Rain Rate-Radar Reflectivity Relationship for Drop Size Distribution and Rain Attenuation Calculation of Ku Band Signals

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Abstract—With the increased demand for long distance Tele communication day by day, satellite communication system was developed. Satellite communications utilize L, C, Ku and Ka bands of frequency to fulfil all the requirements. Utilization of higher frequencies causes severe attenuation due to rain. Rain attenuation is noticeable for frequencies above 10ghz. Amount of attenuation depends on whether the operating wave length is comparable with rain drop diameter or not. In this paper the main focus is on drop size distribution using empirical methods, especially Marshall and Palmer distributions. Empirical methods deal with power law relation between the rain rate(mm/h) and radar reflectivity(dBz). Finally it is discussed about the rain rate variation, radar reflectivity, drop size distribution, that is made for two rain events at K L University, Vijayawada on 4th September 2013 and on 18 th August 2013.

Keywords-Rain rate, Radar Reflectivity, Drop size distribution

I. INTRODUCTION

Now a days it is necessary to fulfil all the requirements like long distance communication, small antenna size, wider spectrum availability, and high data transmission above 10GHZ frequency band. Usage of high frequency has an advantage of providing proper platform for the development of telecommunication system[9]. Electromagnetic wave is usually effected due to rain in three ways via, the signal attenuation, increase in the system noise temperature and changes in the polarization. Received signal strength quality was degraded due to all the above three effects. Major effect due to rain is that it attenuates the signal either by absorption or by scattering of electromagnetic wave by the liquid water drops. In the process of absorption Electromagnetic wave is in resonance with water Molecules, due to this the molecular energy of the water increases, which results in equivalent signal strength degradation of the electromagnetic wave. Attenuation is negligible due to snow or ice crystals, in which molecules are tightly bounded and do not interact with the waves. Attenuation increases as the wavelength approaches the size of the a typical rain drop[11]. Rain drop appear as an obstacle to an electromagnetic wave and the wave reflects from the obstacle which was measured by using OTT Parsivel Disdrometer as Radar reflectivity. Radar reflectivity is converted in to the rain rate using existing empirical relations[10].

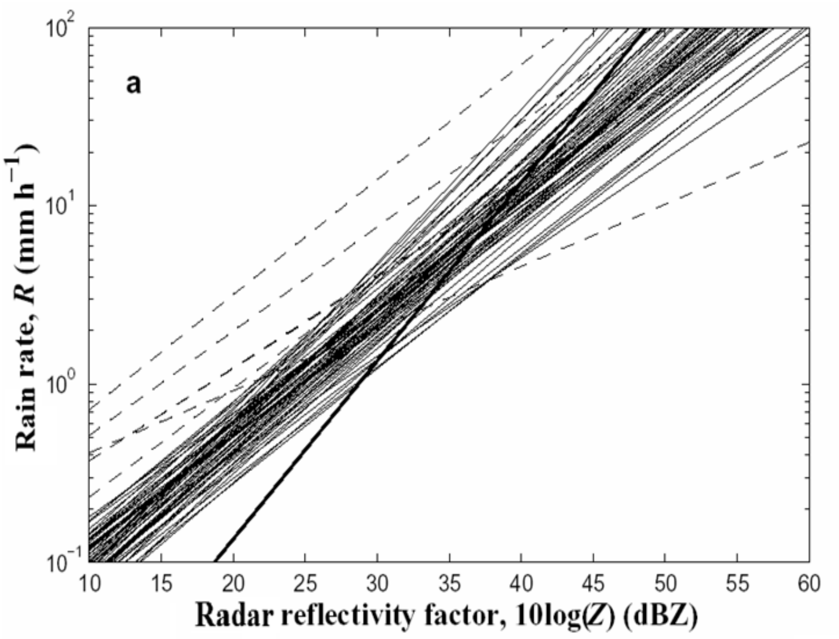

Fig. 1. 69 Power law Z-R relation ships[4]including five deviating relationships as indicated by dashed lines, four of which have prefactor a significantly smaller than 100 and one of which has an exponent b as high as 2.87.the bold line in the figure represents the linear relation ship as proposed by the list [3] .

Radar reflectivity Z is related to the size of drop and drop size distribution as(according to Battens,1973)

$$Z=\int_0^\infty D^6 N_v(D)dD \quad (1)$$

where Z is the Radar reflectivity in dB ,D Drop size in mm and $N_v(D)dD$ represent the mean number of rain drops with equivalent spherical diameters between D and D+dD (mm) present per unit volume of air. V Represents the volume.

Rain rate R is related to the drop size and drop size distribution as

$$R=6\pi\times10^{-4}\int_0^\infty D^3 V(D)N_v(D)dD \quad (2)$$

where v(D) represents the terminal fall velocity in still air(m/s).R is the Rain rate(mm/h).Comparing the equations (1) and (2), it is interesting to note that Z and R are coupled by drop size distribution, consequently the power law relation of Z and R becomes fascinating for drop size distribution calculations [10].

