GPS TEC Anomalies Observed Prior to the Peru Earthquake of 26 September 2005

***Irina E. Zakharenkova*[1], *Irk I. Shagimuratov*[2], *Nadezhda Yu. Tepenitsyna*[3]**

[1] West Department of IZMIRAN, 41 Av. Pobeda, Kaliningrad, 236010, Russia, e-mail: zakharenkova@mail.ru

[2]As (1) above but e-mail: shagimuratov@mail.ru

[3]As (1) above but e-mail: pcizmiran@gazinter.net

Abstract

In the given paper the features of pre-earthquake ionospheric anomalies observed prior to 26 September 2005 Peru earthquake in the total electron content (TEC) data obtained on the basis of regular GPS observations are presented. 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), 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.

1. Introduction

For more than sixty years the equatorial ionosphere arouses strong interest of numerous researchers. Equatorial anomaly (EA) 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. The equatorial trough in the latitudinal distribution of electron concentration Ne(φ) 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, season and with solar and geomagnetic activity.

At the same time there has been great interest in research into the influence of electrical fields caused by seismic processes on the equatorial ionosphere. It is known that EA reacts sensitively to all changes (of any origin) in electrical fields. The ionospheric anomalies related to earthquakes have been reported recently (see list of references in [1,2]).

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 epicenter were 5.67°S, 76.4°W. It is necessary to note that the first step in the investigations of such kind effects is to consider the geomagnetic situation. It was analyzed the variations of geomagnetic activity indices (Kp, Ap, Dst) and auroral electrojet index (AE) in September 2005 - the geomagnetic situation was rather quiet prior to the earthquake. During 17-25 September, days directly preceding the earthquake, the sum of Kp did not exceed 20. The Dst index did not vary greatly.

2. Data Analysis and Results

The GPS permanent network provides regular monitoring of the ionosphere on a global scale with high resolution of the ionospheric total electron content (TEC) measurements. The data of TEC obtained in the regular GPS observations from the network of IGS (International GNSS Service) stations served as initial data. For the analysis of pre-seismic modification of the ionosphere, the Global Ionospheric Maps (GIM) of TEC at the IONEX format were used. IONEX data are accessible at the site: ftp://cddisa.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 hours; one TEC unit (TECU) is equal 10^{16} electrons/m^2. In this investigation we use TEC maps produced by Jet Propulsion Laboratory (JPL).

The analysis of TEC distribution was made for American longitudinal sector. The Latitude-Time TEC (LTT) plots (λ=75°W) were constructed for 20-27 September (Fig. 1). It is clearly seen that on 22-24 and 26 September the

modification of the TEC distribution in evening hours of LT (0-6 UT corresponds 19-01 LT) took place. One can see the "tail" part of EA lasted into the evening time; the presence of well-defined trough is of peculiar interest. It is rather atypical situation for this region and this season – we have analyzed LTT plots for 3 months from August to October 2005, such peculiarity was found out only once – on 14 September, but this date is inside the geomagnetic disturbed period of 10-15 September. Calculations LTT made by use of IRI-2001 model have also demonstrated that during evening hours the TEC latitudinal distribution had the "restored" normal structure with a single maximum near the magnetic equator.

