Cosmic noise absorption during geomagnetic substorms and the possible influence of substorms on Global Electric Circuit

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Abstract. The geomagnetic substorms are important consequences of solar wind-magnetosphere-ionosphere coupling. The enhanced particle precipitation in the Earth's ionosphere during the coupling results in the enhanced absorption of the galactic cosmic radio noise. Simultaneous analysis of magnetometer and riometer data shows the enhanced absorption of cosmic noise during the substorms. The global thunderstorm activity maintains a potential difference of a few hundred kilovolt (kV) between the ionosphere and the Earth's surface. As a result of the small but finite conductivity of the lower atmosphere, a small current of order of pico Ampere (pA) flows from the ionosphere to the Earth in the fair weather regions. Though the global electric circuit (GEC) is mainly due to global thunderstorms, physical processes such as ionospheric and magnetospheric dynamos, geomagnetic activities, solar flares, coronal mass ejections do have finite contributions towards GEC. In this paper we present simultaneous study of geomagnetic activities (monitored by DFM at Maitri), cosmic radio noise absorption (recorded by 32 MHz riometer at neighboring Russian station, Novo) and the possible influence of substorms on GEC parameters (recorded at Maitri) during year 2007.

1. Introduction

The classical picture of global electric circuit (GEC) suggests that thunderclouds in the troposphere drive upward currents, charging the ionosphere to a potential of a few hundreds of kV with respect to the Earth surface. In the fair-weather regions, return currents to the Earth through the weakly conducting atmosphere produce vertical electric fields of the order of 100 Volt/meter (V/m) near the ground. According to the modern view of GEC, other than the dominant contribution of global thunderstorms, physical processes such as ionospheric and magnetospheric dynamos, geomagnetic activities, solar flares, coronal mass ejections do have finite contributions towards GEC. It is suggested that sources other than thunderstorms may cause perturbations of ± 20 % in the ground electric field and Maxwell current at high latitudes (Roble et al., 1979).

In this study we investigate the effect of substorm activity on global atmospheric electricity parameters, namely potential gradient, current density and conductivity, from the observations at Maitri, Antarctica (geographical location 70° 45′ S, 11° 44′ E). A geomagnetic substorm is a transient process initiated on the nightside of the Earth in which a significant amount of energy derived from the solar wind-magnetosphere interaction is deposited in the auroral ionosphere and in the magnetosphere (Akasofu, 1977). The substorms can be recognized by geomagnetic field observations such as bays in H-component, auroral breakups, Pi2 pulsations at mid and low latitudes (Rostoker et al., 1980). When the galactic cosmic radio noise is received on the ground, the radio noise passes through the ionosphere and is absorbed with varying degree of absorption. The majority of cosmic noise absorption events are caused by the precipitation of high energy electrons and protons into the atmosphere during the substorms where they generate excess ionization; at low altitudes. Typically, the processes causing ionospheric absorption of radio waves take place at altitudes ranging from 60 to 100 km (Stauning, 1996). The precipitation of energetic particles, and thus the associated radio wave absorption processes are most intense in the aurora1 and polar regions.

The distribution of the ionospheric electric field and conductivity are known to change during substorms and hence substorms could provide an additional source of large enough horizontal scale to contribute to the global electric circuit.

The paper has been organized in as under: Section 2 gives an account of various data sets used in the investigation, section 3 presents the variation of cosmic noise absorption level recorded at Novo in simultaneity with geomagnetic field variation recorded at Maitri. Section 4 describes as to how GEC parameters get affected during geomagnetic substorms as compared to geomagnetic quiet period. Finally, we summarize our findings and conclude the paper in section 5.

