Surveying the Earth's electromagnetic environment from space

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MEETINGS

Surveying the Earth's Electromagnetic Environment From Space

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The scientific objectives of DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) are the detection and characterization of the ionospheric perturbations associated with natural phenomena (such as earthquakes, volcanic eruptions, tsunamis) or with anthropogenic activities. To achieve these objectives, the microsatellite, which was launched at the end of June 2004, surveys the Earth's electromagnetic environment. DEMETER is the first in the Myriade series of microsatellites developed by the Centre National d'Etudes Spatiales (CNES, France) for low-cost science missions.

The mission includes sensors designed to measure six components of the electromagnetic (EM) field (magnetic antennae, electric antennae) in a wide frequency range, and sensors designed to analyze the ionospheric plasma (particle detector, ion spectrometer, and Langmuir probe). It also includes a technological payload (large onboard memory and high-bit-rate telemetry) that allows it to record data all around the Earth except in the auroral zones. The satellite was launched on 29 June 2005 into a circular Sun-synchronous polar orbit at an altitude of 710 kilometers (which was changed to 660 kilometers in mid-December 2005).

Results from this mission and recent advances in the seismoelectromagnetic effects and ionospheric physics were presented at a recent international symposium held in Toulouse, France. This meeting marked the second year in space for DEMETER and brought scientists from several disciplines to share their latest results. More than 125 participants from 27 countries attended this symposium from various research and academic institutions (representing the fields of earthquake hazards, tectonophysics, volcanology, EM emissions, and ionosphere modeling, among others) interested in this comprehensive mission.

Earthquakes and Statistical Analyses of Electromagnetic Signals

Satellite and ground-based observations of electromagnetic environments related to seismoelectromagnetic events can help researchers gain a better understanding about the physics of EM signals related to earthquakes preparation processes.

Presentations of three statistical analyses of the correlation between the EM signals from DEMETER and earthquakes were among the major contributions of this meeting. In the first presentation, Michel Parrot (Centre National de Recherche Scientifique (CNRS), Orléans, France) considered the statistical correlation of the electron density from the Langmuir probe experiment ("Instrument Sonde de Langmuir"; DEMETER ISL) with seismic activity using more than 20 months of data for day and night. This analysis included 2718 strong-type earthquakes with ($M > 4.8$), and depth less then 40 kilometers, registered in the mid latitudinal regions (geomagnetic latitude less than 50°) and during the quiet electromagnetic days (level of $Kp < 4$). The time window considered was 32 hours prior to and after the events. Results showed a systematic increase of electron density 12–24 hours prior to the earthquake occurrence and a significant decrease afterward.

Frantisek Nemec (Charles University, Prague, Czech Republic) then presented analyses that were performed of electrical very low frequency (VLF) fields with the electric field instrument (ICE; data included electric component of the VLF emission up to 20 kilohertz) during the 15 months of satellite operation, which included 2628 crustal earthquakes (depth less than 40 kilometers) with $M > 4.8$. The study was performed in a 20-hour time window prior to and after an earthquake in which a possible correlation between the earthquake occurrence and wave intensity was found.

Jacob Bortnik (University of California, Los Angeles) gave the third presentation in which a statistical analysis of the magnetic component of VLF/ELF (extra low frequency) emissions observed by the Instrument Magnetometer Search-Coil (IMSC) sensor on DEMETER in seven frequency bands (1 hertz to 1 kilohertz) had been performed with a superposed epoch analysis (30 days prior and 10 days after the events), and distance up to 3000 kilometers. Results showed no significant correlation between IMSC data and earthquake occurrence. Following the presentations, participants asked many questions about the applied statistical techniques and addressed multiple recommendations that could increase the future reliability of similar analyses.

Several presentations focused on the physical understanding of EM signals generated by geodynamic activities (seismic or volcanic) including theory, numerical modeling, and/or laboratory experiments. Some authors (Oleg Molchanov, Institute of the Earth Physics (IEP), Moscow, Russia) were considering the use of a VLF transmitter as a monitoring tool for ionospheric perturbations related to seismic activity. One study using powerful transmitters showed that it is possible to conduct sounding of the atmosphere and ionosphere to record changes related to large earthquakes. Reception of the VLF transmitters at the ground shows signatures with a period of several days; these observations were recorded before an earthquake.

Theorizing the Mechanisms of Atmosphere-Ionosphere Coupling

A few papers made the attempt to unite the observed precursors by a general lithospheric-atmospheric-ionospheric (LAI) coupling mechanism, a concept presented at this meeting by Sergey Pulinets (Institute of Earth Magnetism, Ionosphere and Radio Waves, Troitsk, Russia). This mechanism theorizes that the primary process of EM disturbance is the air ionization produced by increased emanation of radon from the Earth's crust in the vicinity of active tectonic faults before an earthquake, which triggers reactions from the ground level up to the ionosphere and magnetosphere of the Earth.

This ionization leads to a change of the air conductivity, and as a consequence a change of the near-ground atmospheric electric field, a latent heat and radiation release. The ionosphere reacts to the changes of electric properties of the near-ground layer, and the electric field induced within the ionosphere causes ion drift and the creation of irregularities of electron concentration. An anomalous electric field penetrating into the ionosphere is mapped along the geomagnetic field lines in the magnetosphere up to the conjugated point of the opposite hemisphere.

