

## SESSION A

### PRESENT STATUS AND STRATEGY OF SHORT-TERM EARTHQUAKE PREDICTION

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In common sense, earthquake prediction means short-term prediction. This is what people expect and scientists should try to achieve. Short-term prediction needs some precursor(s). However, this simple fact does not seem to be accepted by earthquake scientists, the seismologists. More precisely speaking, they well know the needs of precursor(s), but they also know that seismology is not fit for finding them, because they are normally not earthquakes and not recorded by seismometers.

“Since we experts of earthquake science can not, nobody else can. Therefore, research on precursor(s) should be stopped. Scientists should forget about short-term prediction and spend time and money on the fundamental research in seismology.” As a result, there is practically no funded research on short-term prediction in Japan. Roughly speaking, this is what has happened everywhere. Ordinary citizen is not informed about this lack of research at all, and is kept in unfounded belief that research on short-term prediction is in steady progress. This current tide is fundamentally wrong because the short-term prediction will be accomplished by and probably only by non-seismological approach.

In fact, many credible precursors have already been found. Examples are pre-seismic anomalies of hydro-geochemical features, radon/helium emissions, telluric currents, geomagnetic field, and electromagnetic wave transmission. Unfortunately, the observations have mostly been made isolatedly, so that overall credibility and repeatability have been doubted. These phenomena have to be jointly observed and thoroughly documented by dense multi-disciplinary networks and consistent theories have to be developed as soon as possible. At this stage, the greatest drawbacks to real success are the lack of funding to operate such networks. We need a wise strategy. If any partial funds become available anywhere, Indonesia, India, China or anywhere else (Japan is unlikely!), best way to quick success would be to internationally concentrate our resources and wisdom there to perform ideally designed field work on the ground and cooperate with satellite-borne observations.

# SEISMO ELECTROMAGNETICS: REVIEW

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A review on our recent activity on Seismo electromagnetics is presented. We list the topics of our research one by one, and present some important findings for each topic.

## 1. Seismogenic ULF emissions (Lithospheric effect)

The observation of seismogenic ULF emissions has been continued for the last several years in the Tokyo area. This Kanto network consists of several observing stations (Izu peninsula, Boso peninsula, Kakioka, Chichibu, Matsushiro), the spacing of which is of the order of 70-80 km in order to respond to any big earthquakes in the Tokyo area.

The highlight from this Tokyo ULF network was the event of Izu islands earthquake swarm in July, 2007. We have found a significant ULF signature of this earthquake swarm by using different kinds of signal processing (Principal component analysis (Gotoh et al., 2002; Uyeda et al., 2002; Hattori et al., 2004), direction finding (Kopytenko et al., 2002; Ismaguilav et al., 2003), fractal analysis (Gotoh et al., 2003; 2004) etc.).

Because of the nature of the observation of seismogenic ULF emission as a local measurement, the number of reliable ULF signatures of earthquake is still no many, being of the order of 20-30 events so far (Hayakawa et al., 2007). Hence it is highly required for us to accumulate as many events as possible. This means that more sophisticated signal processings are of essential importance in identifying weak seismogenic ULF-emissions. Our recent main concern is the use of fractal (mono- and multi-)analyses for a few particular earthquakes in order to understand the nonlinear process taking place in the lithosphere. These analysis results are to be included in the improvement of the generation mechanism previously proposed by Molchanov and Hayakawa (1995).

## 2. Seismo-atmospheric effect (Observation of over-horizon VHF signals)

### 2.1. Atmospheric perturbation

We established a VHF network in Japan, covering from Sendai (Tohoku region) down to Kagoshima, and we are ready to look for any earthquakes near the coast of Pacific Ocean (Nankai, Tohankai, Takai earthquakes) (Hayakawa et al., 2005). Based on our previous works by Fukumoto et al. (2001) based on the direction finding, it is found that the reception of over-horizon VHF signals (FM transmitters) is due to the atmospheric perturbation due to the earthquake (definitely not ionospheric perturbations). The VHF network observation is working good.

As for our scientific research, we have recently published a few papers on this subject. Yonaiguchi et al. (2007) have performed a study on the statistical correlation of over-horizon VHF signal (FM Sendai- Chofu) with radio duct occurrence and earthquakes, and have found that the radio duct effect is rather dominant in July-September, but the VHF signal is correlated with earthquakes in other seasons. Then, Hayakawa et al. (2007) have proposed a generation mechanism of such atmospheric perturbations based on the changes in geochemical quantities associated with earthquakes.

### 2.2. Atmospheric radiation

The observation of lithospheric VHF electromagnetic noise (radiation) was carried out in collaboration with Tohoku Intelligence Communications, Ltd. in the Sendai area. The VHF radio noise data observed at several stations have been analysed on the basis of SOC (Self-organized criticality) concept by using different kinds of fractal analyses (spectrum slope, Detrended

fluctuation analysis, Wavelet based analysis etc.) for a particular large earthquake in August, 2005 (Miyagi-ken oki earthquake) (Yonaiguchi et al. (2007a, b, in press)).

### 3. Seismo-ionospheric perturbations

#### **Anomalous Schumann resonance phenomena**

Schumann resonance is a resonance phenomenon in the Earth-ionosphere cavity, which is triggered by the background lightning activities in the three lightning centers (Africa, Asia and America) (Nickolaenko and Hayakawa, 2002). The fundamental frequency is 8 Hz, and its harmonics are 14, 20, 24 Hz or so. The stability of these fundamental and higher harmonics is so stable that it can be used exactly like the VLF/LF transmitter signal.

We have found the anomalous Schumann resonance phenomena observed in Japan, which are thought to be associated with the earthquakes in Taiwan. Hayakawa et al. (2005) have found the 1st event for the Chi-chi earthquake in Taiwan ( $M = 7.6$ ) on September 21, 1999. The anomaly in Schumann resonance in Japan, was characterized by (1) an enhancement in the fourth harmonic and (2) the frequency of this 4th harmonic is significantly shifted from the conventional value by about  $\sim 1.0$  Hz. This anomaly is interpreted as interference between the direct signal from South America and the wave scattered from the ionosphere over Taiwan associated with this earthquake. Later, this experimental result has been further confirmed by a much larger data set during 6 years observation in Nakatsugawa (Chubu University, Prof. Ohta's group). Land earthquakes in Taiwan are found to trigger the anomalous Schumann resonance in Japan (Ohta et al., 2006), and further improvement in model computations has been done (Nickolaenko et al., 2006).

#### **VLF subionospheric observation of seismo-ionospheric perturbations**

The routine observation of VLF/LF transmitter signals has been continued in Japan by means of our VLF/LF network. The observing stations are (1) Moshiri (Hokkaido), (2) Chofu, (3) Chiba, Tateyama, (4) Shimizu, (5) Kasugai (Nagoya), (6) Maizuru (Kyoto), Kochi. At each station, we observe simultaneously several VLF/LF transmitters; (1) JJY (Fukushima, 40 Hz), (2) JJI (Kyushu, Ebino), (3) NWC (Australia), (4) NPM (Hawaii), and (5) NLK (USA). The data have been accumulated in Chofu nearly for about ten years.

As a new observation, we have just started the observation at Chofu of Doppler shift for JJY signal in collaboration with Dr. Asai. The data are being accumulated.

#### 3.1. Statistical correlation between the ionospheric perturbations and earthquakes

Six years data are used for the statistical study by using the propagation path from the JJY transmitter to the receiver at Kochi (Maekawa et al., 2006). The way of analysis is based on the difference (residue) of the signal,

$$dA(t) = A(t) - \langle A(t) \rangle$$

where  $A(t)$  is the amplitude at a time  $t$  for a current day and  $\langle A(t) \rangle$  is the corresponding average at the same time  $t$  for  $\pm 15$  days. Two physical quantities are treated; (1) average amplitude (or trend), (2) amplitude dispersion (fluctuation). The statistical test study has yielded the following conclusion. (1) the amplitude is significantly decreased (about 3 dB) a few days before the earthquake and (2) the fluctuation is significantly enhanced before the earthquake. This study has yielded a significant correlation between the LF characteristics (amplitude and fluctuation) and earthquakes with magnitude greater than 6.0.

#### 3.2. Case studies on seismo-ionospheric perturbations

We have done a few case studies including (1) Niigata earthquake (Hayakawa et al., 2006) and (2) Indonesia, Sumatra earthquake (Horie et al., 2007a, b).

Here we show the summary of our study on ionospheric perturbations associated with the latter

Sumatra earthquake on 26 December, 2004. The magnitude of this earthquake was 9.0 and the focal depth was 30 km. We use the propagation paths from the Australian VLF transmitter, NWC ( $f = 19.8$  kHz) to the Japanese stations (Kochi, Chofu, Chiba). The distance of these great circle paths to the epicenter is 2,000 km, so that it is impossible for us to detect any ionospheric effect for the earthquake with magnitude 6-7. By using the fluctuation method (as mentioned before), we have found that there were a few periods with significant nighttime fluctuation (December 8 and December 21, 2004 to January 2, 2005). During the latter period, the Japanese stations (Kochi, Chofu and Chiba) have exhibited the significant enhancement in fluctuation, which seems to be a precursory effect of this earthquake. Hence, the radius of possible ionospheric perturbation is found to be, at least, 2,000 km (Horie et al., 2007a).

