First Results from Imaging Riometer Installed At Indian Antarctic Station Maitri, Antarctica

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Abstract

An imaging Riometer has been installed at Indian Antarctic station Maitri (Geographic 70.75 degree S, 11.75 degree E; corrected geomagnetic 63.11 degree S, 53.59 degree E) in February 2010. This paper presents some of the salient results obtained during the year 2011 in 30 Indian Scientific Expedition to Antarctica.

Sidereal shift of around 2 hours in the diurnal pattern validates the data obtained from the newly installed instrument. Moreover, the strength of cosmic noise signal on quiet days also varies with months. This is apparently due to solar ionization of D-region ionosphere causing enhanced electron density where collision frequency is already high. The main objective of installing the imaging Riometer at Maitri is to study magneotspheric-ionospheric coupling during substorm processes. In the current study, we present two typical examples of disturbed time CNA associated with storm-time and non-storm time substorm. Results reveal that CNA is more pronounced during storm-time substorm as compared to non-storm time substorm. The level of CNA strongly depends upon the strengthening of convectional electric field and the duration of southward turning of interplanetary magnetic field before the substorm onset.

Keywords: *imaging Riometer, CNA, Magnetospheric substorm, Geomagnetic storm, Auroral electrojet.*

1. Introduction:

Studies of ionospheric absorption of radio waves are thus of considerable interest to the communication engineers and space researchers. So requirement of an instrument to monitor the lower ionosphere is unavoidable. Earlier wide beam Riometer has been used for this purpose since 1950s. Basically, Riometer is the acronym of Relative Ionospheric Opacity Meter using Extra Terrestrial Electromagnetic Radiation. It is an important ionospheric diagnostic tool which uses the randomly fluctuating, almost 'white', noise from galactic radio sources as probing signals to investigate the upper, ionized part of the Earth's atmosphere [Little, 1954; Little and Leinbach, 1958, 1959]. Outside the influence of the Earth's environment these radio signals have fairly constant intensities [Stauning, 1984]. Absorption of the cosmic radio signal is experienced due the ionosphere at frequencies above 15 MHz when highly directional antennas are pointed towards the particular part of the sky. Celestial objects like Quasars, super dense objects that lie far from Earth, emit electromagnetic waves in its entire spectrum including radio waves.

1.1 Indian perspective of Ionospheric study using Cosmic Noise study:

Indian contribution to the study of cosmic noise started six decades ago. Mitra and Shain [1953] introduced cosmic noise method for the first time. The ionospheric absorption was measured by comparing the signal strength of extraterrestrial radio waves received on a fixed receiving system with the signal strength received on the same system at the same sidereal time under conditions of negligible ionospheric absorption. Bhonsle and Ramanathan [1958] reported absorption in the D-region over Ahmedabad, India (geographic: 23.02ndegree N, 72.38 degree E) by using riometer at 25 MHz. Occurrence characteristic of ionospheric absorption in the time period from afternoon to evening is consistent with the daily variation of the ionospheric F- region absorption associated with increases of foF2 which were obtained from the statistical analysis of the riometer absorption on 25 MHz at Ahmedabad in India [Abdu et al., 1967]. Diurnal and seasonal variation of total ionospheric absorption (L) at an equatorial station, Trivandrum (dip 0.6 S, geographic long 76.56 degree E) has been studied using two years riometer data [Parameshwan et al.,1976]. They have investigated the dependence of L on geophysical parameters and sunspot numbers. In addition to that, they have estimated the electron tempearature of F-region from the F-region contribution to the total absorption. Lunetta and Abdu [1971] suggested that the absorption of cosmic radio noise varies with the latitude of the observations.

2. Technique for deriving QDC:

The method of determining QDC of cosmic noise signal has been discussed extensively by several authors [e.g., Mitra and Shain, 1953; Lusignan, 1960; Steiger and Warmick, 1967; Armstrong et al. 1977; Krishnaswamy et al.,1985; Tanaka et al., 2007, etc]. Recently, Moro et al, [2012] have presented new modified technique for Riometer Network (SARINET) data from South America with respect to method of Tanaka et al., [2007]. In that paper, two criteria have been followed: (1) Riometer data selection according to the geomagnetic activity and (2) data cleaning with respect to electromagnetic interference as well as some other noises.

