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Tropospheric radio wave propagation related to precipitation in North East region of India

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Abstract

Some studies on propagation of radio wave in relation to its attenuation due to different forms of hydrometeors over Indian North Eastern region have been reviewed and reported in this presentation. The potential aspects of present days modern radars and future scope of work related to atmospheric science and communication also have been highlighted.

Keywords: 1;water vapour 2;Attenuation 3;atmospheric noise 4;radars 5;communication

1. Introduction

Prediction on performance of radio systems at VHF, UHF and microwave frequency bands is a difficult exercise because such propagations are effected by precipitation , rain drop sizes and orgraphic situation , to name a few . In spite of intense research to overcome these problems, it has not been possible to develop a generally acceptable model system. Researchers on this field have formulated modules based on their experiments, but such modules require rigorous validation process before attaining a reliable status [Sarkar, 2007]. In this presentation an attempt has been made to present the work on tropospheric radio wave propagation mainly related to attenuation of radio signal due to rain, cloud and water vapor over the north eastern region of India. The capabilities of the modern day radars for estimation of various parameters of different form of hydrometeors [Sarkar, 2006] as well as scopes of future work on atmospheric science are also highlighted here.

It is well known that radio wave above 10 GHz is affected by precipitation in terms of attenuation due to its high dielectric constant. The parameters, which affect the microwave communication and radar propagation are mainly rain rate, horizontal extension of rain, rain height, rain drop size distribution, cloud characteristics and cumulus cloud cells as well as water vapour concentration. All these varibilites are taken as input parameters for estimating performance of microwave communication systems as well as for radar propagation and remote sensing application. Techniques such as rapid response rain gauge, conventional rain gauge, several forms of radar, lidar, radiosonde etc., are used to deduce such parameters. In addition to precipitation measurements, it is necessary to monitor communication links operating in Ku and K bands both over terrestrial and earth space paths to investigate the effects of hydrometeors on the performance of communication systems and radar propagation.

2. Effects of precipitation on communication in NE region

As far as the North Eastern part of India is concerned, the role of rain and cloud on communication is observed to be very significant. This is more so when there is a shift in the focus of research work both for horizontal and satellite communications from C band to higher bands in recent years. The use of higher frequency bands for communication systems has also become a necessity as there is huge congestion in lower bands over all locations in India. Some results related to rain and cloud have been generated and deduced over different Indian tropical stations located in NE states. It is also observed that though the effect of rain on radio wave is more prominent than by cloud, the occurrence of cloud is more prevalent than the rains [Rajesh Kumar and Sarkar,2001; Sarkar ad Rajesh Kumar,2002; Sarkar et al.,2005; Devi 2013,2014], over the Assam Valley.

Rain rate distributions at different percentage levels from 0.001% to 0.1% of time including non rainy period have been estimated at different places of Assam. In Gauhati , rain fall rate is found to vary from 2.5 mm/hr to 180 mm/hr. The year to year variability of rain rate is within ± 10%, ± 15% and ± 20% at 0.001%, 0.01% and 0.1% respectively over the values of all years (five year period). Rain height, Hi, in relation to 0^{o}C isotherm was determined on the basis of radiosonde observations. Over Guwahati, Hi is found to vary from 2.5 km to 5.5 km during all months, from 3.0 km to 5.5 km during summer and from 4.5 km to 5.6 km during monsoon. The average Hi during winter is minimum as compared to that during monsoon. The results on one way total attenuation for earth space path were deduced by using the measured rain rate and by taking the actual rain heights at 10 GHz, 20 GHz, 30 GHz, 50 GHz, 70 GHz, 90 GHz and 100 GHz. It is found that attenuation varies at 10 GHz from 1.40 dB to 5.90 dB at 0.1% probability level while at 50 GHz, the attenuation range is between 75.00 dB and 100.00 dB at 0.01% probability level while at 0.001% probability level, the attenuation may go as high as 117.00 dB to 160.00dB.

3. Cloud occurrences morphology

The cloud data is available with the India Meteorological Department, Pune for different locations in Assam such as Guwahati, Dhubri, Dibrugarh, Gopalpur and Silchar.All the stations have different topographical (terrain) features and meteorological situations. The cloud observations in India are taken four times during day and four times during night. The observations are taken during 0830 hrs IST, 1130 hrs IST, 1430 hrs IST and 1730 hrs IST in the day and also at 2030 hrs IST, 2330 hrs IST, 0230 hrs IST and 0530 hrs IST in the night. Some typical diagrams on cloud coverage in Oktas observed during early morning and late evening in different month over Dhubri (Figure 1), Silchar (Figure 2) and Guwahati (Figure 3) located in Assam are provided. The cloud cover percentage in all these stations is found to be significal during June, July, August and September both during day time and night time.

