Space-Based System for Short-Term Earthquake Warning

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ABSTRACT

The mitigation of earthquake damage and loss of life remains of great concern. Recent studies demonstrate the ability of space technologies to monitor the variations at near-earth space plasma, atmosphere and ground surface with approaching sever earthquakes. These variations are known as earthquake precursor and they can appear within five days before the seismic shock near the seismic active area. The present paper will propose a space-borne system for earthquake precursors monitoring for short-term earthquake prediction.

INTRODUCTION

It is estimated that the recent earthquake in Sendai, Japan caused about $265 billion in damage and while much of that would have been unavoidable, many lives would have been saved and much secondary damage avoided if an early warning system had been in place [1]. Currently no reliable space-based early warning system has been developed for earthquake short-term prediction.

In the last twenty years, observational evidence provides a clear pattern of transient anomalies preceding the earthquake [2]. These anomalies are suggested to be attributed to lithosphere-atmosphere-ionosphere (LAI) coupling effects associated with seismic activities and are named earthquake precursors. Although the evidence of earthquake precursors have been reported but still the current state of art is not enough to develop reliable early-warning system. These is attributed mainly to shortage in data needed to develop theoretical and statistical models. The objective of the current proposal is to deploy dedicated satellite constellation along with coordinated ground stations for earthquake precursors detection and monitoring.

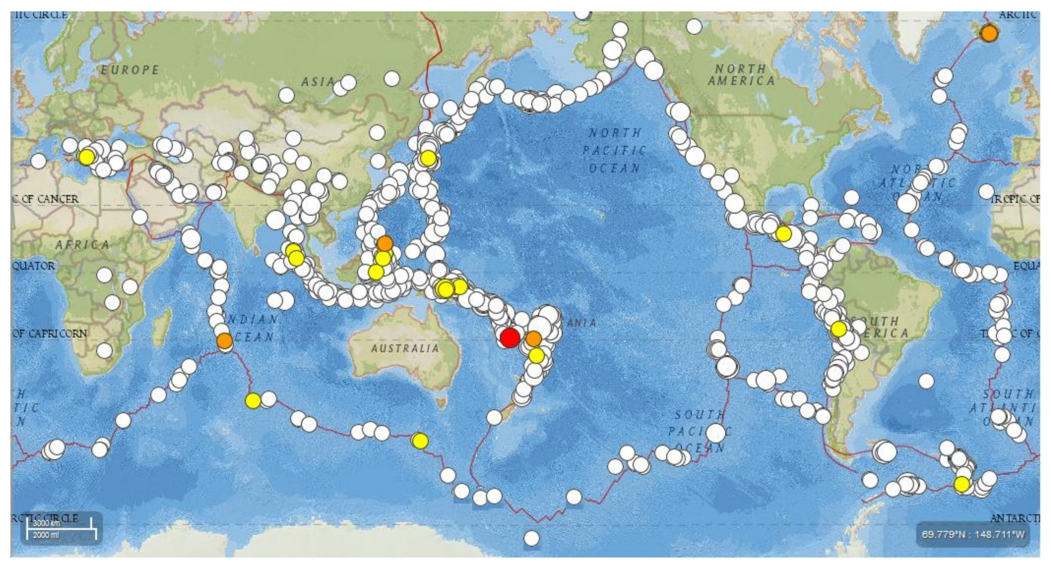

Figure 1 World earthquake map of M ≥ 5 during one year (November 2013-November 2014) (1713 earthquakes in total as per the USGS earthquake Catalogue)

MISSION OBJECTIVES

The objective of the proposed mission are:

1. Provide real time data of well know earthquake precursors related to Lithosphere-Atmosphere-Ionsphere (LAI) coupling phenomena for earthquakes of Magnitude 5 or higher.
2. Develop and validate theoretical models addressing the short-term (1-5 days) earthquake precursors.
3. Possible integration with the ground-based early warning and monitoring systems.
4. Identify the source of the precursors variations (whether it is due to seismic activity or it is of solar and magnetosphere origin.
5. Prompt international collaboration with nations of active seismic activities (e.g. Japan, Latin American Countries, ..etc)

CONCEPT OF OPERATION

A constellation of micro-satellites will be employed to provide reasonable spatial and temporal resolutions for a number of parameters which is linked with lithosphere-atmosphere-ionosphere (LAI) coupling. The payload onboard the micro-satellite will provide the measurements for the following parameters:

- Ionosphere precursors registration using topside sounder and mass-spectrometer (Critical frequency, ionization profile, TEC, ion composition and electron temperature)
- VLF emission registration
- Thermal precursors registration.
- Measurement of DC electric field.
- Measurement of Magnetic Field.

