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Key Points:

- The electricity parameters have discrepancy with the expected global diurnal pattern
- There are three dominant diurnal patterns during the fair-weather days
- The katabatic winds influence the of fair-weather electrical parameters

Correspondence to:
K. Jeeva,
jeeva@iigs.iigm.res.in

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Anomalous diurnal variation of atmospheric potential gradient and air-Earth current density observed at Maitri, Antarctica

K. Jeeva[1], S. Gurubaran[2], E. R. Williams[3], A. K. Kamra[4], A. K. Sinha[2], A. Guha[5], C. Selvaraj[1], K. U. Nair[1], and Ajay Dhar[2]

[1]Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Tirunelveli, India, [2]Indian Institute of Geomagnetism, New Panvel, India, [3]Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, [4]Indian Institute of Tropical Meteorology, Pune, India, [5]Department of Physics, Tripura University, Agartala, India

Abstract The scope of this paper is to explore the mechanisms operating over Maitri (70.76°S, 11.74°E, 117 m above mean sea level), a coastal Antarctic station, that produce an anomalous fair-weather diurnal pattern of the atmospheric electric potential gradient (PG) and air-Earth current density (AEC). The anomaly in the diurnal variations of AEC and the PG is displaying an ostensible minimum at ~10 UT and a diminished response to the thunderstorm over the African continent in the 14–16 UT time frame. The data sets (2005–2014, except 2012) of the PG, and to some extent, AEC, from Maitri, are used to explore this anomaly. It follows that the fair-weather electrical phenomena over Maitri can be ascribed to global electrified convection on the one hand and to regional phenomena like convection due to the replacement of warm air by katabatic winds on the other hand. The katabatic winds originate on the polar plateau and blow from ~130° at Maitri which are likely to transport various elements from the mountain slopes, and space charge from the polar plateau is expected to produce various disturbances in the PG and AEC monitored over the coastal Antarctica. This mechanism may be responsible for peaks in the early UT hours and also for the anomalous behavior of atmospheric electrical parameters observed at Maitri. Maitri data are compared with that of Carnegie cruise and Vostok to explain the source of anomaly.

1. Introduction

Monitoring of the global atmospheric electric circuit parameters is emerging as a useful tool in the study of climate changes because of its direct connection with lightning activity. They are directly related to the global electrified convection and therefore act as proxy variables for the mean global surface temperature [*Markson*, 1986; *Markson and Price*, 1999; *Williams*, 1992, 2005; *Price*, 1993]. It is also considered to be an important study to understand the relationship changes in the global circuit and space weather [*Rycroft et al.*, 2000, 2012]. The atmospheric electricity data, for such a study, should not be contaminated by any local anthropogenic and meteorological disturbances. Monitoring the atmospheric electricity parameters over the ocean, the data obtained during the 1915–1928 Carnegie Expedition [*Whipple and Scrase*, 1936] were found to be stable and systematic probably because there was no contamination from meteorological disturbances and radioactivity sources that were typical over the continental stations. Furthermore, aerosol concentrations over the oceans are markedly more dilute in comparison to the situation over land. In addition, it was believed that the fair-weather global signatures of the electrical parameters could be monitored from the remote continent, Antarctica, for the following reasons [*Cobb*, 1977]: (1) anthropogenic influences are nearly absent; (2) the surface of Antarctica is expected to be smoother than the typical continental surface, and as a result the air turbulence is negligible; and (3) the absence of radioactive soil. *Deshpande and Kamra*, [2001] cited three additional points. They are the following: (1) the weather remains clear for 70% of the time; (2) high surface winds which generally prevail over the continent generate mechanical turbulence by friction with the rough bare ground that is almost nonexistent or very much less intense; and (3) deep temperature inversions suppress the local atmospheric convection. Being an area of large-scale subsidence, the convective turbulence is very small.

Given these prevalent conditions over Antarctica, measurements from Amundsen and Scott (South Pole station) and Vostok (the interior continental stations over the Antarctic Plateau) proved to be suitable to reproduce the Carnegie-type diurnal pattern [*Burns et al*., 1995; *Reddell et al*., 2004] at least in a seasonally averaged sense. The Antarctic continent, particularly the plateau region, thus has the potential to host suitable locations to monitor the global features of the fair-weather electric environment. The coastal regions of Antarctica, where the majority of the scientific research bases are situated, are characterized by different orographic and atmospheric features. These can modify the expected fair-weather electrical environment thereby causing deviation of the observed electrical parameters from the Carnegie pattern. The research stations in the interior of the continent are nearly free from the complicating physical phenomenon discussed below which are the disadvantages of the coastal Antarctic stations.

1. Cyclonic storms caused by circumpolar troughs are very frequent in the periphery of the continent and result in a considerable reduction in the number of fair-weather days. The circumpolar trough is the result of many depressions that are found just north of the edge of the continent. These lows are responsible for much of the precipitation that falls in the coastal region [*King and Turner*, 1999].
2. A net longwave radiation on the Antarctic plateau cools the near-surface air. The colder and denser air flows down the slope replacing the less dense air at lower elevations [*Ishikawa et al*., 1982]. In the continental interior, katabatic wind speeds are low because of the small topographic slopes [*Renfrew and Anderson*, 2006], but near the steep-sloped coast, wind speed increases because of the above scenario [*Nylen and Fountain*, 2004]. Observations of *Dhanorkar and Kamra* [1993a, 1993b, 1994] and *Kamra et al*. [2015] show that the katabatic flows can significantly influence the atmospheric electrical parameters in the basins of valley.
3. The katabatic winds are expected to carry minute ice crystals which can modify the electrical properties of the atmosphere over the coastal Antarctic stations [*Contini et al*., 2010].
4. An electrical phenomenon often ignored by most of the authors in the study of fair-weather electrical environment over Antarctica is the electrode layer. The electrode layer over the icy continent can produce various complications in the fair-weather electric environment. In fact, the land surface covered by thick ice sheet is considered to be the best location to study the electrode layer due to the absence of the radioactive sources and radon gas emanating from the Earth to ionize the air close to the surface of the Earth [*Ruhnke*, 1962].
5. The Antarctic aerosols in majority are the sea salts and biogenic aerosols [*Fattori et al*., 2005]. If these aerosols are transported toward Maitri, they may provide significant perturbations to the electrical environment. The back trajectory study over Maitri indicated the presence of some aerosols in the winds from the polar plateau [*Chaubey et al*., 2011].
6. Another important aspect of the electrical disturbance is the mapping of magnetospheric electric field and the katabatic winds. The open magnetic field lines over the polar region offer free access to the charged particles ejected from the Sun during severe solar activity. The electric field of the magnetospheric origin is mapped down through the highly conducting magnetic field lines to enhance the atmospheric electric field [*Roble*, 1985]. There is a very clear indication by *Ogawa* [1977] that during disturbed katabatic winds the electric field at ground level went off scale. This is an additional disadvantage of the periphery of the Antarctic continent to host the atmospheric electricity laboratory for the observation of the unperturbed Earth-ionospheric potential.

Measurements of the PG from two Antarctic coastal stations (Davis and Syowa) in the coastal regions of Antarctic continent [*Burns et al*., 1995; *Minamoto and Kadokura*, 2011] are available. The sites for the present work, Maitri, and these two stations, have orographic features that are different from those of the interior stations like Amundsen and Scott and Vostok. Davis and Syowa are situated on the exposed rocky terrain near the ocean, whereas Maitri is about 80 km inland far from the ocean. From a study carried out from Davis station, *Burns et al*. [1995] concluded that local influences due to surface winds contaminate the data to the level of no value for further investigation. Presenting their observations from Syowa, *Minamoto and Kadokura* [2011] arrived at similar conclusions. These results elucidate that the fair-weather atmospheric electricity parameters are highly contaminated. The probable cause could be the surface winds carrying aerosols and particles. Most of the stations from Antarctica have the facility of monitoring either the potential gradient or the air-Earth current. To have a complete understanding on the atmospheric electricity, the monitoring of all the three basic parameters of electricity, namely, the electric field, current, and the conductivity, is preferable. The conducting characteristics of the atmosphere are caused by the ion clusters (small ions) produced by the cosmic rays and terrestrial sources. These ions are to flow vertically downward under the influence of the vertical Earth-ionosphere potential gradient in the absence of any other dominant mechanical forces that lift the air parcels with ions. Convection and changes in the dimension of the planetary boundary layer are a couple of examples of mechanical forcing. The flow of ions causes air-Earth conduction current density of the order of $10^{-12}\,\mathrm{A\,m^{-2}}$ across the total columnar resistance. The total electrical resistance for a unit area of the atmosphere is called the columnar resistance R_C. The atmospheric Ohm's law connects all three parameters as in equation (1)

$$V_I = J_C R_C \tag{1}$$

By convention, the electric field (E) is referred to as potential gradient (F in equation, PG in text). It is defined as the negative value of the electric field

$$F = -E \tag{2}$$

At the surface the PG is caused by J_C flowing through the feeble conducting atmosphere. It is therefore Jc that permits the variability of the global electric circuit to be measured at the surface, either directly through the measurement of J_C or by PG. However, PG is also a function of the local air conductivity (σ). Away from sources of the charge separation, i.e., the active thunderstorm regions, the air conductivity (σ), potential gradient (F), and conduction current density are related by Ohm's law.

$$F = J_C/\sigma \tag{3}$$

In the fair-weather part of the global electric circuit, the small ions dominate the charge transport since they have a larger electrical mobility than the medium and large ions. Therefore, an increase in small ion concentration will increase the air conductivity by providing more charge carriers. The aerosol concentration in the atmosphere reduces the small ion density by attachment and decreases the air conductivity. A change in aerosol density subsequently modifies the total columnar resistance (R_C) and the conduction current (J_C) and consequently has an indirect effect on the PG through equation (3). A decrease in the conductivity is an increase in the electric field.