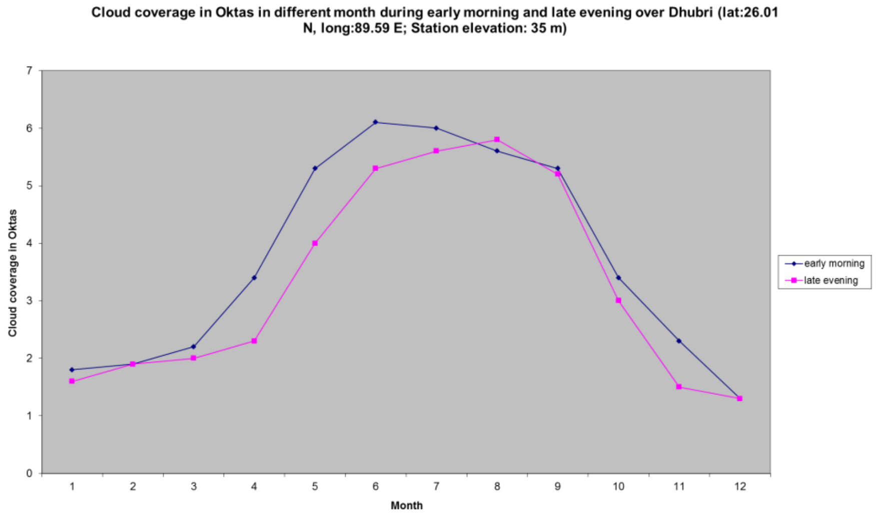

Figure1. Cloud coverage in Oktas during day time and night time over Silchar

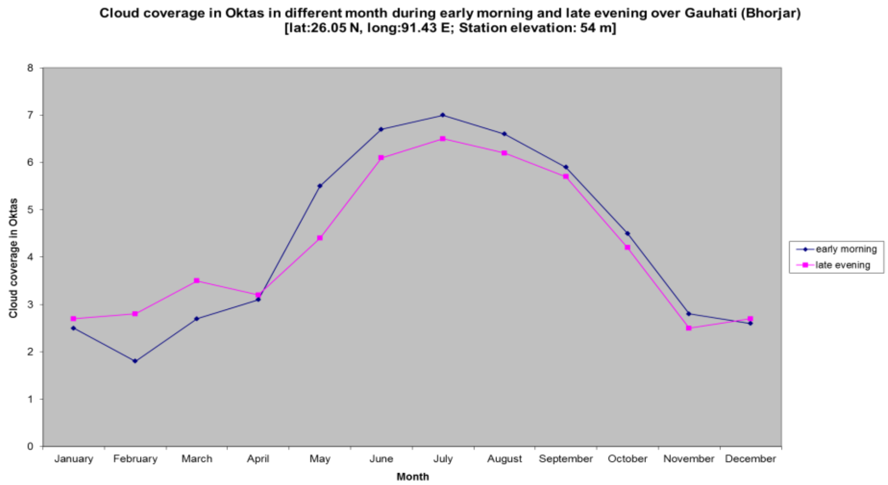

Figure 2. Cloud coverage in Oktas during day time and night time over Guwahati

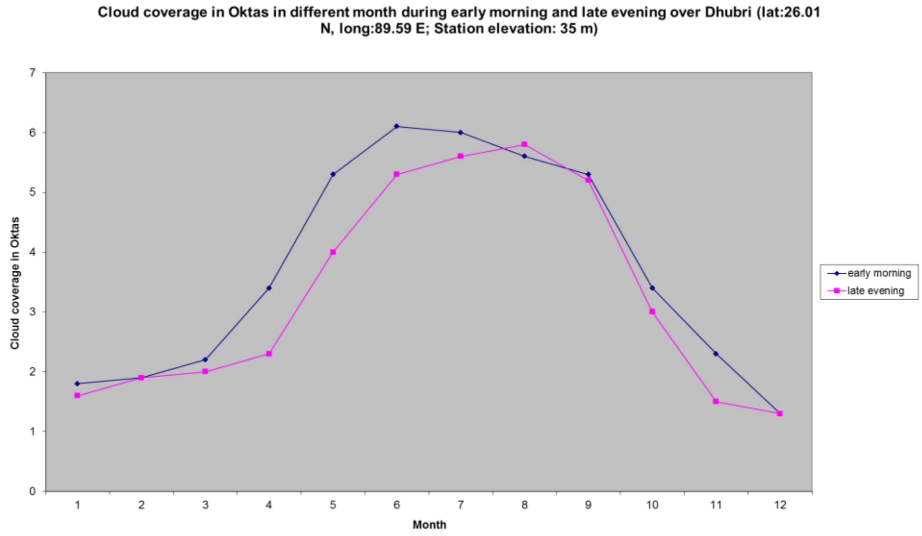

Figure 3. Cloud coverage in Oktas during day time and night time over Dhubri

4. Attenuation of radio wave due to cloud

On the basis of cloud temperature, cloud water particle density and wavelength of the radio wave, the specific attenuation of radio wave at different wave length is deduced.The rain bearing cloud height in relation to 0^{o}C isotherm height obtained from the upper air data for the worst months is estimated [Mondal et al, 2001; 1997; 2003; Sarkar et al, 1996; Sarkar and Mondal,1998, 1999, 2005, Sarkar et al, 2006].

It is observed that during monsoon months (worst months) there is hardly much variation in 0^{o}C isotherm height over these stations. The 0^{o}C isotherm height is around 5.5 km. Once cloud height is obtained then cloud temperature is estimated by using the temperature lapse rate of 6.5^{o} C/km The temperature of cloud particles differs from the temperature of the surrounding air usually by only a few tenths of a degree. The specific attenuation of the radio wave for cloud liquid water content of around 1 gm/m^3 and cloud temperature 260^{o}K are estimated [Slobin, 1982] for different frequencies. Specific attenuation at 10 GHz, 18 GHz, 32 GHz, 44 GHz and 70 GHz are 0.15 dB/km, 0.50 dB/km, 1.60 dB/km, 2.96 dB/km and 6.95 dB/km respectively.

The total attenuation of radio wave at 10 GHz,18 GHz, 32 GHz, 44 GHz and 70 GHz for cloud with thickness of 1 km are 0.15 dB,0.49 dB,1.46 dB,2.67 dB and 7.05 dB respectively ; and for cloud thickness of 1.5 km the attenuation values are 0.29 dB, 0.72 dB, 2.24 dB, 3.97 dB and 10.62 dB ; and with cloud thickness of 2 km, the attenuation values at the respective frequency goes to 0.72 dB, 0.94

dB, 2.90 dB, 5.86 dB and 13.10 dB. Such attenuation results are utilized to deduce noise temperature magnitudes generated by the cloud.

The attenuation amgiitudes of radio wave due to oxygen over Guwahati at 10 GHz, 18 GHz, 32 GHz, 44 GHz and 70 GHz are also estimated and the values are found to be 0.04 dB, 0.05 dB, 0.12 dB, 0.40 dB and 2.05 dB respectively.

