Using Remote Sensing technology for detection of Electromagnetic Earthquake precursors

Bahram Safaee
Department of Remote Sensing, Faculty of Geomatics Engineering, K N Toosi University of Technology, Tehran, Iran,
Email: b_safaiy@sina.kntu.ac.ir
Abbas Alimohammadi
Department of GIS, Faculty of Geomatics Engineering, K N Toosi University of Technology, Tehran, Iran,
Email: alimoh_abb@yahoo.com

Abstract: Management of earthquakes as an important natural disaster for high seismic regions is regarded as a critical task. Therefore, definition of high risk seismic regions and prediction of the earthquake is very important. By precise prediction of earthquakes, the hazards and loss of lives and Properties would be effectively controled .

Many seismic, geodetic, electromagnetic and biologic earthquake precursors have been reported but scientific communities have often been in doubt about the usefulness of short term earthquake precursors because of the lack of a reliable mechanism for the sources of these precursors. Recently a new theory for the mechanism of these precursors named as P holes theory has been introduced which can be applied to many of the above mentioned precursors. However, now investigations in this field are followed with a great concern. At the other hand advancements in remote sensing technology have lead to considerable progress in detection of these signals.

In this paper, different electromagnetic earthquake precursors such as the low frequency electromagnetic signals, change of earth magnetic field, ionospheric perturbations and ionosphere total electron content changes have been evaluated. Potentials of the remote sensing satellites like Cosmos 1809, Quakesat, and Demeter for detection of these precursors have been investigated. Finally contribution of future satellites and remote sensing projects for prediction of the earthquakes has been reviewed.

Keywords: Earthquake Prediction, Remote Sensing, Electromagnetic EQ[1] precursors, Ionospheric perturbations, Total Electron Content

1. Introduction

Devastating earthquakes are often followed by some precursors which in case of being detected by proper technologies, they would play a major role in earthquake disaster management. Electromagnetic precursors are regarded as an important pre-earthquake phenomena. Introducing the new mechanism for emerging of these phenomena named as P-Holes by Freund (2002) is also a promising approach for increased investigations in detection of non-seismic pre-earthquake phenomena in recent years. Anyway electromagnetic precursors are categorized as the short-term earthquake precursors, providing the means for prediction of earthquakes in days and months period.

Low price, global coverage, detailed information and continuous observations are important characteristics of using the remote sensing technology, which can compensate the inadequacies of EQ precursor stations on the ground and lead to considerable improvements of the present system of EQ's monitoring and forecasting systems.

2. Theories for mechanism of Earthquake precursors

Most rocks are insulators and the resistivity of the crust is high. However, many of the phenomena that precede the earthquake activity, from deep in the Earth to the ionosphere, require electric currents flowing in the crust.

For decades, attempts to understand how currents could be generated in the otherwise insulating crust have focused on two well-known physical processes: piezoelectricity and streaming potentials. But for some reasons these two theories are not capable of explaining the earthquake precursor's mechanism. Recently a new theory has been introduced by Freund named P-Holes theory which can be applied to many of earthquake short term precursors.

This theory can be expressed as follows

While most rocks are good insulators, they contain dormant charge carriers. The charge carriers are defect electrons in the oxygen (O2–) sublattice. The defect electrons "live" in the valence band of the otherwise insulating minerals. They are called positive holes or p-holes for short. Chemically, one can think of a p-hole as an O– in a matrix of O2–. More appropriate, however, is a more physical concept, namely that a p-hole is a delocalized electronic charge which travels by jumping from O2– to O2– site at lattice phonon frequencies (>1012 Hz). Because the valence band of oxides and silicates is dominated by O 2p states, the p-holes can propagate through rocks almost as electrons propagate through metals. This implies that the p-holes may flow through rocks at high speed and with

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[1] Earthquake

relatively little attenuation. Experimentally, the speed with which a p-hole charge cloud can propagate has been defined to be of the order of 100-300 m/sec. A p-hole carries a spin, and as such it is unstable. It stabilizes by pairing with another p-hole to form a positive hole pair, PHP.