II. EMPIRICAL RAIN RATE AND RADAR REFLECTIVITY RELATIONSHIPS

In order to measure the Rain drop size distribution, there exist a empirical evidence[4] that follow power laws of the form

$$Z= aR^b \quad (3)$$

where a & b are empherical coefficients that may vary from one season to other, one location to other location and also different for different rain types.

Equation(3) gives the power law relation between Z&R, by taking arithmetic and geometric mean of the coefficients, a and b respectively.

$$Z=238R^{1.50} \quad (4)$$

Equation(4) was proposed by battens in 1973 and Marshall Palmer proposed another power law relation between Z & R that is most suitable for most of the rain fall types and for most of the areas in the world.

$$Z=200R^{1.6} \quad (5)$$

Marshall palmer is the best suitable method for the tropical regions like India. In this paper mainly it is discussed about the Radar reflectivity variation and estimation of rain rate from Radar reflectivity using the empirical relations and also the drop size distribution along with size and velocity estimation [3].World wide,69 power law relations are proposed depending on environmental conditions, out of which it is possible to use four for 'orographic' rain fall, five for 'thunder storm' rain fall, ten for 'widespread' or 'stratiform' and six for showers. The remaining 44 empirical relations are unambiguously not associated with any type of rain fall. In this paper Marshall and palmer relation is used which is suitable for rain type in our region[10]. To carry out the work, OTT Persivel Optical Disdrometer was placed at KLUniversity, Guntur, Andhra predesh, India. With the help of ASDO soft ware package and an interfacing device(MOXA TC100) between RS232 and RS 485(2wire terminal in active) rain data was logged on the computer.

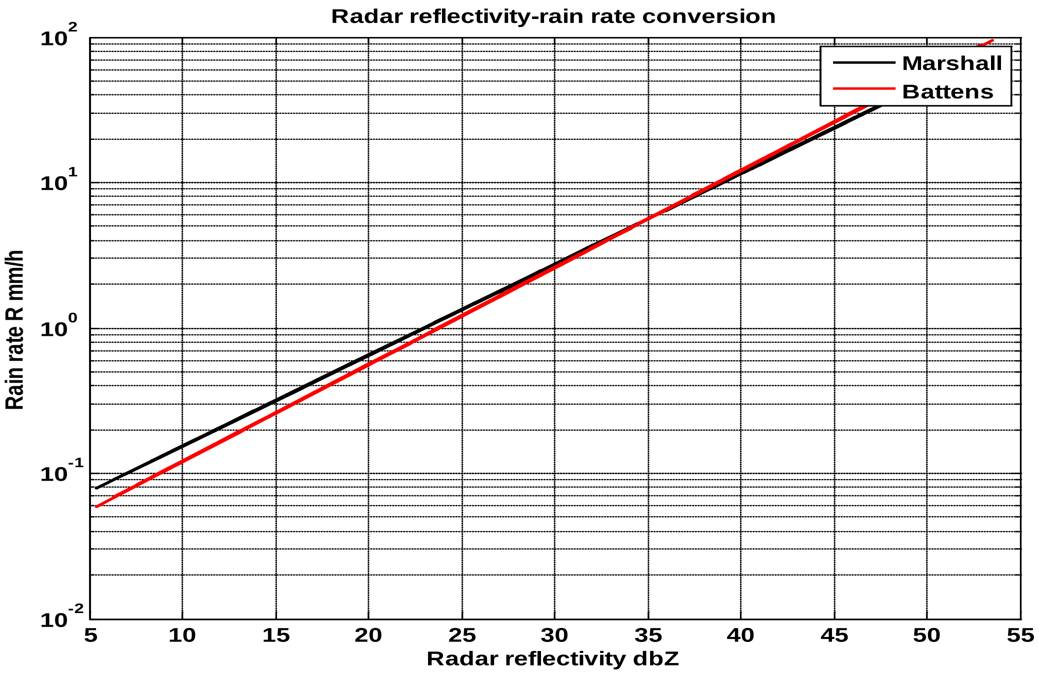

Fig. 2. The solid linein black represents the Marshall et al and solid line in red represents the mean Battens relation for the experimental data recorded at KLUniversity.

III. RAIN RATE CALCULATION FROM RADAR REFLECTIVITY

Rain rate is calculated by neglecting wind effects, interaction between drops and by using empirical power law relation between Rain Rate(R) and Reflectivity factor (Z).Radar Reflectivity is taken from the data recorded in the OTT Percival Disdrometer, that is placed at K L University. With the help of equation (4) and (5) the Rain Rate(R) can be measured. Clear air condition radar reflectivity is negative rain intensity is zero and no variation in received spectrum amplitude. Attenuation due to rain for any EMwave depends on rain intensity and also on frequency of EM wave.