5. Surface Water Vapour and its role on radio communication .

Atmospheric water vapour plays an important role in radio communication for both terrestrial and earth space communication systems as well as for global climate change studies and weather forecasting. Consequently the water vapour datasets usage and the method of data computation are the key factors in evaluation of atmospheric water vapour trends and usage. For the last few decades many studies in this aspect are conducted in India, however there are variations in computational results while comparing earlier work with very recent years. Such anomaly in result is maily due to limited observational approaches available in earlier years while in recent years, the technology and resources have improved tremendously.

The recent results deduced by using modern computational techniques on water vapour distribution over the surface for various Indian regions [Kongara et al, 2012]. In general Radiosonde observations are the primary source of upper air water vapour data and are being used for estimation of different atmospheric parameters. Radiosonde observations over around 40 Indian stations pertaining to a period of 15 years from 1996 to 2011 obtained from the British Atmospheric Data Centre are integrated and analyzed from the different met parameters of air temperature, dew point temperature and pressure levels for water vapour concentrations estimation over surface (different surface has different pressure with respect to sea surface). The integration of data sets has been carried out by using modern data warehousing techniques and applied better reporting analytics for precise results. The observational results of surface water vapour distribution patterns and trends are presented in the form of regional, annual and seasonal charts for better decision supporting systems. A typical diagram of distribution of surface water vapour distribution in gram per meter^3 over different Indian region including north east of India is also shown Figure 4.

The signal attenuation at different frequencies by the water vapour obtained over different locations are then estimated. It is seen that attenuation due to water vapour varies from 0.25 dB to 1.95 dB at frequency varying from 10 GHz to 70 GHz.

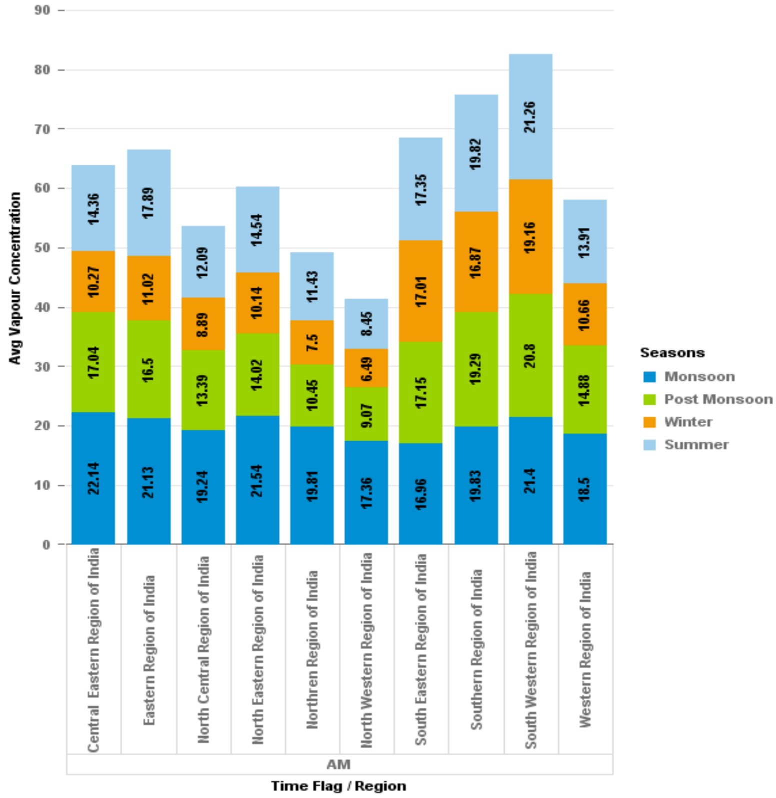

Figure 4. Surface water vapour concentration over Indian north eastern region in comparison with other regions in India [Sheshanna et al, 2012].

6. Total atmospheric noise temperature

The total atmospheric noise temperature due to clear air (contribution from oxygen and water vapour) including the noise temperature from cloud for different cloud thickness of 1 km, 1.5 km and 2.0 km also are deduced during worst months. The total atmospheric noise temperature has been found to vary from around 160 K to 460 K at different radio frequency over Guwahati.

7. Rain attenuation over a hilly terrain Shillong in the earth space path

The significance of rain attenation for both terrestrial and earth- satellite links above 10 GHz is already highlighted. In tropical climate in particular, the incidence of rainfall on radio links becomes important even for frequencies as low as around 7 GHz, since these regions are characterized by high convective rainfall and raindrops are large. Therefore, knowledge of rain attenuation over a particular location is very important in planning of a high reliable communication and radar systems [Ojo and Sarkar, 2009; Timothy et al, 1998, 1995; Dissanayake et al, 1997; Emiliani et al, 2004, 20010; Ippolito ,1981].

