Space-borne observations of atmospheric pre-earthquake signals in seismically active areas. Case study for Greece 2008-2009

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Abstract: We are conducting theoretical studies and practical validation of atmosphere/ionosphere phenomena preceding major earthquakes. Our approach is based on monitoring of two physical parameters from space: outgoing long-wavelength radiation (OLR) on the top of the atmosphere and electron and electron density variations in the ionosphere *via* GPS Total Electron Content (GPS/TEC). We retrospectively analyzed the temporal and spatial variations of OLR an GPS/TEC parameters characterizing the state of the atmosphere and ionosphere several days before four major earthquakes (M>6) in Greece for 2008-2009: M6.9 of 02.12.08, M6.2 02.20.08; M6.4 of 06.08.08 and M6.4 of 07.01.09.We found anomalous behavior before all of these events (over land and sea) over regions of maximum stress. We expect that our analysis reveal the underlying physics of pre-earthquake signals associated with some of the largest earthquakes in Greece.

1. Introduction

The evidence for more than thirty years of data provides a large number of examples of transient signals preceding these earthquakes. Some of them have shown (Tronin et al., 2002; Liu et al., 2004; Pulintes and Boyarchuk, 2004; Tramutoli et al., 2004) that studying atmospheric variability could also reveal active tectonic processes in the Earth's crust. Despite the many singular reports showing an enhancement in the atmospheric transient fields around the time of major earthquakes (Ouzounov et al., 2007; Parrot, 2010, Pergola et al, 2010), there is still ~~of~~ a lack of coordinated multisensory observations shown in ~~(~~Ouzounov et al., (2011a,b), which are required for an understanding of the complex physical processes associated with major earthquakes.
This study explores the relationship between atmospheric processes and the occurrence of four major earthquakes (M>6) in Greece for 2008-2009: M6.9 of 02.12.08, M6.2 02.20.08; M6.4 of 06.08.08 and M6.4 of 07.01.09 by analyzing data from ground and satellite observations (Table 1, Figure 1).

Table 1. List of major earthquake events in Greece (2008-2009) with depths less then 50km, Source; University of Athens, Seismological Laboratory (http://www.geophysics.geol.uoa.gr/stations/maps

	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude (Mw)
	14/02/2008, 10:09:22.75	36.5490°N	21.7723°E	25	6.7
	14/02/2008, 12:08:54.79	36.3496°N	21.9283°E	10	6.1
	20/02/2008, 18:27:05.46	36.2106°N	21.7119°E	14	6.0
	08/06/2008, 12:25:28.18	37.9727°N	21.5157°E	20	6.4
	01/07/2009, 09:30:09.00	33.9200°N	25.4700°E	25	6.2

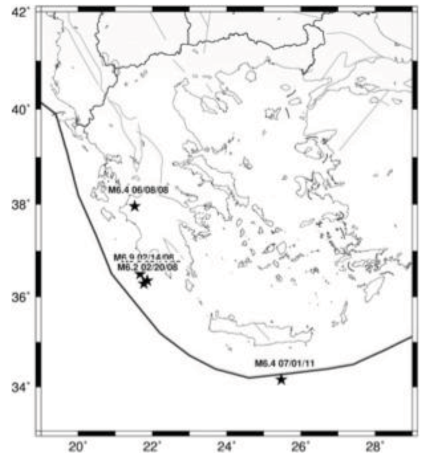

Figure 1. Reference of map of Greece and location of 2008-2009 earthquakes from Table.1. Stars indicate epicenters; tectonic plate boundaries are in bold black, faults shown by gray lines

2. Data Processing and analysis

We have analyzed two different physical parameters characterizing the state of the atmosphere during the time of four earthquakes in Greece: 1. Earth outgoing long wave earth radiation (OLR) measured at the top of the atmosphere; and 2. Ionospheric variability of GPS, Total Electron Content (TEC). This approach could minimize the biased estimate of using only a singular parameter and provide information about the scale and physics of the changes in the atmospheric processes related to tectonic activity.

2.1 Earth radiation observation

OLR is one of the main parameters used to characterize the earth's radiation environment at the top of the atmosphere (300mb) and includes emissions from the ground, atmosphere and clouds. OLR is not directly measured, but is calculated from observations using a separate algorithm. The National Oceanic an Atmospheric Administration (NOAA) Climate Prediction Center web site (http://www.cdc.noaa.gov/) provided these daily OLR data. The OLR algorithm for analyzing the Advanced Very High Resolution Radiometer (AVHRR) data is from Cruber and Kruger (1984) and integrates (Infrared) IR data between 10 and 13 microns. These data are mainly sensitive to near surface and/or cloud temperatures. A daily mean (by 2.5 ^{o} x 2.5 ^{o}) was used to study the main OLR variability in the earthquake area (Ouzounov et al., 2007, Ouzounov et al, 2011a). This has been proposed to be related to tectonic stresses and thermodynamic processes in the atmosphere and an increase in emitted radiation. The abnormal indicator, named – E-index, is defined as an change detection in OLR field (Ouzounov et al, 2007), indicating the presence of an anomalous thermal trend, similar to the RETIRA index (Tramutoli et al., 1999). The E_index represents the statically defined maximum change in OLR values for specific spatial locations and predefined times:

