CHAPTER 2

RADIOWAVE FOR RAIN, CLOUD AND THUNDERSTORM STUDIES

2.1 Introduction

The e.m wave propagating through the atmosphere is always affected by the changing densities and the type of the molecular/atomic constituents of the medium and suffers refraction. This refraction along with the scattering and displacement currents results in attenuation of the propagating wave. The refraction of the radiowaves leading to the attenuation is a fairly understood phenomenon. Microwaves in the range of frequencies from 10GHz to 100GHz suffer scattering particularly in case of the rain filled path (Shavit et al, 1998). The raindrops having the size of the order of the wavelength of the propagating wave are responsible for the scattering of the radiowave and hence loss of energy of the wave.

While investigating the attenuation of propagating radiowave, some more useful physical entities that have been felt to be equally important also been dealt. An attempt has been made to see the hydrometeor constituents through the total atmosphere in a broad spectrum of the microwave. The use of microwave communication and the associated studies on some of the very important atmospheric hydrometeor constituents has been dealt extensively.
For this, the some key parameters of the microwave propagating through the atmosphere have been considered for the different types of hydrometeors. In light of these objectives the present status of the studies on rain, water vapour and cloud of the atmosphere employing different methods have been reviewed. One of these is the attenuation of the microwaves by the rain filled medium. For this particular parameter, critically reviewed the works of earlier workers on rain attenuation (Fig. 2.1) starting from (Olsen and Olsen et al., 1978) to the present date. Other parameter is the noise temperature estimates dealt by (Slobin, 1982) due to different hydrometeors, which have been found very useful. This was further considered for exploring many more aspects of the atmosphere. It would be observed from the analysis of the results that several new ideas emanates from the study (Mali et al., 2001) in the range of selected frequency of the microwaves.

If whole of the atmosphere is probed by Microwave satellite communication, it is seen the e.m wave suffers attenuation due to plasma heating of the ionosphere on the top. This aspect is also key factor when the total atmosphere is considered. In order to work out the total attenuation contribution at the frequency of operation it will actually mean the total sum of the losses due to each of the constituents in atmosphere affecting the propagation in the communication link. However, different frequency
Fig. 2.1 Specific Attenuation $\gamma_R$ due to rain (CCIR Report, 1986)
regimes are affected differently. Accordingly, different targeted regions and constituents need monitoring of different frequencies.

2.2 Microwave and millimetre wave propagation through atmosphere.

Propagation of an e.m wave through a medium is governed by the Maxwell’s equations. If $E$ is the electric field vector, $H$ is the magnetic field intensity, $\mu$ and $\varepsilon$ are the magnetic and electric permittivities of the medium through which the e.m wave is propagating, then, the equation of the propagating wave is

$$\nabla^2 E = \mu\varepsilon \frac{\partial^2 E}{\partial t^2}$$

where

$$v^2 = \frac{1}{\mu\varepsilon}$$

$v$ is the velocity of propagation of the e.m wave in a given medium, given by Snell’s law as $v = c/\mu$. $c$ is the velocity of light in free space with the following solution for the electric field $E$.

$$E = E_0 e^{-i\alpha} = E_0 \cos(kz - \omega t)$$

When an e.m wave propagates through the atmosphere, it is always affected by the changing densities and the type of the molecular/atomic
constituents of the medium that is why the e.m wave propagating through the medium suffers refraction. Even otherwise, at every point the time varying magnetic field induces a voltage gradient in space. This voltage gradient is the electric field, which also varies with time and could be considered to be equivalent to current, even though the electric charge is not actually conducted. This current is called displacement current. The component of displacement current actually taking part in the conduction process is also a contributor for attenuation. The refraction of the wave leading to the attenuation is an well-understood phenomenon. This refraction along with the scattering and displacement currents results in the total attenuation of the propagating wave. The frequency dependence of the total attenuation with the type of constituents of the medium has been observed and explained. Further, it has been observed that, the microwave in the range of frequencies from 10GHz to 100GHz suffer scattering particularly in case of the rain filled path. The raindrops having 'the size of the order of the wavelength scatter the propagating wave and results in loss of energy (Oguchi, 1981). When total path traversed by the e.m wave from a satellite based source is seen in totality, we see that the microwave also suffers attenuation due to plasma heating of the ionosphere. This aspect is also a key factor for consideration when the total atmosphere is considered. So the total attenuation contribution at the frequency of operation is actually total sum of
the losses due to each of the constituents in atmosphere affecting the propagation in the communication link.

