T52D MCC: 3007 Friday 1340h

Ground and Space Methods for Monitoring EM Preearthquake Phenomena II *(joint with GP, S, SA, V)*

Presiding: **D Ouzounov,** NASA Goddard Space Flight Center**; F Freund,** San Jose State University

T52D-01 1340h INVITED

The ESPERIA Mission

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ESPERIA is an equatorial mission planned with a Low-Earth-Orbit small-satellite and a multi-instrument payload for monitoring preseismic electromagnetic emissions in the near-Earth space and consequent perturbations and instabilities they produce in the atmosphere, ionosphere, and magnetosphere. The space project has been proposed by an International Consortium lead by the University Roma Tre, for an electromagnetic, plasma, and particle mission.
The primary aim is to study ionospheric and magnetospheric effects caused by seismicity to develop methods for the evaluation of seismic risk (providing for disaster assessment) and give contribution in earthquake forecasting studies.
At present, a phase A study has been completed for the Italian Space Agency (ASI).
To achieve the objectives with maximum reliability, the ESPERIA scientific program is planned with strong emphasis on coordinated, simultaneous, and continuous ground-based and space observations. On board the satellite ULF $\div$ HF electromagnetic fields, fluxes of charged particle (300 keV $\div$ 2GeV), and ionospheric plasma temperature and density will be detected. Ground-based measurements of mechanical (tilt and strain) and electromagnetic fields will be carried out in several test areas.
The same space project is also planned for investigating electromagnetic emissions of anthropogenic origin (power line harmonic radiation, VLF and HF transmitters).
With some augmentation and/or changes in the payload, ESPERIA can also be used for defining the near-Erth electromagnetic, plasma, and particle environment, studying important phenomena during thunderstorm activity (or sprites, blue jets, elves, gamma and electromagnetic emissions), or investigating equatorial electrojets.

T52D-02 1355h INVITED

Electron Density Variations in the Ionosphere During the Gujarat Earthquake Event

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Ionospheric perturbations by natural geophysical activity, such as volcanic eruptions and earthquakes, have been studied since the great Alaskan earthquake in 1964. Measurements made from the ground show a variation of the critical frequency of the ionosphere layers before and after the shock. In this paper, we present an experimental investigation of the ionospheric electron density variations around the time of the Bhuj earthquake in Gujarat, India (23.4N, 70.3E, M = 7.6, d = 17 km). Several experiments have been used: the low-altitude satellite TOPEX-POSEIDON which measured fluctuations in the integrated electron density or TEC (Total Electron Content) between the satellite and the ground to correct the altimetry measurement, a GPS experiment which gives another TEC measurement from a fixed ground-based station in Bangalore (13.02N, 77.57E), and a ground-based ionospheric sounder in Ahemadabad (23.0N, 72.4 E). Anomalous electron density variations have been detected both in day and night times before the quake. A possible mechanism which could explain these variations is given.

T52D-03 1410h INVITED

Ionospheric precursors of earthquakes. Theory and practical applications

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The recent ten years were successful for understanding of the nature of seismo-ionospheric coupling. The physical model was created which permits to explain the most of precursory phenomena observed in the near ground atmosphere and ionosphere in the form of electromagnetic emissions and ionospheric plasma modification associated with prepared earthquake. The main parts of the model are: the model of anomalous electric field generation in the earthquake preparation area, penetration of the anomalous electric field into the ionosphere, and electric field effects within the ionosphere. The model is self-consistent in the way that all parameters of the model correspond to the values measured experimentally. The specific ionospheric variations appearing over the area of the earthquake preparation 1-5 days before the earthquake and named as ionospheric precursors of earthquake are now well studied. Their main phenomenological features are clarified what permits to create the techniques of their automatic recognition. The advantage of the ionospheric precursors is that they permit to answer on the main three questions of the short-term prediction: When? Where? How strong? Both the model of seismo-ionospheric coupling and techniques which can be used in short term earthquake prediction will be described.

T52D-04 1425h INVITED

Observed Weather Satellite Thermal Responses Prior to and After Earthquakes

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The observance of a “thermal anomaly” 15 hours prior to the occurrence of the Hector Mine, California earthquake of October 1999 by thermal infrared sensors (10.4-12.5 microns) on Landsat-7, lead to further investigation of the phenomenon with polar orbiting and geosynchronous weather satellites. New techniques were developed to assure the precise co-registration of all satellite scenes and permit accurate time-series analyses of satellite observations, studies not previously undertaken for significant earthquake events. Contrary to expectations, apparent measurable ground temperature increases of limited area extent near the faults were observed only hours prior to the earthquake and observed over a much broader area for a short duration afterwards. Investigation of two other large earthquakes, on 17 August 1999 near Izmit Turkey and on 26 January 2001 near Bhuj, India, showed similar elevations in apparent ground surface temperature shortly prior to the events and up to a day after each event. These results would appear to rule out explanations in the literature because of the rapidity of pre-event thermal change and the broad extent of post-event apparent temperature elevation. A possible explanation for these observations may be that thermal infrared luminescence rather than emissivity is the contributing mechanism.