2. Data

The present study includes the ground-based magnetometer data and GEC parameters, namely potential gradient, current density and conductivity, from the observations at Maitri (geographical location 70° 45′ S, 11° 44′ E). Both the above data sets are sampled at 1 second. For the study of cosmic radio noise absorption Riometer data of neighboring Russian

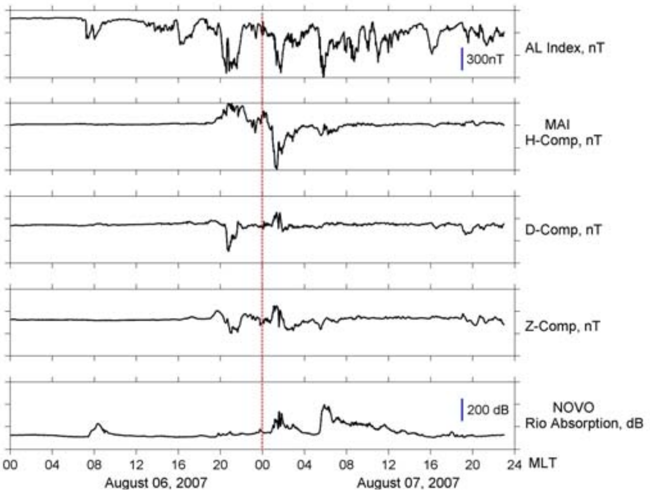

Fig. 1. AL index and Simultaneous variations of geomagnetic field components and cosmic radio noise absorption.

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3. Geomagnetic field variation and cosmic noise absorption

The top panel of Figure 1 shows the AL index on geomagnetically disturbed days August 06-07, 2007 having a series of substorm activities. Panels second, third and fourth from the top show the variations in geomagnetic field components at Maitri and 32 MHz cosmic radio noise absorption at a nearby Russian station Novo is shown in the bottom panel of Figure 1. The vertical dashed line represents the magnetic midnight at Maitri. The typical characteristics of substorms at high-latitudes, positive bay in the pre-midnight time and negative bay in the post-midnight side, are clearly evident in the H-component (Atkinson, 1967). The D and Z-components show simultaneous disturbances respectively in panels third and fourth from the top. The bottom panel of the figure shows the absorption of cosmic radio noise during the substorms. The enhancement in the absorption is more pronounced during the post-midnight time.

4. GEC parameters during geomagnetic substorms

The location of Maitri is just outside of the auroral electrojet towards the equator during the magnetically quiet conditions. As a result Maitri will be under the influence of the global thunderstorm activity. At the time of enhanced substorm activity the location comes under the influence of Auroral Electrojet (Rajaram et al., 2002). This will clearly affect the observed parameters whose behavior should be different during geomagnetically disturbed time from those during quiet conditions.

In the present study, all the substorm time GEC data have been divided into pre-midnight and post-midnight magnetic local times [MLT=UT-0100 hr] on fair-weather days during April to December, 2007. The days with wind speed less than 10 meter/second (m/s), no snow fall or snow drift and clouds less than 3 octa have been considered as fair-weather days. In order to get better effect of substorm on GEC parameters only those days are selected when the magnetic field disturbance is more than 300 nT in pre-midnight time (1800-2359 MLT) and is more than 400 nT in the post-midnight time. Restricting to these criteria, we got 9 pre-midnight events and 11 post-midnight events. Further we selected 13 pre-midnight and 13 post-midnight GEC values during geomagnetically quiet times on fair-weather days. All the quiet days are selected in the vicinity of already selected disturbed days. The GEC parameters were originally sampled at 1 second. For further analysis, spikes in the data have been removed and downsampled to 1 minute.

In Figure 2 the averaged GEC parameters, pertaining to substorm time, are shown by thick lines and in absence of substorms, are shown in by thin lines during the magnetic pre-midnight time. The top panel of the figure shows potential gradient (PG) in V/m during the substorms and in absence of substorms. At the time of substorm, PG is higher than that on geomagnetically quiet time. Also the short period fluctuations are more pronounced during substorms in comparison to quiet times. In the second panel (from the top) of the figure, Maxwell current in pA/m^2 shows almost consistently higher values during the substorm time in comparison to those during absence of substorms. In the bottom panel local positive conductivity during the substorms does not show consistently higher value like PG and current density.