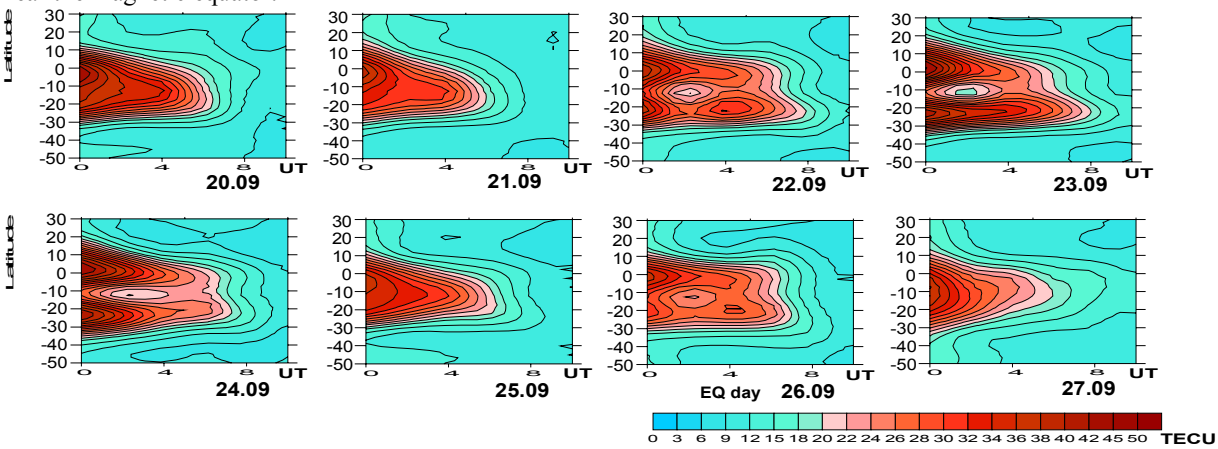

Fig.1. The Latitude-Time TEC plots (λ=75°W) created for 20-27 September.

It is known that equatorial anomaly structure (crests-trough) might be observed even at evening and night hours of local time, but it is usually right for solar maximum epochs and for cases of intensification of equatorial ionization anomaly, for instance, during severe geomagnetic storms, such peculiarity is observed in global scale, at least within one longitudinal sector: American, African and Asian.

To demonstrate the locality of the ionospheric modification observed, Figure 2 presents the Latitude-Time TEC plots constructed for 23 September 2005. There are 6 graphs shown the dynamics of EA during 24 h at different longitudes: 60°E, 30°E, 0°, 30°W, 75°W, 120°W. One can see the dynamics of EA in TEC measurements – the anomaly is intensively developed (crest-to-trough ratio is highest and the crests are farthest from the magnetic equator) around local noon (12-14 LT) as it is observed, in fact, during the solar minimum epoch. It is clearly seen the intensification of the day-time EA at the earthquake longitude (75°W) with more distinctly expressed crests and appearance of the "trough" in the "tail" part of EA.

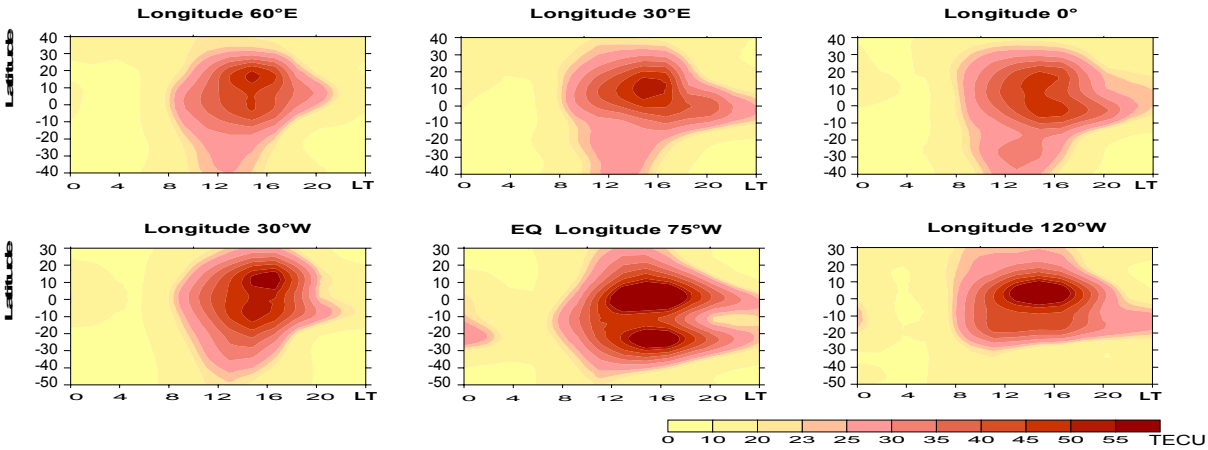

Fig.2. The Latitude-Time TEC plots at different longitudes created for 23 September 2005

For more visual demonstration of this phenomenon separate diagrams in the form of the meridian sections (λ=75°W) of TEC spatial structure were created for the moment of the anomaly maximum manifestation 02 UT corresponds to the 21 LT (Fig.3). The comparison of the current day values (thick lines) and median meaning, calculated from 1 to 20 September, has shown that some days prior to the earthquake we can see the precise

deformation of electron content latitudinal distribution in evening hours of local time in the form of double-crest curve with trough near the epicenter position. The geographical position of two crests is distinctly symmetrical relative to the magnetic equator. The difference of TEC values in crests and trough reached 16-18 TECU.

