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

B.J. Ahmedov

Institute of Nuclear Physics &
Ulugh Beg Astronomical Institute, Tashkent
UZBEKISTAN

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Coauthors and Publications

- Sardor Tojiev, PhD student, Jacobs Universitat, Bremen, Germany
- Dr Yusuf Tillayev, Senior Researcher, UBAI, Tashkent, collaborator of GFZ Potsdam
- Husan Eshkuvatov, INP/UBAI, Tashkent
- ——————————————————————————
- S. R. Tojiev, B. J. Ahmedov, H. E. Eshkuvatov, Ionospheric precursors of earthquakes recorded by VLF receiver at Tashkent IHY station, **Adv. Space Res.**, 2014, V.54, Issue 4, pp. 628-643.
- S. R. Tojiev, B. J. Ahmedov, Y.A. Tillayev, H. E. Eshkuvatov, Ionospheric anomalies of local earthquakes detected by GPS TEC measurements using data from Tashkent and Kitab stations, **Adv. Space Res.**, 2013, V.52, pp.1146-1154.
- Tojiev S. R., Morozova V. S., Ahmedov B. J., H. E. Eshkuvatov, Electromagnetic studies of ionospheric and magnetospheric perturbations associated with the Earth, atmospheric and astrophysical phenomena, Proc. 13th Regional Conference on Mathematical Physics, World Scientific, U. Camci, I. Semiz Eds, 2012, pp. 254-278.

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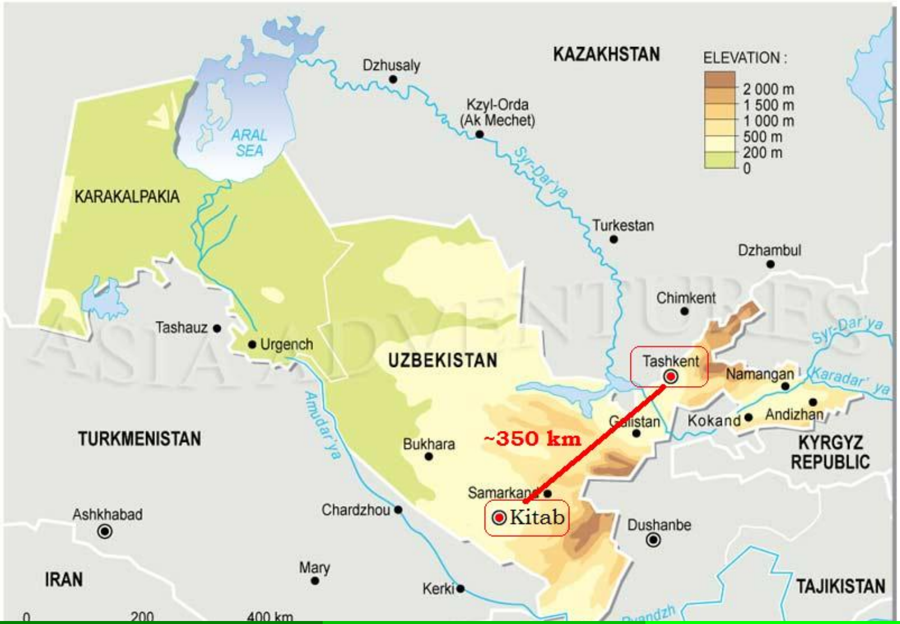
GPS Station in Tashkent and Kitab



GPS Station in Tashkent and Kitab

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TEC extraction

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

$$P_i = \rho + c\,(dT - dt) + \Delta_i^{iono} + \Delta^{trop}$$

Effect of F-layer of ionosphere with thickness 870 km

$$\Delta_i^{iono} = -\frac{40.3}{f_i^2}\mathbf{TEC}$$

Total Electron Content

$$\mathbf{TEC} = \frac{f_1^2 \cdot f_2^2}{40.3\,(f_1^2 - f_2^2)}\,(P_1 - P_2)$$

Receiver Independent EXchange (RINEX) FORMAT

observation file
tash1740a.08o

navigation file
tash1740a.08n

Tashkent GPS station

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

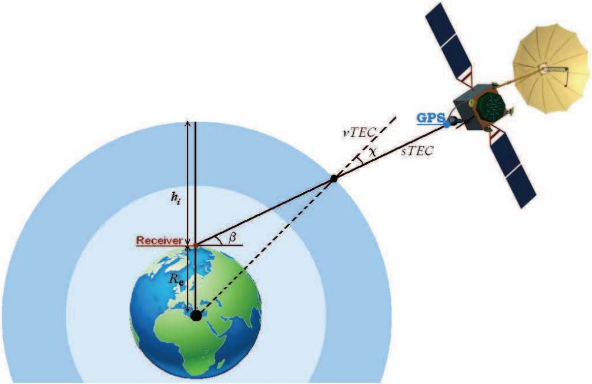
ftp://cddis.gsfc.nasa.gov/gps/data/daily/2008/174/00/tash1740a.08n

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

S. R. Tojiev, B. J. Ahmedov, Y.A. Tillayev, H. E. Eshkuvatov, Ionospheric anomalies of local earthquakes detected by GPS TEC measurements using data from Tashkent and Kitab stations, **Adv. Space Res.**, 2013, V.52, pp.1146-1154.

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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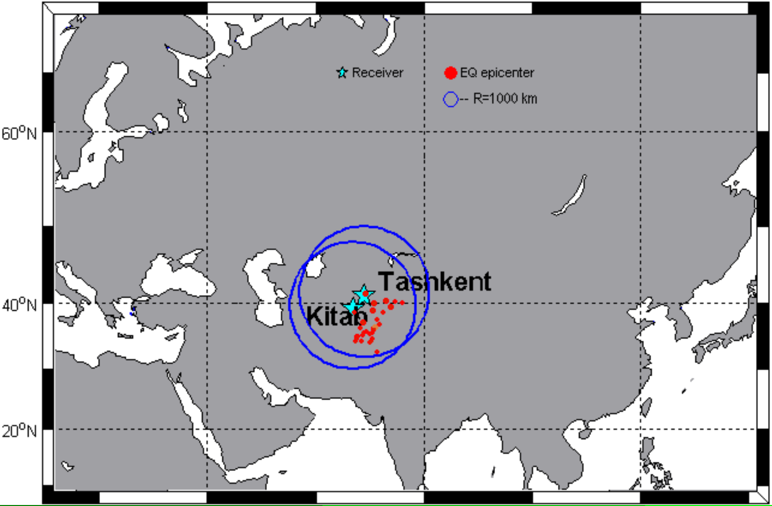
Local Earthquake Observations

Cyan stars indicate positions of GPS stations in Tashkent and Kitab. Red circle indicates the position of earthquake epicenter.



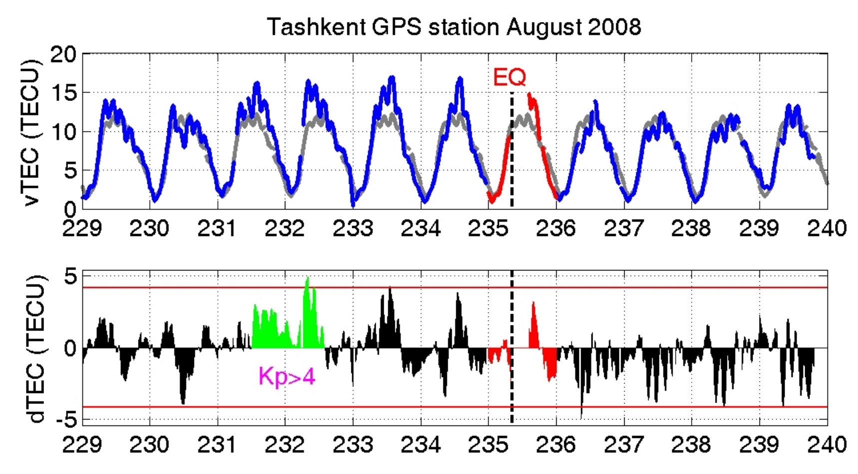
Catalog of M>5.0 earthquakes analyzed

EQ	YY	MM	DD	Lat.	Lon.	M
1	2006	07	06	39.12N	71.84E	5.8
2	2006	07	29	37.26N	68.83E	5.6
3	2006	07	29	37.13N	68.81E	5.4
4	2006	08	06	37.37N	74.73E	5.6
5	2007	07	20	42.91N	82.38E	5.6
6	2007	07	21	38.94N	70.49E	5.2
7	2007	07	22	30.88N	78.24E	5.1
8	2007	07	25	36.08N	70.36E	5.0
9	2007	12	31	41.11N	71.94E	5.0
10	2008	01	01	40.28N	72.98E	5.6
11	2008	06	24	40.03N	70.84E	5.0
12	2008	07	08	39.52N	73.18E	5.0
13	2008	08	12	36.55N	71.47E	5.0
14	2008	10	05	39.53N	73.82E	6.7
15	2008	12	21	35.96N	71.41E	5.0