T52D-05 1440h

Earth-Atmospheric Coupling Before Earthquakes by Analyzing Multi Parameter Satellite Data

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Satellite thermal imaging data indicate long-lived thermal fields associated with large linear structures and fault systems in the Earth's crust but also short-lived anomalies prior to major earthquakes. Because the short-lived anomalies come and go so quickly, the possibility that they would be caused by an actual heat pulse arriving at the surface from deep within the Earth can be ruled out. Despite the multitude of models, no comprehensive explanation has been offered until now that the science community found acceptable. Here we address some of the challenges posed by the short-lived thermal anomalies: (i) How can be identify the source and mechanism of the apparent surface temperature increase;(ii) How do the thermal anomalies correlate in space and time with the earthquakes and their epicenters; and (iii) How can we account for the rapid appearance and disappearance of the anomalous temperature field. This work is presented here only as an introduction to answer these questions. First we present several examples of EOS Terra/MODIS and Aqua/MODIS land emissivity and atmospheric water vapor anomaly data that have been used to track mid-IR anomalies, which appear to be related to impending earthquake activity (M>5). Next, we touch on the question how transient shallow sea surface temperature anomalies (SST), which have been observed,may be related to impending major seaquakes. We are exploring the idea that SST or anomalous chlorophyll and salinity values that can be derived from IR satellite observations may correlate with the location of some shallow seaquakes. Lastly, we describe high resolution mid-IR emission (7-14 micron range) spectra recorded from the outer surface of blocks of rock, which were centrally loaded until failure. The spectral signature obtained leads to a better understanding of the physics of pre-earthquake ”thermal anomalies”.

T52D-06 1455h

Seismically Active Areas Monitoring by TIR Robust Satellite Techniques: a Sensitivity Analysis on Recent Events Occurred in Europe

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Space-time fluctuations of Earth's emitted Thermal Infrared (TIR) radiation observed from satellite, months to weeks before earthquakes occurrence, have been, by several authors interpreted as pre-seismic signals. A robust approach (RAT) has been recently proposed (and successfully applied in the field of the monitoring of the major environmental risks) that permits to give a statistically based definition of TIR anomaly also considering the other natural (e.g. due to space-time changes in atmospheric transmittance or surface emissivity and morphology) and observational (time/season, but also solar and satellite zenithal angles) factors that, rather than earthquake occurrence, could be responsible of observed TIR signal fluctuations. In this work the actual potential of satellite TIR surveys for seismically active areas monitoring is evaluated on the base of several years of NOAA/AVHRR and METEOSAT observations over Europe. TIR signal anomalies, possibly associated to earthquakes recently occurred in Europe, have been particularly considered in order to evaluate the robustness of the proposed approach against the possibility of false events detection (specially important for this kind of application) as well as its intrinsic exportability not only on different geographic areas but also on different satellite instrumental packages.

T52D-07 1510h

A Collaborative Approach for Providing Low-Cost ELF Monitoring from Ground and Space

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This paper describes a collaborative effort among several groups, including a small business (QuakeFinder,LLC), dozens of high schools in northern California, several universities (Stanford and Cal Poly SLO), and Lockheed Martin in Sunnyvale to build a combined ground-based and space-based ELF monitoring system. The goal is to monitor and characterize the raw RF spectrum in the ELF band, and to look for pre- and post-earthquake signatures. Previous attempts at monitoring ELF signals associated with earthquakes have always been summarized with the statement, **more data is needed**. QuakeFinder is a small business that approached the problem with a different strategy. Rather than deploy a few, expensive, commercial high sensitivity, AC magnetometers on the ground, a collaboration was formed with high school physics classes to build a large number of medium sensitivity magnetometers from partially-assembled kits, and to deploy these sensors in a close spacing along the major California earthquake faults. The strategy was to have a 3-axis ELF ground monitor within 15 km of any large (>M5) quake– before, during, and after the event. To date, 34 sites have been deployed (out of 50 planned), and they now collect and display daily averages from these 3-axis monitors on a web site (www.earthquaketracker.com).
Likewise, satellite-based monitoring is severely restricted by the high cost of building and flying space-based ELF monitors. QuakeFinder formed a collaboration between Stanford Space System Development Laboratory and Lockheed Martin to design and build a nano-satellite (4.5 kg) whose mission was to collect ELF background signatures. QuakeFinder built and donated a single axis ELF (1-1000Hz) magnetometer payload and provided integration and a launch opportunity for “QuakeSat I”. The satellite was launched on June 30, 2003 into a 820 km circular polar orbit, and has recorded natural signals (lightning, whistlers, auroral noise, and several unidentified signatures) as well as man-made (radar) signals. At this writing, it is early in the project, and more signal analysis and statistics are needed to determine if earthquake-related signals are present. The paper will report on the result of QuakeSat tasking over epicenters of >M6 earthquakes for post seismic correlations, and over seismically active areas worldwide for pre-seismic correlations of increasing ELF signals.