Usefulness of the radar in observation of precipitation has been recognised by many investigators (McMillan et al, 2002; Evans et al, 2002). Numerous studies (Lin et al, 2001, Yeo et al, 2001) have also been undertaken to determine the type of rain and efforts are still on to improve upon the accuracy in the estimation of rain rate (Fig. 2.2a & Fig. 2.2b) and other atmospheric parameters (Sarkar et al., 1987). It is for this reason now weather radars are used throughout the world for weather forecasting, tracking and warning. Many meteorological and climatological processes are also predicted from the radar data (Kozu and Nakamura, 1991; Wolf et al, 1999 & 2000; Gossard et al, 1997). Mainly, ground-based radars are in use, many airborne and ship borne radars have also been used for the purpose of the scientific study of many phenomena of interest (Avery et al, 1983; Röttger et al, 1995; Wolf et al, 2000).

It has also been found that the space-based rainfall measurement by use of radars is quite useful (Chandrasekhar et al, 1987, Deeter et al, 1998). Some of the important uses of radar measurements in this context are enumerated below:
The variation of attenuation with rain rates for different values of $\gamma$ at 11 GHz with $\theta = 56^\circ$, and for (a) $H_r = 5.5$ km; and (b) $H_r = 4.5$ km.
(i) The radar can provide rainfall estimates independent of microwave emission properties of the background land and ocean, unlike passive microwave sensors.

(ii) Radar has the ability of range profiling. Data for the vertical turbulence structure (Steiner et al., 1995) is an important parameter for the development of accurate algorithm to convert the microwave data to rainfall (CCIR, 1986, Mondal et al. 1997).

(iii) It is also useful for estimating the latent heat release profile and cloud studies (Fox and Illingworth, 1997, Gossard et al. 1997).

(iv) The radar can extend the dynamic range of rain rate estimate for higher values. It can be utilised to estimate the path averaged rain rate.

(v) The storm structure and the related rain rate recorded by the radars (Steiner et al, 1995; Rosenfeld et al, 1994) could be utilised for determination of rainfall within radar field of view and beyond along with the passive microwave data (Fig. 2.3a & b).
Fig 2.3 a  Radar Reflectivity (in dBz) in relation to Rain Rate (mm/hr.) seen at different ranges (Rosenfeld et al 1994)

Fig 2.3 b  Received Power (dBm) in relation to Rain rate at different ranges
(vi) Microwave attenuation data and the radar reflectivity data in combination can be used for the obtaining the rain drop size distribution (RSD). Such data (Rosenfeld et al, 1994; Tokay and Short 1996; Yuter et al, 1997) along with the rain rate observations may be used to establish relation in between radar reflectivity and rain rate (Goldhirsh, 2000).

The use of microwave communication and the associated studies on some of the very important atmospheric hydrometeor constituents (Smith et al, 1981; Sen et al, 1993, Liljegren et al, 2001) have been dealt in this dissertation quite extensively. For this, the various parameters of the microwave propagating through the atmosphere are considered for the different types of hydrometeors. Present status of the studies on rain, water vapour and cloud of the atmosphere (Rosenkranz, 1998; Yackerson 1998; Kulessa et al, 1998; Weastwater et al, 2001) have been reviewed. Variations of the attenuation, noise temperature and radar reflectivity estimates due to different hydrometeors which have been found very useful are discussed (Westwater, 1978).
2.3 Attenuation of e.m waves passing through a medium

It can be shown analytically that refraction of the propagating wave leads to the attenuation. Propagation of an e.m wave through a medium is governed by the Maxwell's equations. If $E$ is the electric field vector, $H$ is the magnetic field intensity, $\mu$ and $\varepsilon$ are the magnetic and electric permittivities of the medium through which the e.m wave is propagating.