More detailed study on the fine structure in the amplitude records at the Japanese stations, have indicated the presence of wave-like structures in the fluctuation. By using the cross-correlation and superimposed epoch analyses, we came to the following. (1) The fluctuation spectrum in the period range from 20-30 minutes to 100 minutes (the frequency of atmospheric gravity waves) is enhanced before the earthquakes. (2) The time delay at Chiba is about 2 hours with respect to Kochi, and the propagation velocity is  $\sim 20$  m/s (Horie et al., 2007b).

The same NWC signal was detected on board the Demeter satellite, and this satellite results indicates that the signal intensity is significantly depressed before the earthquake (Molchanov et al., 2006). This can be explained in terms of the enhanced absorption of whistler-mode VLF signals in the lower ionosphere (as detected by the subionospheric propagation).

#### 4. Lithosphere-atmosphere-ionosphere coupling

We have already proposed a few possible mechanisms; (1) chemical channel, (2) acoustic channel and (3) electromagnetic channel. We have found that the channel (3) seems improbable due to the emission intensity from the lithosphere, which is too weak to induce any ionospheric effects. So, both channels (2) and (3) are likely to be in operation. Our previous section has indicated an example of atmospheric gravity waves playing a key role in the lithosphere-atmosphere-ionosphere coupling. However, the channel (1) is also worth examining extensively (Molchanov and Hayakawa, 2007).

## **SESSION B**

### **THE DEMETER MISSION: OBJECTIVES AND FIRST RESULTS OF THE STATISTICAL ANALYSIS**

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DEMETER is an ionospheric micro-satellite launched on a polar orbit at an altitude of 710 km. Its main scientific objective is to study the ionospheric perturbations in relation with seismic activity, and then, its scientific payload allows to measure electromagnetic waves and plasma parameters all around the Earth except in the auroral zones. First the paper will present the scientific payload and the mission. Second the paper will show specific events where the ionospheric parameters are perturbed prior to large earthquakes above the future epicentre. Although, these examples have been carefully selected (close in time and space to the earthquakes, abnormal variations relative to the background level for the same location, the same local time and the same magnetic activity) it is always possible that the perturbations are due to other natural mechanisms because the ionosphere is highly variable and mainly under the control of the sun. Only a statistical analysis of the data is able to remove this ambiguity. As there are now nearly three years of data, a statistical study has been set about the variation of these parameters during the seismic activity. The statistic is done as functions of the geographic position, the local time, and the magnetic activity. Geographical maps with average data are obtained to be used as background levels, and the superposed epoch method is applied to merge the data recorded during seismic activity. Comparison is done when we remove the aftershocks from the statistics.

## **IONOSPHERIC PERTURBATIONS PRIOR TO A STRONG EARTHQUAKE IN THE INDONESIAN REGION**

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This paper presents the ionospheric variability observed by the micro-satellite DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) during a strong earthquake. The DEMETER is the first micro satellite developed by CNES (French National Space Agency) for seismo-ionospheric studies. The scientific objective of DEMETER is the detection and characterization of electro-magnetic signals associated with natural phenomena (such as earthquakes, volcanic eruptions, tsunamis) or anthropogenic activity. The satellite registered data prior to a large earthquake of magnitude 8.7 which occurred in the Sumatra region of Indonesia on 28<sup>th</sup> March 2005. The epicentre of this earthquake lies in the equatorial region. Density variations and electrostatic turbulence have been observed during six days before the main shock. The statistical study of electron density postulates the observed ionospheric variations may be attributed to the seismic activity.

## **EVIDENCES SHOWING SUDDEN VARIATIONS OF ELECTROMAGNETIC SPECTRUM DURING SEISMICITY IN THE IONOSPHERE**

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Ionospheric effects of earthquakes (EQs) have been intensively investigated during the last two decades. However, it is still open for the debate. In this paper efforts have been made to show seismic associated precursory electric and magnetic burst, detected in the topside of the ionosphere (>600kms) by micro-satellite, DEMETER (Detection of Electro Magnetic Emission Transmitted from Earthquake Region). From the obtained results, it could be shown that the possible earthquakes influence on ionosphere can be explained in terms of modification of near equatorial anomaly by solar activity and internally generated gravity waves that are penetrated from troposphere above the earthquake epicenter.

**Keywords:** Electric burst, ionosphere, magnetic burst, micro-satellite, solar activity.

## CONSUMPTION OF PHOTOELECTRON ENERGY DUE TO ENHANCED ELECTRON DENSITY - EFFECT OF THE WESTWARD ELECTRIC FIELD-

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To study the effect of the earthquake on the ionosphere, we need to take 3 stages. We first need to grab general features of Te/Ne such as on local time, season, solar flux, latitude and longitude (Su et al., 1997, 1997, 1998). After we understood features above, we have constructed Te/Ne model. Te behavior during geomagnetic disturbance has been studied by applying models. We found that both Te/Ne models are quite reasonable. Especially Te model shows that 50 degrees K deviation at night has geophysical meaning (Oyama et al., 2005). Finally the third step is to try to find deviation of Te from the model value associated with earthquake. So far we have studied three earthquakes; those are: EQ1, which occurred on 22 November 1981 with magnitude of 6.6, depth of 37 km, and epicenter of 14.09E/ 124.35 N, EQ2, which occurred on 11 January, 1982 with magnitude of 7.4, depth of 45 km, and epicenter of 13.75E/ 124.36N, and EQ3, which occurred on 24 January, 1982 with magnitude of 6.6, depth of 37 km, and epicenter of 14.09 E/124.35 N.

We found that Te in the afternoon overshoot reduces prior to and after earthquake. Ionogram data which was obtained at Manila show the reduction of NmF2 as well as reduction of h'F in the afternoon, whilst Taipei ionogram shows a slight increase of nmF2, but no clear h'F variation was not detected.

Combination of satellite data as well as ground-based data implies the existence of westward electric field. The westward electric field reduces the eastward electric field, which is generated by neutral wind (dynamo electric field). Accordingly crest of the equatorial ionization anomaly moves equator ward and at the same time Ne at the crest region reduces. The westward electric field becomes more dominant as the latitude increases, pushes ionospheric plasma down, and forms a high electron density region. This high-density region remains after later afternoon, than normal days. The photoelectrons which travel along magnetic line of force through the high-density region consume their energy there and they have not sufficient energy to heat ambient electrons when they reach at the height of 600km.

The westward electric field through the entire longitude region suggests that narrow region where positive charge exists in the west edge and negative charge exists in the east edge around epicenter. The variation of the electric field is very slow.



## INTERACTION OF UNSTABLE MODES OF IONOSPHERIC PLASMA AND MODES OF NEUTRAL ATMOSPHERE

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Interaction of waves of different physical nature in the unstable ionosphere is very important for seismoionospheric coupling and “space weather” phenomena. Interaction between mechanical oscillations of neutral ionosphere and electromagnetic oscillations of neutral plasma in equatorial region F is considered in two regimes.

(1) The first corresponds to the development of Rayleigh-Taylor instability (RTI) in the presence of given packet of atmospheric gravity waves (AGW) of the lithospheric origin. The process is described by the system of equations:  $\partial n_k / \partial t = \gamma_{eff} n_r + q(t) U_k$ , where  $k$  is mode number,  $n$  and  $U$  are amplitudes of relative perturbations of electron concentration and of AGW respectively,  $\gamma_{eff}$  is increment of RTI.

Proposed theory corresponds qualitatively well to the results of satellite observations of seismogenic plasma and neutral perturbations in near-equatorial F region of the ionosphere [1].

(2) In addition to the “common” regime of RTI, a possibility of “heat pumping” instability of AGW is considered due to “backward” influence of plasma current on AGW. To describe this process, additional equation is added to the equation presented above, namely  $(p/\rho)d\rho/dt = \alpha J$ . Here  $\rho, p$  are density and pressure of neutral atmosphere,  $J$  - ionospheric current,  $\alpha$  - some coefficient. Development of such common “AGW--RTI” instability is possible only with synchronism between AGW and plasma modes and needs rather large drift plasma velocity. In this case we get  $\delta\omega''/\omega \sim 0.1$ , where  $\omega, \delta\omega''$  are AGW frequency and increment of the instability, respectively.

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## **INCREASES IN RADON EXHALATION AND CHANGES OF ATMOSPHERIC ELECTRIC PARAMETERS ACCOMPANYING PERCOLATION PROCESS IN CRUST**

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Accelerated moment release is often preceded by large earthquakes, and defined by rate of cumulative Benioff strain following power-law of time-to-earthquake relation. This temporal seismicity pattern appears accompanying with a damage process of crust. The process can be described by percolation model as well as irreversible thermodynamic model, and therefore, an increase in migration of radon in crust obeys the power-law of time-to-failure. Analyzing atmospheric radon concentration prior to the 1995 Kobe earthquake, we can treat the anomalous increment of the radon concentration on the basis of the percolation model. On the other hand, radon, which is a radioactive nuclide, ionizes aerial gases. Reconstructing the vertical distribution of atmospheric conductivity preceding the earthquake under quasi-stationary condition, the radon enhancement increases the conductivity by 40-50% in the planetary boundary layer. This change corresponds to about 20% decrease of the columnar residence between ionosphere and ground surface around a monitoring station. Furthermore, the growth of atmospheric conductivity leads to decline in atmospheric electric field comparing with that in the 1965 Matsushiro earthquake swarm. In contrast, considering the dynamics of charged aerosol particles, the anomalous radon exhalation induces the atmospheric electric field of 104-105 V m<sup>-1</sup> near ground which is two to three orders of magnitude larger than usual values in fair-weather condition. This generation of the electric field is related to preseismic phenomena such as a great change of atmospheric electric field and ionospheric perturbations.

