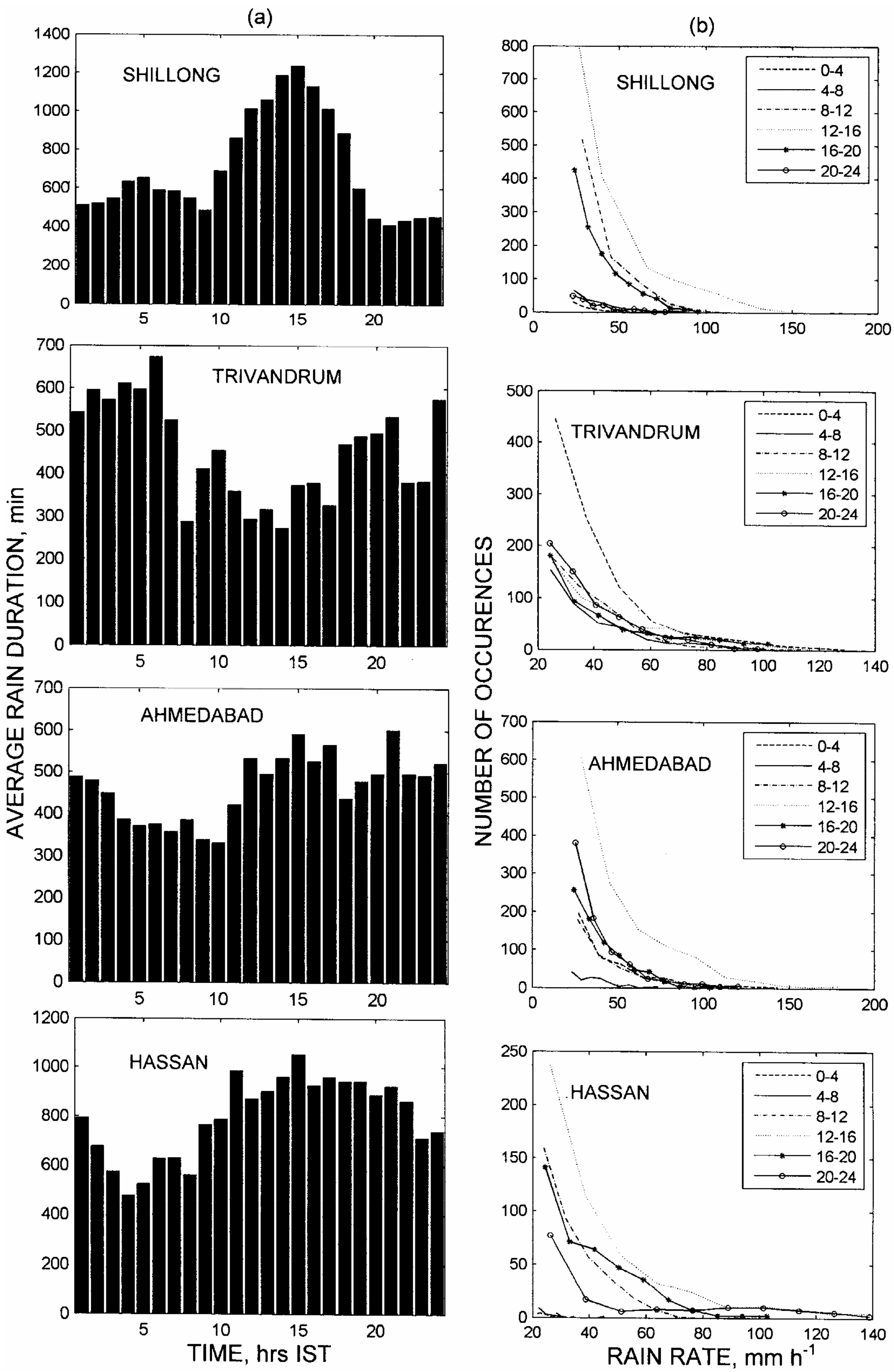

Fig. 3 — Distribution of (a) average rain durations; and (b) rain occurrence pattern at different locations

divided by the number of measurement years to arrive at the relative distribution of rain duration in a year.