Using, the energy radiated due to an oscillating dipole

$$\bar{\xi} = \frac{\omega^4 e^4 E_0^2}{12\pi \varepsilon_0 \rho^3 m^2 (\omega_0^2 - \omega^2)^2}$$

...(2.2)

Thus, when $N$ represents number of atoms per unit volume, then total energy radiated away per unit volume would be $N\bar{\xi}$.

We assume the e.m wave to be propagating along a particular direction, then the intensity of the wave is given by

$$I = \frac{1}{2} \varepsilon_0 c E_0^2$$

For, calculating the change in intensity of the e.m wave as it propagates through a distance $dx$ can be obtained by
\[ dl = -N\xi dx \]

\[ \Rightarrow \frac{dl}{l} = -\gamma dx \]

where \[ \gamma = \frac{N\xi}{l} \]

\[ \Rightarrow \xi = \frac{\omega^4}{12\pi\varepsilon_0 c^3} \frac{e^4 E_0^2}{m^2 (\omega_0^2 - \omega^2)} \quad \ldots(2.3) \]

Thus, when \( N \) represents number of atoms for unit volume, then total energy radiated away per unit volume would be \( N\xi \)

\[ dl = -N\xi dx \]

\[ \Rightarrow \frac{dl}{l} = -\gamma dx \]

where \[ \gamma = \frac{N\xi}{l} = \frac{\omega^4}{6\pi\varepsilon_0 c^4} \frac{Ne^4}{m^2 (\omega_0^2 - \omega^2)^2} \quad \ldots(2.4) \]

Implies that \( \gamma \) represents the attenuation coefficient (Mali et al., 2001); could be used for obtaining attenuation of the e.m wave in that particular frequency regime.
Integrating the above gives the

\[ I = I_0 e^{-\gamma x} \]

Implies that \( \gamma \) represents the attenuation coefficient.

The radiowave propagation in the centimetre and millimetre wavelengths suffer from absorption and scattering. Presence of a rain filled medium is responsible for noticeable effects on the radiowaves. The wave frequencies in these domains are quite responsive to the raindrop size and geometry apart from the dielectric property of the medium. When an electromagnetic wave strikes the raindrops of oblate shape the wave gets scattered and the scattered energy losses can very well be estimated from the resultant electric field of the scattered waves.

The scattered electric field is given by

\[ E_s(r, \theta, \phi) = jk_0 E_0 \frac{\exp(-\beta_\phi r)}{r} \times \left[ \hat{e}_h A_h(a, \theta, \phi) \sin \theta - \hat{e}_v A_v(a, \theta, \phi) \right] \]  

in terms of \((r, \theta, \phi)\) spherical polar coordinates where the subscripts of \(v\) and \(h\) are used for the vertical and the horizontal polarization components.

Calculations of scattering amplitudes have been one of the main concerns of the researchers for years. Different workers for their problems have defined scattering amplitudes in various ways. Forward scattering formulation proposed by Ozunoglu et al, (1977)

\[ A_{vh}(\beta, \bar{a}, \lambda) = A_{vh}(\pi/2, \bar{a}, \lambda) \sin^2 \beta + A_{vh}(0, \bar{a}, \lambda) \cos^2 \theta \]  

...(2.6)
Fig. 2.4 Specific Attenuation $\gamma_R$ due to rain for Vertical polarization (V) and Horizontal polarization (H), CCIR Report, 1986.
Imaginary amplitude is

$$I_m A_{m,h}(\beta = \pi / 2, \sigma, \lambda) = \eta_0(\lambda) A_{c,h}(\lambda) \cdots (2.7)$$

Using the raindrop size distribution we get

The specific attenuation $\gamma_{sh}(\text{db/km})$ on slant path with varying horizontal and vertical polarizations (Fig. 2.4) in a location dealing with Marshall-Palmer rain drop size distribution follows equation (2.6). By considering the imaginary part to be the attribute for the attenuation, as dealt chapter 7, the scattering of the waves from the centres existing in one kilometre gives the following expression:

$$\gamma_{sh}(\text{db/km})=8.68 \times 10^3 \lambda N_0 \left[ \eta_b \sin^2 \beta \frac{\Gamma(\rho_b + 1)}{A_{b+1}^*} + \eta_c \cos^2 \beta \frac{\Gamma(\rho_c + 1)}{A_{c+1}^*} \right] \cdots (2.8)$$

