Twenty Seventh Indian Antarctic Expedition 2007-2009
Ministry of Earth Sciences. Technical Publication No. 25, pp 133-144

Response of the Ionosphere During the Low Solar Activity Period 2008 Over Maitri, Antarctica

Purushottam Bhawre[1], Rupesh M. Das[2], R. S. Dabas[2] and A. K. Gwali

[1]Department of Physics and Electronics, Barkatullah University, Bhopal

[2]Radio & Atmospheric Science Division, National Physical Laboratory, New Delhi

ABSTRACT

Present study, based on dual frequency GPS, derived preliminary results of the diurnal and seasonal variations of Total Electron Content (TEC), amplitude scintillation (S4-Index) and response of TEC during the minor geomagnetic disturbances over the Indian base Station Maitri (Latitude -70.65° N, Longitude 11.45°E) Antarctica, during the low solar activity period (Jan.-Dec. 2008). Month-wise TEC values are highest during the months of January and December, as compared to June month. As regarding seasonal variations, in winter months i.e. June, July and August 2008, TEC values were lowest because ionization process are very low, due to the absence of sunlight; whereas during southern summer season TEC values reaches its maximum, due to the presence of 24-hour sunlight and hence the ionization radiation from the sun. The observation revealed that the high latitude L-band scintillations are observed only during night time, and since it was a low solar activity period, hence the observed scintillations were generally weak type (s4 index less than 0.5). Season-wise, their maximum percentage occurrence is observed in winter season, i.e. polar night periods from May to August 2008, as compared to summer and equinox seasons. A minor geomagnetic storm event occurred on 11 October 2008, the response of ionospheric TEC during the minor magnetic field disturbance is also observed at Maitri. On sudden storm commencement, the TEC showed a 50% enhancement, compared with its regular pattern associated with magnetic storm in high latitude region Antarctic.

Keywords: Ionosphere, Total Electron Content, Magnetic Storm, L-band Scintillations, GPS.

1.0 INTRODUCTION

The Polar Region offers exclusive a vantage point and an open natural laboratory for ionospheric research. Ionospheric studies at Polar Regions are of interest to users of satellite transmissions and those studying aeronomy. A network of stations has been reporting data on a continuous basis for the long and short term predictions. Ionosperic Total Electron Content (TEC) data were recorded every 30 seconds, throughout the year 2008 during the 27th Indian Antarctica Expedition. The Polar Regions are directly affected by the energy of charged solar particles and thus theionosphere shows high fluctuations. The TEC fluctuations over Polar Region depends on various factors and one of them is the ionization process in a high latitude region. Ionization process depends on suns activities and zenith angle of the sun. TEC is highly variable with time and season. Several studies have demonstrated that the TEC strongly depends on solar activates (Da Rosa et al., 1973; Soicher, 1988; Feitcher and Leitinger, 1997; Van Velthoven, 1990). Many studies predicted that the maximum of the 11-year solar activity cycle will be reached in 2000 or 2001, during the high solar activity period; and the ionosphere will have a strong influence on the GPS. The end of the solar activity cycle will be reached in 2008; and during this period of negligible solar activity, the ionosphere will have weak influence on the GPS (Bhawre et al., 2011; Gwal et al., 2011; Purohit et al.).

