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Space Weather and Irregular Ionospheric Patches at "MAITRI"

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INTRODUCTION

Space weather refers to conditions in geospace which are controlled by the solar activity and which can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socio-economic losses. Most of the time, space weather is of little concern in our everyday lives. However, when the space environment is disturbed by the variable outputs of the Sun, technologies that we depend on, can be affected. Space weather disturbances are generally caused by transient events in the solar atmosphere, which trigger disturbances in the Earth's environment. Geomagnetic storms are accompanied by a variety of ionospheric disturbances, which are presumably caused by the intensification of the solar wind. However, not all solar proton flares result in geomagnetic storms and even more significantly, not all geomagnetic storms can be associated with solar flares. Some of the most dramatic space weather effects occur in association with eruptions of material from the solar atmosphere into interplanetary space. Such eruptions are sometimes associated with flares and they now appear to be a primary cause of geomagnetic activity.

The ionosphere plays an active role in the complex space weather relationships which affects the distribution of plasma in the ionosphere from low to high latitude. During the periods of disturbed space weather, the ionosphere can be filled with small-scale irregularities. Radio signals traversing the disturbed ionosphere are disrupted by these irregularities which cause phase and amplitude fluctuations in the signals. This problem is particularly worst at high latitudes in the region of the auroral, sub auroral ovals and in the equatorial region where ionospheric bubbles (not associated with solar disturbances) occur. When charged particles ejected from the Sun arrive at the Earth, they can cause perturbations in the geomagnetic field the ionosphere where the electron density (number of electrons in a given volume) can vary considerably, both in time and space. The cloud of charged particles (which also bring with them parts of the solar magnetic field) will interact with the Earth's magnetic field when the magnetic clouds reach the Earth's orbit. This results in a disturbance of the Earth's magnetic field and the auroral particle precipitation into the atmosphere increases. The aurora is a dynamic and delicate visual manifestation of solar-induced geomagnetic storms. The electromagnetic interaction of radio waves with charged particles of the ionospheric plasma may cause the signals degradation. These changes in phase, amplitude and polarization of transmitted radio waves can be effectively used to obtain essential information about ionospheric state.

Geomagnetic quiet and disturbed conditions include a competition of many different processes in the magnetosphere-ionosphere-thermosphere system. At high latitude, it becomes dominant and these complex phenomena need comprehensive measurements of ionospheric parameters. The occurrence of large scale effects in the F-region in association with geomagnetic storms was initially reported by Appleton and Ingram (1935). Later on Berkner et.al. (1939) and Berkner and Seaton (1940) have reported an opposite effect near the magnetic equator. Ionosphere at high latitude is considerably more complicated than the mid or low latitude. Here geomagnetic field lines are nearly vertical and connects high latitude to the outer part of magnetosphere which is driven by the solar wind and is accessible to energetic particle emissions. The dramatic changes take place very frequently in the auroral and polar ionosphere with the different geophysical conditions. During the storm large and medium-scale irregularities occur in the high-latitude ionosphere. Drastic changes in ionosphere vertical TEC can be produced by intense disturbance electric fields originating from the magnetosphere–ionosphere interaction (Tsurutani et al., 2004). Baran, et al., (2002) have seen the essential changes of TEC registered in the auroral and sub-auroral ionosphere, attributing to the effect of the trough.

The measurements of Global Navigation Satellite System (GNSS) signals offer an unique opportunity to obtain valuable space weather information by measuring amplitude and phase of navigation signals. Total Electron Content (TEC) of the ionosphere can be derived from dual frequency navigation code and carrier phase measurements at the L-band frequencies. Since the ionosphere is a dispersive medium, the speed of propagation of the electromagnetic waves transmitted by the GPS satellites decreases as they travel through it. The carrier phase advance and group delay of GPS transmitted radio waves in the ionosphere is proportional to electron content integrated along the propagation path.

Study of Polar Cap Irregular Ionosphere patches (Polar cap patches are regions of enhanced ionization which drift across the polar cap in an anti-sunward direction from the source region near the dayside auroral oval). Ionospheric irregularities are responsible for scintillation of trans-ionospheric radio signals.

