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Commissioning of Space Physics Laboratory at Indian Permanent Research Base "Maitri", Antarctica to study the impact of space weather events on high latitude ionospheric region

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ABSTRACT

Ionosphere plays an important role for long distance HF communications as well as affects the satellite communication and navigation services especially in high and equatorial latitudes. Inview of this CSIR-NPL planned to establish a state of art Space Physics Laboratory at Indian Permanent Research Base "Maitri" to study the space weather impact over high latitude ionospheric region and its coupling with the low latitude region. In connection to this a Canadian make Advanced Digital Ionosonde (CADI) system along with a Novatel make Global Ionospheric Scintillation and Total Electron Content Monitoring (GISTM) system has been installed during IPY period. The said systems are capable of monitoring different ionospheric parameters like bottom side vertical electron density profile, peak electron density and heights of different ionospheric layers, Ionospheric Total Electron Content (ITEC), L-Band Phase and Amplitude Scintillation etc. on real time basis. This knowledge is important to study the morphology and dynamics of high latitude ionosphere.

INTRODUCTION

The near Earth space environment also known as space weather condition has a great impact on earth's atmosphere specially on upper atmospheric heights known to be as ionosphere. The ionosphere is the ionized part of the earth's upper atmosphere which comprises free electrons and positive ions, generally equal in numbers. This causes the media to be as electrically neutral. However, the spatial distribution of ionization is not homogeneous and the ion density varies with the geographic latitudes. The spatial distribution of ion density depends upon the various background parameters like solar zenith angle, regional electro-dynamic properties, neutral wind pattern etc. In view of this, the terrestrial ionosphere may be divided mainly into three region as low, mid and high latitude regions. Among, all three regions, the low and high latitude ionospheric regions are very sensitive and very unstable in nature. The low latitude ionospheric zone is strongly influenced by electro-dynamic process arising over the equatorial region due to nearly horizontal geomagnetic field line perpendicular to east-ward electric field. On the other hand, the high latitude ionospheric zone is directly affected by solar wind due to nearly vertical geomagnetic field lines. They connect this region with the outer magnetosphere which is directly driven by solar wind. Highly variable solar wind, widely affects the high latitude ionospheric region by producing additional ionization. In general, the polar latitudes are most sensitive and significantly affected due to slight change in space weather conditions. Nearly open or vertical geomagnetic field lines over the polar region allow the solar wind along with the associated high energy particles to penetrate up to lower altitudes. The charged particle precipitation produces aurora with simultaneous increase in the ionospheric conductivities. Such effects are not homogenous throughout the polar region hence the polar region is further divided into three parts i.e. sub-auroral, auroral and polar cap region. The auroral zone is a region of continuous and intense precipitation of energetic particles emanating from the Earth's plasma sheet (Lui et al., 1977; Earther et al., 1976). However, in the sub-auroral region, the energetic particles can be stored and accelerated to very high energies (10KeV to several MeV) before eventual precipitation into the middle atmosphere (in the altitude range between 50-100 km). On the other hand, in the polar caps, the geomagnetic field lines are generally thought to be open and connected to the interplanetary medium. This permits direct access for energetic particles of solar or galactic origin. Though the three regions have different behaviour and responses to the changing space weather condition but combination of the three decides the electro-dynamic properties of polar region. The electric field mapping from the magnetosphere into the ionosphere along with magnetic field lines establishes the dawn-to-dusk field in the polar cap; the field-aligned currents connect the currents flowing in the magnetosphere and ionosphere, forming a three dimensional current system. Hence, the upper atmosphere exhibits various stormy features, affecting mainly the auroral regions. However, the excessive amount of energy deposition over the high latitude region causes the phenomenon known to be as Joule's heating phenomenon. Such phenomenon is further responsible to modulate the conventional wind direction and strength. The modulated wind pattern is responsible for transportation of TIDs from high latitude region to low latitude region. The TID's are often associated with molecular enriched chemical composition and perturbs lower latitude ionospheric regions within a few hours of actual commencement of geomagnetic storms.

In view of such unique behaviour of high latitude ionosphere, CSIR-National Physical Laboratory, New Delhi planned to establish a state of art Indian Polar Space Physics Laboratory (IPSPL) at Indian Permanent Research Base "Maitri", Antarctica during International Polar Year for continuous and real time monitoring of high latitude ionosphere to address the scientific interest of high latitudinal ionospheric consequences caused by the modulation of near-earth space environmental conditions.