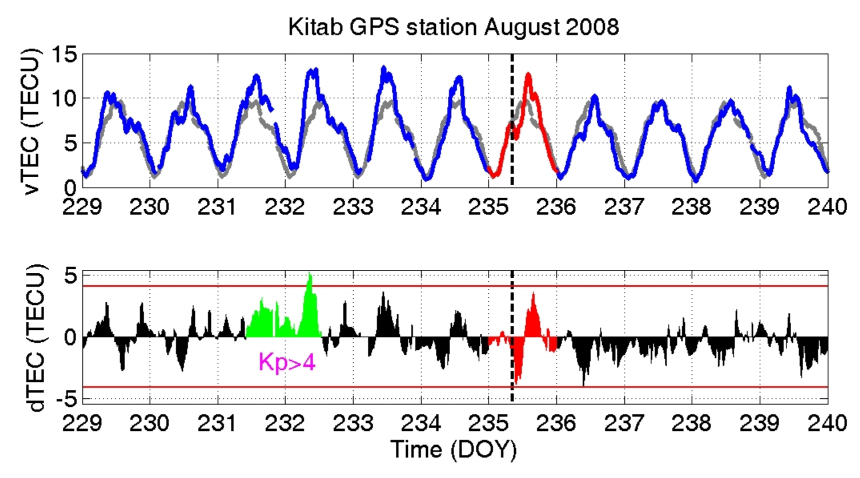
Catalog of M>5.0 earthquakes during analyzed

EQ	YY	MM	DD	Lat.	Lon.	M
16	2008	12	29	36.39N	71.07E	5.8
17	2009	01	03	36.42N	70.74E	6.6
18	2009	01	04	36.44N	70.88E	5.7
19	2009	01	20	35.87N	69.93E	5.2
20	2009	01	25	38.18N	72.24E	5.0
21	2009	02	20	34.20N	73.90E	5.5
22	2009	02	20	40.66N	78.69E	5.3
23	2009	10	13	38.79N	70.70E	5.0
24	2009	10	15	36.99N	71.38E	5.0
25	2009	10	16	40.17N	76.96E	5.0
26	2009	10	22	36.52N	70.95E	6.2
27	2009	10	25	34.85N	80.38E	5.0
28	2009	10	25	29.57N	63.88E	5.6
29	2009	10	29	36.39N	70.72E	6.2
30	2009	10	30	34.18N	70.02E	5.1

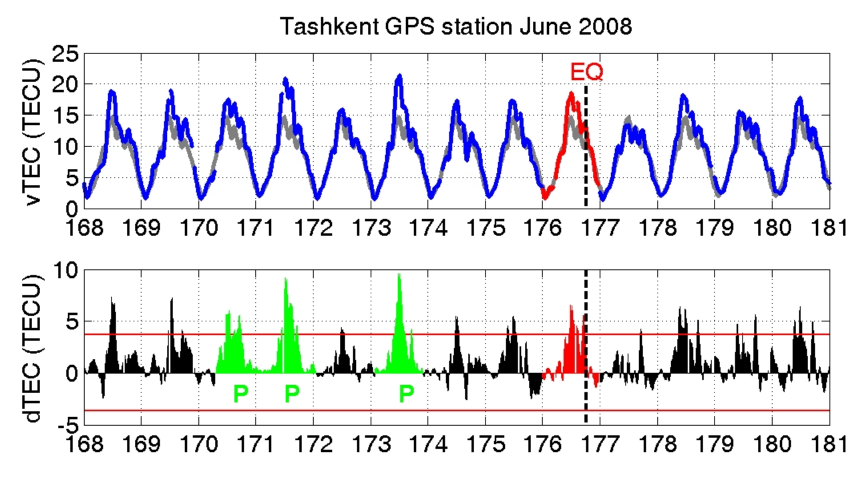
Vertical and Differential TEC variations (blue line) above Tashkent for 11 consecutive days, including Tashkent earthquake (M=4.4) date: August 22, 2008 (day 235) in comparison with the monthly mean.



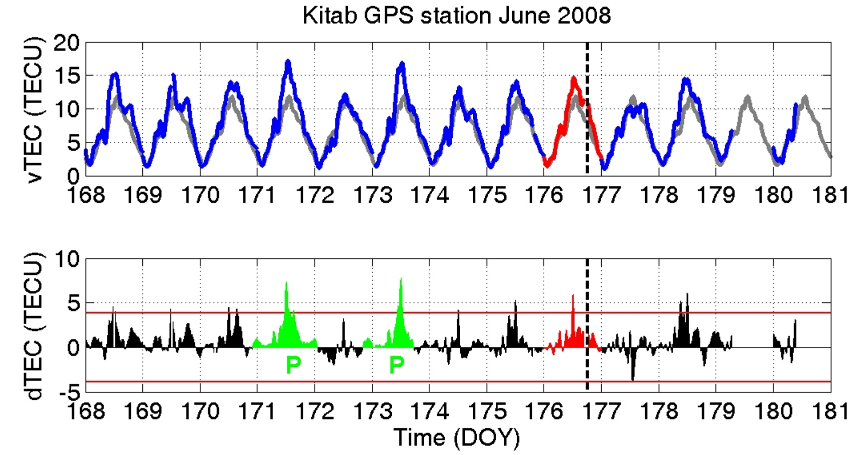
Vertical and Differential TEC variations (blue line) above Kitab for 11 consecutive days, including Tashkent earthquake (M=4.4) date: August 22, 2008 (day 235) in comparison with the monthly mean.



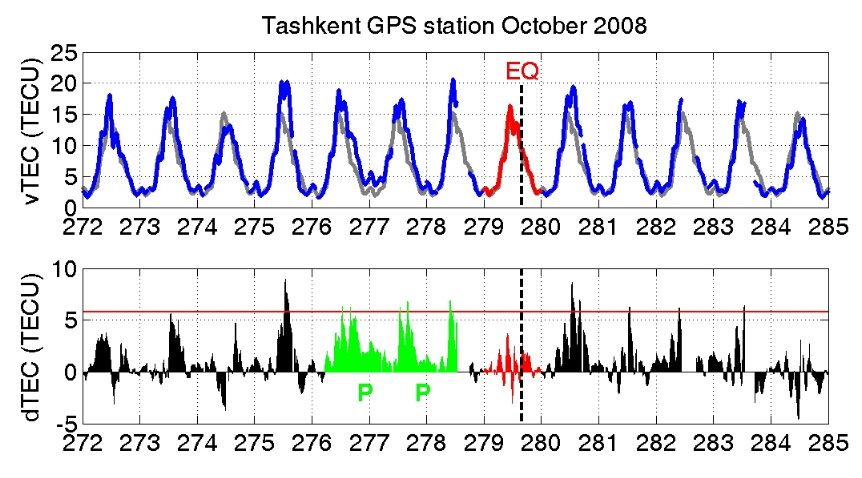
Vertical and Differential TEC variations above Tashkent for EQ on 24-Jun-2008 in comparison with the monthly mean. P character denotes the precursor day.



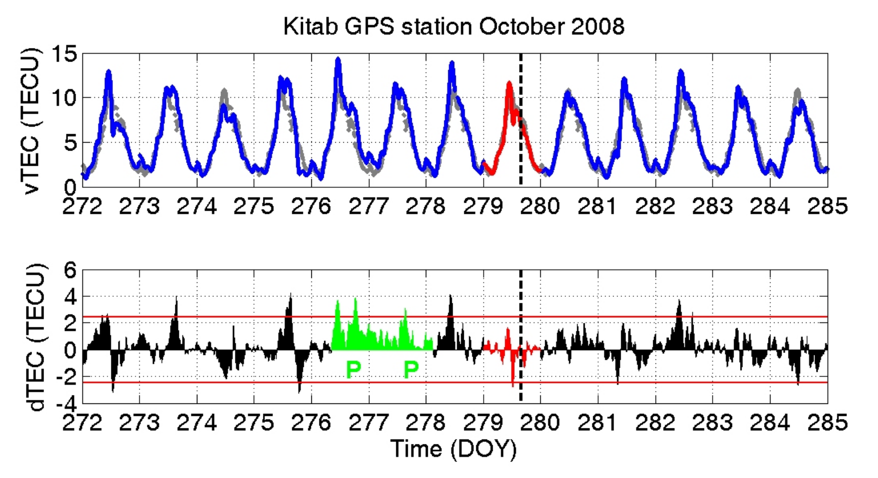
Vertical and Differential TEC variations above Kitab for EQ on 24-Jun-2008 in comparison with the monthly mean. P character denotes the precursor day.