The high latitude ionosphere often remains turbulent and develops electron density irregularities due to solar flares-magnetosphere-ionospheric interactions. The dimensions of these high latitudinal ionospheric irregularities (Polar Patches) range from few meters to kilometers and cause the GPS signals to scatter in terms of amplitude and phase, commonly referred to as scintillations. These types of scintillations are also known as auroral scintillations. It is well known that ionosphere is a dispersive medium, in which RF signals are refracted by the amount dependent on the signal frequency and the electron density in regions of irregularities, resulting in random phase variations in the emerging wave front, known as phase scintillations. Diffraction of signals also leads to variations in signal amplitude referred to as amplitude scintillation (or amplitude fading for degradations in signal strength). These effects are strongest in equator, auroral and polar cap regions. High latitude auroral irregularities are formed from a precipitation of energetic electrons along terrestrial magnetic field lines into the high latitude ionosphere. These electrons are energized through complex interaction between the solar wind and the earth magnetic fields, resulting in optical and UV emissions commonly known as the auroras. This phenomenon characterizes the magnetospheric substorm, where associated irregularities in electron density lead to scintillations (Arons, 1982). At high latitudes scintillations are found to be associated with large scale plasma structures. Experimentally, the two states of the polar ionosphere controlled by the IMF, and their association with high latitude large scale plasma structures known as patches, blobs and sun-aligned arcs, have been discovered in the 1980's (Weber et al., 1984,1986; Tsunda, et al.,1988; Basu and Valladares,1999). It is well known that ionospheric scintillation is produced by electron density irregularities in the ionosphere, which becomes highly disturbed at times. A radio wave crossing these drifting ionospheric irregularities suffers a distortion of phase and amplitude and the magnitude of fluctuations vary with the frequency used, magnetic and solar activity conditions, and time of the day, season and location. Severe amplitude fading and strong phase scintillation affect the reliability of GPS navigational systems and satellite communications (Kersley et al., 1988; Purohit, et al., 2011; Gwal et al., 2011, 2013). Therefore, it is desirable to obtain further understanding of ionospheric scintillation and its effects on GPS by means of a receiver capable of performing in such conditions (Bhawre et al., 2011; Gwal et al., 2011). Ionospheric scintillation, which is produced by ionospheric irregularities, affects GPS signals in two ways, broadly classified as refraction and diffraction. Both types of effects originate in the group delay and phase advance that a GPS signal experiences as it interacts with free electrons along its transmission path.

2.0 MEASUREMENT SETUP

The measurement systems for this work are based on the NovAtel GPS, which were stationed at Indian base station Maitri, Antarctica. The system was installed in January 2008 during the 27th Indian Antarctic Expedition. It consists of a 24-channel, high precision, dual-frequency GPS receiver, GPS antenna modal 702 or 701 for low-noise amplifier (LNA) boosts the power of the incoming signal to compensate for the line loss between the antenna and the receiver, RF Antenna Cable, 12V Power Adapter Cable, Null Modem Data Cable, Data Communications Equipment.

3.0 DATA AND METHOD OF ANALYSIS

We used GSV400B GPS receiver. The purpose of the GSV400B GISTEM is to collect ionospheric scintillation and TEC data for all visible GPS satellites (up to 10), and up to three SBAS-GEO satellites, and output data logs, called ISMRB or ISMRA, to a serial port in either ASCII or binary format. Either of two (NovAtel GPSolution4 or SLOG) programs can be used to control the GSV400B operations, but SLOG is recommended for collecting scintillation logs.

Ionospheric scintillation measurement was performed using the GPS Ionospheric Scintillation/ TEC Monitor (GISTM), model GSV4004 (Van

Dierendonck et al., 1993). The system is NovAtel's Euro4 dual-frequency receiver version of the OEM4 card with special firmware, which was developed to maintain lock even under strong scintillation conditions. The amplitude scintillation was monitored by computing the S4 index, which is defined as the standard deviation of the received signal power normalized to the average signal power. It is calculated for each 1-minute period based on a 50-Hz sampling rate. The GISTM also computes the S4 index due to ambient noise in such a way that a corrected S4 index (without noise effects) can be computed (Van Dierendonck et al., 1993). A series of experiments were set up to study the effects of cutoff frequency for amplitude and phase filtering (Forte, 2005). Comprehensive discussion about the effects of filtering parameters on scintillation can be found in Forte and Radicella (2002, 2004).

The corrected S4 is obtained by differencing the S4 Correction from the Total S4 is an RSS sense. If the S4 Correction is larger than the Total S4, simply set the corrected S4 to 0, since the S4 value is obviously due to noise.

4.0 RESULTS

In this section, for the investigation of ionospheric behavior, we have used one year GPS data and geomagnetic conditions.

