УДК 550.388.2

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ANOMALOUS VARIATION IN GPS TEC PRIOR TO THE 26 MAY 2013 BULUNG'UR, EARTHQUAKE: KITAB GPS STATION

Abstract. The results show anomalous enhancements before the local earthquakes, for expamle, before strong earthquake of magnitude of 5.7 occurred on 26 may 2013 near the north-east of Samarkand, Uzbekistan. To identify the anomalous values of TEC we calculate the differential TEC (dTEC) which is obtained by subtracting monthly averaged diurnal vTEC from the values of observed vTEC at each epoch of the day. This procedure removes normal diurnal variations of vTEC. Anomalies are occurred 2-9 days before the local earthquakes and we regard them as an ionospheric electromagnetic precursors.

Keywords: TEC, anomalous, ionospheric precursors.
Ключевые слова: ПЭС, аномальный, ионосферные предвестники.

Introduction. The ionosphere is an inhomogeneous (it consists of a number of horizontal layers (D, E, F) in an altitude between 60-1000 km with varying density of charged particles), anisotropy (the refractive index depends on the propagation direction of the wave) and dispersive (the phase velocity of a wave is frequency dependent) medium. The D-region of ionosphere is the innermost layer (from 50 km to 90 km above the surface of the Earth) where ionization is due to Lyman series-alpha hydrogen radiation. In addition, when the Sun is active with 50 or more sunspots, hard X-rays (wavelength < 1nm) ionize the air. During the night cosmic rays produce a residual amount of ionization. Recombination is high in the D-region, thus the net ionization effect is very low and as a result high-frequency radio waves are not reflected by the D layer. The frequency of collisions between electrons and other particles in this region during the day is about 10 MHz. The D layer is mainly responsible for absorption of radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset, but remains due to the galactic cosmic rays.

The Global Positioning System (GPS) derived total electron content (TEC) disturbances before earthquakes were discovered in the last years using global and regional TEC maps, TEC measurements over individual stations as well as measurements along individual GPS satellite passes. Since GPS data can be used to measure the ionospheric TEC, the technique has received attention as a potential tool to detect ionospheric perturbations related to the earthquakes. In our preceding study [1] we produced Total Electron Content (TEC) time series Tashkent and Kitab and applied them to detect anomalous TEC signals preceding or accompanying the local earthquakes occurred in years 2006 – 2012.

Total Electron Content. TEC is a frequently used quantity in ionospheric science. Since the number of electrons approximately equals to the number of positive ions, the TEC represents a suitable parameter for the degree of ionization. The TEC is defined as the integral over the electron density distribution N_e along a defined path s:

$$TEC = \int N_e ds\,. \tag{1}$$

Since N_e is a volumetric density and TEC is defined by the integral over a path, the TEC can be thought as the total number of electrons that is contained in a volume with a cross section area being equal to 1 m^2 and length being equal to the path length. The common unit used for measuring the TEC is called Total Electron Content unit (TECU) and 1 TECU is equivalent to 10^{16} el/m^2. Depending on local time, Solar activity, geomagnetic conditions, region of the Earth, etc., the vTEC can vary from about 1 to 180 TECU.

Method of data analysis. Space segment of GPS (Global Positioning System) nominally consists of 24 main satellites and four spares. Spacecrafts are moving along six circular orbits at 20200 km with the inclination angle 55° and evenly spaced in the longitude by 60°. This configuration assumes that at any point on the Earth at any time in the zone of radio visibility there are 6-8 satellites which allow the continuous monitoring of the ionosphere. Each GPS satellite emits two high-stable signal at the frequencies f_1 = 1575.42 MHz and f_2 = 1227.60 MHz. The signals are refracted due to electron density gradients, and since the ionosphere is a dispersive medium, the ray paths of the f_1 and f_2 signals will be slightly different. The obtained phase and pseudorange measurements contain information about the TEC along the ray paths. Dual-frequency group delay measurements of signals of GPS satellites can provide ionospheric delay of the signal, and accordingly determine the absolute value of TEC, which is proportional to this delay [2, 3].