In the context of earthquake research the most important process by which PHPs can split and release p-hole charge carriers is the mechanical deformation. During deformation, mineral grains that are experiencing high levels of stress produce dislocations. The dislocations move through the crystal structure. Whenever they intersect a PHP, they lead it to split and to emit a p-hole into the valence band. Therefore when p-holes are activated, any rock will instantly turn into a p-type semiconductor. [1]

3. Electromagnetic precursors

3.1 Magnetic Field Anomalies

Some reports have been published about observation of the earth magnetic field anomalies about 1-2 months before the earthquakes continued until the earthquake time. These observed anomalies happened in 20-30nT range and low frequency band of 0.01-10Hz. It should be noted that a major problem with recording ULF[1] magnetic signals of this type is that the magnetic field anomalies tend to follow an inverse cube power law with distance from the source, as expected from a dipole. Hence, meaningful data can only be obtained when using the recording instruments with adequate sensitivity and bandwidth very close to the epicentral area. [2]

The main reason for this precursor can be explained by current fluctuations caused by the P holes activity and the resulting magnetic field changes.

Some of the outstanding observations of these precursors can be listed as follow:

- Recording of a persistent 23 nT magnetic field anomaly a few days prior to the 1978 *M*s 7.0 Alay earthquake. [2]
- Broadband spectral recording of the 1989 *M*s 7.1 Loma Prieta earthquake made by a group at Stanford University also provide information about the spectral characteristics and amplitudes of the geomagnetic field changes in nine frequency bands between 0.01 and 10 Hz, at a distance of only 7 km from the epicenter. These data show a significant elevation in magnetic activity in the .01–5 Hz frequency range starting about two weeks prior to the earthquake, with peak amplitudes in the 1–3 nT range. About three hours before the event, however, the largest signals exceeded the dynamic range of the instrument, *exceeding* 6 nT as measured in the 0.01–0.02 Hz band. [2]
- And the most outstanding one observed before 1999 M 7.7 Chi-Chi earthquake. In 1999 an 8-station magnetometer network was in operation in Taiwan, recording the magnetic fields at their locations every 10 min. Two stations were situated close to the 120-km-long, S–N-trending fault line that ruptured during the September 21,1999,M 7.7Chi-Chi earthquake, causing vertical displacements of nearly 10 m: station LY about 20 km N of its northern end and station TW about 60 km S of its southern end, close to the October 22, 1999, M 7.1 Chai-Yi aftershock. LY recorded strong magnetic field fluctuations that began about two months before the Chi-Chi earthquake and lasted until the Chai-Yi aftershock. TW recorded fluctuations that moved southward after the Chi-Chi event and ended shortly after the Chai-Yi aftershock. None of the HL, YL, and TT stations along the Pacific coast recorded any comparable fluctuations.

  The signals recorded at the three Pacific coast stations were subtracted from the LY signals to remove ionospheric magnetic storm contributions, due to the solar wind interacting with the Earth's magnetosphere and ionosphere. The subtraction leaves a small ripple of diurnal variations during the quiet time (Fig. 1a). The ripple and the offset in the overall values are due to latitude differences in the station locations. Also it should be noted that average north/south gradients in total intensity are in the range of 5–10 nT/km. In contrast, large magnetic field pulses were recorded during the active time, prior to the Chi-Chi earthquake and through the aftershock series. The magnitudes of the magnetic field anomalies are of the order of 100–200 nT, almost 0.5% of the Earth's magnetic dipole field (Fig. 1b). These anomalous pulses are local and as such are associated with the impending earthquake. They display a complex periodicity. The individual magnetic pulses during the last days before the Chi-Chi earthquakes are well separated from each other (Fig. 1c). Most are slightly asymmetric with a sharp onset and trailing end as one would expect from an oscillating coupled two-current system, where each pulse begins with a sudden outflow of charge carriers. Each pulse lasted typically for several hours. [3]

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[1] Ultra Low Frequency

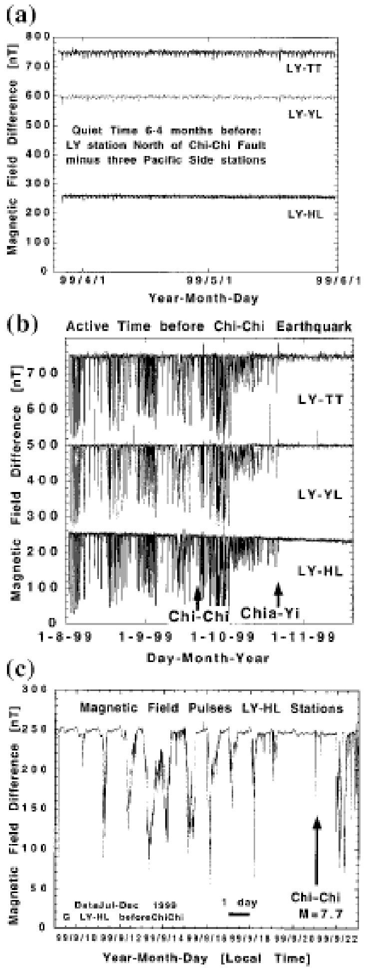

Fig. 1:

(a) LY-TT, LY-YL, and LY-HL signals during a quiet period, April–June 1999;
(b) LY-TT, LY-YL, and LY-HL signals during the active period, August–December 1999, which includes the Chi-Chi earthquake and Chai-Yi aftershock;
(c) Enlarged LY-HL section, 14 days long, spanning the Chi-Chi event [3]

3.2 Low-Frequency EM Signals

When currents wax and wane in the Earth's crust over periods of a few hours per pulse, strong enough to generate magnetic field anomalies as shown in Fig. 1, they will radiate strongly in the low-frequency magnetic regime. Indeed, around the same time as the magnetic field anomalies began in Taiwan, an increase in the ultra–low frequency (ULF) noise level in the 0.007–0.013-Hz window was observed in Japan, suggesting that the ground currents in Taiwan led to EM emission, which propagated over more than 4000 km through the ionospheric conductor.[3]

There have been numerous reports, some very well documented, of earthquake-related ULF[1], ELF[2] and VLF[3] EM emissions measured on the ground and also by satellites. By introducing the p-holes theory as the charge carriers there is also physically more advanced explanations for the mechanism of these precursors as the p-holes can be generated in the crust and produce currents of large magnitude.

Sometimes Different ELF/VLF EM emissions are divided into two groups: precursor emissions (a few hours before an EQ in the frequency range 0.01-1000Hz) and emissions after an EQ (or after a volcanic eruption), the latter being attributed to acoustic-gravity waves. Though the EM precursors cover a wide frequency range, they seem to have three common features: emissions appear 5-10 days before an EQ and few days afterwards; they are mostly related to the tectonic type of EQ; and they are only observable within a radius of 500 km of the focus. [4]

3.3 Ionospheric Perturbations

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[1] Ultra Low Frequency (Frequency range between 0-3Hz)

[2] Extremely Low Frequency (Frequency range between 3-300Hz)

[3] Very Low Frequency (Frequency range between 3-30KHz)

The list of pre-earthquake phenomena includes many reports on ionospheric perturbations on the scale of 1000 Km or more. These reports include Ionosphere Plasma density variation, Total Electron Contents (TEC) change, both positive and negative, ionospheric Temperature variation, absorption of long wavelength radio waves in the Earth-ionosphere wave guide and other anomalies[4]. These perturbations are generally observed about 5–10 days before large seismic events and disappear within 1–2 days [3] but sometimes these perturbations have been observed even some days after the earthquakes. These precursors are often occurred at the lower layers of Ionosphere, E and F layers.

According to Liperovsky et al. [5] Ionospheric precursors can be divided to the following categories:

- **Whistler belts.** Electromagnetic and quasi-electrostatic ELF-VLF hisses filling large regions of the ionosphere and magnetosphere, this type of emission fills a wide part of *L*-shell conjugated with earthquake epicenter. The emission is localized along the geomagnetic latitude in comparatively narrow angle range *dø* ~ 5-20° but it is widely spread in longitude: *dλ* ~ 100°. The idea about the whistler belt spatial structure appeared due to the scanning of the belt at every satellite pass. At heights 600~1000 km the "typical" whistler belt takes about 1000 km in the latitude direction and about several thousands km in the longitudinal direction. The spectrum occupies the broad band in the range from hundreds Hz up to tens kHz (ELF and VLF wave bands).
- **Alfven waves structures.** In contrast with the previous case this type of emission is rather well localized in space. It represents the MHD oscillations of a part of L-shell initiated earthquake epicenter zone (more exactly, at epicenter projection to the height of ionospheric E layer). Alfven waves occupy a sector that is rather wide in the longitudinal direction *dλ* ~ 10° but is extremely localized within latitudes *dø* ~ 0.5-1°. At heights 600-1000 km this structure looks like a wide but thin "film". The thickness of the film is about 40-100 km; the length along the geomagnetic parallel is about 1000 km.
- **Plasma inhomogeneities.** The distribution of plasma density as well as the macroscopic motions of the ionospheric layers is precisely detected from the Earth by ionosounding methods up to the heights of absolute maximum of the ionospheric concentration (hmax = 250 -300 km). A large data set about the seismogenic perturbations of lower ionosphere, particularly, the perturbation of vertical plasma profile *np*(z) have been collected in the literature. The following effects have been detected in the case of powerful earthquake:
    - The stable modification of the ionosphere both at and above the F layer peak height. Electron density is gradually reduced and its spatial distribution looks like a funnel located either immediately over the epicenter or from its one side.
    - The increasing of the frequency of sudden and quick Es layers spreading (in time interval < 15 minutes).
    - The generation of the drifting ionospheric (of the slow MHD waves with periods *T*~2-3 hours),
    - The turbulent motion of plasma layers and the generation of small-scale plasma inhomogeneities (with inhomogeneity scale about ten meters and more and plasma density variations δnp/np~0.01).
- **The variations of the fluxes of precipitating energetic particles.** The small but statistically reliable increments of the particles number precipitated from radiation belts were registered by satellites. ~100 keV electrons and 100 MeV protons. Precipitation events were localized in a wide zone which configuration is more or less similar to the configuration of whistler belts described above.

