Ionospheric anomalies of local earthquakes detected by TEC measurements at Tashkent and Kitab GPS stations

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December 04, 2014
UN/ICTP Workshop
on the Use of GNSS for Scientific Applications
Coauthors and Publications

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- Husan Eshkuvatov, INP/UBAI, Tashkent

1. Introduction
① Introduction

② TEC extraction from GPS data at Tashkent and Kitab stations
1 Introduction

2 TEC extraction from GPS data at Tashkent and Kitab stations

3 GPS Data Analysis and Ionospheric Variations
1. Introduction

2. TEC extraction from GPS data at Tashkent and Kitab stations

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4. Ionospheric disturbances in D-layer recorded by VLF receiver at Tashkent IHY station
   VLF observations
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GPS Station in Tashkent and Kitab

Ionospheric EQ Precursors: Kitab & Tashkent Gl
GPS Station in Tashkent and Kitab
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GPS measurements use time delay between radio signals at two frequencies

\[ f_1 = 1575.42 \text{MHz} \quad \text{and} \quad f_2 = 1227.6 \text{MHz} \]

Pseudorange

\[ P_i = \rho + c (dT - dt) + \Delta_{i \text{ono}} + \Delta^{\text{trop}} \]

Effect of F-layer of ionosphere with thickness 870 km

\[ \Delta_{i \text{ono}} = -\frac{40.3}{f_i^2} \text{TEC} \]

Total Electron Content

\[ \text{TEC} = \frac{f_1^2 \cdot f_2^2}{40.3 \left( f_1^2 - f_2^2 \right)} (P_1 - P_2) \]
TEC extraction from GPS data at Tashkent and Kitab stations

Receiver Independent EXchange (RINEX) FORMAT

- Tashkent GPS station
- observation file: tash1740a.08o
- navigation file: tash1740a.08n

ftp://cddis.gsfc.nasa.gov/gps/data/daily/2008/174/00/tash1740a.08o
ftp://cddis.gsfc.nasa.gov/gps/data/daily/2008/174/00/tash1740a.08n

- **Pseudo lengths** P1 and P2 are extracted from observation file
- Ephemerides (coordinates & orbits of satellites) are extracted from navigation files

Slant and Vertical TEC

Slant TEC is extracted from pseudoranges $P_1$ and $P_2$

Vertical TEC

With help of navigation file containing 28 parameters being responsible for satellite coordinates vertical TEC is calculated in MatLab
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5. Conclusion
Cyan stars indicate positions of GPS stations in Tashkent and Kitab. Red circle indicates the position of earthquake epicenter.
Catalog of M > 5.0 earthquakes analyzed

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Catalog of $M \geq 5.0$ earthquakes during analyzed

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Vertical and Differential TEC variations (blue line) above Tashkent for 11 consecutive days, including Tashkent earthquake (M=4.4) date: August 22, 2008 (day 235) in comparison with the monthly mean.
Vertical and Differential TEC variations (blue line) above Kitab for 11 consecutive days, including Tashkent earthquake (M=4.4) date: August 22, 2008 (day 235) in comparison with the monthly mean.

![Graph showing TEC variations over time with notable peaks around day 235.](image-url)
Vertical and Differential TEC variations above Tashkent for EQ on 24-Jun-2008 in comparison with the monthly mean. P character denotes the precursor day.
Vertical and Differential TEC variations above Kitab for EQ on 24-Jun-2008 in comparison with the monthly mean. P character denotes the precursor day.

Kitab GPS station June 2008

Time (DOY)

vTEC (TECU)

dTEC (TECU)
Vertical and Differential TEC variations above Tashkent for Kyrgyzstan EQ (M=6.7) on 05-Oct-2008 in comparison with the monthly mean. P character denotes the precursor day.
Vertical and Differential TEC variations above Kitab for Kyrgyzstan EQ (M=6.7) on 05-Oct-2008 in comparison with the monthly mean. P character denotes the precursor day.
Vertical TEC variations above Tashkent for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.
Differential TEC variations above Tashkent for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.
Vertical TEC variations above Kitab for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.

Kitab GPS station December 2008

Kitab GPS station January 2009
Differential TEC variations above Kitab for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.
Vertical and Differential TEC variations above Tashkent for EQs on 22, 25, 29-Oct-2009 in comparison with the monthly mean.
Vertical and Differential TEC variations above Kitab for EQs on 22, 25, 29-Oct-2009 in comparison with the monthly mean.
Vertical and Differential TEC variations above Tashkent for Afghan M=5.0 EQ occurred on 13-Jan-2012 in comparison with the monthly mean.
<table>
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   - VLF observations

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Atmospheric Weather Electromagnetic System for Observation Modeling and Education
Ionospheric disturbances in D-layer recorded by VLF receiver station

IHY station

Ahmedov (INP/UBAI)

Ionospheric EQ Precursors: Kitab & Tashkent Gl

Trieste, 04.12.2014
Ionospheric disturbances in D-layer recorded by VLF receiver at Tashkent IHY station

Ahmedov (INP/UBAI)

Ionospheric EQ Precursors: Kitab & Tashkent Gl

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Ahmedov (INP/UBAI)

Ionospheric EQ Precursors: Kitab & Tashkent GPS Stations

Trieste, 04.12.2014 37 / 65
The ionospheric D layer is not transparent for radio VLF waves (frequencies 3kHz to 30 kHz) and behaves like a mirror.

