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TEC mapping for the Determination of Seismo-Ionospheric Anomaly Behavior

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Abstract

Total electron content (TEC) is an ionospheric parameter and has its influence on number of communication applications like earth space radio communication and space weather prediction. There is a non uniform distribution of ions in the upper atmosphere. Around 35% of the global ionization is concentrated in a narrow equatorial belt thus causing perturbations in the media of satellite communication and navigational systems.

The communal interaction between the earth and the sun results in different anomalistic behavior on the ionosphere yielding an excellent demonstration that both are the part of the solar system. In this paper results are presented from a study on effects of geomagnetism on equatorial ionospheric anomaly during 23rd solar cycle. Objective of this research is to present a biased free GPS based mapping of electron contents during unusual seismic waves. MATLAB and Leica GNSS were the tools used to obtain the results. The research will help in determining seismo-ionospheric anomaly behavior.

Keywords: Total Electron Content, seismo-ionospheric anomalies, GPS Data

1. Background

Sun radiations are liable for ionospheric hypothesis. Molecules present in the region of 50 km to 500 km of the atmosphere are classified in to ionosphere which is further classified in to different layers of the ionosphere. Molecules are ionized by the radiation of the Sun thus forming ionosphere. In actual interaction between extreme ultra violet and X-ray radiation yields free electrons and ions [2]. Total Electron Content is one significant factor of ionosphere that has implications on earth-space radio communication and satellite navigation system thus enables us for space weather prediction [1]. TEC values facilitate to retrieve the electron density of the ionosphere (Nava et al., 2006) and can provide accurate specification of ionosphere (Wang et al., 2004).

Rise and fall activity observed in the Sun is known as solar cycle with the quasi period of around 11

years (Smith and Marsden, 2003) [7]. Rise and fall activity of the sun is determined by the number of sun spots appearing. The probability of occurrence of large solar flares is very high during solar maximum as compared to the solar minimum with less or nearly no probability of occurrence of giant solar flares. At different instants of solar cycles, the ionosphere pattern also changes and this phenomenon is more pronounced over equatorial anomaly. The region around the geomagnetic equator, located between ± 20° of geomagnetic latitude is characterized by an anomaly on the ionospheric behavior, called the Ionospheric Equatorial Anomaly (IEA) [8]. Solar cycle 23 can be summarized by Table 1.

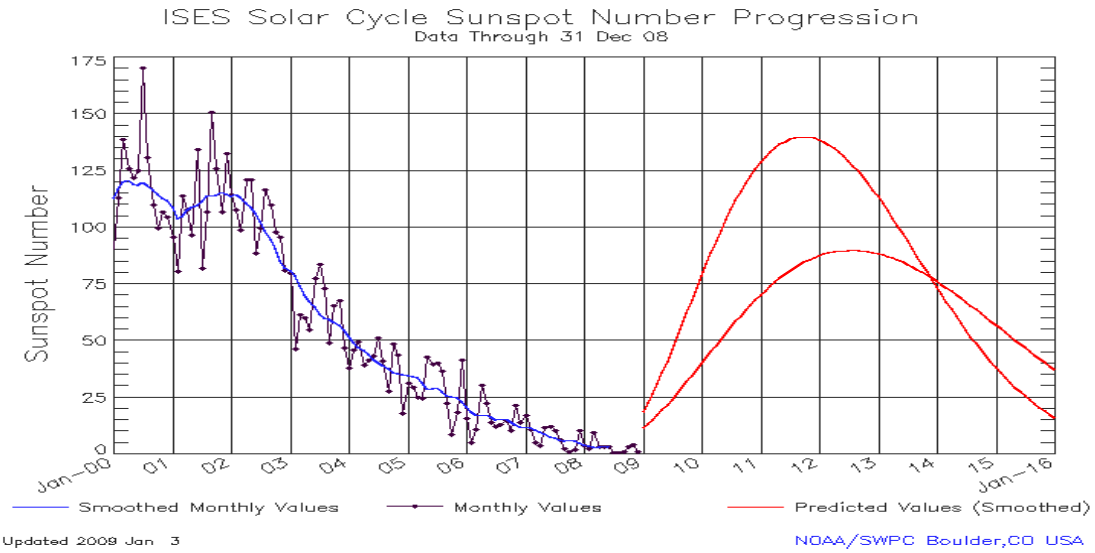

Fig 1. Showing partial solar cycle 23 and the predicted solar cycle 24. (Courtesy by NOAA)