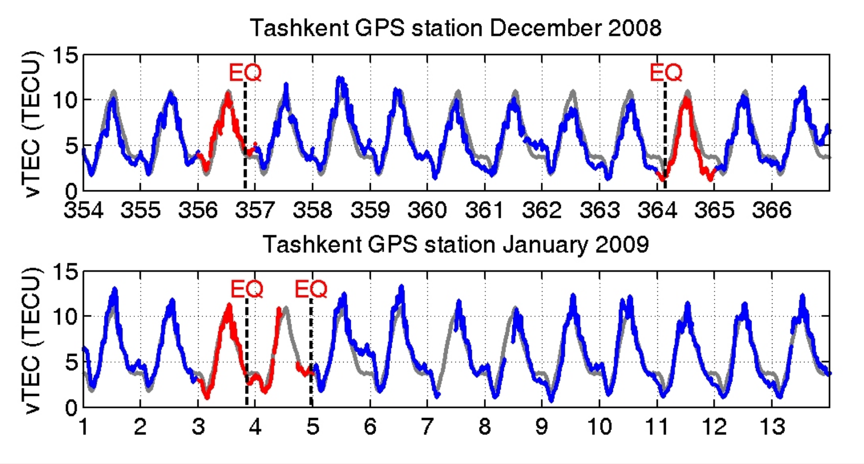
Vertical and Differential TEC variations above Tashkent for Kyrgyzstan EQ (M=6.7) on 05-Oct-2008 in comparison with the monthly mean. P character denotes the precursor day.



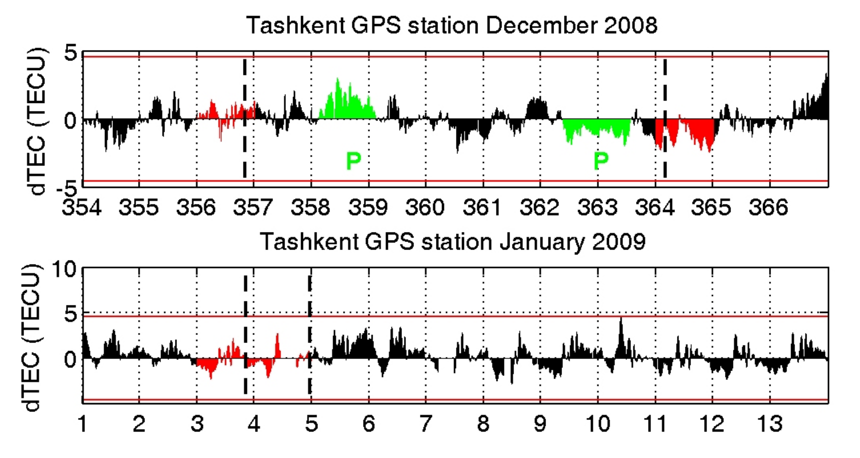
Vertical and Differential TEC variations above Kitab for Kyrgyzstan EQ (M=6.7) on 05-Oct-2008 in comparison with the monthly mean. P character denotes the precursor day.



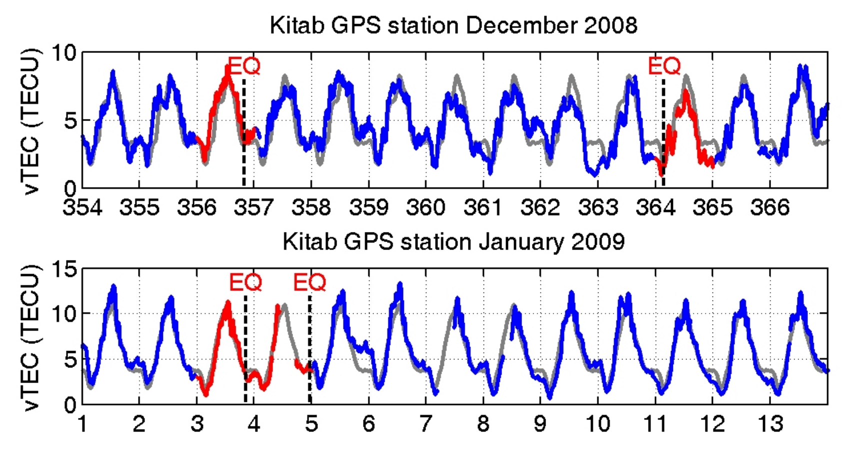
Vertical TEC variations above Tashkent for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.



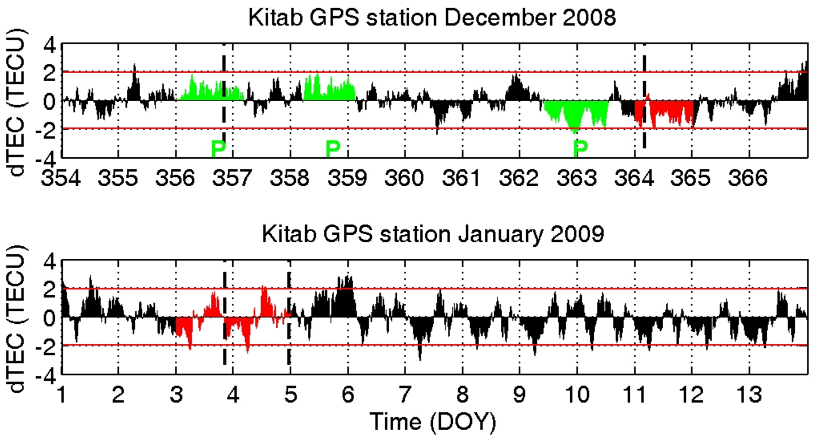
Differential TEC variations above Tashkent for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.



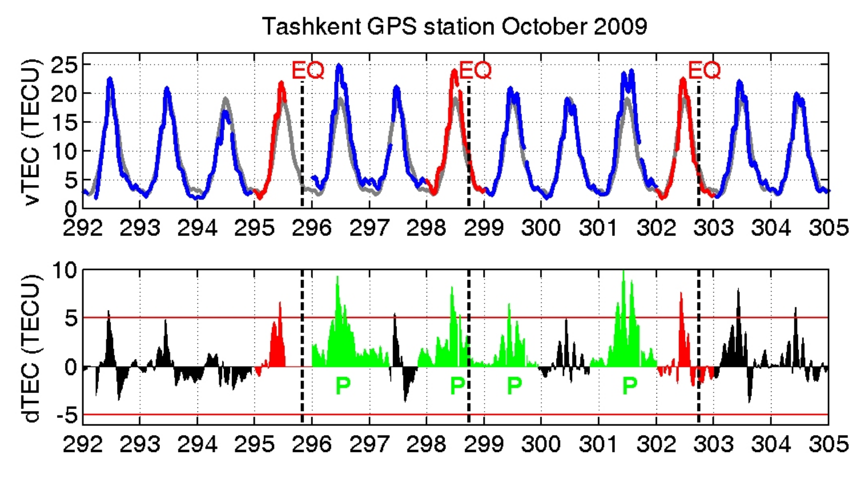
Vertical TEC variations above Kitab for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.



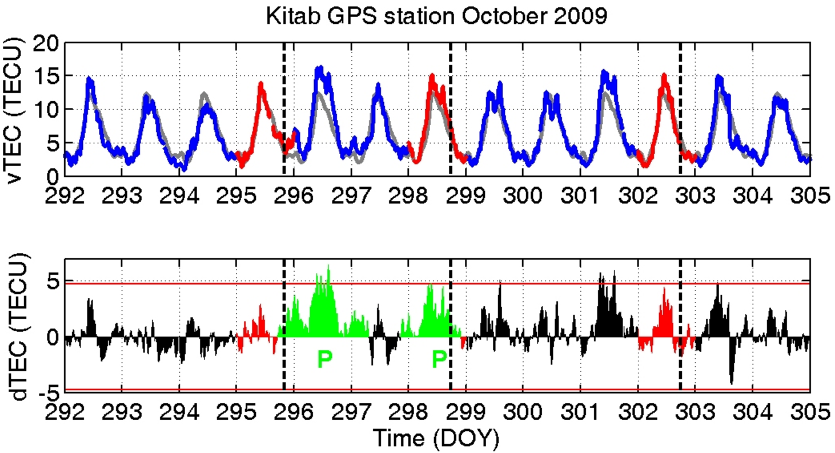
Differential TEC variations above Kitab for EQs on 21, 29-Dec-2008 and 03, 04-Jan-2009 in comparison with the monthly mean.



