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Anomalous modification of the ionospheric total electron content prior to the 26 September 2005 Peru earthquake

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ABSTRACT

This paper investigates the features of pre-earthquake ionospheric anomalies in the total electron content (TEC) data obtained on the basis of regular GPS observations from the International GNSS Service (IGS) network. For the analysis of the ionospheric effects of the 26 September 2005 Peru earthquake, Global Ionospheric Maps (GIMs) of TEC were used. The possible influence of the earthquake preparation processes on the main low-latitude ionosphere peculiarity—the equatorial anomaly—is discussed. Analysis of the TEC maps has shown that modification of the equatorial anomaly occurred a few days before the earthquake. In previous days, during the evening and night hours (local time—LT), a specific transformation of the TEC distribution had taken place. This modification took the shape of a double-crest structure with a trough near the epicenter, though usually in this time the restored normal latitudinal distribution with a maximum near the magnetic equator is observed. Additional measurements (CHAMP satellite) have also confirmed the presence of this structure. To compare the vertical TEC measurements obtained with GPS satellite signals (GPS TEC), the International Reference Ionosphere, IRI-2001, was used for calculating the IRI TEC.

1. Introduction

For more than 60 years the equatorial ionosphere arouses strong interest of numerous researchers. One of the main and most interesting low-latitude ionosphere peculiarities is the equatorial (Appleton) anomaly. Equatorial anomaly refers to the anomalous double-humped structure in the latitudinal distribution of F-region ionization densities with crests on either side of the dip equator and a trough centered right on the dip equator. This unique signature of the geomagnetic field control of F-region plasma was first discovered by Maeda et al. (1942) and Appleton (1946), and has been extensively investigated since then, both experimentally and theoretically. Many review papers deal with the equatorial F-layer, its morphology and dynamics (Rastogi et al., 1972; Rajaram, 1977; Rishbet, 1977, 2000; Moffet, 1979; Fejer, 1981; Raghavarao et al., 1988; Fejer, 1991).

The equatorial trough in the latitudinal distribution of electron concentration $N_e(\varphi)$ exists in the quiet magnetic conditions from mid-morning to late evening, and is aligned with the geomagnetic dip equator, where the peak electron density NmF2 is typically 30% or so less than at the crests which lie 15°–20° to the north and south, reaches its greatest development in the afternoon and then gradually disappears. The depth of the trough varies considerably with place, local time (LT), season and with solar and geomagnetic activity. As a rule, if the anomaly is more strongly expressed, the crests are located further from the magnetic equator (Hanson and Moffett, 1966; Abdu et al., 1981; Fejer et al., 1999; Rishbet, 2000; Tsai et al., 2001).

At the same time there has been great interest in research into the possible influence of electrical fields

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caused by seismic processes on the equatorial ionosphere. It is known that the equatorial anomaly reacts sensitively to all changes (of any origin) in electric fields.

The electromagnetic anomalies related to earthquakes have been reported recently. In the last 20 years an international intensive research in the new science field of seismo-electromagnetics has been carried out in many countries such as Russia, Japan, Taiwan, China, Greece, France, Italy, India, Mexico, USA (Gokhberg et al., 1983; Parrot and Mogilevsky, 1989; Liperovsky et al., 1992; Hayakawa, 1999; Strakhov and Liperovsky, 1999; Pulinets and Boyarchuk, 2004).

Anomalous ionospheric variations associated with the earthquake preparation processes have been registered using the different techniques of ionosphere monitoring. Mostly the ground-based vertical sounding as well as the topside vertical satellite sounding had been used for these purposes.

Modification of the F-region electron density had been revealed a few days before strong earthquakes by means of the ground-based vertical sounding (Gokhberg et al., 1988; Gaivoronskaya and Zelenova, 1991; Pulinets, 1998; Liu et al., 2000; Silina et al., 2001; Rios et al., 2004). But usually only one ionosonde gets into the epicentral area of the earthquake (R~500 km); as a result of this, we deal with single-position measurements. The character size of the diagnosed area of the ionosphere by using ground-based ionosonde is about several kilometers. In the absence, for the most part, of other ionosondes in the considered seismic active region it is practically unfeasible to study the spatial modification of the ionosphere. Moreover, in the last years the ionosonde network has been significantly reduced, only a part of stations (less than 60 all over the world) is routinely operational. So at present, it is impossible to receive time-continuous data of the ionosphere sounding in global scale—it is the main disadvantage of this method.