Figure 3 shows the effect of substorms on GEC parameters in the magnetic post-midnight time [0000-0600 MLT]. Top panel shows the averaged potential gradient during substorms (in thick lines) and averaged potential gradient during geomagnetically quiet time (in thin lines). During substorms the potential gradient shows, in general, higher value than the potential gradient in the absence of substorms. It is noticeable that the short period fluctuations are more pronounced during the substorm time (thick line). Middle panel of the figure shows the comparison of Maxwell current. Maxwell currents during substorms and in absence of substorms are almost equal but the shorter period fluctuations appear more pronounced. In the bottom panel positive conductivity is shown. Conductivity during the substorms in the post-midnight time is consistently higher than that of quiet time conductivity.

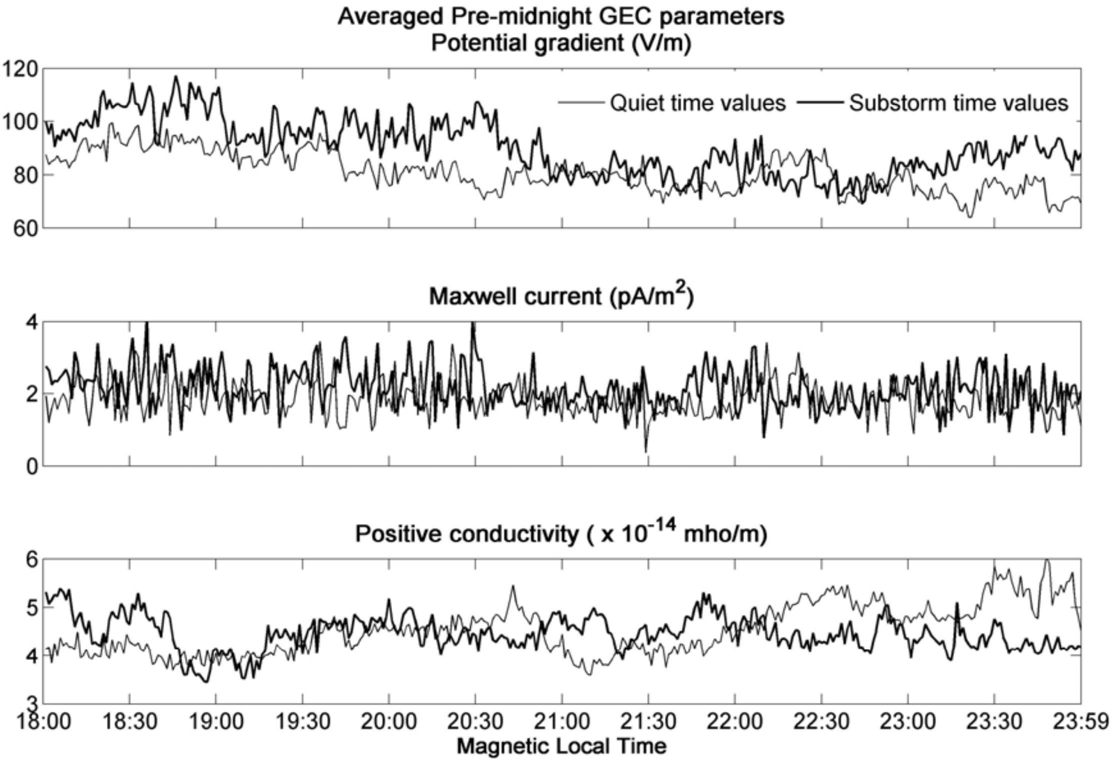

Fig. 2. Averaged potential gradient, Maxwell current and positive conductivity during geomagnetically disturbed and quiet times on fair-weather days in pre-midnight times.