A case study demonstrating this effect, presented by Sergey Pulinets and Dimitar Ouzounov (Science Systems and Applications, Inc (SSAI), Greenbelt, Md.), was shown with measurements of intensive ELF emissions in the range of 0–200 hertz registered by the VLF DEMETER/ICE device in conjugated points on 22 March 2005. This measurement was made six days before an $M8.7$ seismic shock when the satellite passed close to the earthquake epicenter. The registered emission was associated with the formation of plasma bubbles floating up to the DEMETER orbit altitude, demonstrating cold rarified plasma in conjugated points. The observed effects can be interpreted as strong electrostatic turbulence development due to anomalous electric field of seismogenic origin.

Another approach of explaining preseismic LAI coupling was supported by other authors (Oleg Molchanov, IEP; G. Lizunov, Lviv Centre of Institute of Space Researches, Lviv, Ukraine) who postulated that near-surface water/gas releases produce atmospheric gravity waves (AGW), which penetrate into the ionosphere and lead to modifications of ionospheric turbulence (IT). This could be the reason for VLF signal resonant scattering observed on satellites. The two theories of LAI coupling were debated during the course of the meeting, and they need additional validation with ground and satellite observations.

In addition, Philippe Lognonne and Francois Crespon (Institut de Physique de Globe de Paris, France) presented multiple case studies of postseismic effects, created mostly by earthquake and tsunami events, and the corresponding observed related effects in the ionosphere generated by AGW propagation.

Studying Other Ionospheric Phenomena

DEMETER satellite and ground-based observations provided new data about the ionospheric processes related to some natural and man-made activities connected with solar-terrestrial relations.

Searching for human-made activities that influence the ionosphere (such as power line harmonic radiation (PLHR), VLF transmitters) requires initial filtration of small oscillations from the background noise. A demonstration of such an approach, the artificial intelligent methods suitable for level 3 DEMETER data analysis, was made by Oleg Batanov (Space Research Institute, Moscow, Russia). Jean-Andre Sauvaud (Centre d'Etude Spatiale des Rayonnements (CESR-CNRS), Toulouse, France) showed that using the particle detection instrument (IDP) spectrometer, wave-analyzed anthropogenic electron precipitations are found to be modulated by the geomagnetic activity which fills the inner radiation belt. Multiple observations of magnetospheric line radiation (MLR) events show that they probably are produced at low altitudes over wide areas and triggered by PLHR. Nemec then illustrated that the systematic search of PLHR using data from DEMETER shows evidence for wave-particle interactions. A detailed explanation requires additional theoretical studies and modeling simulations.

Active experiments were conducted from the ground to perform and study controlled ionospheric perturbations. A presentation by Umran Inan (Stanford University, Calif.) confirmed that DEMETER provides an outstanding opportunity to understand the loss of energetic radiation belt particles by injecting coherent signals of known origin.

One type of experiments involves the use of High Frequency Active Auroral Research Program (HAARP) high-frequency heating facility in Gakona, Alaska, which is used to inject signals in the frequency range of few tens of hertz to a few kilohertz, for detection on DEMETER during its overpasses of either HAARP or its geomagnetically conjugated region.

Wave analysis was performed using IDP data to search for signatures of electron precipitation. A similar analysis was shown using the NPM facility in Hawaii and Sura in Russia, injecting several tens of pico Tesla. Because of the record of data all around the Earth, DEMETER offers a good opportunity to study the natural ionospheric phenomena in particular.

Several papers examined ionospheric processes occurring in equatorial and midlatitude regions related to solar activity or thunderstorm activities and associated events (Ondrej Santolik, Charles University; Jean-Louis Pinçon, CNRS; Feng Li, CNRS; Jean-Jacques Berthelier, Centre d'Etudes des Environnements Terrestre et Planétaires, Saint-Maur-des-Fossés, France).

EM ground-observed signatures of transient luminous events (TLEs) were detected in the electrical and magnetic DEMETER data, and some results show correlation between TLEs and ULF bursts of quasi electrostatic field above the stormy regions (François Lefeuvre, CNRS).

The final session of the symposium was dedicated to future missions and instrumentation. Because of the vast international interest in the DEMETER mission, several new mission concepts similar to it were presented. The main opinion expressed during the session confirms that the mission exceeds its main dedicated goal to study the seismoelectromagnetic phenomena and could provide valuable information on the natural phenomena connected with solar-terrestrial relations. The mission has stimulated the creation of several new satellite systems in Kazakhstan, Japan, Turkey, and China, and the current DEMETER design and type of payloads were used as a model for the future systems.

Details about the DEMETER mission and the science program of symposium can be found online (see http://smsc.cnes.fr/DEMETER/index.htm and http://www.cta-events.com/demeter/comprogrammegb.htm). A description of the major science payload can be found in a special issue of *Planetary and Space Science* (volume 54, 2006).

The DEMETER International Symposium, "Results of the DEMETER project and of the recent advances in the seismo-electromagnetic effects and the ionospheric physics," was held 14–16 June 2006 in Toulouse, France.

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