4.1 Geomagnetic Conditions

Ionospheric behavior not only depends on space weather but is also affected by geomagnetic conditions. For this study we have analyzed some solar and geomagnetic conditions during this low solar activity periods. **Figure 1** shows the conditions of geomagnetic and solar activity for the period of low solar activity; this data is monthly average of daily data. In the figure, the first panel of this figure shows AE-Index variation. The second panel of these figures shows the variation of radio flux F10.7 index, this index is measure of the noise level generated by the sun at a wavelength of 10.7 cm at the earth's orbit. The third panel shows the sunspot condition during the low solar activity period 2008. The forth panel of this figure shows the proton density and the last panel of this figure shows the variation of magnetic field (Bz) disturbance of the earth.

4.2 Monthly Variation of Total Electron Content (TEC)

The observation for monthly variation of TEC is based on 12 months GPS data. During the month of January TEC fluctuated between the range of 10 to 22 TECU. In the starting of polar night month May, minimum

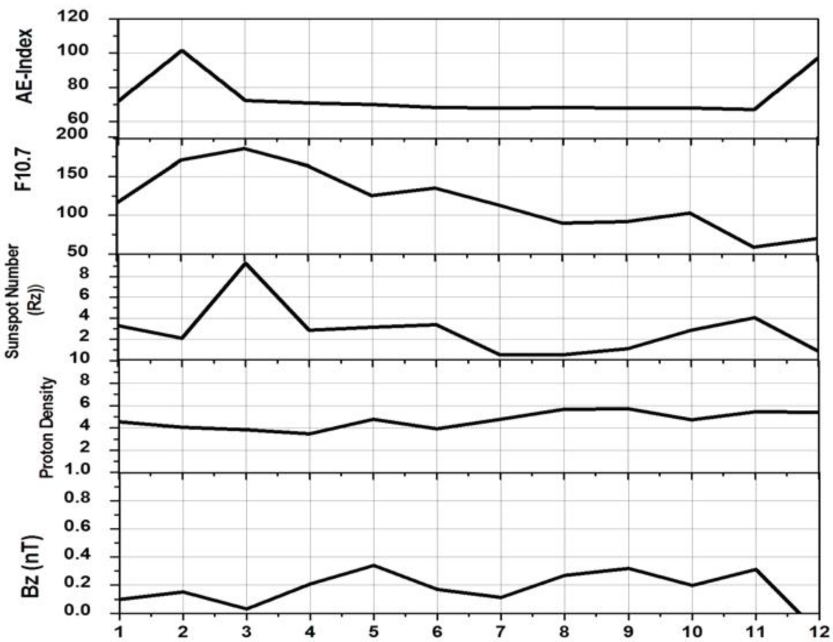

Fig. 1: Geomagnetic conditions during the observation period 2008

TEC of 7 TECU and maximum TEC of 15 TECU was observed. In a dark month of June, minimum TEC of 4 TECU and maximum TEC of 15 TECU was observed due to absence of ionization process. In the month of July, minimum TEC goes to 3 TECU and maximum TEC goes to 16 TECU. With the starting of sun activity, the months of September and October show a minimum TEC of 3-7 TECU and a maximum TEC of 22 TECU. Again, in the summer months of November and December, TEC variation was observed between the range of minimum 6-8 TECU and maximum 26-27 TECU. This type of behavior of TEC in Polar Regions depends on ionization process and solar zenith angles of the sun. **Figure 2** shows the 12 month TEC behavior. We noted in every month TEC peak shifts pattern. Between the months of January to May, TEC peak shifted right side; between the months of June and July, TEC peak almost observed an overlap. But with the sun rising in August to summer month of December, TEC peak was noted towards left side. This type of peak shifting pattern depends on solar zenith angle.