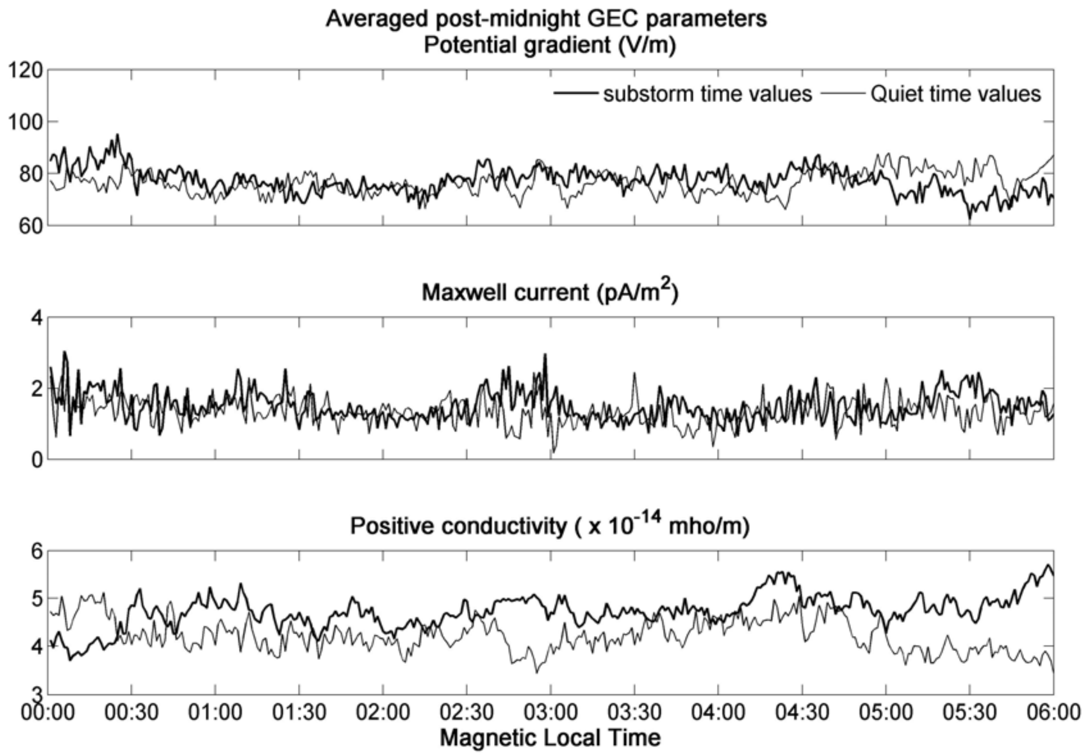

Fig. 3. Same as figure 2 during magnetic post-midnight time

It is well established that the global electricity follows Ohm's law (J = σE) during fair-weather days. This property holds during geomagnetically disturbed times as well. Enhancement in current density is well correlated with enhancement in Maxwell current density in Figure 2 and Figure 3. The ground level geomagnetically disturbed positive conductivity, during pre-midnight,does not show consistent enhancement while the post-midnight values of positive conductivity shows enhancement in comparison to quiet time values.

5. Conclusions

This work shows the enhanced absorption of cosmic radio noise during substorms in the lower ionosphere over sub-auroral locations, Maitri and NOVO. We have also investigated the influence of substorms on fair-weather GEC parameters. The study shows consistent enhancement in GEC parameters, potential gradient and Maxwell current density during substorms in comparison to geomagnetically quiet conditions. From the Figure 2 and Figure 3 it is evident that the GEC parameters, PG and current density are more fluctuating during the substorm period than during quiet period. The positive conductivities during various local times do not show significant enhancement in short period fluctuations during substorm period than quiet times. The enhancement in conductivity may be because of local effects. The ground level conductivity is expected to be unaffected by substorms even at subauroral locations. The enhancement in potential gradient and Maxwell current density and dominance of short period fluctuations during substorm clearly demonstrate that the near-Earth environment is clearly affected by geomagnetic activities.

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