Ground stations should be place in location to minimize data latency and processing.

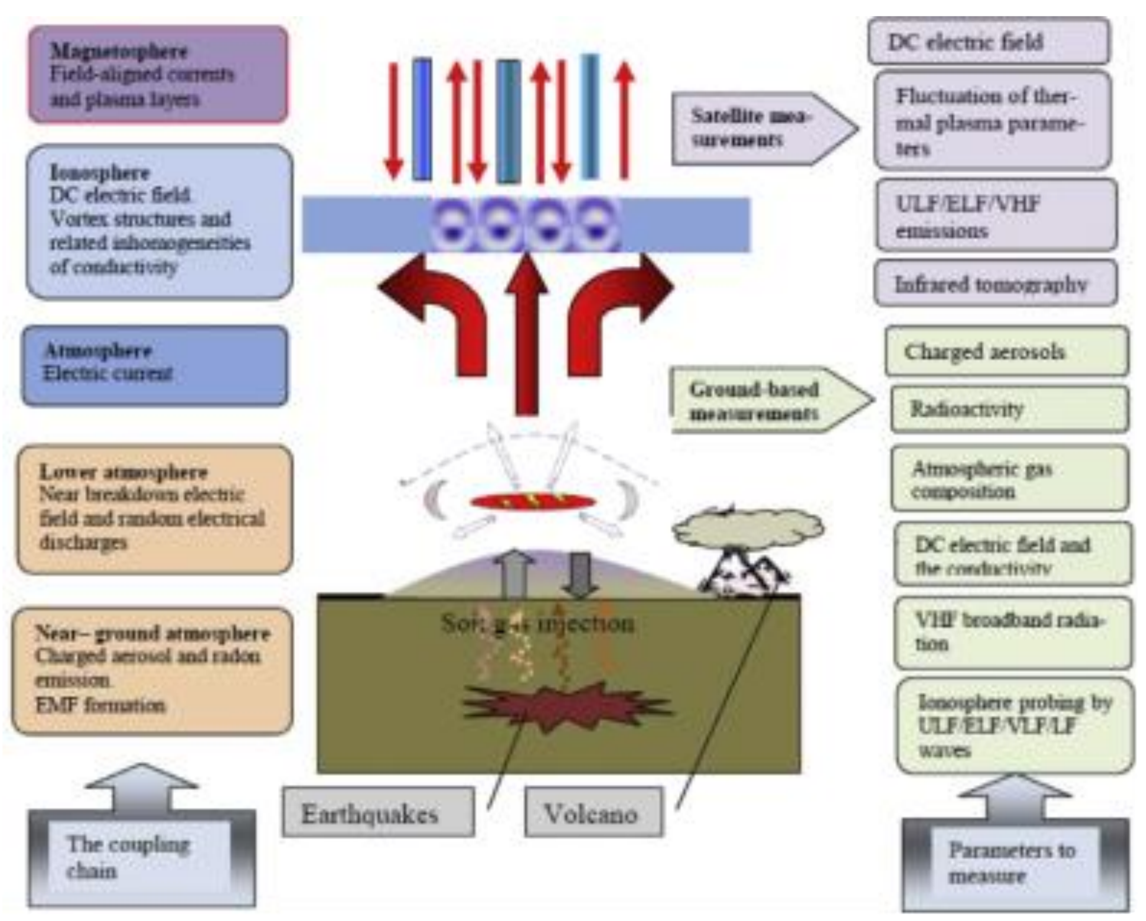

Figure 2 A schematic of the Lithosphere–Atmosphere–Ionosphere electrodynamic coupling [1].

KEY PERFORMANCE PARAMETERS

The key performance parameters are:

- Mid/Low Wavelength Infrared Cameras
- Topside sounder for vertical profiles of electron concentration
- Mass-spectrometer for ion composition at the satellite orbit altitude (about 700 km)
- VLF wave complex
- DC Electric Field and Magnetometer
- Steerable S-Band antenna

SPACE SEGMENT DESCRIPTION

The space-based system consists of constellation of four micro-satellites in sun-synchronize orbits with orbits distributed equally in longitudinal (or in local time). It is well known that within the 5-day interval before the seismic shock the precursors can appear every day [2]. It was shown by Pullinets et al. [2] the duration of any precursor lasts nearly 4 hours. Therefore, the four-satellites constellation should cover the 24 h of Local time of target area(s) and could register any deviation in any of the precursors. A Micro-Satellite of mass slightly more than 50 kg is proposed in this mission for a mission period of 2-3 years. The attitude control stability per axis has to be within 0.005º /s and the position accuracy has to be within 70 m. The peak power consumption is about 100 watt.