Table 1: Solar conditions of 23rd solar cycle with respect to years

Solar Conditions	**Year**
Started	1996
Solar Maximum	2000 to 2002
Solar Minimum	2007 to 2008
Moderate Solar Conditions	2004 to 2005
Ended	January 2009

2. Introduction

TEC mapping using GPS data is comparatively a novel method to predict more about ionosphere. There are multiple factors which are responsible for perturbations in ionosphere. These variations include solar winds, number of sun spots appearing, solar cycle season, and traveling ionospheric disturbance and seismo ionospheric anomalies. The influence of solar activities on ionosphere is more pronounced over polar and equatorial region. The reason of equatorial ionospheric anomaly (EIA) is generally refers to the fountain effect. During day timings, the plasma moves vertically upwards and magnetic field at geomagnetic equator is horizontal which results in an eastward ionospheric electric field [9]. In equatorial region, spatial gradients and absolute slant TEC are known be to highest in the world (Komjathy et al., 2003b) [3].

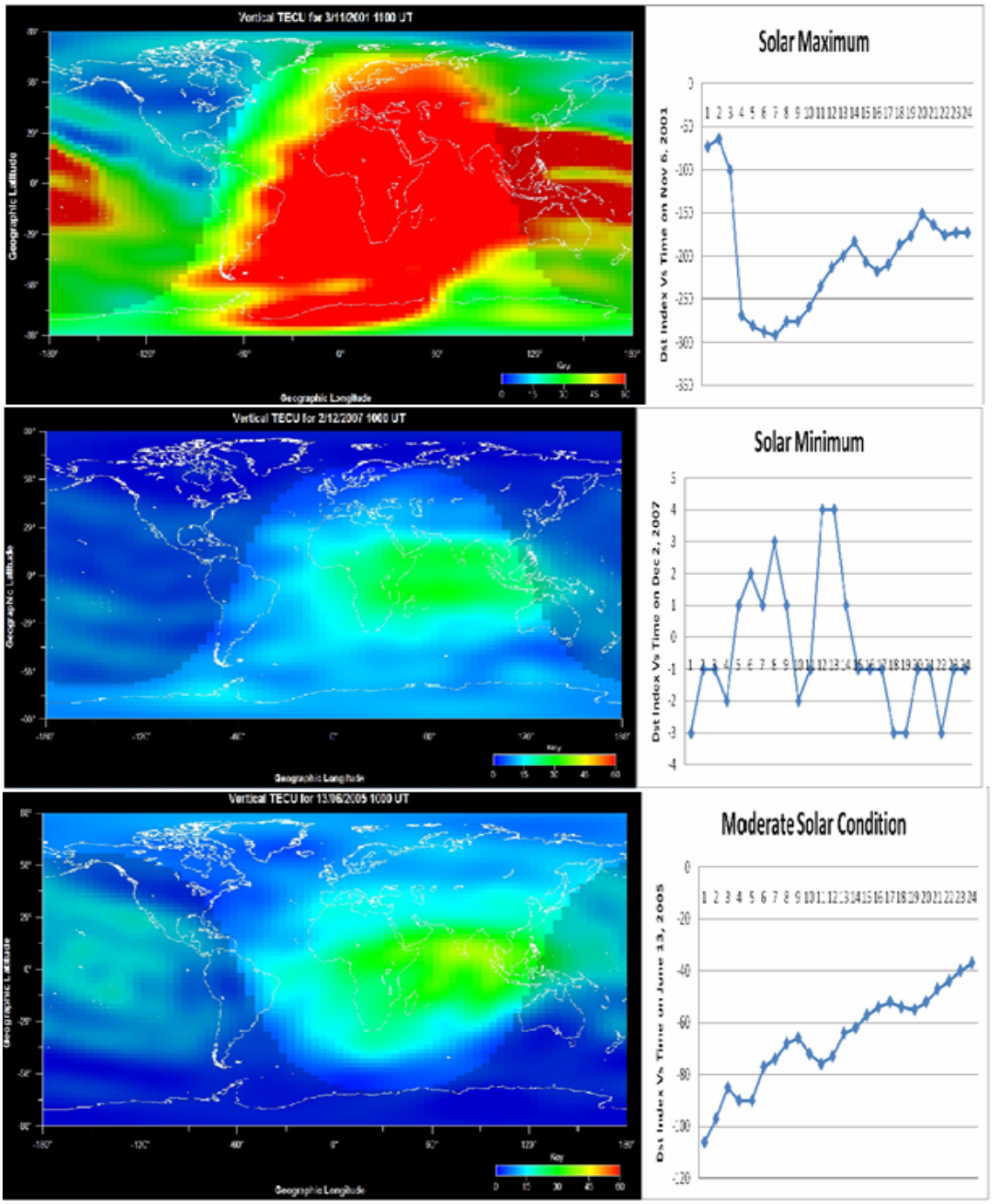

Fig 2. Showing TEC Mapping of different epochs of solar cycle 23 and Dst index of the respective day

Without any significant geomagnetic or/and solar disturbance, perturbations in the upper atmosphere gives clues about the earthquake precursors. The ionospheric anomalies in general occur in the D, E and F layer of the iononsphere. F region can be further subdivided into F1 and F2 layer. Life time of free electron in F2 region is the most as compared to the lives of free electrons in other ionospheric

layers. Anomalies in the above mentioned layers can be seen 1 to 10 days prior to the earthquake and its influence remains even for few days after the earthquake (Parrot 1995; Liu el at., 2004). Different theories describing seismic electromagnetic includes production of waves because of compression of rocks near epicenter, discharge of warm gases produced by water belt under the earth and release of radioactive gas [11]. It has been observed that anomalies exist in TEC in the vicinity of epicenter (Liu et al., 2008). It has been recorded by the researchers that ionospheric plasma critical frequency (foF2) reduces few days back before earthquake. (Liu et al., 2000, 2006, Liperovskya et al., 2006) [4],[5].

For three different epochs i.e. during solar maximum, solar minimum and moderate solar conditions, graphs have been shown in figure 2.

3. Methodology