In the current approach for deriving QDC of cosmic noise signal, we have used two criteria as followed by Moro et al.[2012]. For fulfillment of the first criteria, the average of imaging Riometer data for the five international quietest days was used to derive QDC for a particular month. Table 1 is showing the list of days taken in a month during the year 2010-2011 for deriving QDC. It should be noted that only 6 days data were available during December,2010, out of that only one day was magnetically quiet($K_p < 3$). The second criteria are taken for removing electromagnetic interference. This may be produced due to presence of man-made interference, thunderstorms or solar noise bursts. These bursts can affect the estimation of the QDC leading to an increase of the QDC level. [Moro et al, 2012]. Here, we have taken the selected days for the year 2010 and 2011 confining to quietest days of month. The error limit of QDC curve ranges from 0.02 dB to 0.30 dB. The maximum error value has been recorded in January month and minimum in the September month. Since imaging Riometer can serve both the narrow beam application as well as wide beam application, we have chosen the solar zenith corrected wide beam data for this study. The imaging riometer data set has inbuilt provision to differentiate wide beams and narrow beams. In figure (1), QDC of each month have been plotted.

Table:1 List of number of quiet days considered for QDC analysis of cosmic noise signal. Conitunes 12 months period of imaging Riometer data have been taken from November,2010 to October, 2011. This period is taken as per the data availability and quality.

Year	Months	No. of days
2010	November	04
	December	01
2011	January	04
	February	05
	March	05
	April	05
	May	05
	June	05
	July	04
	August	05
	September	05
	October	05

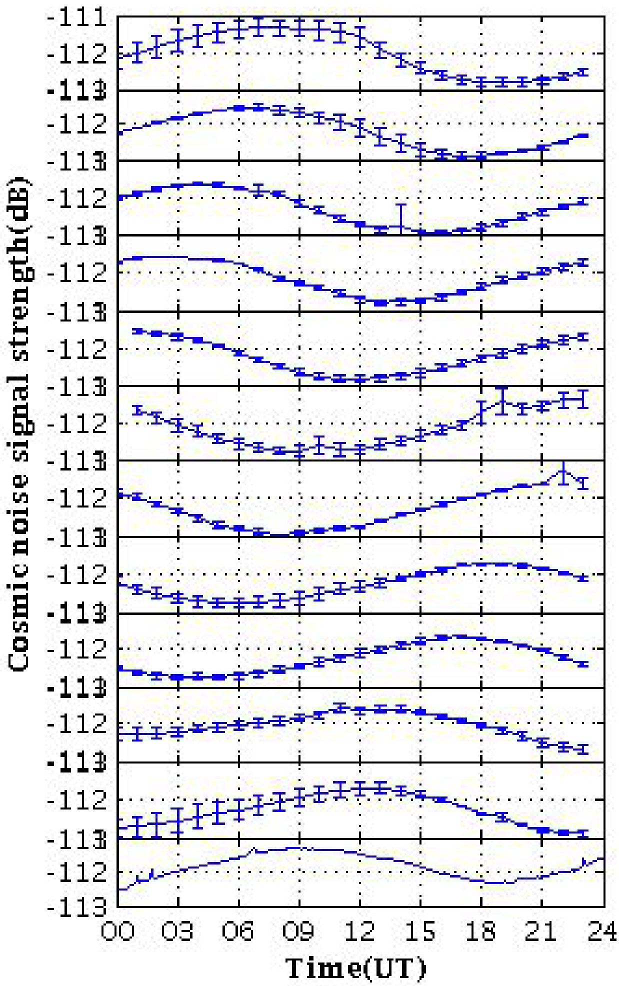

Fig. 1: *Quiet Day Cosmic noise signals or, Quiet day curves(QDCs) for each months of year 2010-11.Here wide beam(beam 17) data of imaging Riometer was used for deriving QDCs.*

2.1 Sidereal time and Monthly variation of QDC at Maitri, Antarctica:

The signal strength of radio noises, coming from the inter-stellar space varies with sidereal time (time scale based on earth's rate of rotation measured relatively to fixed stars) and months. In general, average sidereal day is of 23 hr 56 min and 4 seconds where as the solar day is of 24 hrs. So there is an approximately 4 minute difference between sidereal and solar day. Imaging Riometer data is in solar time format. While deriving QDC, with respect to solar time, we would expect a shift of about 2 hr (30days X 4 min) in the diurnal pattern of signal strength between consecutive months. This seems to be a genuine tool to assess the accuracy as well as the correctness of data and thereby validating the new dataset.