We list here a few measurements made on the atmospheric electricity parameters from Maitri over the past two decades. Most of the results contradict with each other. *Deshpande and Kamra* [2001] made measurements of atmospheric electric potential gradient and conductivity for the first time from Maitri. They derived the current density from these two parameters. As reported by these authors, the diurnal pattern of the PG strongly deviated from the Carnegie pattern by having a prominent maximum at about 13 UT and a secondary maximum at about 19 UT. The measurements were carried out between January and February 1997, and 20 fair-weather days were considered in their work. The wind speed on those days was less than $10\,\mathrm{m\,s^{-1}}$. The cloud amount was less than 3 okta, and there was no precipitation during their period of observations. *Panneerselvam et al*. [2007] presented another set of results on the diurnal variation of the PG and Maxwell current density. In their report, the mean diurnal variations were obtained from 69 fair-weather days from the austral summer months distributed as 10, 12, 10, and 37 numbers of days during the years 2001–2004, respectively. In their studies the selection of fair-weather days was done solely based on the conditions used by *Deshpande and Kamra* [2001]. Neither the 69 day mean nor the annual mean showed the dominant peak at 13 UT as shown by *Deshpande and Kamra* [2001]. On the contrary, a noticeable depression was evident around this time. Their results could reproduce the majority of the features first reported for the Carnegie curve. However, they failed to describe the markedly noticeable depression near ~12 UT. *Jeeva et al*. [2011] analyzed the PG and Maxwell current density data for 44 days and atmospheric conductivity data for 16 days during December 2006 to February 2007 and demonstrated that there is a significant day-to-day variability in the fair-weather electrical environment highlighting the broad depression found at ~12 UT. The fair-weather days were selected as per the existing criteria described in the aforesaid reports. Later, another report emerged on the diurnal variation of the PG observed from Maitri [*Siingh et al*., 2013]. They considered 12 fair-weather days distributed over the months of January and February 2005. In this report, the diurnal variation of potential gradient was seen as a replica of the Carnegie curve with a correlation coefficient ~0.93 at a significance of <0.0001. This work also claims that wind velocities of less than $10\,\mathrm{m\,s^{-1}}$ and surface temperatures lower than 7°C have had almost no impact on the electric field. These authors observed neither a peak PG at ~13 UT observed by *Deshpande and Kamra* [2001] nor a depression in the

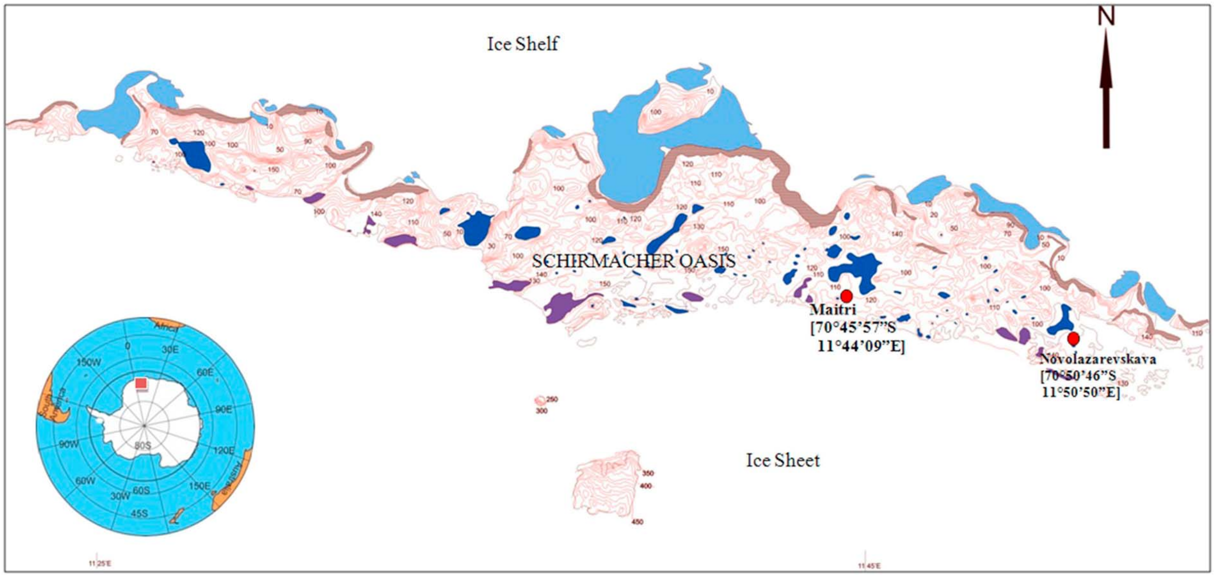

Figure 1. Geographical location of Maitri in Schirmacher Oasis surrounded by polar ice sheet and ice shelf.

prenoon hours observed by *Panneerselvam et al*. [2007] and *Jeeva et al*. [2011]. The reason for such varied results from the same location and same experimental setup could be using a small quantity of data or data pertaining to austral summer alone.

It is understandable from the previous studies of the air-Earth current density (AEC) and the PG observed from the stations over the periphery of the Antarctic continent that they do not provide consistent UT-dependent characteristics. In the present work, we attempt to bring out a predominant behavior of PG and AEC over Maitri, by analyzing the data from the years 2005 to 2014. The use of the maximum available data from the Maitri station would certainly reduce the uncertainty and ambiguity of the results obtained in the previous years, which often focused on data during austral summer alone. The current study also includes the validation of the PG data by verifying the linearity of the electric field meter (EFM) used in the earlier studies from Maitri and deducing an appropriate scale factor for the instrument operated there. Based on the validation of the data and scale factors, the data for the years 2005 to 2011 were corrected by determining a common scale factor. The geomagnetic data and meteorological weather parameters provided complementary information on the influence of space weather and boundary layer processes on the atmospheric electrical environment, respectively. In section 2 a brief description of the experiment site is provided. This includes the geological features of the site, orographic features, meteorological weather, and climatological conditions. Section 3 provides details of the instrumentation and the criteria followed for the fair-weather days to select the data. Section 4 provides the results. First, we present the results obtained from the fair-weather days of each year from the year 2005 to 2014 to show the anomaly of the diurnal pattern in the PG. Thereafter, a few case studies are shown to demonstrate various diurnal patterns of the AEC and the PG and their interactions with katabatic winds and the seasonal variations. The results are discussed in section 5, and the concluding remarks with future plans for study are presented in section 6.

2. Description of the Experiment Site

Figure 1 (adopted from *Shrivastava et al*. [2015]) gives a broad view of the location of Schirmacher Oasis in the eastern Antarctica where Maitri is situated. It is in the region of Queen Maud Land (the sector between 0° and 30°E) at the fringe of the downslope of the polar plateau over the exposed part of the continent called Schirmacher Oasis. This oasis is a small moraine of the Antarctic glacier with an area of ~35 km^2 with a range of low-lying hills at different altitudes ranging from 50 m to around 130 m. The Maitri station is situated in a valley-like place between the raised polar ice sheet and ranges of the foresaid hillocks. An ~80 km stretch of shelf ice lies between Maitri and the ocean. The slope of the ice sheet is from the SE quadrant from which intense katabatic flow is expected [*Kumar et al.*, 2007]. A few results from the aerosol studies over Maitri showed that the characteristics were nearly identical to the values found over the Arabian Sea and Indian Ocean. *Gadhavi and Jayaraman* [2004] reported a lower aerosol optical depth of about 0.03 at 400 nm and a dry aerosol concentration mass of about 7 $\mu g\,m^{-3}$ for the PM_{10}. However, in comparison with other Antarctic stations such as McMurdo (77°51′S, 166°40′E), the Maitri value is high. *Mazzera et al.* [2001] have found average PM_{10} in the range of 3.21 to 4.81 $\mu g/m^3$ during the years 1995–1997, at two different locations over McMurdo station. A typical annual mean concentration value of the PM_{10} for an urban site, Agra, India, is ~148.4 $\mu g\,m^{-3}$ [*Kulshrestha et al.*, 2009]. *Deshpande and Kamra* [2004] reported that the condensation nuclei concentrations at the coastal stations are 2–5 times higher than those at the South Pole and interpretations of the results of aerosol size distribution over the Antarctic coastal region are more difficult than those from the stations over the plateau. This is because of the intermixing of the effects of strong continental drainage flows due to sloped inversions and katabatic winds and the baroclinic disturbances generated over the Southern Ocean regions surrounding the Antarctic continent. Moreover, submicron-sized particles are suspended throughout the troposphere and lower stratosphere over the ice sheet of Antarctica. Their concentrations show a strong seasonal variation, being as low as a few cm^{-3} in winter to as high as several thousand cm^{-3} in summer [*Hogan*, 1975]. These observations are important from the atmospheric electricity point of view. These particles are expected to cause severe disturbances of the electrical environment by modifying the electrical conductivity, AEC, and the PG. Katabatic winds caused by radiative cooling of near-surface air are a nearly ubiquitous feature of the Antarctic coastal slopes. The majority of the katabatic winds flow from the direction 130°. The radiative cooling of the near-surface air is expected to cause a thermal inversion, resulting in a favorable pressure gradient for the downslope wind component [*Gosink*, 1989]. The Maitri station has the facility of continuously monitoring the geomagnetic field variations and meteorological parameters by professionals. Additional orographical features and wind patterns over Maitri have already been demonstrated [*Siingh et al.*, 2013].