GPS technology is realized simultaneously measuring the group (P1, P2) and phase (L1, L2) delay signals f_1 and f_2, which can be written as follows [4]:

$$P_i = \rho + c(dt^{rec.} - dt^{sat.}) + \Delta_i^{iono.} + \Delta^{tropo.} + \Delta^{instr.}, \tag{2}$$

$$L_i = \rho + c(dt^{rec.} - dt^{sat.}) - \Delta_i^{iono.} + \Delta^{tropo.} + \Delta^{instr.} + \lambda_i N_i, \tag{3}$$

where the index i = 1; 2 corresponds to the carrier frequencies f_1 and f_2; P is the code pseudorange measurement (in distance units); ρ is the geometrical range between satellite and receiver; c is the vacuum light speed; $dt^{rec.}$ and $dt^{sat.}$ are the receiver and satellites clock offsets from GPS time; $\Delta_i^{iono.} = 40.3 \cdot TEC / f_i^2$ is the ionospheric delay; TEC is the Total Electron Content; $\Delta^{tropo.}$ is the tropospheric delay; $\Delta^{instr.}$ is the receiver and satellite instrumental delay; L_i is the carrier phase observation (in distance units); is the wavelength; N_i is the unknown integer carrier phase ambiguities.

Combining the pseudoranges observations P_i, a TEC value is obtained

$$TEC_P = 9.52 \cdot (P_2 - P_1)\ , \tag{4}$$

which is very noisy.

And after combination of carrier phase observations L_i we get

$$TEC_L = 9.52 \cdot [(L_1 - L_2) - (\lambda_1 N_1 - \lambda_2 N_2)] \tag{5}$$

which is less noisy than TECP, but ambiguous. In practice, the calculation of TEC using the pseudorange data only can produce a noisy result. It is desirable to use in addition the relative phase delay between the two carrier frequencies in order to obtain a more precise result. Differential carrier phase provides a precise measurement of relative TEC variations. However the absolute TEC cannot be found unless the pseudorange is also used because the actual number of cycles of phase is unknown. Pseudorange gives the absolute scale for the TEC while the differential phase increases measurement precision.

Slant and Vertical TEC. Slant TEC is a measure of the Total Electron Content of the ionosphere along the ray path from the satellite to the receiver, represented in Figure 1 as the quantity sTEC. It can be calculated by using pseudorange and carrier phase measurements as described above. As sTEC is a quantity which is dependent on the ray path geometry through the ionosphere, it is desirable to calculate an equivalent vertical value of TEC which is independent of the elevation of the ray path. In order to refer the resulting vTEC to a point with specific coordinates, i.e. in order to assign the vTEC value to a specific point in the ionosphere, the so-called single-layer (or thin-shell) model is usually adopted for the ionosphere [5].

Figure 1 shows a schematic representation of this model. In this model all free electrons are contained in a shell of infinitesimal thickness at altitude hi. This idealized layer is usually set to be at 350, 400 or 450 kilometers, approximately corresponding to the altitude of maximum electron density. Figure 1 depicts the relationship between slant (sTEC) and vertical (vTEC) TEC. vTEC can be regarded as:

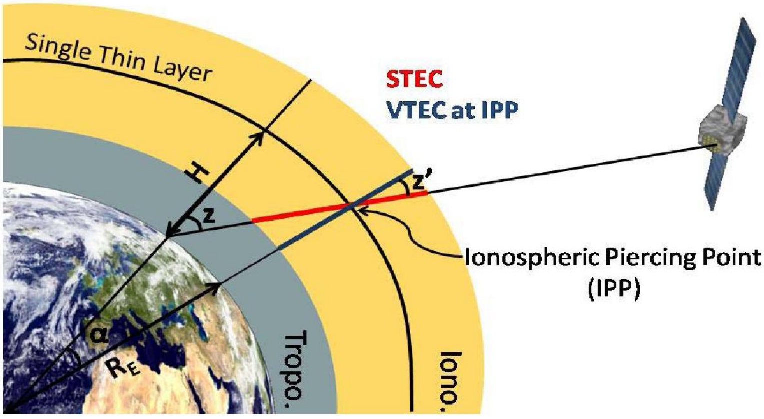

Fig.1 – Geometry of Satellite-Receiver

$$vTEC = sTEC \cdot \cos z' \tag{6}$$

where R_e is the mean Earth radius of 6371 km, h_i is the maximum height of the electron density.

