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Ionospheric TEC modelling for earthquakes precursors from GNSS data

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ABSTRACT

In present study, we measured the Total Electron Content (TEC) variation in the ionosphere from Global Navigation Satellite System (GNSS) data which might have been induced by earthquakes in the Himalayan region. The results were analysed with other inducing factors (geomagnetic storm and solar flare) affecting TEC in order to constraint the causative factor. The study has been performed to understand a relationship between ionospheric electron content and earthquakes occurrences with special emphasis on Himalayan region and provides information on spatio-temporal variation of TEC from GNSS observation stations vis-à-vis prominent earthquakes of the region. The results indicate that the ground based GNSS (GPS) observations show the deviation in vertical total electron content (vTEC) in ionosphere few days prior to the seismic event as evident from our two continuously operating reference stations (CORS) as well as from CORS of UNAVCO data centre. Ionospheric perturbation has also been observed in case of low magnitude earthquakes (Mw 4.9 in present study) whenever recording station lies very close to the epicentre. TEC variation is found to increase as the epicentre distances decreases. In case of Mw 7.8, 2015 Nepal earthquake the TEC variation is found to increase by 15–20 TEC unit recorded at station separated by 60 km apart. This may provide us the avenue for epicentre detection as TEC concentration was found to increase as we move closer to the epicentre. TEC variations (mostly high TEC) have been observed during a period of 0–8 days prior to 4 earthquakes: 1st April 2015 Pipalkoti earthquake (4.9Mw), 25th April 2015 Nepal earthquake (7.8Mw), 26 April 2015 (6.7Mw) and 12th May 2015 (7.3Mw) Nepal earthquakes. Significant low TEC values were also observed before 13–14 days prior to first two earthquake events. Overall the study has revealed that low TEC followed by couple of high TEC values correlate well with the seismic events in Himalayan region.

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1. Introduction

Identification of earthquake precursor has remained as an elusive goal even after decades of active research into various physical and geological processes involving earthquake phenomena (Stathis, 2010; Catherine, 2004; Malik and Nakata, 2003; Sharma and Lindholm, 2012). However, very promising studies have been carried out on pre-earthquake ionospheric anomalies that occur before an earthquake using ionosonde stations as well as Global Satellite Navigation System (GNSS) signals, primarily by using Global Positioning System (GPS) signals (Pullinets, 2004; Liu et al., 2011; Dimitar et al., 2011; Heki, 2011, Heki and Enomoto, 2013., 2015). Based on the results of such studies, ionospheric Total Electron Content/Count (TEC) has emerged as one of prime candidates of earthquake pre-cursors studies that needs to be thoroughly understood in order to get appropriate forewarning of earthquake events. Ionospheric perturbations studies have come to light since the great Alaskan earthquake of 1964. Various studies have revealed that measurements made from the ground based instrumentation (GPS receivers, Ionosonde etc.) show a variation in the frequency of the ionosphere layers before and after the major shock (Zaslavski et al., 1998). Review on earthquakes and ionosphere total electron content indicates that prior to large earthquakes, the Earth sends out transient signals, sometimes strong, more often subtle and fleeting (Pulinets, 2007). These signals may consist of local magnetic field variations and electromagnetic emissions over a wide range of frequencies which constitute a variety of atmospheric and ionospheric perturbations.

Total electron content (or TEC) is an important descriptive

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quantity for the ionosphere of the Earth. TEC is the total number of electrons present along a path between two points, with units of electrons per square meter, where 10^{16} electrons/m^2 = 1 TEC unit (TECU). In the area of earthquake preparation zone, active geochemical processes like emanation of several types of gaseous components including radon take place (Pullinets, 2004). The initial stage for ionospheric precursor is the ion-molecular reactions. Pullinets (2004) gave a detailed description of the process of ion cluster formation in the near ground layer in earthquake preparation zone. In the next stage the generation of the anomalous electric field takes place. The gases released during earthquake preparation play a dual role. By generating air motion they create instabilities which initiate the generation of acoustic gravity wave. Secondly these air movements destroy neutral clusters because of weakness in the Coulomb interaction. As a result the near ground layer of atmosphere becomes rich in ions leading to generation of an anomalously strong vertical electric field (Pullinets et al., 2002). Depending on the direction of the electric field on the ground surface, negative or positive deviations may be created in the electron concentration (Pulinets, 1998). The electric field without any decay penetrates to the higher levels of the ionosphere which is manifested in periodic electron density oscillations registered at different ionospheric heights as well as large-scale irregularities of electron concentrations in the F2 region of the ionosphere (Pulinets and Legen'ka, 2002). These irregularities can be observed by satellites and ground based ionosondes and network of GPS receivers (Liu et al., 2004).

According to theory postulated by Freund et al., 2009 stress building in the rocks prior to earthquake releases positive holes, which travel to the unstressed part of the rock at the surface of the earth and subsequently ionises the near ground atmosphere. This result in production of positive ions which travel through troposphere to ionosphere and join electrons and as the process continues, it leads to increase in concentration of electrons thus leading to high TEC values. The basic hypothesis of near surface layer ionisation has been demonstrated by experimental set up and instrumental observation in different parts of world by same set of authors and other workers (Freund et al., 2009; Freund, 2011; Grant et al., 2015).

