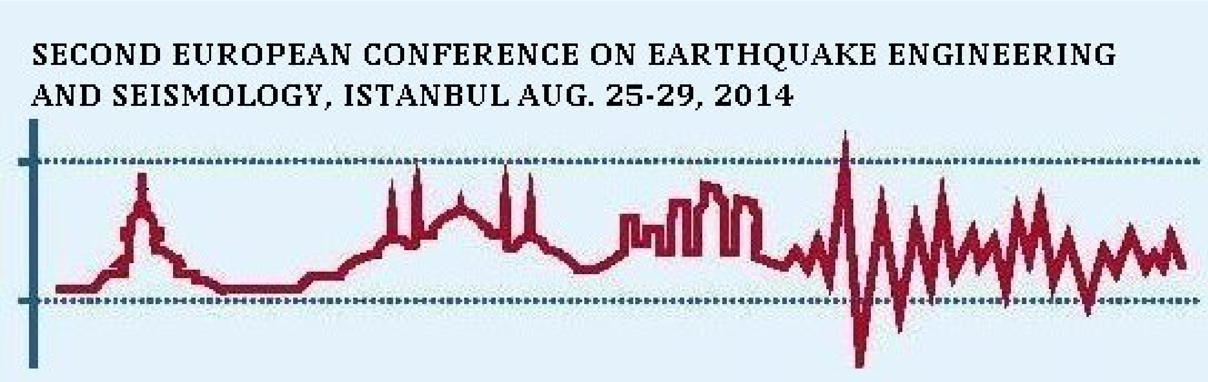

A MULTIPARAMETRIC APPROACH FOR SEISMIC AREA MONITORING: THE CASE OF ELAZIG EARTHQUAKE (MW 6,1; 8 MARCH 2010)

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ABSTRACT

In the framework of the EC-FP7 project named PRE-EARTHQUAKES (Processing Russian and European EARTH observations for earthQUAKE precursors Studies, http://www.pre-earthquakes.org/), the real time integration of independent observations related to different parameters, together with the refinement of data analysis methods were pursued in order to improve our present knowledge of preparatory phases of earthquakes and of their possible precursors. To accomplish this purposes, observations collected from 20 different satellite systems and more than 100 ground stations, were used to study the anomalous variations of surface and atmospheric parameters (up to the ionosphere) that have been for a long time proposed as possible precursors (e.g. thermal anomalies, total electron content, radon concentration, etc.) of strong earthquakes.

During the first (learning) phase of the project the study was devoted to the integration of independent observations related to seismic events occurred in the past on 3 selected testing areas (Italy, Turkey and Sakhalin peninsula). Due to the availability of a major number of independent observations, for Turkey area, the Elâzığ seismic event (Mw 6,1; 8 March 2010) was selected as

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Turkish test-case. In this paper, for this test case, we present preliminary results of a space-time correlation analysis which demonstrate the added value of a multi-parametric approach for a time-dependent seismic hazard assessment (t-DASH).

INTRODUCTION

The appearance of anomalous space-time patterns of geophysical parameters measured from days to week before earthquakes occurrence have been reported by several authors in the past years. However, even in presence of physical models able to justify the observations (Tronin, 1996; Revil and Glover, 1997; Pulinets, 2009; Tramutoli, 2013), up to now no one single measurable parameter, no one observational methodology has demonstrated to be sufficiently reliable and effective for the implementation of an operational earthquake prediction system (see for example Geller, 1997). The extension of our present observational capabilities and the refinement of data analysis methods could improve our present knowledge of preparatory phases of earthquakes and of their possible precursors. However only from the integration of different observations (parameters) we expect to obtain false alarm rates and precision (in the space-time domain) of the earthquakes predictions useful for a time-Dependent Assessment of Seismic Hazard (t-DASH).
This was also the main goal of PRE-EARTHQUAKES FP7 project which, to this aim, committed together, different expertise and observational capabilities. In the learning phase, different parameters (e.g., thermal anomalies, total electron content, radon concentration, etc.), measured from ground and satellite systems and analyzed by using different data analysis approaches, have been studied for selected geographic areas and specific seismic events in the past.

As far as the Turkey testing area is concerned, due to the availability of a major number of independent observations, the Elâzığ- Kovancilar earthquake (March 8, 2010, Mw = 6.1) was selected as test case and, in the following, the results of the integration of satellite and ground based observations produced (Table.1) by PRE-EARTHQUAKES partners, at that time will be discussed.