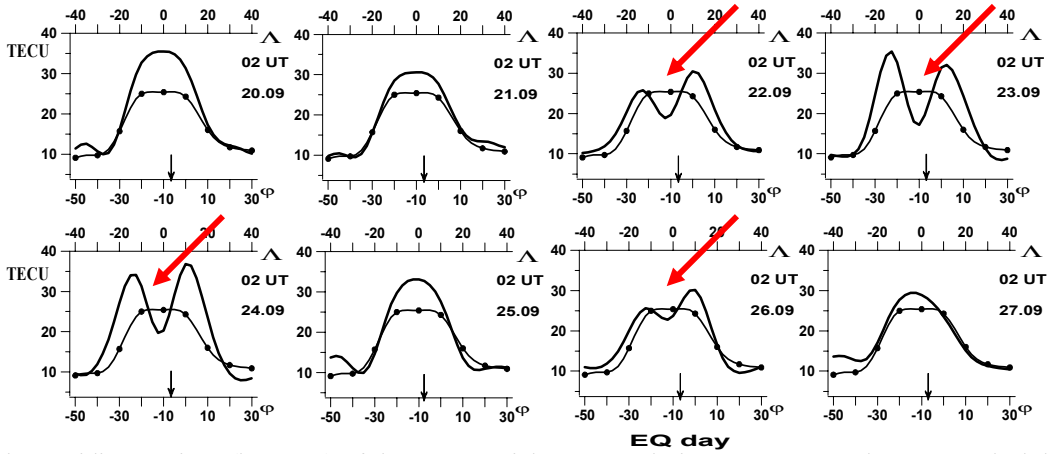

Fig.3. The meridian sections (λ=75°W) of the TEC spatial structure during 20-27 September 2005. Black line with dots - median value calculated for 1-20 September. Left axis shows TEC units, bottom axis - geographical latitude, top axis - geomagnetic latitude. The epicenter position is marked by arrow.

In addition to the ground-based GPS receivers network there is the possibility to use measurements provided by space-based GPS receivers of Low Earth Orbiting (LEO) satellites. CHAMP (Challenging Mini-Satellite Payload) is a German small satellite mission for geoscientific and atmospheric research and applications, managed by GFZ (http://isdc.gfz-potsdam.de/). CHAMP satellite is in almost circular, near-polar orbit (inclination 87.3°) with altitude of ~400 km, orbital period is about 93 min. Thus, the CHAMP satellite moved in the meridional direction almost at the height of the ionospheric electron concentration maximum. Figure 4 presents TEC variations derived on the base of CHAMP measurements along satellite passes filtered in the longitudinal diapason of 90°W-60°W during 02-03 UT (21-22 LT) for 23 September. One can see the presence of the double-crest structure with trough near the magnetic equator (about 10°S of geographical latitude).

3. Discussion and Conclusion

The analysis of global TEC maps has shown that modification of EA took place a few days prior to the Peru earthquake. In the days prior to the earthquake, the ionosphere modification was found out as the EA enhancement with forming of well-defined tail part. This modification took the shape of a double-crest structure with a trough near the magnetic equator (epicenter position was closed to the magnetic equator). Additional measurements (CHAMP satellite) have also confirmed the presence of such structure. This effect was most pronounced in the evening and night hours (local time). It was found out that for this time and region the EA was formed from mid-morning to 16-18 LT, reached the maximal development of the crests at 12-14 LT, at the evening and night time the restored normal latitudinal distribution with single maximum near the magnetic equator is observed.

In [3] the Alouette-2 data had been used to investigate possible anomalous influence of the preparation processes of the earthquakes with epicentre located near magnetic equator on F2 layer latitudinal distribution. It was found out that approximately one day before the earthquake the latitudinal dependence of critical frequency (foF2) on magnetic inclination (I) took shape of a double-crest curve with trough near the epicentre (Fig.7). The plasma concentration over the epicentral area was reduced more than 10 times related to normal conditions. This modification was registered at the time of evening and night hours (LT), though the similar ionospheric structure (certainly, with greater amplitude) can be observed only in the daytime.

One can see that anomaly revealed on the base of Alouette-2 data in foF2 measurements (Fig.5) bears resemblance to the distribution of electron concentration observed in TEC measurements for the case of Peru earthquake (Fig.3,4). So, obtained peculiarities are in a good agreement with early investigations, but it is necessary to mention that GPS TEC measurements provide much more advantages for global scale investigations as compared to data of ground-based ionosondes or separate satellites.