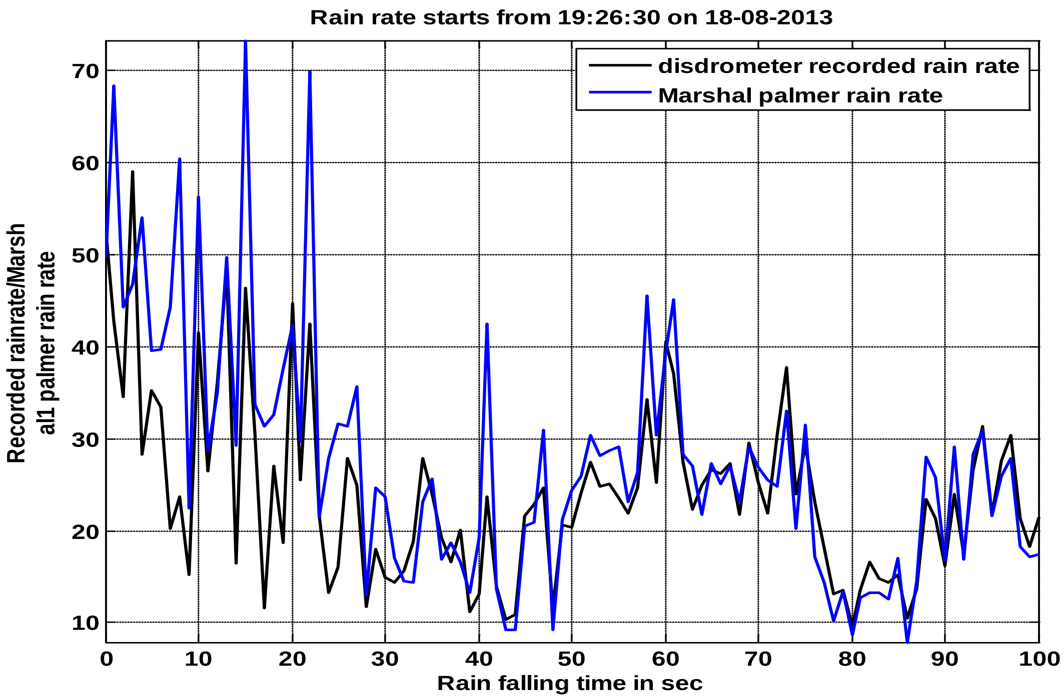

Fig. 3. Solid line in black represents the measured rain rate on 18-09-2013 starts at 19:26:30,solid line in blue represents the rain rate calculated from measured Radar reflectivity using Marshall et al, power law relation

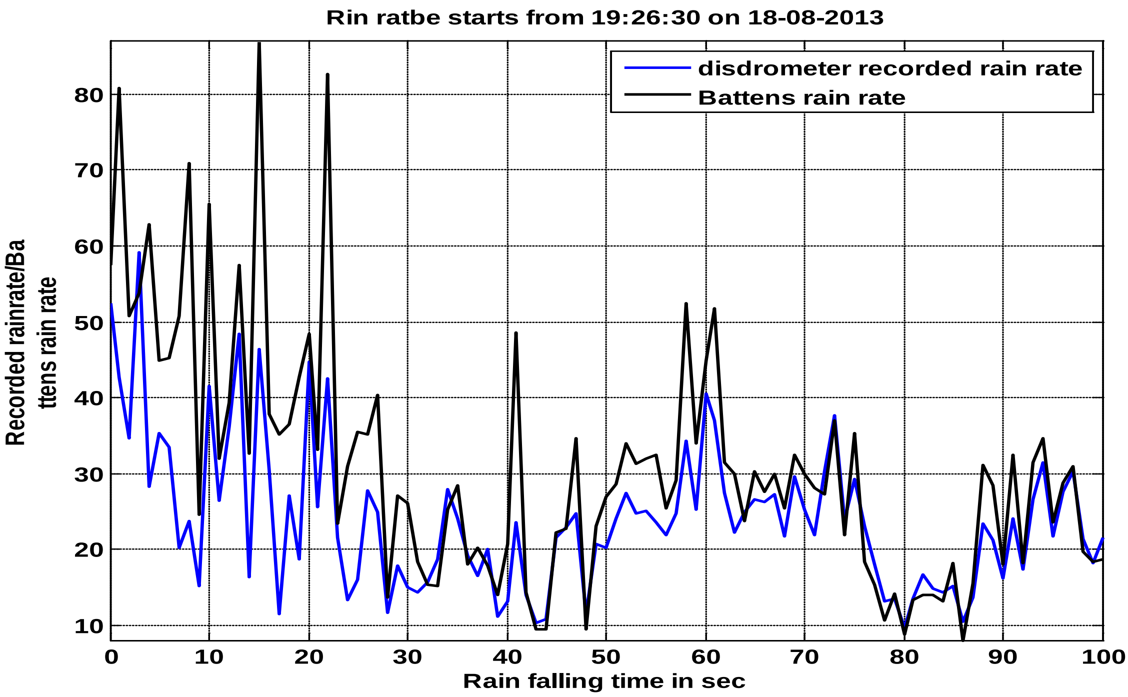

Fig. 4. Solid line in blue represents the measured rain rate on 18-09-2013 starts at 19:26:30,solid line black represents the rain rate calculated from measured Radar reflectivity using battens , power law relation.