In discussion of the generation of these precursors, there are some arguments which we should be introduced here:

- ✓ The F layer is dominated by positive ions and, hence, it is positively charged. It appears that, prior to large earthquakes, a strong electric field builds up on the ground, the polarity of which is most often such that it pushes the F layer aside, allowing energetic electrons from the higher ionospheric layers to penetrate to lower levels. Such a positive electric field rising from the ground is consistent with the p-hole charge clouds, which arrive at the Earth's surface, generate a positive ground potential. [3]
- ✓ The normal ground potential varies between 0.1- 100V/m, but, in the case of thunderstorms or in areas of an impending earthquake, it can rise to values up to 1000V/m. Such high ground fields influence the conductivity of the lower atmosphere. Gas emanation including radon release from the ground affect the aerosol content and cause the conductivity to increase up to fivefold above the background level. As a result, prior to an EQ, the vertical profiles of humidity, pressure and temperature are changed; Changes in the lower atmosphere-ground conductivity are related to the migration of EM carriers from lower atmosphere to the ionosphere (F–region). [4]
- ✓ The generation of the electromagnetic earthquake precursors might also be result from the trapping of natural VLF emissions into the seismogenic plasma ducts appearing above an earthquake epicenter. [5]
- ✓ The post and co-seismic signals observed in the ionosphere can also be satisfactorily explained thanks to the acoustic waves generated by the ground movement caused by the seism. [6]

One of the main challenges about the electromagnetic precursors is in extracting pre-earthquake signals from ionospheric perturbations caused by other sources.

However, different techniques can be used to detect these precursors:

- ★ Using GPS Receivers

  By using the 24 GPS satellites with local receiver networks it is possible to continuously monitor the ionosphere. The ionosphere acts as a dispersive medium for the GPS signals, while the troposphere is non-dispersive. After removing from the received signal tropospheric effects on the carrier phase and correction for the pseudo-range, the group delay of the propagating signal along the travel path becomes a measure of the Total electron Content (TEC). Recent studies have shown that anomalies of the TEC values correlate with strong EQs 1-4 days before the main event. Most relevant project is UNAVCO [4].

  A typical example of Ionospheric perturbation before earthquake was observed before the 13 February 2001, M=6.6, El Salvador earthquake. during analysis of data, ionospheric perturbation before this, Systematic decreases of the ionospheric total electron content during two days before the earthquake onset were observed at set of stations near the earthquake location and probably in region of about 1000 km from epicenter. [8]

- ★ Using ground instruments

  In this mode, different Ionosphere parameters are identified by using ground instruments. In fact, GPS Receivers are one type of this group, but because of their importance discussed here in a separate group. An example of detected anomalies by using ground instruments is as follows:

  - ▪ The TEC value significantly decreased 1, 3 and 4 days before the 21 September 1999, Chi-Chi earthquake of M7.7 [8]. It has been also reported that variations of the maximum plasma frequency in the F-region, foF2, and in the sporadic E layer, foEs, of the ionosphere recorded by ionosondes during the Chi-Chi earthquake were examined and found that the foF2 significantly decreased 4 and 3 days before the earthquake onset at two stations. Meanwhile, the foEs of these two stations abruptly increased 3 days before the earthquake. Results indicate that the seismoionospheric anomalies in the F-region appearing before a large earthquake could reach about 1000 km from the epicenter, while in the E-region these are rather localized to about 700 km [9].