For an empirical methodology of rain attenuation prediction for a given location, an appropriate rainfall rate of 1-minute integration time is needed. However, daily rainfall accumulation is universally recorded while hourly data as well as those of different integration time are also available by national weather bureaus [Timothy and Sarkar, 1998]. Even where data are available in minute, they are usually in long-term integration (like 20, 15, 10 and 5 minutes). Since rainfall itself is a natural and time varying phenomenon, the cumulative rainfall rate distribution measured depends on the sampling time of the rain gauge. In India, effort has been made by some researchers and the Indian Meteorological Department (IMD) to obtain rain rate data; for example IMD has taken some measurements of rainfall data over a large number of stations using tipping bucket rain gauges. These rain gauges are in operation on twenty-four hours basis with integration time of 15 minutes and 5 minutes. However, these integration times are not suitable for radio communication purposes since these have an impact on the dynamics of rain attenuation, and these are also not in the best agreement with the ITU-R stipulations for the design of microwave radio links. Therefore there is a need to convert the available long-term integration data to one-minute rain rate data for radio communication applications [Ojo and S.K Sarkar,2008; Ojo et al., 2009, 2010]. The observations of 15 minutes rain rate data for 5-year taken over Indian tropical station , Shillong (25^o 34′ N, 91^o 53′ E) are converted to 1- minute integration time rain rate using EXCELL Rainfall Statistics Conversion model and hence forth referred to as EXCELL RSc, [Ojo and Sarkar,2009]. Finally, results on rain attenuation at frequencies between 10 GHz and 40 GHz are estimated for different rain rates over Shillong . There are however other models related to prediction of point rainfall-rate cumulative distribution [Capsoni et al, 2008; Chebil and Rahman, 1999; COST 255, 2002; Crane 1985]. But the EXCELL–RSc model is based on the knowledge of the rainfall statistics with longer integration time *T,* referred to as $P(R)$ T and is developed using a physical foundation based on the simulated movement of synthetic rain cells (obtained from the EXCELL model) over a virtual raingauge whose translation velocity depends on the type of precipitation (stratiform or convective) and on the local yearly mean wind speed.

The annual average accumulation of 2415 mm was recorded in Shillong. The average monthly rainfall depends on the effects of the monsoon system. The rainfall in usually falls during the southwest monsoon (June-September). The maximum deterioration of signal level is observed during the worst calendar months (monsoon moths). This information is needed by the link planner to compensate for the fade margin provided by the rainfall rate at a specific percentage of time [Ojo and Sarkar, 2009].

At higher time percentage of 0.1 %, the original 15 minute rainfall data in Shillong is 33 mm/h, while the converted 1-minute rain rate, the data are equivalent to about 48.5 mm/h. Also at lower time percentage of 0.01% and 0.001%, the original 15-minute rainfall data recorded are 80 and 140 mm/h respectively, while the converted 1-minute rain rate data are equivalent to about are117.7 and 205.9 mm/h, respectively. Also at lower time percentage of 0.001%, the original 15 minutes rainfall data recorded is 124.3 mm/h . Therefore, outage probabilities and fade margins would be inaccurately determined if the 15-minute integration rainfall data are used. It was also observed that the current ITU-R model grossly underestimates the predicted rain rate values over Shillong. For example, at 0.01% unavailability of time, it could be observed that the percentage of underestimation by the ITU-R model is about 20% for Shillong. This margin if is not considered then it will lead to underestimation of the the effect of rain on the links, thereby severely impacting end users [Ojo and Sarkar, 2009].

Results of the cumulative distributions of the predicted rain attenuation at different frequencies (Ku- and Ka-band frequencies) over Shillong using the 0^{o}C isotherm height as well as effective height were also deduced. For Shillong with an average annual rainfall of 2415 mm, the recorded attenuation at Ku-band 12/14 downlink/uplink frequency is about 16 dB and 23 dB respectively at 0.01% of time, while it is ~ 29 dB and as high as 39 dB at 0.001% of time.However, at 0.1% of time there is only difference of 4 dB within the Ku-band frequencies. At Ka-band frequencies of 30 GHz and 40 GHz and 0.01% of time, the predicted rain attenuation values is about 86 dB and 120 dB respectively, while it is about 131 dB and 175 dB at 0.001% of time. Also at 0.1% of time, the difference is as high as 22 dB within the Ka-band frequencies. The results from the figure also show a difference between Ku-and Ka-band predicted attenuation values. At 0.1% of time, while there is a difference of about 15 dB between the downlink frequencies of the two bands, the difference is as high as ~32 dB in the uplink frequencies. There is also a difference of about 6 dB (downlink) and as high as ~ 65 dB (uplink) at 0.01% between the two frequencies bands [Ojo and Sarkar, 2009]. It is also found that rain rate- rain and attenuation relationship over Shillong links is better with lognormal distributions fit for frequencies of 30 GHz and 40 GHz. Some representative diagrams related to cumulative distribution of rain rate of 15 minute-integration time, 1-minute converted rain rate and ITU-837-5 rain attenuation model and cumulative distribution predicted rain attenuation at both Ku- and Ka-band as well as Cumulative distribution of the predicted rain rate (mm/h) and rain attenuation at Ku-and ka-band frequencies over Shillong are presented in Figures 5, 6 and 7 respectively.

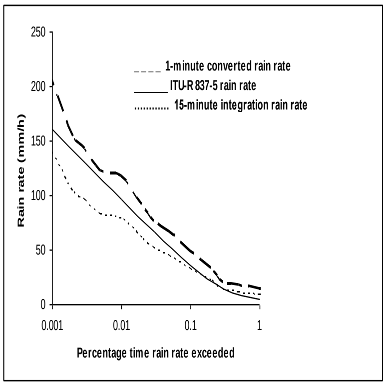

Figure 5. Cumulative distribution of rain rate of 15 minute- integration time, 1-minute converted rain rate and ITU-837-5 model over Shillong [Ojo and Sarkar, 2009]

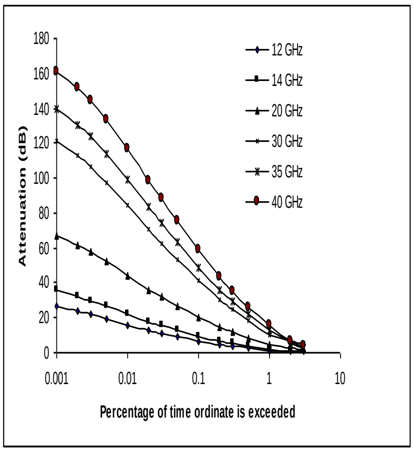

Figure 6. Cumulative distribution of the predicted rain attenuation at both Ku- and Ka-band Shillong [Ojo and Sarkar, 2009]