The Rain rate is calculated from radar reflectivity using Marshall Palmer relation and Battens relation. Marshall Palmer result is very close to the measured rain rate than Rain rate obtained from Battens relation, particularly at the point of sudden variations in rain intensity.

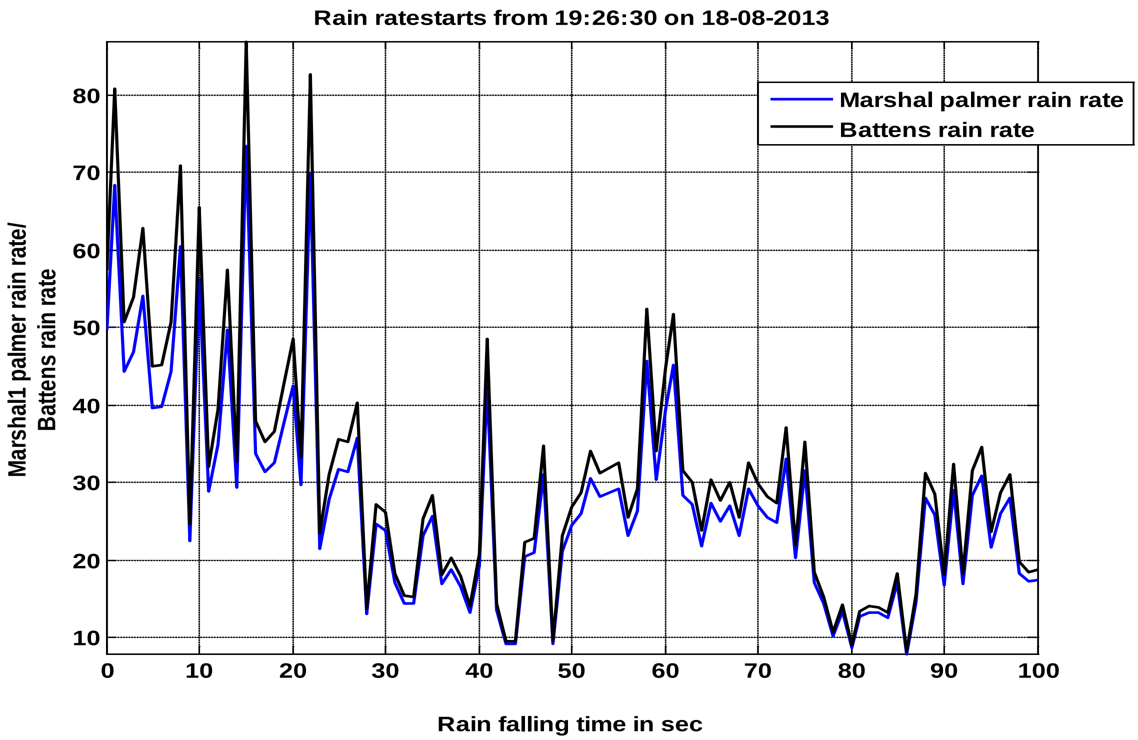

Fig. 5. Solid line in blue represents the simulated rain rate using Marshall et al on 18-09-2013 starts at 19:26:30,solid line in black represents the simulated rain rate from measured Radar reflectivity using Battens, power law relation.

Rain rates calculated using Marshall and palmer, Battens are shown in fig.5, where both gives the same rain rate for constant increment and constant decrement and are slightly differed by small value at sudden transition points.

IV.RAIN DROP SIZE DISTRIBUTION

Form equations (1) and (2) both Z and R are related to rain drop side distribution $N_v(D)$.Different procedures have been proposed by different methods, like ***gamma***(Ulbirch,1983), and ***lognormal***(Feingold and Levin, 1986).In this paper mainly used method is ***exponential drop size distribution***[2],[3].

Negative Exponential Drop size distribution

$$N_v(D) = N_0(-\Lambda D) \quad (6)$$

where $\Lambda(mm^{-1})$ is drop size distribution slope factor which is the inverse of rain drop mean diameter present in a volume of air[14],[15], $N_0(mm^{-1}m^{-3})$ is drop size distribution for D=0, Marshall and palmer found that N_0 was approximately constant for any rain rate[3].

$$N_0=8.0\times10^3 \quad (7)$$

slope factor Λ decreases with the increase of Rain rate R and is given by

$$\Lambda = 4.1R^{-0.21} \quad (8)$$

Necessary data that is recorded from September2012 to Nov2013, using a OTT Percival Disdrometer , is used in this study. The Percival Disdrometer is capable of measuring drop velocity and drop diameters ranging from 0.3mm to 10mm,velocity ranging from $0.1\text{-}20ms^{-1}$. It distinguishes rain drops with a time interval of about 1 ms. The rain drops of diameters ranging from 0.3mm to 10mm are divided into 32 different bins, similarly drops with terminal velocity $0.1\text{-}20ms^{-1}$ are also divided in to 32 different bins with 1 minute integration time .