If the transmitter is at large distance (800 to 2000 km) then the radio waves are guided like in a waveguide consisting of the D layer and the earth surface. Any change in the quality of this waveguide results then in the VLF signal change.
Ionospheric disturbances in D-layer recorded by VLF receiver at Tashkent IHY station

VLF observations

Ahmedov (INP/UBAI)

Ionospheric EQ Precursors: Kitab & Tashkent Gl

Trieste, 04.12.2014
Таблица: List of narrowband transmitters commonly recorded by AWESOME VLF receiver in Tashkent IHY station

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The parameters of $M>5.0$ earthquakes used in this study

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</table>

Earthquake Preparation Zone

- The area on the ground surface where precursory phenomenon associated with the approaching Earthquake are observed. It is also called the activation zone.

- The radius of preparation zone is given as:

\[ \rho = 10^{0.43M} \text{ km} \]

Where \( \rho \) is radius of preparation zone, \( M \) is Earthquake magnitude (Dobrovolsky et al 1979)
Nighttime Fluctuation Method

Diurnal variations of the amplitude and phase of subionospheric VLF signal are known to change significantly from month to month and from day to day. Therefore, we use, for our analysis, a residual signal of amplitude $dA$ as the difference between the observed signal intensity (amplitude) and the average of several days preceding or following the current day:

$$dA(t) = A(t) - <A(t)>$$

where $A(t)$ is the amplitude at a time $t$ for a current day and $<A(t)>$ is the corresponding average at the same time $t$ for $\pm 15$ days (15 days before, 15 days after the earthquake and earthquake day). In the paper by Rozhnoi et al. (2004), they have defined an anomalous day when $dA(t)$ exceeds the corresponding standard deviation. In our analysis we have studied the nighttime variation (in the U.T. range from U.T. = 15 h to 23 h) (or L.T. 20 h to 04 h)). Then, we use two physical parameters: average amplitude (we call it "amplitude") (or trend) and amplitude dispersion (we call it "dispersion") (or "fluctuation"). We estimate the average amplitude for each day (in terms of U.T.) by using the observed $dA(t)$ and one value for fluctuation for each day.
Nighttime Fluctuation Method

We estimate the following two physical quantities of amplitude: trend (as the average of nighttime amplitude) and nighttime fluctuation (NF)

\[ trend = \frac{\int_{N_s}^{N_e} dA(t) \, dt}{N_e - N_s}, \quad NF = \int_{N_s}^{N_e} (dA(t))^2 \, dt \]

where Ns and Ne are the times of starting and ending the nighttime in our analysis.

We have proposed the use of so-called standardization. We deal with two physical quantities of amplitude, trend, and NF and we estimate the following normalized trend (\(\text{trend}^*\)) and normalized NF (\(\text{NF}^*\)). When we take an EQ with a particular date, we estimate the trend on this day and we then calculate the average <trend> over ±15 days around this date. Then, the normalized trend (\(\text{trend}^*\)) is defined as \((\text{trend} - <\text{trend}>) / \sigma_T\) (\(\sigma_T\), standard deviation over ±15 days around the current date). The same principle is applied to NF to obtain the normalized NF (\(\text{NF}^*\)).
Amplitude variation of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008
Trend and NF of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008
Dispersion of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008
Trend and NF of NSC signal for Italy M=5.5 EQ on 7 April, 2009
Dispersion of NSC signal for Italy M=5.5 EQ on 7 April, 2009
Normalized Trend and NF of NSC signal for Italy M=5.5 EQ on 7 April, 2009
Normalized Dispersion of NSC signal for Italy M=5.5 EQ on 7 April, 2009
Trend and NF of DHO signal for Italy M=5.5 EQ on 7 April, 2009

[Graph showing trend and NF of DHO signal for Italy M=5.5 EQ on 7 April, 2009]
Dispersion of DHO signal for Italy M=5.5 EQ on 7 April, 2009

[Bar chart showing dispersion data for DHO signal with respect to Tashkent station, with days from -15 to 1 plotted on the x-axis and dispersion values on the y-axis.]
Normalized trend and NF of DHO signal for Italy M=5.5 EQ on 7 April, 2009
Normalized dispersion of DHO signal for Italy M=5.5 EQ on 7 April, 2009

![Graph showing normalized dispersion of DHO signal for Italy EQ on 7 April, 2009. The graph displays the dispersion over days, with bars indicating the normalized dispersion values above and below the mean.]
Ionospheric disturbances in D-layer recorded by VLF receiver at Tashkent IHY station

Trend and NF of ICV signal for Georgia M=6.0 EQ on 7 September, 2009

ICV-Tashkent

Trend

N.F.*
Dispersion of ICV signal for Georgia M=6.0 EQ on 7 September, 2009
Normalized trend and NF of ICV signal for Georgia M=6.0 EQ on 7 September, 2009