T52D-08 1525h

integrated Search for Taiwan Earthquake Precursors (iSTEP)

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Taiwan is located in an active part of the Circum-Pacific seismic belt. Due to intense collision between the Philippine Sea and Eurasian plates, Taiwan experienced many disastrous earthquakes in the past. The incessant plate collision means that we will inevitably face earthquake hazards in the future. Unfortunately, occurrence of earthquakes still cannot be forecast, much of this is due to lack of predictive capability. The problem of earthquake prediction has been under intensive investigations for nearly forty years in Japan, China, and the U.S. Yet relatively little progress is made thus far. Our frustration over the surprising difficulty of earthquake prediction problem has recently led to a serious debate within the seismological community on predictability of earthquakes. At the heart of the debate is the question on whether there are recognizable precursors of earthquakes? What could be precursors of impending earthquakes? A multitude has been suggested, but it is not clear which, if any, may become reliable. To search possible seismo-precursors and take into account the strength of our research team we decide to undertake this overall project, called Research on Seismo-Electromagnetic Precursors of Earthquakes (or integrated Search for Taiwan Earthquake Precursors (iSTEP) during April 2002 - March 2006. It consists of five inter-related sub-projects covering the following precursor topics: Sub-project I - A Study of seismological variations; Sub-project II - variations of the geomagnetic and gravity fields; Sub-project III - Radar interferometry for detection of surface deformation; Sub-project IV - Ionosospheric variations; and Sub-project V - Statistical studies of earthquake precursors. We then correlate the observed precursors by our sub-projects, as well as by other research organizations, with existing earthquake preparation models to (i) identify any possible, yet reliable precursory phenomena of earthquakes, including seismological, geodetic, geomagnetic, and ionospheric changes, and others, (ii) characterize feasible mechanisms behind the identified precursory phenomena in order to give quantitative physical interpretations and (iii) correlate the identified precursory phenomena with existing or emerging earthquake preparation models in order to lay foundation for future earthquake prediction. In this paper we report the current status and some latest results of the iSTEP.

T52E MCC: 3005 Friday 1340h

Structure and Dynamics of the Oceanic Upper Mantle IV *(joint with OS, S, V)*

Presiding: **J Korenaga,** Yale University**; S Zhong,** University of Colorado

T52E-01 1340h

Mantle Flow Beneath Slow-Spreading Ridges Constrained by Seismic Anisotropy in Atlantic Lithosphere

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Seismic anisotropy within the oceanic lithosphere provides one of the most direct means to study deformation associated with convection in the mantle. Advection beneath a mid-ocean ridge spreading center deforms the mantle rocks, and as the rocks cool to produce the oceanic lithosphere, they retain a record of this deformation in the form of lattice-preferred orientation (LPO) of olivine grains. LPO direction and strength can be estimated from directional and/or polarization dependence (anisotropy) of seismic wave speeds, and mid-ocean ridge mantle flow properties can be inferred. Mantle flow beneath the slow-spreading Mid-Atlantic Ridge (MAR) is suspected to be strongly three-dimensional due to the influence of hotspots and other thermal variations, and this thermal heterogeneity may be related to buoyancy-driven flow beneath the ridge. This notion is supported by two analyses of lithospheric anisotropy in the Atlantic, which until recently had not been well characterized. Radial anisotropy imaged near the hotspot-influenced Reykjanes Ridge implies a quasi-vertical (rather than horizontal) orientation of the lithospheric fabric. Azimuthal anisotropy within a narrow swatch of western Atlantic lithosphere that was formed via ultra-slow spreading is weaker than that found in the Pacific by a factor of two. Both can be interpreted in terms of buoyancy-driven flow beneath the MAR. Here we extend these results using regional surface-wave analyses of the Atlantic basin. Earthquakes from Atlantic source regions recorded at broad-band seismic instruments located on Atlantic islands and the surrounding margins provide excellent sensitivity to oceanic lithosphere structure, without contamination by continental heterogeneity. By characterizing such structure in both hotspot-influenced (e.g. Azores) and normal slow-spreading lithosphere, and comparing these structures to the Pacific, we evaluate the degree to which spreading rate and/or mantle source temperature control fabric and mantle flow beneath mid-ocean ridges.