Table 1: Collection of observations and used data analysis methods for Elâzığ EQ (Turkey) test case.

Parameters	Observations Technologies.	Methodologies	Products	Partner
Thermal InfraRed (TIR) Earth's emission	SEVIRI/MSG	RST Technique (Tramutoli et al., 2005)	TIR anomaly maps	University of Basilicata (UNIBAS)
Land cover	CLC2006	Corine Land Cover 2006	Land cover map	
Electrons density	CHAMP	Radio Occultation technique (Jakowski et al., 2002, 2005)	Electrons density vertical profile	Deutsches Zentrum für Luft- und Raumfahrt E.V. (DLR)
	GRACE			
Plasma frequency	CHAMP		Plasma frequency vertical profile	
	GRACE			
TEC from ground based GPS	GPS station (IGS and EUREF network)	Algorithm of TEC maps creation; Algorithm of differential mapping. (Baran et al., 1997); Algorithm of wave-like disturbances calculations (Krankowski et al., 2005).	TEC maps	West Department of the russian academy of sciences Institute of terrestrial Magnetism, Ionosphere and Radio Wave propagation (WD IZMIRAN)
		Afraimovich test Afraimovich et al., 2008)	GPS TEC punctual time series	Fedorov Institute of Applied Geophysics (FIAG)
	Ankara-Turkey/ANKR	Algorithm for vertical TEC reconstructions, (Baran et al., 1997)		(WD IZMIRAN)
	Istanbul-Turkey/ISTA			
	Yerevan-Armenia/NSSP			
Radon concentration	Station n. 44 at Elâzığ-Helindir-Çitli	Time series data analysis (İnan et al., 2007)	Radon ground emission	TÜBİTAK Marmara Research Center (TUBITAK)
	Station n. 46 ElâzığSogukpinar			

Since July 2012 the PRIME (PRE-EARTHQUAKES Real-time Integration and Monitoring Experiment) started attempting to perform, on the base of independent observations collected and integrated in real-time through the PEG (PRE-EARTHQUAKES Geo-portal), a time-Dependent Assessment of Seismic Hazard (t-DASH) on selected geographic areas of Europe (Italy, Greece and Turkey) and Asia (Kamchatka, Sakhalin and Japan).

8 MARCH 2010 ELAZIĞ - KOVANCILAR (TURKEY) EARTHQUAKE: THE TEST CASE

The East Anatolian Fault (EAF) is one of the major seismic sources in Turkey, running approximately 550 km along the tectonic boundary between the Anatolian Plate and the northward-moving Arabian Plate (Taskin and Tugsal, 2011). With the South-Western end at Dead Sea Transform in Antakya, EAF meets the North Anatolian Fault (NAF) at Karliova Triple Junction at the north-eastern end.

On March 8, 2010 at 02:32 GMT, an earthquake of Mw = 6.1 (USGS) struck Kovancilar town of Elazığ province, Turkey, which settles on the Bingol-Palu-Hazar segment of EAF. The moderate earthquake with a hypocenter depth of approximately 12 km was recorded by several accelerographs of the national permanent strong motion network within the area. The region, being one of the most seismic prone zones of Turkey, is classified with the highest seismic hazard by the Turkish Earthquake Resistant Design Code (TERDC). Followed by the main event, an aftershock of ML = 5.6 hit the same region at 07:47 GMT; this time damaging the town of Palu and its villages Kokluce, Arindik, Cakirkas and Gokdere. Figure 1 illustrates the epicenter location for the mainshock and the main shallow tracks of tectonic lineaments in the Turkey region.