$$E(t)=(S^*(x_{i,j},y_{i,j},t)\quad \bar{S}^*(x_{i,j},y_{i,j},t))/\quad_{i.j} \qquad (1)$$

Where: t=1, K – time in days, $S^*(x_{i,j},y_{i,j},t)$ the current OLR value and $\bar{S}^*(x_{i,j},y_{i,j},t)$ the computed mean field, defined by multiple years of observations over the same location, local time and normalized by the standard deviation $_{i.j}$ (Ouzounov et al, 2007, 2011a).

2.2. GPS/TEC analysis

Analysis was made of the Athens GPS receiver, NOA1 (National Observatory of Athens), which for all earthquakes was inside the earthquake preparation area determined, by Dobrovolsky et al. (1979) or Bowman et al. (1998). The vertical TEC was calculated with a time resolution of 2 minutes. In the second step the percentage deviation from the running mean was calculated:

$$TEC = 100 \cdot (TEC \quad TEC_{av}) / TEC_{av} \qquad (2)$$

as a background level TEC_{av} the running mean was taken for 15 preceding days for every time moment of UT. At the third stage the 3-D pattern of ΔTEC was constructed where the X-axis is in days (7 days before earthquake and 4 after), Y-axis – UT, and Z-axis (scale bar) - ΔTEC. We used the technique proposed first in Pulinets et al., (2002)

In every figure we demonstrate the time series of the vertical *TEC*, standard deviation σTEC, Percent deviation ΔTEC and global equatorial geomagnetic *Dst* index. At the left panel the OLR anomalies are demonstrated, and at the bottom panel – the 3-D pattern of ΔTEC.