- ★ Using satellites

  Satellites' observations of ionosphere are also another type of earthquake precursor observations. By using satellites, different ionosphere parameters can be measured and searched to detect electromagnetic precursors.

4. Ancient satellites launched to detect Electromagnetic precursors

In addition to installing ground instruments near faults, there is a great interest to use satellites to test existing hypotheses on electromagnetic precursors. Sometimes even satellites with different aims like Cosmos 1809 have recorded some signals related to earthquakes which encourage investigators to work on this field. It should be noted that some scientists like USGS officials are skeptical of those space-based reports because of the difficulty in detecting earthquake-related ELF signals from space [10]. Anyway the reasons of great interest in using space to detect precursors can be summarized as follow:

- Earthquakes are global phenomena.
- Collection of electromagnetic signals from space provides global coverage.
- Probability to detect powerful earthquakes with magnitudes greater than 6 will increase by searching more areas.

4.1. Russian Cosmos 1809 satellite

As mentioned before, the goal of this satellite wasn't primarily to detect earthquake precursor signals, but this satellite detected some signals relating to earthquakes that the important one was the detected 140 Hz and 450 Hz signals (fig. 2) just after a M6+ earthquake in Spitak, Armenia in 1989 [12].

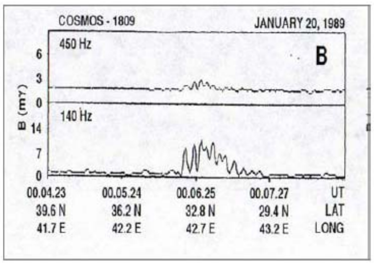


Fig. 2: ELF Data of Cosmos 1809 satellite [11].

4.2. French Auerol 3 satellite:

This satellite also recorded signals similar to the above signals by global searching of ELF signals on active seismic zones. For example temporal variations of the magnetic field at a frequency of 800 Hz at a height of 460 km of this satellite has been recorded during a magnitude 5.4 earthquake on the 2 January 1982 (fig. 3). The highest peak on the left is observed in the vicinity of the epicenter of the seism; the peak on the right, the smallest one, is its symmetrical point in the Southern hemisphere [6].

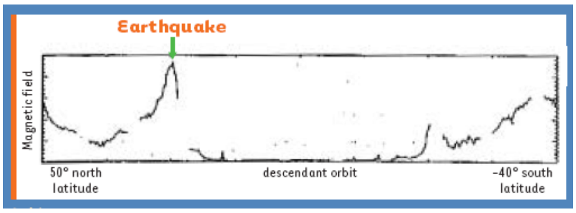


Fig. 3: Variations of the magnetic field detected by Aureol 3 satellite during a magnitude 5.4 earthquake in 1982. [6]

4.3. Russian Compass satellite

Compass-1 satellite launched in 2001 with the goal of detecting electromagnetic signals, but unfortunately this satellite failed to communicate with ground stations [10]. After that, to check some ideas and technological developments the pre-system pilot project COMPASS-2 will be launched in the first half of 2005 [13].

In addition to the above mentioned ancient satellites, recent investigations have lead to launch some satellites with similar goals. These are briefly discussed in the next part of this article.

5. Recent satellites launched to detect Electromagnetic precursors

5.1. Quakesat satellite

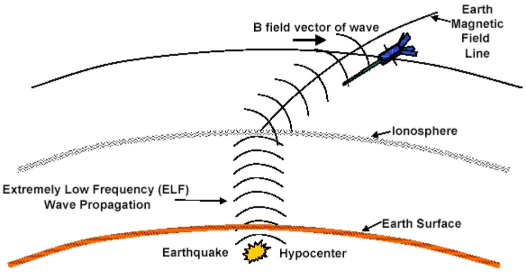
This satellite is one of the most recent satellites that launched on 30 June 2003 with the goal of collecting electromagnetic signals related to earthquakes. Launch of this nanosatellite provided the required global data for investigation. This satellite parameters are as below:

- Sun synchronous orbit at 840Km height
- Satellite of Cubesat type with 35×11×11Cm size
- Satellite weight: 4.5Kg
- Nominal satellite lifetime: 1 year

