Estimation of rain induced attenuation on earth-space path

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Abstract - This paper describes research on earth-space attenuation on a microwave communications link set up at Belgaum-RC Nagar (Karnataka State), India, during July to September, each year. The rain data secured from India Meteorological Department, Bangalore has been used for analysis with the live data of rainfall recorded with the aid of two tipping bucket rain gauges, and a disdrometer. A simple model of interpretation of attenuation has been utilized with simple formulae to suit the purpose. The results of this experimentation are in agreement with the disdrometer observations and the data collected through experiment tallies with the Micro Rain Radar (MRR) Recorded data secured from the ISRO-operated-MRR rainfall data. The model used in the experimentation, it is hoped, would enable further research in to the aspects attenuation of microwave signals in different Tropical stations.

Keywords: Rain Drop Size Distribution (RDSD), 00C isotherm height (Hi), Disdrometer, power law, specific attenuation. Log-normal function.

I. INTRODUCTION

Satellite communication systems operating at Ku band (12 to 24 GHz) and Ka band (20 and 30 GHz) frequencies are used for broadband multimedia and internet based services. Among all the propagation impairments such as cloud attenuation, tropospheric and ionospheric scintillations, water vapour attenuation, and rain and ice depolarization, etc, rain attenuation is the most crucial parameter. Rain drop size distribution (RDSD) was measured with disdrometer at the location Raichur, a Southern Indian tropical region.

RDSD is assumed to be lognormal to model the rain attenuation in the frequency range of 10-150 GHz. It is further assumed that rain attenuation is a phenomenon of single scattering of spherical rain drops.

The comparison between ITU-R model with other models such as the Marshall-Palmer mechanisms, and the RDSD derived experimental values reveals that the RDSD depends on climatic conditions, the location characteristics, rainfall intensity, type of precipitation, wind shear, cloud type, etc. As such, it is very difficult to formulate a single DSD model to describe the actual raindrop size distribution for all locations and rain types. Log-normal distribution studies are suited for lower-end drop spectrum than the gamma distribution.

Indian Space Research Organization (ISRO) is presently conducting earth-space propagation experiments over Indian region; ground-based measurements at five different geographic locations, i.e., Ahmadabad, Shillong, Trivandrum, Kharagpur and Hassan as these locations that fall in different climatic zones.

Monsoon

The word monsoon originated from the Arabic word “mowsum”, meaning “season” to describe a system of alternating winds over the Arabian Sea. These winds appear to blow from the northeast for about six months and from the southwest for another six months. When wind blows southwest, India and adjacent areas experience very heavy rainfall. The southwest monsoon onsets on the Kerala coast of India beginning in the first two weeks of June. The north-east monsoon in Tamilnadu begins typically in October.

All the stations in the present study are in tropical peninsular India which experiences an intense precipitation during the Indian summer monsoon. The South-western (summer) monsoon occurs from June to September. South-east Asia experiences large amounts of rainfall. The North-eastern (winter) monsoon takes place from October to December. Again, Southeast Asia receives large amounts of rainfall. These are: the South-West (SW) monsoon (June–September), North-East (NE) monsoon (October–December) and Pre-monsoon (January–May). Rainfall during the SW monsoon is mostly from stratiform clouds, and during the other two seasons, rain is from cumuliform clouds, mostly thunderstorms.

As such, this study selected Belgaum-RC Nagar link. It is impossible to estimate the parameters for the study physically and therefore, empirical methods are in use for the analysis of ground-space path attenuation.

II. Parameters for the study

RAIN DROP SIZE DISTRIBUTION [RDSD]

Knowledge of Drop Size Distribution (DSD) is highly essential to calibrate the instruments and sensors, for different seasons. Tracking the rain DSD along their falling path is a direct way of even measuring rain evaporation (Li and Srivastava, 2001) [1]. One method for obtaining drop size distribution (DSD) functions requires normalization of measured drop diameters and concentrations. This normalization has been proposed by Sekhon and Srivastava (1971, 78) [2].