The GIM TEC data for further processing is obtained from Center of Orbit Determination in Europe (CODE), University of Berne, Switzerland which has more than two hundred International GPS Service (IGS) receivers to produce global TEC with a resolution of 2.5° geographical latitude to 5° geographical longitude with a gap of two hours. The software tool which was used for plotting TEC maps is Leica GNSS QC and MATLAB was used to obtain the regional plots. Kp and Dst indexes were the key parameters to compare geomagnetic anomalies with pre-earth quake anomalies.

4. Observations

We can see from figure 2 that during solar maximum, there are large number of solar flares which results in increased Dst index and touching the extreme values of -300. During moderate solar conditions, Dst index is not too high nor too low. In contrast during solar minimum, the value of Dst index is varying around 0 representing the absence or less abundance of solar flares.

Tsunami generated seismo waves and as a consequence some disturbance was reported in the ionosphere. As Indonesia, Malaysia, Thailand falls in equatorial region and on equatorial region, equatorial ionospheric anomalies are more pronounced. The seismo-ionospheric anomaly is very crucial to monitor. For December 2004 Tsunami, concentration of electrons was enhanced in F region which give clues about some geomagnetic commotion. It has been reported in the literature Chimonas and Hines (1970) sudden emission of energy into the atmosphere can activate various kinds of waves which are power enough to travel upwards in the atmosphere and reach to F-region. This phenomenon is shown in Figure 3. TEC maps were computed using Leica GNSS for preceding and proceding days of earth quake. The GPS days for which TEC maps were plotted are 355 to 362 for year 2004. Location for the earth quake was 3.316 N, 95.854 E. It was proposed (Namgaladze et al. 2007) that the principle cause of the appearance of the local anomalies in the form of the increased (decreased) total electron content of the ionosphere, observed on the base of GPS signals measurements, is the vertical drift of F2-region ionospheric plasma upward (downward) under the influence of the zonal electric field of seismogenic origin directed to the east (west) [10]. In addition to that is has been found that the enhanced discharge of infrared radiation over the epicenter of Sumatra earthquake 5 days prior to the earthquake resulting in changed in electromagnetic environment.