3. Instrumentation and Fair-Weather Days and Data Selection

Long-wire antenna is used to detect the air-Earth current. The basic principle of this setup is that the antenna suspended in the atmosphere will accumulate charges guided by the vertical electric field lines. If these charges are discharged through a suitable electrometer, the current variation will be representing the atmospheric current. In the present experimental setup, a long wire of length 10 m and thickness 3 mm is kept horizontally stretched parallel to the ground at a height of 1.2 m. The wire is mechanically supported by means of masts. By using Teflon rods at their ends, it is ensured that the antenna wire is electrically insulated from the supporting masts. The input is fed through the electrometer (Model AD 549) that has high input impedance and permits extremely low input bias current (10^{-14} A). The electrometer measures the current up to 1 nA (corresponding to the output voltages whose limit is ±5 V) with a feedback resistance of 5×10^9. A unity gain operational amplifier (LM308) amplifies the electrometer output signal. The amplified signal is then taken in a shielded cable over a distance of 10 m to the control room where it is fed to a PC-based data logger. The sensitivity of the digitized signal is 2.44 mV that corresponds to a current of 0.5 pA. The data are recorded at a sampling interval of 1 s. Though there lays complication in using the effective area [*Tammet et al.*, 1996], we obtained it from the equation $A = hc/\varepsilon_o$ [*Kasemir and Ruhnke*, 1959]. This equation simply considers the air between the long-wire antenna and the Earth as dielectric medium. The two conductors are the long-wire antenna and the Earth. A is the effective area of the antenna, h is height of the antenna, c is the capacitance of the antenna, and ε_o is the dielectric constant of atmosphere.

A field mill which is of Boltek manufacture (EFM-100) was installed at Maitri in the month of December 2008. Though this instrument is meant for the detection of lightning for safety purposes, it can also be used to measure the fair-weather electric field [*Raulin et al.*, 2014]. The sensitivity of the EFM is 1 V/kV in dual-output mode and 0.5 V/kV in single-ended output. At present, the EFM output is availed from single-ended output. The data from the years prior to 2009 have been normalized according to the new EFM. For the convenience of continuous operation the EFMs are installed over a mast at the height of 1.0 m. To get the correction factor for these EFMs, an additional experiment was carried out. At Maitri the permanent EFM is close to the Nandadevi

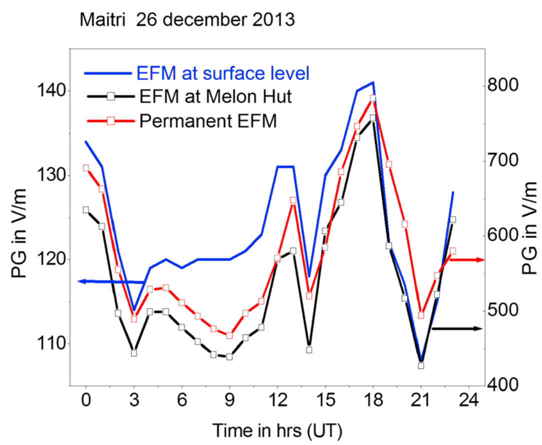

Figure 2. Comparison of the diurnal variation of the PG obtained from three different locations around Maitri on 26 December 2013 to calculate the scale factor for the permanent electric field mill.

hut. A test EFM was installed near the Melon hut (50 m away from Nandadevi EFM) on a tripod with 1 m height and another one flush mounted with the ground. These two EFMs were monitored from the Melon hut.

Figure 2 shows the hourly mean diurnal variation of the PG monitored on 26 December 2013 from three different EFMs at three different locations as mentioned above. The correction factor is obtained as below. To obtain the correction factor first, the raw data are multiplied by the scale factor (1 V per kV/m for differential output and 0.5 V per kV/m) and then the mean of the day is calculated. This is done for the reference EFM as well as the permanent EFM.

$$\text{Correction} = (24\text{ h mean of the reference EFM in V/m})/24\text{ h mean of the reference EFM in V/m}$$

We also used this opportunity to verify the sensitivity of the EFM successfully, through Faraday-shielding method involving the application of a stepped-range voltage on periodic basis. Considering Maitri's proximity to the Antarctic coast, fair-weather days satisfying the prescribed conditions are rare. In most of the results from Maitri published in previous years, the conditions for fair-weather days when there is no precipitation and high clouds are less than 3 oktas throughout the day and wind speed is less than 10 m^{-1} [*Deshpande and Kamra*, 2001]. These conditions were originally proposed by *Ruhnke* [1962] for the location in Greenland, and these were reviewed for the actual conditions at Maitri. Most of the measurement sites in Antarctica lie at the periphery of the continent over the icy surface or the exposed landmass with raised hillocks. In the present work extreme care has been taken in the selection of fair-weather days. Further, the variations caused by charge separation, most probably by winds, were removed following earlier procedure [*Burns et al.*, 2005, 2012]. Table 1 lists the number of fair-weather days and some more statistical details obtained from the comparison of curve of Maitri PG obtained from the fair-weather days of every year. The fair-weather days are relatively fewer in the years 2009 and 2010. This is due to severe blizzards, and the number of fair-weather days in austral summer was very poor for these years.

4. Results

4.1. Annual Mean Diurnal Variation of Potential Gradient

Figure 3a shows the fair-weather annual mean diurnal variation of the PG monitored at Maitri during the years 2005–2008, 2011, and 2013–2014. Data for the year 2012 are found to be not satisfactory due to faults in the logging software and hardware connections. The annual mean diurnal variation of the PG is correlated

Table 1. Number of Fair-Weather Days From Each Year Considered in This Work and the Annual Mean Potential Gradient (in the Second Row), Correlation Coefficient (in the Third Row), and Its Significance (in the Fourth Row)[a]

	Year								
	2005	2006	2007	2008	2009	2010	2011	2013	2014
No. of FW days	102	168	131	149	47	25	127	118	139
Annual mean PG in V m^{-1}	134	130	123	124	-	-	125	128	143
R value between Maitri and Carnegie curve	0.7	0.6	0.8	0.8	-	-	0.7	0.5	0.7
Significance	<1E^{-4}	9.9E^{-3}	<1E^{-4}	<1E^{-4}	-	-	3.2E^{-4}	9.7E^{-3}	1.7E^{-4}

[a]The winter data of the years 2009 and 2010 are not used as they were quite noisy.

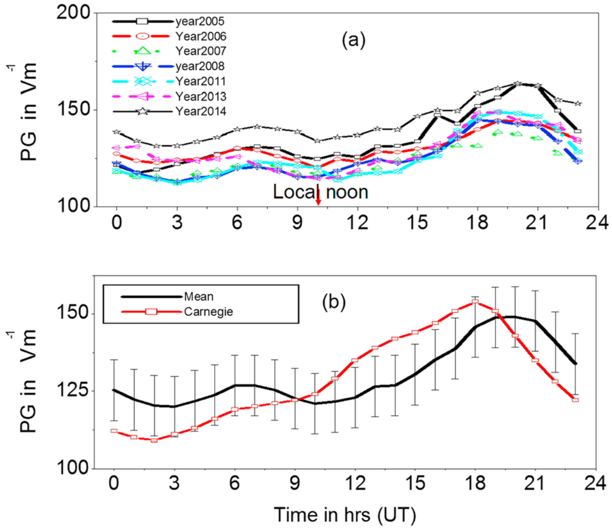

Figure 3. (a) Annual mean fair-weather days variation of PG obtained at Maitri during the years 2005 to 2014 and (b) comparison of mean diurnal variation PG of Maitri obtained from the same years from Maitri with Carnegie curve.

with the Carnegei curve. The correlation coefficient and level of significances are listed in Table 1. There is a considerable difference among the correlation coefficient (0.5 to 0.8) and level of significance. A possible cause for such a deviation could be the variability in the magnitude of the global lightning flash rates. For example, *Satori et al.* [2009] reported that global lightning is slightly enhanced in the warm El-Niño phase and slightly suppressed in the cold La Niña phase. *Dowdy* [2016] recently established a correlation between the variability in the lightning activity and the El Niño Southern Oscillation variation. The annual mean value of the PG varies very systematically. The mean PG for the year is 134 V m^{-1}. This keeps decreasing till 2007 (123 V m^{-1}) and thereafter a steady raise till 2014 (143 V m^{-1}). Though it is appealing to examine the presence of these features over the atmospheric electricity parameters, we opine that it is worth doing after resolving various ambiguity in the fair-weather diurnal patterns of the AEC and PG as discussed in section 1. The Maitri curve differs from the Carnegie curve by having a secondary peak at ~07 UT and an additional minimum at about 11 UT. Though the minimum at 03 UT and maximum at 19 UT show maximum of the global thunder storm activity, the 11 UT minimum makes the Maitri diurnal curve depart from the Carnegie curve pattern. Usually, the Carnegie curve is explained based on the timing of the thunderstorm activity over three different tropical chimneys, namely, the Asia/Australia/Maritime Continent (08 UT), Africa (15 UT), and Americas (19 UT). A closer examination of the diurnal curve at Maitri reveals that the contribution of the African chimney is suppressed indicating that the possible role of local disturbances superposed on the expected diurnal pattern has presumably caused the observed deviation.

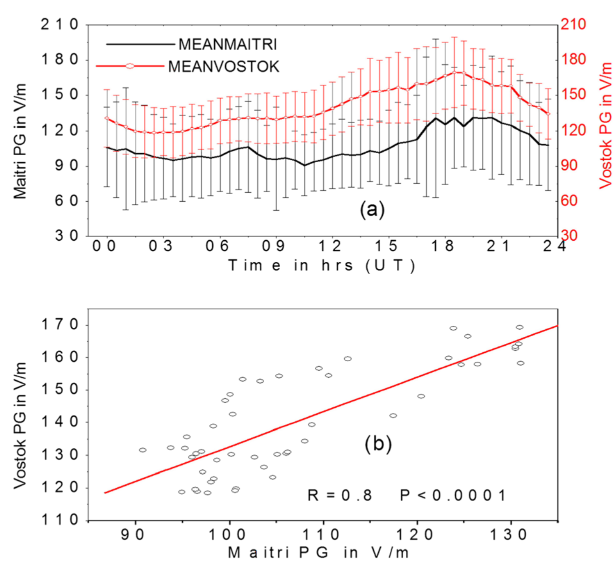

Figure 4. Comparison Maitri PG and Vostok PG. (a) Comparison of 30 min averaged diurnal variation of PG obtained from 46 fair-weather days simultaneously monitored at Maitri (coastal station) and Vostok (interior plateau station) simultaneously during the year 2011. (b) Linear relationship between Maitri and Vostok.