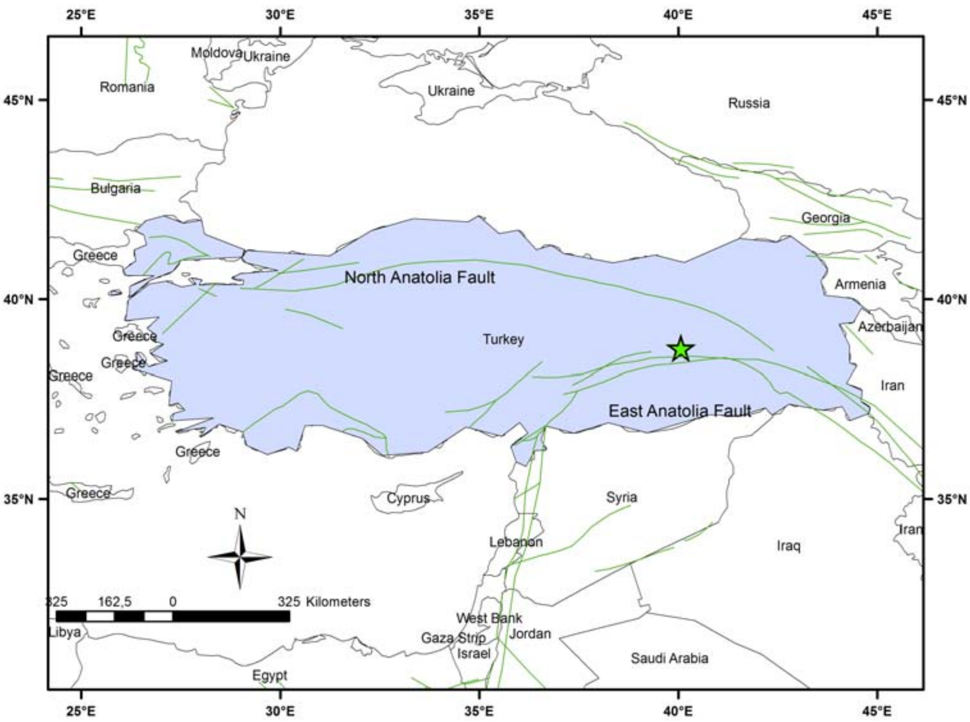

Figure 1: The green star on map shows the epicentral location of Elâzığ EQ occurred on 8 March 2010, Mw=6.1, The USGS reported the epicentre of the earthquake as 38.873°N-39.981°E with a focal depth of 12 km. The green line on map shows the main tectonic lineaments.

As reported by Tal et al., 2011 near the vicinity of the mainshock, 12 major aftershocks $M_W \geq 4$, were recorded during the observation period between 10 March and 30 May 2010. The mechanism solutions of these aftershocks are in good agreement with that of the mainshock; all indicating left-lateral strike-slip faulting in NE-SW orientation.

MULTIPARAMETRIC APPROACH FOR ELAZIG TEST CASE

In the learning phase of PRE-EARTHQUAKES project, different parameters, measured from ground and satellite systems and analyzed by using different data analysis approaches, have been studied for selected geographic areas and specific seismic events in the past.

In Table 1 is reported the collection of observations and data analysis methods produced by PRE-EARTHQUAKES partners for Elâzığ EQ test case.

Anomalous and persistent (in the spatial and temporal domain) fluctuations of Earth's emitted Thermal Infrared (TIR anomalies) radiation were identified by the University of Basilicata team (UNIBAS) by applying the RST (Robust satellite Techniques, Tramutoli et al., 2005) approach to an homogeneous data set of 6 years (from 2005 to 2010) of TIR satellite images collected at over Turkey the same time of the day (00:00 GMT) during the same period (February-March) of the year.