Total Electron Content (TEC)

One can derive TEC by comparing the phase delays of the L1 and L2 signals. Algorithms and routines are used to derive TEC are discussed in Liuet al. (1996). The TEC is the integral of electron number density along the line of sight path from a receiver to a satellite (which is known as radio – visibility of GPS receiver), and can vary dramatically from day to day (Huang et al., 1989; Rastogi and Klobuchar, 1990). The ionospheric slant Total Electron Content (TEC) in the high latitude region is studied by analyzing dual-frequency signals from the global position system (GISTM – GPS). Total electron content (TEC) exhibits significant variations in both space and time depending upon latitude, longitude, solar cycle, UTC, and season; these variations can have potentially negative effects on communication and navigation systems. Thus GPS measurements are commonly used to investigate the structure and dynamics of the ionosphere. Recently, several authors have applied the GPS network data to study the TEC irregularities during storm (Ho et al., 1998; Musman et al., 1998; Jakowski et al., 1999; Baran et al., 2001).

During extreme space weather effects such as magnetic storms, the TEC of the ionosphere is often subject to large spatial and temporal variations over the globe (Essex et al. 2001 (a)). In general, ionospheric storms have been observed to include both a positive (TEC or electron density increase) and a negative TEC (TEC decreases) phase.

Vertical Total Electron Content (TEC)

Vertical TEC is defined as the electron content in a vertical column of unit cross-sectional area from the sub-ionospheric point at the ground to the satellite. A TEC unit is defined as 1×10^{16} electron m^{-2}. Vertical TEC can be written as:

$$\int_{0}^{h} Ndh = \cos \quad {}_{m} \int_{s}^{s} Nds$$

$$VerticalTEC = \cos \quad {}_{m} \times slantTEC$$

where ${}_{m}$ is the zenith angle in the ionosphere of the satellite relative to an observer. N (number of electrons per m^{-3}) is defined as the ionospheric electron density at an assumed height of 400 km, h is the height of the satellite, and s is the slant range from the satellite to the ground observer.

Scintillation

In passing through the ionosphere, radio signals sometimes show rapid phase and amplitude variations that are called ionospheric scintillation [Knight et al. 1996]. These fluctuations are caused by large electron density gradients along the ray path of the signal. Scintillation is one of the least expensive ground based techniques that has been used quite successfully to study the ionospheric irregularities. Scintillation technique is based on interaction between radio waves and inhomogeneties in the medium, the performance information can be deduced by analyzing the signal received on the ground from the satellite. Diffraction of the signal (interference across the wavefront) 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 the equatorial (±10° – 20° geomagnetic latitude), auroral (65° – 75° geomagnetic latitude) and polar cap (>75° geomagnetic latitude) regions. Additionally, amplitude fades can cause the signal-to-noise-ratio (SNR) to drop below receiver threshold, resulting in loss of code lock. In regions of small-scale irregularities in electron density, rapid random phase variations can be produced by phase irregularities in the emerging wave front [Hargreaves, 1992]. These are referred to as phase scintillations. Study of scintillation is very important from the point of view of GHz and VHF communication. GPS performance, accuracy, integration and flexibility depend on the observed scintillation index. Scintillations can be particularly troublesome for receivers that are making carrier-phase measurements and may result in inaccurate or no position information. Code-only receivers are less susceptible to these effects. This paper focuses on high latitude sub auroral scintillations, which are associated with an enhanced solar activity.

Amplitude Scintillation

The GISTM used in this analysis measures both amplitude and phase scintillation. Amplitude scintillation is defined by the S4 index that is derived from detrended intensities of signals received from satellites [Dierendonck et al., 1996]. This is referred to as the Total S4 (or S4T). The normalized S4 index, including the effects of ambient noise, is defined as follows [Dierendonck et al., 1993; Fremouw et al., 1978]

$$S_{4T} = \sqrt{\frac{\langle P^2 \rangle - \langle P \rangle^2}{\langle P \rangle^2}} .$$

Phase Scintillation

Phase scintillation is determined from monitored measurements of the standard deviation, Δ , and the power spectral density of detrended carrier phase from signals received from GPS satellites [Dierendonck et al., 1997]. The phase is measured over 1, 3, 10, 30 and 60-second intervals. As with the amplitude measurements, the 60-second averages are used in this analysis. The detrended phase measurements are used to define the spectral parameters strength, T_1, and slope, P , and are given below in coming equation [Dierendonck et al., 1996] as a function of the frequency v .in rad^2/Hz for frequencies greater than 1 Hz:

$$\Phi \ (v) = T_1 v^{-p}$$

Similar to the amplitude measurements the phase is also detrained.