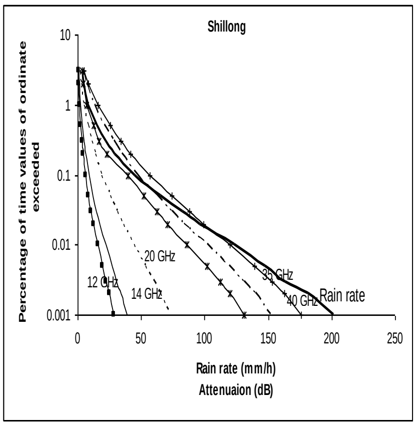

Figure 7. Cumulative distribution of the predicted rain rate (mm/h) and rain attenuation at Ku-and ka-band frequencies over Shillong [Ojo and Sarkar, 2009]

8. Capabilities of present days radars in monitoring of atmospheric systems

Important issues of today in reliable prediction in the moderm mode of communication, are to enrich our knowledge in interactive phenomena between atmosphere , weather , air pollution, climate change, water management etc [Ippolito, 1981; Sarkar, 2003, 2007]. These aspects are the driving forces towards the development of advanced observation techniques from ground, space and aircraft. The radar technology is based on the principle that all natural objects scatter electromagnetic waves in all directions. By sending the electromagnetic wave from radar for example to cloud, rain, thunderstorm, atmospheric irregularities etc., and analyzing the backscattered the reflected signal we are able to deduce the physical properties of the object [Sarkar, 2007]. The radars of today are sophisticated, computer controlled with smaller in size and weight [Sarkar 2003, 2006, 2007]., with high resolution cabability whether in collection of precipitation information, cloud coverage or even rain drop sise measurements .

Doppler Weather radars observations operating/under operation in S-band/X-band are availableover,Patiala,NewDelhi,Jaipur,Lucknow,Patna,Dibrugarh,Srnagar,Bhuj,Bhupal,Agartala,Kolkata,Nagpur,Mumbai,Paradip,Gopalpur,Vishakhapatnam,Hyderabad,Machlipatnam,Goa,Sriharikota,Chennai, Karaikal and Kochi. Non Doppler radar observations operating/under operation in S-band and X-band are available over Guwahati, Sri Ganganagar, Jaisalmer, Ahmedabad, Ranchi, Benearaluru, Mangalore, Trivanthapuram.

MST/ST radar (in operation/under installation):Gadanki, Cochin University, Calcutta University, AIRES,Nainital, Gauhati University.

In present day's radio communication scenario, there are the most three important issues which are reliability, directivity and regulation of transmitted power [Sarkar, 2005, 2007]. All such issues can be taken care provided the characterization of our tropospheric medium both in terms of clear air and precipitation is done with good degree accuracy [Sarkar, 2005 and Sarkar and Mondal, 2000].

By using modern radars, the following important parameters of rain and cloud can be estimated [Sarkar et al, 2003, Sarkar et al, 2005 and Sarkar and Kumar, 2007].

(a) Extension of rain cells

The statistical morphology of radar reflectivity as a function of horizontal and vertical extension of rain is of considerable interest for assessing the possible interference between terrestrial and earth-space satellite communication links. A sophisticated and computer controlled radar has the capability [Sarkar et al, 2003] to estimate the horizontal and vertical extension of rain. Usually the typical characteristics of the X-band radar of IMD are having frequency = 9.375 GHz; Transmitted power = 200 kW; Beam width = 1^{o} ; Pulse width = 0.8 μs and 2 μs; Pulse repetition frequency = 1250 pps and 750 pps, Range for maximum time = 240 km; Maximum range = 400 km; Accuracy = 2 dB at 240 km for Rainfall (1 mm/hr) ~23 dBz. The horizontal and vertical extension of rain is estimated from radar plan position indicator (PPI) and range height indicator Range (RHI) measurements [Sarkar et al, 2003]. Detailed results of horizontal rain extension are deduced as a function of radar reflectivity factor (dBz) [Sarkar et al, 2003]. It is well known that radar reflectivity factor is the measure of the strength of the scattering cross section of the rain cells. The scattering cross-section is responsible for causing interference to the radio signals. By taking all PPI measurements of X-band radar, horizontal extension of rain are derived. It is usually seen that the horizontal extension varies from ~14 km to 4 km while the radar reflectivity varies from 28 dBz to 53 dBz [Sarkar et al, 2003]. The large value of reflectivity is an indication of high rain rate and is associated with low horizontal extension of rain. The radar reflectivity of ~43 dBz (which is a measure of rain rate ~ 18 mm/hr), is associated with the horizontal extension of ~ 8 km, while the radar reflectivity of ~ 33 dBz (which is a measure of rain rate ~2.6 mm/hr) is associated with the horizontal extension of ~ 10 km. The low radar reflectivity is associated with large horizontal extension [Sarkar et al, 2003].

The variation of vertical extension of rain with radar reflectivity suggest that the height from where the rain of different intensities occurs. It is seen that the vertical extension of rain varies from 9 km to 5.75 km [Sarkar et al, 2003]. It is observed that the low vertical extension of rain ~5.75-km is associated with the radar reflectivity of ~ 53 dBz when the rain intensity is ~ 74 mm/hr. The vertical extension of rain from 8 km to 9 km is found to be associated with 28 - 43 dBz and the rain rate varies from ~ 2.4 mm/hr to 18 mm/hr [Sarkar et al, 2003].

