CHAPTER 4

Analysis of local atmospheric electrical parameters

4.1 Introduction

Measurements of the potential gradient (PG), air-Earth conduction current density ($J_c$) and total conductivity ($\sigma$) made at Equatorial Geophysical Research Laboratory (EGRL), Tirunelveli (8.7°N, 77.8°E), which is a regional center of Indian Institute of Geomagnetism, Mumbai under Department of Science and Technology, Government of India. All of these parameters have been recorded simultaneously since 1995 onwards. The environmental and meteorological conditions at the measuring site and the orography relevant observation on atmospheric electricity and data selection reported below and location of atmospheric electrical parameters measuring site shown in Fig. 4.1.

![Map showing location of GEC site in India](image)

Fig. 4.1 Map showing location of GEC site in India
The experiment site (~30 m above mean sea level) is more than 12 km southeast of the twin towns of Tirunelveli and Palayamkottai. The nearest cement factory is located at a distance of about 15 km to the northwest. It may be noted that moderate-to-intense southwesterly winds blow during one half (April–September) of the year over the region of observation, while moderate north-easterlies blow during the other half (October–March) of the year. The site is about 35 km from the Bay of Bengal, and the nearest hills of Western Ghats are at distances of approximately 45 km to the west and the southwest.

Further, the crustal part of the Earth underneath the site is fixed on solid rocks, and hence does not support dense vegetation. The experiment site receives rainfall normally in the months of October and November during the northeast monsoon, while occasional rains occur during the summer when the southwest monsoon prevails in the Indian subcontinent. Scanty rainfall over most of the year in this region permits a large number of atmospheric electricity measurements to be made. Being in the tropics, this region is under the influence of convection that is expected to be severe around summer period (April–June).

Measurements of atmospheric electrical parameters have been carried out at Tirunelveli since March 1995. After initial test runs for more than 1 year, the Maxwell current data have been available for analysis since May 1996. In the present study type of data set included days on which disturbed local weather conditions, other than fair weather, occurred; these include (1) thunderstorm and showers, (2) fog conditions and (3) Sunrise effects briefly discussed in this chapter.
In 1999, we have started GEC experiments at Maitri, Antarctica with the same instruments which is operational at EGRL. The Indian Antarctic station, Maitri is located in the Schirmacher oasis in the Dronning Maud Land, East Antarctica (117 m above the mean sea level) and location of the site shown in Fig. 4.2. Antarctica has only around 2% of its area that is free from ice. The nearest steep cliff of the east-west trending glacier on the southern side of the station is more than 700 m away from the station and is 300 m in height. The snow-covered surface during summer season was more than half a kilometer away from the station. The instruments were installed on barren land near the station. The surface of the station area is mainly covered by sandy and loamy sand types of soil. The solar zenith angle at Maitri varies from 48° to 88° during summer months. There was no sunset till the third week of January, but periods of short nights slowly increased during February. The variations in surface meteorological parameters were measured by automatic weather station which is installed during this expedition. The cloud cover over the station occurs mainly under the influence of subpolar low-pressure systems and shows an alternating sequence of the sky changing from overcast to clear as the system moves away (Deshpande and Kamra, 2001). In the present study type of data set days on which disturbed local weather conditions during (1) Effect of Wind Speed, (2) Blizzard and drifting snow and (3) effect of fog conditions also discussed in this chapter.
Fig. 4. 2 Map depicting location of Maitri, Antarctica.

From these atmospheric electrical measurements and those of standard meteorological parameters using Automatic Weather Station (AWS) data, it is possible to resent both an electrical “climatology” of the EGRL and a comparison work carried out between electrical and meteorological parameters. Additionally, inter-comparison of electrical parameters will be made and results compared to other instruments which one is measuring the same parameters with some other technique. The variation of PG and $J_C$ during fog, Thunderstorm and shower, blizzard and snowfall conditions investigated from both the place (Equatorial and polar region).
4.2 Analysis of Disturbed Weather Conditions (at EGRL)

