A case study of Seismo-generated gravity waves and associated ionospheric fluctuations observed by the ground-based GPS receivers

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Abstract - *It has been known since a long time that the Seismo-generated atmospheric gravity wave (AGW) could trigger fluctuations in ionospheric constituents before the initiation of an earthquake activity. In order to verify such characteristic features associated with an earthquake occurred near the border of Nepal and the Indian state of Sikkim (27.3⁰ N, 88.3⁰ E), ionospheric total electron content (TEC) data measured by the ground-based global positioning system (GPS) receivers have been analyzed. The presence of AGWs is observed in the temporal variations of TEC on 13, 14, 15, 16, and 17 September 2011 very near to earthquake epicenter. Since the above days belong to magnetically quiet day category, it is, therefore, conjectured that these AGW signatures generated due to the Seismo-electromagnetic signals (SESs), a strong evidence of lithosphere-ionosphere coupling. Further, the global ionospheric TEC maps (GIMs) derived with ground-based GPS receivers of IGS (international GPS service) have also provided crucial evidences on these SESs.*

Key Words: Earthquakes, Atmospheric Gravity Waves, Lithosphere-Ionosphere Coupling, TEC, GIM Maps

1. INTRODUCTION

Prior to an earthquake event, vertical motions of the Earth's surface produce mechanical disturbances (popularly known as acoustic gravity waves or AGWs), in the neutral atmosphere, which propagate into the upper atmosphere (ionosphere) and interact with the constituents of that region according to Davies [1] and could imprint transients variations in the ionospheric constituents as suggested by Liu et al. [2]. Evidences on such type of transient variations have been observed since a longtime, for example, see Bolt [3], Leonard and Barnes [4], Davies and Baker [5], Tanaka et al [6], Afraimovich et al. [7-9], and references there in. Further, according to research conducted by Roznoi et al. [10] changes in spectra of the low-frequency (LF) signal perturbations are found several days before and after earthquakes and such changes were noticed inside the Fresnel zone of the Japan- Kamchatka wavepath.

The present research focuses to present one of such events associated with an earthquake occurred near the border of Nepal and the Indian state of Sikkim (27.3⁰ N, 88.3⁰ E) by using TEC data measured by a ground-based GPS receiver located at lhaz (29⁰ N, 91⁰ E) and GIM data. The 2011 Sikkim earthquake or 2011 Nepal earthquake was associated with magnitude of (M_W) 6.9 and it occurred at 18:10 IST (12:40 UCT) on Sunday, 18 September 2011. The location of earthquake epicenter is shown in figure 1, in which red circles indicate the expected radial coverage of earthquake effect.

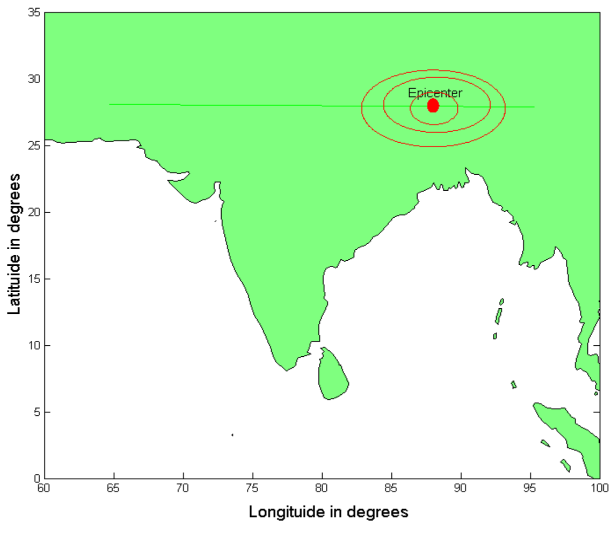


Figure 1 shows the location of epicenter with closed red dot and open red circles show the expected radial coverage of the earthquake effect.

2. DATA AND METHODOLOGY

The total electron content is one of the most important parameters used in the study of the ionospheric properties. The dispersive nature of ionospheric medium, Ratcliffe [11], causes a time delay and a phase advance to the radio waves that radiate from a GPS satellite at an altitude of ~20,200 km and the net effect of this delay is directly proportional to the integrated electron density along the signal path from the position of the satellite to the receiver on Earth according to Klobucher [12]. The GPS-TEC has enormously been contributed to the studies on space weather monitoring and ionospheric pre-cursor signatures for earthquake events, for example Calais and Minster [13], Liu et al. [14], Otsuka et al. [15]. TEC measurements have a large advantage of high time and spatial resolutions. However, it is not very easy to detect any vertical structure because TEC values are the integrated quantity along the radio propagation path penetrating the ionosphere. In this study, temporal variations of TEC data measured by a ground-based GPS receiver located at lhaz (29^0 N, 91^0 E) near China have been used critically to verify the ionospheric signatures associated with this earthquake and the temporal variations of TEC of individual stations near to the epicenter have also been evaluated in order to verify the Seismo-generated AGWs and their significant imprints on TEC variations.