# COASTAL GEOPHYSICAL INSTRUMENTS FOR ULF MAGNETIC LOCATION OF THE FORTHCOMING STRONG EARTHQUAKE ( $M \geq 5$ ) ZONE IN THE OCEAN AND SYSTEM TSUNAMI WARNING

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Geophysical instruments for tsunami warning are composed of two parts:

1. Marine part: An underwater buoy/bottom geophysical station consisted of:

- component (X, Y, Z) magnetometer;
- pressure sensors;
- accelerometer sensors (X, Y, Z);
- temperature sensor;
- microprocessor.

Arrangement of three buoys (100 m depth) for sea bottom geophysical stations in the ocean along a profile orthogonally to coastline at distances 100, 200 and 300 km from the coast

2. Ground's part: Base coastal geophysical complex is a final point of a profile situated orthogonally to a coast. The complex ULF serves to observe gradients and phases of magnetic, telluric and seismic phenomena. One coastal geophysical complex consists of three points (3 – 7 km distance one point from the others) equipped by of the same type geophysical devices. Synchronous measurements at three points give an opportunity to construct gradient and phase velocity vectors of magnetic disturbances along the Earth's surface.

Under sea bottom, strong earthquakes ( $M \geq 6$ ) can be a reason of a tsunami. To determine (in the ocean crust) a position of an epicenter of a forthcoming strong earthquake by method of ULF magnetic location we propose to install second coastal geophysical complex at ~ 100 km (along the coast) distance from the base complex. Two spaced coastal geophysical complexes permit to triangulate (using the gradient and phase velocity vectors) an epicenter of a forthcoming strong earthquake in the ocean.

It allows to us to control a tsunami origination and propagation process (if we observe anomalies in magnetic disturbances, the pressure). To control a big ocean space (300 x 300 km) we propose to install two under water profiles installed orthogonally to a coast (200 km apart from the first profile) and three base points at the shore.

SPbF IZMIRAN has unique developments of ground geophysical complexes "Ochag-1" for the investigations of anomaly effects in the gradients and phase velocities of magnetic and telluric perturbations arising in the Earth's crust in a region of a hypocenter (including under the sea bottom) before the strong earthquake. In 1998 together with Japanese colleagues, we had installed magnetic devices for ULF magnetic location in seismic area of Japan. Using geophysical devices and data acquisition systems, which were manufactured in the SPbF IZMIRAN.

## MAGNETIC FIELDS INDUCED BY TSUNAMI

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A tsunami is a train of large waves created when undersea earthquake occurs causing sudden movement of the seafloor. The seafloor's movement generates a sudden impulse that causes the water column to displace vertically. The result is a series of traveling waves with length much more than the depth of ocean. These waves can reach large dimensions and travel across ocean with little lost of energy. The large scale wave propagation in the presence of the Earth's magnetic field produces electromagnetic signal. It was shown that quasi-constant magnetic fields ( $b_z \geq 30$  nT) induced by tsunami can be found by sea bottom (buoy's) chain of the digital three component magneto-variation stations (3 or 4 units) installed in the oceans along normal direction to coast line at distances 50, 100, 200, 300 km from shore. We suppose to observe also considerable polarization magnetic disturbances variations from shifting devices by tsunami wave. One of the power signal we'll have 20 and 10 minutes from propagation waves before arrival tsunami at shore. From the other side some less intensity ( $\sim 0,2$  nT) and spectral peculiarities of alternate magnetic field we suppose to search in the ULF background by one or two high sensitive digital magnetic variation stations at the shore ten minutes before tsunami arrival on the coastline.

Thus quasi-constant and alternate magnetic fields induced by tsunami can be used in system warning about an approaching tsunami.

## SESSION C

### **ELECTROMAGNETIC INVESTIGATIONS ON VOLCANOES: APPLICATION TO SOUFRIÈRE (GUADELOUPE, FRANCE) AND TAAL (PHILIPPINES) VOLCANOES**

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Imaging volcanic structures is the necessary basic step for efficiently monitoring the activity and for better understanding the mechanisms giving rise to eruptive events.

Among the available techniques Electromagnetic (EM) methods can be very powerful if they can be integrated in a multi-parametric approach and sometimes combined with other techniques as thermal or geochemical techniques.

Each volcanic edifice has its own specific electromagnetic signature which is fashioned by the addition of several markers prevailing at depth. Country rocks enclose magnetic minerals which generate a magnetic field; a hydrothermal system and the related ground fluid circulation carry electric charges and give rise to an electric (and magnetic) field; magma supply, fluids and thermal transfers yield a low electrical resistive medium. Regional setting and tectonic structures (faults, craters rim ...) introduce drastic irregularities superimposed to the large scale EM signature. At a given time, the EM signature defines a quasi static image of the volcano structure versus depth.

On the other hand, the eruptive dynamism depends on the nature of the deep plumbing system, as well as the superficial structural environment. Energy and thermal transfers partly control this dynamism depending on the superficial hydrothermal state. Major part of geothermal energy is released through the groundwater circulation, hot gas emission and thermal convection. Thus, it is utmost important to know the hydrological and thermal interactions, as well as the induced flanks instability.

Depending on the mechanisms which can be involved in the activity, several EM techniques as Self-potential (SP), audiomagnetotelluric (AMT), magnetic (TMF), and Very Low Frequency (VLF) soundings can be combined to image volcanic structures as well as monitor volcanic unrest. We will analyse the observations made on two volcanoes on which the hydrothermal activity may have a key role in the eruptive activity.

**La Soufrière of Guadeloupe (Lesser Antilles arc).** EM investigations were carried out on La Soufrière of Guadeloupe (Lesser Antilles) during the last 20 years, during which the volcano slowly awakes. VLF soundings and SP mappings outline the hydrothermal system, the ground water channelling and the self sealing of faults opened during the 1976 eruption. La Soufrière turns to a cap locked active hydrothermal system. Moreover, AMT soundings evidence a slippage discontinuity formed by crater Amic floor on which La Soufrière dome could partly collapse.

**Taal volcano (Philippines).** Since 1572, 33 phreatic to phreatomagmatic eruptions have occurred on this 311 m high stratovolcano. Taal activity appears to be controlled by dikes injection and magma supply, and buffered by a hydrothermal system. In early 2005, a multi-disciplinary project (Japan-France-

Philippines) started. Combined SP, TMF, ground temperature (GTE), carbon dioxide soil (CO<sub>2</sub>) degassing surveys, and satellite thermal imaging of the Crater Lake, are performed. Reiteration of profiles evidences SP, TMF, CO<sub>2</sub> degassing and GTE changes with time. The observations suggest that most of heat and fluid transfer operate close to the acid Crater Lake. The northern flank of the volcano is reactivated during seismic crises and this sector could be subjected to a flank failure.

## GEOMAGNETIC ANOMALIES OBSERVED AT VOLCANO POPOCATEPETL, MEXICO

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The results of the ULF geomagnetic monitoring of the volcano Popocatepetl (Mexico) and their analysis are summarized and presented for the period 2003-2006. Our analysis reveals some anomalies, which are considered to be generated by local volcanic origin: the EM background in the vicinity of the volcano is significantly noisier than in other reference stations; the sporadic strong noise-like geomagnetic activity observed in the H-component; some geomagnetic pulsations observed only at the Tlamacas station (located at 4 km near the volcano). The results are supplied with original physical mechanism, further perspective directions to study volcanic geodynamical processes besides the traditional ones are given.

## **ELECTROMAGNETIC IMAGING OF ANDAMAN-NICOBAR REGION: PRELIMINARY RESULTS**

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To image the electrical conductivity distribution of Andaman-Nicobar Region, fluxgate magnetometers (Geomagnetic Depth Sounding experiment) are operated at five different Islands. Magnetotelluric soundings have also been carried out in Middle Andaman region.

The observed induction arrows in Andaman Islands are found to point towards east despite deep sea located towards its west. This indicates that eastern part of Andaman Islands (volcanic and forearc regions) is more conducting than the region of outer non-volcanic island arc. Thin sheet modeling requires the conductance of 10000-25000 S (with increase conductivity towards south) for explaining the observed induction pattern. Both, sediment filled Andaman-Nicobar deep and volcanic arc are contributing to the high conductivity. The increase of its conductivity towards south indicates the concentration of magma chamber as well as partial melts along the volcanic arc. The high conductivity observed over Andaman-Nicobar deep can be explained in terms of high conducting sediments with trapped fluids at mid-crustal depths during the upward migration of fluids released by subducting sediments during the subduction of Indian plate beneath Eurasian plate.