The launch and evolution of the GPS and GLONASS satellite navigating systems, along with the creation of specialized projects investigating the earthquake and volcanic eruption effects in the atmosphere and ionosphere and the vigorous development of worldwide and numerous regional networks of satellite signals receivers, have all led to a new stage of research into ionospheric variations observed before and after strong earthquakes. As a result, over the last 10 years many articles have been published dealing with explanations of the physical mechanisms of lithosphere–atmosphere–ionosphere coupling, along with descriptions of the main features of seismo-ionospheric phenomena and the first results of a statistical analysis of pre-earthquake effects (Parrot, 1999; Hayakawa and Molchanov, 2002; Strakhov and Liperovsky, 1999; Plotkin, 2003; Pulinets et al., 2003; Afraimovich et al., 2004; Chen et al., 2004; Liu et al., 2004, 2006a; Pulinets and Boyarchuk, 2004; Zakharenkova et al., 2007; Parrot and Li, 2007).

The disastrous Sumatra earthquake of 26 December 2004 ($M = 9.0$) causes the new wave of interest to investigations of low-latitude ionosphere response to the seismic activity (Li and Parrot, 2006; Dasgupta et al., 2006; Liu et al., 2006b; Zakharenkova et al., 2006; Horie et al., 2007).

The aim of the present paper is to study the modification of the equatorial and low-latitude ionosphere before strong earthquake with $M = 7.5$, which occurred at 01.55 UT, 26 September 2005, in the Northern Peru. The geographical coordinates of the epicenter were 5.67°S, 76.4°W; geomagnetic coordinates—4.55°N, 355.33°. The depth of the hypocenter was 127 km.

Fig. 1 presents the variations of geomagnetic activity indices (Kp, Ap, Dst) and auroral electrojet index (AE) in September 2005. During 17–25 September, days directly preceding the earthquake, the sum of Kp did not exceed 20. The Dst index did not vary greatly. One can see that the geomagnetic situation was rather quiet on all days prior to the earthquake.

2. Data analysis and results

At present, the GPS technique is one of the most efficient means for the regular monitoring of the ionosphere modification and dynamics. GPS constellation consists of 24 satellites in ~12 h orbits with 55° inclination angle; at least 6–8 satellites are visible from any location on the Earth. The satellites broadcast highly stable and coherent navigation signals using two carriers at frequencies of 1575.42 MHz (L_1) and 1227.60 MHz (L_2). Dual-frequency radio signals that propagate through the ionosphere are subject to a differential phase change due to the dispersive nature of the plasma. As a first-order approximation the change in the differential phase shift is directly proportional to the change in the total electron content (TEC) between the transmitter and the receiver.

The GPS permanent network provides regular monitoring of the ionosphere on a global scale with high resolution of TEC measurements. The TEC data obtained on the regular GPS observations from the network of International GNSS Service (IGS) stations were served as initial data.

To analyse the pre-seismic modification of the ionosphere, the Global Ionospheric Maps (GIMs) of TEC at the IONEX format were used. IONEX data are accessible at the site: ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex. The global TEC maps are generated routinely by the IGS community with resolution of 5° longitude and 2.5° latitude and temporal interval of 2 h; one TEC unit (TECU) is equal to 10^{16} electrons/m^2. In this investigation we use TEC maps produced by the Jet Propulsion Laboratory (JPL). Use of GIM TEC provides the possibility to monitor the ionosphere changes of different origin continuously and on a global scale with high accuracy and reliability. However, it is necessary to mention that error of TEC estimation during the creating process of global maps by JPL amounts the value of 10–17% for the considered time and region.

The analysis of TEC distribution was made for American longitudinal sector. The latitude–time TEC (LTT) plots ($\lambda = 75°$W) were constructed for 20–27 September (Fig. 2). It is clear that on 22–24 and 26 September the modification of the TEC distribution in evening LT hours