The radiowave propagation in the centimetre and millimetrewave bands suffers from attenuation due to rain (Moupfouma, 1997; Fig. 2.5). This has been the subject of research for tropospheric communication links since long. Presently, the emphasis is laid on establishing prediction techniques for the estimation of attenuation for a particular propagation path. For estimating the path attenuation, meteorological data are very important. The complex nature of rain structure, its regional variabilities and the difficulty of measuring high rate of rainfall have made the task hard enough to establish a relationship between different variables.
Fig 2.5 a  Rain attenuation on earth-satellite microwave link (Moupfouma, 1997) with new method ___ and kR^a relationship — (at 17.7 GHz, 5.1 Km Hor-pol) ■ measured data.

Fig 2.5 b  Rain attenuation on earth-satellite microwave link (Moupfouma, 1997) with new method ___ and kR^a relationship — (at 19.3 GHz, 23 Km, Hor-pol) ■ measured data.
Fig. 2.6 Comparative results of cumulative rain rate distributions of mid Atlantic coast and Wallops rain gauge rain gauge network (Goldhirsh et al., 1997; Goldhirsh, 1982) alongside cell model.
Fig. 2.7 Theoretical attenuation by water clouds at various temperatures as function of frequency.
Spatial and temporal distribution of rainfall as well as the total amount of rainfall are poorly known and has been the objectives of research by different international bodies including ITU-R. The point rainfall rates, vertical and horizontal structures of rain are of immense importance for estimating rain attenuation. Over the last several years, many models have been proposed and extensive research activities have been conducted to improve the already existing prediction models. Fedi (1981) outlined some desirable features for prediction model. According to him (i) the model should be checked for observed data and validated. (ii) It should be tested for measured data from different regions and (iii) it should be simple and structured to accept modifications. The radio science was always in search for refined propagation model taking in consideration all the factors including meteorological parameters. Weather Radar data was used by Rogers (1976) to develop a rain storm model to convert rainfall statistics to path attenuation as shown in Fig. 2.6 (Goldhirch, 1997). From a comparison of radar based attenuation and measurements of simultaneous path, Goldhirsh (1979) indicated that the rain below the bright band is responsible for attenuation (Fig. 2.7). The bright band, the so-called melting layer, was thought to be due to the melting of ice and available as large water coated snow particles which might produce significant attenuation. Crane (1978) from the measurements of change in cross-section for linearly polarised radar concluded that the melting of ice mainly takes place below the bright band (as the bright band itself is dominated by snow) and this significant melting occurs at a height near 0° isotherm. The
process of melting goes on and produces minute droplets at the extremities of snowflakes. This grows bigger and finally becomes raindrop. The attenuation was found to be proportional to the melted water till it became raindrops. The view that raindrops from the melt water produce significant attenuation was supported by the observation made by Goldhirsh (1979).

2.4 Rain attenuation

In relation to different rain parameters, the propagation characteristics have been examined by Moupfouma (1987) and Timothy et al., 1994. Crane (1993) described statistical uncertainty in attenuation prediction (including that of rainfall) and provided a procedure to estimate the risk associated with prediction of earth-satellite link (Fig. 2.8).

De Maagt et al (1993) reported the diurnal variation of rain attenuation at 11.2 GHz on satellite path in Indonesia over a three-year period. The Ku-band services were found suffer more in the late afternoon and evening hours during wet months, because the incidence of thunderstorms
Fig 2.8a Rain attenuation on earth-satellite microwave link (Moupfouma, 1997) with new method and $kR^n$ relationship — (at 11.8 GHz, Cir-pol), measured data.

Fig 2.8b Rain attenuation on earth-satellite microwave link (Moupfouma, 1997) with new method and $kR^n$ relationship — (at 20.1 GHz, 16.6 km Ver-pol), measured data.
2.5 Microwave propagation measurements: Attenuation due to water vapour

A technique based on an approximation on the use of the Van Vleck-Weisskopf line with coefficients (Sarkar et al, 1987) adjusted to match the computer calculations led to the following formulae

\[ \gamma = \left[ 0.066 \frac{24}{(f-2223)^2 + 66} + \frac{7.33}{(f-1883)^2 + 5} + \frac{44}{(f-3238)^2 + 10} \right] f^2 \rho \times 10^4 \]  \ ...(2.9)

Where \( \gamma \) is the specific attenuation coefficient due to water vapour, \( f \) is the frequency and \( \rho \) is the water vapour density expressed in gm/m\(^3\).