(b) *Rain drop size distribution*

Raindrop size distribution (RDSD) at different rain intensities from radar reflectivity measurements can also be deduced [Mali et al, 2003; Timothy and Sarkar, 1997, Minakshi Devi, 2013,2014]. Some Integral Rainfall Parameters (IRP) is used to deduce RDSD. The formulation obtained in terms of radar reflectivity factor and rain rate is quite simple. The well known equations, that relate radar reflectivity factor (Z) in dBz, effective radar reflectivity factor (Z_e) in $mm^6\ m^{-3}$, rain rate (R) in mm/hr, rain drop diameter (D) in mm, drop size distribution N(D) in m^{-3} mm^{-1}, back scattering cross section (σ_b) in m^2, terminal velocity of rain drop (V) in m/s, dielectric constant of water (K_w) and the wavelength of the operating radar (λ) in m were utilized to deduce N(D) [Mali et al., 2003].The most probable raindrop diameters at different radar reflectivity and rain rate are estimated. It is seen that the most probable raindrop diameter, D varies exponentially with radar reflectivity, dBz. The values of D vary from ~ 0.1 mm to 1.4 mm, while the radar reflectivity varies from 23 dBz to 58 dBz. The values of D have also been found to vary exponentially with rain rate. At higher rain rate of ~ 100 mm/hr, D is around ~ 1.25 mm. The values of N (D), at rain rates ~ 49 mm/hr and 75 mm/hr are also estimated. It is observed that the maximum number of drops is around ~ 1800 per m^3mm^1 and associated with most probable raindrop diameter around ~ 0.75 mm at 49 mm/hr. Significant number of rain drops is associated with diameters more than ~1.5 mm and large numbers of small rain drops also are observed at ~ 49mm/hr. For rain rate ~ 75 mm/hr, the maximum number density, N(D) per m^3mm^1 was observed around ~ 640, while the maximum rain drop diameter was around ~ 3.9 mm. Considerable large number of rain drops with large diameter are observed at ~75 mm/hr. The number of drops [N(D)] per m^3mm^1 associated with rain drop diameter ~ 1 mm, 1.5 mm, 2 mm, 2.5 mm and 3 mm have been found to be ~ 630 , 530, 300 ,150 and 10 , respectively at ~ 75 mm/hr [Mali et al., 2003].

(c) Cloud characteristics by radars

It is well known these days that effects of rain in relation to attenuation of radio wave above 10 GHz over the tropical Indian stations are quite serious but the noise temperature generated by cloud is also significant for the signal to noise ratio of the microwave radio receivers. The cloud occurs weeks together over tropical regions of India. Cloud attenuation and cloud noise temperature can be deduced effectively if more measured parameters in relation to cloud morphology are available. Such cloud related parameters are of cloud coverage, cloud height, cloud thickness, cloud liquid water content etc. It is seen that such cloud parameters can also be deduced from the C-band and X-band Doppler weather radars (DWR) belonging to the India Meteorological Department. The Doppler radar operates in S-band and C-band. Several cloud parameters viz. radar reflectivity, cloud thickness, cloud height, cloud vertical integrated liquid water content etc. can be deduced in probability distribution scale also [Sarkar, 2006;Sarkar, 2007; Sarkar and Kumar, 2007]. The horizontal extension of rain is important to deduce rain attenuation results for terrestrial communication links. The typical representative rain bearing cloud/

rain events observed on Doppler radar PPI (plan position indicator) modes are presented in Figure8 [Sarkar, 2006, Sarkar and Kumar, 2007].

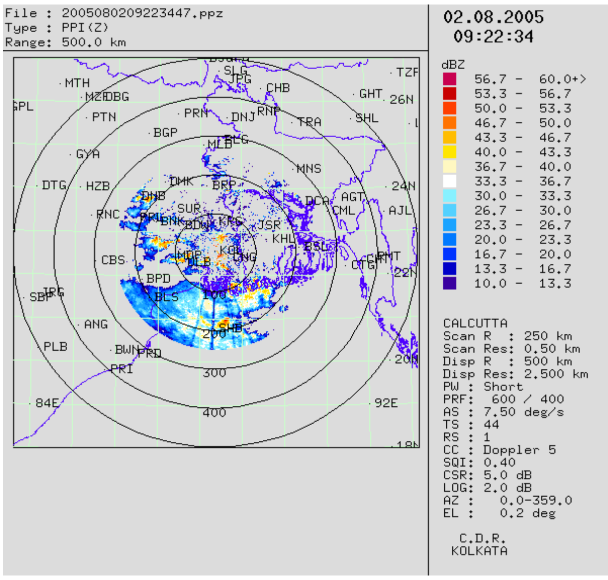

Figure 8. Radar reflectivity in PPI observed by Doppler radar (Sarkar, ,2006)

It is seen that rain of low intensity is scattered all over the places and the rain of higher intensity is found to occur over small region. The rain/rain bearing cloud of high intensity is much localized phenomena. Similarly the vertical extension of rain/rain bearing cloud can also be estimated from the Doppler radar reflectivity observations when radar is operated in RHI (range height indicator) mode. One of the important parameters for estimation of attenuation of radio wave due to cloud/ rain bearing cloud is cloud thickness. The Doppler radar provides results on cloud/rain bearing cloud base height and cloud/rain bearing cloud top height over the radar scanned region. Figures 9 and 10 provide the cloud base height and cloud top height over the radar scanned area [Sarkar, 2006]. The difference of rain bearing cloud top height and rain bearing cloud base height provides the cloud thickness. One of the important parameters for route diversity work for communication links is the results on rain characteristics over different locations. Doppler radar also provides the facilities y to deduce the results on rain rate intensity (mm/hr) and rain accumulation (mm) occurring simultaneously over different locations. Figures 11 and 12 present the measured results of rain intensity and rain accumulation over different locations within a range of 120 km [Sarkar, 2006]. For rain bearing cloud attenuation, another important parameter is the vertical integrated liquid. Such results on vertical integrated liquid (VIL) are also deduced from Doppler radar measurements. The vertical integrated liquid (VIL) results spread over different locations are presented in Figure13 [Sarkar, 2006]. The Doppler radar measurements of rain provide the results on rain intensity over several radar scanned locations simultaneously. It is seen that higher rain intensity occurs for less percentage of time. It is always useful to deduce results by using as many systems/techniques as possible. Since the availability of Doppler radar, the vertical integrated liquid with in cloud/rain bearing cloud is available over various locations of radar scanned region. Such results on VIL are useful for the results on attenuation of radio wave due to cloud as VIL is the most important requirement for attenuation estimation. The results on measured velocity results of rain fall for rain drop size distribution work are very essential. Most of the work on drop size distribution of rain drop is carried out on the basis of rain fall velocity results obtained theoretically. From the Doppler radar measurements of rain fall velocity, the distribution of rain fall velocity can also deduced. The radar is to be put in operation in vertical mode to deduce rain fall velocity. It is seen that the rain fall velocity varies from 0.4 m/s to 15.4 m/s. It is important to mention that most of the rain fall velocity is of around 0.4 m/s. More such observations of rain fall velocity by using Doppler radar available at different places are to be taken [Sarkar and Kumar, 2007].