5. Results and Discussion

From the graphs it can be seen that various colors in TEC map pattern enables us to know the concentration of electrons in the upper atmosphere. Sun is the most dominant factor for the presence of ionosphere and it can be seen that the concentration of electrons in far more over the regions which has local day timings. During night time, as Sun is not facing directly towards that particular part of the earth so the concentration of electrons above that area reduces. Furthermore, the thick patch of electrons moves in a sinosidal path over equatorial region instead of straight line.

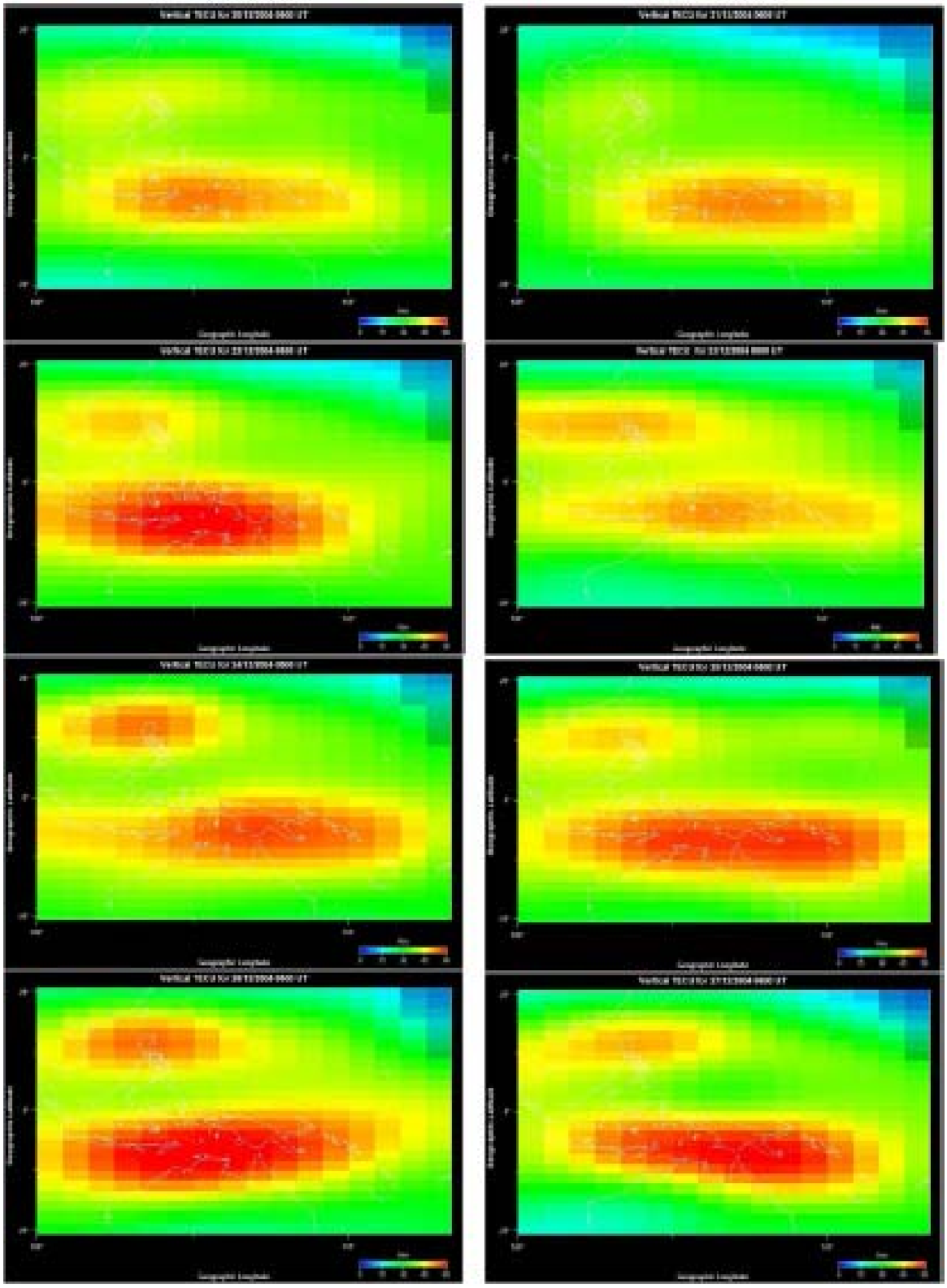

Fig 3. TEC Maps have been plotted for different GPS days of year 2004. All the maps are plotted for time 10:00 UT starting from GPS day 355 to 362

From the graphs, it can also be deduced that pre-earthquake anomalies started appearing 5 days before the earthquake. The geomagnetic activities were moderate before Tsunami while implies that the variation in the ionosphere were because of pre-seismic waves. The above mentioned discussion gives only clues about the prediction of earthquake however detailed investigation is mandatory for better ionospheric modeling and prediction. The radius of seismic area can be estimated by using Dobrovolsky formula $R = 10^{0.43M}$ where M is the earthquake magnitude and R is the radius of the earthquake preparation zone.[6]