Water vapour is not at all a well-mixed constituent of the atmosphere and hence it shows variation due to change of site, season and local meteorological conditions. Also the vertical and horizontal distribution of water vapour varies with space and time. Resch (1983) estimated the atmospheric emission around 22GHz for two different vertical distributions of water vapour. To calculate brightness temperature, a constant relative humidity was assumed. It was taken 81.6% for the height region 0-1 Km and 99% for 1-3.8 Km.
2.6 Scattering of the radar signals from different types of refractive index variations

Radiowaves scatter from discontinuities in the refractive index of the medium through which it propagates and encounter the changes due to density as well as refractive index changes that match the Bragg Condition

\[ k = k_i - k_s \]  

where \( k_i \) (rad/m) is the incident wave vector, \( k_s \) (rad/m) is the scattered wave number vector and \( k \) (rad/m) is the wave-number vector of the refractive index perturbation that fulfills the Bragg condition. For back-scatter i.e. \( k_s = -k_i \)

\[ k = 2k_i \]  

In other words, backscatter systems see refractive index structures at half radar wavelengths

In neutral atmosphere the energy in the refractive index fluctuations goes up with length scale (Cho, 1987). This is true whether the fluctuations are generated by turbulence or by some other mechanism.

Therefore, the Bragg scattering cross section is generally larger for longer wavelength radar. Other consideration such as resolutions and cost put together restricts the practical clear weather radar. For the studies on macroscopic
particles by radar the Rayleigh’s approximation hold good and it will be scattered according to

\[ \sigma_i = \frac{\pi^5 |k|^2 D_i^6}{\lambda^4} \] ...

\[ \text{(2.12)} \]

where \( \sigma (m^2) \) is the back scatter cross section, \( D_i \) is the diameter of each particle, \( \lambda \)--radar wavelength and

\[ k_i = \frac{m^2 - 1}{m^2 + 2} \] ...

\[ \text{(2.13)} \]

with \( m \) as the complex refractive index.

It is immediately seen that Rayleigh’s scattering with decreasing radar wavelength due to this the weather radar use much higher frequencies as \( |k|^2 \sim 1 \) for water.

The radar refractivity per unit volume (m \(^{-1}\)) is given by

\[ \eta = \frac{\sum \sigma_i}{V} \] ...

\[ \text{(2.14)} \]

where, \( V \) is the radar volume. So for size distribution of droplets across \( m \) bins
where \( N_i \) is the particle number density for each diameter. Here, assumption is made that \( K \) is same for a given drop/particle size. In operational meteorology the further assumption of \( K \) constant for all particle sizes is made arrive at the equation:

\[
\sigma_i = \frac{10^{-18} \pi^5 |k|^2 Z}{\lambda^6}
\]  

...(2.16)

Where \( Z = \sum_{i=1}^{M} N_i d_i^6 \)  

...(2.17)

is called the radar reflectivity factor. The study related to radar reflectivity in relation to the determination of rain structure rain drop size distribution (as shown in Fig. 2.9 and Fig. 2.10) has been dealt in detail in subsequent chapters.

### 2.7 Microwave radiative transfer equation

Rayleigh-Jeans equation of radiative energy finds useful application in most of the microwave applications. Radiative transfer equation which has been used to deduce the noise temperature due to cloud (Slobin, 1982; Sen et al, 1993) deduced by Chandrasekhar(1960) is dealt in the following section in order to substantiate the observed absorbed energy.

Considering specific Intensity \( I_i \) as the instantaneous radiation power that flows out through point in the medium, per unit area, per unit frequency interval at a specific frequency in a given direction per solid angle.
Fig. 2.9  Showing Raindrop size distribution at rainrate – 49 mm/hr
Comparison of measured RDSDs of Dehradun (India) and Nigeria with log-normal models of Nigeria and Brazil.
Considering specific Intensity $I_v$ as the instantaneous radiation power that flows out through point in the medium, per unit area, per unit frequency interval at a specific frequency in a given direction per solid angle.