We observed an approximate shift of around 2 hr in the consecutive months that can be seen in figure (3). In January, the maximum value of the signal strength has been obtained at around 0900 UT, whereas in February month, the occurrence time of maximum value has shifted around 0700 UT. Similarly for other months, the shift of 2 hrs is consistently observed. Moreover, if one follows the red tone which represents the maximum strength of QDC, around 2 hr/month shift is consistently observed.

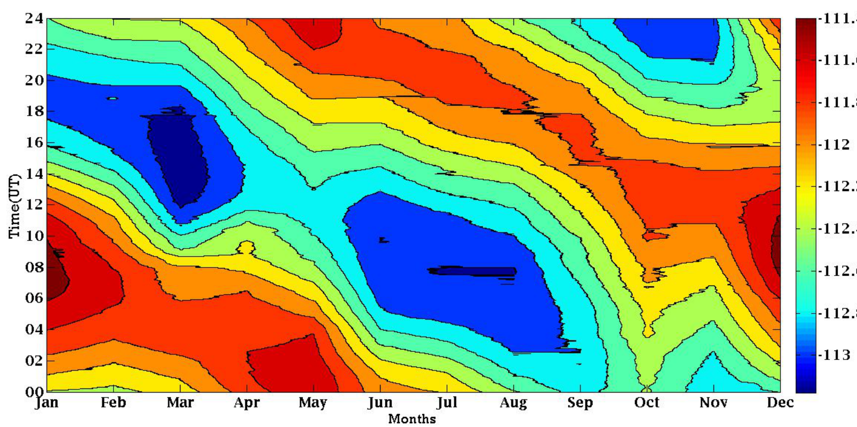

Fig. 2: *Coantour plot for Sidereal shift of maximum signal strength of Cosmic noise signal for consecutive months. For the month January to May, shift of ~ 10 hours (~ 10 UT to 00 UT) of maximum signal strength is seen. Similarly, for the month June to December, shift of ~14 hours (~24 UT to 10 UT) is seen.*

In quiet conditions of ionosphere over the station of Maitri, cosmic noise signal has a regular diurnal pattern (figures (2) and (3)). However, sun can also influence the level of signal through following mechanism. The ultraviolet rays of the sun enhances the ionization of the ionosphere which ultimately causes more absorption of signal of cosmic noises even in a quiet day, when there is no additional input of particle flux from the magnetosphere, e.g., during substorm phenomena [Browne et al., 1995]. At Antarctica, seasonal variation of strength of quiet day curves of cosmic noises has been observed. Figure (3) shows a seasonal variation of the cosmic noise signal strength. In three panels, average strength, maximum strength and minimum strength of the QDC of cosmic noise signal for each month have been plotted respectively. There is comparatively maximum drop of signal strength (average, maximum and minimum) in the month of March (autumn equinox month) and August (pre-spring equinox month). However, the average strength of cosmic noise signal is maximum (~ -112.03 dB) in the month of May, which is in winter season and (~ -111.95 dB) in

December month in summer at Antarctica. From Equation (1), one would expect higher cosmic noise signal strength during winter (no-Sun) months when ionospheric conductivity is less and opposite for summer (sunlit) months. However, in our observation, we see very complex behavior of signal strength variation over months (Figure 4). When austral winter approaches (March onwards) signal strength rises (as expected), whereas for the rest of the months variations are quite random. For example, sudden drop in signal strength from January to March (summer season), May to June (winter in progress) and relatively constant variation till the commencement of austral summer and further increase cannot be explained on the basis of solar illumination. It makes us to believe that other factors significantly contribute towards the seasonal variation of signal strength of QDC.