4.2.1 Thunderstorm and showers

In this section we have carried out analysis during the disturbed weather conditions like rain, shower and lightning. July 24, 1998 is considered to be a good example of days in which there was rain and thunderstorm activity. On this day, intense convection led to the development of a thunderstorm during the afternoon. For the period of lightning the variation in the current for this day between 09:30 and 11:30 UT is shown in Fig. 4.3. The thunderstorm activity with a few visible lightning strokes took place over the measuring site between 10:15 and 10:45 UT. Severe rains persisted between 10:00 and 11:00 UT. It may be noted in Fig. 4.2 that at times of lightning strokes the current fluctuated between the extremes. The onset of rainfall is clearly marked by the rapid increase in the current that commenced at approximately 09:45 UT. With the traditional view that lightning brings down negative charges and rain positive charges (Israel, 1973), one would expect a downward or upward current trend depending on the incoming charge polarities. A change in the sign of the measured current clearly indicates the dominance of lightning current around these times and conforms to the traditional view that the fairweather electric field changes its direction during thunderstorm activity.
Fig. 4.3. Maxwell current variation on 24 July 1998 in response to thunderstorm and rain.

On the other hand, during the course of rain, the condensed water droplets normally forming near the top of the thundercloud are expected to carry positive charges and, hence, on precipitation near the ground they are expected to cause an increase in the measured current density. Despiau and Houngninou (1996) carried out measurements of electric charges of raindrops, electric field, and Maxwell current during intense storms and showers at a tropical location in West Africa. One of the characteristic features of the storms was the presence of predominantly positive hydrometers with charges between 80 and 240 pC. The observed features described above clearly indicate that the horizontal antenna wires do respond to the electrical disturbances occurring in the near-Earth space environment. At the onset of precipitation the measured current increases, while during intense rainfall, the measurements reveal saturation at their detectable levels. This behavior has been observed at every occurrence of strong downpour is shown in Fig. 4.4.
Fig 4.4. Maxwell current variation during sharp downpour at EGRL

On 7th February 2000 at about 1400 IST there was lighting with light drizzling started and then at about 1445 IST heavy downpour started and continued about 2 hours. During the heavy downpour the measured current density is so high. It is due to the rain drops carries the positive charges. On the other hand, during individual lightning strokes, the current detected by the long-wire antenna fluctuates between extreme values (±1 nA). It is possible that the sign of the current reverses in response to the reversed polarity of the electric field at such instances.

4.2.2 Fog effect

Fog is one of the factors that influence the Maxwell current variation. The necessity of studying the electrical properties of fog is also dictated by a number of practical problems, such as possible means for the fog forecast and control, influence of aerosol and dust systems to the electric field and current in the atmosphere, and the search for mechanisms of solar-terrestrial relationship (Smirnov, 1992). It has been observed that the conductivity of the atmosphere decreases significantly at the onset
time of the fog (Hoppel et al., 1986). An unseasonal rain that occurred over the measuring site on 24 and 25 July 1997 provided an ideal condition for fog development to occur. The variation in the measured current density for this period is depicted in Fig. 4.5.

![Fog Current Variation Graph](image)

**Fig. 4.5.** Maxwell current variation on 24–25 July 1997 in response to fog.

The fog was centered near the sensor complex at approximately 01:30 UT on 25 July, and then drifted towards the east at about 01:40 UT. During this period, the current level decreased to a minimum between 00:30 and 01:30 UT. This observation agrees with the results reported in earlier works by Dolezalek (1963) and Serbu and Trent (1958). Prospero (1984) showed that before fog visibly forms, the growing droplets capture atmospheric ions, thereby increasing the resistivity of air and leading to a rapid reduction in the current density. When the droplets begin to fall, the thickness of the fog layer decreases and, consequently the columnar resistance of the air decreases. This is expected to cause an increase in the measured current density. The present experiment is thus shown to be consistent with these previous observations.
Studying the electrical properties of fog requires the development of modeling with consideration for the microphysics of particle charging and the availability of external sources of ionization and the electric field in the atmosphere (Sorokin, 2001; Anisimov et al., 2003; Mareev and Anisimov, 2003). The fog developed due to radiation cooling of the air in the surface layer; in the morning, the advection of the warmer moist air took place. A characteristic feature of the fog typically causes the current density to decrease (Anisimov et al., 2005). At times of fog development, the current tends to diminish in its magnitude, recovering later as the fog disappears. This feature is explained based on the reasoning that as the fog thickens, the growing droplets reduce the conductivity and, hence, the current flowing to the sensor. As the fog dissipates, the evaporation of water drops leads to a slow recovery of the conductivity, and the current returns to the initial values. Burke and Few (1978) observed a similar fog effect on the air–Earth current density measured at Houston.