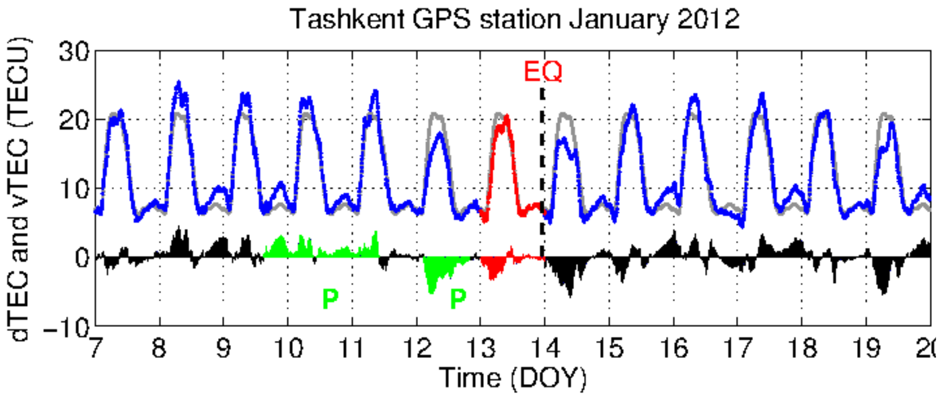
Vertical and Differential TEC variations above Tashkent for EQs on 22, 25, 29-Oct-2009 in comparison with the monthly mean.



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.



EQ	Y	M	D	Lat	Lon	M	P_{kit3} (P_{tash})
1	2007	07	20	42.91N	82.38E	5.6	3, 5 (3)
2	2007	07	21	38.94N	70.49E	5.2	4, 6 (4)
3	2007	07	22	30.88N	78.24E	5.1	5, 7 (5)
4	2007	07	25	36.08N	70.36E	5.0	2 (×)
5	2008	06	24	40.03N	70.84E	5.0	3, 5 (3, 5, 6)
6	2008	10	05	39.53N	73.82E	6.7	2 (1, 2)
7	2008	12	29	36.39N	71.07E	5.8	1, 6, 7 (1, 6)
8	2009	01	03	36.42N	70.74E	6.6	5, 6 (5, 6)
9	2009	01	04	36.44N	70.88E	5.7	6, 7 (6, 7)
10	2009	10	25	34.85N	80.38E	5.0	2 (2)
11	2009	10	25	29.57N	63.88E	5.6	2 (2)
12	2009	10	29	36.39N	70.72E	6.2	4, 6 (1, 3, 4, 6)
13	2009	10	30	34.18N	70.02E	5.1	5, 7 (2, 4, 5, 7)

Content

AWESOME

A tmospheric

W eather

E lectromagnetic

S ystem for

O bservation

M odeling and

E ducation

UN

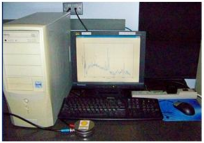
UN

UN	AWESOME	Umran Inan	**Prof. Hans J. Haubold** *UN Office for Outer Space Affairs Vienna International Centre*
	SUPERSID STANFORD SOLAR CENTER	Deborah Scherrer	