Figure 3b shows a comparison of the Maitri mean curve obtained from all the fair-weather days (as per Table 1) with the Carnegie curve. During the hours between 19 UT and 08 UT (the majority of the hours are night hours for Maitri), the amplitude of the PG at Maitri is greater than the Carnegie curve, and during the hours between 8 UT and 19 UT (day hours at Maitri), it is lower. It appears that there is a superimposed local signal, caused by a local generator, setting in at about 19 UT to enhance the PG and making it deviate from the Carnegie curve. This

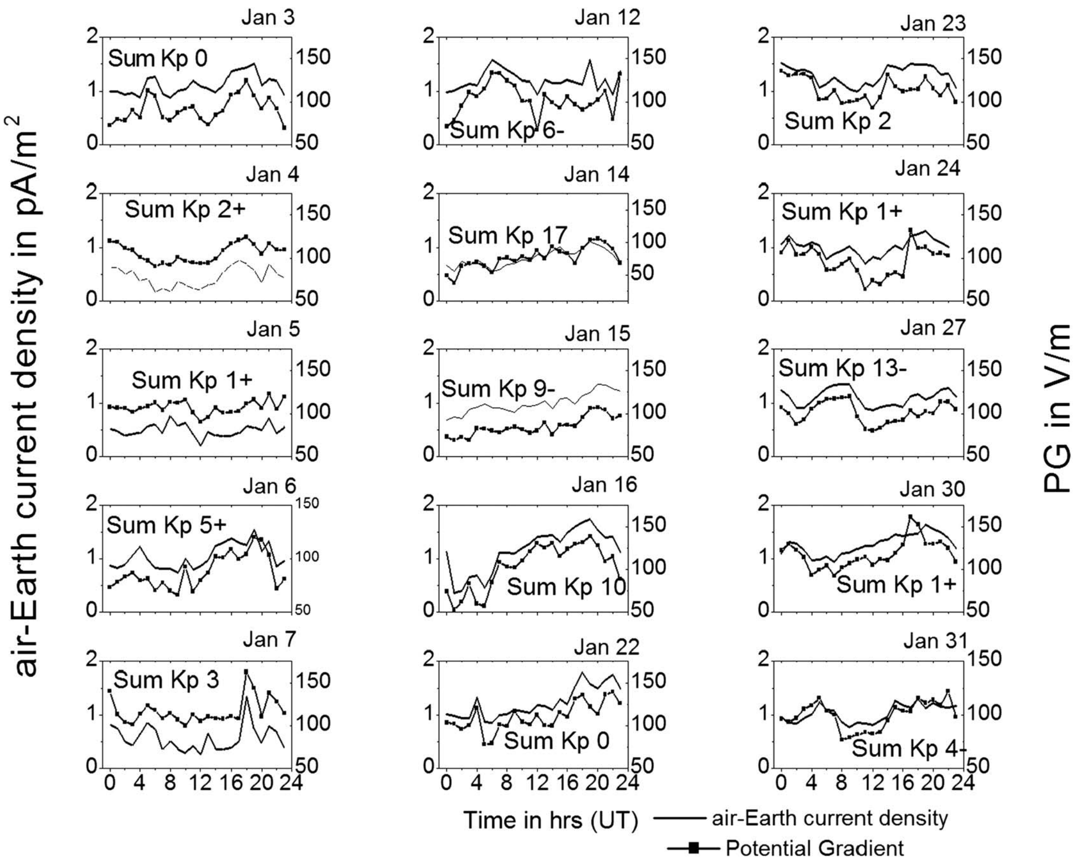

Figure 5. Various patterns of diurnal variation of AEC and PG observed for 15 fair-weather days from the month of January 2013 along with the ΣKp values to explain the geomagnetic activity on these days.

deviation becomes largest around 00 UT hours to gradually decrease and cease at about 09 UT thereby resulting in the anomalous diurnal pattern over Maitri. The anomaly has further been deciphered through the comparison of the simultaneous observation of PG between Maitri, a coastal Antarctic station, and Vostok, an interior Antarctic polar plateau station for a randomly selected year 2011. Figure 4a shows the comparison of 30 min averaged mean diurnal variation of PG of Maitri and Vostok. Figure 4b shows the correlation coefficient between Maitri and Vostok which indicates that there is a significant agreement among these two mean diurnal curves. When hourly average of PG of Maitri and Vostok is compared with that of Carnegie curve, the correlation coefficient for Maitri is 0.68 with $2.2e^{-4}$ significance and for Vostok it is 0.97 with significance $<1e^{-4}$. This is an indication for the presence of local disturbances over Maitri. The narrowing of the difference between Maitri curve and Vostok curve, around the time sector between the midnight to noon and evening when the katabatic wind speed is at its maximum, to midnight appears that there is enhancement of Maitri PG around these hours. Emphasis is given in the rest of the present work to explore the mechanism that might have produced this anomalous pattern, particularly the features appearing during 00–08 UT and 19–24 UT.

4.2. Different Types of Fair-Weather Diurnal Variation

Figure 5 shows, for example, the hourly mean diurnal variation of all fair-weather days available for the month of January 2013. The significance of selecting this month is that this is one among the months which have a good number of fair-weather days. Usually, the months from October to March, we can have relatively more number of fair-weather days than the other months. Additional information provided for each day is the ΣKp, an indicator of geomagnetic disturbances. There are few indices in the study of geomagnetism to denote the geomagnetic activity. The Kp is one among them which denotes the 3-hourly disturbance status. The ΣKp provides the geomagnetic activity for a day. The reader is referred to *Bartels* [1957, 1963] for a detailed

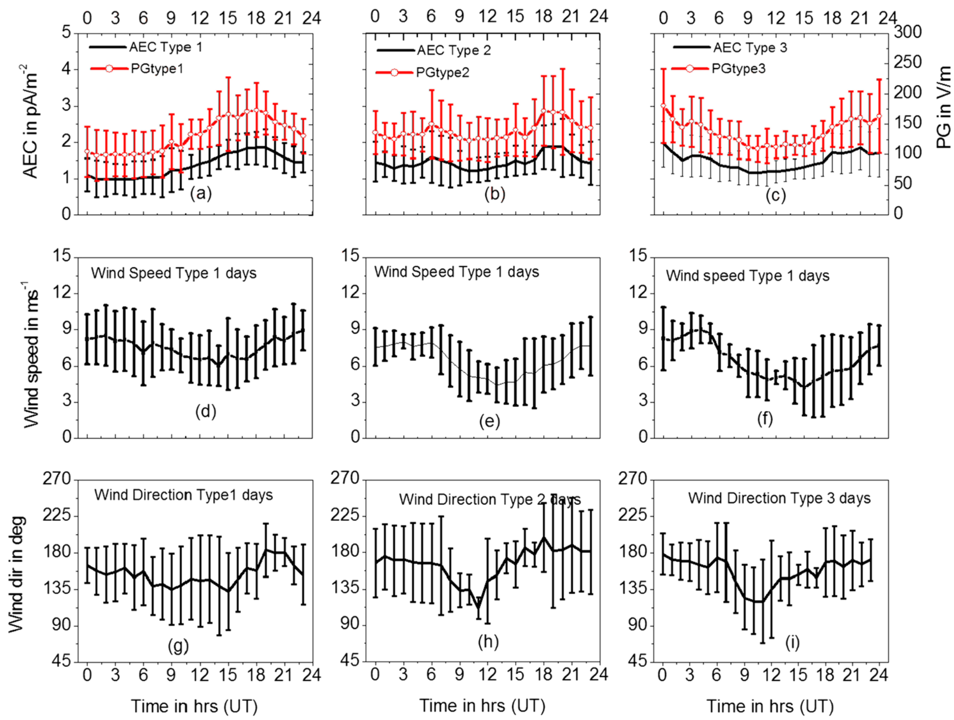

Figure 6. Hourly mean diurnal variation of AEC and PG obtained from (a) Type 1, (b) Type 2, and (c) Type 3 days and the hourly mean diurnal variation of (d–f) wind speed and (g–i) wind direction corresponding to Type 1, Type 2, and Type 3 days, respectively.

description of the geomagnetic indices. It is clear that different diurnal variations emerge on different days with many of them deviating from the Carnegie pattern. This suggests that the fair-weather atmospheric electricity parameters are not free from local disturbances but undergo severe disturbances on a day-to-day basis. The days 14–16 and 22 January 2013 display nearly identical diurnal pattern with a broad maximum between the hours 08 UT and 20 UT and a minimum in the early UT hours. The days 3, 27, and 31 January 2013 are displaying nearly identical characteristics having a double peak one at about 06 UT and the other at about 19 UT. The days 4 and 23 January 2013 are a different type having two maxima one at about 00 UT and the other at about 19 UT. Further examination of the diurnal variation has led to the construction of three dominant types of diurnal patterns as discussed below.