Ahmedov (INP/UBAI)  
Ionospheric EQ Precursors: Kitab & Tashkent Gl  
Trieste, 04.12.2014
Normalized dispersion of ICV signal for Georgia M=6.0 EQ on 7 September, 2009

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### The ionospheric precursors of the selected EQs

<table>
<thead>
<tr>
<th>EQ</th>
<th>M</th>
<th>$P_{trend}$</th>
<th>$P_{NF}$</th>
<th>$P_D$</th>
<th>$P_{trend^*}$</th>
<th>$P_{NF^*}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M=6.7</td>
<td>$-10^\uparrow; -11^\uparrow$</td>
<td>$-11^\uparrow$</td>
<td>$-10^\uparrow; -11^\uparrow$</td>
<td>$-10^\uparrow; -11^\uparrow$</td>
<td>$-10^\uparrow; -11^\uparrow$</td>
</tr>
<tr>
<td>2</td>
<td>M=7.1</td>
<td>$-2^\uparrow$</td>
<td>$-11^\uparrow$</td>
<td>$\times$</td>
<td>$-2^\uparrow$</td>
<td>$-11^\uparrow$</td>
</tr>
<tr>
<td>3</td>
<td>M=6.6</td>
<td>$-5^\uparrow$</td>
<td>$-5^\uparrow$</td>
<td>$\times$</td>
<td>$-5^\uparrow$</td>
<td>$-5^\uparrow$</td>
</tr>
<tr>
<td>4</td>
<td>M=6.2</td>
<td>$0^\uparrow; -4^\downarrow$</td>
<td>$0^\uparrow; -4^\downarrow$</td>
<td>$-6^\uparrow$</td>
<td>$0^\uparrow; -4^\downarrow$</td>
<td>$0^\uparrow; -4^\downarrow$</td>
</tr>
<tr>
<td>5</td>
<td>M=6.3</td>
<td>$0^\uparrow$</td>
<td>$0^\uparrow$</td>
<td>$0^\uparrow$</td>
<td>$0^\uparrow$</td>
<td>$0^\uparrow$</td>
</tr>
<tr>
<td>6</td>
<td>M=5.5</td>
<td>$-8^\uparrow; -9^\uparrow$</td>
<td>$-9^\uparrow$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$-9^\uparrow$</td>
</tr>
<tr>
<td>7</td>
<td>M=5.4</td>
<td>$-10^\uparrow; -13^\uparrow$</td>
<td>$-10^\uparrow$</td>
<td>$-10^\uparrow$</td>
<td>$-10^\uparrow; -13^\uparrow$</td>
<td>$-10^\uparrow$</td>
</tr>
<tr>
<td>8</td>
<td>M=6.0</td>
<td>$-7^\downarrow$</td>
<td>$-7^\uparrow$</td>
<td>$\times$</td>
<td>$-7^\downarrow$</td>
<td>$-7^\uparrow$</td>
</tr>
</tbody>
</table>
Solar Eclipse 2009

Path of the Eclipse Through Asia
Total Solar Eclipse of 2009 July 22

From JJI

China

India

Path Begins At Sunrise

From NWC

Maximum Eclipse At Sunrise


01:00 UT 04m06s 21°
01:10 UT 05m43s 34°
01:20 UT 05m36s 43°
01:30 UT 05m36s 50°
01:50 UT 06m12s 63°
01:50 UT 06m12s 63°
01:40 UT 05m56s 57°
02:00 UT 06m24s 68°
Solar Eclipse

Solar Eclipse is observed during sunrise from 00:23:59 UT to 01:50:27 on 22 July 2009. The results are signals of JJI transmitter.
1 Introduction

2 TEC extraction from GPS data at Tashkent and Kitab stations

3 GPS Data Analysis and Ionospheric Variations

4 Ionospheric disturbances in D-layer recorded by VLF receiver at Tashkent IHY station
   VLF observations

5 Conclusion
• Ionospheric data in F-layer obtained on ground based navigation stations in Tashkent and Kitab are used for analysis of earthquake precursors.

• High magnitude earthquakes have ionospheric precursors.

• Ionospheric precursors are observed in the form of values of dTEC being almost positive or negative during the whole day.

• Ionospheric TEC deflection three days before Tashkent, 22-Aug-2008 earthquake probably is not an effect of the earthquake since the geomagnetic index $Kp$ was bigger than 4 and we can not define this deflection as ionospheric precursor.
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• Significant changes in amplitude parameters are observed: few days before the strong EQs occurred on the path way to the Tashkent VLF receiver.

• The anomalies occurred 0-13 days before the strong EQs are identified as ionospheric EQ precursors and are in agreement with the other observations of EQs precursors in VLF data reported by various researchers.

• X-ray solar flares and total solar eclipse are also studied. Solar eclipse is observed on 22 July 2009 on the pathes of VLF signals from JJI (Japan), NWC (Australia) and VTX (India) transmitters.
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Thank You