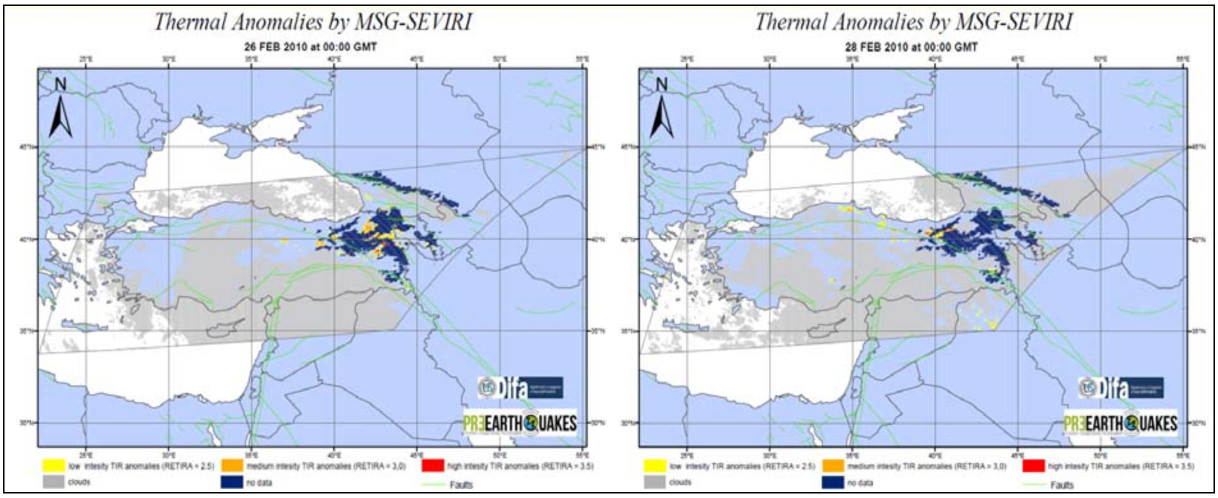

Figure 2: Space-time persistent TIR anomalies 11 and 9 days before Elâzığ earthquake occurrenceon March 8, 2010 (Mw 6.1). The green star on the maps show the epicenter position. Main Turkish fault systems are also reported by green lines.

More than 80 continuously operating radon stations were made available by the team of TUBITAK Marmara Research Center (hereafter simply TUBITAK). For the selected test case radon data exhibited some correlation with the preparation periods of the main seismic shocks in the area (Figure 3). The data shows that seismic shocks took place few days after the local maximum in radon data even if not for all minor events (e.g. not in the case of the minor event 3) nor in correspondence of the same absolute threshold. The Elâzığ earthquake corresponds to the maximum level of radon at Helindir station (which is the closer one to the Elâzıg earthquake epicentre, red square 4 in figure 3)

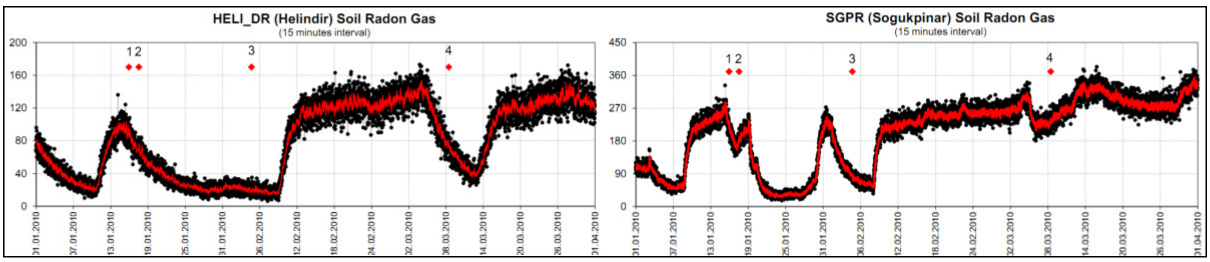

Figure 3: Radon data for stations Helindir and Sogukpinar for period January – March 2010. High level of radon have been measured 4-5 days before the main shock and after a period of marked increase of radon level started around February 10 (i.e. about 26 days before the earthquake).

In order to detect local ionospheric anomalies, the so called Afraimovich test (Afraimovich et al., 2008) was applied by FIAG to Total Electron Content (TEC) data (IONEX) to identify possible pre-seismic ionospheric anomalies. Such comparison for the case of Elâzığ earthquake showed (Figure 4) anomalies since 13 days (until 3 days) before the main shock. The test compares the normalized variations of the Global TEC index, the index of the solar radio flux, and the local TEC index in order to discriminate very local ionospheric anomalies (possibly related to earthquakes preparatory phenomena) from large scale variations due to solar activity variation.

Moreover, ionospheric anomalies have been obtained by WD-IZMIRAN partner by processing TEC data from ground GPS and Ionosonde Radio Occultation (IRO) observations. In particular, due to a strong increase of the number of used GPS stations (more than 150 in the second year of project) differential TEC maps for the European region were generated at a higher spatial resolution (Figure 5).