Figures 6a–6c depict the mean diurnal variation of AEC and the PG from the fair-weather days of January, February, September, October, and December 2013. The data from these months are more suitable for analysis than the winter months (May-June-July-August). The fair-weather days are grouped on the basis of diurnal characteristics and are classified broadly into three types, namely, Type 1 (Figure 6a), Type 2 (Figure 6b), and Type 3 (Figure 6c). The diurnal variations having a minimum near 04 UT and maximum near 19 UT (as is the case of the Carnegie curve) are considered to be of Type 1. The variations having two minima one at ~02 UT and the other one at ~10 UT and two maxima, one at ~06 UT and the other at ~19 UT, are of Type 2. The diurnal variations having a broad depression, centered at ~11 UT, are of Type 3. The selection of these days classified by their type does not bear any reason except that we could identify the well-defined patterns from these days of the year 2013 and with other years as well. If one considers that the location where the atmospheric electricity parameters are measured can provide globally representative data, then any diurnal variation similar to Type 1 (Figure 6a) is desirable. This variation has a minimum AEC of ~1 pA m^{-2} at 04 UT and maximum of ~1.8 pA m^{-2} at 19 UT. The minimum of the PG is ~100 V/m at 01 UT, and the maximum is 174 V/m at 18 UT. For the Carnegie curve the minimum was 109 V/m at 02 UT, and the maximum was 154 V/m at 18 UT [*Israel*, 1973]. The reported diurnal variations herein can be considered nearly within the range of the expected values of the globally representative curve. In Type 2 (Figure 6b) we observe a very significant departure from Type 1. There is a considerable enhancement in the values of AEC and the PG. The increase in the value at 00 UT was relative to the Type 1 variation nearly 31%. Almost similar values of

Table 2. The Statistical Details of the AEC, PG, and Wind Speed for Four Different Groups of Wind Speed

Group	Degree of Direction	AEC (pA m^{-2})	PG (V m^{-1})	Wind Speed (m s^{-1})	Wind Direction (deg)	Type
1	100–125	----	---	---	---	
2	126–150	1.3	131	7.0	141	
3	151–175	1.2	119	7.7	159	Type 1
4	176–200	1.6	149	8.3	173	
1	100–125	----	---	---	---	
2	126–150	1.3	127	5.4	134	
3	151–175	1.4	134	6.9	167	Type 2
4	176–200	1.7	156	5.9	186	
1	100–125	1.2	112	5.2	122	
2	126–150	1.3	120	5.2	145	
3	151–175	1.6	145	7.0	167	Type 3
4	176–200	2.0	180	8.2	177	

the PG and AEC are seen for the second minimum at ~10 UT. The maximum was observed at ~19 UT with AEC ~1.8 pA m^{-2}. We do not see any significant difference in the magnitude of the maximum at 19 UT between the Types 1 and 2. The first maximum (~1.8 pA/m^2) of Type 2, at 06 UT, is a prominent one. The minimum of the PG at ~03 UT was 125 V/m against ~100 V/m of the Type 1 minimum. The enhancement was about 25%. While examining Type 3 (Figure 6c), the value of AEC is ~2 pA m^{-2}, which is twice the value for Type 1 and 50% more than the Type 2. A similar magnitude change is noticed in the PG as well. It appears that an additional electrical generator was prevalent on these days. In general, the atmospheric electricity parameters can easily be altered either by anthropogenic activities or the local meteorological parameters. The interesting feature observed in this comparison is that the maximum values at the hours near 19 UT, for either in the PG or the AEC, were identical to each other for all the three types. However, the magnitude at 00 UT varied from type to type.

We examined the relationship between the AEC, the PG, and meteorological parameters like wind speed, direction, temperature, relative humidity, and atmospheric pressure for all the selected fair-weather days. Among these parameters, the wind speed and direction appeared to be relevant to the variation of AEC and the PG and other parameters did not show any significant relationship. Figures 6d–6f show the mean diurnal variation of wind speed, and Figures 6g–6i show the mean diurnal variation of wind direction corresponding to the days in Type 1, Type 2, and Type 3. The diurnal pattern of wind speed was nearly similar for all the three types with slight difference in the dip centered at ~12 UT. It has two broad maxima one at ~00 UT and the other at ~24 UT and a minimum at about ~13 UT. Though the wind direction analysis indicates that the wind blows from the directions between 110° and 200°, there is a noticeable difference among them. It is, for Type 1, a low and broad dip centered at ~13 UT. This becomes prominent for the Types 2 and 3 with a sharp dip ~11 UT (the local noon hours). The geographical features around Maitri can be explained in four quadrants. The first quadrant is between north and east. The second quadrant is between east and south. The third quadrant is between south and west, and the fourth quadrant is between west and north. While the fourth and first quadrants represent the ocean-dominated region ice shelf and fast ice, the second and third quadrants are mainly filled with polar ice sheet, nunataks, and mountain ranges. Since the dominant wind direction is in the second quadrant and it has combination of mountain ranges, nunataks, polar ice sheet, and the Russian research base, these features motivate an elaborate investigation to understand the impact on the PG by the wind speed and direction which prevails in this quadrant.

The wind speed and wind direction over PG are binned into four different groups from the range of wind direction observed for all the three types of diurnal variation. Group 1 is having the wind direction between 100° and 125°. Group 2 is from the directions between 126° and 150°. Group 3 is from the directions between 151° and 175°. Group 4 is from the direction 176°–200°. Table 2 shows the mean values of AEC, PG, wind speed, and direction obtained for each group. Figures 7a–7c show the comparisons of wind direction and the PG for the three types, respectively. Figures 7d–7f show the comparison of the PG and wind speed. The AEC is not considered in this analysis as it closely resembles the PG. The bar diagrams reveal the following points: For Type 1 the predominant wind directions are between 142° and 173°, for Type 2 the direction is between 134° and 186°, and for Type 3 the direction is between 122° and 177°. Figure 8 is a schematic diagram that illustrates the above features. It is evident from these

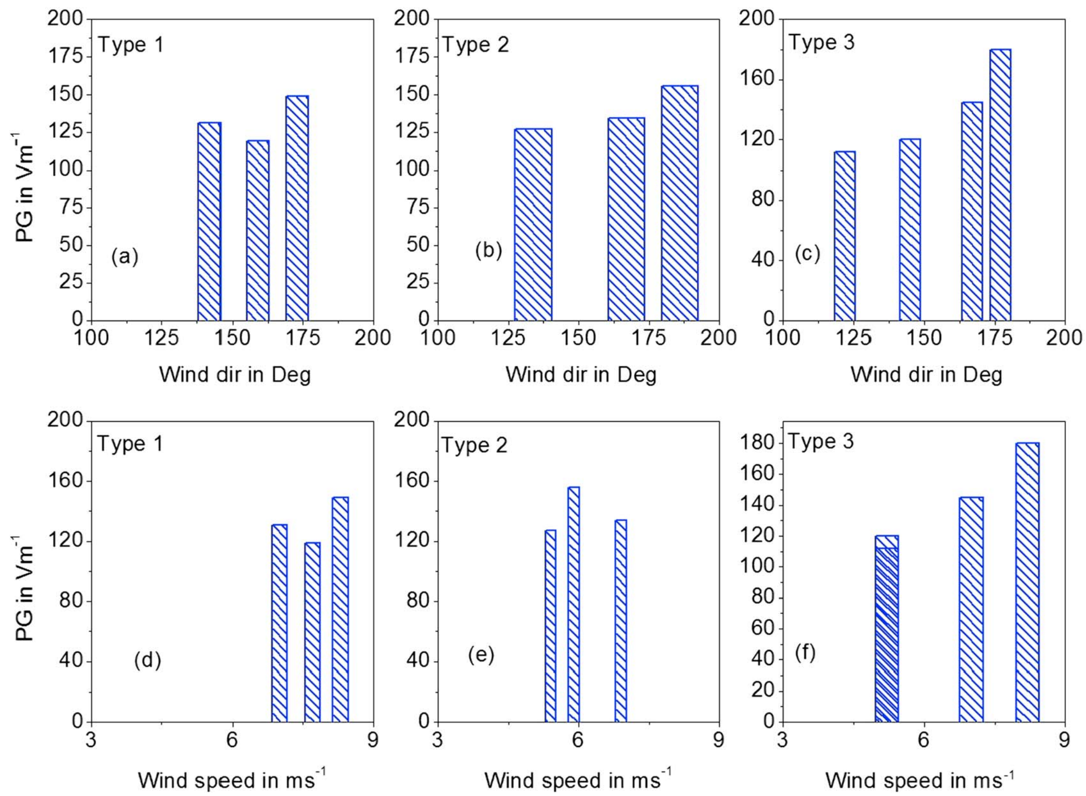

Figure 7. Bar diagram to identify the dominant wind direction and magnitude of PG. Comparison of the PG with wind direction for (a) Type 1, (b) Type 2, and (c) Type 3. Comparison of the PG with wind speed for (d) Type 1, (e) Type 2, and (f) Type 3.

results that the Type 3 pattern prevails when wind blow is from east-southeast (~135°). The mathematical modeling of katabatic winds over Schirmacher region [*Kumar et al.*, 2007] showed that the wind velocities are on actual terrain slope around 130° in which direction maximum katabatic flow moves toward the periphery of the continent. We infer from these figures that the PG value increases as the distribution of wind direction becomes broader or the lower limit moves toward the east and it is the katabatic winds that produce the Type 1 diurnal pattern.