Apart from this, GIM data provided by IGS have been used to ascertain the presence of AGWs. Although GIM data are having two-hour temporal resolution and 5^0 X 2.5^0 (Longitude, Latitude) spatial resolution and three-dimensional (3D) maps are constructed by interpolating individual TEC data available at around 150 stations worldwide, it has capability to detect ionospheric precursors, see research work of Akhoondzadeh et al. [16]. Further, geomagnetic index (Kp) value is retrieved from the World Data Center, Kyoto University, Kyoto, Japan and the Kp index is used to check whether any geo-magnetically disturbed activity was present during days prior to this serious earthquake event or not.

3. RESULTS AND DISCUSSIONS

It has been reported that the ionospheric precursor signatures of an earthquake event can be seen within 500 to 600 km away from the epicenter for the earthquakes occurred with magnitude of greater than six as revealed by the research findings of Liu et al. [17-18]. In view of the above, a ground-based GPS receiver at Ihaz (29^0 N, 91^0 E), which is located away from the epicenter around less than 200 km only, is selected and the temporal variations of TEC measured by that receiver are plotted in Fig 2. As can be seen from the Figure 2 that the wavy signatures are noticed in the temporal variations of TEC measured by the ground-based receiver (bottom panel) as well as in TEC variations of GIM data (top panel) five days (13, 14, 15, 16, 17 and 18 September 2011) prior to the earthquake event and also including on the day of occurrence of earthquake event and the wavy signatures are marked with a dashed inclined line in both figures.

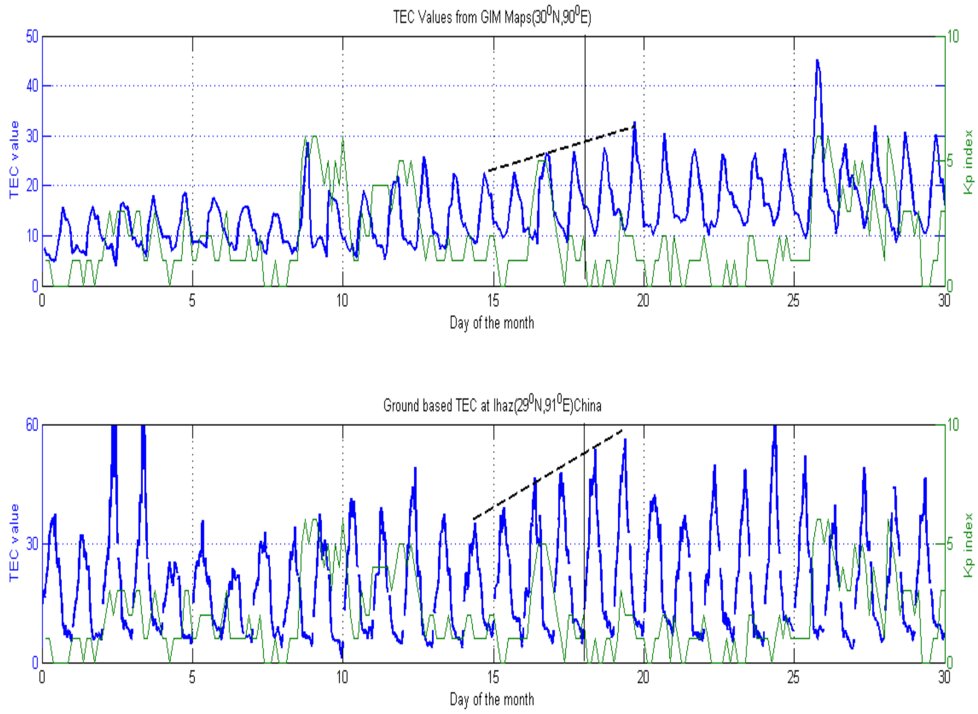


Figure 2 depicts the wavy signatures in temporal variations of TEC (lower panel) measured by a ground-based GPS receiver near to the earthquake epicenter, while the upper panel shows the variations in GIM data. Also note that the Kp index values are given in the right ordinate.

The geomagnetic index (Kp) is shown in the right ordinate of both figures and the earthquake day (18 Sept 2011) is shown with a black line. Since those five days fall in geomagnetic quiet period, the possibility is that the AGWs generated prior to this earthquake have propagated to such higher altitudes to produce ionospheric variations. In general, an atmospheric gravity wave associates with downward phase velocity, while group velocity associates with upward direction. To verify the presence of gravity wave, the temporal variations at different altitudes or different latitudes will be critically evaluated. In order to carry-out such an evaluation, the temporal variations of TEC measured by the ground-based GPS receiver at different latitudes (however at same longitude) on 13 September 2011 are presented in figure 3.