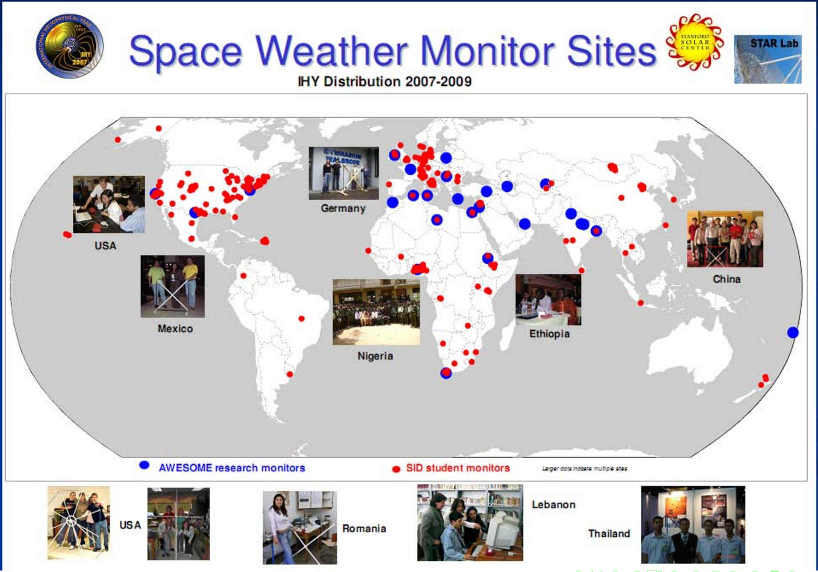
THE AWESOME RECEIVER

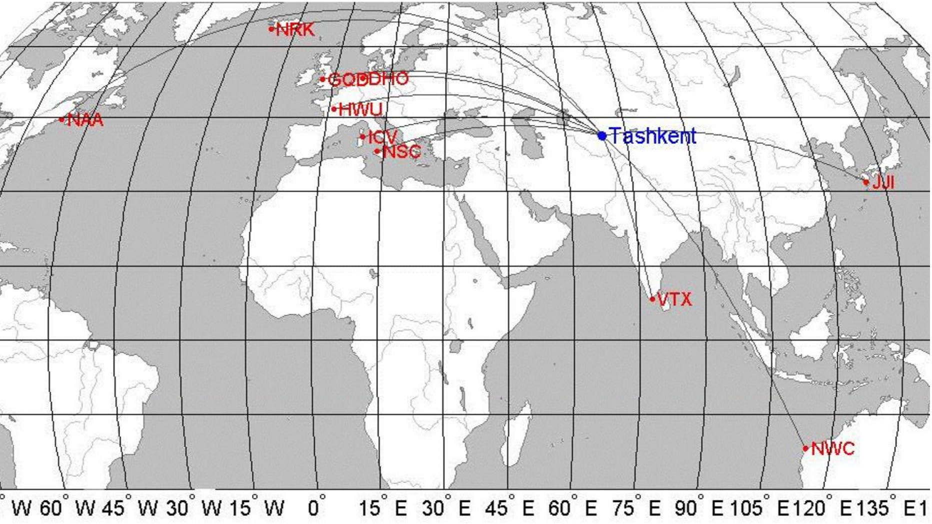
STANFORD SOLAR CENTER

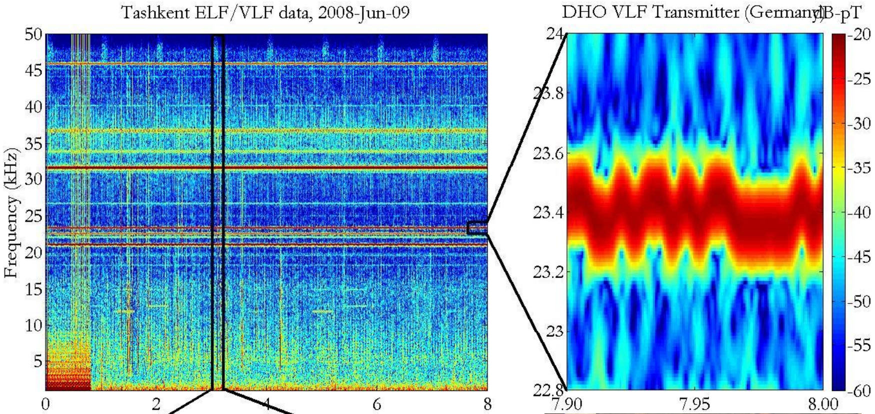
SuperSID

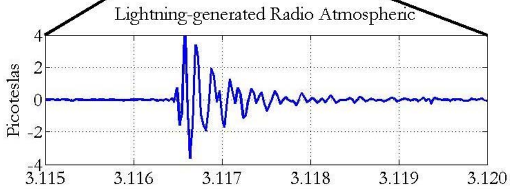


World SID & AWESOME Sites

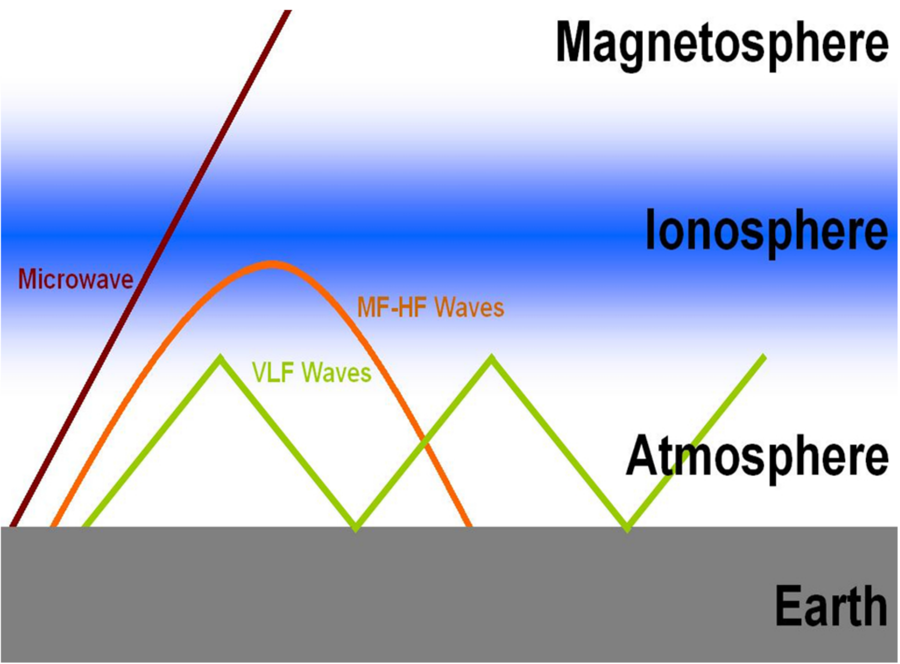



NRK
GQDDHO
HWU
NAA
ICV
NSC
Tashkent
JJI
VTX
NWC
W 60° W 45° W 30° W 15° W 0° 15° E 30° E 45° E 60° E 75° E 90° E 105° E 120° E 135° E 1


Tashkent ELF/VLF data, 2008-Jun-09
Frequency (kHz)
Seconds after 23:00:00 UT
DHO VLF Transmitter (Germany)
dB-pT


Lightning-generated Radio Atmospheric
Picoteslas

Content


Magnetosphere
Ionosphere
Microwave
MF-HF Waves
VLF Waves
Atmosphere
Earth

VLF signal propagation

Physics

- 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.

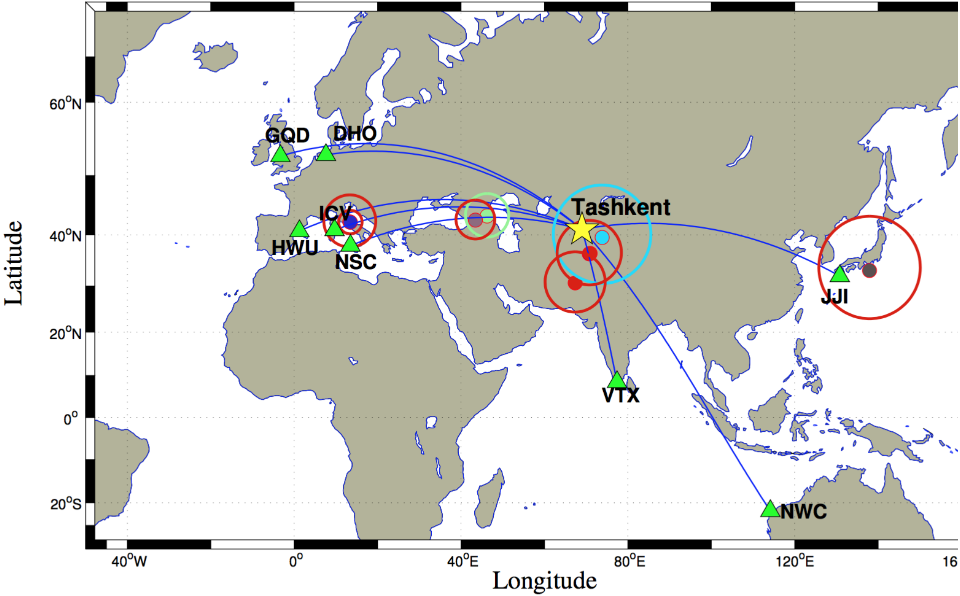

GQD
DHO
ICV
HWU
NSC
Tashkent
JJI
VTX
NWC
60°N
40°N
20°N
0°
20°S
40°W
0°
40°E
80°E
120°E
Latitude
Longitude

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

LAT	LON	FREQ	SIGN	LOCATION
8.47	77.40	18.20kHz	VTX	Katabomman, India
40.70	1.25	18.30kHz	HWU	Rosnay, France
-21.80	114.20	19.80kHz	NWC	North West Cape, Australia (USA)
40.88	9.68	20.27kHz	ICV	Isola di Tavolara, Italy (NATO)
25.03	111.67	20.60kHz	3SA	Changde, China
52.40	-1.20	22.10kHz	GQD	Anthorn, Great Britain (NATO)
32.04	130.81	22.20kHz	JJI	Ebino, Japan
53.10	7.60	23.40kHz	DHO	Rhauderfehn, Germany (DHO)
44.65	-67.30	24.00kHz	NAA	Cutler, Maine, USA
38.00	13.50	45.90kHz	NSC	Sicily, Italy (USA)

The parameters of M>5.0 earthquakes used in this study

EQ	YY	MM	DD	Lat.	Lon.	M	Place
1	2008	10	05	39.53N	73.82E	6.7	KYRGYZSTAN
2	2009	08	09	33.16N	137.94E	7.1	JAPAN
3	2009	01	03	36.41N	70.74E	6.6	AFGHANISTAN
4	2009	10	22	36.51N	70.95E	6.2	AFGHANISTAN
5	2009	04	06	42.33N	13.33E	6.3	ITALY
6	2009	04	07	42.27N	13.46E	5.5	ITALY
7	2009	10	28	30.63N	67.35E	6.4	PAKISTAN
8	2009	09	07	42.66N	43.44E	6.0	GEORGIA

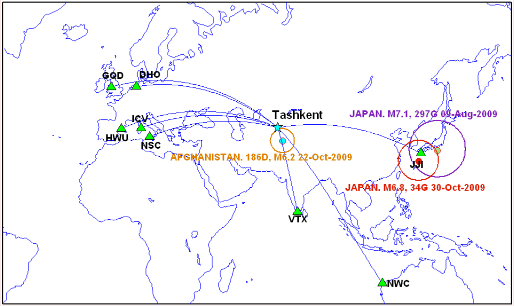
S. R. Tojiev, B. J. Ahmedov, H. E. Eshkuvatov, Ionospheric precursors of earthquakes recorded by VLF receiver at Tashkent IHY station, **Adv. Space Res.**, 2014, V.54, Issue 4, p. 628-643.

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 :

$$\rho = 10^{0.43M}\,\mathrm{km}$$

Where ρ 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, 15days 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

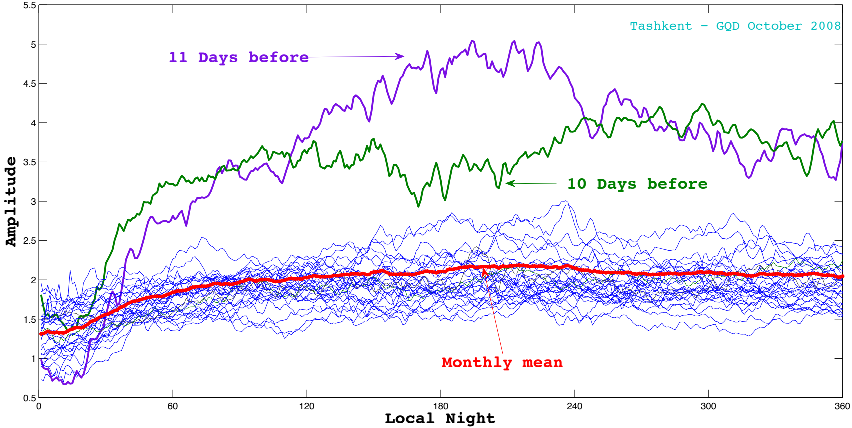
We estimate the following two physical quantities of amplitude: **trend** (as the average of nighttime amplitude) and **nighttime fluctuation** (NF)

$$trend = \frac{\int_{Ns}^{Ne} dA(t)\ dt}{Ne - Ns}, \quad NF = \int_{Ns}^{Ne} (dA(t))^2\ dt$$

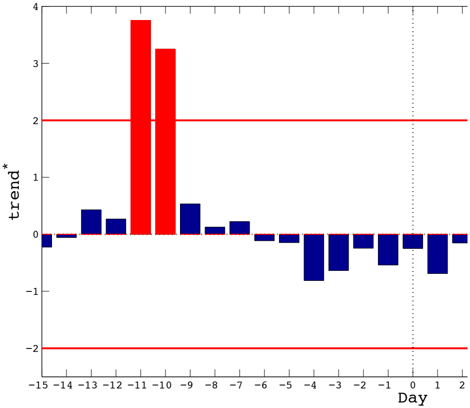
where Ns and Ne are the times of starting and ending the nighttime in our analysis.

