Anomalous diurnal variation obtained from the comparison of atmospheric electrical potential gradient from the measurements of Maitri and, Vostok.

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Abstract

This paper identifies the existence of an anomalous signature in the atmospheric electrical potential gradient monitored at Maitri (70° 45' 52" S, 11° 44' 03" E, 117m AMSL), Antarctica. The identification is carried out from the comparison of the Potential Gradient data monitored at Maitri and Vostok (~78.5° S, 106.8° E).

1. Introduction

Monitoring the fair-weather air-Earth current density (AEC) and potential gradient (PG) is considered to be important for understanding global warming and Sun-weather relations [Roble and Hays 1979; Tinsley et al., 1998, 1994]. These parameters integrate with global thunderstorm activity and act as proxy variables for the mean global surface temperature. They are much more sensitive to global warming than the mean global temperature itself [Williams, 1992]. The atmospheric electricity data for such a study should not be contaminated by anthropogenic and meteorological disturbances. While monitoring the atmospheric electricity parameters over the ocean, during the Carnegie expedition 1915-1928 [Whipple and Scrase, 1936], data were found to be stable and systematic, probably because of no contamination from drastic meteorological disturbances and radioactivity sources over the ocean. Furthermore, aerosol concentrations were markedly reduced compared to the situation over land. In addition to the measurements over the ocean, it was believed that monitoring to monitor the fair-weather global signature of the electrical parameters from the remote continent, Antarctica (excluding coastal region) plateau, for the following reasons [Deshpande and Kamra, 2001]:

1. In Antarctica, the weather, for nearly 70% of the time, remains clear.
2. The surface of the continent is expected to be plainer than the continental surface as a result, turbulence of the wind is reduced.
3. Deep temperature inversions suppress the local atmospheric convection.
4. Further, the convective turbulence is very small in the Antarctic region.

Based on the above aspects, Amundsen and Scott (South Pole station] and Vostok (the interior continental stations over the Antarctic Plateau] proved to be suitable for reproducing the Carnegie-type diurnal pattern [Bering et al., 1995; Tinsley et al., 1998; Burns et al., 1995; Reddell et al., 2004]. The Antarctic continent, particularly the plateau, thus hosts suitable locations to monitor the global features of the fair-weather electric environment. Nevertheless, the coastal regions of Antarctica, where the majority of the scientific research bases are situated, have different orographic and atmospheric features. These can modify the expected fair-weather electrical environment, thereby causing deviation from the standard Carnegie pattern, the de-facto standard for globally representative data. We presume that the disadvantages of the coastal Antarctic stations are:

i] Coastal cyclonic storms are very frequent, leading to a considerable reduction in the number of fair-weather days. This also leads to the deposition of a large quantity of soft snow, which is often lifted up by the mild winds even on fair-weather days to cause invisible particle suspension in the atmosphere.

ii] The winds evolve at high on the Antarctic plateau, where net longwave radiation losses heat and cool the near-surface air. The air density increases and flows downslopes replacing the less dense air at lower elevations [Hoinkes, 1961; Ishikawa et al., 1982]. The wind flow is referred to as katabatic winds. In the continental interior, katabatic wind speeds are low because of the small topographic slopes, but near the steep-sloped coast, wind speed increases.

iii) The katabatic winds are also expected to have minute particles of ice crystals which can modify the electrical properties of the atmosphere over the coastal Antarctic stations [Contini et al., 2010]

Measurements of PG from two additional stations (Devis and Syowa) in the coastal regions of the Antarctic continent [Burns et al., 1995; Minamoto and Kadokura, 2011] are also available. Maitri, along with these two stations, has different orographic features from those of the interior stations like Amundsen and Scott, and Vostok. Devis and Syowa are situated on the exposed rocky terrain near the ocean, and Maitri is about 80 km from the ocean. Burns et al. [1995] reported from the study of the geo-electric field at Davis station, Antarctica, that the local influences, particularly the surface winds, prevented the determination of the magnetospheric influences on the atmospheric electric field. Minamoto and Kadokura [2011] presented the results from the measurements of the electric field at Syowa station, and they reported the presence of local factors.

2. General Concept of fair-weather atmospheric electricity

The well-known concept of the fair-weather global atmospheric electric circuit is the separation and leakage of charge in the spherical capacitor formed by two conducting layers viz. the Earth's surface and the base of the ionosphere with the atmosphere as a dielectric medium of the natural capacitor. The charging of this spherical capacitor is maintained by the globally upward lightning current of ~1000 A to maintain a vertical potential of ~250 kV with respect to the ground [Adlerman and Williams 1996; Burns et al., 1995; Rycroft et al., 2000]. This upward lightning current is from the thunderstorms and shower clouds from three major locations around the world i.e. Africa, Asia/Maritime Continent, and America (see, for example, Bering III, 1995; Rycroft et al., 2000; Williams, 2002]. The longitudinal separation of these three tropical chimneys is considered to be responsible for the spatial and temporal variations in the clean environment fair-weather vertical electric field and air-Earth current density near the Earth's surface. Figure 1 describes the relationship between the three major thunderstorm regions and the potential gradient measured during the Carnegie cruise [Parkinson and Torrenson 1931; Whipple and Scrase 1936]. The conductivity characteristics of the atmosphere is 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 Earth-ionosphere potential in the absence of any other dominant mechanical forces that lift the air parcels with ions. Convection and change in the dimension of the Planetary Boundary Layer (PBL] are examples of such forces which can affect the flow of ions.