The Z-R-relationship (Z=aRb) is established by using drop size distribution as recorded by disdrometer at ground level and transferring it to radar data. Therefore, these relationships have been calculated from the mean spectra described by regression with the independent variable R (rainfall) and the dependent variable Z (reflectivity). Variable b is equal to the regression coefficient (Wagner et al., 2004) [3].

Lognormal function

Lognormal distribution was explored by Feingold and Levin (1986) [4]. It showed better fit with the observed raindrop size distribution. Normalization is totally free of any assumption about the shape of the DSD. This new normalization (Lognormal) function has been successfully applied to the airborne microphysical data of the Tropical Ocean and Global Atmosphere. Taking this function in to account the DSD normalization, and Z-R relationship, Rain Drop Size Distribution has been studied empirically.

DSD measurement

Disdrometer manufactured by Disdromet Company of Switzerland, the RD-80 type has been installed at each of the locations under this case study. The drop diameter has been estimated from the terminal velocity using the Gunn-Kinner relation [5]. It is noticed that bigger drops are not spherical and therefore, introduce error in the estimation of rain rate and rain attenuation from the DSD so obtained. However, it is observed that the deviation of rain rate as calculated and measured by co-located rain gauge may not vary much. The effect of the smaller drops is less on rain attenuation and is within 5% error limit [6]. The data collected for 3 years (2009-12) has been used for analysis. A cumulative frequency of the data available for these years has been used to model the rain induced attenuation on ground-space path.

0oC Isotherm Height (Hi)

The 0oC isotherm height, a parameter needed for the estimation of attenuation of microwave and millimeter wave for earth-space communication, has been estimated for different stations spread over India. Crane, in 1980; Hall, in 1979 established that rain height is very close to 0oC isotherm height (Hi). This Hi varies from season to season over each location separately.

III. The case study

In a case study over Belgaum-RC Nagar link, at Belgaum, Operating in the 23 GHz Digital Wideband link, an inland station (Karnataka), the statistical analysis reveals that the number of rain occurrences goes beyond 220 times for rain rate up to 15 mm/hr. It was observed also that the number of events suddenly falls to 65 for rain rates 15-25 mm/hr. The brightness temperature as measured by the radiometer sharply increases up to rain rate 10-12 mm/hr. But above this rain rate, radiometer brightness temperature slowly increases and has a tendency of saturation at all frequencies.

A slight departure is observed in variation pattern of attenuation at 22 GHz during 21:30:00 to 23:45:25 hrs (local time), when rain rate is very low. Below 5 mm/hr, the measured attenuation is found to be higher than the calculated attenuation. This might be due to the fact that the heated earth surface evaporates water vapor and subsequently is filling up the antenna beam by a more amount of vapor when rain drop falls on the surface.

This becomes prominent only at 22 GHz since the frequency of the radiometer lies just at the water vapor resonance line, although weak. This kind of anomaly is not recognized at the pressure independent frequency 23 GHz. So it appears that rain attenuation measurements at 22 GHz are contaminated by the unwanted presence of water vapor.

This effect is minimized at the window frequency region (around 30 GHz) where attenuation due to water vapor is very less. It was also noticed that rain attenuation increases monotonically with rain rate with an exception at 23 GHz.

During the study it was also observed at 23GHz that the attenuation always is a a minimum irrespective of any rain rate within the water vapor band. Hence, 23 GHz frequency may be considered as a good choice of radiometric measurement in the water vapor band. It is interesting to point out that effective rain height measured at 23 GHz matches well with the physical rain height.

Rain attenuation in the microwave band is currently considered to be a major concern in the design of satellite communication systems at frequencies above 10 GHz. The prediction of rain attenuation generally starts from known point rainfall rate statistics, considering the vertical and horizontal structures of rain cell using climatology parameters. These data can be used to estimate rain attenuations with the help of physical and statistical modeling procedures.

Attenuations can be estimated experimentally from radiometric measurements of sky noise temperatures with certain assumptions made regarding the atmospheric medium. The vertical extent of rain can be estimated from meteorological measurements of the height of the zero degree isotherm or radar reflectivity measurements (Mawira et al., 1981) [7], from which rain attenuations along the path through the atmosphere can be determined.