4.2.3 Sunrise effect

In order to examine the sunrise effect in more detail we have used the one-minute averaged data that are shown in Fig. 4.6. These data are plotted in Indian Standard Time (IST) which is 5.5 hours ahead of UT. It is seen that Electric field (E) and Current (I) begin to rise 30 minutes before ground sunrise (sunrise time at Tirunelveli is 0631 IST (the local time is 18.8 minutes behind IST) for this month). The increase in the measured parameters before ground sunrise is perhaps related to the process at some height in the atmosphere that will see an earlier sunrise. A time difference of nearly 30 min between the rise time of the electrical parameters and the ground sunrise time reveals that such height could be somewhere in the region between stratopause and the ionosphere. The maximum that occurred at 1900 UT in
Figs. 4.6 and 4.7 is believed to be associated with the global thunderstorm activity. The other local processes that contaminate the global signal are due to dew and mist that may be present in the morning hours on some days. The space charges that exist at the time of evaporation from dew or mist may contribute to the observed variations in electrical parameters (Karasnogorskaya and Pokhmelnik, 1983, for example).

Fig. 4.6 Diurnal variations of Maxwell current and electric field (one-minute data) on 20 January 2002
Fig. 4. 7 Diurnal variations of Maxwell current and electric field at Tirunelveli averaged over 8 fair weather days during January/February 2002.

The variations observed in $I$ and $E$ at this low latitude station differ markedly from those reported from other low and middle latitudes (Israel, 1973; Burke and Few, 1978; Reiter, 1985; Adelman and Williams, 1996). Israel (1973) found no characteristic fundamental behavior among the measurements from ten continental stations. This can be realized if one considers the relationship between the field intensity ($E$), current ($I$), and column resistivity ($R$), given by $E = wV/R = wI$, where
$w$ is the resistivity at the observation point, $V$ is the total potential difference between
the earth’s surface and the atmospheric electric equalization layer, and $I$ is the current.
Though the field intensity depends strongly on the meteorological processes through
its dependence on the local resistivity $w$, the current, given by $I = V/R$, is less sensitive
to local changes in conductivity. However, changes in the columnar resistance,
induced by the atmospheric suspension content and its vertical transport, may be
expected to dominate the vertical current and its variations. Thus the behavior of $I$
depends on whether the percentage changes in $V$ or $R$ dominate. Over the continental
stations one can expect that the changes associated with $R$ are larger than those
associated with $V$ (Israel, 1973). Gringel et al. (1986) showed that the first two km of
the atmosphere contribute about 50 percent to the total columnar resistance and the
first 13 km about 95 percent. With observations conducted at Weissnau, Germany,
Gringel et al. (1986) measured a variation in $R$ of about 30 percent, and attributed the
variation to a changing ionization near ground and by varying aerosol concentrations
in the lower troposphere. Muir (1975, 1977) tried to explain it on the basis of sunrise
effect at the height of electrosphere leading to build up of a potential through dynamic
motion associated with tides.

During the course of this investigation pre-sunrise effect is most
noticeable. Muir (1975, 1977) has suggested that the processes of ionization in the
ionosphere and polarization in the electrosphere at sunrise would result in an increase
in the potential of that part of the electrosphere experiencing sunrise. This would be
possibly detected as an increase in the atmospheric electrical parameters at the
ground. This pre-sunrise effect would be caused by a tidal sunrise effect at the height
of the electrosphere (where sunrise occurs earlier than sunrise at the ground). Further studies are needed to be sure of the cause of the pre-sunrise effect.

4.3 Analysis of Disturbed Weather Conditions (at Maitri, Antarctica)

4.3.1 Effect of Wind Speed on atmospheric electrical parameters

The surface atmospheric electrical parameters at a place can be influenced by wind speed if some space Charge is either advected or locally generated by wind. There is known anthropogenic source of space charge upwind of our instruments. The local generation of space charge can be neglected during periods of low wind speeds. However, when wind speeds are high, the blowing snow or raising of dust particles may generate and introduce some space charge in the atmosphere. During the period of our observations the ground at Maitri is not covered with snow, and there was no incidence of blowing snow. However, when wind speeds are very strong (say > 10 ms\(^{-1}\)) some dust is observed to be blown off ground. The dust particles so stripped off from the ground may be highly charged and influence the local GEC parameters. If the wind speeds higher than 10 ms\(^{-1}\) may lower the GEC parameters is shown in Fig. 4.8.
Fig. 4. 8. GEC parameter variation on clear sky data with high wind