It is demonstrated that the surface wind on fair-weather days over Maitri, Schirmacher Oasis is primarily katabatic winds. Its speed is generally in the increasing trend between the hours 18 and 24 UT and in decreasing trend between the hours 00 and 06 UT. The response of the AEC and the PG observed at Maitri shows an enhancement during the disturbed geomagnetic activity [*Anil Kumar et al.*, 2008, 2009; *Jeni Victor et al.*, 2015]. All these observations reported the enhancement of the atmospheric electricity parameters to occur during the hours between 18 and 24 UT. It has already been pointed out that the PG can go off scale during disturbed katabatic winds [*Ogawa*, 1977]. At Maitri though the measurement of the PG does not go off scale during katabatic winds, it is certainly enhanced by a factor of 2 in comparison with the other fair-weather days (Type 1). Since the high-latitude atmospheric electricity parameters respond to geomagnetic storm activity, it is essential to rule out the enhancement of the AEC and the PG, during the katabatic wind disturbances, as being due to the geomagnetic storm activity. Figures 9a–9c show the diurnal variation of the AEC and PG for the days 4, 23, and 24 January 2013 which are of the Type 3 diurnal pattern. Figures 9d–9f show the horizontal component of geomagnetic field (H) and the Dst values for the same three days. It is well known that the newly injected solar particles into the magnetosphere increase the ring current and cause a decrease in the geomagnetic field H component and in the Dst index [*Huang et al.*, 2004]. On all these days, shown in Figure 8, the geomagnetic H component displays the S_q current characteristic which means that the overhead ionospheric current system is not under the influence of geomagnetic substorms or storms. The wind speed and direction are shown in Figures 9g–9i. Among those three days there were noticeable

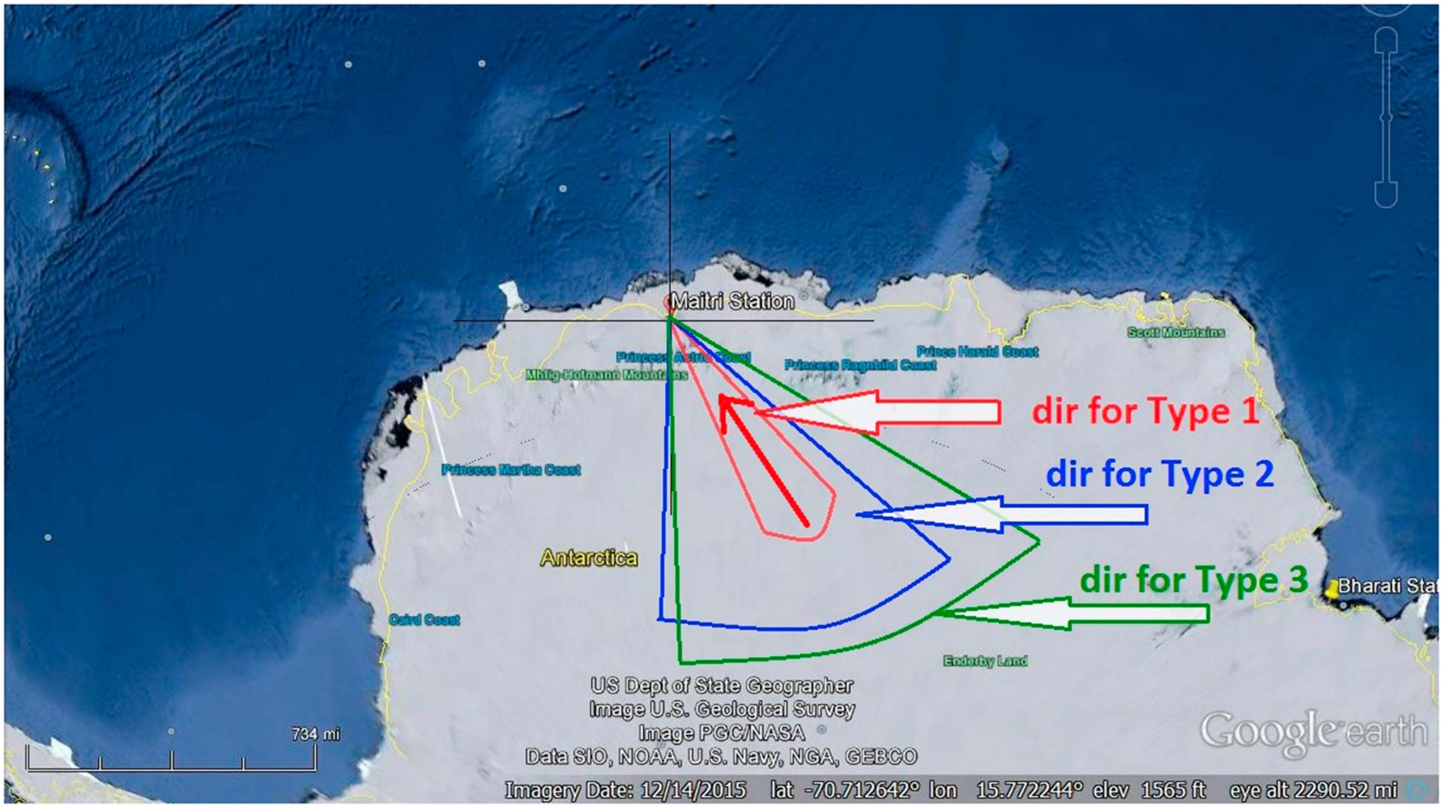

Figure 8. Location of Maitri in Antarctica and the direction of dominant wind for Type 1 (red), Type 2 (blue), and Type 3 (green).

differences that appeared in the wind speed but the wind direction remained nearly uniform for all the three days having the ~130°, the direction of katabatic winds. Figure 10 shows the same parameters and in the same order as in Figure 9 but for three different days. The days are 7–9 October 2013. The days 7 and 8 October 2013 show the diurnal characteristics nearly similar to Carnegie curve. The wind direction was steadily from south (~180°). A Similar feature is observed on 9 January 2013, but the difference is that the PG value is steadily increasing even after 19 UT. Neither geomagnetic nor katabatic disturbance is present. During the hours between 18 UT and 24 UT the wind speed was less than 4 m s^{-1} from the first quadrant and due east. This might play some important role in transporting the aerosols either from the ocean or from the nearby Russian research base. A simple exercise is carried out to find the correlation coefficient between the AEC and the PG for the time sector 18–24 UT for all the three days. It is revealed that the correlation coefficient for the days 7 and 8 October 2013 was nearly 1.0 and for the day 9 October 2013 it was 0.5. This is an indication that the AEC and PG patterns slightly departed from their usual parallel trend during these hours. We believe that there could be transport of aerosols either from the coastal region or from the nearby Russian research station. The air mass grouping study carried out at Maitri revealed that considerable amount of air mass was being transported from the nearby Russian station. The first group (~75%) is from the east, the second one (~20%) is from the west, and the third one is from the oceanic region (~5%). Hence, on fair-weather days having low wind speed from due east and north is expected to contaminate the atmosphere over Maitri. We infer that when the katabatic winds are not present, i.e., winds are not from 130°, the PG enhancement, observed during 00 UT to 06 UT, does not occur. The geomagnetic disturbance, <-62 nT, does not influence the atmospheric electricity parameters observed at the surface level, and the wind from the first quadrant and from due east can enhance the PG. It is possible that the atmosphere over Maitri is loaded with Antarctic aerosols or under the anthropogenic influence from the nearby Russian station.

4.3. Seasonal Variation

We include all fair-weather days to study the seasonal variation without separating them on the basis of their diurnal patterns because the main interest is to show different trends and their dominance over the seasons.

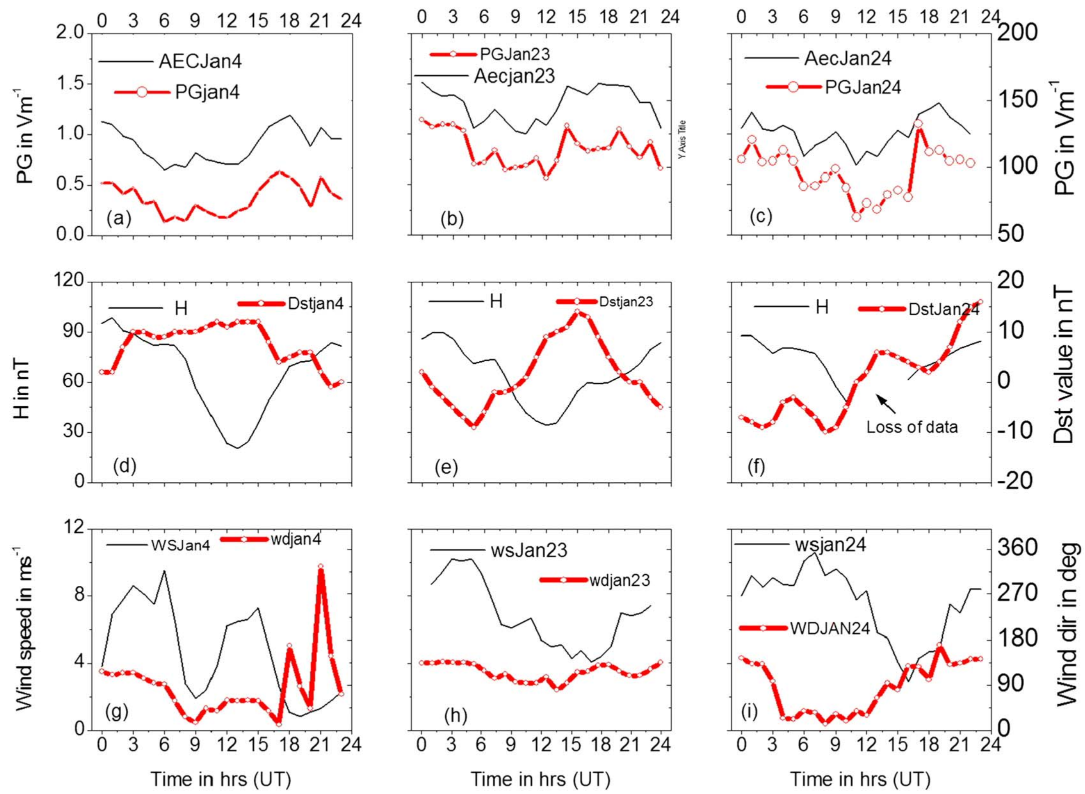

Figure 9. Comparison of Type 3 diurnal pattern of PG with *H* component of geomagnetic field variation, *Dst*, and wind speed and direction for three individual days (a) 4 January 2013, (b) 23 January 2013, and (c) 24 January 2013, (e–g) the *H* component diurnal variation and *Dst* values corresponding to these days, and (g–i) the wind speed and direction.

Seasons have been classified as austral summer (November, December, January, and February), equinox months (March, April, September, and October), and austral winter (May, June, July, and August) when the Sun is over the Southern Hemisphere, near the equator, and in the Northern Hemisphere, respectively. We consider only the PG for the seasonal studies because (i) we have long series of data since the year 2005 and the AEC data are available from 2010 and (ii) since AEC and the PG are often found to be linearly related, we expect that the seasonal variation of the PG and AEC would be similar.