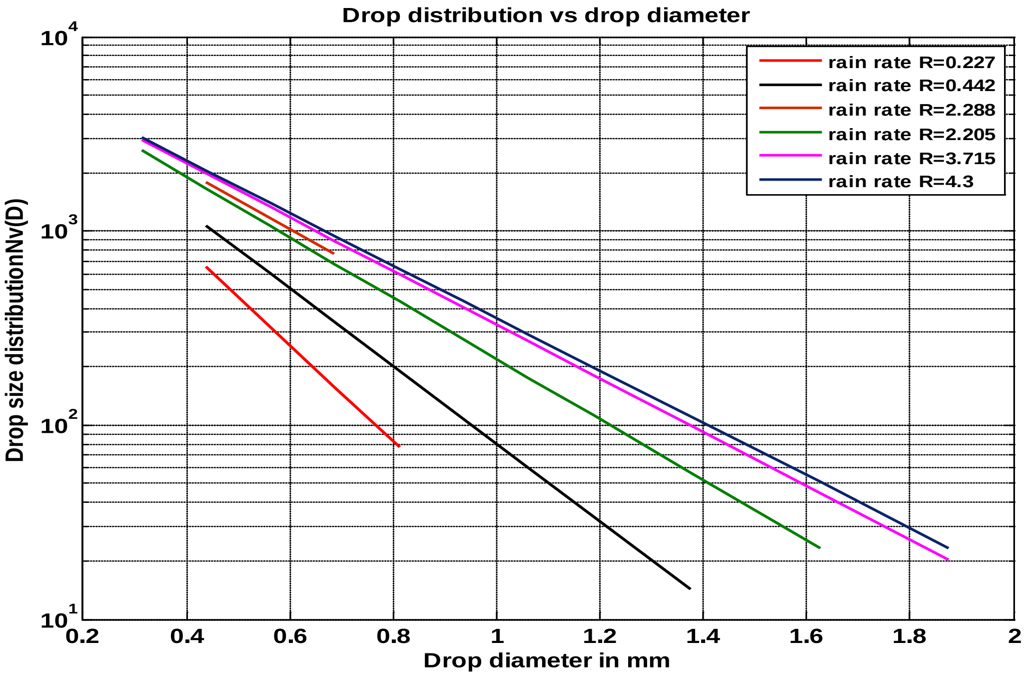

Fig. 6. Experimental rain drop size distribution present in a volume of air for different rain rates .

V. RADAR REFLECTIVITY CALCULATION FROM RAIN RATE BY USING EMPIRICAL POWER LAW RELATION

Empirical power law relations always gives the exponential variation between Radar Reflectivity Z and Rain rate R, from which reverse calculation of Radar reflectivity from rain rate variation can also be done. In this paper Z was calculated using Marshall Palmer relation and compared with Measured Radar reflectivity recorded by using Disdrometer.

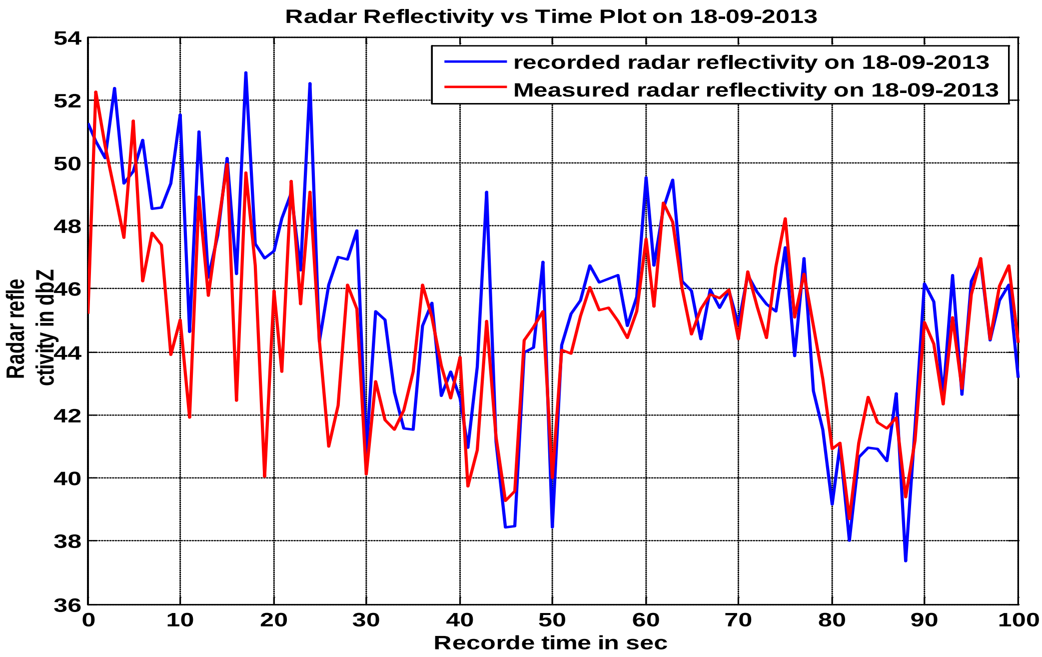

Fig. 7. Radar Reflectivity variation with respect to time .solid line in blue Recorded radar reflectivity(dBZ), solid line in red Calculated Radar Reflectivity (dBZ) for small interval.