T52E-02 1355h

Cause and Effect: Seismic Anisotropy Measurements Using Full Wavefield Simulations in Realistic Mantle Flow Models.

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The supra-slab mantle wedge is a site of relatively small-scale flow of mantle material. Wedge flow is controlled by the rate, angle and direction of slab descent, the shape of the subducting slab and the nature and behavior of the overriding plate. The simplest geodynamic model for the mantle wedge is a 2-D corner flow driven by the shear coupling to the down-going plate. An upper mantle wedge at a convergent margin that deforms in corner flow should develop a trench-normal olivine LPO texture detectable by seismic anisotropy studies. It is considerable concern therefore that most studies of seismic anisotropy within supraslab wedges do not conform to expectations from this simple 2-D corner flow regime. We perform a systematic exploration of seismic anisotropy indicators expected in a subduction zone. Our primary goal is to separate effects of "true" anisotropy from other contributions to the complexity of S waveforms, like propagation in complex 3D structure, specific biases of individual measurement techniques, frequency content of the wavefields etc. We use models composed of the mantle, the slab, the supraslab wedge and the crust. Anisotropy may be prescribed in one or more regions of the model. In particular, in the supraslab wedge we prescribe flow lines, and an associated pattern of anisotropic seismic velocities. Our wave propagation code allows for 3D heterogeneity in (anisotropic) velocity structure (crust, slab, subslab mantle, supraslab mantle) plus tilt for alignment with flow fields of any geometry. The code uses a finite difference solution of the elastic wave equation and allows for both point sources and upcoming plane waves of any back-azimuth and inclination (Okaya and McEvily, 2003). We compute S wavefields for a range of incidence parameters, and perform measurements of anisotropy as we would if these were real data. To evaluate resulting birefringence, we use two commonly used techniques for estimating shear wave splitting. The first method seeks a rotation of observed seismograms that would yield waveforms on two components that are most similar, and then evaluate the delay between them via cross-correlation. The second method seeks a combination of a rotation and a delay which, once it is used to correct for the effect of anisotropy, would minimize one of the components of motion. We also use a recently developed algorithm of Menke and Levin (2003) that is based on explicit wavefield comparison of "observed" and "predicted" wavefields, and allows to search for group solutions using multiple observations. Preliminary results show that the combined influence of effects other then anisotropy cause significant "deviations" of seismic anisotropy parameters recovered by standard measurement techniques from the "true" flow patterns in the model mantle. Of particular importance is the geometry of the wave propagation relative to the flow pattern.

T52E-03 1410h

Trapped Heat in the Mantle: The Origin for Topographic Flattening at Old Seafloor.

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It is well known that the rates at which seafloor topography and heat flux vary with age are greatly reduced at old seafloor (i.e., flattening), compared with the predictions from the half space cooling model. The origin for the reduced rates remains unresolved. In the conventional plate model, plate cooling is arrested at old seafloor through sublithospheric small-scale convection (SSC) that removes the bottom part of lithosphere and homogenizes it with the underlying mantle, leading to a constant lithospheric thickness at old seafloor and reduced rates of variations in topography and heat flux with age. While recent surface-wave tomography studies in the Pacific provide evidence for SSC and its associated lithospheric structure, it has been long debated whether SSC leads to topographic flattening or deepening, given that SSC could cool the mantle more efficiently to give rise to a even colder mantle below old seafloor than that without SSC. We have formulated numerical models to examine the effects of SSC under a mobile plate on the seafloor topography. In models with flow-through boundary conditions that best mimic the cooling of initially hot flow and isolate the effects of SSC, We found over a large parameter space for mantle rheology and plate motion that SSC has little influence on the topography which undulates around but closely follows the prediction from the half-space cooling model. However, in more realistic models with significant internal heating in a closed box, we found that heat tends to accumulate below old lithosphere, leading to topographic flattening. The heat accumulation below old lithosphere occurs because the thick lithosphere results in less efficient heat transfer than that at young seafloor. When SSC is absent, the accumulated heat is distributed over a large depth range. However, SSC brings the heat to shallow depths below the thinned lithosphere and causes largely uniform temperature in the underlying mantle.

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