This satellite is designed to collect data over special seismic zones and no data are recorded over poles and oceans. It also provides data on 5 frequency bands: Band 1: 0.5 to 10 Hz narrow band magnetic; Band 2: 10 Hz to 150 Hz wide band magntic; Band 3: 10 Hz to 1000 Hz wide band magnetic; Band 4: 130-150 Hz narrow band magnetic; Band 5: 130-150 Hz narrow band electric field. [12]

The goals of this satellite are:

- Demonstration and verification of the existence of pre-earthquake signals and abilities for their detection from space
- Measuring low frequency electromagnetic precursory signals in 0.5-1000 Hz Range (Fig. 4)
- Building of a cheap nanosatellite by utilizing commercially-off-the-shelf (COTS) components originally used in non-space applications. It should also be noted that there were some questions in precursory signals level, signals structure, frequency ranges, time and environmental noise that were making it difficult to use a bigger scientific satellite to test these signals. Therefore, the mission tended to make a nano satellite.



Stanford University

Fig. 4: QuakeSat Mission Concept [12]

Although the quakesat mission used the magnetometer of 10PT sensitivity, but the noise was somewhat higher than expected before launch and decreased the productivity of magnetometer. Therefore, only a few signals were detected by this satellite.

A total of nearly 2000 magnetometer collections were made of all modes, primarily 10 to 150Hz. The areas targeted were primarily, 1) likely earthquake regions, hoping to catch a signal before an event and 2) significant post earthquake collections in the region surrounding the earthquake. In addition, over a 100 collections were made looking for lightning strikes and several global 1-10Hz surveys were made.

By analysis of collected data set approximately 25 signal types are currently cataloged. Some of these are known or highly likely to be satellite generated, a few we suspect to be satellite or satellite environment related. However, a number of them have signatures that we might expect to be related to the earthquake, wide band frequency and wide time span (i.e. not impulsive). In addition, some aural signals detected over the Polar Regions, up to 80Hz and a number of lightning strikes 10-1000Hz (fig. 5).

The signal's propagation path is still not fully understood. Factors that likely impact the path include ionosphere height, atmospheric disturbances, signal frequency, etc. This can also be investigated using detected lightning strikes. Lightning strikes have a powerful, wide frequency pulse. Their impulsive nature allows better understanding of where they are generated and how they are received by Quakesat. A characteristic J hook shape, (a rear facing J), indicates that the propagation path is different for different frequencies. This type of signal has been detected by many ground based systems. This may prove useful in geo-locating earthquake related signals, by using the difference in time of detection and path to determine multiple eclipses of possible signal origination.

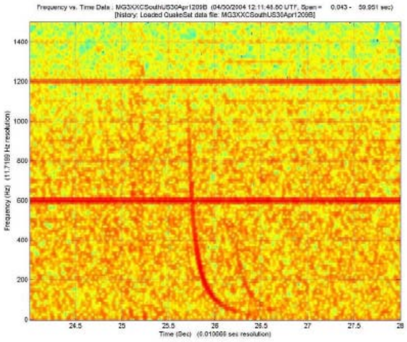


Fig. 5: Lightning collection over the southern US [11]

Cosmos 1809 had a narrow band instrument, measuring 140 Hz and 450 Hz (ie creating two vertical planes at 140 and 450 Hz through a time vs frequency vs intensity surface). Quakesat carried a wider band instrument covering the 10-150Hz and 10-1000Hz bands. While this reduced the overall sensitivity at a specific frequency; it increased the range of frequencies we could look at, creating a 3D view (fig. 6) of the signals.

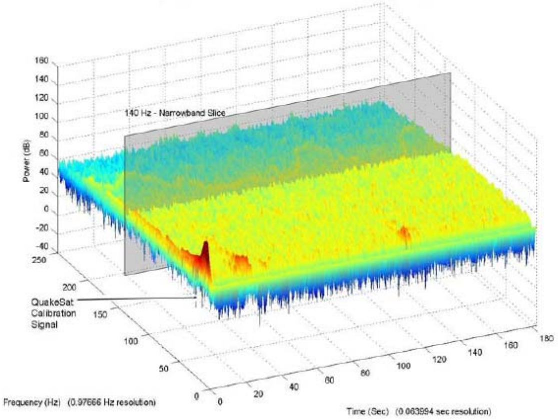


Fig. 6: A 10-150Hz collection over New Zealand with a 140Hz narrowband slice for illustration purposes [11]

It is currently believed that the wide band bursts of energy seen a number of times, may be the peaks of the signals similar to the ones Cosmos 1809 detected over Spitak-Armenia. These signals also were seen over a broad range of frequencies up to about 150Hz.