Magnetotelluric studies have delineated a major thrust zone striking approximately NNE-SSW and dipping at more than  $60^{\circ}$  to the east, beneath Rangat in the Middle Andaman. This has been interpreted as line of suture and eastward subduction of the Indian plate beneath the Andaman Plate. The Andaman flysch, which have thickness varying between 4 and 10 km are delineated up to depth of about 17 km along the observed thrust. The variations in thickness and resistivity of the crust (east is more conductive than west) have been attributed to the ongoing tectonic process.



**ELECTROKINETIC EFFECT IN SEISMOELECTRIC PHENOMENA:  
A RESEARCH OF COMPLEX SYSTEM PHYSICS GROUP INSTITUT TEKNOLOGI  
BANDUNG**

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Seismoelectric phenomenon occurs when a seismic wave propagating in a medium induces electrical field or radiates electromagnetic wave. The phenomenon itself created from several mechanisms. One of them is the electrokinetic effects. Using this effect, we're trying to image sub-surface layers especially to detect groundwater reservoir. The research was done by an overview on its theoretical formulation, several field measurements, data analysis, and numerical modeling. In theoretical formulation, the mechanism of seismic wave conversions into an electromagnetic wave and the characteristics of seismoelectric response were explained; and, the governing equations and derivations of seismoelectric wave solutions in homogeneous-isotropic material were determined. Accompanying theoretical formulation we've created a finite-difference algorithm provides an alternative method to simulate seismic wave propagation in fluid saturated porous media. Next, we measure seismoelectric response in the field. We've created an amplified pair of electric dipole to be use as an electric field receiver connected to a standard seismic recording system. With this equipment we've manage to acquire data sets from two locations in Bandung. Different approaches are used to minimize harmonic noise domination of these records. Although the results are far from excellence, we've created an opportunity for further developments on this research.

*Key words: Electrokinetic effect, Seismoelectric Phenomenon, Seismoelectric imaging, Seismoelectric modeling*

## SESSION D

### APPLICATION OF GEOELECTRIC METHOD IN POSSIBILITY OF THE SOURCE OF GEOMAGNETIC ANOMALY AREA IN LOMBOK ISLAND

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#### 1.

Regarding the results of the last research (Zubaidah et al., 2006) can be interpreted that there are two possibilities of the source of geomagnetic anomaly in Lombok Island, i.e a local fault in this region that could be associated with a source of seismic hazard (especially earthquakes), and a specific local structure composed by a quite big magnetic body. The region be estimated lie in around minimum geomagnetic anomaly ( $8^{\circ}45'36''\text{S}$ ,  $116^{\circ}1'48''\text{E}$ ) until maximum geomagnetic anomaly ( $8^{\circ}43'48''\text{S}$ ,  $116^{\circ}5'24''\text{E}$ ).

Geoelectric method with vertical electrical sounding (VES) configuration have been applied in three VES point to know the first structure of possibility of the source anomaly geomagnetic in Lombok Island, i.e one point between profile the minimum geomagnetic anomaly and maximum geomagnetic anomaly (X1:  $8^{\circ}46'42.9''\text{S}$ ,  $116^{\circ}04'07.7''$ ), two another point outside of profile minimum geomagnetic anomaly and maximum geomagnetic anomaly (X2:  $8^{\circ}46'03.3''\text{S}$ ,  $115^{\circ}58'39.9''\text{E}$  dan X3:  $8^{\circ}42'11.6''\text{S}$ ,  $116^{\circ}08'27.2''\text{E}$ ).

Result of geoelectric method with vertical electrical sounding (VES) configuration e.i, X1 point have resistivity value about  $0.287 - 4052 \Omega\text{m}$  from surface until the depth more of 17.33 m, X2 point have resistivity value about  $13.4 - 25.493 \Omega\text{m}$  from surface until the depth more of 33.49m and X3 point have resistivity value about  $966-0.895 \Omega\text{m}$  from surface until the depth more of 33.32 m. This results can be related with the values of geomagnetic anomaly each VES point, e.i, X1 point lie between value of -200 nT and +200 nT , X2 point lie between value of -100nT dan -200nT and X3 point lie between value of +100 nT dan +200 nT . The X2 point with the depth more of 33.49 m has high resistivity with geomagnetic anomaly is negative, while the X3 point with the depth more 33.32 m has low resistivity with geomagnetic anomaly is positive.

**MONITORING OF THE EXISTENCE OF HIGH INTENSITY  
GEOMAGNETIC ANOMALY PATTERN ALONG THE JAVA TRENCH:  
FIRST YEAR RESULTS**

*(DETERMINATION OF GEOMAGNETIC ANOMALY VARIATIONS TO PREDICT  
TECTONIC EARTHQUAKES OCCURRENCE IN THE SUBDUCTION ZONE)*

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An advanced research to predict tectonic earthquake occurrence systematically along the *Java trench*, which coincides with the contiguous negative-positive high intensity geomagnetic anomaly pattern, has been conducted focused in Lombok Island – West Nusa Tenggara (the location of the highest intensity of geomagnetic anomaly in this region). Three geophysical methodologies (i.e. Geomagnetic, DC-Resistivity and Very Low Frequency Electromagnetic) will be applied systematically, to map and interpret in detail the geomagnetic anomaly value related to the geological conditions and tectonic situations. Understanding these conditions is important in order to predict tectonic earthquake occurrence, in which the early warning system and minimizing fatal risks of natural hazard could be reached. This paper will report the first year results of geomagnetic monitoring in Lombok Island, by conducting a *ground-based* geomagnetic survey at 56 stations (i.e. repeat survey at 36 old stations, and additional survey at 20 new stations), visualizing of the interpolated data in the form of 2D and 3D Isogam maps, and generating forward models and their interpretations. A lower value of geomagnetic anomaly (in comparison with the previous results) and a new dipolar structure location has been found, with the minimum point located on (-8.760N, 116.030E) and the maximum point on (-8.730N, 116.090E). The Isogam maps also indicated a general geomagnetic anomaly pattern in Lombok Island: repeated contiguous negativepositive anomaly (i.e. low anomaly in the North, high anomaly in the middle, low anomaly in the South and supposed that will be more decreased to the negative value in the Southern areas). These results are well matched with the global geomagnetic data and regional geological conditions as well as tectonic situations. By extracting a profile connecting the new dipolar structure from (-8.790N, 115.980E) to (-8.700N, 116.160E), two kind of forward modeling have been performed. The first model uses an uniformly magnetized sphere assumed as the source of the anomaly. This could be interpreted as a specific local structure composed by a quite big magnetic body with its centre located on (-8.740N, 116.070E). The second model uses the *Mag2dc* program (Cooper, 2003), in which two adjacent prismatic bodies with different susceptibilities have been chosen, could be interpreted as a potentially local fault with strike length of 100 km existing in this region at depth of about 450 – 1500 m.

**Key words:** Geomagnetic anomaly, Isogam map, Dipolar structure, Horizontal gradient

## **A CASE-STUDY OF EQUATORIAL IONOSPHERE VARIABILITY ASSOCIATED WITH STRONG EARTHQUAKES.**

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In this paper the anomalous ionospheric variability at low latitudes associated with seismic activity is investigated. For this purpose we use TEC (Total Electron Content of the ionosphere) maps derived on the base of GPS-IGS network permanent observations. The possible influence of the earthquake preparation processes on the main low-latitude ionosphere peculiarity – equatorial anomaly (Appleton anomaly) – is discussed.

We consider several case-studies of low-latitude earthquakes that took place in Southeast Asia and South America – Sumatra earthquake (M9.0) of December 26, 2004 and Peru earthquake (M7.5) of September 26, 2005. Analysis of the IONEX TEC maps has shown that modification of the equatorial anomaly occurred a few days before these strong earthquakes. It was found out that in the days previous to the earthquake the meridian section of TEC spatial structure took shape of a double-crest curve with trough near the epicenter position. The effect was best pronounced in the evening and night hours of local time, though for these concrete temporal intervals the normal latitudinal distribution with one maximum near the magnetic equator was observed. The TEC enhancement in the crests for the case of Peru EQ reached the value of 9-13 TECU, this value is about 50-70% relatively to the quiet conditions; TEC decrease (in trough) was equal -20-30%. For the case of Sumatra EQ TEC increase in crests reached the maximal value of 30%, TEC decrease (in trough) amounted -20%.

The results obtained are in a good agreement with early ones. So, Depueva and Ruzhin (1995) have considered the case of Chile earthquake (M6.8) of April 13, 1963 on the base of Allouette-2 satellite data. It was found out that one day before the event the latitudinal dependence of critical frequency ( $f_oF_2$ ) on magnetic inclination ( $I$ ) looked like curve with two maxima symmetrically located around magnetic equator in midnight hours of local time. The plasma concentration over the epicentral area was reduced more than 10 times related to normal conditions.

It is shown that anomalous electric field generated near epicenter of imminent earthquake could cause the phenomenon like natural “fountain-effect” and might be a possible reason of the observed ionospheric pre-seismic anomalies. As result, the seismo-ionospheric effect occurred as a specific modification of equatorial anomaly processes.