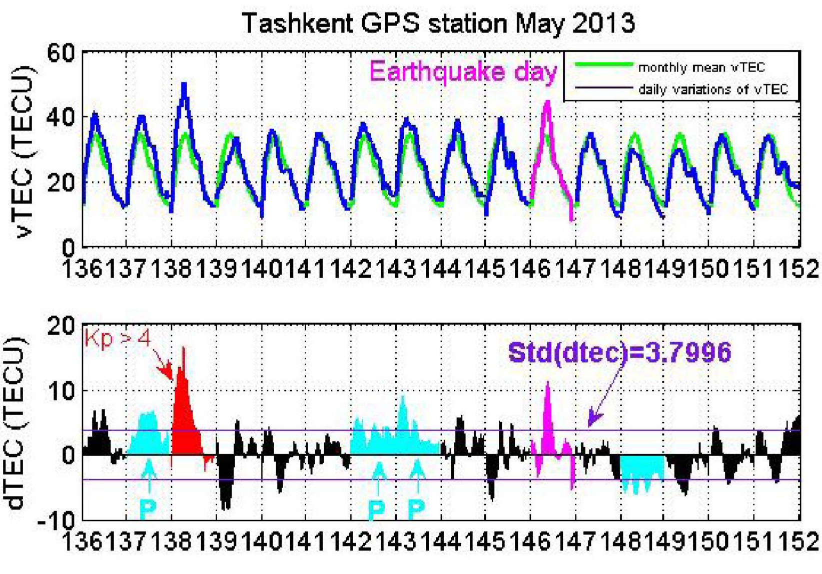

Fig. 2 – Vertical and Differential TEC variations Kitab for Bo'lung'ur,Uzbekistan M=5.7 EQ occurred on 26-May-2013 in comparison with the monthly mean. P character denotes the precursor day

Ionospheric perturbations caused by the earthquakes. We have analyzed GPS derived TEC disturbances from two GPS station located in Kitab, for possible earthquake ionospheric precursors. On 26-May-2013, at 11:08 (LT), the M = 5.7 Bulung'ur earthquake occurred in Uzbekistan. The epicenter with Geographic Latitude (N) $39^{\circ}92'$ and Longitude (E) $67^{\circ}39'$ was located in the territory of the Bulung'ur district of Samarkand region, Uzbekistan at the distance less than one hundred kms from the GPS station operating in Kitab. A thorough analysis of the data shows abnormal variations in TEC in the form of enhancements. For a detail study of the data, we have calculated dTEC values for all the months and examined the anomalous TEC variations before the earthquakes (the sample result is shown in Fig. 2).

Conclusion. The results obtained show principal possibility to detect the earthquake precursors before the occurrence of earthquake. A few steps further should be taken to study more details about this topic. Some research on predicting and modeling of the hazardous (earthquake, tsunami, volcano, flood, storm) system can be considered as the future enhancement. This result is useful to give an early information about the occurrence of earthquake will be happened. The risks caused by possible earthquakes in Tashkent and Samarkand (near to GPS station in Kitab) could be minimized.

Concluding the Kitab GPS data analysis for years 2006- 2013 we can state:

1. Ionospheric data in F-layer obtained on ground based navigation stations in Tashkent and Kitab are used for analysis of earthquake precursors.
2. In general the anomalies occurred 2-9 days before the earthquakes as precursors. The similar anomalies were detected in Kitab GPS station which is at the distance of about 100 kms from the epicenter.
3. The obtained results have revealed a fine agreement with TEC anomalies observed in Tashkent and Kitab GPS station during strong earthquake in Tashkent and we demonstrate the capabilities of the GPS technique to detect ionospheric perturbations caused by the earthquakes during last years starting from 2006.

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Резюме

Результаты показывают аномальное усиление перед местными землетрясениями, например, перед сильным землетрясением магнитудой 5.7, которое произошло в 26 мая 2013 года к северо-востоку от Самарканда (Узбекистан). Для выявления аномальных значений ПЭС вычислено дифференциальное дПЭС, которое получается путем вычитания среднемесячного суточного ТЕС от значений, наблюдаемых вПЭС на каждой эпохе дня. Эта процедура удаляет нормальные суточные вариации вПЭС. Аномалия возникли за 2-9 дня до местных землетрясений, они рассматриваются как ионосферные электромагнитные предвестники.

Ключевые слова: ПЭС, аномальный, ионосферные предвестники.