The above figure shows the variation of reflectivity parameter with time over a short interval of time like more than one minute and here is the reflectivity variation shown below for the complete rain event. Because of exponential variation between rain rate and reflectivity parameter there will be a slight deviation between the two values only at peaks.

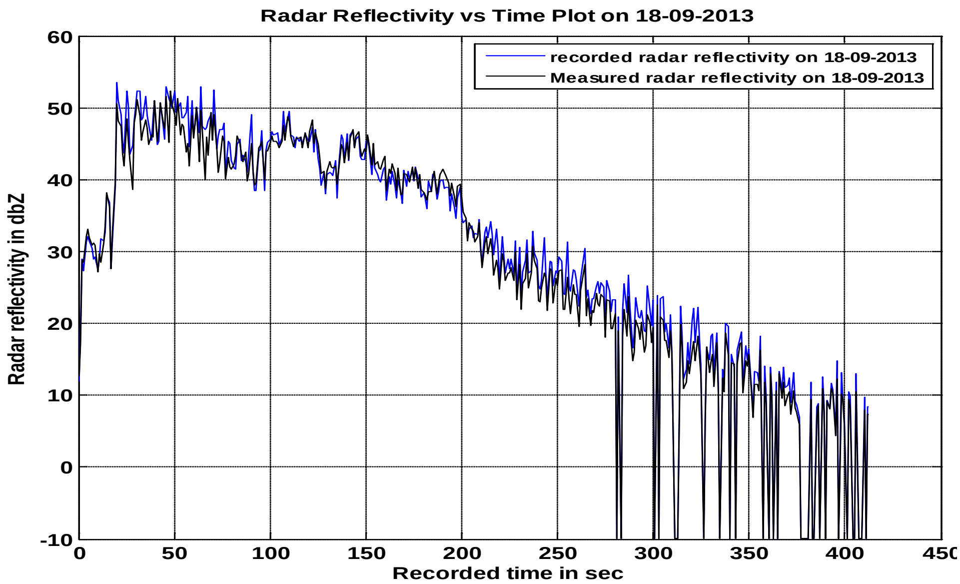

Fig. 8. Radar Reflectivity variation with respect to time .solid line in blue Recorded radar reflectivity(dBZ), solid line in black Calculated Radar Reflectivity (dBZ) for complete rain event.

VI. RAIN RATE CALCULATION FROM RADAR REFLECTIVITY FOR OTHER RAIN EVENTS

Rain rate calculation for rain event on 4th September 2013 at KLUniversity campus are shown below.The data is taken from OTT Percival Disdrometer and calculated by using empirical Radar reflectivity and Rain rate relations[2],[4].

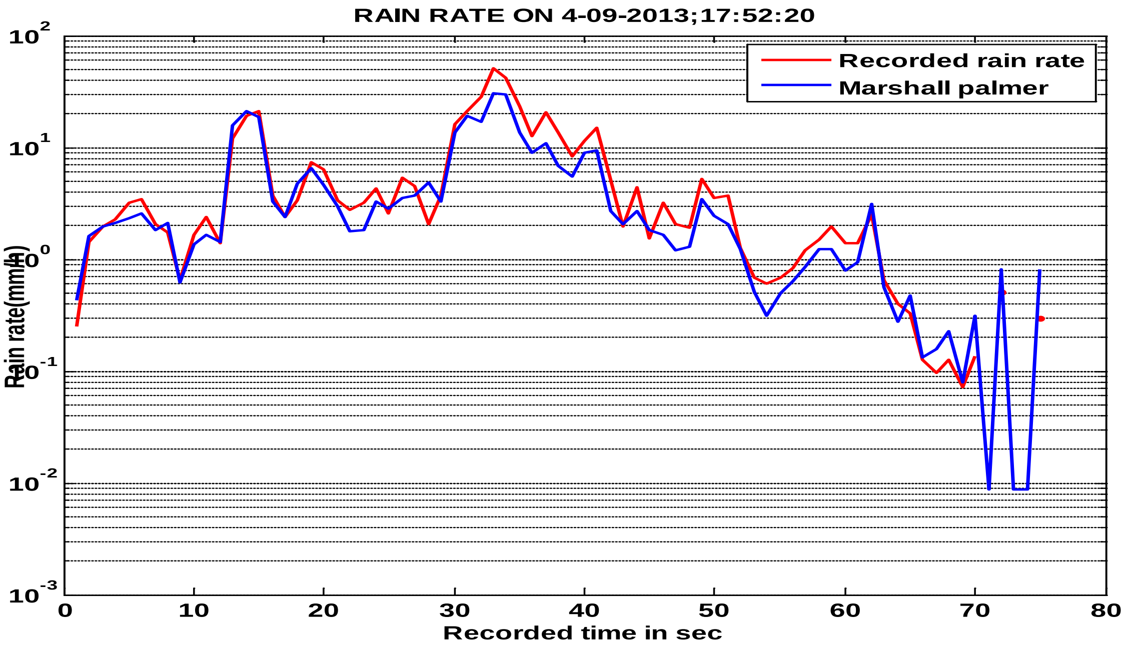

Fig. 9.Solid line in red represents the measured rain rate on 4-09-2013 starts at 17:52:20, solid line in red represents the rain rate calculated from measured Radar reflectivity using Marshall et al, power law relation