Thus understanding the physical processes that are involved in linking the entire system, which begins at the Sun and ends on the Earth. This will improve our capacity to provide timely specification and forecasting of conditions on the Sun, and in solar winds, magnetosphere, ionosphere, and thermosphere that can impair the performance and reliability of space-borne and ground-based technological (Communication, Positioning, etc.) systems.

Experimental Setup and Data Collection

Dual frequency data from the constellation of GPS satellites and ground stations are being used to study the effect of magnetic storms and their effects on the variation of TEC at sub auroral region. For this purpose a dual frequency GISTM (GSV 4004A GPS) receiver is installed at "MAITRI", Indian Antarctic Research Station (Figure 1). The main aim of this study is to observe the space-weather effects on polar region ionosphere using Ionospheric Total Electron Content (TEC) and Amplitude Scintillation (S4 index). The data monitored by using GISTM system over high latitude region (Maitri, Antarctica). The study is limited during the period of January to March 2005 and 2006 basically for the duration of the summer expedition period of Indian Scientific Antarctica Expedition. A typical event high Solar proton eruption observed during the January 21-22, 2005 shown in Figure 2. The resulting effect

Fig. 1: GISTM (GSV4004A) antenna installed at MAITRI, during 25th Indian Antarctic Expedition

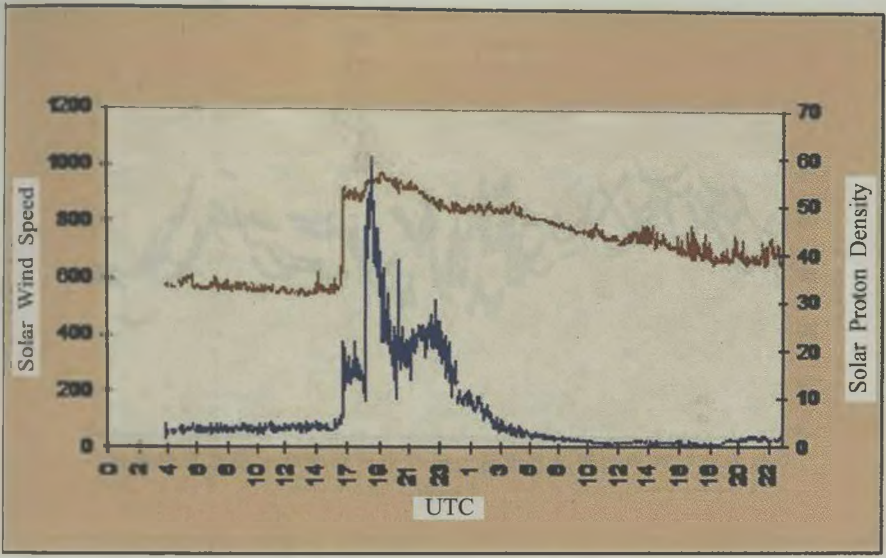

Fig. 2: Solar Proton Density and Solar Wind Speed plot for 21-22 January 2005

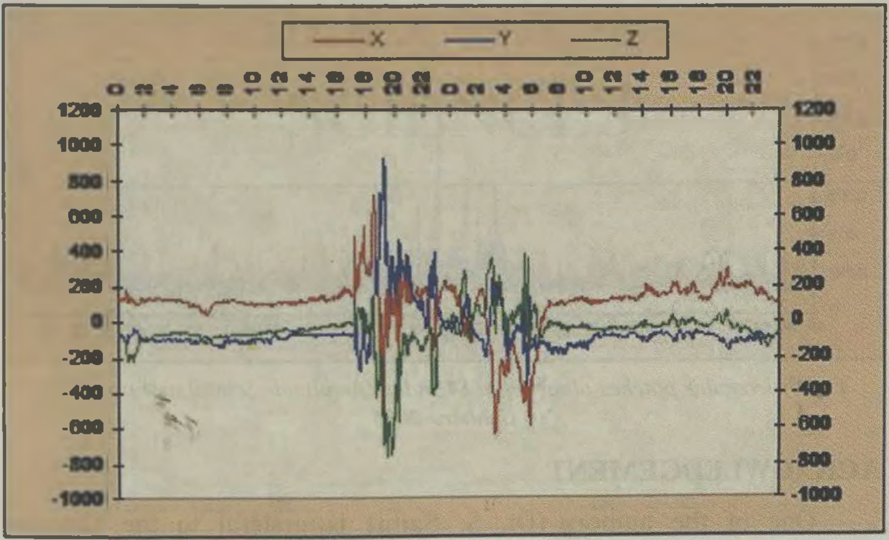

Fig. 3. Variation in Earth Geomagnetic Field on 21-22 January 2005 (Data Provided by IIG, Mumbai)

of Space weather disturbance on Earth magnetic field (Figure 3) and its adverse effect on Ionospheric TEC and Scintillation is shown in Figures 4 and 5.

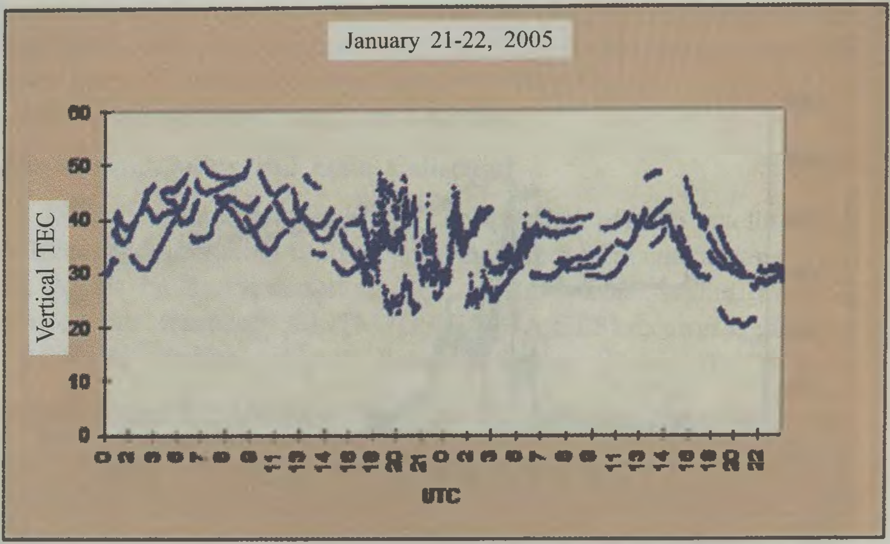

Fig. 4: Ionospheric irregular patches observed in VTEC on 21-22 January 2005

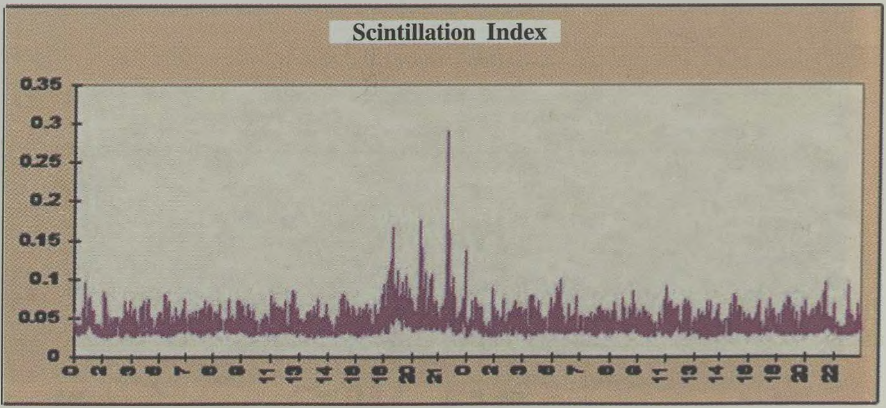

Fig. 5: Irregular patches observed in S4 Index (Amplitude Scintillation) on 21-22 January 2005

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