## **THE CHARACTERISTICS OF THE GEOELECTRIC FIELD AROUND THE BEIJING AREA PRECEDING WEN'AN MS5.1 EARTHQUAKE**

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On July 4, 2006, an Ms5.1 earthquake occurred in Wen'An country(38.9<sup>0</sup>N, 116.3<sup>0</sup>E) , Hebei province according to the determination of China Seismograph Network and Hebei Seismograph Network. The epicenter distance of the earthquake is 110 kilometers from Beijing and 80 kilometers from Tianjin. There was no person hurt and no obvious damage but slight fissure on some civil buildings. The earthquake was felt strongly in Wen'an area, and was felt popular in the areas of Beijing and Tianjin. It was perceptibility in some areas of Hebei, Shanxi and Shandong provinces also.

Many stations for the observation of the electric field variations of the earth have been built for recent years in China, and a lot of observation data have been accumulated, but this situation is seldom to appear that there were several stations for observing the geo-electric field around the area of the epicenter of a middle earthquake or strong earthquake in China. The distributing situation among the epicenter of Wen'an earthquake and the several stations of the geo-electric field around it supply us a good earthquake example for study. The six geoelectric field monitoring stations have been in operation for several years around the Beijing area to examine the relationship between electric field changes and earthquakes. In this paper the data recorded in the stations were studied and a lot of abnormal signals preceding the Wen'an earthquake were selected, in which five abnormal signals of the geoelectric field are finally considered as the precursory signals. The result shows that ①the precursory signals of the geoelectric field preceding the Wenan Ms5.1 earthquake really exist; ② there were sensitive sites in the spatial distribution of the abnormal variation of geoelectric field; ③ the anomalous signals didn't appeared in the same time for different stations, and the intervals of the time from the end of the precursors to the quake occurrence were not same in different stations; ④ the amplitude of the abnormal signals recorded in Baodi station were smaller than that in Changli station, while the former station is near the epicentral area and the later is far from it.

## **ANOMALOUS VARIATION IN TOTAL ELECTRON CONTENT (TEC) ASSOCIATED WITH EARTHQUAKES**

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It has been fairly well established that strong earthquakes ( $M > 5$ ) preparation can cause anomalous total electron content (TEC) variations. To detect seismo-ionospheric disturbances in the TEC we used the data obtained from GPS Ionospheric Scintillation and TEC monitoring (GISTM) system which is in operation at Agra, India (Geographic Lat.  $27.2^{\circ}\text{N}$ , Long.  $78^{\circ}\text{E}$ ) since 24 June, 2006 on a routine basis. We analysed the TEC data corresponding to two strong earthquakes which occurred on 08 January, 2007 ( $M=6.0$ , Lat.  $39.80$ , Long.  $70.31$ ) and on 05 May, 2007 ( $M=6.2$ , Lat.  $34.23$ , Long.  $81.94$ ). The analysis of the TEC data of January, 2007 shows abnormal variation in TEC during 08 January to 10 January, 2007. The anomaly in TEC was found in night hours of 08/09 January, 2007 when there was an enhancement from normal values followed by a large daytime enhancement on 10 January, 2007. This TEC anomaly was found on the same day as well as on the next two days of the occurrence of the earthquake. Similarly, anomalous variation in TEC was also observed on 03 May, 2007 two days before the occurrence of the earthquake on 05 May, 2007. During the above two earthquakes there was no magnetic storm and therefore, the anomalous variation in TEC on 08-10 January, 2007 and on 03 May, 2007 may be considered as precursors of the earthquakes. The variation in TEC due to earthquakes may be interpreted in terms of  $E \times B$  drift generated by seismic associated electric field.

## **ON THE ATTENUATION OF SEISMOGENIC EMISSIONS IN THE EARTH CRUST**

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The earth crust comprise of three layers (upper, middle and lower) of which the conductivity of the middle layer is lowest ( $\sim 10^{-4} - 10^{-6}$  mho/m). The attenuation calculations have been carried out for the electric field assuming an ensemble of “elementary radiators” randomly oriented and distributed in space and time in a wide band of frequency ranging from Ultra Low Frequency (ULF) to High Frequency (HF) in the middle layer. It has been found that signal can propagate from the source to lower boundary of the upper crust without much attenuation (because of low conductivity) and have significant strength to be observed specially in the ULF-ELF range. These signals emerge on the earth surface through some “windows” where the conductivity is much lower than average conductivity in the upper layer. These windows may be formed because of emergence of some basement rocks under special geological conditions. The theoretical results are compared with the experimental one and it has been suggested that the middle layer can serve as waveguide for the signals of ULF – ELF range for long distance propagation. These results are consistent with those carried out by the earlier workers.

## **OBSERVATION OF ULTRA LOW FREQUENCY (ULF) BURSTS AS PRECURSORS OF EARTHQUAKES AT AGRA, INDIA**

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The study of ULF magnetic field emissions associated with earthquakes employing a three component search coil magnetometer (Lemi 30i) has been in progress at Bichpuri, Agra station since September, 2002. The dynamic frequency range of magnetometer is 0.01-30 Hz and the observations are taken round the clock. The re-installation of the magnetometer at a remote location at Bichpuri, Agra station recently has produced some very interesting results. The results include observation of ULF bursts corresponding to some nearby earthquakes that occurred in Uttarkashi, China, and Nepal with moderate magnitudes ranging between  $M_w = 4.0$  and  $5.0$ . The burst occurred as precursors in the case of China and Nepal earthquakes whereas it occurred after the main shock in the case of Uttarkashi earthquake. The frequency time spectrograms of these bursts show enhancement of intensity between 0 and 20Hz. The occurrences of these bursts are similar to Loma Prita, Spitake, Racha, and more recently Miyagi and Taiwan earthquakes. It is suggested that these bursts are generated as a result of cumulative emissions from different source centres created by microfracturing around the epicentral region. The detailed studies of the observed events are in progress using statistical analysis of the data.



## **A MORPHOLOGICAL STUDY OF TOTAL ELECTRON CONTENT FROM GPS DATA AND IT'S VARIATION WITH MAGNETIC STORMS AND EARTHQUAKE**

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The monitoring of Total Electron Content (TEC) has been started at Bichpuri, Agra (Geographic Lat.27.2<sup>0</sup>N, Long. 78<sup>0</sup>E) by employing a GPS Ionospheric Scintillation and TEC Monitor (GISTM) System (Model GSV4004B) since 24 June, 2006 on a routine basis. The obtained slant TEC (STEC) from the output of the receiver is converted into vertical TEC (VTEC). Eleven months data from September, 2006 to July, 2007 are analysed and temporal variation of VTEC are studied for the ionospheric region around Agra. The results show that the mean TEC varies from a minimum from 0500 hrs LT to a peak value at about 1400 hrs LT and then decreases. Abnormal variation from this regular feature is seen between 11 November and 12 November 2006 following a magnetic storm occurred on 10 November 2006 ( $\Sigma Kp=34$ ). Similar effect has been observed following the storm of 01 April 2007 also. The effect of earthquake on the variation of TEC is identified by studying the case of an earthquake ( $M_w=5.0$ ) occurred on 23 July, 2007 in Uttarakhand (Lat.31<sup>0</sup>N, Long. 78.29<sup>0</sup>E) India, which is located at a distance of 422 Km. from the observing station at Agra. It is seen that evening time TEC is enhanced three days before the occurrence of main shock followed by a reduction from the mean value. The result is interpreted in terms of electric field induced by internal gravity waves of radon emission from the epicenter region.

# VHF ANOMALOUS PROPAGATION POSSIBLY ASSOCIATED WITH THE 2007 OFF-SHORE MID NIIGATA EARTHQUAKE OBSERVED BY INTERFEROMETER

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Earthquake-related anomalous electromagnetic phenomena have been reported in various frequency ranges in a few decades. The anomalous propagation of the VLF/VHF transmitter waves is one of the most promising approaches on the short-term prediction and crustal activity monitoring. The anomalous propagation is considered to be generated by as disturbances of the ionosphere / atmosphere for some reasons in above the epicenter or the propagation path before large earthquakes. Consequently, significant changes occurred in amplitude, phase, and other parameters of VLF transmitter waves. On the other hand, for VHF transmitter waves, over-horizontal invisible propagation was received. Recent studies on the cross-correlation between the earthquake occurrence and the anomalies shows that the appearance of anomalies was significantly enhanced within 5 days before earthquakes (Magnitude  $\geq 4.8$ )[1]. However, it has not been clarified about the direction where does the electromagnetic wave come from.

The purpose of this study is to design an interferometer system for VHF radio wave and to identify the position between space-time of earthquake precursory atmospheric disturbance. Therefore, we developed interferometer finding direction system at the Chiba University (Nishi-Chiba campus). The target FM radio station is located in Sendai and the frequency is 77.1 MHz with horizontally polarization (5 kW). The distance between the receiver and the transmitter is approximately 300 km that is over-horizontal range. We will show you preliminary results in the presentation.

On July 16 2007, off-shore mid Niigata earthquake with magnitude 6.8 occurred. We observed anomalous signal before and after the earthquake. The result of direction of arrival indicated that a few days before the EQ the signal seems to come from the future epicenter region. The present result suggested that phenomena possibly associated with the earthquakes.