The Indian subcontinent is a seismically active region of the world where devastating earthquakes have occurred in the past. Majority of seismic activities in Indian sub-continent is concentrated along the geologically young and active Himalayan arc because of the ongoing continent-continent collision between Indian and Eurasian plates. These tectonic activities are also reported to be manifested by crustal rock deformation as well as sediment deformation and changes in geomorphic landform (Ponraj et al., 2010; Kumar et al., 2007). The Himalaya region has a long history of frequent strong earthquakes and has been shaken by four great earthquakes (M_w = 8.7, 1897; M_w = 8.1, 1905; M_w = 8.4, 1934 and M_w = 8.7, 1950) in the past two centuries. Historically, Nepal has experienced five earthquakes (1255, 1408, 1505, 1833 and 1934) with magnitude exceeding 7.5 since 1255. In the last three decades, five strong earthquakes (1980 M 6.6; Uttarkashi, 1991 Mw 6.8; Chamoli, 1999 Mw 6.6; Kashmir, 2005 Mw 7.6; and Sikkim, 2011 Mw 6.9) have caused significant loss of life and property in Himalayan region (Thapa and Wang, 2013). The most recent one is the 7.8 Mw Nepal earthquake of 25 April 2015 that killed over 8000 people (source: CNN). This earthquake struck Nepal at Lamjung, 77 km to the northwest of Kathmandu. The main shock was followed by many aftershocks, some of which had magnitude greater than 6 Mw. Overall bounded by the western and eastern syntaxes, the Himalayan region has experienced number of earthquakes during a seismically very active period from 1897 to 1952 (Gupta et al., 2012) followed by 1–2 devastating events in every decade since 1990s. Therefore, monitoring TEC in Himalayan region has emerged as an important research priority to understand the phenomena along with earthquakes of the region. Although many global studies have addressed seismo-inospheric coupling, however such studies are yet to take off in this seismically very active region of the world. In the present study we have made an attempt to investigate the TEC variations/anomalies possibly caused by earthquakes in the Himalayan region by analysing GNSS (GPS) data from our own continuously operating reference stations (CORS) as well as similar data available from UNAVCO data centre. We have considered 4 major earthquakes (Table 1) of 2015 that occurred in Himalayan region (Uttarakhand, India and Nepal).

2. TEC and earthquakes occurrences

TEC is measured to estimate the impact of ionosphere on the signals transmitted by GPS satellites to the receivers on Earth. Ionospheric TEC is the carrier phase delay of received radio signals transmitted from satellites which are located above the ionosphere (Norsuzila et al., 2010). TEC varies with time and space and it depends on solar activity, geomagnetic storm and receiving station location. The currents and energy introduced by a geomagnetic-storm increases the total height-integrated number of ionospheric electrons, or the TEC. During a geomagnetic storm, the solar wind energy dissipates into the ionosphere and thermosphere, and the energy transportation processes within the ionosphere become extreme and more complicated (Buonsanto and Fuller-Rowell, 1997; Mendillo, 1971; Fuller-Rowell et al., 1996). One of the outcomes of the magnetosphere-ionosphere coupling is the significant variation of electron density during a storm (Danilov and Mikhailov, 2001) and is a matter of concern in the present case.

Solar flares are giant explosions on the sun that send energy, light and high speed particles into space. These flares are often associated with solar magnetic storms known as coronal mass ejections (CMEs). These disturbances have profound effects on radio communications and navigations over the entire radio spectrum (Davies, 1990). During a solar flare, the sun releases energy in the form of electro-magnetic waves, which disrupts the normal balance of ion and its formation and recombination in the ionosphere. These factors result in the spatial variability of the ionosphere and cause ionospheric delays in the GPS signals. Above all, during the earthquakes preparatory process the electron contents in the ionosphere is affected by the seismogenic causes explained before. Therefore, earthquake precursor studies using TEC has many challenges to overcome mainly due to paucity of data (due to lack of sufficient observation stations) and because of the complications in the results due to various other factors influencing TEC data (Pulinets,

Table 1
Earthquakes analysed and data used for TEC analysis.

Earthquakes	Latitude	Longitude	Date and time	Magnitude (Mw)	Data used
Pipalkoti, India	30.3521	79.5107	21:23 UTC, 1st April 2015	4.9	GOPE CORS, AIUB, NOAA
Lamjung,Nepal	28.1473	84.7079	06:11 UTC, 25th April 2015	7.8	GOPE, IIRS, CHLM CORS, AIUB, NOAA
Kodari, Nepal	27.7711	86.0655	07:09 UTC,26th April 2015	6.7	GOPE, IIRS, CHLM CORS, AIUB, NOAA
Kodari, Nepal	27.8087	86.0655	07:05 UTC, 12th May 2015	7.3	GOPE, IIRS, CHLM CORS, AIUB, NOAA

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