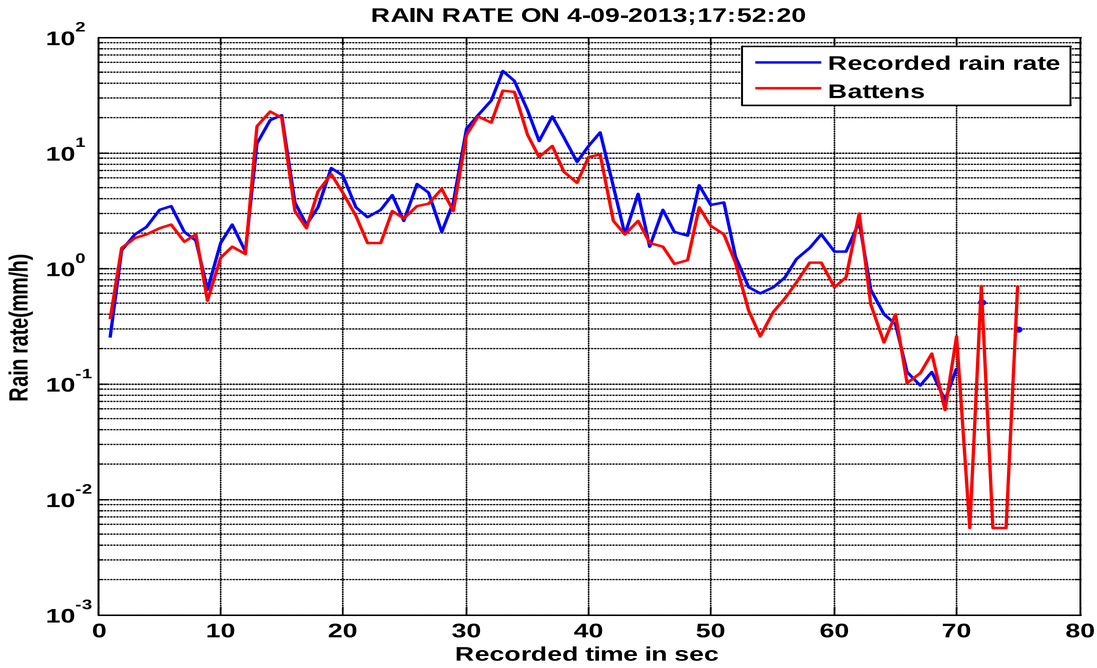

Fig. 10. Solid line in blue represents the measured rain rate on 4-09-2013 starts at 17:52:20 solid line in red represents the rain rate calculated from measured Radar reflectivity using battens , power law relation

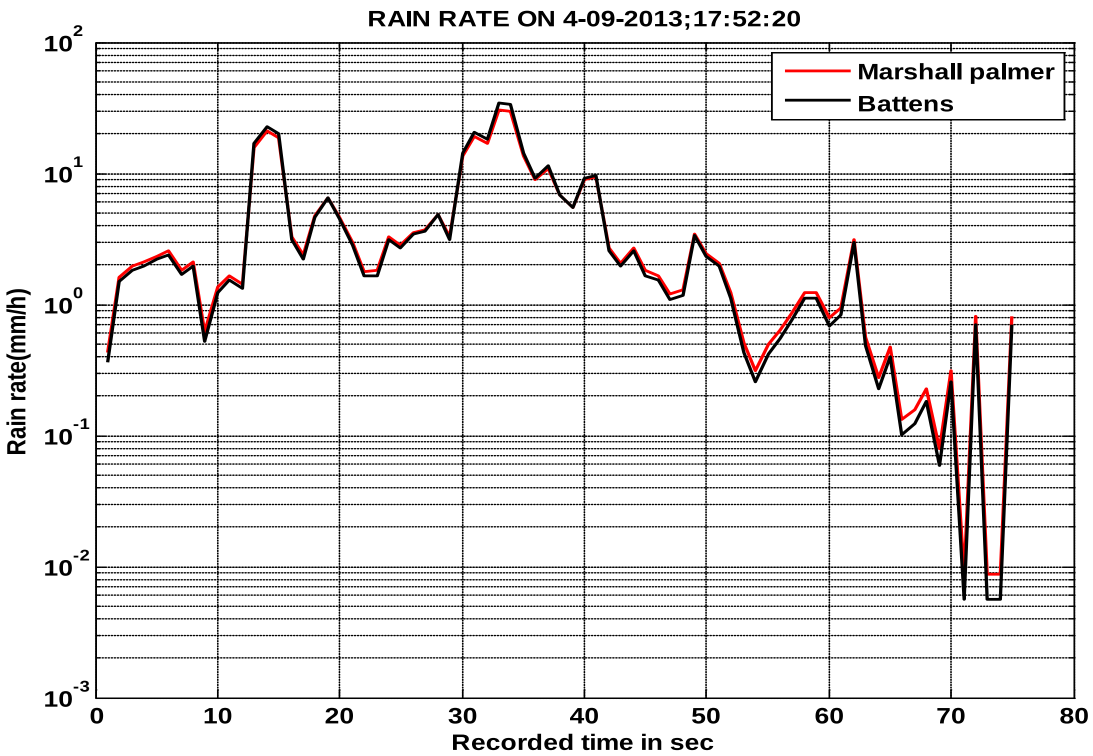

Fig. 11. Solid line in red represents the simulated rain rate using Marshall et al on 4-09-2013 starts at 17:52:20,solid line in black represents the simulated rain rate from measured Radar reflectivity using Battens, power law relation.