On February 6, 2002 the whole day the sky is clear and shinny, but the wind speed is high more than 10ms\(^{-1}\). This may well be because of the presence of the negative space charge formed by the negatively charged dust particles in the lower atmosphere which are blown off the ground with high wind speeds [Kamra, 1969, 1972]. Wind speed may also be caused by the blowing off of the space charge caused by the electrode effect or convection currents. Such electrode effect / convection
current caused deviations in atmospheric electrical parameters. In fair weather, gamma radiation from the ground and from space ionizes air, separating charge and creating an electric field at the Earth’s surface. The field is extremely variable, averaging 120 V m\(^{-1}\) at 1m height (Iribarne and Cho, 1980). The atmospheric electric field reverses direction and its magnitude increases in the region occupied by blowing particles, indicating excess negative charge density above the surface (Schonland, 1953). Electric field strength diminishes with increasing height in the transport region (Schmidt and Dent, 1994), as expected if excess charge density is associated with the distribution of moving particles. During clear sky days the conductivity is more or less stable, so as per the ohms law if the electric field varies and the conductivity is stable the current should vary according to the field which is seen in Fig. 4.8

### 4.3.2 Effect of Blizzard

Blizzards are generally described by low temperatures, strong winds, large quantities of snow (Bostwick 1916; Breton 1928; Huschke 1959; Bozman 1970; Hank 1976; McLeod and Hanks 1982; Whittow 1984; Barnhart and Barnhart 1984; Gretz 1986; Sinclair 1992) and with long duration (Funk 1956). While the words ‘blizzardly’, ‘blizzarded’ and ‘blizzardous’ (adjectives) are terms to describe a blizzard tending to occur or to produce a blizzard (Gove 1961; Klein 1971; Barnhart and Barnhart 1984; Schwarz 1989; Simpson and Weiner 1989; Schwarz 1993). Sometimes a blizzard is called a ‘white-out’ where blizzard conditions occur with a total snow cover. Under these conditions it is extremely difficult to find one’s direction. The impression is of being swathed in a white opacity (Monkhouse 1970). White-outs are common in polar region and leads to loss of balance and sense of balance (Whittow 1970). Today, in general terms the word means a severe snowstorm
in nearly every English-speaking country (Tufty 1987). According to Barnhart and Barnhart (1984) a similar storm of wind-blown sand or dust is also called a blizzard.

In Antarctica, blizzards are associated with winds spilling over the edge of the ice plateau at an average velocity of 160 km/hr (Anonymous 1915; Monkhouse 1970; Monkhouse and Small 1976; Hudson 1979; Gretz 1986). In the USA, the US Weather Bureau in 1958 defined a blizzard as one characterized by winds of 56 km/hr or more, a temperature of -7 °C or less and driving snow to limit visibility to 150 m, while a severe blizzard is one where winds exceed 72 km/hr, visibility near zero and temperatures of -12 °C or lower (Huschke 1959; Considine 1976; Gretz 1986; Tufty 1987; Ahrens 1991; Meteorological Office 1991). The Canadian Weather Service describe a blizzard as winds of 42 km/hr (Force 6) or above; visibility 0.8 km or less; temperatures 22 °F (-7 °C) or less and to last six hours or more (Hudson 1979). The blizzard duration is likely to be dependent upon the scale and shape of cyclones. The number of severe blizzards is not controlled by “in situ” annual mean meteorological conditions, but by the number of strong cyclones having time scales of several days coming from the lower latitude region.

Antarctica is the windiest continent on the earth. The land mass is scoured by a regime of persistent and powerful katabatic or gravity winds which are the result of cold dense air rolling down the continental slope from the high plateau. The term katabatic is defined as a wind that flows downslope (due to negatively buoyant air being acted upon by gravity) with a vertical profile that possesses a near-surface jet, such that the wind speed measured at some level near the surface is greater than the wind speed at the adjacent level above. Generally, a katabatic wind’s low-level wind
maximum is located within the lowest 100 m of the atmosphere. These katabatic winds interact with warmer air from the ocean to produce clouds, fog and extremely strong blizzards in association with moving low pressure systems. The local winds are strengthened with the passage of low pressure systems and wind speed of 88 knots gusting to more than 100 knots. A combination of two moderately strong cyclones is also important in the formation of severe blizzards.