Features of Indian Polar Space Physics Laboratory (IPSPL):

Following scientific instruments are installed in the Indian Polar Space Physics Laboratory.

1. Canadian Advanced Digital Ionosonde (CADI):

Ionosonde is simple High Frequency (HF) radars which utilise the radio pulses to detect and range the plasma density in the bottom side ionosphere. The CADI measurement technique is based on the ionosonde Doppler drift or imaging Doppler interferometry (IDI) technique. Basically the CADI system consists seven major blocks which includes Transmitting antenna system, receiving antenna system, Transmitter section, Receiver section, Frequency Synthesizer, Storage & Analyzing computer and Time Synchronizer Global Positioning System. A double delta antenna system is used for CADI Instrument in Maitri, Antarctica. CADI provides sounding capability using high power radio frequency pulses at vertical incidence. Different plasma parameters of Ionosphere is being collected and recorded properly and continuously. Observable quantities include: - echo delay (height) versus frequency; phase and amplitude of echo; angle of arrival; polarization of the echo; real time monitoring of magnetic disturbances and increased ionization in the ionosphere. The frequency of the vertically transmitted wave determines the plasma density from which the pulse is reflected in the ionosphere. The time delay between transmission and reception of the reflected pulse on the ground is a measure of the height of the ionospheric layer from which the pulse was reflected. In this way the height of a specific plasma density is obtained. An ionosonde operates by stepping the frequency of the pulses from say 1 to 20 MHz, thereby producing a map of the bottomside ionosphere. The result is an ionogram. Ionograms are recorded tracings of reflected high frequency radio pulses generated by an ionosonde. Unique relationships exist between the sounding frequency and the ionization densities which can reflect it. The ionogram measurements were synchronized on 10-min boundaries, beginning at 00 min of the hour, and the fixed frequency measurements were nominally synchronized to the nearest minute.

The said system was inaugurated by HSH Prince Albert II of Monaco on 19th January 2009 (see figure- 1 & figure 2).

Figure 1. Indian Polar Space Physics Laboratory, Maitri, Antarctica

Figure 2. Ionosonde Laboratory inaugurated by HSH Prince Albert II of Monaco on 19th January 2009

2. Global Ionospheric Scintillation and TEC Monitoring (GISTM) System:

A Novatel make dual frequency 12 channel GISTM system (figure 3) has been installed for real time and round the clock monitoring of Ionospheric Total Electron Content (ITEC). Along with L-band phase and amplitude scintillation occurs due to various types of ionospheric irregularities. The system is also able to find out the accurate position and location of the monitoring station with a maximum error of 1 meter. For minimizing the multipath reflection a chock ring antenna system is used. The collected GISTM system data now used to study the day-to-day and seasonal variation of Ionospheric Total Electron Content (ITEC) and occurrences characteristics of polar ionospheric scintillation and its dependence on space weather events. The GISTM data will also be used for mapping of macro and mesoscale plasma structure and its movement.

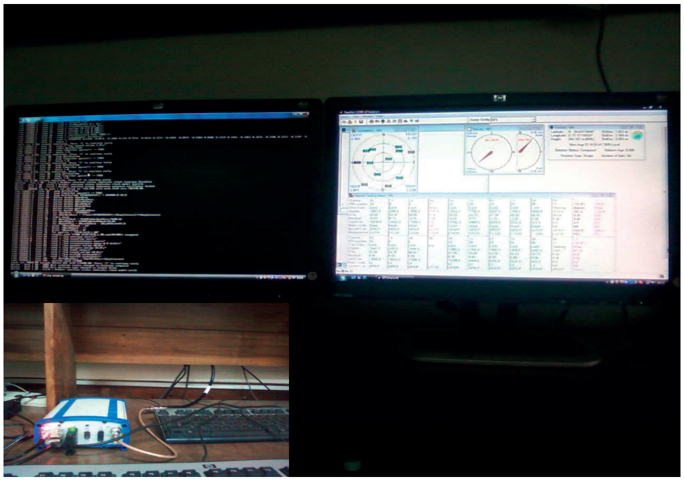

Figure 3: Global Ionospheric Scintillation and Total Electron Content Monitoring (GISTM) System

Preliminary Scientific Results:

The ionospheric parameters observed with the help of instruments described above have been utilized to perform various scientific studies. The main focus of the work is to characterise high latitude ionosphere along with impact of changing space weather conditions. Some preliminary scientific results are illustrated below.

i) Study of Solar wind - magnetosphere - ionosphere coupling process during adverse Space weather conditions

This work is an attempt to examine the Solar wind - Magnetosphere - Ionosphere interaction phenomenon during the changing space weather condition. The main focus of the work is to study the influence of substorms on the high latitude ionospheric region as well as on global geomagnetic field pattern. Previously many researchers have explained the sub-storm system (Heppner et al., 1967; Siscoe and Cummings, 1969; Lui and Burrows, 1978; Tanskanen et al., 1987; Rothwell et al. 1988; Galperin and Feldstein, 1989; Elphinstone et al., 1990; Lopez and Lui, 1990; Lui, 1991) but there are many conflicts in their explanations. The sub-storm system is yet to be fully explained. The present study is divided into two major parts i.e. the global response of earth's magnetosphere to the sub-storms and the impact of the consequences developed due to the sub-storms over the high latitude ionospheric region (southern hemispheric polar ionosphere). To analyze the impact sequence of solar wind- magnetosphere- ionosphere coupling process, an event that occurred on 11^{th} October 2008 has been considered. The ionospheric impact analysis has been performed with the help of GPS based Ionospheric Total Electron Content (ITEC) observed at four GPS receiving stations, located at different defined high latitude ionospheric regions. The considered stations (see figure 4) are sub-auroral station Maitri (70.65 S, 11.45E), Auroral Stations Syowa (69.006 S, 39.58 E) and Mawson (67.604S, 62.87E) along with a polar station Casey (66.28S, 110.53E). The process sequence has been analysed with the help of global solar wind-magnetosphere-ionosphere coupling model "GUMICS" of CCMC (Community Coordinated Modeling Center). The GUMICS model is capable of simulating the near-earth changing magnetospheric dynamics by utilizing the different solar parameters obtained from ACE satellite system. The background IMF-Bz data during Oct. 11, 2008 study are very unstable in nature and for very long time. Such variability in the north-south orientation of the IMF causes episodic energy loading-dissipation cycles termed as magnetospheric sub-storms. The results (see figure 5) clearly show that the unstable nature of southward turned IMF-Bz is responsible for large amount of energy loading into magnetotail. This process further progresses as thinning of plasma sheet during the period of southward turned IMF-Bz followed by burst of energy release towards Earth. The consequences are first observed over auroral oval region in terms of significantly enhanced ITEC value observed over Syowa and Mawson stations (see figure 6). This release of energy further causes equator-ward expansion of auroral region (as explained by Akasofu, 1968; Baker et al., 1994) and secondary enhancement on ITEC value has been also observed at Maitri along with Syowa and Mawson. This is clearly evident that the sub-storm events are not only responsible for abrupt enhancement in plasma density but expands the auroral oval region. On the other hand, the GUMIC model output (Figure 7) clearly shows that the said plasma sheet thinning process has occurred thrice (i.e., at around 0540UT, 0616UT, and 0712UT) during the period of southward turned IMF-Bz (from 0530 UT to 0100 UT) followed by burst of energy release towards Earth. The cumulative effect of the three sub-storms mentioned above has been observed in terms of occurrence of moderate type geomagnetic storm with smooth negative excursion of Dst (-55 nT) after 0800UT, followed by a long recovery phase. It is clearly shown in the results that the southward turning of Bz-IMF at around 6 UT leads to precipitation of energetic particles into the auroral region. However, the ITEC parameter recorded at different polar region stations show that effect of particle precipitation has been confined to auroral oval region only. The time delay in ITEC enhancement (second peak) at MAWSON (glat: 67.604S, glong: 62.87E) show the anti-sunward transportation of TOI (Tongue of Ionization). Similar results are also reported by Sato and Rourke in 1964. However, bay-like structure of IMF-Bz allowed the TOI to be broken into polar cap patches. The ionospheric structures of enhanced ITEC at CASEY gives evidence of it i.e. resemble to polar cap patches. This gives a clear scenario of complete process of activity triggered by penetration of solar wind to the polar ionosphere perturbing Earth's magnetosphere.