A number of prediction procedures were developed for earth space paths over the last for temperate climate, but overestimate rain attenuations in tropical region (Dissanayake et al., 1990) [8]. This overestimation is result of an incorrect estimate of the effective path length, leading to an inaccurate estimation of path attenuation. More accurate rain attenuation models applicable to tropical climates require more experimental data from tropical regions. It has been considered that the equivalent vertical path length through the rain is not equal to the physical rain height. The ITU-R has developed a model for the path length reduction coefficient for the horizontal projection of the path, LG, with the vertical path equivalent to the height of zero degree isotherms (Ajayi et.al, 1990) [9]. An empirical vertical reduction factor for earth-space paths have been proposed to derive an effective rain height from the height of the zero degree isotherm during rainy condition (CCIR, Doc. 5/387-E, 1989) [10].

In order to study the attenuations in the microwave band, continuous measurements of sky noise temperatures at 22, 23 and 30 GHz were conducted using a ground based radiometer during July-September, 2009 at the select station under study, separately. The experimental measurements were supported by the results obtained from a fast response optical rain gauge co-located with a radiometer.

Radiometer

Radiometers (MP-3000A) are available from www.radiometrics.com. The selected frequency bands in the said Radiometer were (i) Water vapour absorption band (22-30 GHz) and (ii) Oxygen absorption band (50-60 GHz). Only the water vapour band has been selected for the present study. The radiometer is controlled by Radio metrics proprietary software and preinstalled control computer with Graphic user-Interface (GUI) that allows the selection of user-defined observation and automated calibration. Real time observation and calibration data are displayed in graphical format.

Depending upon the choice of operating codes, it begins logging data to level ‘0’ file (raw sensor data in volts), level ‘1’ file (brightness temperature) and others along with calibration file. The radiometer antenna has its beam width and side lobe 4.9-6.3 deg.; -24 dB (for 22-30 GHz band) respectively. The dynamic range of the radiometer is from 0 to 400 K. It has channel bandwidth 300 MHz and depending on the integration time it possesses the resolution of 0.1 to 1.0 K. This study chose 1.0 K resolution. Rainfall intensity and particle size of 0.16 mm diameter is measured.

Rain attenuation is characterized by the non-uniformity of rainfall intensity, raindrop number density, size, shape or orientation and raindrop temperature in addition to its intrinsic variability in time and space.

Rain attenuation on an earth space path is—

$$A(s) = \int^{\infty} \lambda(s)\, ds \qquad (1)$$

where, ds represents the incremental distance from the ground along the earth-space path, and λ(s) is specific attenuation (dB/km). Rain attenuation is approximated to a simple power law for a number of rain drop size distributions and temperatures in the form of a simple power law.

Rain attenuation approximated to a simple power law:

$$A(s) = \int_{o}^{L_s} \alpha R^b \, ds \qquad (2)$$

where, 'α'and 'b' are coefficients dependent on frequency, temperature and rain drop size distribution; R is the rain rate in mm/hr and λ is substituted as aRb, dB/km. The parameter LG is the projection of the rainy earth-space path along the ground and is given by:

$$L_G = [(H_R - H_S)/\tan(\theta)] \qquad (3)$$

where, θ is the angle of elevation, HR the rain height and HS the height from sea level. The parameter LS is the slant path below the rain height and is given by:

The rain attenuation (dB) may be determined from the measured rain intensity data assuming that the rain is spatially uniform.

$$L_S = [(H_R - H_S)/\sin(\theta)] \qquad (4)$$

However, in practice, rain is generally not uniform over the entire radio path. Therefore, the entire path may be divided into small incremental volumes δV in which the rain rate is approximately uniform. According to Semplek and Bodtman (Semplek et al., 1969; Bodtman et al., 1974) [11], an approximate choice of δV was considered to be 1m3 for meaningful measurement of very low rain intensity.
In an experimental study (Lin, 1975) [12] indicates that heavy rain also has finite structure of the order of m3. With this choice of δV, total path attenuation may also be obtained as the integral of the attenuation coefficient (dB/km) along the entire radio path. The values of the coefficients 'a' and 'b', applicable to the chosen frequencies are taken from ITU-R (ITU-R p.618-8, 1995) data base, where the rain drop size was assumed to obey the log-normal distribution. These values are frequency and polarization dependent and are shown in Table below.