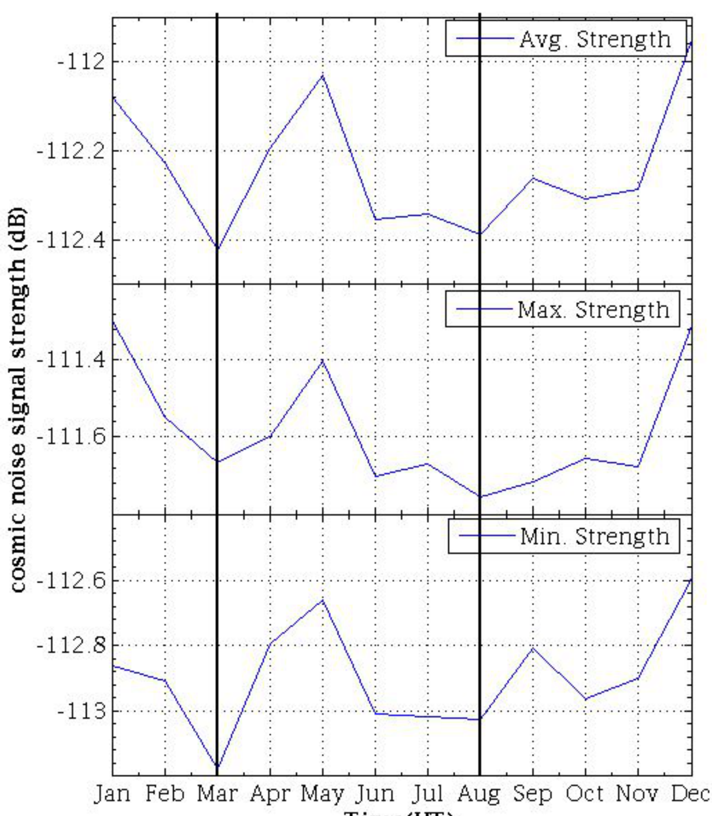

Fig. 3: *Seasonal variation of cosmic noise signal strength: Upper, middle and lower panels are respectively for average, maximum and minimum strength value.*

3. Observations of CNA during storm-time and non-storm time substorms:

In the present study, we have examined CNA characteristics during storm time substorm and non-storm substorm occurring near midnight hours at Maitri on 12 April 2011 and 09 July 2011 respectively. We observe that Maitri comes under the influence of westward electrojet for both the events. However, there is a subtle difference to note between these two events.

12 April 2011 Event *of CNA during the storm time substorm:*

Cosmic noise absorption (CNA), in association with the magnetospheric substorm occurred during 0600-0800 UT on 12 April 2011 has been shown. For this event Maitri station would lie in 0500-0700 MLT interval as MLT = UT-1 for our station. In figure (4), we depict the interplanetary magnetic field (IMF) and solar wind velocity as observed by instruments aboard ACE satellite located outside of the Earth's magnetosphere (at X = 229.6 *Re*, Y = - 21.5 *Re*, Z = - 40.9 *Re* in GSM coordinate system: here R*e* is the radius of the earth ~ 6378 km). In order to corroborate the interplanetary observations with ground magnetic data, IMF and solar wind data have been delayed by 60 minutes taking into account

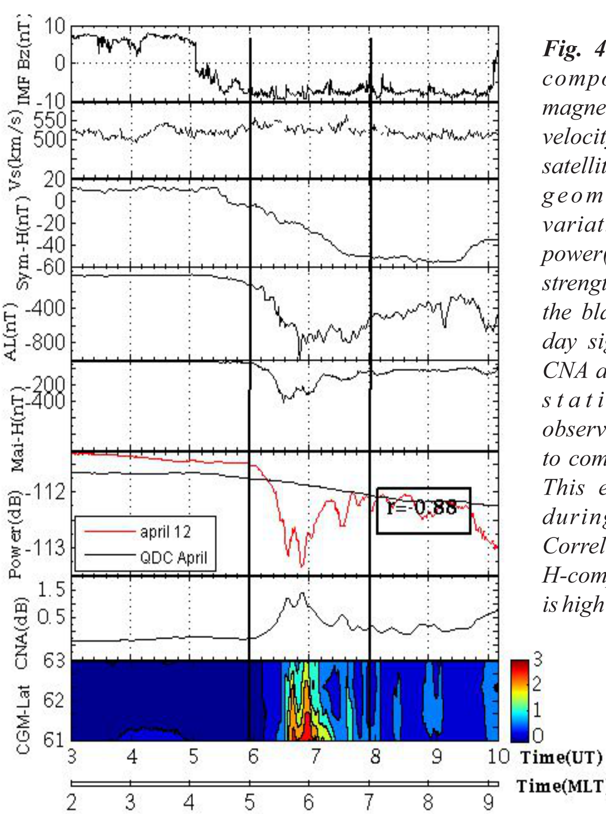

Fig. 4: *(form top to bottom) Bz component of interplanetary magnetic field (IMF) , solar wind velocity (Vs) as observed by ACE satellite, Sym-H index , AL index, geomagnetic H-component variation, cosmic noise signal power(red line indicates the signal strength of 12 April 2011, where as the black line indicates the quiet day signal for the April month), CNA and image of CNA at Maitri station. Interplanetary observations are delayed by 60 min to compare with the gorund data. This event represents the CNA during storm time-substorm. Correlation coeffiecient between H-componet and CNA in this case is high (r= -0.88).*

the travel time of solar wind at an average speed of ~ 500 km/s from the location of the satellite to the magnetopause of the earth. The upper first two panels represent the IMF Bz and solar wind velocity (Vs) respectively. In the next two panels, SYM-H and AL-index have been plotted respectively. The bottom four panels represent the H-component of geomagnetic field, cosmic noise signals, relative CNA and image of CNA over Maitri station. In the sixth panel, quiet day signal of April month and signal of individual day (12 April 2011) has been plotted. We obtained CNA (the bottom most panel) for the day by taking difference of cosmic noise signal of that day in a month from the QDC of the same month. The bottom most panel shows the image plot of CNA during the event. It has been observed that CNA become more intense during the period of 0630-0730 UT.