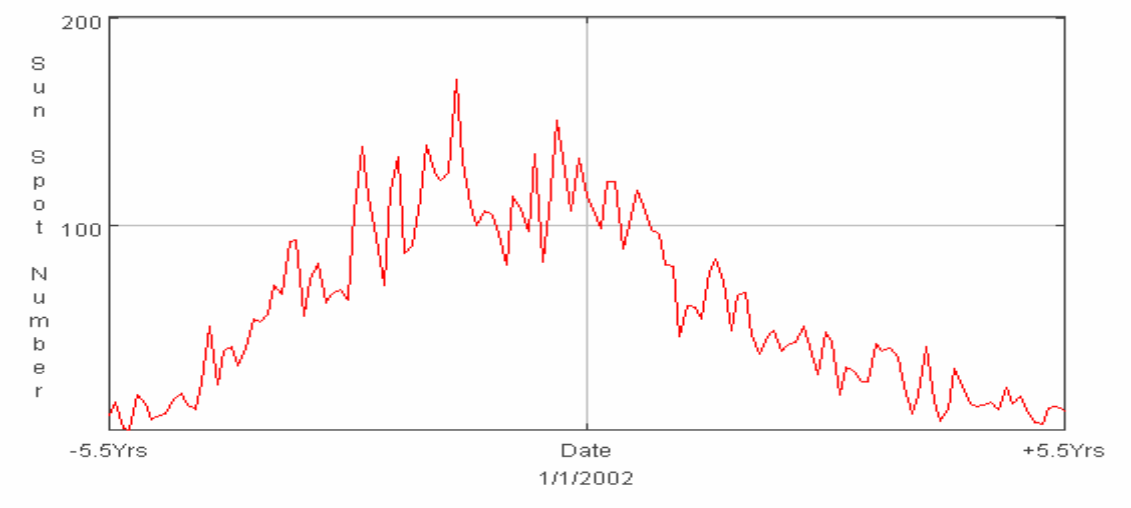

Figure 4: Showing average number of sunspots per month Vs years

6. Conclusion

Pre seismic electric field is responsible for the transfer of charged particles in the lower layers of the ionosphere. The unusual disturbance of charged particles in the ionosphere is basically the ionospheric anomalies. As disturbance in the ionosphere may be because of multiple reasons, it is therefore quite essential to discriminate these effects from seismic activities. It has been observed that the enhanced emission of infrared radiation over the epicenter of Sumatra earthquake on 21st December 2004 prior to the earthquake (on 26th December 2004) resulting in changed in electromagnetic environment.

Better and spatial time resolution of ionosphere has become crucial as influence number of applications like space weather prediction and earth space radio communication. Sun and the earth are the parts of a solar system and both influence on ionosphere. If we look into the solar cycles it has been found that current solar cycle is more extreme in nature than foregoing ones and natural disasters in the current solar cycle are also more extreme and frequent.

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