4.3 Seasonal Variation of Total Electron Content (TEC)

The observation for seasonal variation of ionospheric TEC over Antarctica divided into three seasons. First summer season (November,

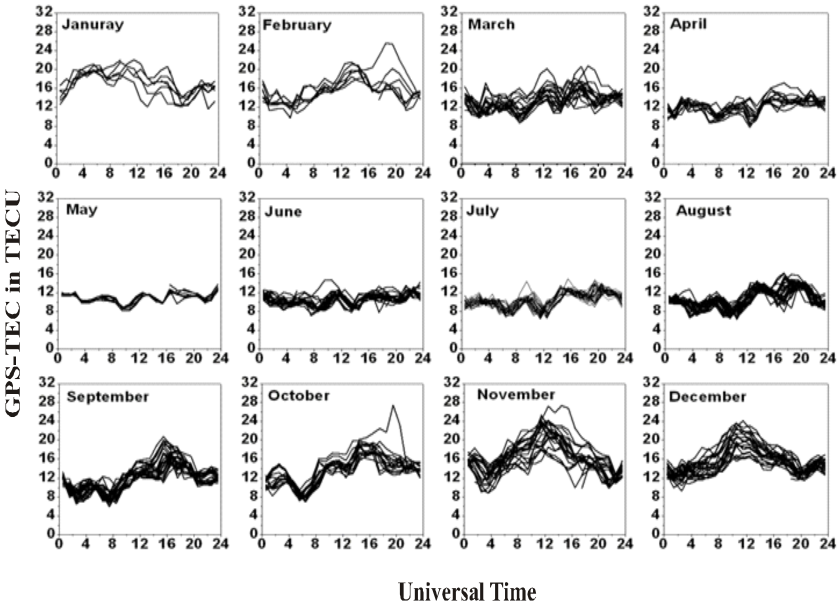

Fig. 2: Monthly Variation of TEC during the low solar activity period 2008 over Maitri, Antarctica

December, January and February); Second winter season (May, June, July and August); and third Equinox period divided into two equinox seasons, according to solar activities, first Autumnal Equinox (March, April) and other Vernal Equinox (September and October). In the summer period, TEC monthly median value fluctuated in the range of 11-20 TECU. This type of behavior of TEC in summer period was due to the presence of 24-hour solar activity in the Polar Region. In the period of winter, TEC monthly median value dropped and fluctuated in the range of 8-14 TECU. It is because during the winter period solar activity is negligible, as compared to summer period. The study of equinox period is classified into two parts, first is Autumnal Equinox from March to April and the second is Vernal Equinox from September to October 2008. In the Autumn Equinox, TEC monthly median value varied in the range of 8-16 TECU; in this period solar activity is decreasing. In Vernal Equinox, TEC fluctuated between 8-18 TECU; during this period solar activity is increasing. **Figure 3** shows seasonal variation of TEC over Maitri, Antarctica.

4.4 Amplitude Scintillation (S4- Index) Variation

In this paper scintillation morphology is described in terms of percentage occurrence in specified threshold level according to intensity and