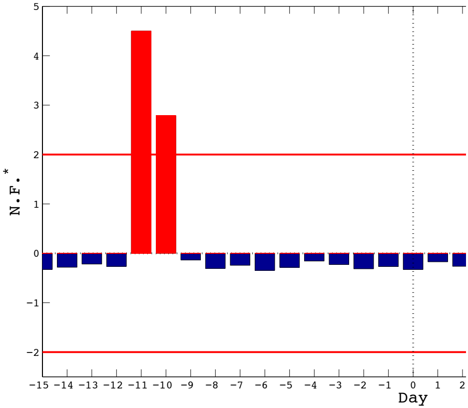
We have proposed the use of so-called standardization. We deal with two physical quantities of amplitude, trend, and NF and we estimate the following **normalized trend** (trend*) and **normalized NF** (NF*). When we take an EQ with a particular date, we estimate the trend on this day and we then calculate the average <trend> over $\pm$15 days around this date. Then, the normalized trend (trend*) is defined as $(trend - < trend >)/\sigma_T$ (σ_T, standard deviation over $\pm$15 days around the current date). The same principle is applied to NF to obtain the normalized NF (NF*).

Amplitude variation of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008

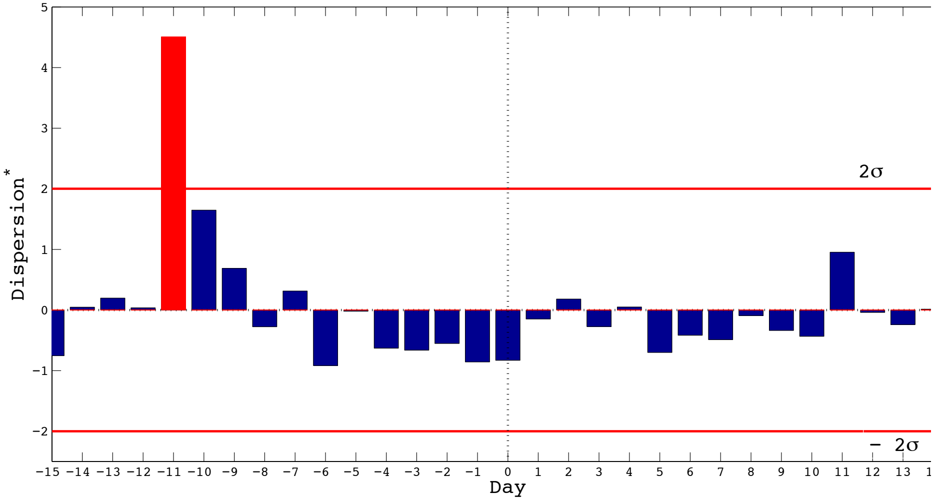


Trend and NF of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008

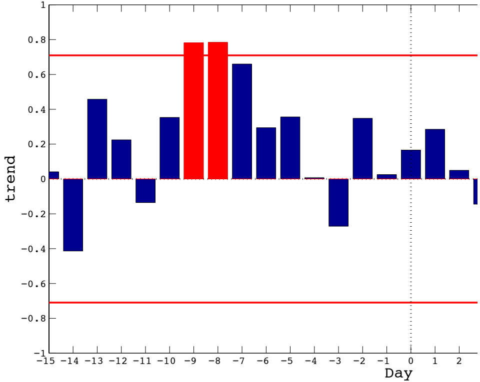


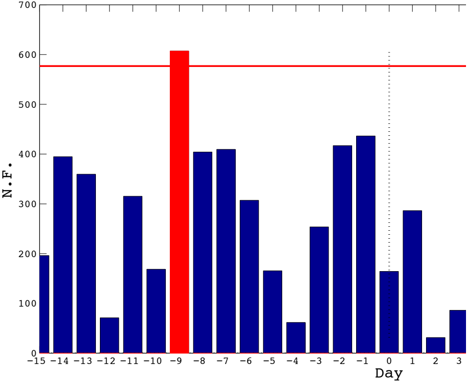