It can be noted that the rain occurrence probability and rain intensity differs from time to time. This behaviour is strongly dependent on local climatology as different climatic condition prevail over these regions. It can be seen from the left panel of Fig. 3 that in the morning time, rain fall is relatively less in Ahmedabad than the afternoon hours. However, it is reversed in case of Trivandrum. It can be seen that the lowest rainfall time is observed around 0008-0010 hrs IST and maximum rainfall is observed around 0014-0016 hrs IST at Ahmedabad. In fact, most of the locations show high rainfall around noon or during afternoon hours and low rainfall occurs in morning or early morning period.

The observations are in agreement with the previously published results[17,30,31]. However, measurement reported from Amritsar[32] shows the minimum rain accumulation at noon hours. The different rain pattern, amongst the locations, indicates that the local topography has important role in determining the rain formation.

In general, tropical rainfall is mostly from the cumulus or cumulonimbus clouds formed by deep convection. The heating of ground due to solar radiation is mostly responsible for such cloud formation. Therefore, over land surface, initial thunderstorms start around 1430 hrs IST, coinciding with maximum ground temperature[18]. Thus, the maximum rain occurs at afternoon period over Indian land mass. However, over coastal regions, sea and land breezes play an important role and maximum convective rain occurs in the early morning hours[32].

However, the distribution of rain rate is also important as high rain rate for shorter time duration can also cause high fade as the rain attenuation depends primarily on the rain rate. So, in Fig. 3(b), the rain rate distribution measured for continuous 4-hour time span is shown for respective locations. The total number of times rain crosses a particular rain threshold during the 4 hour span is counted and then annual average is estimated. The afternoon hours, 1200-1600 hrs IST, show highest occurrence of rain and early morning hours, 0400-0800 hrs IST, show lowest occurrence of rain for Ahmedabad. The similar pattern is seen for all other experimental locations except Trivandrum. In Trivandrum, rain exceedance is maximum for 0400-0800 hrs IST. Trivandrum is an equatorial coastal location where sea breeze can play a significant role and thus, rain climate can differ from that of other tropical locations.

3.3 Diurnal variation of rain attenuation

To understand the temporal behaviour of rain attenuation, diurnal variation of rain attenuation is studied. The 24 hours is divided in 12 blocks of 2 hour duration and rain attenuation exceedance is then calculated for each segment. The diurnal rain attenuation exceedance probability is shown in Fig. 4 for 2 hour continuous periods. The dotted line shows the annual rain attenuation exceedance and solid line represents 2-hourly exceedances.

It is observed, as expected, in afternoon hours higher fade margin is required for mitigation of rain attenuation for same link availability than the other times of the day at most of the locations. It is also observed that the probability of fade exceedance is lowest during 0400-0600 hrs IST and fade margin of 25 dB at 30 GHz is required for 99.99% link availability which is much less than the fade margin computed from yearly attenuation distribution (~80 dB) for Ahmedabad. The similar trend is observed for all the locations and summarized in Table 2. However, the minimum and maximum rain outage periods are different for different locations as indicated in the figure. Thus, the temporal variation of rain can also be used effectively to avoid the high fade possibility. The service can use a specific time period of day for high link availability data transmission.

It is also to be noted that the distribution is much narrower for Trivandrum as the presence of equator limits the diurnal variability. However, Hassan, which is also a low latitude region, shows significant diurnal variation due to the local topography, as it is also an important determining factor for convective activities. In general, the convective activities, which are mostly responsible for severe fades in tropics, are encountered in the second half of the day.

The results, therefore, provide a clearer picture of the amount of possible fading in Ka band communication channel which turns out to be rather unrealistic for simple uplink power control system. However, exploiting the diurnal characteristics of rain attenuation as shown in this paper, system designer can effectively reduce the fade margin for high link availability. Further, other fade mitigation techniques, like site diversity or coding can be used in conjunction with this time diversity technique, which