It was suspected that these earthquake signals were likely broad band and one of the missions of Quakesat was to determine how broad and what frequency might be best.

Signals of this or similar type were seen immediately following the 21 August 2003, 7.2M South Island NZ quake, the 22 December 2003 6.5M San Simeon CA quake, and the 1 December 2003 6.0M Kazakhstan-Xinjiang Border Region earthquake.

An example of data collected after San Simeon earthquake has been depicted in figure 7.

The high noise level and the dawn dusk nature of orbit has satellite flying over targets while the ionosphere is in a turbulent transition period between night and day, are likely reasons why we have seen only a few signals of the type we believe may be similar to the earthquake signals Cosmos 1809 detected over Spitak-Armenia.

Another achievement of this satellite was that now we can answer the question “is it possible to use a nonosatellite for scientific investigations?”.

To answer to this question it can be said yes, we probably can’t answer all questions on a single nanosat flight, but important insight into the problem and collection of preliminary data can be very important in solving or understanding the complete problem. [11]

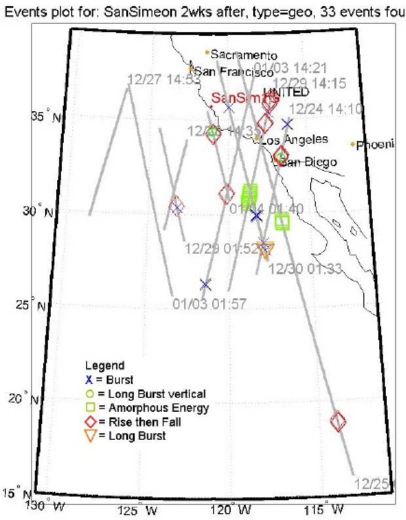


Fig. 7: Quakesat collections during the 2 week post the San Simeon earthquake [11]

5.2. Demeter satellite

Detection of EM Emissions Transmitted from Earthquake Regions satellite

This is also another one of most recent microsatellites designed and built by France Space Agency (CNES) with the goal of detecting pre earthquake electromagnetic signals and ionospheric perturbations and launched on 29 June 2004. This satellite parameters is as below:

- Sun synchronous orbit at 710Km height and inclination of 98.3 Degree
- Satellite of Cube shape with 80×80×80Cm size
- Satellite weight: 120-130Kg
- Nominal satellite lifetime: 2 years
- Use of Electromagnetic shielding extensively **to reduce interference with scientific instruments** that the satellite itself could produce.

The instruments used to detect signals and anomalies as shown in fig. 8 are:

- IMSC: an instrument to measure 3 components of magnetic field in wide frequency range 10Hz-18KHz
- ICE: an instrument to measure the 3 components of the electric field, over a large frequency range (from DC to 3MHz).
- IDP: Instrument to Measure the energetic particle spectra. This Plasma Detector Instrument used to measure the energy spectrum of the electrons at right angles to the magnetic field in order to measure the disturbances in the radiation belts.
- IAP: Instrument to analyze plasma. This Plasma Analyzer Instrument is designed to measure the plasma’s main ionospheric parameters: density, temperatures and the speeds of majority ions whose variations indicate the disturbances in the ionosphere.
- ISL: Instrument to Measure the density and electronic temperature. This Instrument used to measure the total density of the plasma, the electronic temperature and the satellite potential (in the +/-5V range).

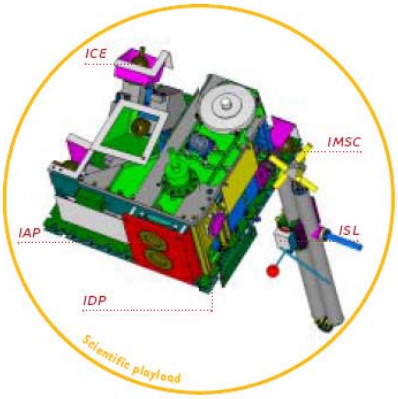


Fig. 8: Instruments used in Demeter satellite for detection of the earthquake precursory signals [6]

It also has two data acquisition modes –low-rate anywhere above the surface of the earth to provide global surveillance at low resolution, and high-rate over areas of seismic activity.