Dispersion of GQD signal for Kyrgyzstan M=6.7 EQ on 5 October, 2008

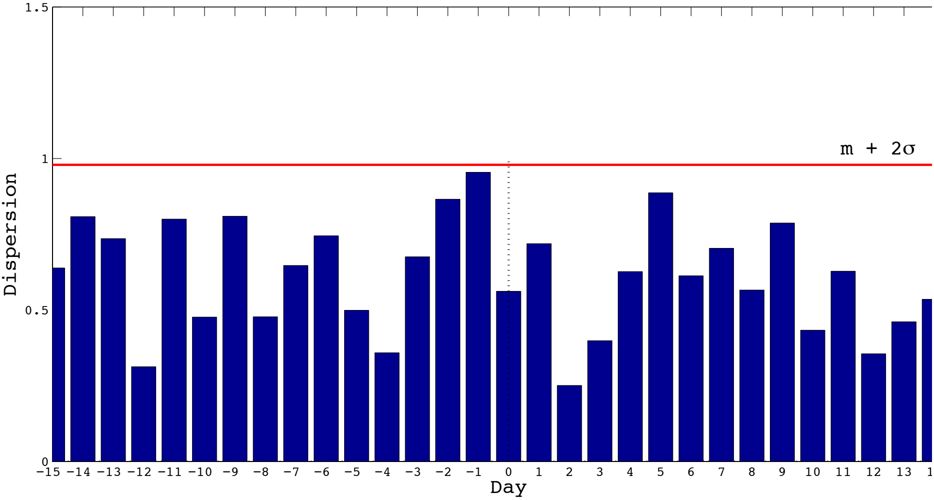


Trend and NF of NSC signal for Italy M=5.5 EQ on 7 April, 2009

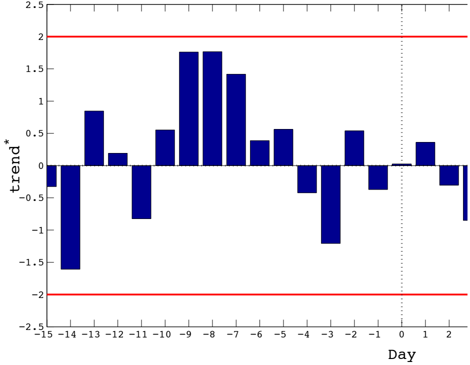


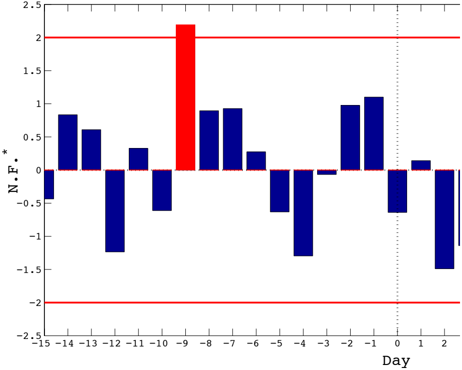


Dispersion of NSC signal for Italy M=5.5 EQ on 7 April, 2009

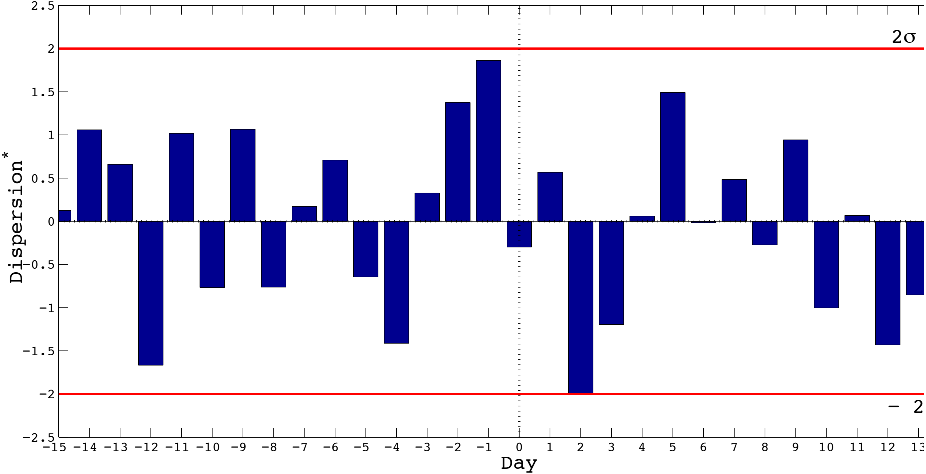


Normalized Trend and NF of NSC signal for Italy M=5.5 EQ on 7 April, 2009

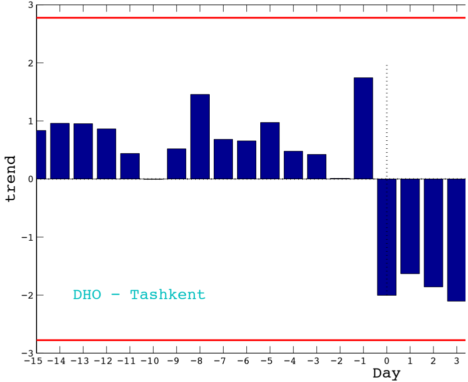


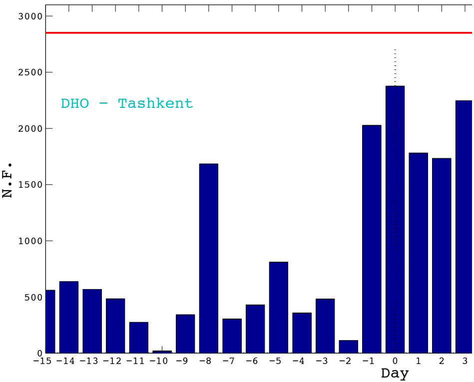


Normalized Dispersion of NSC signal for Italy M=5.5 EQ on 7 April, 2009

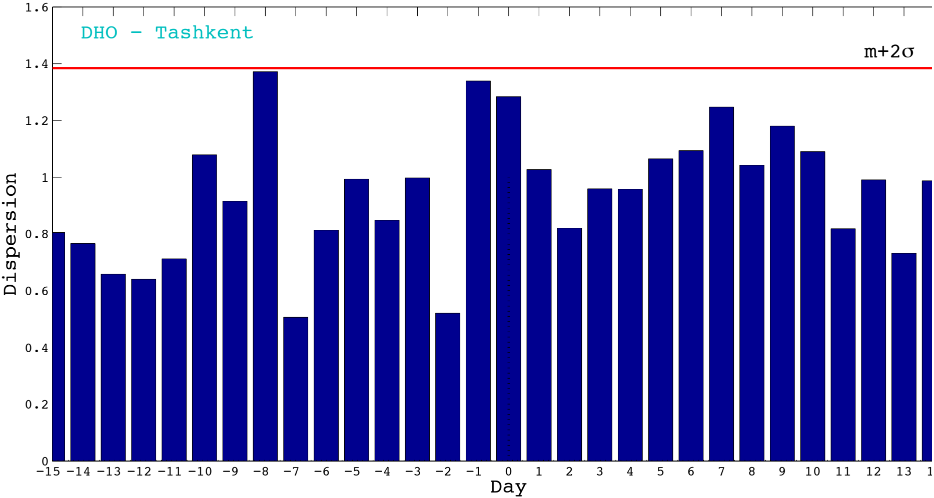


Trend and NF of DHO signal for Italy M=5.5 EQ on 7 April, 2009

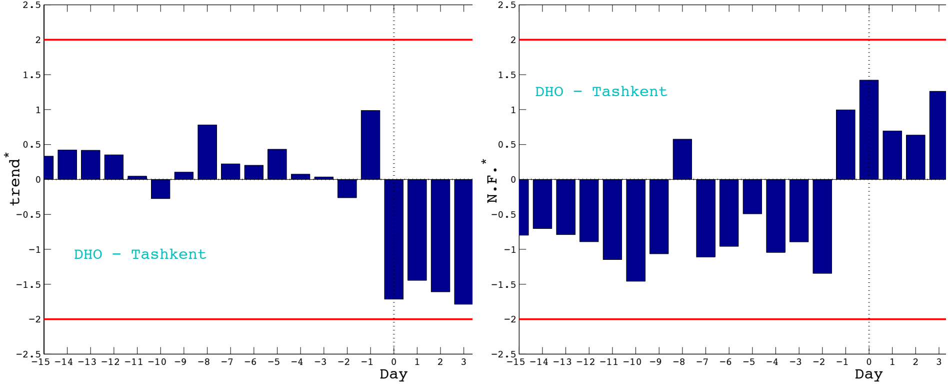




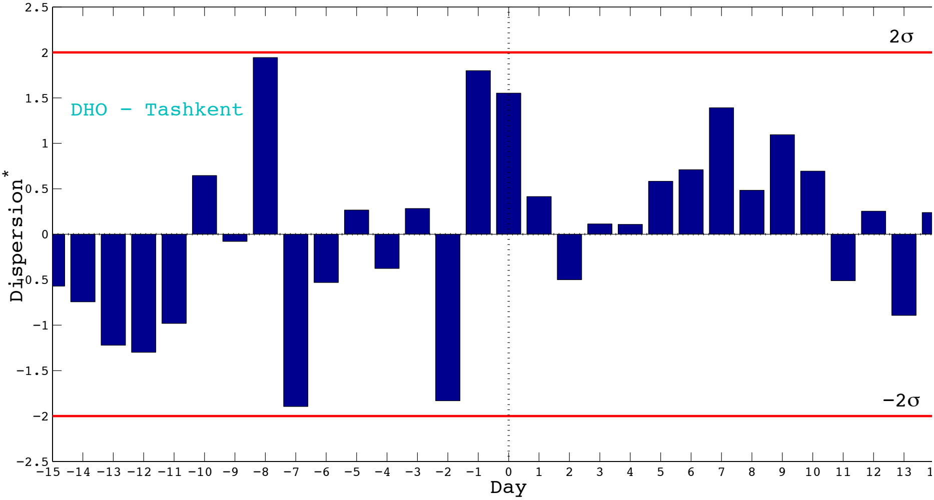
Dispersion of DHO signal for Italy M=5.5 EQ on 7 April, 2009



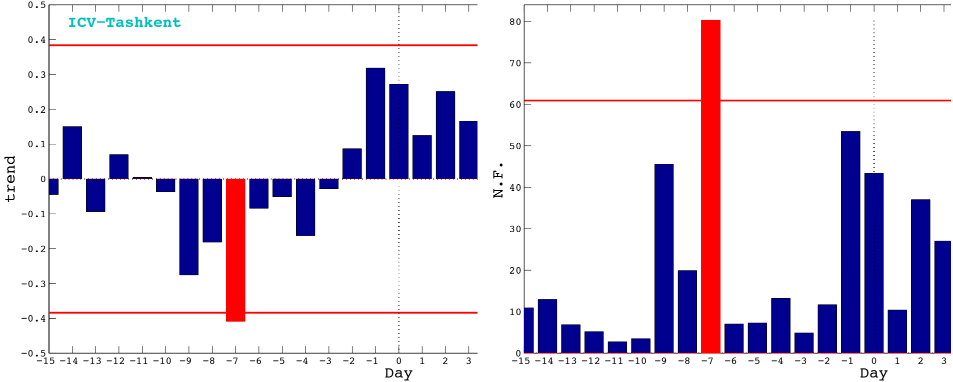
Normalized trend and NF of DHO signal for Italy M=5.5 EQ on 7 April, 2009