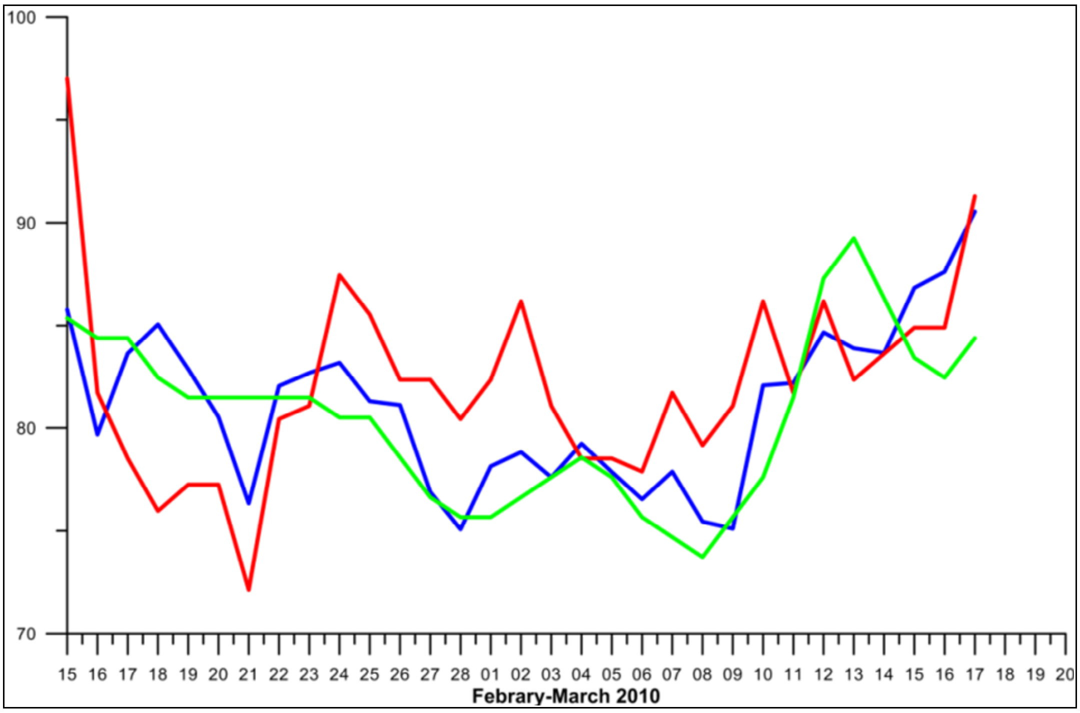

Figure 4: Test performed by FIAG comparing the normalized variations of the Global TEC index blue line, the index of the solar radio flux green line and the local TEC index red line.

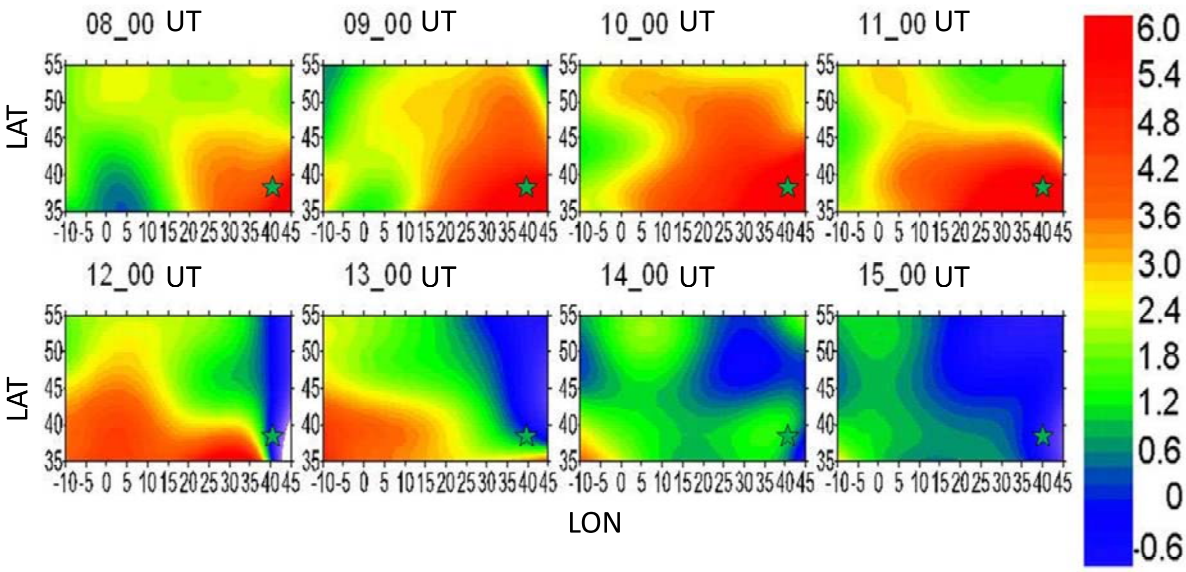

Figure 5: High spatial resolution differential TEC maps obtained, for 26 of February 2010, by using more than 150 GPS stations. Anomalies are observed during interval 0800-1100 UT. The green star on the maps show the epicenter position of Elâzığ earthquake.