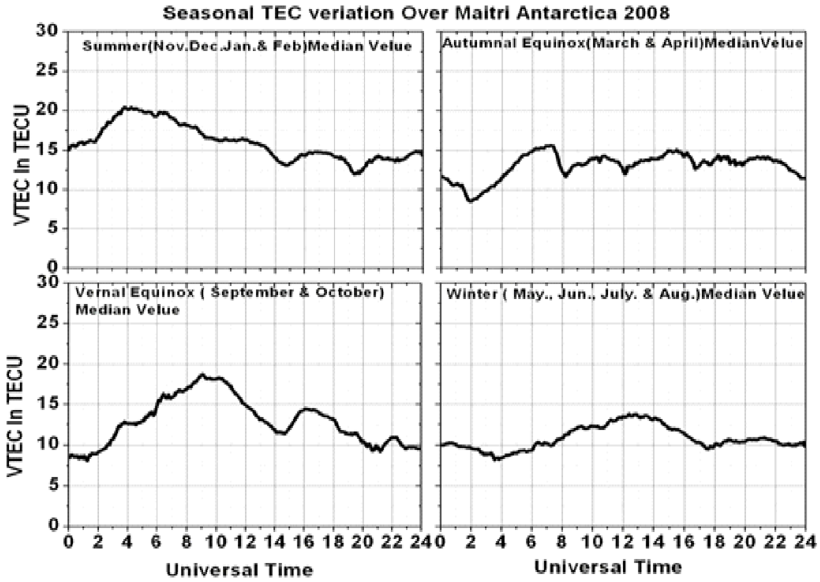

Fig. 3: Seasonal variation of TEC over the Maitri, Antarctica in 2008

differential phase of S4-Index respectively, when S4 is greater than 0.1, 0.3 and 0.5. The study is based on yearly variations of S4-Index observed by GPS data at Maitri Antarctica. **Figure 4** shows the scintillation occurrences with different S4 index values i.e. S4 is greater than 0.1, 0.3

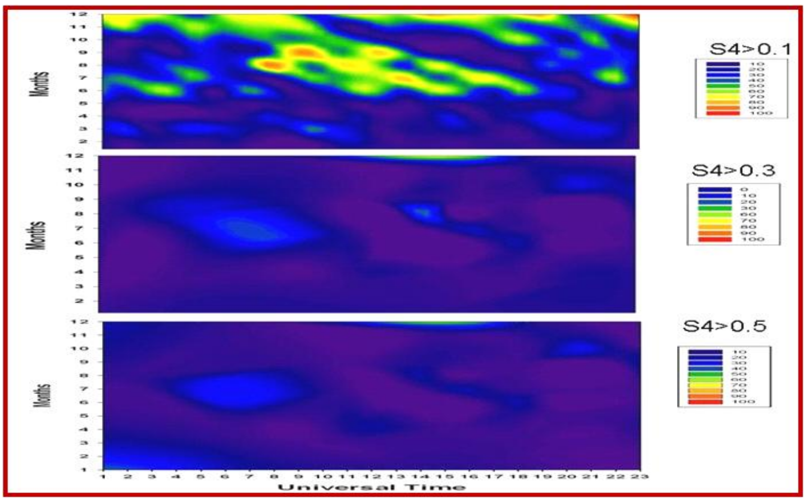

Fig. 4: Contour plot shows the percentage occurrence of scintillation at universal time in a year

and 0.5. Firstly, when S4 is greater than 0.1, this type of small disturbance was regularly observed most of the time throughout the year during the observation period, because polar ionosphere is disturbed most of the time due to solar and magnetic activity disturbances (Base et al., 1988). When S4 is greater than 0.3, the maximum percentage occurrence of 30% is observed in the morning hours (~ 0400 to 0700 UT) of winter months and after noon-time hours (~1300 to 1800 UT) of summer months. Further when scintillation index S4 is greater than 0.5 maximum occurrences up to 28 % were observed in the morning hours (0500 to 0700 UT) and in the evening hours (1600 to 1800) in winter and summer months, respectively.

4.5 Seasonal Variation of Amplitude Scintillation (S_{4-} Index)

Figure 5 shows the seasonal scintillation activities for different levels of S4 index during the summer season (November, December, January and February) when solar radiation is present for all the 24-hours in Polar Region. The percentage occurrences of ~30%, 18% and 12% are observed when S4 is greater than 0.1, 0.3 and 0.5, respectively. In the winter period (May, June, July and August) when solar radiation is completely absent, i.e. polar nights, the percentage occurrences of ~18% is observed when S4 is greater than 0.1 whereas at higher S4 it is less 10 %. During equinoxial months (March, April, August and September) the occurrence of scintillations is about 19 %, 8% and 5% respectively when S4 is greater than 0.1, 0.3 and 0.5 in the morning as well as in the evening hours.

