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Earthquake science research with a microsatellite

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Reliable, repeatable earthquake forecast is a subject surrounded by controversy and scepticism. What is clear is that reliable forecast would be a critical tool for effective earthquake disaster management. It is proposed that satellites and ground-based facilities may detect earthquake precursors in the ionosphere a few hours or days before the main shock. A low-cost 100 kg class satellite carrying a topside sounder is proposed, to make systematic measurements over seismically active zones. The mission aims to confirm or refute the hypothesis of ionospheric earthquake precursors, define the reliability and reproducibility, and enable further scientific understanding of their mechanisms.

Keywords: seismo-ionospheric precursors; vertical electric field; topside sounding; microsatellites; low-cost research mission

1. Introduction

Reliable, repeatable earthquake forecasting is a subject surrounded by controversy and scepticism. What is clear is that a reliable forecast could be a critical tool for effective earthquake-disaster management. Substantial progress has been made on the development of methods for earthquake-hazard analysis on a time-scale of a few decades. However, the forecast of specific earthquakes on time-scales of a few years to a few days is a highly complex problem.

It has been proposed that satellites and ground-based facilities may detect earthquake precursors in the ionosphere a few hours or days before the main shock. In addition, forecasting of the magnitude of the events, as well as an indication of the seismic centre, should be possible. Further data are required to verify the hypothesis and substantiate the existing models describing seismo-ionospheric relations and in order to be able to establish a clear scientific understanding of their mechanisms.

A 100 kg class Surrey Satellite Technology Ltd (SSTL) microsatellite, carrying an RAS topside sounder and complementary payload, is proposed to make regular measurements over seismically active zones around the globe. The low cost of the microsatellite mission offers a financially low-risk approach to facilitate this invaluable research. We present an overview of the scientific basis, scientific goals and proposed platform for this research mission.

One contribution of 25 to a Theme 'Science and applications of the space environment: new results and interdisciplinary connections'.

2. Earthquake forecast science: research background

The forecast of specific earthquakes on time-scales of a few years to a few days is a complex problem, and research continues into many hypothesized correlations between geophysical phenomena and seismic activity. There are many different theories for observable phenomena that appear to correlate with seismic activity, but all areas are very much in their infancy. The most widely publicized phenomena are electromagnetic (Dea *et al.* 1991; Parrot *et al.* 2000; Hayakawa *et al.* 2000) and ionospheric (Pulinets 1998*a*). This proposed mission focuses on the investigation of seismo-ionospheric phenomena with potential for secondary investigations into seismo-electromagnetic correlations. The main goals of this low-cost research mission are substantiating the existing models that describe seismo-ionospheric relations and establishing a clearer physical understanding of their mechanisms.

3. Investigation of seismo-ionospheric precursors

It has been proposed that satellites and ground-based facilities may detect earthquake precursors in the ionosphere a few hours or days before the main shock (Pulinets 1998*b*). A physical model derived from statistical studies by the Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation at the Russian Academy of Sciences now backs this hypothesis. This model incorporates an understanding of the main morphological features of seismo-ionospheric precursors that allows them to be separated from background ionospheric variability (Pulinets *et al.* 2000). In addition to forecasting the time of the quake, forecasting of the magnitude of the events and an indication of the seismic centre may also be possible by this method.

Most existing models of seismo-ionospheric coupling acknowledge the important role of atmospheric electricity. It is proposed that, due to the anisotropy of atmospheric conductivity at heights greater than 60 km, the large-scale, high-intensity (*ca.* $1000\ \mathrm{V\ m^{-1}}$) vertical electric field appearing at seismically active regions a few days before strong earthquakes can penetrate into the ionosphere and create specific irregularities of electron concentration in this region (Pulinets *et al.* 1998). This anomalous quasistatic electric field generated on the ground in a seismo-active zone is detected through the seismogenic variations in the near-Earth plasma due to the high conductivity along the geomagnetic field lines. This is manifested in many physical parameters of space plasma which could be measured on board the satellite.