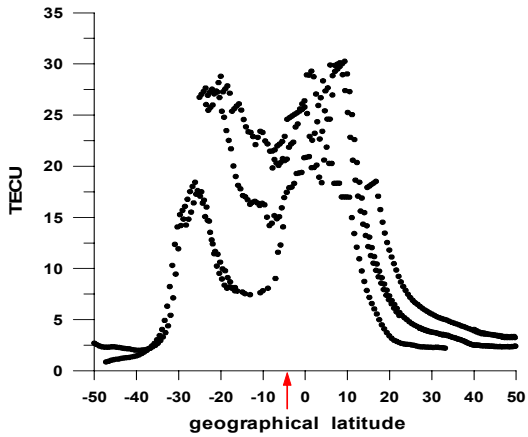

Fig.4. TEC variations on the base of CHAMP measurements during 02-03 UT (21-22 LT) in the considered longitudinal sector for 23 September 2005

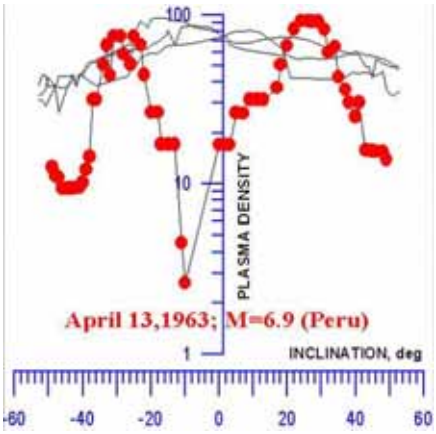

Fig.5. Seismogenic equatorial anomaly (red dots) observed in ionosphere 1 day prior to Chile earthquake 13.04.1963 (Depueva and Ruzhin, 1993)

It is known, EA reacts sensitively to any changes of any origin electrical fields. In the course of the preparatory stage of the equatorial earthquake, there is a penetration of abnormal electrical fields of seismogenic origin into the ionospheric heights, which strengthens or weakens the natural field of equatorial electrojet. In the considered case of Peru earthquake, the epicenter position was located in the area of the anomaly trough between crests. If the zero inclination gets into the zone of earthquake preparation, the additional upward plasma rejection arises in the sector above the magnetic equator, caused the subsequent spatial distribution of electron concentration - an increase in the maximal values of electron concentration Ne relative to the crests of EA and the trough amplification. As it has been already shown, in the discussed case the character of the anomalous TEC modification do was rather symmetrical relative to the magnetic equator.

In [4] it has been considered that the very probable reason of the NmF2 and TEC disturbances observed before the earthquakes is the vertical drift of the F2-region ionospheric plasma under the influence of zonal electric field of seismogenic origin. The efficiency of the proposed mechanism was investigated by means of model calculations of the ionosphere response to the action of zonal electric field produced by seismogenic sources located at the low latitudes. It was shown the action of the near-equatorial source intensifies the EA of F2 layer in the near-epicentral area of the ionosphere by deepening the minimum of foF2 over the magnetic equator and displacing of the anomaly crests from equator to the middle latitudes.

Thus, the anomalous total electron content behavior revealed on the base of GPS measurements in the form of evening crests-trough structure is in a good agreement with others results deal with EA response to the seismic activity and also with results of numerical calculations. It is assumed that anomalous electric field generated near epicenter during the earthquake preparation time could cause like natural “fountain-effect” phenomenon and might be a possible reason of the observed ionospheric anomaly. Taking into account that this period was rather geomagnetically quiet, we conclude that the observed ionospheric perturbations were very likely associated with the imminent earthquake.

4. References

1. S.A. Pulinets and K. Boyarchuk, “Ionospheric Precursors of Earthquakes”, Springer, Berlin, Germany, 2004. 315 p.

2. M. Hayakawa (Eds.). “Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes”, Terra Scientific Publishing Company, Tokyo, Japan. 1999.

3. A.Kh. Depueva and Yu.Ya. Ruzhin, “The equatorial earthquake preparatory stage as a reason of “fountain-effect” in the ionosphere”. Preprint № 82 (1029). Moscow: IZMIRAN. 1993. 10 p. (in Russian)

4. A.A. Namgaladze, I.I. Shagimuratov, I.E. Zakharenkova, O.V. Zolotov and O.V. Martynenko, “Possible mechanism of the TEC enhancements observed before earthquakes”. XXIV IUGG General Assembly, Perugia, Italy, 02-13 July 2007. Session JSS010.