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Space-Borne Observations for Short-Term Earthquake Predictions

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Abstract

A two-day workshop in Istanbul, Turkey, assessed the feasibility of a space-based earthquake prediction program. On invitation by the Turkish government and industry, experts from around the world convened to discuss different techniques, their probability of detecting earthquake precursors, and their spatial and temporal resolution. There was wide consensus that only space-borne sensors can adequately survey the Mediterranean earthquake-prone region, and provide an early warning of several hours or days.

Keywords: Earthquakes; infrared image sensors; satellites; remote sensing; ionosphere

1. Introduction

The recent devastating tsunami in the Indian Ocean region and the terrible earthquakes in Pakistan have again called attention to the development of short-term earthquake-warning systems. Earlier in the year, on February 1 and 2, 2005, experts from around the world assembled in Istanbul, Turkey, for a Workshop on Early Warning Systems for Earthquake Monitoring Using Space Technology. Renowned seismologists, data analysts, radio scientists, and space experts attended the workshop, held at the B. U. Kandilli Observatory and Earthquake Research Institute (KOERI) in Istanbul. They came from several countries, including Japan, Taiwan, Russia, Turkey, Italy, Spain, France, and the USA (Figure 1). The objective of the workshop was to determine the merit of a dedicated Turkish satellite project to register short-term earthquake precursors from space. Ever since the large Kocaeli-Izmit earthquakes ($M = 7.4$) in August, 1999, destroyed life and large sections of Istanbul, the Turkish government has been under public

Figure 1. The delegates at the workshop.

Table 1. The resolution of satellite observations and techniques for earthquake studies [10].

Geophysical Parameter	Satellite Platform	Spatial Resolution	Temporal Resolution	Disadvantages	Advantages
Ground displacement	ERS, JERS, RADRSAT	3 m-18 m	27-44 days	No pre-seismic indicator, low temporal resolution	High spatial resolution
Surface temperature (land and sea)	Polar orbit: AVHRR, EOS(MODIS, ASTER	90 m-5 km	1-2 days	Cannot penetrate clouds	Multiple IR platform, over land and sea, high temporal resolution, long historic record, pre-seismic indicator
	Geosynchronous: GOES, METEOSAT	1-4 km	20 min-1 h		
Atmospheric gas %, aerosol contents	TOVS, AIRS	13-20 km	1 day	Cannot penetrate clouds	High temporal resolution, pre-seismic indicator
Ionospheric perturbation, EM waves, and plasma parameters	DEMETER	–	1 day	External, natural and man made EM noise	Low atmospheric disturbances, pre-seismic indicator

Table 2. An instrument suite for earthquake precursor monitoring satellites [3, 4].

No.	Instrument	Measured parameters
1	Topside sounder	Vertical profiles of electron concentration (topside)
2	Mass-spectrometer	Ion composition at the satellite orbit altitude
3	Local plasma spectrometer	$T_{e\perp}, T_{e\|\|}, T_{i\perp}, T_{i\|\|}, N_e, N_i$
4	ELF/VLF wave complex	Multi-component measurements of the electromagnetic emissions and fields in ELF/VLF bands
5	Particle spectrometer	Measurements of energy spectrum and pitch angle distribution of energetic particles
6	Drift meter	Local DC electric field measurements
7	Optical spectro-photometer (optional)	Measurement of optical emissions in oxygen lines 5577 and 6300
8	Radio beacon (optional)	Emitting coherent signals at two frequencies for ionospheric tomography
9	GPS receiver (optional)	Radio occultation measurements

pressure to establish a reliable warning system. Prof. Mustafa Erdik, of BU KOERI, showed that Turkey is at the center of the hazardous region extending from Spain to Iran (Figure 2). John Rundle, of the Center for Computational Science & Engineering at the University of California in Davis, presented his forecasts of $M > 5$ earthquakes in the Istanbul region for the period 2005 to 2010. Figure 3 shows the epicenter locations with highest probability of occurrence. Dr. Rundle's forecasts were widely discussed in the press and on television in Turkey during the time of the workshop.

2. Space-Based Versus Ground-Based Monitoring

The evolving consensus at the workshop was that while ground-based monitors are essential for the development of a comprehensive warning system, only remote sensing from satellites would provide the capability to efficiently monitor the entire region. NASA's Dimitar Ouzounov compared the ground resolutions that can be obtained with different space-borne measurement techniques, varying from ~10 m to 100 km (Table 1); Table 1 also lists the advantages and disadvantages of the different monitoring techniques.

3. Space-Borne Techniques

A complete set of sensors onboard several monitoring satellites was recommended. Dr. Sergey Pulinets, of the Universidad Nacional Autónoma de México, and the Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Russia, listed the important instruments that should fly on a number of satellites, as shown in Table 2.

The internationally respected seismologist Prof. Seiya Uyeda, of the International Frontier Research Program on Earthquakes (Japan), stated in his workshop presentation that strict seismological techniques are unable to make any precise forecasts of earthquakes, but that electromagnetic sensor techniques have an excellent forecasting potential. Thermal infrared (TIR) monitoring from satellites has long been considered to be a viable possibility for correlating pre-earthquake thermal infrared anomalies with earthquakes. Valerio Tramutoli, of the University of Basilicata, Italy, reported on the different satellite programs that are using this technique. The main difficulty is the identification of thermal-infrared anomalies that are related to earthquakes, but ongoing analysis indicates better and better results. Unfortunately, any optical-monitoring technique is frequently blinded when clouds cover the surface, a disadvantage that does not occur for the radio-frequency (RF) techniques using the ULF to UHF bands. Instrumentation on