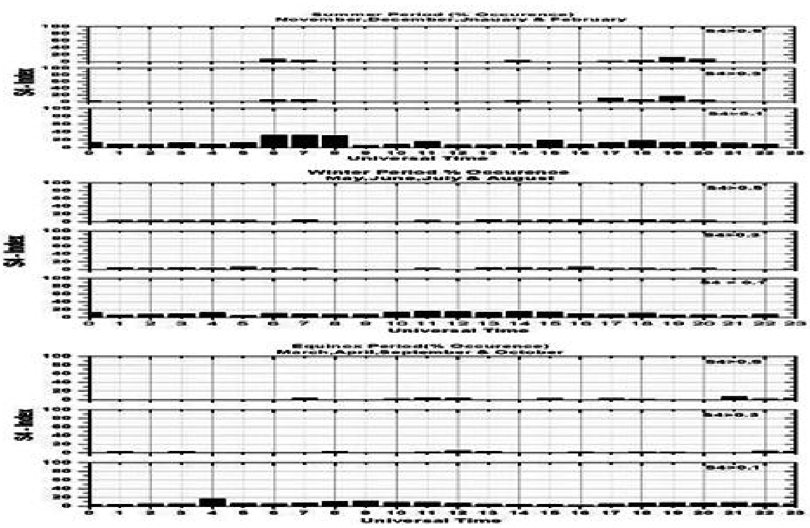

Fig. 5: Shows the seasonal percentage occurrence of S4 index

4.6 TEC Response during the Minor Geomagnetic Disturbance

Many studies have been carried on with respect to the ionospheric response during magnetic storms (Balan et al., 1990; Buonsanto et al., 1999; Skone et al., 2000; Shagimuratov et al., 2002; Abdu et al., 2007; Rama Rao et al., 2009). October 2008 includes a few magnetic active periods observed at Maitri, during low solar activity. In October 2008, a minor storm occurred which caused the magnetic field and ionospheric TEC disturbances. We discuss the intensive disturbances of 9-13 October 2008.

The sudden storm commencement was observed at 12:00 UT on 11 October. The geomagnetic conditions present in **Figure 6** were observed during the storm period. The maximum sum of Kp-index reached to 6nT on October 11 and at similar time Auroral Electrojet index (AE) reaches 887nT and Dst value dropped to -60nT, the positive phase development of Dst started on 10 October around 03:00 UT and negative phase development started on 11 October at 11:00 UT which was continued up to 13 October, during whole duration of storm period.

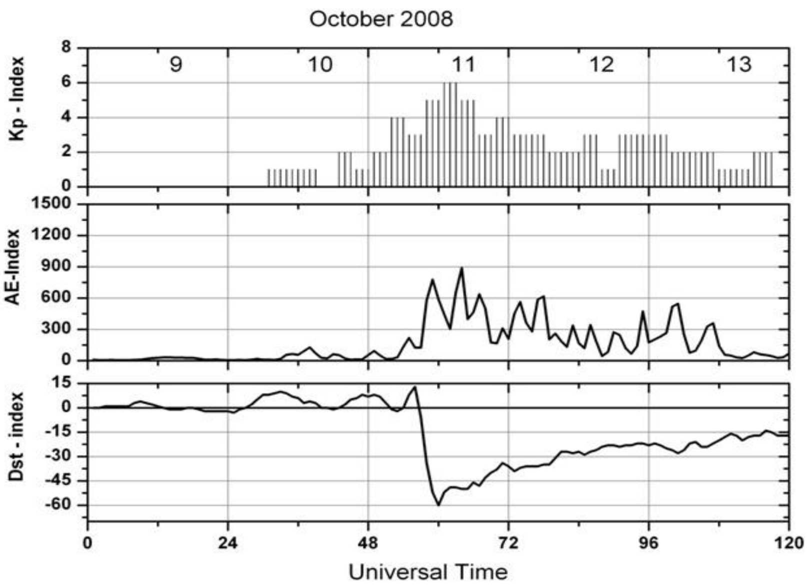

Fig. 6: Variation of Dst, AE and Kp indices during storm event of 11 October 2008

The ionospheric TEC response was observed during the month of October 2008 from dated 9-13. Figure 6 shows the two days (9 and 10 October) before magnetic disturbance, the TEC behavior was normal ~20

TECU, during the day of storm TEC enhancement starts around the 12:00 UT and reached to a maximum ~30 TECU (50% enhancement) around 14:00 UT from its normal behavior, TEC value dropped at 16:00 UT and get its normal behavior after the two days (12 and 13 October) of storm, TEC showed its regular pattern ~20 TECU. The above enhancement of total electron content can be compared with auroral electrojet index (AE-index) given in the **Figure 7** which shows the variation with Kp-index in a polar region.