The onset of substorm can be clearly seen at ~ 0600 UT in the AL-index with a sharp depression of ~1000 nT (figure 5). This appears to be a storm time substorm event as the SYM-H index value has gone down to -50 nT [Hsu et al, 1998). The solar wind velocity on that particular day was high (~ 500km/sec) and steadily increased up to 550 km/sec. The solar wind velocity was steady during all the phases of substorm. The Substorm triggering initiated with sharp southward turn of IMF Bz at ~ 0500 UT. It remained southward for 5 hrs then turned northward at 1010 UT approximately. At the onset of substorm, simultaneous occurrence of westward electrojet and cosmic noise absorption (CNA) has been observed over Matri. Intensity of the westward electrojet is weaker over Maitri (H depression ~-350 nT) than what is observed in the AL index. This could be due to the fact that Maitri station was around 0500 hr MLT and quite away from the center of the westward electrojet which peaks around midnight [Allen and Kroehl, 1975; Singh et al., 2012]. Moreover, due to the absorption of cosmic radio signal, it was attenuated by more than 1.5 dB in comparison to monthly QDC (see bottom panel of Figure 5). It should be noted that the correlation coefficient (r) between H-component and strength of CNA during the event (0500-0700 MLT) at Maitri for this event is very high (r= -0.88).

***09 July 2011 event of CNA during non-storm time substorm event**:*

On 09 July 2011, we observed a substorm during 0300-0500 UT which is not accompanied by storm. For this event, Maitri station would be in the post-midnight hour (0200-0400 MLT). Top two panels of figure (5) depict the IMF Bz and solar wind velocity (Vs) as observed by instruments aboard ACE satellite. During this event the location of ACE was at X = 237.9 *Re*, Y = 40.4 *Re*, Z = 23.0 *Re* in GSM coordinate system. In order to relate the interplanetary observations with ground magnetic data, IMF and solar wind data have been delayed by 71 minutes taking into account the travel time of solar wind at an average speed of ~ 340 km/s from the location of the satellite to the magnetopause of the earth. In the next two panels, SYM-H and AL index have been plotted respectively. The bottom four panels respectively show H-component of geomagnetic field, Cosmic noise signals, relative CNA and image of CNA respectively at Maitri. In the sixth panel, quiet day signal of July month and signal of 09 July 2011 has been plotted. We obtained CNA (the bottom most panel panel) for the day by taking difference of cosmic noise signal of that day in a month from the QDC of the same month. The bottom most panel shows the image plot of CNA during the event. It has been observed that CNA become relatively stronger during a small period of 0340-04310 UT.