1. Mid/Low Wavelength Infrared Cameras: Thermal Infra-Red (TIR) Camera with GSD of about 300m and swath ≥ 100km. The sensor has its range in either 4µm or 10-12µm.
2. Topside sounder for vertical profiles of electron concentration. Topside sounder based on SSTL platform which has antennas of 15 m tip-to-tip > 5 MHz; 50 m tip-to-tip < 5MHz. The main antenna configuration options: three orthogonal dipoles, two V-shaped dipoles, two crossed dipoles
3. Mass-spectrometer for ion composition at the satellite orbit altitude (about 700 km). Mounted on platform, inlet directed along the satellite velocity vector.
4. VLF wave complex: Four components of the electric field of VLF-band electromagnetic waves are measured. The same VLF system proposed by Kamogawa et al. [6].
5. Magnetometer: Deployed on boom of at least 2-4m to minimize disturbances from the spacecraft
6. The GPS is used to obtain the precise position as well as the total electron content (TEC).
7. Electron density and Temperature: The electron density and temperature measurements are carried out with a Langmuir probe similar to that deployed in the DEMETER Satellite [7].

Table 1 and Table 2 show the scientific payload weight and power budget and the satellite bus specification, respectively..

Table 1 Mission and Bus Requirement for Scientific Payload

Payload	Sampling	Data Rate	Power	Weight
TIR Camera	Frequent	~5 Mbps	Less than 5 Watts	2-3 kg
Topside sounder	1Hz	~2 Mbps	~5 Watts	~10 kg
Mass-spectrometer	1Hz	~2 kbps	~20 Watts	~8 kg
VLF wave complex	1Hz	~5 kbps	~4 Watts	~3 kg
Magnetometer	1Hz	~5 kbps	~2 Watts	~1 kg
TEC	1Hz	~2 kbps	~2 Watts	0.06 kg
Electron Density and Temperature Measurements	1Hz	~5 kbps	~2 Watts	~1 kg

Table 2 Satellite Bass Specification

Size	≈ 500 × 500 × 500 mm
Mass	≈ 50 kg
Payload	≈ 25 kg
Communication	S-band transmitter and receiver (two antennas) With data rate of 10 Mbps (downlink) UHF-band transmitter with four antennas and data rate of 9600 bps
Power	Maximum generation of about 100 Watts Solar array: Indium Tin Oxide Cell Maximum consumption > 50 Watt Li-ion Battery: 8 series × 2 parallel
Orbital Determination Accuracy	< 70 m
Attitude Determination accuracy	< 0.005 deg

ORBIT/CONSTELLATION DESCRIPTION

Four-satellites in sun-synchronize orbits constellation that cover the 24 h of Local time of target area(s) and could register any deviation in any of the precursors. The orbits distributed equally in longitudinal (or in local time). In principle it is enough to have the high inclination obit of about 83o at an altitude of 600-700 km.

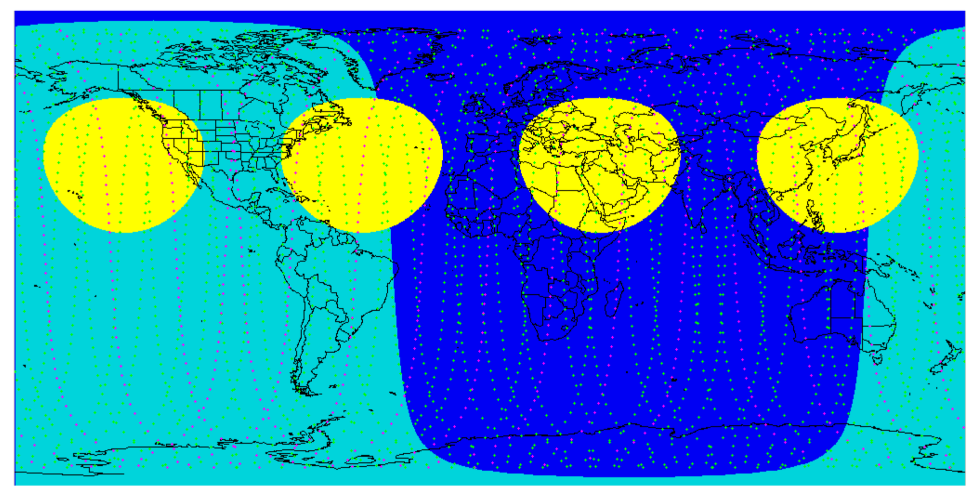

Figure 3 Constellation ground track

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