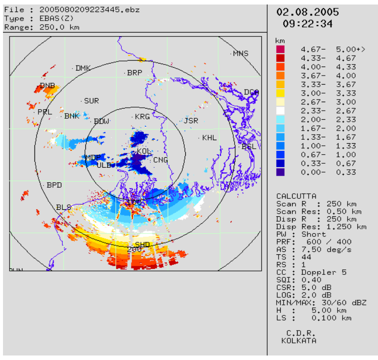

Figure 9. Cloud base height observed by Doppler radar [Sarkar,2006]

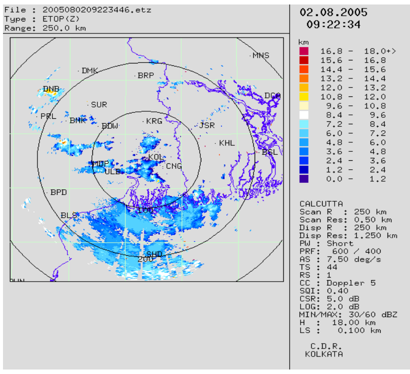

Figure 10. Cloud top height observed by Doppler radar [Sarkar,2006]

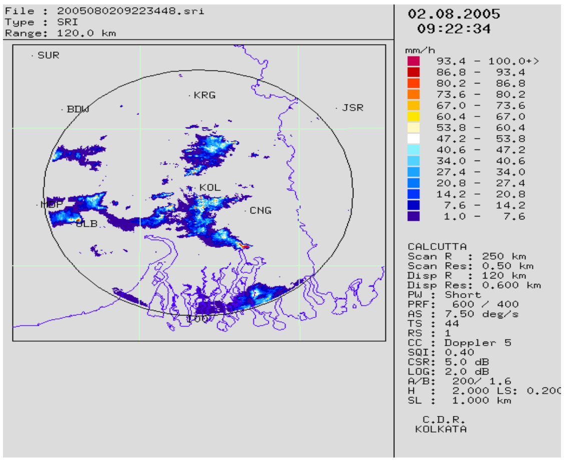

Figure 11. Surface rainfall intensity over different location deduced by Doppler radar measurements [Sarkar,2006]

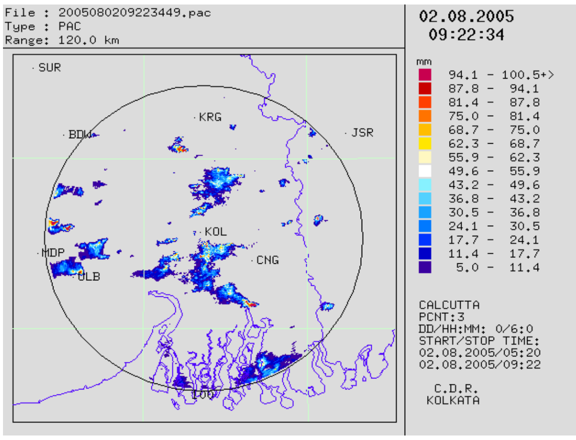

Figure 12. Precipitation accumulation observed by Doppler radar [Sarkar,2006]

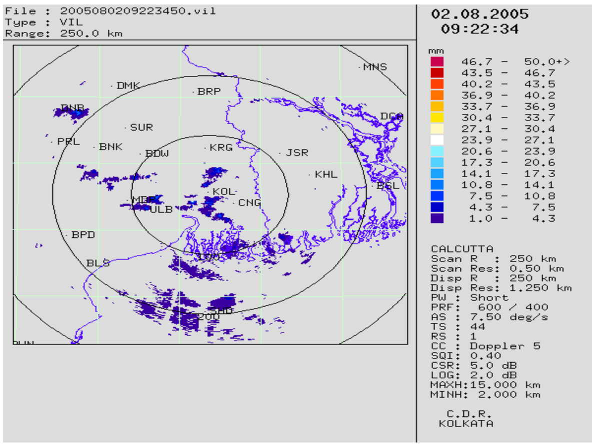

Figure 13. Vertical integrated liquid with in the cloud observed by Doppler radar [Sarkar,2006]

9. Scope for future work

There is shift in use of frequency from UHF band to higher bands due to the requirement of larger bandwidth for high data transmission rate for communication purposes and for remote sensing application work to get the finer structures of the objects in recent years in India [Sarkar, 2005, 2007]. There is tremendous increase in demand of the use of radio systems in the form of telephone, internet, multimedia etc., by the people particularly, our youngsters. In earlier time, reliability of radio system used to be the only criteria of priority. Looking at the present scenario of microwave communication in India, one has to deal with variety of other criteria [Sarkar, 2005, 2007]. Increasing the power of the system particularly of the transmitter we can increase the reliability of any radio system. In doing so, we are not only affecting the working of other radio systems, which are near the vicinity of the receiving site in the form of radio interference, but such transmitted power also affect the performance of other systems like medical gadgets such as pace maker, ECG machines, systems working on Nuclear magnetic resonance principle (NMR) [Sarkar,2005, 2007]. There is quantum jump in the use of such medical systems in recent years in India. It has also been seen recently that some user organizations have gone on increasing the transmitting antenna without realizing its effects on human lives. Another important point to be observed is that earlier at the place where such transmitting towers particularly in metropolitan cities were installed, there was not much population. But, with time, population has also become dense in and around many transmitting towers. This is also an issue of great concern [Sarkar, 2005, 2007].