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## DEVELOPMENT OF DATABASE SYSTEM FOR SPACE EARLY WARNING AT LAPAN

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Long-term data of the Sun-Earth system are essential for developing a capability in space early warning. The data related to Sun-Earth system is very huge and therefore should be managed efficiently. To initiate a study on the Sun-Earth system as well as to construct a space early warning system at LAPAN, we have developed a relational data base system based on web technologies (MySQL database server, Apache web server and PHP). We utilized the Sun-Earth data from various sources: (1) sunspot (1987–2007) from Watukosek Solar Observatory (WKSO, LAPAN), (2) flare events (1975-2005) from Space Environment Center (SEC), NOAA, (3) coronal mass ejections (CMEs) based on SOHO-LASCO CME catalog from CDAW, and (4) Dst index (1957–2005) from World Data Center (WDC) for geomagnetism, Kyoto University. It is shown that identifying a solar-originated disturbance (*e.g.* CME) that causes a severe geomagnetic storm (Dst index less than -100 nT) can be achieved efficiently by querying into database using some criteria. The method, therefore, can be applied to the recent data to forecast the arrival time of a solar-originated disturbance at the Earth's orbit.

**Key words:** *Sun-Earth system, relational database, coronal mass ejection, space early warning*

# MAGNETOTELLURIC RESISTIVITY IMAGING OF THE SHALLOW SEDIMENT AND ITS IMPLICATION TO THE HIGHLY DAMAGED ZONE DUE TO MAY 2006'S YOGYAKARTA EARTHQUAKE

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Magnetotellurics (MT) data were acquired across the southern part of Yogyakarta in order to map shallow young volcanic sediments related to the highly damaged area. This survey was carried out after the occurrence of 27 May 2006 (M6.1) earthquake in this area. The data were acquired at two lines with a total of 36 sounding sites, and each line consists of audio frequency magnetotellurics (AMT) sites and AMT+MT sites. The collected time series data were processed by applying the robust estimation and cross-reference evaluation. The obtained complex impedance tensor describes resistivity distribution of the subsurface.

Inverted 2-D models show some dominant features, i.e. resistive basement (100–10000  $\Omega\text{m}$ ) that is interpreted as Tertiary limestone. This basement varies in depth along the survey line. The shallowest basement is about 500 m and the deepest is 2 km. The basinal structure in this area is filled with conductive materials that less than 100  $\Omega\text{m}$ , and is interpreted as young volcanic sediments possibly associated with Quaternary product of Merapi volcano. The form of the basin indicates the existence of a structural break in the basement that can be associated with the Opak fault.

The thick young sediment coincides with the severely damaged zone is found around Bantul area. This thick young sediment is also confirmed by gravity data, i.e. low anomalies. Therefore, it can be concluded that severe damage in this area is due to amplification of seismic wave in unconsolidated sediments.

**Key words:** *magnetotellurics, Yogyakarta earthquake.*

## **ELECTROMAGNETIC MONITORING FOR CRUSTAL ACTIVITY IN INDONESIA**

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Indonesia is one of the countries which are attacked by natural disaster of crustal activity such as earthquakes and volcanic eruptions. The 2004 Sumatra-Andaman earthquake, the 2006 Yogyakarta earthquake, Mt. Merapi eruption gave many casualty. A forecasting or monitoring of these activities are strongly required. However, the conventional mechanical approach for short-time prediction does not carry out the short-term prediction yet even their long time efforts. Recently a lot of electromagnetic phenomena possibly related to large earthquakes have been reported. Among of them, the ULF electromagnetic phenomena and ionospheric perturbations are one of the promising phenomena. Therefore, we started to observe the ULF electromagnetic fields in Indonesia and to analyze the ULF data, ionospheric disturbance using ionosonde and GPS data.

In order to establish the new observation system in effectively, we consider the configuration of the observation network installed by other researchers. Therefore, we installed ULF geomagnetic and geoelectric potential monitoring system at Liwa in South Sumatra and PL Ratu in East Jawa and geoelectrical monitoring system at Kototabang, in West Sumatra.

In this paper, we would like to show our activity during 2005-2007.

## **ELECTROMAGNETIC APPROACH TO MONITOR LANDSLIDE PROCESS**

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A landslide is considered to occur as follows; the water (rain water) penetrates vertically into the subsurface, saturated area is produced, and then a slip starts. In order to try monitoring and forecasting a landslide, the investigation on the condition of the underground water is required, such as how much saturated created and the direction of flow. In this paper we would like to show you the preliminary results of the underground water motion derived by laboratory experiments under the control of the precipitation.

The scheme of the experiments is as follows; self potential (SP), pore pressure, water mass flow, and soil displacement have been measured. The Pb-PbCl<sub>2</sub> electrodes are used for SP measurements and these are installed at 20 cm and 50 cm depth with intersensor distance of 1 m. Gaugemeters for pore pressure measurements are set at the 10, 40, and 65 cm depth with intersensor distance of 1 m as shown in Fig. 1. The soil thickness is uniform and 70 cm. The angle of the upper slope is 32° and the lower, 10°. The width and the length of the slope is 1m and 9 m, respectively. The precipitation rate is adjusted by 80 mm/h.

The landslide occurred at the upper slope about 110 min and it means the total precipitation was about 145 mm. The observed data show the clear changes 50-20min before the landslide. There is a tendency that these changes start earlier in the lower and deeper electrode. The change of 20 min before the collapse is remarkable. The details will be shown in the presentation.

## SESSION E

### IONOSPHERIC PRESEISMIC PERTURBATIONS OBSERVED FOR MEDITERRANEAN EARTHQUAKES OF 1999-2001

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In this paper the temporal and spatial characteristics of the ionosphere modification prior to the earthquakes of Mediterranean region on the base of data provided by the network of European GPS receivers are presented.

The Mediterranean region is the very interesting region to research of seismo-ionospheric effects because the midlatitude ionosphere behavior in different geomagnetic condition is rather well investigated. For this analysis we consider several strong earthquakes registered in this region during 1999-2001.

Measurements from the GPS-IGS European network are employed to the study of the ionospheric total electron content changes during the earthquakes preparation time. The spatial modification of the ionosphere was investigated with use of TEC maps (global maps at the IONEX format and regional maps with high spatial-temporal resolution). Using the differential method comparing pre-seismic time maps with quiet time maps we found out that significant TEC decrease (the negative effect) was the major feature of the seismo-ionospheric precursors observed 10-30 h prior to event. The seismo-ionospheric anomaly was found out as the cone-shaped decrease of total electron content of the ionosphere; it had the sizes of about 4000 km in longitude and 1500 km in latitude. The maximum of the affected area was situated in the immediate vicinity from the epicenter position.

The effect of TEC decreasing observed in the TEC maps was strongly pronounced in the TEC variations over the separate GPS stations located closely to the epicenter position. This decrease is sometimes anticipated by the rapid TEC enhancement. Thus the seismo-ionospheric modification is given by specific "positive-negative" formation appearing some hours before the main event. The general deviation (max-min) amplitude exceeds the value of 15-20 TECU ( $\text{TECU}=10^{16} \text{ el/m}^2$ ).

In all considered cases amplitude of the negative deviation amounted to the 30% level relative to the non-disturbed conditions, the amplitude of this effect exceeds the day-to-day ionospheric variability (15-25%). The analysis of the differential TEC maps anomaly has shown that according to the series of characteristics (its locality, affinity with the epicenters, cone-shaped zone of manifestation and characteristic time of appearance) it may be associated to the precursors of seismic activity.

# **IONOSPHERIC EFFECT OF EARTHQUAKES AS DETERMINED FROM GROUND BASED TEC MEASUREMENT AND SATELLITE DATA**

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The satellite DEMETER was launched in circular orbit at the height of 710 km on 29 June, 2004 and it has made many passes over the Indian and subcontinent longitudes. The Agra station has been awarded user-1 category for the analysis of the satellite data. Recently we have installed GPS receiver (Model: GSV4004B) for the study of Total Electron Content (TEC), Scintillation, and other ionosphere parameters. Electron Density Variation in the ionosphere recorded by satellite DEMETER and Total Electron Content (TEC) variation recorded by GPS receiver at Agra station for the month of May, 2007 have been correlated with an earthquake (M=6.2) which occurred in China (Lat. 34.23, long. 81.9) on 05 May, 2007. The results show that VTEC and Electron Density are enhanced two days before the occurrence of the earthquake. Efforts are in progress to find out similar seismo-ionosphere effect corresponding to other earthquakes in the satellite and TEC data. The observed effect is interpreted in terms of generation of electric field between ionosphere and cluster which are formed below the ionosphere by radon gas emanation through seismic region and followed by triggering of these cluster by green house gases. The electric field so generated penetrates the ionosphere and bring out structural and dynamical changes in the ionospheric parameters.



# **IONOSPHERIC GPS TEC ANOMALY PRIOR TO 22 NOVEMBER 2004, NEW ZEALAND EARTHQUAKE**

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In this paper the analysis of the ionospheric total electron content (TEC) behavior prior to the strong New Zealand earthquake of 22 November 2004 is presented. The earthquake magnitude was about 7.1. The epicenter position was (46.7°S, 164.8°E); the depth of seismic focus was 10 km.

To detect pre-seismic anomaly in the ionosphere we used GPS TEC measurements provided by IGS stations located in the considered region. Diurnal variations of TEC over individual stations during 10-days interval prior the earthquake served as initial data in this analysis. The significant decrease of electron content was found out 1 day prior the event. The maximal effect took place during day-time on 21 November 2004.