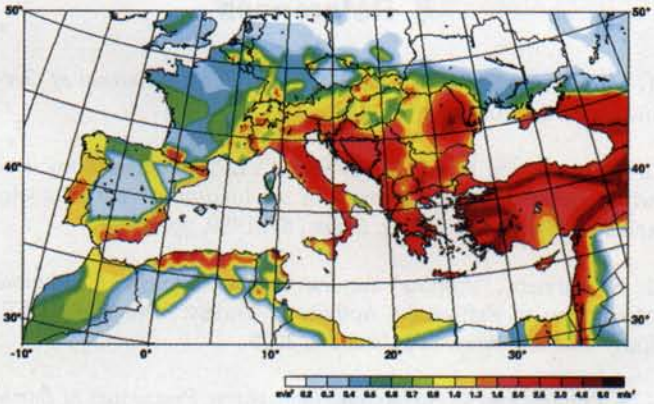

Figure 2. A Mediterranean hazard map (from [11]).

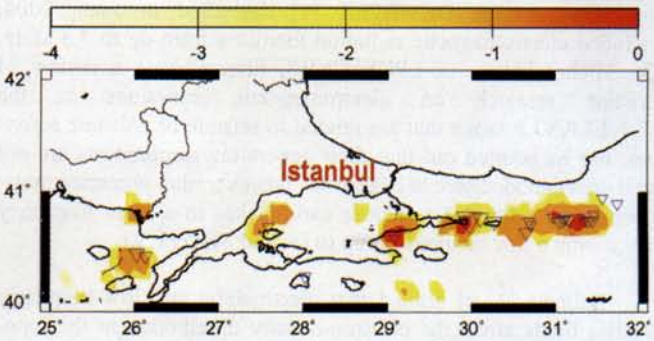

Figure 3. Rundle's forecast of $M > 5$ earthquakes for 2005-2010 in the Istanbul region (from [12]).

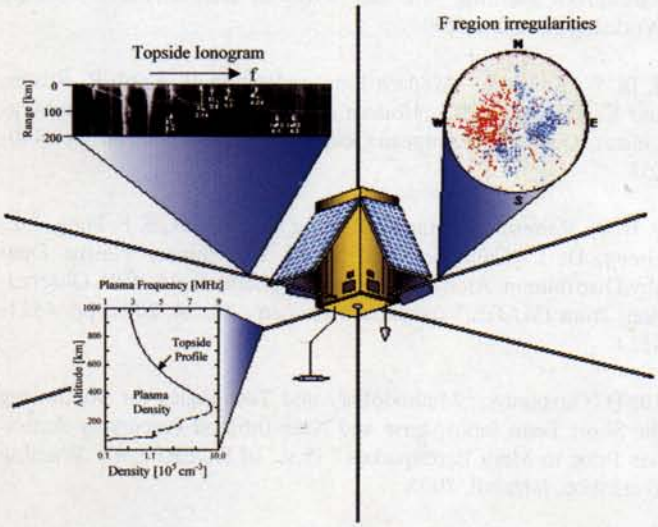

Figure 4. A modern ionospheric radar for the sounding of the topside ionosphere can provide information in real time on disturbances in the electron-density profiles [7].

Figure 5. The proposed Vulkan-Kanopus platform for the warning mission.

the micro-satellite DEMETER [1], launched in June, 2004, included electromagnetic radiation monitors from dc to 3.5 MHz. Dr. Michel Parrot, of LPCE CNRS, France, gave a review of existing research on electromagnetic emissions in the ULF/ELF/VLF range that are related to seismic or volcanic activities, but he pointed out that their generation mechanisms are not well understood. There is consensus, however, that precursor emissions occur a few hours before earthquakes in a large frequency range from a few hundred Hz up to several MHz [1, 2].

Pulinets [3, 4] argued that electrostatic and low-frequency electric fields affect the electron-density distribution in the ionosphere. These modifications can be conveniently monitored from the ground and from orbiting satellites by ionospheric sounders operating in the HF range, as well as with the well-known GPS total-electron-content (TEC) measuring technique [5, 6]. Pulinets [3] proposed the use of four to eight micro-satellites to globally monitor the ionosphere on a quasi-continuous basis. The topside ionosondes should orbit at an altitude of ~1000 km to measure the electron-density distribution between the spacecraft and the peak of the F2 layer. Reinisch presented the design of an advanced topside Doppler sounder, capable of providing real-time electron-density profiles and detecting irregularity structures [7], as illustrated in Figure 4. The design is based on the widely used ground-based Digisondes [8], and the Radio Plasma Imager on NASA's IMAGE satellite that was launched in March, 2000 [9].

4. Conclusion

The workshop established the foundation and feasibility for the launch of a space-borne earthquake-warning system. The attending scientists and engineers presented the available evidence for the feasibility and the need of developing such a space-borne system. Delegations from the Russian Federation (Dr. Vladimir Kuznetsov, director of IZMIRAN, Troitsk; Dr. Anatoly Dudkin of the Federal Aviation and Space Agency; and Dr. Vladimir Degtyar of the Makeev State Rocket Center) announced that they are interested and ready to provide the spacecraft and launch technology for the earthquake-warning missions (see Figure 5). Messrs. Lenikov and Komissarov of Aviaexport in Russia indicated that Aviaexport is the designated general manager for the project, an experienced company for such space missions.

On a personal note, I want to thank the Turkish organizers from industry, government, and academia for taking the initiative of organizing this workshop, and thus planning ahead for the future. Special thanks go to Mr. Pulat Akcin, of the Anadolu Bank, and to Messrs. Selim Bora and Ali Bulent Yildiz, of SOMMA, for their financial support and visionary initiative.

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