Table 1: Values of Constants 'a' and 'b' from ITU-R model:

Frequency (GHz)	**Value of 'a'**	**Value of 'b'**
22.234	0.0766	1.1074
23.834	0.0906	1.1014
30	0.1581	1.0427

In the simplified model, the rain intensity in the rain medium is considered not to vary along the path, i.e., the rain intensity is homogeneous along the vertical path up to a height HR. This height is assumed to be the level from which rain drops with a diameter larger than 0.1 mm fall, and may be described as the physical rain height. The rain attenuation in the zenith direction (z) is then given by:
It may be noted that the physical rain height is not easily measureable and the simplest approximation being identified with the zero degree isotherm height.
The zero degree isotherm height, i.e., the rain height during rainy condition for latitudes less than 36 degree is given by the relation (Fedi 1981):

$$H_R = 3.0 + 0.028\Phi \text{ km} \qquad (6)$$

$$A(z) = (H_R - H_S)\,\alpha R^b \text{ dB} \qquad (5)$$

where, Φ is the latitude in degrees. For tropical latitudes, i.e., for Φ <36 degree, it has been proposed that a path reduction factor deduced in this regard using ITU-R model (ITU-R, p.618-8, 1995) to be incorporated while calculating HR. the path reduction factor was evaluated for 0.01 percent of time in a year. The restricted rain rate for the present study is within 20-25mm/hr.

Referring to equation (4), for a zenith-pointing radiometer (θ=90 deg.), the equation to use is:

$$\mathbf{LS= H_R - H_s} \qquad \mathbf{(7)}$$

The measured brightness temperature Ta, during rain, have been converted to total attenuation (dB) using the relation (Allnutt, 1976)

$$A=10\log10 ((Tm-Tc)/(Tm-Ta)). \qquad (8)$$

where, Tm is the mean atmospheric temperature. For tropical latitudes the values of Tm will be higher than those in temperate latitudes, due to the higher temperatures and larger water vapour content (Sen et al., 1990) and is defined as (Wu,1979) [13].

For tropical latitudes the values of Tm will be:

$$T_m = \frac{\int T(z)\alpha(z)\exp \alpha(z)\, dz}{\int \alpha(z) \exp - \int \alpha(z)\, dz\, dz} \qquad (9)$$

temperature and the corresponding vertical profile of attenuation coefficients. The value of TC was considered as 2.75K (Ulaby 1986). The attenuation coefficients are calculated by using the Millimeter Wave Propagation model (Marshall Palmer Model) by Liebe (1985) [14] where the input parameters were temperature, pressure, humidity of the ambient atmosphere.

To get the relation between the surface temperature Ts, an attempt has been made to correlate with a linear relation and subsequently it was found that Tm=M+NTs (Mitra et al. 2000) [15], where M and N are the regression coefficients derivable for different frequencies. Tm is the mean atmospheric temperature dependent on frequency and is related to surface (ground) temperature. The values of M and N for 22, 23 and 30 GHz were calculated as M=270.05, 270.03 and 270.00 K, respectively; N=0.778, 0.791 and 0.816 K/0C. The values of Tm would be different for different frequencies.

Hence, by observing the ground temperature and using the appropriate values of M and N, the mean atmospheric temperature Tm were found out. Now with the knowledge of Tm and TC and by using equation 8, the attenuation values were found out where Ta is the measured brightness temperature at each frequency.

Brightness Temperature

Using the microwave brightness temperature, a new scheme has been developed to classify convective and stratiform (C/S) precipitation areas over oceans by Hong et al. (1999) [16]. Brightness temperature is considered to verify the influence of water vapour on the signal. The maximum brightness temperature Ta observed by the radiometer was around 291 K for the water vapor frequency band (20 – 30 GHz). There were several events in which the sky noise temperatures exceeded 290 K. The brightness temperature sharply increases up to rain rate 10-12 mm/hr. above this rain rate, brightness temperature increases and has a tendency of saturation at all frequencies.