Based on retrospective analysis of existing satellite measurements of seismo-ionospheric variations and existing models, the following set of ionospheric parameter measurements is proposed:

(i) density in the F-layer maximum (critical frequency);

(ii) height of the F-layer maximum;

(iii) vertical profiles of ionization (both for topside, and bottomside ionosphere);

(iv) the total electron content (TEC);

(v) ion composition;

(vi) electron-temperature measurements.

Table 1. *Strawman payload*

(The payload mass allocation is 25 kg. There is potential for additional payloads for measurements of electric and magnetic fields, VLF emissions and energetic particle fluxes.)

strawman payload accommodation	comment
topside sounder	antennas: 15 m tip-to-tip > 5 MHz; 50 m tip-to-tip < 5 MHz; main antenna configuration options: three orthogonal dipoles, two V-shaped dipoles, two crossed dipoles. Based on the IS-138 flown on Intercosmos-19.
mass spectrometer	mounted on platform, inlet directed along the satellite velocity vector
magnetometer	deployed on 2–4 m boom to minimize disturbances from the spacecraft

To make these measurements regularly over the seismically active zones, a topside ionospheric sounder and complementary payload will be flown on a low-cost SSTL microsatellite. Depending on the proposed payloads, the measurements of electric and magnetic fields, very low-frequency (VLF) emissions and energetic particle fluxes could also be considered.

In order to identify variations with local time, global and regional variations, it is critical to ensure that satellite and ground-based measurements are coordinated wherever possible. The mission should be organized such that data are processed in near-real time and are available to a broad sector of the scientific community. The exchange of satellite and ground-based measurements data should be provided, especially with establishments conducting ionospheric measurements: ground-based vertical ionosondes, radars and global positioning system (GPS) receivers providing the GPS TEC data. Coordination with the seismic network and groups providing atmospheric electricity, radon and aerosol measurements should also be organized. Such close cooperation of ground-based and satellite measurements should dramatically improve our understanding of the physical mechanisms of seismo-ionospheric coupling.

4. The microsatellite mission concept

The proposed platform is a 100 kg class low-cost SSTL platform, which has on-board data storage, three-axis stabilization and moderate downlink data rates to support the payloads. A baseline orbit at 70–85° inclination and between 500 and 1000 km altitude will enable good measurements of the topside ionosphere. Using only a single SSTL S-band ground station would enable roughly 50 min worth of payload data to be downloaded per day. The mission return may be significantly increased through use of additional low-cost ground stations. This mission solution is a balance between performance and cost. The proposed platform is based on the TopSat satellite (Wicks *et al.* 2001), which is jointly funded by the British National Space Centre (BNSC) and UK Ministry of Defence (MoD) and is currently under construction at SSTL.

The platform has a payload mass allocation of 25 kg. A strawman payload is given in table 1. A swept frequency topside sounder is the main payload and 15–50 m

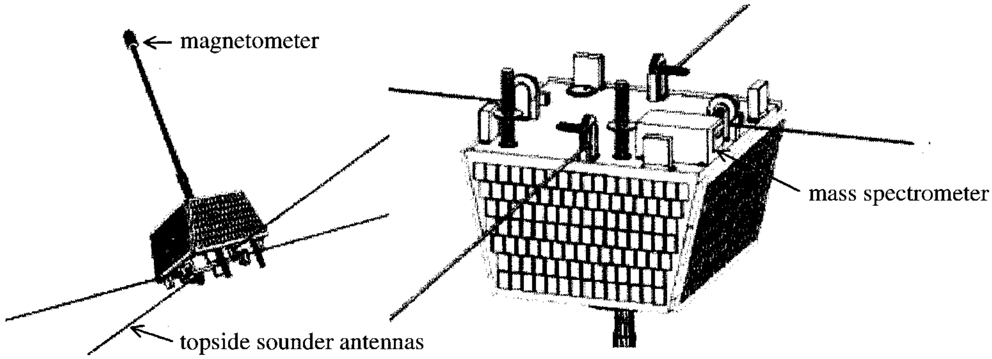

Figure 1. Microsatellite concept for earthquake-science research.