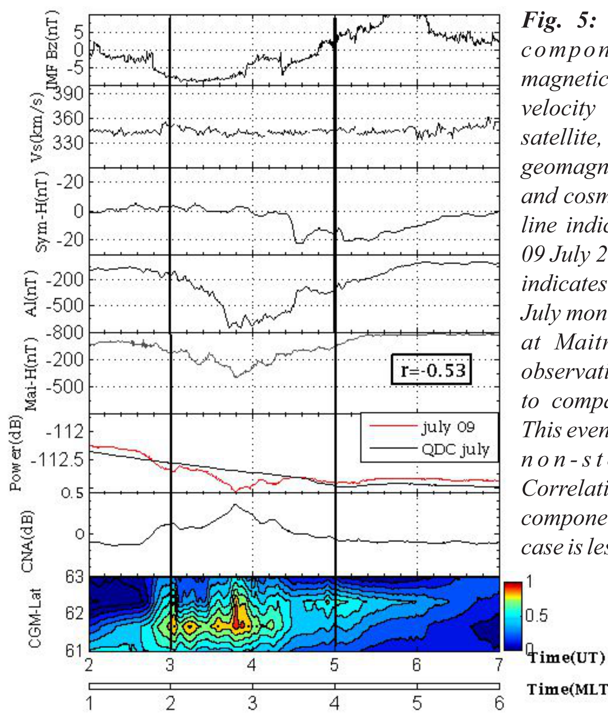

Fig. 5: *(form top to bottom) Bz component of interplanetary magnetic field (IMF) , solar wind velocity (Vs) as observed by ACE satellite, Sym-H index , AL index, geomagnetic H-component variation and cosmic noise signal power (red line indicates the signal strength of 09 July 2011, where as the black line indicates the quiet day signal for the July month), CNA and image of CNA at Maitri station. Interplanetary observations are delayed by 71 min to compare with the gorund data. This event represents the CNA during non-storm time substorm. Correlation coeffiecient between H-componet and strength of CNA in this case is less (r= -0.53).*

Generally, non-storm time substorms have no sign of simultaneous storm [Hsu et al, 1998]. At the time of onset (~ 0300 UT) of substorm the sym-H index was ~ 1 nT, which clearly shows no signature of enhancement of ring currents. The magnitude of AL-index was ~700 nT. Simultaneous observation of solar wind velocity for ACE satellite showed steady and slow flow of solar wind having velocity ~340 km/s with southward IMF Bz. This non storm time substorm led to a less amount of absorption of cosmic noise (~0. 4 dB) along with almost same magnitude of westward electrojet (-350 nT) despite the fact that AL-index was less (~700 nT) as compared to storm-time substorm of 12 April 2011 seen over Matri station. This is for the reason that Maitri was at around 0200 hr MLT and relatively nearer to the centre of westward electrojet (discussed earlier in the figure 5). The correlation coefficient between H-component and strength of

CNA during the event (0200-0400 MLT) at Maitri in this case was found to be less (r= -0.53) as compared to storm-time substorm case of 12 April 2011. However, we obtained better (r= -0.75) when we restrict the calculation of correlation coefficient within the time limit (0200-0330 MLT). This time limit has been taken due to the fact that CNA lasts for this period of time only during the event.

4. Discussion and Conclusion:

For the first time, data of imaging Riometer at Maitri, Antarctica have been used to study the substorm activity at Maitri in this work. The observation of CNA using Imaging Riometer could be a great asset for carrying out the research in sub-auroral ionosphere. The usefulness of this instrument is remarkable in understanding of precipitation dynamics due to substorm processes at sub-auroral latitude region. In this paper we have given a brief account of the background, theory and instrumentation with an emphasis on validating the newly obtained data set.

The quiet day curve (QDC) of any new instrument is most essential part of study. One has to understand the daily and seasonal variation of QDC of new instrument for further research. So, here we have discussed about the sidereal and monthly variation of QDCs. A consistent sidereal shift of ~2hrs in each consecutive month has been seen which signify the consistency and reliability of the new instrument. Thus, the shifting of the main source of the cosmic noise signal with sidereal time can be clearly identified.

Monthly variation of cosmic noise signal in quiet condition i.e QDCs not only depends on the source of galactic cosmic noise but also on other factors. It seems other things such as orbital motion of the earth, the distance of the sun from the earth and level of ionization in the D-region during various months, responsible for cosmic noise during various months have simultaneous impact on the cosmic noise signal variation with months.

And finally, we have shown two different cases of CNA during storm time and non-storm time substorms, both occurring in post midnight to early morning sector. Magnetic reconnection [e.g., Baker et al., 1996] and dipolarization/ current disruption e.g. [Lui, 1998] in the near-earth magnetotail have been suggested as the cause of substorm expansion onsets. Initially it was suggested that storm and nonstorm time substorms are manifestation of different mechanism, namely magnetic reconnection and current disruption respectively [Baumjohan et al., 1996]. But later it was shown that storm and non-storm time substorms do not differ qualitatively in the generation mechanism [Hsu and McPherron, 1998]. Nevertheless, the energy accumulation and the dipolarization tend to be more significant during storm time substorms.