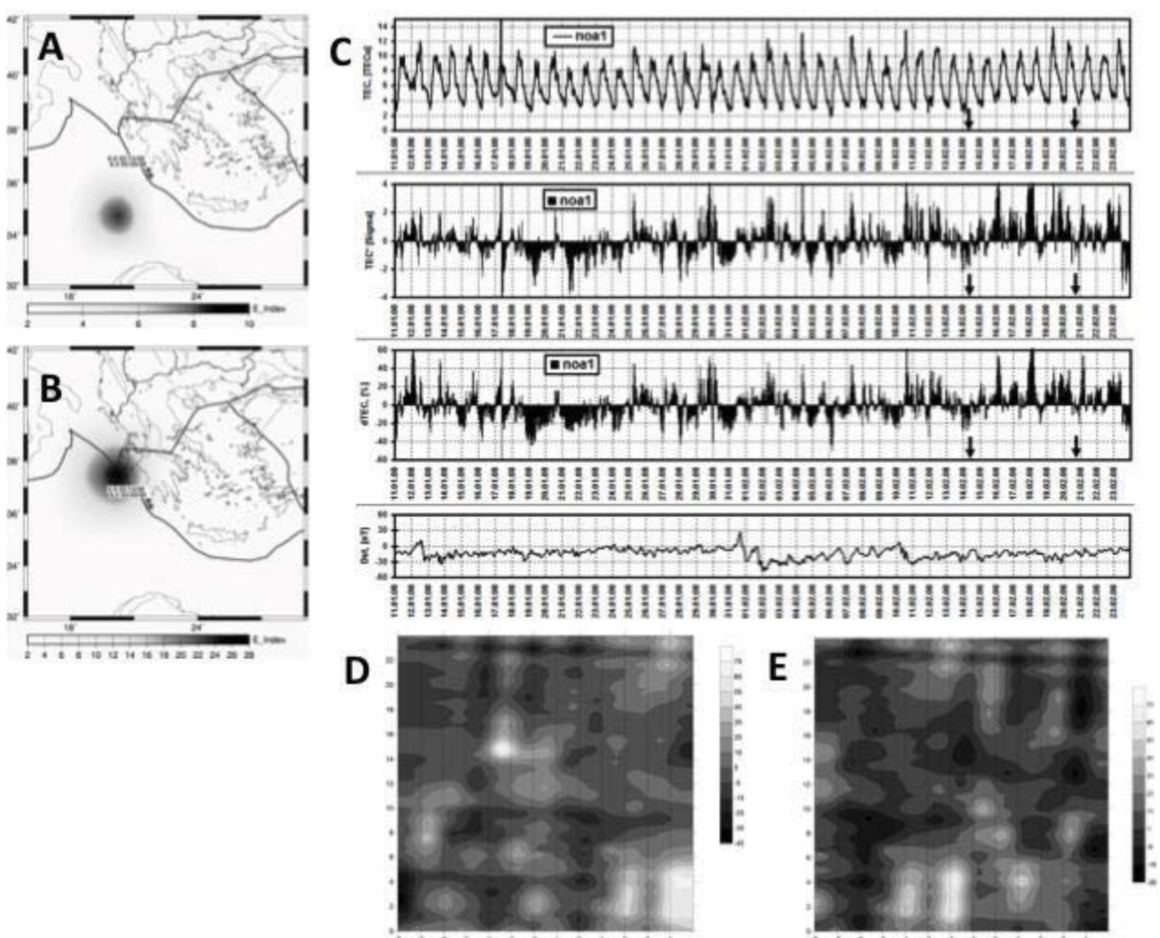

Figure 2. OLR and GPS/TEC analysis for M6.7 of 02.14.08 and M6.0 of 02.20.08 A. OLR anomaly from 02.17.08(07.30LT). B OLR anomaly from 02.20.02 (07.30LT). C.GPS/TEC time series (01.01.08-02.23.08);D. TEC map for M6.7 of 02.14.08; E. Map of 3-D pattern of ΔTEC for M6.0 of 02.20.08

3. Summary of Results and Conclusions

Our OLR study includes analysis of NOAA AVHRR data between 2003 and 2009. The OLR survey containing the pixels closets to the epicentral area show that the initial formation of a transient atmospheric anomaly was detected before the following earthquakes: on Feb 7. 2008 (-7 days); M6.9 of 02.12.08; (Figure 2.A); on Feb 20, 2008 (few hours in advance); M6.2 02.20.08 (Figure 2.B); on June 8th, 2008 (few hour in advance); M6.4 of 06.08.08 (Figure 3.A); and on Jun 11, 2009 (19 days in advance) for M6.4 of 07.01.09 (Figure 4.A).

The OLR reference field was computed for each preceding month and 15 day after the event using all available data (2003-2009) and with a confidence level (+2/-2 sigma). All OLR anomalies (Figure 2.AB; Figure 3.A and Figure 4.A) show a strong transient OLR anomalous field (with a confident level greater than +2 sigma) near the epicentral area, over the major faults. The enhancement of radiative emission could be explained by the anomalous flux of the latent heat over the area of increased tectonic activity observed within few days before the earthquake (Ouzounov et al., 2007; Pulinets and Ouzounov, 2011a).