In Figure 6 are reported the results achieved for differential TEC index performed by WD-IZMIRAN before and after Elâzığ earthquake occurrence. Quite significant anomalies were identified during the time interval 08:00 - 11:00 UT on February 26, 2010, i.e. about 10 days before the event.

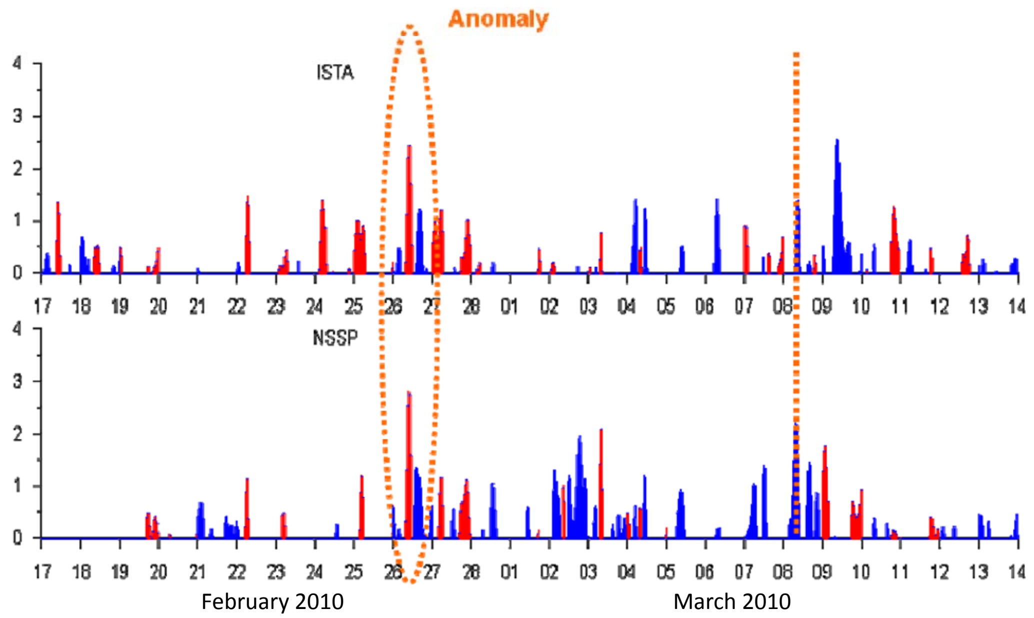

Figure 6: Differential TEC index performed by WD-IZMIRAN. Records with positive and negative anomalies(red line and blue line respectively) are reported. Anomaly value (orange circle) occurred around 26 February 2010, 10 days before the main shock.

DISCUSSION AND CONCLUSIONS

Due to the availability of a major number of independent observations, the Elâzığ seismic event (Mw 6,1; 8 March 2010) was selected as Turkish test-case of PRE-EARTHQUAKES learning phase devoted to have an integration of different parameters (e.g., thermal anomalies, total electron content, radon concentration, etc.), measured from ground and satellite systems and analyzed by using different data analysis approaches.

Looking at results obtained, it's possible to note that several parameters (at least, TIR, ionospheric TEC and ground radon emission), exhibit significant anomalies since February 10 (i.e. 26 days before) until 1 day before Elâzığ earthquake (Table 2), with the major superimpositions (>2) in the period from 10 to 5 days before the event and a particular concentration of independently observed anomalies (>5) on February 26, 2010, (i.e. 10 days before the main shock).

Table 2: Synthetic view of the data products analysis performed for Elâzıg earthquake test case during the first (learning) phase of the PRE-EARTHQUAKES project.

	Products	**-26 up to-16**	**-15**	**-14**	**-13**	**-12**	**-11**	**-10**	**-9**	**-8**	**-7**	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**EQ**
TURKEY Elâzığ Eq 08/03/2010 Mw 6,1	TIR anomaly maps MSG SEVIRI (UNIBAS)																	
	Electrons density vertical profile (DLR)																	
	GPS TEC punctual time series (IZMIRAN)																	
	TEC maps (IZMIRAN)																	
	Radon ground emission (TUBITAK)																	
	GPS TEC punctual time series (FIAG)																	
	TOTAL	1	1	1	2	2	2	>5	2	3	2	2	3	2	1	1	1	

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