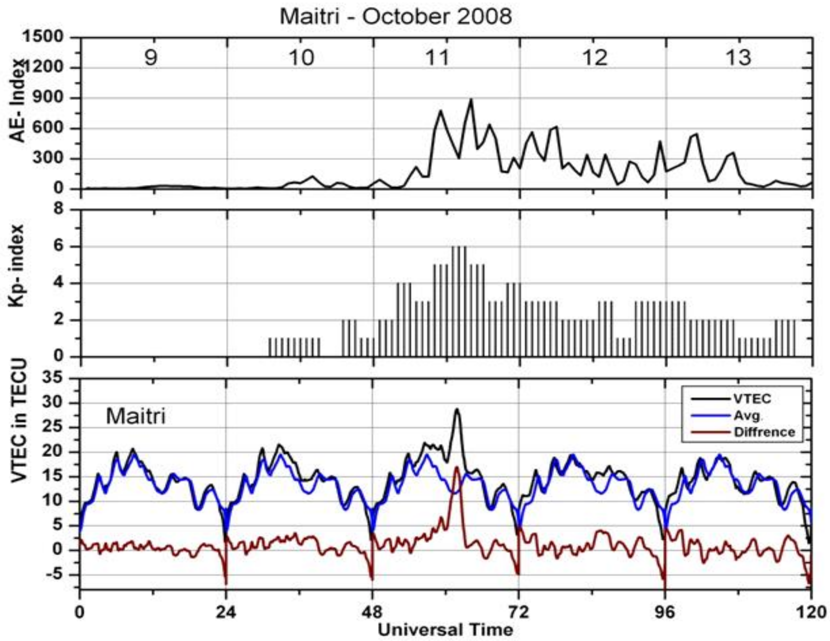

Fig. 7: Total Electron Content Variation with Kp and AE indices during storm event of 11 October 2008

5.0 CONCLUSIONS

We have processed and analyzed GPS data of the year 2008 from Indian base station Maitri, Antarctica. This shows the presence of strong relationship between GPS -TEC and its dependence on solar activities. In the first month of January, TEC value goes to a high as compared to June month. TEC value again goes to a high in December month. It is because in January and December months, solar activity is high as compared to June month. The seasonal study of TEC shows that total solar activity is absent in winter season and due to no ionization processes, TEC value goes to the minimum. The study of summer season is just apposite of winter season; the total solar activity high and due to this reason ionization process is continuous in presence of 24-hour sunlight; thus the TEC value goes to its maximum. Equinox season is divided into two parts, because in the first equinox period (Autumnal Equinox, March and April months) solar activity is low, according to solar zenith angle, as the sun goes to sunset point. But in the second equinox period (Vernal Equinox, September and October), solar zenith angles go towards maximum and solar activity increases, again starting the ionization process, during this period TEC variations are high as compared to autumn equinox period.

The scintillation study can be summarized as follows. The weak scintillations (S4>0.1) are observed all the 24-hour of the day in almost all the seasons, whereas during morning and afternoon hours slightly higher magnitude scintillations (S4 < 0.5) are also observed during the solar minimum period of 2008. Season-wise maximum occurrence is noted during summer months; whereas in a winter and equinox seasons, scintillations are observed mostly in early morning hours as well as night hours.

The behavior of TEC during the minor storm was very complex and includes interesting ionospheric effects. The storm-time response depends on latitude, longitude and local time. The study highlights the threat to GPS based navigation system due to minor magnetic disturbances. Also, in the low solar minimum period of 2008, 50% TEC variation is observed at Maitri, Antarctica.