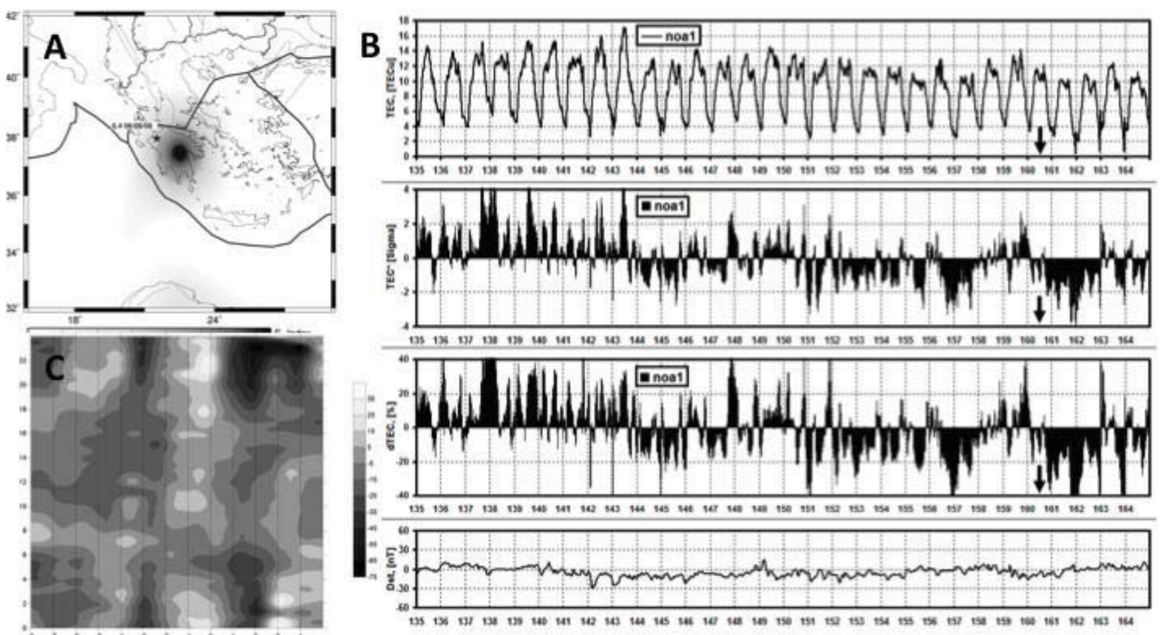

Figure 3. OLR and GPS/TEC analysis for M6.4 of 08.06.08 A. OLR anomaly from 06.08.08(07.30LT). B.GPS/TEC time series (05.15.08-06.14.08);C. Map of 3-D pattern of *ΔTEC* for M6.4 of 06.08.08;

For the GPS/TEC analysis the most complex case was the first one (Table 1, Figure 2) when two consecutive shocks M6.9 and M6.2 were observed with the time interval 6 days (14 and 20 February 2008). That is why at the first anomalous pattern related to the 14 Feb earthquake we are able to observe the positive deviations (pre-sunrise 0-4 AM), which are the precursors of the second event on 20 February (Figure 2. C, D, E)

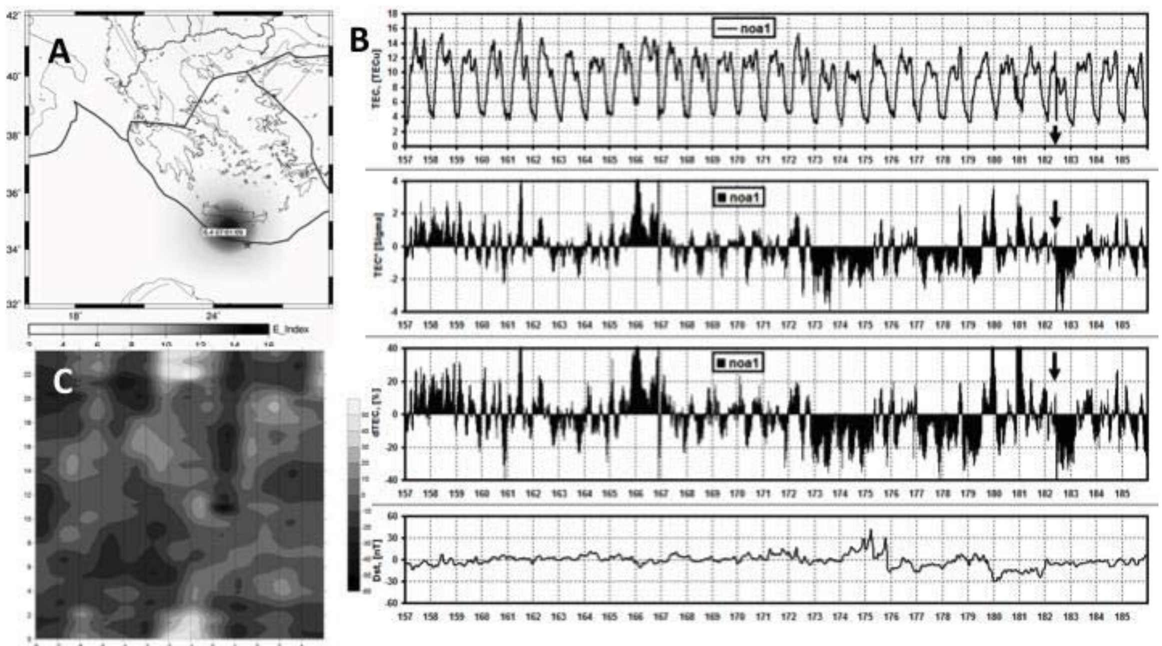

Figure 4. OLR and GPS/TEC analysis for M6.2 of 07.01.09 A. OLR anomaly from 06.11.09(07.30LT). B.GPS/TEC time series (06.06.09-07.07.09);C. Map of 3-D pattern of *ΔTEC* for M6.2 of 07.01.09;

The same figures were created for two other cases of June 8, 2008 (Figure 3 C, D) and July 1, 2009 (Figure 4 C, D). Besides the four major earthquake described in the present paper we analyzed five M>6 earthquakes in Greece with the same technique and created an averaged pattern from all 9 cases which we name the "precursor mask". For individual cases (like the four earthquakes shown in Table 1) we are able to observe sometimes only the part of this time interval of a different duration, shown on (Figure 2, D, E; Figure 3 C; Figure 4, C). The averaged pattern demonstrates that the most stable part of the precursory phenomena is the positive TEC deviations during the afternoon hours (from 4 PM till midnight) and a day before the earthquake and again positive deviations during pre-sunrise hours (0-4 AM) at the day of the quake (totally 12 hours).

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