Attenuation

From the observed values of brightness temperature at three frequencies in the water vapor band, the vertical path attenuation (i.e. total attenuation) was calculated using Equation (8). The time variation of measured and calculated path attenuations (see Equations 5 and 6) and rainfall rate for a particular event at Raichur on January 20, 2009 have been computed. It is to be mentioned here that disdrometer and radiometer were co-located at the location(s) of stations under study.

A slight departure is observed in variation pattern of attenuation at 22GHz during 21:35:00 to 23:43:25 hrs (local time), when rain rate is very low. Below 5 mm/hr, the measured attenuation is found to be higher than the calculated attenuation. This might be due to the fact that the heated earth surface evaporates water vapor and subsequently is filling up the antenna beam by a more amount of vapor when rain drop falls on the surface. This becomes prominent only at 22 GHz since the frequency of the radiometer lies just at the water vapor resonance line. This shows the larger sensitivity of water vapor at 22 GHz frequency is pressure broadened and hence not suitable for accurate estimation of water vapor. This kind of anomaly is not recognized at 23GHz which is found to be pressure independent.

So it appears that rain attenuation measurements at 22 GHz are contaminated by the unwanted presence of water vapor. This effect is minimized at the window frequency region (around 30 GHz) where attenuation due to water vapor is very less.

The peak rain rates and the calculated attenuations at all the frequencies are much higher than those of the measured attenuations. It is very prominent at 30 GHz as this is the highest frequency in our study. An attempt has been made to work out regression analyses to a power law. This yielded the following best-fit relations, at the said frequencies.

The equation **A (dB) = HR a(R-Rc) b**

Best-fit relations:

A 22(dB) =3.63× 0.367 (R+1.944) 0.536 (r^2=0.797)

A 23(dB) =3.63× 0.332 (R+1.373) 0.587 (r^2=0.797)

A 30(dB) =3.63× 0.353 (R+0.394) 0.675 (r^2=0.797)

The experimental results were compared with those obtained theoretically for different frequencies, using the values of „a" and „b" listed in table1. It was found that the calculated rain attenuations deviated significantly from the measured values, at higher rain rates. For this reason best fit curves have been drawn up to 20 mm/hr rain rates and corresponding 'a' and 'b' co-efficient matched very well up to this rain rate.

It is to be noted here that attenuation at all frequencies maintained a minimum threshold level. At 30 GHz it is nearly 0.685 dB and at 22 GHz it is around 1.906 dB, even when rain rate is zero. This is because of the fact that the frequencies around 22 GHz are water vapor sensitive; but 30 GHz is not that much sensitive to water vapor. So it is suggested that for higher frequencies from 22 up to 30 GHz, the water vapor sensitivity becomes lesser. From the Regression analyses of attenuation taking 22GHz as reference frequency, we get:

A 23 (dB) =1.133 (A 22.234 - 0.6204) 1.003 (r2=0.999)

A 30 (dB) =1.823 (A 22.234 - 1.5280) 0.982 (r2=0.997)

Using these equations, one can have the idea of getting an approximate value of rain attenuation at the said two frequencies by measuring rain attenuation.

IV. Conclusions

The studies presented here give an idea of rain attenuation measurement by radiometer applicable to tropical climate. From the measured result it has found that extra attenuation caused by evaporation of water vapor from heated earth surface at the time of the start of rain, particularly at low rain rates below about 5mm hr-1, misleading the measured attenuation which is an extra error in the measurement. The several experimental results over the different parts of the world including temperate and tropical regions reveal that the 0°C isotherm varies with several factors.

A case study of a link between Belgaum-Rc Nagar has been taken up to assess the specific attenuation. Simultaneously, for all the rainy months, the specific attenuation tables were worked out and tabulated. On observing the level of rain rate cumulative distribution graph, this can be ascertained. The rain rate was 50 mm/hr on an average as computed. But still, the station recorded attenuation because of the water vapour content in the atmosphere that hindered the reception of the signal by the antenna. As otherwise, the link performs well on other normal days of working when there is rain or no rain. It is because of the heat absorbed water vapour that dominates the receiving signal of the antenna in question.

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