Acknowledgements

This study is supported by the National Center for Antarctic and Ocean Research (NCAOR), Goa, under the Ministry of Earth Sciences; officers and staff of NCAOR are thanked for their scientific and logistic supports. The author acknowledges National Physical Laboratory, New Delhi for providing an opportunity to be at Maitri during Winter Expedition and Council of Scientific and Industrial Research (CSIR) for awarding a Senior Research Fellowship.

References

Aarons J., (1982). Global morphology of ionospheric scintillation. Proc. IEEE 70, 360-378.

Basu S. and Valladares C., (1999). Global aspects of plasma structures. J. Atmos. Solar Terr, Phys. 61, 127-139.

Tsunoda R. T., (1988). High latitude F region irregularities: A review and synthesis. Rev. Geo-phys. Space Phys. 26, 719-760.

P.K. Purohit, Purushottam Bhawre, Azad A. Mansoori, Parvaiz A. Khan and A.K. Gwal, "GPS Derived Total Electron Content (TEC) Variations over Indian Antarctica Station, Maitri", (Proc. of World Academy of Science, Engineering and Technology 59, France, pp 597-599, 2011).

A. K. Gwal, Purushottam Bhawre and Azad Ahmad Mansoori "Study of GPS derived Total Electron Content and Scintillation Index variations over Indian, Arctic and Antarctic stations" (Publication in National SaGAA, 2011, Proceeding Book Chapter).

A.K. Gwal, Purushottam Bhawre, Azad A. Mansoori and Parvaiz A. Khan "Study of GPS derived Total Electron Content and Scintillation Index variations over Indian Arctic and Antarctic stations" Journal of Scientific Research 5 (2), 255-264, Bangladesh.

Purushottam Bhawre, Azad A. Mansoori, Ritesh Yadav, Prakash Khatirkar, A. K. Gwal R. S. Dabas and Sudha Ravindran "The Response of Polar ,Equtorial and Low Latitude Ionosphere to the Minor Magnetic Disturbance of 11 October 2008" (Publication in International Journal of Engineering Science and Technology, ISSN: 0975-5462, Vol.3 No.1, Page 150-155, Jan 2011).

L. Kersley, C. D. Russell, and D. L. Rice, "Phase Scintillations and Irregularities in the Northem Polar Ionosphere," Radio Science, 30, 1995, pp. 619-629.

Van Dierendonck, A.J., J. Klobuchar and Q. Hua (1993).Ionospheric scintillation monitoring using commercial single frequency C/A code receivers, In:ION GPS-93, Proceedings of the Sixth International Technical Meeting of the Satellite Division of the Institute of Navigation, (Salt Lake City, U.S.A., September 22-24, 1993), 1333-1342.

Forte, B. and Radicella, S., Problems in data treatment for ionospheric scintillation measurements, Radio Science 37 (6), 1096-1100, 2002.

Forte, B. and Radicella, S. Geometrical control of scintillation indices: what happens for GPS satellites, Radio Science 39, RS5014, 2004.

Abdu, M. A., Maruyama, T., Batista, I. S., Saito, S., Nakamura, M., 2007. Ionospheric response to the October 2003,superstorm longitude/local time effects over low and middle latitudes. JGR, 112, A10306,doi:10,1029/2006JA012228.

Balan, N., Rao, P. B., 1990. Dependence of ionospheric response on the local time of sudden commencement and the intensity of geomagnetic storms. J. Atmos. Terr. Phys. 52, 269-275.

Buonsanto, M. J., 1999. Ionospheric storms- A review. Space Sci. rev. 88, 563-601.

Rama Rao, P. V. S., Gopi Krishna, S., Vara Prasad, J., Prasad, S. N. V. S., Prasad, D. S. V. V. D., Niranjan, K., 2009.Geomagnetic storm effects on GPS based navigation. Ann. Geophys. 27, 2101-2110.

Shagimuratov, I.I., Baran, L. W., Wielgosz, P., Yakimova, G. A., 2002. The structure of mid and high latitude ionosphere during September 1999 Storm event obtained from GPS observations. Ann. Geophys. 20, 655-661.