Other studies will also be conducted at the same time to back up the mission:

- Complementary ground research undertaken in some geographical zones such as on the site of the European Observatory in the Gulf of Corinth, in order to compare ground and satellite measurements of geological events [14]. The installation of a multi-parameter geophysical observatory in this region began in 1996. Various instruments will be installed to supervise the site: seismometers, gravimeters, radon detectors, and electromagnetic station (ULF, ELF, and VLF). More than this, a borehole is used to install seismometers at depths of around 70 m [6].
- Ionospheric sounding using the Global Positioning System (GPS) system and Doris orbitography (Orbit Determination and Radio Positioning Integrated by Satellite) will investigate the total electronic content of the ionosphere in two dimensions, thus complementing the DEMETER measurements [6].

Therefore, by using these instruments it is expected that the promising results for earthquake prediction are achieved by the end of this satellite mission.

6. New and future Missions

More than what mentioned above There are some other satellites and projects designed to launch during the recent and future years for the same purposes. One of these satellites is the SICH-1M satellite named VARIANT mission under AIRUS project which has been posed by Ukraine space agency. This satellite scheduled to launch in 2002 at the circular orbit with the inclination of around 80 Degree and altitude 670±30 km [5].

Another program in this field is the ELMOS mission which has been implemented in Japan.

The VULKAN project of Russia is also another project that has proposed launch of small satellites in two 500 and 1000Km orbits to detect Ionospheric short term precursors. To test some of theories and technological improvements the Compass-2 pre-system project has been scheduled to launch in 2005 [13].

In addition, efforts are underway for the preliminary design of Quakesat 2, a larger, (likely a small microsat) improved version of Quakesat. Additions include multi-axis magnetometers; reduced satellite noise, increased sensitivity, additional attitude control, higher communication data rate. Launch time is still to be decided, but likely it will be in early 2006.

7. Conclusions

The earthquake prediction field of study is one of the most complex field of investigations that even by reporting wide range of precursors, nobody has been completely successful in predicting the earthquakes. There were some researchers and scientists that correctly predicted earthquakes, but after some predictions, they failed to continue their correct predictions. The first correct earthquake prediction was the Haicheng earthquake prediction in china in 1975 which was based on the increase of underground water levels, earthquake patterns, peculiar animal behavior and some other precursors. Some hours before this earthquake, people of area warned of such an earthquake and by early evacuation, more than 100000 people were saved. However the china scientists failed to predict the 7.8 earthquake in Tangshan in 1976. As another case professor Keilis-Borok, UCLA seismologist and mathematical geophysicist, in 2004 announced that major earthquakes can be predicted months in advance and their method which used the pattern of small earthquakes on the region succeeded to predict two major earthquakes around the world but their final prediction didn't happen at the predicted time range. However, we should also note that the works in this field have not been adequate to develop a reliable method to predict earthquakes.

Electromagnetic precursors are one of earthquake precursors that have been reported very extensively. Use of these precursors for prediction of earthquakes need more studies, observations, measurements and investigations. Extraction of pure earthquake related signals from those of artificial sources is another difficulty in this field as the VAN method in about 1996 was criticized to be the result of human works and not related to earthquakes. More observation and statistical analyses can lead to a reliable method for prediction of earthquakes based on these precursors. Use of satellites for detection of these signals is also another new technique that can be used as a complementary system to ground equipments and can have some advantages like: low price, broad cover area, full information and dynamic observation. In addition to electromagnetic precursors discussed here, there are other earthquake precursors which should be investigated to develop a reliable method. These are: thermal infrared anomalies which satellite sensors like MODIS, AVHRR can be used to detect them. Geodetic precursors which we can use the GPS and SAR interferometry technologies to measure a small displacements on the ground around the faults. Seismic patterns are diversely studied to make long term and short term earthquake prediction. Preshocks, foreshocks, earthquake clouds, peculiar animal behavior, increase of the underground water levels, increase of hydrogen concentration, emission of different gases like sulfurous gases from faults, increase of radon gases at the underground waters and some other precursors are examples of promising signals to be utilized for earthquake prediction.

Anyway, the role of space technology in earthquake field of study is also very important, because not only the remote sensing technology can play an important role in the field of EQ forecast, but also Remote sensing data can be applied to: Regional / local / building level damage assessment, Response coordination, Assessment of damage to lifelines, Search and rescue, Tracking fires and Hazardous materials release.

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