![Graph](image)

Fig. 4.9 Variation of GEC parameters during blizzard day.
Simpson [1919] observed that blizzards are intensely electrified and produce high positive potential gradients on the ground. In our observations we observe that whenever high winds are accompanied with some snowfall, i.e., atmospheric Maxwell current, Air-earth-current, electric field of all the three categories begin to decrease about 3 – 4 hours before the appearance of blizzard. For example, on December 28, 2008, winds begin to strengthen at 1200 UT and blizzard started from 1500 UT shown in Fig 4.9. Devendraa Siingh, Vimlesh Pant and A K Kamra made similar observations at the same place in summer 2005 on atmospheric air-earth current density, temperature are below freezing point, positive ion concentration of all four categories begin to decrease 3-4 hours before the onset of blizzard. The decrease observed in all types atmospheric electrical parameters during snowfall indicates that snow particles effectively scavenge the ions. The fact that the air-earth current density and electric field almost reduces to zero value indicates that scavenging of atmospheric ions is almost total at that time. The observations that the decrease in different ion categories is not always parallel to each other are likely to result from the non-uniform rate of scavenging of the ions of different sizes. This observation can be used as a forecasting for the convoy persons and other activities around Maitri for human safety and preliminary percussions. The detailed mechanisms underlying the formation of severe blizzards are not yet well understood and form one of the interesting topics for future polar research.

4.3.3 Effect of Fog

The fog was formed due to advection of southeasterly winds by high moisture containing northwesterly winds, blowing from the ocean over the cold ice shelf,
which leads to the condensation of moisture, thereby forming fog at Maitri, Antarctica. Stratiform clouds are common near the Antarctic coast. Fog is essentially a dense cloud of water droplets, or cloud that is close to the ground. Fog is also an important alternative source of moisture for plants. Virtually no higher plant life-form exists on the Antarctic continent. However, minute organisms survive in small pockets of ice-free areas. In the driest and coldest habitats, especially where fog and dew are the major water sources, desiccation-tolerant algae or cyanobacteria, bryophytes and lichens may form the only vegetation (M.A., Lazzara et al., 2003). Fog is the biggest forecast problem related to flights aborted due to bad weather and few studies have been undertaken on the Antarctic fog. Fog and haze at Maitri, Antarctica have been rarely recorded.

Fog is defined as a cloud that touches the ground and reduces the visibility to 1 km or less. There is no physical difference between a fog and a stratus cloud, other than altitude. Unlike thick, rain-producing clouds which are characteristically formed by the expansion and cooling of rising air, the cooling of humid surface air below its dew point temperature usually causes fog. This cooling can result from radiational processes, from the mixing of warm and cool air masses, or from warm moist air moving over a cooler surface. The induction of warm, marine oceanic air to the interior causes low-level cloud over the Maitri.
Fig. 4.10 Fog on 10th February 2004 at Maitri, Antarctica

On February 10, 2004, the PBL dynamics revealed unique sodar facsimile features shown in Fig. 4.10. The fog was seen between 1600 – 2345 UT and the Maitri region was under the influence of thick fog. The fog layer ultimately diminished, as the flow of northerly air weakened and was taken over by the gravity-driven flow (katabatic wind) around 2400 h on 11 February 2004. During this period the electric field and Maxwell current went well below zero and become negative. However, further investigation on the wind direction gives us an idea of how the fog was formed. The direction of the surface wind on 10 February 2004 remained basically from the NE sectors for most of the time during the foggy period. It is pertinent to mention here that the wind directions over Maitri are dominated by the ESE direction; these are mostly katabatic winds flowing from the interior of the continent. Thus, the present case of winds from the northern quadrants is clearly
oceanic in nature. The above results therefore suggest that the slow wind from the NE quadrant brought moisture-containing air masses from the ocean, which is about 70 km from the oasis. Visual observations suggested that the condensation of fog was considerable and the ground was wet during this episode. The dissipation of fog was only after the katabatic wind started flowing from the interior of the continent. Therefore, this type of fog can be regarded as advection fog (Petterssen, S., 1958). However, in Maitri, the number of days with fog is generally low throughout the year. In Maitri, there is little or no rainfall, and thus the localized fogs contributed atmospheric moisture to the few microbiotic crusts as their sole water source. It is also likely that due to changing climate over Antarctica, frequent fog may occur in the near future.