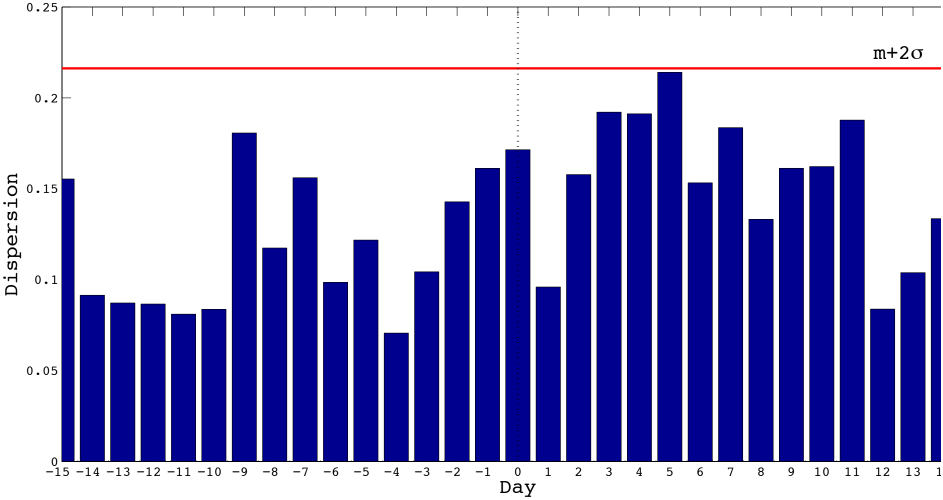
Normalized dispersion of DHO signal for Italy M=5.5 EQ on 7 April, 2009



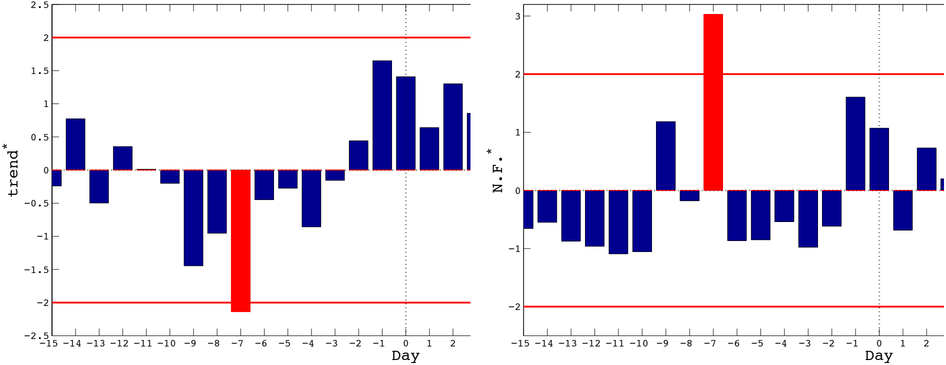
Trend and NF of ICV signal for Georgia M=6.0 EQ on 7 September, 2009



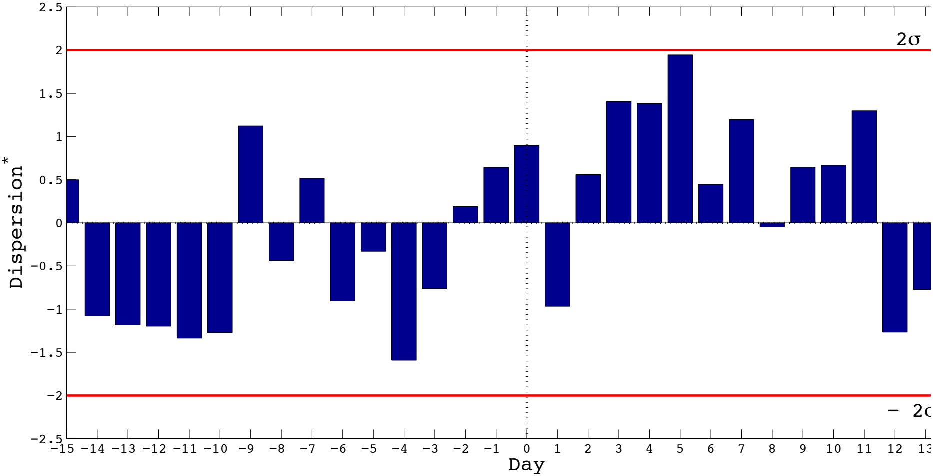
Dispersion of ICV signal for Georgia M=6.0 EQ on 7 September, 2009



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



Normalized dispersion of ICV signal for Georgia M=6.0 EQ on 7 September, 2009

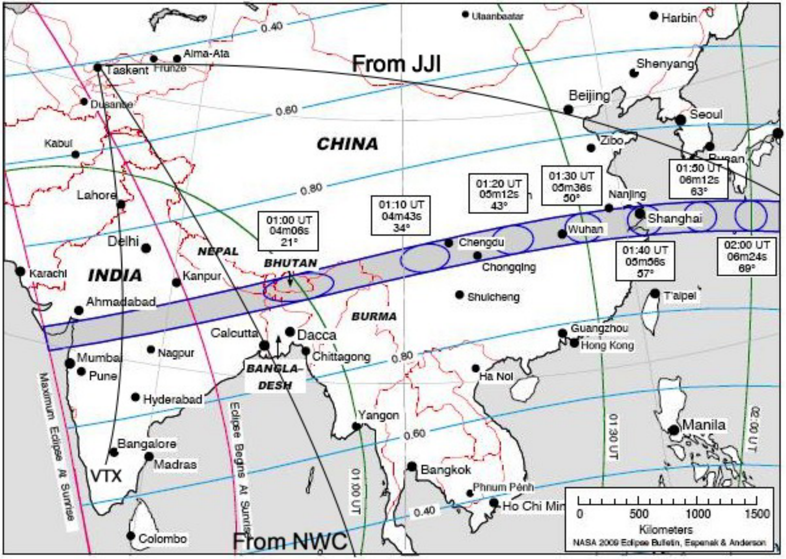


The ionospheric precursors of the selected EQs

EQ	**M**	P_{trend}	P_{NF}	P_D	P_{trend*}	P_{NF*}
1	M=6.7	$-10^{\uparrow}; -11^{\uparrow}$	$-11^{\uparrow}$	$-10^{\uparrow}; -11^{\uparrow}$	$-10^{\uparrow}; -11^{\uparrow}$	$-10^{\uparrow}; -11^{\uparrow}$
2	M=7.1	$-2^{\uparrow}$	$-11^{\uparrow}$	$\times$	$-2^{\uparrow}$	$-11^{\uparrow}$
3	M=6.6	$-5^{\uparrow}$	$-5^{\uparrow}$	$\times$	$-5^{\uparrow}$	$-5^{\uparrow}$
4	M=6.2	$0^{\uparrow}; -4_{\downarrow}$	$0^{\uparrow}; -4_{\downarrow}$	$-6^{\uparrow}$	$0^{\uparrow}; -4_{\downarrow}$	$0^{\uparrow}; -4^{\uparrow}$
5	M=6.3	$0^{\uparrow}$	$0^{\uparrow}$	$0^{\uparrow}$	$0^{\uparrow}$	$0^{\uparrow}$
6	M=5.5	$-8^{\uparrow}; -9^{\uparrow}$	$-9^{\uparrow}$	$\times$	$\times$	$-9^{\uparrow}$
7	M=5.4	$-10^{\uparrow}; -13^{\uparrow}$	$-10^{\uparrow}$	$-10^{\uparrow}$	$-10^{\uparrow}; -13^{\uparrow}$	$-10^{\uparrow}$
8	M=6.0	$-7_{\downarrow}$	$-7^{\uparrow}$	$\times$	$-7_{\downarrow}$	$-7^{\uparrow}$

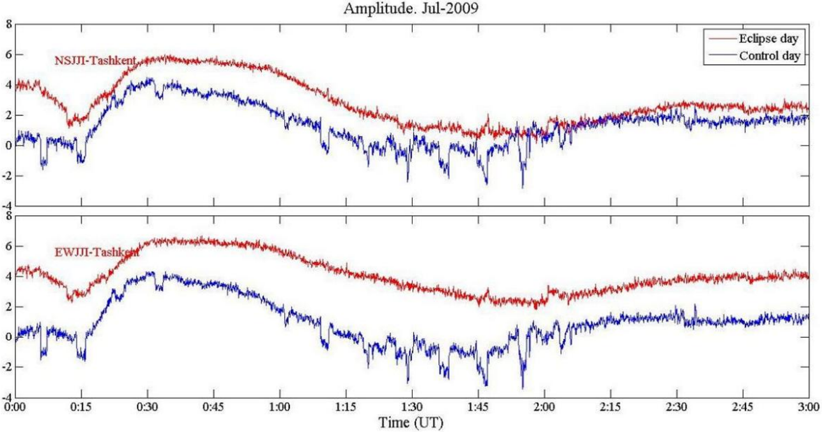
Solar Eclipse 2009

PATH OF THE ECLIPSE THROUGH ASIA
Total Solar Eclipse of 2009 July 22



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



Content

- 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.
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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.
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Thank You