At the Earth's surface, the PG is caused by the current flowing through the feeble conducting atmosphere. Therefore conduction current (J_c) produces variability in the Global Electric Circuit (GEC) measured at the surface either directly through the measurement of J_c or PG. However, PG is also a function of the local air conductivity (σ_T). Away from sources of charge separation (i.e. the active thunderstorm region). The air conductivity (σ_T), potential gradient (F), and conduction current density (J_c) are related by Ohm's law.

$$F=J_C/(\sigma_T) \qquad \ldots \qquad \ldots \qquad \ldots(1)$$

In the fair-weather part of the GEC, the small ions dominate the charge transport since they have larger electrical mobility than the medium and large-size ions. Thus, an increase in small ion concentrations will increase air conductivity. The aerosol concentration in the atmosphere reduces the small ion density by attachment and hence causes a decrease in the air conductivity. A change in aerosol density subsequently modifies the total columnar resistance [R_C) and so the conduction current (J_C), thereby affecting PG through equation (1). To have a comprehensive idea of the behavior of the fair-weather electrical environment, it is mandatory that all three parameters should be measured simultaneously.

3. Description of the experiment site

Maitri is in the Eastern part of Antarctica in the region of Queen Maud Land (the sector between 0^o and 30^oE) 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 50m to around 130m. There is about an 80 km stretch of shelf ice between Maitri and the ocean. The permanent composition of the soil is a mixture of clay, silt, and coarse and fine sand [Ramteke et al., 1997}. On the southern side of the station, the continuously rising polar ice sheet is situated. At Maitri, we often notice significant diurnal variation in the meteorological parameters. The prevailing meteorological conditions and the net radiative and turbulent energy flux are well documented by Koppar [1997] and Gusain et al., [2011] respectively. As far as the emanation of energetic radiation from the surface of the Earth is concerned, the levels of $^{Rn}222$ (from 0.02 to 0.03 Bqm^{-3}) and its daughter products prevailing over Schirmacher Oasis were reported to be nearly equal to those prevailing over the Arabian Sea and the South Indian Ocean region [Ramachandran and Balani, 1995]. A few results from the aerosol studies over Maitri showed that the characteristics are nearly identical to the values found over the Arabian Sea and the Indian Ocean. The surface-level ambient aerosol mass concentration is also low with an average value of 9.14μg m^{-3} [Gadhavi and Jayaraman 2004]. However, 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 station 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 further. Submicrometer 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 to the electrical environment by modifying the electrical conductivity, AEC, and PG.

Katabatic winds caused by radiative cooling of near-surface air are almost ubiquitous features of the Antarctic coastal slopes. 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]. Sublimation is another important phenomenon in Antarctica. In a study on Antarctic sublimation in a high-resolution general circulation model, Michiel

[1997] reported that over the ice sheet, significant summer sublimation of -5 to -15 Wm^{-2} occurs generally below 2000-2500m AMSL. The modeled sublimation for East Queen Maud land (the region where Maitri is situated) was 40 Wm-2 for summer (DJF) and for winter (JJA) -5 to 10 Wm^{-2}. This model study was confirmed by the observations by Weller [1988] and Takahashi et al. [1992]. During the polar night in the winter months, the Sun is below the horizon. After the middle of September, the Sun is visible above the horizon. The snow accumulated during the polar night months (MJJA) starts melting at the end of September onwards. The majority of the snow is melted by the end of December. The Schirmacher Oasis is generally free from snow during the months of January and February.

4. Fair-weather days and data selection

The definition of 'fair-weather' for atmospheric electricity studies has been a matter of concern for a long time [Israel and Lahmeyer, 1948; Reiter, 1982, Burns 2005, 2012]. Considering Maitri's proximity to the Antarctic coast, fair-weather days satisfying the prescribed conditions are rare. The fair-weather conditions for Maitri station followed by Deshpande and Kamra, [2001] and were originally proposed by Ruhnke [1962] for the location in Greenland and these are to be 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 land mass with raised hillocks. The days for which fair-weather conditions are supposed to hold over this station are the days with no precipitation (snowfall/rain), wind speed less than 10 ms^{-1}, and high clouds less than 3 octas through the day [Deshpande and Kamra, 2001]. These are general criteria followed in all the works reported from Maitri in past years. In actual conditions on such a fair-weather day, there could be gustiness of wind to cause fluctuations in the electrical environment to disturb the PG and AEC. Thus it is evident from these examples that the daily average meteorological parameters cannot be taken as granted indicators for fair- weather. We need to eliminate the data pertaining to disturbed weather conditions and follow the techniques suggested by Burns et al., [2005, 2012], for data selection. The technique prescribes that only that data should be considered for which the vertical electric field (Ez) does not exceed 350 Vm^{-1} till two hours prior and the value returns to normal background level within two hours of the data recorded.