Maitri is a sub-auroral station located in Antarctica and it is expected that the auroral oval would expand and cover Maitri location during disturbed days. Hence the station will come under the influence of Auroral electrojet. Here, during both the CNA events associated with magnetospheric substorm, the equatorward expansion of auroral oval has taken place. In case of CNA event occurring 12 April 2011 during storm-time substorm, the auroral electrojet was slightly stronger (AL ~ 1000 nT] as compared with the non-storm time substorm event of 09 July 2011 (AL ~ 700 nT). During both the substorms, clear influence of west ward electrojet of almost the same magnitude (~ 350 nT) with simultaneous occurrence of CNA was observed over Matri. Maitri was nearer to the onset location of substorm of later case (09 July 2011- non-storm time) compared to that during 12 April 2011- storm-time, as the MLT range for the event on 09 July 2011 was 02-04 hrs and it was 05-07 hrs for 12 April 2011. There are different kinds of CNA event depending on the local time and magnetospheric phenomena [stauning, 1994]. However the above two CNA events which have examined in this study, are confirmed to be associated with substorms. This kind of absorption is due to the precipitation of energetic electrons (energy range from 10 to 100 KeV) in the E- region and upper D-region (~ 70-100 km) [Kellerman, 2009].

While comparing the two events, we observed higher CNA for the storm-time substorm event. During storm-time substorm, the south-ward turning of IMF Bz occurred at around 0500 UT and was sustained up to 6 hrs. Moreover, the solar wind velocity (**v**) was high (~550 km.) during the event. Thereby the convection electric field (**- V** X **Bz**) was stronger (5.5 mV/m.) and was sustained for longer period of time (~6 hrs) which we can infer from the figure 5. One thing should be noticed in this storm-time substorm event is the difference of ~01 hr between the south-ward turning of IMF Bz and onset of substorm. That means strengthening of convection electric field occurred much earlier (~ 01 hr) that drove more flux of energetic charge particles in to the magnetosphere and caused subsequent loading of particles in to the magneto-tail region before the re-connection occur. Whereas, the other event of non-storm time substorm (figure 6) clearly shows weaker convection electric field (~3.4 mV/m.) for lesser period of time (~ 2 hrs). During this event the southward turning of IMF Bz occurred only 10 minutes before the onset of substorm and was sustained for comparatively less time (~ 2 hr.) as compared to the storm-time substorm event. In addition to that, the solar wind velocity (**V**) was also moderate (~340 km.) during this event. This clarifies that level of CNA is more related to loading of the particles and intensity of reconnection in the magnetotail. These results also strongly support the difference between storm-time substorm and non-storm time substorm characteristics stated by Hsu and McPherron [1998]. They clearly mentioned in their paper in 1998 that the energy accumulation and the dipolarization tend to be more significant during storm time substorms.

Moreover, the reconnection of higher intensity also triggered a moderate storm which was associated with the 12 April 2011 event.

Finally, we can conclude that depression in geomagnetic H-component and CNA at Maitri are the consequences of flux of electrons intensifying the auroral electrojet and precipitation of electrons enhancing the conductivity of the upper D-region respectively. The correlation coefficient between H-component and CNA strength at Maitri is -0.88 for storm time substorm event and it is -0.53 for non-storm time substorm event. Correlation co-efficient for both the events are significant as enough number of data points (~ 7200) have gone in to the analysis. It is clear that CNA and H-component of geomagnetic field variation correlate well for both the events. However the extent of CNA depends on the strength of the magnetospheric convection electric field and the duration of southward IMF Bz before the substorm onset. Nevertheless, a proper statistical study may explore the possible empirical relationship between convection electric field and CNA at a sub-auroral station such as Maitri.

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References:

1. Abdu, M. A., S. S. Degaonkar, and K. R. Ramanathan, 1967, Attenuation of galactic noise at 25 MHz and 21.3 MHz in the ionosphere over Ahmedabad during 1957–1964, J. Geophys. Res., 72, 1547–1554.
2. Allen, J. H., and H. W. Kroehl, 1975, Spatial and temporal distributions of magnetic effects of auroral electrojets as derived from AE indices, J. Geophys. Res., 80, 3607—end page.
3. Armstrong R.J., Berkey F.T., and Melbye T., 1977,The day to night ratio in auroral zone Riometer measurements, Planet Space Sci., 25, 1193-1198.
4. Arun, T., A. Dhar, K. Emperumal, and Pathan B. M., 2005, IMF BYdependence of the extent of substorm westward electrojet, J. Earth Syst. Sci, 114, 177-184.
5. Baker D. N., Pulkkinen T.I., Angelopoulos V., Baumjohann W., McPherron R. L., 1996, Neutral Line model of substorms: pas results and present view, J. Geophys. Res., 101,12, 975.