Figure 11 depicts the seasonal variation of the PG at Maitri obtained from the selected fair-weather days shown in Table 1. The mean value of the PG for the austral winter and equinox month is 138 V/m, whereas for austral summer months it is 106 V/m, i.e., nearly 25% less than the austral winter and equinox months. Further, we observed that all the three seasonal curves demonstrate a prominent maximum between 18 and 21 UT hours. The minimum of the diurnal variation was clearly seen during the austral winter months, and it became shallow during the equinox months and nearly flat during the austral summer months. There is also a systematic change in the occurrence of the secondary maximum at about 08 UT during the winter months and 07 UT in equinox months. This maximum shifted further to 06 UT during the austral summer months and became insignificant due to the disappearance of the minimum seen in early UT hours in the other two seasons. The most intriguing signature is the depression between 08 and 14 UT in all the three seasonal curves. All these signatures indicate that the fair-weather electrical environment is a combination of globally distributed electrical processes from the global thunderstorm activity and electric field shower clouds as well as from the locally generated disturbances probably due to the katabatic winds.

5. Discussion

The atmosphere above Antarctica is expected to be the cleanest part of the Earth as the continent is free from urban activities and human settlements. This appears to be a suitable location to monitor the fair-weather electricity. However, looking at Figure 3, it is evident that the diurnal pattern of the PG considerably deviates

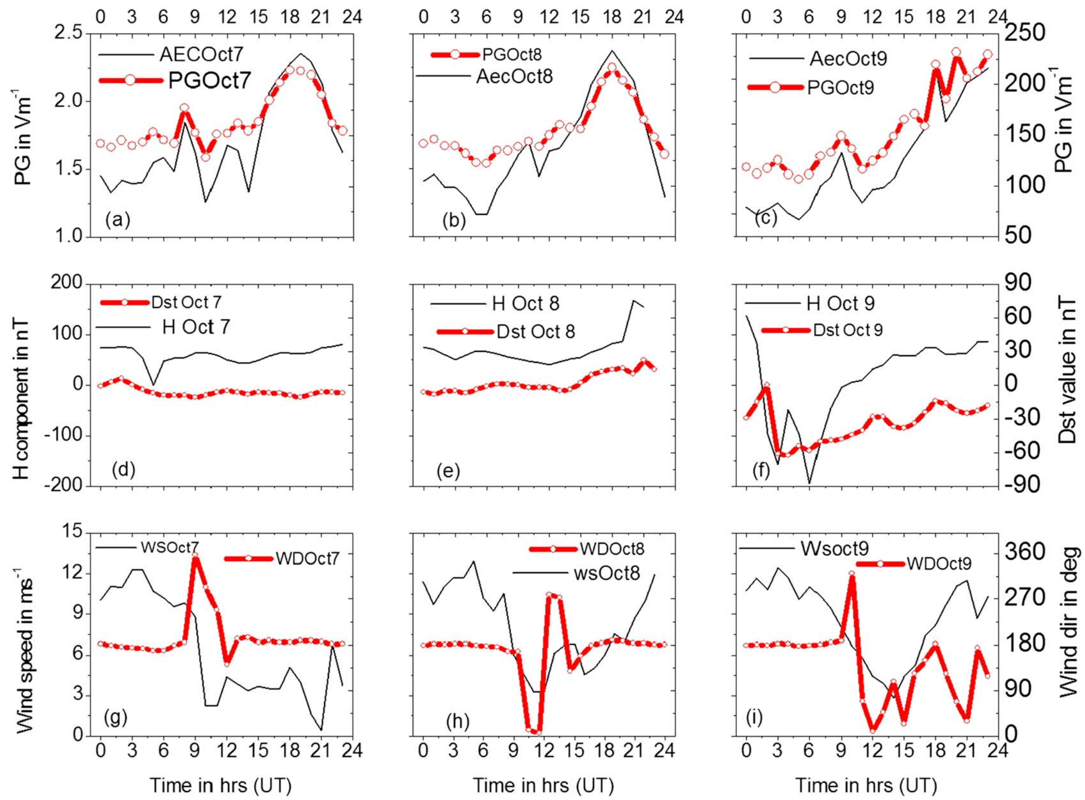

Figure 10. Comparison of Type 3 diurnal pattern of PG with *H* component of geomagnetic field variation, *Dst*, and wind speed and direction for three individual days (a) 7 October 2013, (b) 8 October 2013, and (c) 9 October 2013, (e–g) the *H* component diurnal variation and *Dst* values corresponding to these days, and (g–i) the wind speed and direction.

from the Carnegie pattern. This might be an indication that the atmospheric electricity parameters are contaminated by some unknown sources. The ubiquitous wind characteristic of the continent is the katabatic winds evolve high on the Antarctic polar plateau where the net longwave radiation loss cools the near-surface air. The air density increases, and the flow is downslope replacing the less dense air at lower elevation [*Hoinkes*, 1961; *Ishikawa et al.*, 1982]. It is shown in the present work that the katabatic winds distort the expected diurnal variation of the AEC and the PG. The Antarctic surface wind displays little seasonal variation. Intense radiative cooling in the winter months and enhanced solar heating of the ice slops make the surface wind to have more katabatic wind component in winter months than the summer months [*Parish and Cassano*, 2003; *Nylen and Fountain*, 2004]. Hence, equinox and summer months are preferable. The weather over the Schirmacher Oasis experiences severe katabatic winds flowing from the interior to the periphery of the continent [*Rupinder et al.*, 2013]. The katabatic wind speed is controlled by the terrain slope and the distance at which inversion forms. This direction is found to be ~130°

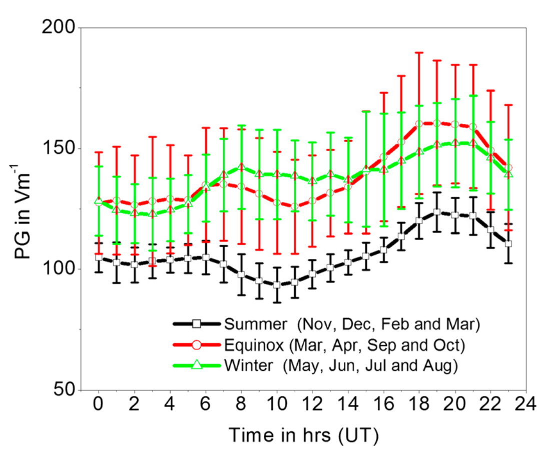

Figure 11. Seasonal variation of PG obtained from the fair-weather days shown in Table 1. The top curve is for the austral summer (November–February), the middle curve is for the equinox months (March, April, September, and October), and the bottom curve is for the winter months (May–August).

(the east-southeast) [*Kumar et al*., 2007]. As the katabatic wind rolls down along the gradient slope from the higher altitude, the air can transport various particles inherited at the surface level through its course of direction. These particles may be ions, aerosols, and radioactive gases accumulated below the inversion layer at Earth's surface along the hillslope [*Porstendorfer*, 1994]. Such transported elements can considerably enhance the PG [*Dhanorkar and Kamra*, 1993a, 1993b, 1994; *Nagaraja et al*., 2003]. The disturbed characteristics associated with katabatic winds can make the electric field off the scale in the measurement [*Ogawa*, 1977]. Recently, *Kamra et al*. [2015] reported that the transport of ions, aerosols, and radiative gases found to be associated with the formation of new particles of the diameter size ranging from 3.85 to 47.8 nm can modify the atmospheric electricity parameters. Thus, we believe that the day-to-day variability in the fair-weather atmospheric electricity parameters shown in Figure 5 could be due to the katabatic winds. This finding is further substantiated by displaying three dominant types of diurnal patterns in Figures 6a–6i and 7a–7e. The results obtained are presented in Figure 8 along with the topography of the Maitri location. This figure shows that the enhancement of the PG, i.e., Type 3, is commonly seen when the wind direction is spreading toward the east-southeast (~135°). The diurnal pattern of Type 1, i.e., the diminished behavior of the PG in the early UT hours, is observed when the wind direction is more from the south or south-southeast. The Type 2 variation is observed when the wind speed is spreading to both directions, i.e., the south and the southeast. The probable cause for this variability could be the other factors of accompanying the wind such as temperature and moisture. A detailed study on the katabatic winds over Schirmacher Oasis revealed that there are occasions of warm and moist air that flows from the polar plateau along the direction 160°, south-south direction, on fair-weather days. The acoustic sounder data from Maitri show that the wind from 160° does not support the convection activity, unlike the cold katabatic winds from 130° as this is more warm and moist than the wind from 130° [*Rupinder et al*. 2013]. Hence, the wind from the south and southeast is desirable to have the true representation of the Earth-ionospheric electric field variation.

Though the anthropogenic aerosols are minimum in Antarctica due to lack of human settlements, there are man-made research stations which operate various diesel generators and vehicles. These sources may produce a considerable quantity of aerosols [*Ruhnke*, 1962]. At times they may accompany the katabatic winds as the nearby Russian research stations due east of the Maitri station. At Maitri the operation of generators and vehicles is on the leeward side of the PG measurement site. The Antarctic natural aerosols are mainly from the sea salt and biogenic types. The transportation of these aerosols to the interior part of the continent, through a favorable air circulation pattern, may play a crucial role in the atmospheric electricity. A good number of studies are carried out on such transport mechanism. Elaborating on them is not very essential for this work. Yet the observations made at Maitri by *Chaubey et al*. [2011] need to be addressed here. It is the 7 day air mass back trajectory study using the Hybrid Single-Particle Lagrangian Integrated Trajectory model that revealed that aerosol properties are modified by wind coming from high-attitude polar regions. This study also exposes the influence of aerosols generated by anthropogenic activity at research stations. An important study on the positive ions and air-Earth current density carried out at Maitri reveals that the concentration of large ions (5×10^3 to $1.2 \times 10^4\,\mathrm{cm}^{-3}$) is more than the expected value for a clean site. One of the probable causes could be that the ions being generated over ice glacier south of Maitri grow to the large ion size during their transportation to Maitri with prevailing wind from the southeast [*Siingh et al*., 2007]. This is an additional mechanism to disturb the fair-weather electrical environment over Maitri.