To estimate spatial size of the anomaly we used global TEC maps provided by IGS community. Global TEC maps have also demonstrated occurrence of large-scale depression over the region of earthquake preparation. The analysis of differential TEC maps has shown that TEC decrease reached the value of 10-12 TECU, it is equal 40% relatively to the non-disturbed conditions. To verify locality of the anomaly we considered parameter of global electron content (GEC) proposed by E.L. Afraimovich. GEC parameter enabled to find out that the observed anomaly had well pronounced local character which didn't become apparent in global scale.

Recently the similar negative anomalies as seismo-ionospheric precursors were found out by us for strong Turkey earthquakes of 1999 and by J.Y. Liu for several Taiwan and Sumatra earthquakes. In accordance with previous investigations this strong anomaly was identified as seismo-ionospheric precursor.

## **SPATIAL DISTRIBUTION OF IONOSPHERIC DISTURBANCES OBSERVED BY GPS-TEC AND NMF2 PRIOR TO LARGE EARTHQUAKES**

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Many anomalous electromagnetic phenomena possibly associated with large earthquakes have been reported. Recent researchers found an apparent reduction in the ionospheric total electron content (TEC) within 1–5 days prior to  $M \geq 6.0$  earthquakes in Taiwan, as exemplified by the 1999 Chi-Chi earthquake ( $M_w 7.6$ ,  $M_L 7.3$ ) and Chia-Yi earthquake ( $M_L 6.4$ ). They attributed this reduction directly to local earthquakes. However, these studies did not consider the simultaneous data sets from other sites outside of Taiwan. In this paper, we investigate whether the anomalies observed during these earthquakes were local or global phenomena using simultaneous data of ionosonde and GPS-TEC in Taiwan and Japan. We have also used GPS-TEC data sets from the global ionosphere maps (GIM) published by the Center for Orbit Determination in Europe (CODE) in order to detect anomalies in various locations throughout the globe. The result shows that the anomalies in Taiwan three days before the Chi-Chi earthquake (18 September), and one and three days before the Chia-Yi earthquake (19 and 21 October) are local phenomena. It means that the ionospheric-disturbed areas were localized around Taiwan, and did not spread all the way to Tokyo. The disturbed areas were within a 2200 km radius and seem to be much smaller. We also obtained similar tendency in the case of the 2004 Sumatra-Andaman earthquake ( $M_w 9.2$ ).

# CHANGE IN METEOROLOGICAL AND ATMOSPHERIC PARAMETERS ASSOCIATED WITH SUMATRA EARTHQUAKE OF DECEMBER 26, 2004

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Due to strong coupling between land, ocean and atmosphere, significant changes have been observed with recent coastal earthquakes. Various land, ocean, atmospheric and ionospheric parameters are found to show changes prior to the earthquake events that may be associated with the build up of stress in the epicentral region. In the present paper, we have carried out detailed analysis of the *Equatorial Atmosphere Radar* (EAR) and the *Boundary Layer Radar* (BLR) over Kototabang, West Sumatera, Indonesia prior and after the Sumatra earthquake event of December 26, 2004. These parameters are compared with a low magnitude earthquake event. The influence of strong tsunami generated by the Sumatra earthquake show strong and characteristic behavior of atmospheric and meteorological parameters. These parameters may provide early information about strong earthquakes if the seismically active oceanic regions are monitored continuously.

**Keywords :** BLR, EAR, and Tsunami

## THE SYNCHRONOUS VARIATIONS OF SEISMIC AND ELECTRIC ANISOTROPY DURING YONGDENG M5.8 EARTHQUAKE

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Qilianshan Mountain is a stronger active tectonic area in China. Under China-France cooperation project, an electro-magnetic station was set up to get electro-magnetic data during 1993-2000. several digital seismic stations set up around this area. The 2-D anisotropic electric structure has been inverted by using the magnetotelluric data with 12 observational sites around this area. The 3-D velocity structure has been inverted by using digital seismic data. A stratified anisotropic deep structure model has been built up according to seismic and electric characteristics. Based on the model we calculated anisotropic parameters, i.e. porosity, aspect ratio of fracture, with synthetic seismograms of 29 earthquakes.

The seismic and electric anisotropy characteristics during Yongdeng M5.8 earthquake occurred at July 22, 1995 in Gansu province, China, were studied. The variations of seismic and electric anisotropy present synchronous. (1) The polarization directions of the fast splitting shear wave are NE-NW-NE before, on and after the main shock. The electric principal axis direction reveal that NE( before June)-NW ( July)-NE (after July), it is basically same as fast shear wave polarization direction. The tectonic stress direction is NE. (2) The time delay between fast and slow shear wave reflect stress level and media structure variation. Since 1994, it increase gradually, but from 1995, it is so lower before main shock, at July 22, the time delay increased violent, and recovery after main shock. The apparent electric resistivity of main axis varied violent imminent main shock for different frequency, especially, the 160s and 226s, reflecte. (3) The forms of anisotropic parameters, i.e. porosity and aspect ratio during Yongdeng earthquake are similar to time delay of splitting shear wave, it is increase sharply before main shock, the forms immediately main shock is similar to apparent resistivity.

The synchronous anisotropy characteristics for seismic and electric media demonstrate that the EDA is a common control foundation. We can study seismic and electric anisotropy simultaneously to get the crust parameters. Of course, the variation of anisotropy characteristics of electric resistivity depend on frequency and tectonic condition, may be it reflects the action of stratified layers, and perhaps it will be helpful for earthquake prediction.

## **STUDY THE RELATION BETWEEN SEISMO-ELECTRIC/MAGNETIC FIELD AND EARTHQUAKE MAGNITUDE**

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Observational,theoretical and laboratory studies have been revealed seismo-electric/magnetic is a natural phenomenon. The currents/potential changes and abnormal electromagnetic appear in some earthquake preparation zone especially. Varotsos(1996) given the empirical relationship between SES amplitude  $E$  and earthquake magnitude  $M$  based on observation data. The recent discussion on the relation between SES amplitude and earthquake magnitude has divided the scientific community point of view into two parts: one accept it and the other rejecting, the key reason which reject it is that the relation has not the strongly theoretical support. So the paper based on vertical dipolar emitter source model, the radiant characters of seismo-electric/magnetic fields in earthquake prepare zone is studied firstly, then analysis the relation between radiant intensity of seismo-electric/magnetic fields and earthquake magnitude, and last discuss the influence factor of the mechanisms of seismo-electric/magnetic type. The results show that vertical dipolar emitter source model is one of the most possible mechanic of inspiring seismo-electric/magnetic field, conversion mechanisms of seismo-electric/magnetic are the main mechanisms which inspire the radiant of seismo-electric/magnetic fields in earthquake prepare zone but not only. The relation between the logarithm of seismo-electric/magnetic field and earthquake magnitude is line which slop depends on the fractal character of earthquake prepare zone.

## SESSION F

### SPACE WEATHER AND SEISMO-ELECTROMAGNETICS

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and MAGDAS Group

Since several studies and measurements of the magnetic field have been made for various purposes, an enormous amount of information has been accumulated for the earth's magnetic field. Space Environment Research Center (SERC) of Kyushu University (KU) has collected geomagnetic data for over 10 years with the Circum-pan Pacific Magnetometer Network (CPMN) system (Yumoto et al., 2001). Currently, SERC is establishing a new real-time Magnetic Data Acquisition System (MAGDAS) in the CPMN region and an FM-CW radar network along the 210° magnetic meridian (MM) for space weather research and applications (Yumoto et al., 2006). The MAGDAS project intends to get the MAGDAS network fully operational and then use the data for studies on space and lithosphere weather. This project aims to establish a continuous monitoring electromagnetic network and utilize the observations for forecasting changes in space and lithosphere environments. This project is actively providing information about the space weather condition through the following: (1) Global 3-dimensional current system - to know electromagnetic coupling of regions 1 and 2 field-aligned currents, auroral electrojet current, Sq current, and equatorial electrojet current; (2) Plasma mass density along the 210° MM - to understand the plasma environment change during space storms; (3) Ionospheric electric field intensity with 10-sec sampling at L=1.26 - to understand how the external electric field penetrates into the equatorial ionosphere.

To forecast changes in the lithospheric environment with electromagnetic (EM) techniques, it is necessary to understand the role of the space environment at the same time because ground-based magnetometers are more affected by space events than by lithospheric events. Lithospheric signal changes are small in comparison to signal changes caused by the space environment.

Numerous studies have been published on electromagnetic precursors and its association with earthquakes and volcanic activity. The ground observations of EM waves in the ULF range ( $f < 10$  Hz) are considered the most promising means for monitoring crustal activity because the skin depth of EM is comparable to the depth at which crustal activities take place, and fluctuations of electric conductivity in the Earth's interior can be detected directly (Park et al., 1993; Molchanov et al., 1992; Hayakawa et al., 2000; Hattori et al., 2002).

ULF emissions have been considered to directly reflect information on microfracturing in the lithosphere. Aside from the direct ULF radiation from the earthquake (EQ) origin zone connected with the earthquake preparation and reflected in ULF electromagnetic emissions, the second model is the changing of geo-electric conductivity inside and nearby the EQ focal zone which leads to the changing of amplitudes of reflected electromagnetic waves generated by non-lithospheric sources (Mogi, 1985; Kovtun, 1980).