We write the following differential equation

$$\frac{\partial I_v}{\partial s} = I_v \alpha + s \quad ...(2.18)$$

where $\alpha$ is the absorption coefficient and $s$ is the source term.

Now, neglecting the scattering losses and considering the absorption only as a scalar characteristic, we write according to Kirchoff's law

$$S = \alpha \beta_v(\tau)$$

where $\beta_v(\tau)$ is the Plank's function and is given by

$$\beta_v(\tau) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

The solution of the differential equation (2.18) gives the following relation.

$$T_v = T_v' e^{-1} + \int T(s) \alpha(s) \left[ \exp \left( - \int \alpha(s') ds' \right) \right] ds \quad ...(2.19)$$

Confining ourselves to Rayleigh-Jeans limit i.e. $h\nu << KT$

when $\beta_v(\tau) = \frac{2KT}{\lambda^2}$
where $\lambda$ is the wavelength and $T$ is the physical temperature and then scaling the Noise temperature

$$T = I_v \frac{\lambda^2}{2K}$$

Noise temperature has been found useful for clouds. The results have indicated proper selection of radiometer frequency. The usefulness of monitoring the wasted energy due to the absorption by the atmosphere has been realised from the obtained results. Re-radiated energy from different constituents of the atmosphere emerges out as an important feature for differential study of its constituents.

Attenuation of the microwave signal has primarily been found important in rain studies for both drop size distribution as well as the rain intensity. Thus, there is a scope to record the rain intensity from the data of the microwave propagation links (W.L. Stutzman and W.K. Dishman, 1982). For terrestrial communications there is no effect of the plasma heating.

The total microwave attenuation below the ionosphere is the sum of the attenuation due to water vapour and oxygen for clear air condition. For cloudy conditions there is an additional attenuation term due to cloud. The attenuation due to clear air and cloudy conditions for the operational
frequencies in the range from 10 GHz to 100 GHz have already been deduced (Jacobs and Stacey, 1974; Falcone and Abreu 1979). It has been observed that noise temperature is more informative and useful for study of characteristics of the constituents of the atmosphere in some cases than the attenuation.

While studies on attenuation are quite direct, but consideration of radiative transfer has been found immensely useful for monitoring both water vapour and the clouds features at a particular site and time. Noise temperature gives a good estimate of water vapour content and the cloud composition. Studies on these have been extended to different frequencies for arriving at some concrete results relating to use of proper frequencies, etc. Wherein, take up the theoretical analysis gradually to show the dependence of the each of the parameters, which have been found useful in the studies of atmospheric hydrometeors. The main parameters, which are responsible for the loss of energy within observable limit, could be used for monitoring the hydrometeor constituents remotely. A suitable algorithm will give instantaneous data of the possible hydrometeors.

2.8 Thunderstorms Generation Mechanism

Satellite observations show that the frequency of lightning discharges is quite significantly more than it is over seas. Although thunderstorm, can occur at any time of the day and night, the activity of storms and lightning is generally
maximum over land in mid-afternoon when the solar activity and convection are maximum.

The size of thunderstorms varies remarkably. However, they do not produce the lightning until they grow to a depth of at least 3 km. While average thunderstorms are nearly 10 km in depth, severe thunderstorms have been observed to exceed 20 km in depth and penetrate well into the stratosphere.

The source of lightning is the charge accumulation and separation over the surfaces of clouds. This happens due to the motion of clouds in all possible directions (vertical, horizontal and other possible orientations) the charge is induced in a similar fashion as the electric charges are induced due to rubbing of two different kind of surfaces.

2.8.1 Cloud-To-Ground (CG) Lightning

The CG discharges are most commonly observed phenomena, where in a sequential way the negative charges descend downwards and are overtaken by the upwards going positive charges producing lightning and thundering sound characterizing one phenomena from the other. The return stroke starts from this junction and travels upwards completing the electrical circuit. It is very similar to gaseous discharges taking place in the discharge tube; when the plasma is subjected to high current flow and may be with steady magnetic field (with
arbitrary orientation) give rise extended spectrum of electromagnetic wave generation. These electromagnetic waves have the signatures of lightning and have been used extensively as diagnostic tool.