VII. RECEIVED KU BAND SPECTRUM VARIATION DUE TO RAIN INTENSITY

To receive the Ku band downlink satellite frequency, an antenna was placed on roof top of the building at KL University with **16.52°** North Latitude and **80.62°** East Longitude and is directed towards INSAT 4B and INSAT 4C having the beacon Frequency 11.699Ghz on the geostationary orbit. Entire work depends on the received IF satellite spectrum in the range of 950-2050Mhz, which is observed using spectrum analyzer. Received spectrum samples are stored with sampling interval of 10s.Amount of attenuation due to rain can be estimated based on spectrum amplitude degradation from clear air condition. As shown below in fig 11. The Reference points 'A' and 'B' are Marked at one time instant. Point A gives the rain rate and point B gives the corresponding signal strength degradation. Similarly at the other pair of point 'C' and 'D', the point D gives the low intensity point and point C gives the raised spectrum amplitude at the same instant.

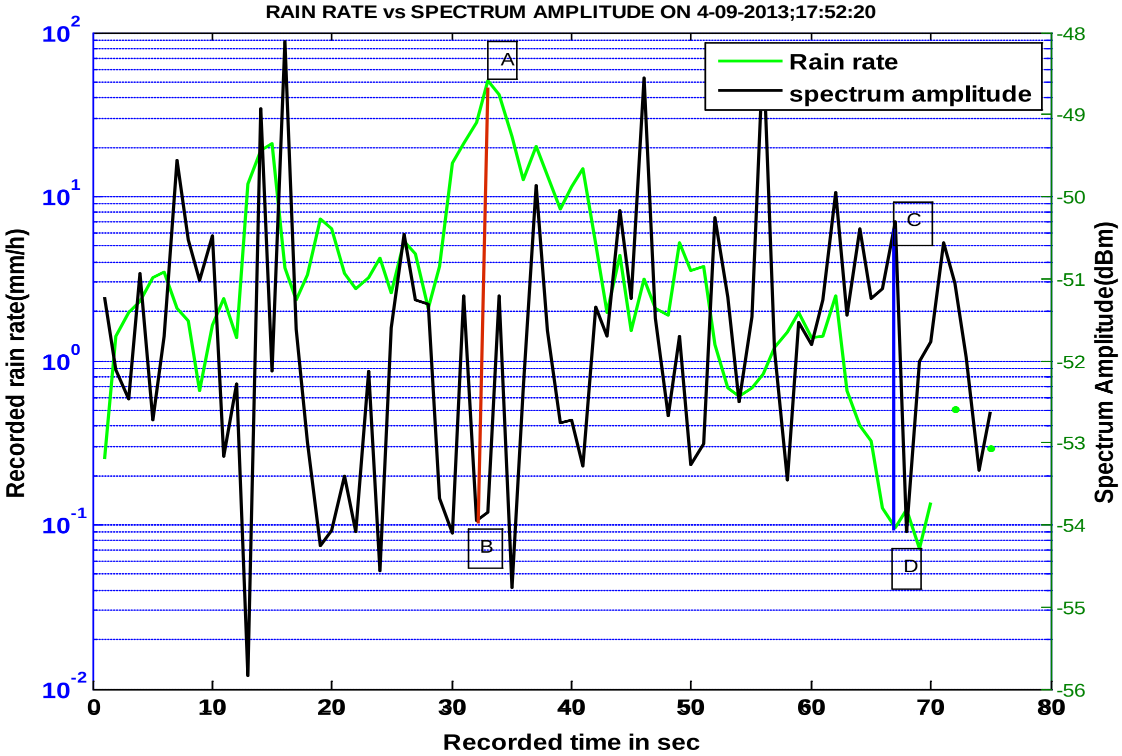

Fig. 12. Solid line in black Spectrum Amplitude variation with time and solid line in green represents the rain rate with time

VIII. CONCLUSION

Rain rate was estimated by using Marshal Palmer and Battens Relations. Measured rain rate coincides with the recorded data except at sudden change in recorded rain. Increased rain rate diminishes the signal quality than clear air condition that was also discussed by using Ku Band satellite Received signal, and also Drop size Distribution was discussed.

FUTURE WORK

The work can be extended to multiple site locations, and also all ionosphere factors which are effecting the propagating wave, predication of attenuation and preparation of contours, can be taken in to account.

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