Atmospheric electricity parameters are often found to be influenced by the electric field that maps downward during the geomagnetic storm conditions. Most of such reports originate from the stations just below the polar cap [*Reddell et al*., 2004; *Burns et al*., 2012]. While discussion on the electrodynamic coupling through the magnetospheric origin of electric field is not within the scope of the present work, it is also not ignored. The general finding here is that the enhancement of the PG during the initial UT hours is not due to geomagnetic disturbances. There are a couple of studies from Maitri on the response of AEC and the PG to the geomagnetic activity. During the geomagnetic storm associated with coronal mass ejection enhancement of the PG is observed [*Anil Kumar et al*., 2008]. The study on the influence of the geoelectrical coupling, before and after magnetic storms and substorms, revealed that solar wind-magnetosphere energy coupling is well correlated with the atmospheric electric parameters during the onset and main phase of the geomagnetic disturbances [*Anil Kumar et al*., 2009]. As previous studies have shown that the fair-weather PG enhancement during geomagnetic disturbances is a general feature, it prompted us to discuss the results from Figure 9 clearly showing that the maximum in the early UT hours is not due to the geomagnetic activity as the *Dst* value and *H* component values are showing the characteristics of geomagnetic quiet days. In Figure 10 the *Dst* for 7 October 2013 was close to 0, and for 8 October 2013 it continued to be nearly the same. A strong disturbance is noticed between the hours 00 and 06 UT reaching the *Dst* level to −62 nT at 04 UT and the *H* value to about −200 nT. The AEC and the PG appear to have no effect on the geomagnetic storm at these hours. As the diurnal pattern of the PG on 9 October 2013 does not resemble either of the previous two days or the Carnegie pattern, we may infer that the source of the enhancement of the PG could be something else. A possible cause for such varied diurnal patterns is the surface wind pattern. The wind which generally blew from the south on 7 and 8 October 2013 has suddenly changed to blow from the direction north for a short time and thereafter from east at 11 UT on 9 October. It is around this time that the PG started increasing steeply. We opine that the wind might transport the sea-salt aerosols/diesel engine-generated aerosols from the ocean and the nearby Russian station, respectively.

The conduction current of the global electrical circuit transports the positive charge vertically to the ground. Due to the lack of ionizing source over the polar ice sheet and the presence of ionization in the atmosphere by the cosmic radiation, there develops an offset between the positive and negative charges. The amount of excess positive charge remains as space charge to form a layer close to the surface of the Earth called the electrode layer. These space charges can cause various complications when we look for the global signatures in the AEC and the PG [*Markson et al*., 1981; *Hoppel et al*., 1986]. The measurements of electric field variation in Antarctica made during the Belgian-Netherlands Antarctic Expedition showed a doubling of electric field intensity from a height of 5 m to the surface. This was reported to be larger in low-wind conditions [*Kraan*, 1971]. This is evident for the accumulation of space charge over the polar ice sheet. The katabatic winds can also transport these space charges from the polar ice sheet. Over the landmass these charges generate a pronounced perturbation in the PG and AEC in the morning hours in response to the surface heating by the solar radiation [*Chalmers*, 1957]. The convection supports the transport of the space charge to get dispersed in the atmosphere [*Latha et al*., 2008; *Raina and Raina*, 1988; *Retalis and Zervos*, 1976]. In Antarctica the presence of the Sun round the clock at the lower elevation during the austral summer and its total absence during austral winter are favorable conditions for suppressing convective overturn. The winds from the three regions shown in Figure 8 are different in nature. The wind from Type 1 region it does not support the convection activity on the fair-weather days as the Type 3 does. The wind from Type 3 is mostly of katabatic origin which supports the convection by replacing the warm and light air over Schirmacher. The Type 2 is having contributions from the other two types. Thus, the wind from Type 1 region is the preferable circumstance in which to monitor the GEC parameters. Thus, it is believed that not all the fair-weather days provide global representative data but there are some fair-weather days which show diurnal pattern has deviation from Carnegie pattern. The wind from 130° significantly affects the diurnal pattern of the AEC as well as the PG.

The occurrence of a prominent maximum at 19 UT and a minimum at ~03 UT in the variation of the seasonal mean value of the PG suggests that the observed variation does indeed represent the Earth-ionospheric potential generated by the global electrical activity. Another observation to substantiate this result in the seasonal mean variation is that the mean PG values for the equinox months and austral winter months are found to be ~25% larger than the values in the austral summer. The seasonal variations of global electrical parameters from various stations showed that they are maximum during the Northern Hemisphere summer, i.e., austral winter [*Adlerman and Williams*, 1996; *Christian et al*., 2003]. The lightning flash rate and total flash count are often used as measures of the electrical activity of thunderstorms. The seasonal behavior of the DC global electric circuit appears to follow the same behavior in phase but with reduced amplitude variation [*Adlerman and Williams*, 1996]. The shift of the peak observed at ~08 UT during the austral winter to 07 UT during equinox months and ~06 UT during the austral summer months could possibly be due to longitudinal shift of the thunderstorm activity. It appears that this peak is a consequence of the electrified storm activity over the Asia/Maritime Continent. We would like to explain its variability based on the global lightning results from *Christian et al*. [2003]. The lightning activity with an intensity of ~30 flashes $km^{-2} yr^{-1}$ was observed over the eastern part of China and the Indian subcontinent in the months of March-April-May and June-July-August between 45°E and 135°E. This has become close to the minimum activity (0.2 $km^{-2} yr^{-1}$) in the austral summer months (December-January-February). At the same time the lightning activity which was minimum over the Maritime Continent, spreading between 150° and 120°, has become maximum (~30 flashes km^{-2} yr^{-}). If one considers the longitudinal center of the lightning activity for these two regions, the former is 90°E, and the later is 135°E; the time difference is ~3 h. Perhaps this is the shift we notice in the peak of the winter curve (~08 UT) and the summer curve (~0530 UT). Thus, the seasonal curves of the PG represent the global thunderstorm activity by displaying a minimum at about 03 UT and thereafter a continuous increase, except the depression centered at ~11 UT, till the peak between 18 UT and 21 UT. The depression noticed around 11 UT is considered to be due to the contribution of Type 3 PG on the days when the katabatic winds were strong. Thus the annual PG variation curve obtained at Maitri has the contribution from the katabatic winds as well as global electrified shower clouds and thunderstorm activity from the three major tropical chimneys namely the Asian/Maritime continent, Europe/Africa and the Americas.

The surface wind in winter months is expected to have more katabatic components than the summer. As per our findings a small change in the direction of wind, maybe from south to southeast, may distort the fair-weather electrical parameters over Maitri. During the summer the land surface is free from snow, whereas during winter there is frequent snow storm to deposit fresh snow and the lifting of the soft snow having electrical charges, not sure about this, may disturb the electrical environment. Earlier studies [*Cobb*, 1977] have suggested problems of this kind.

6. Concluding Remarks

The analysis of the atmospheric electrical parameters obtained during 2005–2014, revealed that the fair-weather electrical environment over Maitri frequently departs from the Carnegie type to produce an anomalous characteristic. The anomalous characteristic is represented by having an additional minimum at ~11 UT and a secondary peak at ~07 UT. This is a specific signature observed at Maitri, and it is a local phenomenon. A thorough investigation has revealed that the 11 UT minimum is an ostensible minimum caused by enhanced PG variations between the hours 00 and 09 UT. Examination of various meteorological parameters and geomagnetic activity confirmed that the cause of the anomaly is the katabatic wind blowing from the direction nearly southeast (~130°) as the gradient of the slope of the polar ice sheet is in this direction. Since the katabatic wind is heavy and cool, it can replace the light and warm air over the Schirmacher Oasis to initiate the charge separation by convection which gives raise to the PG; as a consequence, the Type 3 diurnal pattern emerges on as a consequence of katabatic winds. The Type 2 curves emerge on the days when there develops a prominent peak centered at ~06 UT. This could be attributed to either a strong development of lightning showers over the Maritime Continent or due to charge separation caused by local convective activity. Since there is hardly any difference between the local time and universal time over Maitri, it is difficult to elaborate this issue at this stage. We are not ruling out the role of enhanced thunderstorms and electrified shower over the Maritime Continent which might give a strong PG enhancement between the hours 06 and 08 UT just prior to the ostensible minimum at ~11 UT.

Another new finding of the present study is that the wind from the directions of north and east also considerably enhances the AEC and the PG. This leads to suspicions about whether aerosol loading is playing a role in the enhancement of the PG in the early UT hours. To have a globally representative data of the AEC and the PG, a day should be free from the influence of katabatic winds as well as the surface wind from the north and east directions. This condition is in addition to the conditions laid for the fair-weather days in section 1.

It appears that the PG response to the thunderstorm over Africa is diminished during the hours 14–16 UT. This is because of the ostensible minimum at 11 UT caused by the domination of local meteorological condition over the global one in context of the meteorological conditions. This feature is observed on all the seasons. The evidence for the global representativeness of the PG monitored at Maitri is its response to more abundant electrified continental convections in the Northern Hemisphere and least in the Southern Hemisphere which plays a very significant role in the seasonal variation of the PG. This has an agreement with the study of the PG from an interior continental station Vostok [*Burns et al.*, 2012].

This study has identified two more dominant diurnal patterns of the AEC and the PG which persists on the fair-weather days. This motivates us to have additional experiments for the measurement of space charge and conductivity and network stations of electric field mill with a separation sufficient distance. A balloon experiment appears to be inevitable to understand the dynamics of space charge.

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