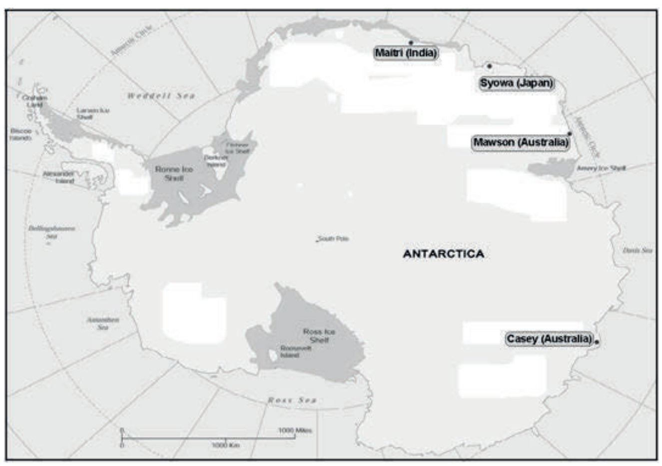

Figure 4: Geographic locations of considered Antarctic based GPS stations

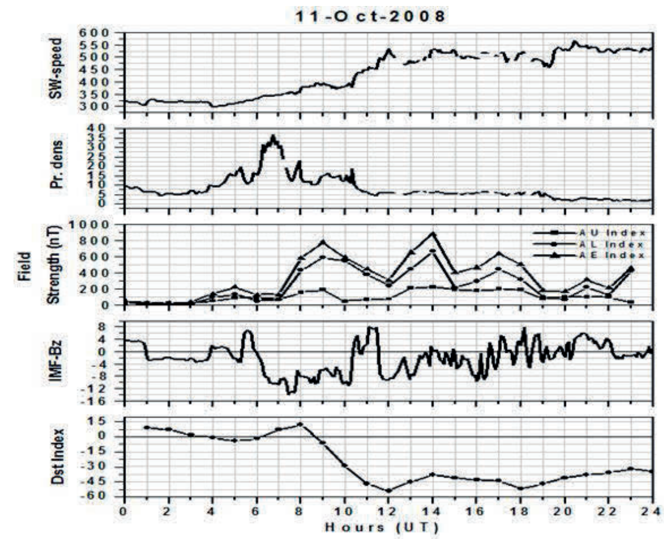

Figure 5: Geo-physical condition along with AE-indices on 11th Oct. 2008

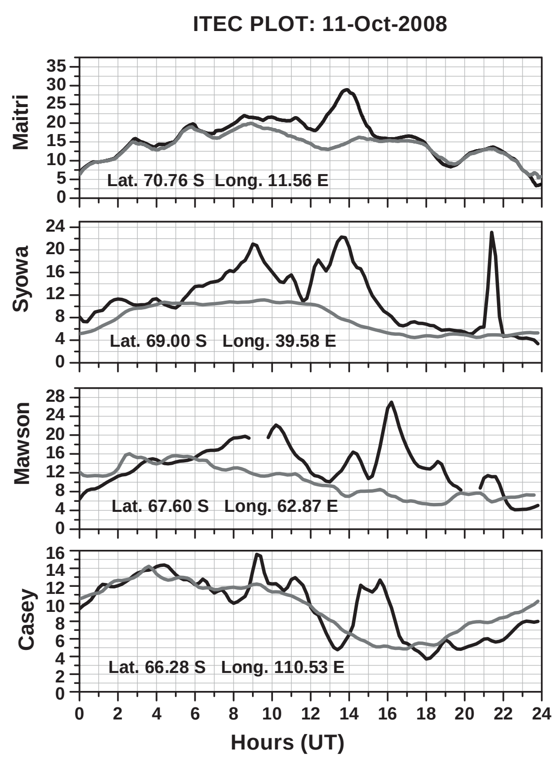

Figure 6:ITEC variations observed over four Antarctic based GPS stations

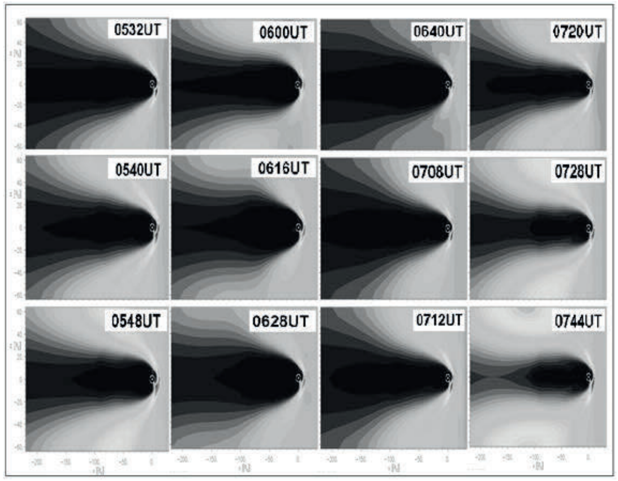

Figure 7: GUMICS model derived magnetospheric condition on 11th Oct. 200

ii) Ionospheric scintillation study over Indian Antarctica Station, Maitri, using GPS data.

The high latitude ionosphere often becomes turbulent and develops electron density irregularities due to solar flares-magnetosphere-ionospheric interactions. The dimensions of these high latitudinal ionospheric irregularities ranging from few meters to kilometers cause scattering of the GPS navigation signals in terms of amplitude and phase scintillation. These types of scintillations are also commonly known as auroral scintillations. To study the L-band scintillations and the associated irregularities, about one year observations are carried out at high latitude Indian Antarctica Station Maitri by using Novatel make dual frequency GPS receiver. The data observed with the help of GPS receiver is then used to study the occurrence characteristics of high latitude L-band scintillation during the low solar activity period in 2008. The observation reveals that the high latitude L-band scintillations are observed only during night time. Since it was a low solar activity period hence the observed scintillations are generally weak type (s4 index less than 0.5). Season wise, their maximum percentage of occurrence is observed during winter season i.e. polar night periods from May to August 2008 as compared to summer and equinox seasons as it can be seen from figure 8.