tip-to-tip antennas would be mounted on the Earth-facing facet of the spacecraft as illustrated in figure 1. The mass spectrometer will be mounted so that the inlet is directed on the satellite velocity vector. The magnetometer would be deployed on an instrument boom, which is mounted on the space-facing facet of the spacecraft. More details on preliminary spacecraft accommodation are given in table 1.

Taking into account the spatial scale of the modified ionosphere region (Pulinets 1998*b*), which is of the order of 30° in latitude and longitude for strong earthquakes, the seismo-ionospheric variations could be registered on two neighbouring orbits which will separated by *ca.* 25° in longitude from each other. So, typically up to four passes per day will be achievable for a given seismic zone. A two-year mission lifetime is targeted to provide some continuity in the collected data.

5. Conclusions

Further data are required both to substantiate the existing models that describe the correlation between seismic activity and ionospheric phenomena and in order to be able to establish a clear scientific understanding of their mechanisms. Based on retrospective analysis of existing satellite measurements of seismo-ionospheric variations and existing models, the mission aims to regularly make a set of measurements of relevant ionospheric parameters.

The prime mission payload is a topside sounder flown in a non-synchronous, near-polar, low-Earth orbit. In total, up to 25 kg of payload may be accommodated on the proposed microsatellite and flight of additional payloads should be possible. Exchange of satellite and ground-based measurement data between a range of establishments conducting atmospheric, ionospheric and seismic research will be critical. Small, low-cost satellites enable a relatively small expenditure in order to advance a highly complex and potentially invaluable area of research.

References

Dea, J. Y. *et al.* 1991 Observations of seismo-electromagnetic precursor radiation signatures along Southern Californian fault zones: evidence of long distance precursor ultra-low frequency signals observed before a moderate Southern California earthquake episode. *Can. J. Phys.* **69**, 1138.

Hayakawa, M. *et al.* 2000 NASDA's Earthquake remote sensing frontier project: latest achievements. In *Proc. 22nd Int. Symp. on Space Technology and Science, Morioka, Japan, 28 May–4 June 2000.* Tokyo: Japan Society for Aeronautical and Space Sciences.

Parrot, M. *et al.* 2000 The micro-satellite DEMETER. In *Proc. 22nd Int. Symp. on Space Technology and Science, Morioka, Japan, 28 May–4 June 2000.* Tokyo: Japan Society for Aeronautical and Space Sciences.

Pulinets, S. A. 1998*a* Strong earthquake prediction possibility with the help of topside sounding from satellites. *Adv. Space Res.* **21**, 455–458.

Pulinets, S. A. 1998*b* Seismic activity as a source of the ionospheric variability. *Adv. Space Res.* **22**, 903–906.

Pulinets, S. A., Khegai, V. V., Boyarchuk, K. A. & Lomonosov, A. M. 1998 The atmospheric electric field as a source of variability in the ionosphere. *Phys. Usp. Usp. Phys. Nauk.* **41**, 515–522.

Pulinets, S. A., Boyarchuk, K. A., Hegai, V. V., Kim, V. P. & Lomonosov, A. M. 2000 Quasi-electrostatic model of atmosphere–thermosphere–ionosphere coupling. *Adv. Space Res.* **25**, 1209–1218.

Wicks, A., Jason, S. & Harrison, J. 2001 An EO constellation based on the TopSat microsatellite: global daily revisit at 2.5 metres. In *Proc. 15th Annual Small Satellites Conf., Utah State University, UT, USA, 13–16 August 2001*, paper no. SSC01-I-6. (Available from http://www.aria.cec.wustl.edu/SSC01/papers/1-6.pdf.)