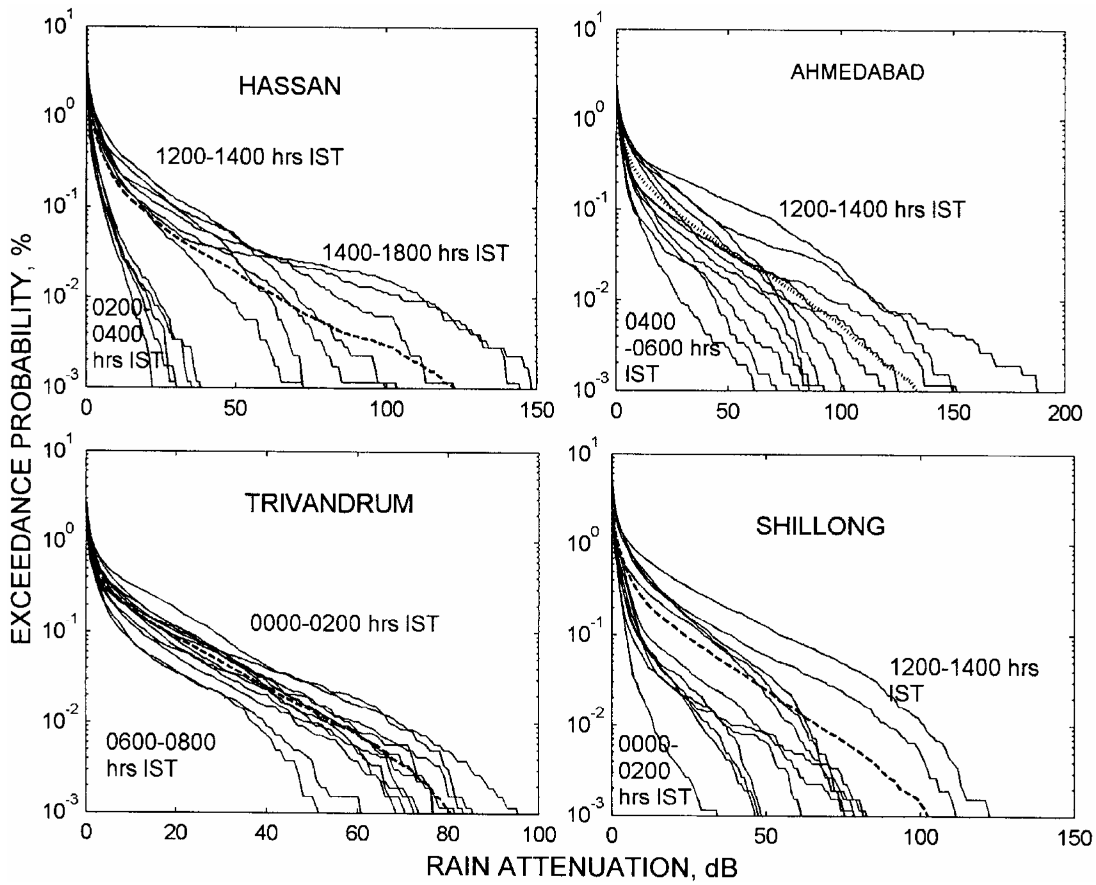

Fig. 4 — Rain attenuation exceedance probability at different time of the day over different location at 30 GHz frequency [dotted line shows the annual distribution and solid line represents 2-hour distribution; time period corresponding to the highest and lowest exceedance probabilities are only indicated]

Table 2 — Rain rate exceedance of 0.01% probability level

Location	Yearly fade margin, dB	Lowest fade period, hrs IST	Lowest fade, dB
Ahmedabad	80	0004-0006	25
Shillong	65	0000-0002	13
Trivandrum	53	0006-0008	36
Hassan	66	0002-0004	15

can effectively reduce the fade margin to very low value. Thus, the results indicate the suitability of such time specific services in high frequency band communication in this part of the globe. Study is also useful to select suitable fade mitigation techniques at different times of the day.

4 Conclusions

Annual and diurnal statistics of slant path rain attenuation are presented for four tropical locations in India. Rain attenuation at these locations is estimated using SST at 30 GHz frequency. It is found that very high fade margins are required for reliable link availability in these frequency bands over this region. However, it is also observed that the rain attenuation probability is lowest in morning time and maximum in afternoon hours at most of the places. These results will be helpful to system designer to select suitable time region for high data rate communication with higher link availability for a low fade margin system.

Acknowledgment

One of the authors (SD) thankfully acknowledges the financial support given under the ISRO sponsored Space Science Promotion Scheme. The authors also acknowledge the support provided by ISRO under the project Integrated Studies on Water Vapour, Liquid Water Content and Rain of the Tropical Atmosphere and Their Effects on Radio Environment.

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