6. Baumjohan W., Kamide Y.,and Nakamura R., 1996, Substorms, Storms, and near-Earth tail, J. Geomagn. Geoelectr., 48, 177-185.
7. Bhonsle R.V. and Ramanathan K.R., 1958, Studies of cosmic radio noise on 25 Mc/s at Ahmedabad, J. Sci. and Ind. Res., 17A, 40-45.
8. Browne S., Hargreaves J. K., and Honary B., 1995,An imaging Riometer for ionospheric studies, Electronics and Communication, 7,209-217.
9. Budden K. G., 1985, The propagation of radio waves, Cambridge University Press, Cambridge.
10. Ellis G. R., 1957, Cosmic radio-noise intensities below 10 Mc/s, J. Geophys. Res., 62, 229-234.
11. Frey, H. U., Mende, S. B., Angelopoulos, V., and Donovan, E. F., 2004, Substorm onset observations by IMAGE-FUV, J. Geophys. Res., 109, A10304
12. Honary F., Marple S.R., Barrath K., Chapman P., Grill M., and Nielsen E., 2011 Digital beam forming imaging Riometer systems, Review of Scientific instruments, 82, 031301(1-13).
13. Hsu, T. –S. and R.L. McPherron, 1998, The main onset of a magnetospheric substorm, Proc. International conference on substorm (ICS-4), edited by S. Kokubun and Y. Kamide, 79-82, Terra Scientific Publishing Company, Tokyo, Lake Hamana, japan,.
14. Jansky, K. G., 1937, Minimum noise levels obtained on short wave radio receiving systems, Proc. IRE, 25, 1517-1530.
15. Kellerman A. C., 2009, On the relationship between auroral absorption, electrojet currents and plasma convection, Ann. Geophys., 27, 473-486.
16. Krishnaswamy S., Detrick D.L. and Rosenberg T., 1985, The inflection point method of determining Riometer quiet day curves, Radio Sci., 20, 123-136.
17. Little C. G., 1954, High latitude ionospheric observations using extra terrestrial radio waves, Proc. IRE, 42, 1700.
18. Little C. G., and Leinbach H., 1958, some measurements of high latitude ionospheric absorption using extraterrestrial radio waves, Proc. IRE, 46, 334-348.
19. Lui A.T.Y., Lopez R.E., Krimigis S.M., McEntire R.W., Zanetii L.J., and Potemra T.A., 1998, A case study of magnetotail current sheet disruption and diversion, Geophysical Research Letters, 15(7), 721-724.
20. Lunetta M. and Abdu M. A., 1971 A Study on the Latitudinal Features of the Ionospheric Absorption Excursion, Revista Brasileira de Física, 1, 369-379.
21. Lusignan, B, 1960, Cosmic noise absorption measurements at Stanford, California, and Pullman, Washington, J. Geophys. Res., 65, 3895-3902.
22. Moro J., 2012, Denardini C.M., Correia E., Abdu M.A., Schuch N.J. and Makita K., A comparision of two different techniques for deriving the quiet day curve from SARINET Riometer data, Ann. Geophys., 30, 1159-1168.
23. Parameswaran K. and Krishnamurthy B. V., 1976, Studies on ionospheric absorption by riometer technique at magnetic equator, Annales de Geophysique,32, 419-427.
24. Rawer K. and Suchy K., 1976, Remarks concerning the dispersion equation of electromagnetic waves in a magnetized cold plasma, J. Atmos. Terr. Phys., 38, 395- 398.

25. Rostoker, G., Geomagnetic indices, 1972, Rev. Geophys. Space Phys., 4, 935-950.

26. Singh, A. K., Sinha, A. K., Rawat, R. Jayashree, B., Pathan, B. M., and Dhar, A., (2012) A broad climatology of very high latitude substorms, Adv. Space Res., 50, 1512-1523.

27. Stauning P., 1984, Absorption of cosmic noise in the E-region during electron heating events. A new class of Riometer absorption events, 46, 395-398.

28. Steiger W.R. and Warmick J.W., 1961, Observations of cosmic radio noise at 18 Mc/s in Hawaii, J. Geophys. Res., 66, 57-66,.

29. Tanaka Y., Makita K., Nishino M., and Ookawa T., 2007, Development of data analysis program for imaging Riometerby using MATLAB, Bulletin of science and engineering, Takushoku University, 10, 61-66.

30. Vichare G., Rawat R., Hinchanal A., Sinha A.K., Dhar A., and Pathan B.M., 2012, Seasonal evolution of S_q current system at sub-auroral latitude, Earth Planets Space, 64, 1023-1031.

31. Wrenn G. L., Rodger A.S. and Rishbeth H., 1987, Geomagnetic storms in the Antarctica F-region. I. Diurnal and seasonal patterns for main phase effects., J. Atmos. Terr. Phys., 49, 901-913.