5. Results and discussions

Fig. 1 shows the comparison of simultaneously observed fair-weather days PG variation at Maitri and Vostok for 52 fair-weather days. Both curves have good agreements on many occasions. For example, Maitri and Vostok show a minimum at ~0300 UT followed by an increase till 0700 UT. The next agreement is that the peak occurs at ~1900 UT. There are a couple of differences between these two. They are the magnitude of PG is lower than that of Vostok. And the other difference is that after crossing the 0700 UT Vostok curve is steadily increasing whereas Maitri is steadily decreasing till about local noon at Maitri. After local noon there is a gradual increase in the Maitri curve which is very much comparable with that of Vostok.

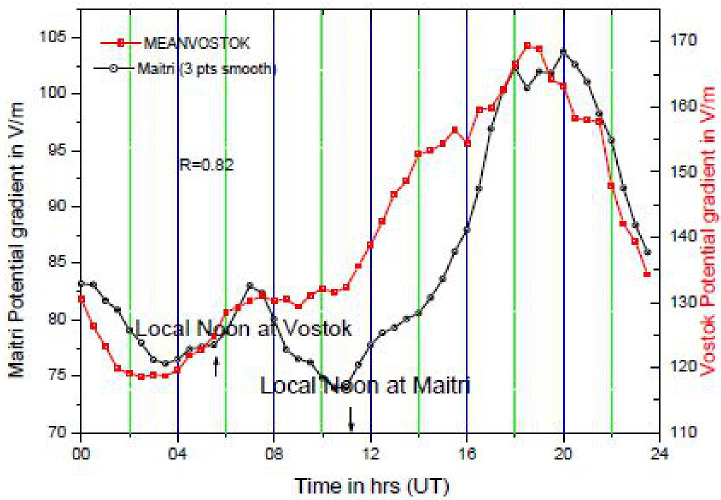

***Fig. 1** Comparison of the hourly mean diurnal variation of Potential Gradient obtained on 52 common fair-weather days at Maitri and Vostok during the year 2011.*

Fig. 2 shows the seasonal distribution of global lightning activity (units of fl km^{-2} yr^{-1}) [After Christian et al., 2003]. The global lightning activity shows a very distinct difference in the season. During the months of DJF i.e December,, January, and February the hot spots are, from east to west, Australia, Africa, and America. In the months of MAM i.e. March, April, and May the lightning activity over Australia disappeared and it developed over the Indian subcontinent and China. In the month of JJA (June, July, and August] the whole of Asia is active with the lightning activity peaking up to 40 flashes/km^2/year against the minimum value 0.1-0.4 flashes/km^2/year over the oceans. By the months of SON (September, October, and November) the lightning activity becomes intense over Australia and, other parts of the Maritime continent. Therefore we believe that the peak observed around 07 UT is attributed to the electrified lightning activity over Australia/Asia. Next to this, the PG of Vostok responds significantly to the African thunderstorm activity whereas Maitri shows a depression which is an indicator of the nonresponsive to the lightning activity. On the contrary, it shows a depression around the local noon hours. After crossing the local noon hours the PG increases steadily and this is attributed to the thunderstorm activity over the western portion of Africa followed by the Americas. Therefore the depression noticed in Maitri PG is an anomalous variation that could be due to a regional mechanism.

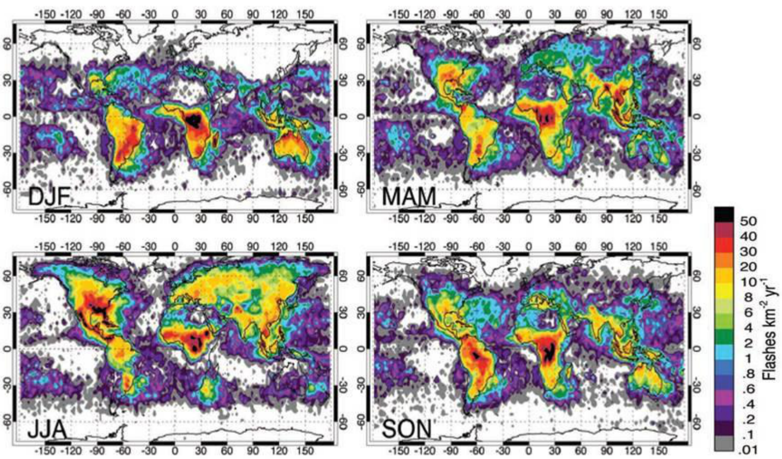

Fig. 2. *The seasonal distribution of the lightning activity (annualized in units of fl km^{-2} yr^{-1}). (a) December, January, and February (b) March, April, and May (c) June, July, and August. (d) September, October, and November [After Christian et al., 2003]*

6. Conclusions

This paper has identified the existence of an anomalous PG over Maitri. The mechanism has to be explored with various supporting data from Maitri and PG data from various other stations. This will be carried out during successive expeditions.

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