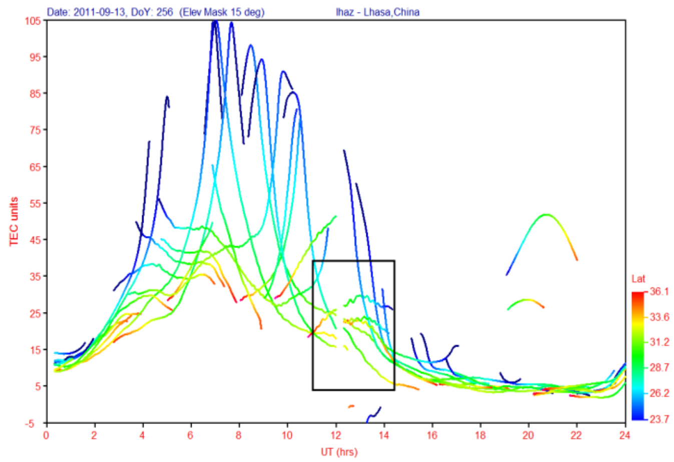
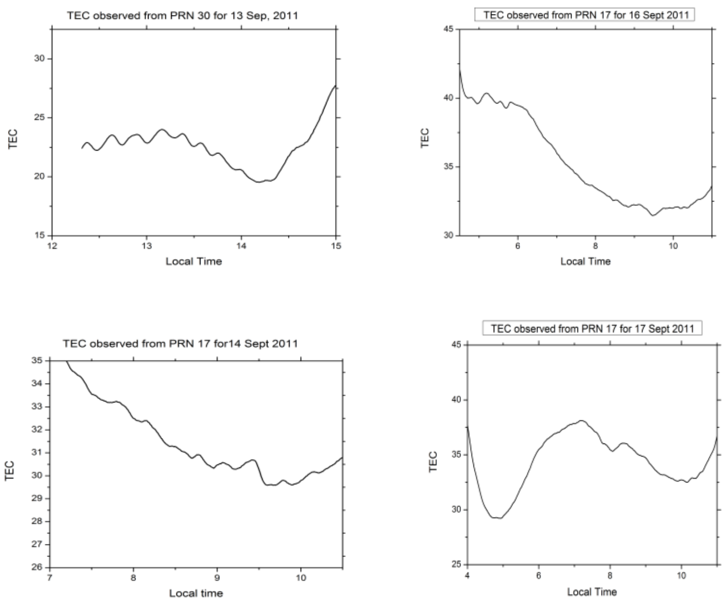


Figure 3 shows temporal variations of TEC measured by the ground-based receiver at Ihaz (29^0 N, 91^0 E) at different latitudes on 13 September 2011 and the presence of gravity wave is shown with an open block box.

The temporal variations of TEC of individual PRN (pseudo-random number) satellites on 13 September 2011 are plotted in Figure 3 and the presence of wavy-signatures are shown with a block color open box. Also note that the elevation angle of 15 or beyond 15^0 of an individual PRN satellite is only selected basing on the fact that in order to record TEC from any individual PRN satellite the elevation angle of that satellite should be at higher elevation angles according to Rama Rao et al. [19] research. A keen observation of figure 3 has revealed that the wavy-structures shown in black box are showing enhancements in TEC with the progress of latitudes, a clear indication of the presence of gravity wave. Similarly, the temporal variations of TEC from 13 to 18 September 2011 (six days) are shown in figure 4 and wavy-signatures are also evident in all days. This research reiterates that lithosphere- ionosphere is one of the important observational studies that need to be studied cautiously that provide appropriate clues regarding the pre and post earthquake, for example see Hike [20] and Parrot [21], signatures in the overlying signatures.



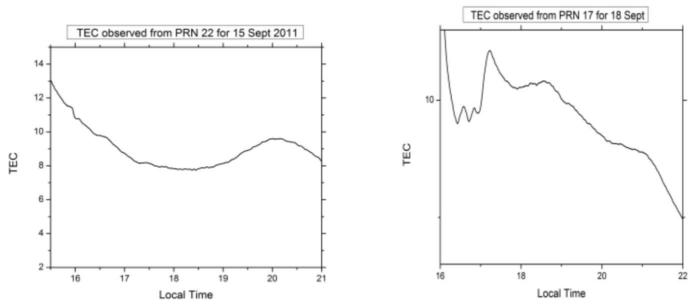


Figure 4 shows the temporal variations of TEC at Ihaz (29^0 N, 91^0 E), China from 13 to 18 September 2011.

4. Conclusions

The following salient features are observed in this present study.

1. Wavy-signatures are noticed in the temporal variations of TEC measured by a ground-based GPS receiver located near (only less than 200 km away from the epicenter) to the earthquake epicenter during 13, 14, 15, 16, 17 and 18 of September 2011

2. The wavy-signatures are also notified in the temporal variations of TEC of GIM data, however with lesser magnitude, and

3. Since there was no severe magnetic activity present during the days, during which wavy-signatures were present, it was reasonable to believe these were due to Seismo-electromagnetic signals originated prior to occurrence of this earthquake.

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