The other important issue of the present days radio communication is the directivity of the transmitted and received power (signal) [Sarkar, 2005, 2007]. Increasing the antenna sizes, we can of course increase the directivity of the transmitted/received signal. But, increasing the antenna size beyond a point, means, we are not utilizing the contributions of maximum scatterers, which are usually atmospheric irregularities. Infact, the scatterers decide the strength of radio signal. So, a compromise between the size of the antenna and maximum radio signal is made in order to get maximum directivity.

In recent years there is tremendous advancement in electronics of radio systems. Such advancement has made it possible the regularization of transmitted power. These days in mobile communication t ransmitted power is regulated depending on the requirement of the received radio signal [Sarkar, 2005, 2007]. A transmitter located in rainy and cloudy area has to be provided with more power than to a transmitter situated in non-rainy and non-cloudy area. Similarly, it may be argued why people living on non-rainy and non-cloudy region should be exposed to electromagnetic effects due to the radiation of high power from transmitter [Sarkar, 2005, 2007].

In India, we have varied rainfall climatic regions (Sarkar, 2005, 2007). For example, annual total rainfall over different geographical regions in India varies between ~350 mm and ~11,420 mm. We have north east India where the total rainfall is around ~ 11,420 mm (Cherrapunji) and Guwahati ~ 1722 mm as well as Dibrugarh~ 2758 mm as well as desert region where we have total rainfall ~ 380 mm (Jodhpur). Over coastal stations, Mumbai, which is located over west coast, has total rainfall ~2700 mm while Kolkata which is another east coastal station has total rainfall ~1570 mm. Similarly, we have different geographical regions like Ahmadabad and Bangalore where total rain fall is around ~820 mm and over Nagpur, the total rainfall in a year is ~ 1127 mm. The total rainfall over an Indian island, Minicoy is ~ 1530 mm over.

In view of these three issues, it is necessary to characterize our rain and cloud environment so that attenuation of radio wave due to rain and cloud can be estimated with good degree of accuracy for proper designing of satellite communication and remote sensing systems [Sarkar, 2005, 2007]. It is also important to mention here that such characterization work has to be upgraded whenever an opportunity arrives. All organizations where latest techniques, which are available in the country, should join hands to make comprehensive efforts to derive radio environment results. It has been seen that most of the intense tropical rainstorms are convective type (melting layer: bright band is missing) in India. Vertical height of the stratiform rain is estimated from the height of the bright band or melting layer. The portion below melting layer can be called rain. Above to it may not be in liquid form. In case of convective rain, the liquid form of hydrometeors can also be found above the melting layer because of up and down drafts. Such type of rain can more often be seen in our country. Due to the availability of the large number of sophisticated computer controlled S-band/C-Band/X-band non Doppler/Doppler/MST radars/Wind-Profiler/ MST/ST radars and rain radars/Lidars etc, over different Indian geographical region, this aspect of rain cell size is to be looked into more rigorously by taking radar reflectivity measurements in PPI (Plan position indicator) as well as RHI (Range height indicator) mode and cloud coverage, cloud height, cloud thickness, liquid water content within the cloud etc. Efforts are to be made to study all such cloud parameters by using extensive radar systems. Other important investigations should be carried out in the area attenuation of radio wave like contributions from frozen and mixed phase fluctuations in addition to rain, millimeter wavelength radiation is highly susceptible to scattering by large ice particles above freezing level and melting hydrometeors around the freezing level provide a significant contribution to total attenuation at frequencies above 10 GHz. In the past, meteorologists have carried out some of these studies but those were for weather forecasting and mainly for monsoon prediction. The ITU-R techniques assume the rain height in relation to 0^oC isotherm height. This assumption holds well over temperate region. This has been found to be unrealistic over tropical Indian stations. The rain height over the Indian stations has to be effective rain height. This requires an effort of local data collection and this aspect is to be looked into immediately. This emphasizes the need for an effective rain height rather than simply the assumption of the 0^oC isotherm height. In recent years, satellite communication in Ku and Ka band will be used extensively for various purposes in India [Sarkar, 2007]. Apart from rain and cloud related work, another important area that needs attention is the measurement of radio signal in Ku and Ka band from satellites as well as by using terrestrial communication links belonging to various user organizations, wherever opportunities are available over different rain and cloud climatic regions [Sarkar,2007].Till now, we do not have much measurement over earth space paths as well as enough measurements over terrestrial paths in our country in these frequency bands. This aspect is also to be looked in.

As far as atmospheric science related work is concerned the stress should be on research related to atmospheric processes, satellite meteorology, climate science, physics and dynamics of tropical cloud, numerical modeling of weather and climate, Air quality, Carbon cycle, modeling of changing water, impact of sea level rise, cloud Physics, aatmospheric Electricity,monsoon Meteorology, boundary layer meteorology, micrometeorology, atmospheric Modelling and remote sensing applications.

The other important area, which needs to be investigated, is biological effect due to electromagnetic radiation. Due to the increase in use of RF energy in our country, the people are more susceptible to the exposure of such radiation. Though some standards are available in terms of exposure time, specific absorption rate in terms of modeling for weather and climate power flux density or field strength due to exposure to RF transmitting source in western countries, standards of such parameters are to be set in our country also. Study related to the diseases caused due to the exposure of RF energy is another area, which is to be explored quite extensively in near future in our tropical India [Sarkar, 2007].

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