2.8.2 Cloud-To-Cloud (CC) Discharges

Based on visual observations of lightning and the absence of the associated sound, the phenomena of cloud-to-cloud lightning was discovered and the understanding of these have grown gradually. Now, it is almost clearly established that the CG and CC discharges are equally distributed phenomena in the Earth's atmosphere. These two phenomena have distinct differences. Some these are like CG discharges take place at low altitude where gaseous density is large, therefore, the discharge voltages are higher. On the other hand in the case of CC Discharge, the height is large; pressure of the gas is low and therefore discharge voltage needed is much lower as compared to CG discharges. However, the striking difference in both these processes is that the CG discharges have to traverse through the lower atmospheres and undergo comparatively large attenuation. Apart from these features, the direction of current flow and the polar diagram of electromagnetic wave radiation are different in both the cases.
Features of EM - Radiation from CG and CC Processes

<table>
<thead>
<tr>
<th>Discharge Process</th>
<th>Discharge voltage</th>
<th>Current flow</th>
<th>Direction of current flow</th>
<th>Polar diagram of EM radiation</th>
<th>Radiated power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>Large ~30KVcm⁻¹</td>
<td>Large</td>
<td>Vertical C-to-G</td>
<td>Figure of Eight horizontal</td>
<td>Large EM Power</td>
</tr>
<tr>
<td>CC</td>
<td>Relatively small</td>
<td>Relatively small</td>
<td>Horizontal C-to-C</td>
<td>Figure of Eight vertical</td>
<td>Smaller EM Power</td>
</tr>
</tbody>
</table>

It is well known that the atmospherics originating in lightning discharges are closely associated with the thunderclouds developed. The thunderstorm is essentially the phenomenon of development of turbulent motion of air parcels due to the development of a low pressure region. It is now well known that the atmospherics originating in lightning discharges are closely associated with the thunderclouds developed. It is assumed that the thunderstorm is essentially the same phenomenon of turbulent mixing of moist and dry air parcels. However, the lightning aspect must meet some mutually consistent set of requirements for complete explanation of the generation of charge and lightning in thunderstorms. Some these are listed below.

(i) A charge of 40 coulomb is essential to supply the first lightning flash within 5-30 min. of the appearance of precipitation particles of radar detectable size (Kimpara 1965)
(ii) The onset of strong electrification at some level, follows the appearances of frozen particles (Maccready 1958). In general, magnitude of fields in cloud containing solid particles are 10-100 times those in all water clouds.

(iii) The charge generation and separation processes are closely related to vertical convection and development of precipitation (Vonnegut, 1963).

(iv) In a thundercloud, there is usually a net positive charge in the upper portion. A third region of net positive charge sometimes appears at the base of the clouds in the central core of the precipitation. In a thunderstorm, the charge on precipitation particles is mainly positive in the upper layers, a mixture of charges in the intermediate levels, and negative on the average, in the lower levels. There is strong tendency for charge of the negative sign to be associated with larger precipitation particles (Chalmers, 1967).

(v) A complete explanation (Reynolds 1954) of thunderstorm electrification should allow for electrification of clouds with temperatures entirely over above 0°C.

(vi) A charge separation process that takes place within the cloud causes lightning. The dominant charge separation process responsible for lightning is produced within the cloud by collisions between the large and small ice particles. By this mechanism,
charge of one sign is transferred to the larger particles and an equal and opposite charge to the smaller ones. The electrical energy responsible for lightning is derived from the fall of charged precipitation particles under the influence of gravity (Williams 1988, Demerjian 1992).

(vii) The negative charge residing on the surface of the earth in fair weather is the result of the action of the many thunderstorms continuously in progress over the earth. Fair-weather electrical phenomena have no significant influence on thunderstorm electrification or other meteorological phenomena. Except for the chemical effects produced by lightning, thunderstorm electricity is without significant influence on processes taking place in lower atmosphere. The effect of lightning is to neutralize the charged particles responsible for electrification of the cloud (Takahashi 1990).

In subsequent chapters some interesting results are obtained using the features presented in this chapter. Many have been the basis for analysis of the data relating to issues of concern. It uses the techniques and instrumentation for the data as given on next chapter for the work undertaken.