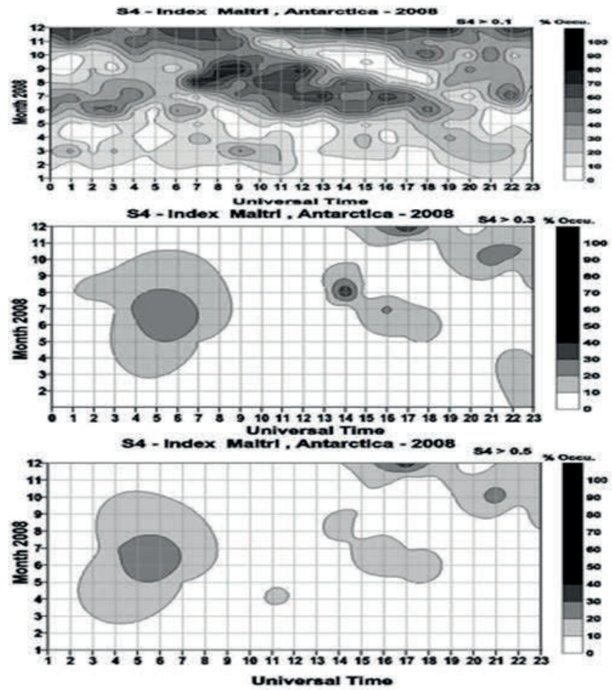

Figure 8: L-Band Scintillation observation over Maitri during the year 2008

Conclusion :

The main achievement of 28th Indian Scientific expedition to Antarctica is commissioning of Indian Polar Space Physics Laboratory and utilising the experimental data to study the high latitude ionospheric response to the adverse space weather conditions. The observation clearly shows that the consecutive sub-storms are responsible for generation of a moderate type global geomagnetic storm. Also, the magnetospheric outburst during sub-storm recovery phase leads to perturb the Earth's ionosphere mainly polar ionosphere. The study provided a clear scenario of complete process of activity triggered by solar wind penetration to the polar region ionosphere perturbing Earth's magnetosphere. However, the L-band scintillation activity is more during the polar winter period i.e. as compared to summer.

Acknowledgement:

On behalf of CSIR-National Physical Laboratory, New Delhi, I would like to thank National Centre for Antarctic and Ocean Research, Goa for providing all the required logistic support for commissioning of experimental facilities in Maitri, Antarctica. I would also like to extend my sincere thanks to Dr.Pradip Malhotra, Leader & Station Commander, Maitri of 28th Indian Scientific Expedition to Antarctica for his constant help, support and motivation during the work. I sincerely thank all the members of 28th ISEA who were a constant source of help and inspiration to me.

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