From case study on 1999/05/12 Kushiro earthquake event ( $M=6.4$ ,  $r = 61$  km from RIK(A1), 205 km from MSR(A2)), It is found that the polarization power ratio (Z/H) at RIK(A1) show a gradual decrease before the EQ, but it is not so clear. The power ratio of Pc 3 H components (RIK(A1)/MSR(A2)) was enhanced 2 weeks before the EQ, while temporal variation of Z-component ratio was small compared to that of H. We also found that the H-component power ratio of each day to one-year average ( $A1/A1'$ ) was enhanced 2 weeks before the EQ, while the Z-component temporal variation of ratio did not show a peculiar change. Using the ratio ( $A1/A2$ ) and ( $A1/A1'$ ), it may be possible to distinguish between space origin wave and seismic origin. These peculiar changes may be associated with the earthquake.

# **EQUATORIAL ELECTRO JET DYNAMICS DURING SIMULATED SOLAR MAGNETO-HYDRODYNAMIC STORM**

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Global dynamics of the EEJ is not yet known well, since its position is not easily accessible both from ground or satellite observations. This simulation work is addressed to have dynamical physics during a simulated solar MHD storm. The most important parameters of EEJ during the simulated storm are resulted from MHD interpretations derived from our modified time-dependent Navier-Stokes partial differential equation. Numerical solution reveals that the EEJ is more dynamics during the storm. Especially the EEJ ring current guiding center height dynamics.

**Key words:** E.E.J., solar MHD storm, guiding center dynamics

## PLANETARY ELECTROMAGNETIC WAVES (PEMW) IN THE IONOSPHERE AND POSSIBLE EFFECT OF EQUATORIAL ANOMALY

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New system of 2D nonlinear equations for PEMW moving in the horizontal plane in the equatorial F region is derived in the approximation of “beta-plane” and incompressibility. In the linear approximation, new dispersion relation was obtained including, in particular, losses connected with finite value of the Pederson conductivity and the effect from the horizontal component of geomagnetic field. Approximation of “anisotropic but non-gyrotropic” F region was used. Losses are determined by the term proportional to the Pederson conductivity and square of wave vector component along longitudinal direction. The numerical estimations of the linear dispersion characteristic and losses was made for altitude ~ 600 km; wavelengths along latitudinal and longitudinal directions are of order of 1000 and 4000 km’s, respectively. The last corresponds, by the order of value, to the longitudinal dimension of the equatorial anomaly. In the case under consideration, phase velocity along latitudinal direction is, by the order of value ~ 5-10 km/s, and corresponding period of oscillations is of order of 100-200 s. If imaginary part of the wave frequency is significant, PEMW could propagate with rather large losses. In this case, in the equatorial anomaly, near the maximum of electron concentration and conductivity, losses are relatively small, and in this region “quasiwaveguide” could be formed for such PEMW. More detailed calculations of possible effect of losses are under consideration now. A possibility of connection of the theoretical results to the results of observations of magnetic oscillations in the region of equatorial anomaly [1] is discussed. Linear modes in E region are also analyzed. PEMW could be used as indicator of influences on the ionosphere by power flow propagating in the system “Litosphere-Atmosphere-ionosphere” both “from below to the top” and in opposite direction.

1. Kotsarenko A., Molchanov O., Perez Enriquez R., Lopez Cruz-Abeyro J. A., Koshevaya S., Grimalsky V., and Kremenetsky I.. Natural Hazards and Earth System Sciences (NHESS), 5, 711–715, 2005



## **THE CAPABILITY OF COMPASS-2 SPACE MISSION TO STUDY THE IONOSPHERE DISTURBANCES RELATED TO SEISMIC, METEO AND HUMAN ACTIVITY**

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Based on observational evidence, we suggest that a series of observational and modeling experiments could be carried out to demonstrate the viability of a satellite-based earthquake prediction program based on a search for earthquake precursors. The micro-satellite COMPASS-2 launched on May 26, 2006. The satellite project has an exploratory character and aims first of all to detect the ionosphere plasma anomalies linked to seismic, meteo and human activity, precisely determining their characteristics, such as the EM frequency spectrum and plasma density structures of disturbances in the ionosphere and the upper atmosphere, and the corresponding precipitations of particles, systematically. It provides the necessary data to work out theories and models likely to explain their origin.

The observations made by the satellite has the very great advantage of very rapidly covering almost the whole of the active seismic regions in the world and monitoring the effects of a large number of earthquakes. COMPASS-2 has the capacity to carry out precise and systematic measurements around the Earth and thus to collect a maximum number of events (<http://www.izmiran.ru>, for more details about the mission). Without modifying the payload, COMPASS-2 is capable for studying the influence of storms in relation between Sun and Earth, and of assessing the impact of human activities on the ionosphere. The detailed COMPASS-2 mission and payload description and also some results of measurements are presented.

## A POSSIBLE MECHANISM OF MODULATION OF INTENSITY OF ALFVEN RESONANCES AT THE EARTH'S SURFACE BEFORE EARTHQUAKES

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Recently, generation of the seismo-related Ultra Low Frequency (ULF, 0.1 – 10 Hz) magnetic perturbations, locally generated geomagnetic pulsations, changes in regular resonant structures was confirmed by different ground based observations. In order to give the possible explanation we link mentioned phenomena with a modification of the parameters of the ionosphere (such as density and the temperature), which is regularly detected during satellite observations over EQ preparation areas (DEMETER Project). Namely, the both fundamental mechanisms of the lithosphere-atmosphere-ionosphere coupling (i.e. coupling through the changes in the atmospheric electricity produced as result of integrated ionization from the increased radon emanation, and the conversion of atmospheric acoustic gravity waves (AGW) and internal gravity (IGW) in the lower ionosphere) can lead to the modulation of the ionosphere parameters, creating transparency of the ionosphere for a passage of the Alfvén waves, which go from the magnetosphere to the Earth surface.

We have calculated the efficiency of the modulation of the Alfvén wave at frequencies  $f = 0.1 - 10$  Hz, which passes from the magnetosphere ( $z > 600$  km) to the ionosphere and, then to the Earth's surface and the lithosphere. The set of equations for the electric field components  $E_{x,y}$  has been solved numerically.

The boundary conditions are as follows. At  $z = 800$  km the amplitude of the downgoing Alfvén wave is assumed as constant (the field of the Alfvén resonator), at  $z = -30$  km (in the deep lithosphere)  $E_{x,y} = 0$ .

The conductivity of the lithosphere is  $\sigma = 10^3 - 10^5 \text{ s}^{-1}$ . It has been obtained that the 20% modulation of the concentration of the ion and electron concentrations at the heights  $z = 200$  km can lead to the same (or higher) modulation of the amplitude of the variable magnetic field at the Earth's surface ( $z = 0$ ) at  $f = 0.1 - 10$  Hz. Moreover, the effect depends weakly on the conductivity of the lithosphere. Therefore, an influence of the coupling mechanisms on the F-layer of the ionosphere could lead to observable effects at the Earth's surface

## **SESSION G**

### **SOME RESULTS OF RECENT JOINT JAPAN -RUSSIA RESEARCH ON SEISMO-ELECTROMAGNETICS AND RELATED PHENOMENA**

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The research is conducting since 1992 to present time in a frame of FRONTIER-NASDA project in Japan (1995-2001) and ISTC projects in Russia (1998-2007) in close collaboration with FRONTIER-RIKEN project in Japan and research projects in Italy (LF sounding) and France (satellite DEMETER). The main objects are the following: a) Analysis of different short-term non-seismic precursors of earthquakes (EQ) on reliability and quality of observation; b) Estimation of their applicability to EQ forecast (space distribution and probability gain in time); c) development of theoretical models of selected precursors and of EQ preparation model as whole. The details are well described in monograph by Molchanov and Hayakawa, "Seismo-electromagnetics and related phenomena: History and latest results", Terrapub, 2007. In particular, I am going to discuss: 1) Noise-like ULF magnetic field variations (0.003-0.1 Hz) , which probably related to fracturing near EQ hypocenter; 2) Seismo-acoustic (SAE) and ULF pulses distributed around the EQ preparation zone due to electro-kinetic effect (non-seismic foreshocks); 3) Hydro- gas/ion chemistry anomalies due to induced fluid migration in the crust; 4) ULF/ELF emission (2-20 Hz) , which originate in the lower atmosphere above EQ epicenter; 5) VLF signal anomalies observed both at the ground and satellite and related to seismogenic upper atmosphere/ionosphere perturbations.

## **ULF/ELF MAGNETIC PHENOMENA POSSIBLY ASSOCIATED WITH THE 2004 SUMATRA-ANDAMAN EARTHQUAKE**

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Anomalous ULF geomagnetic field change is one of the most convincing and promising phenomena for earthquake-related electromagnetic studies such as emissions from the crust of the source region. There has been a good deal of accumulated and convincing evidence of ULF/ELF magnetic signatures before large earthquakes as reported in the previous studies. In this paper, the signature possibly associated with the 2004 Sumatra earthquake has been investigated. The studied features are (1) the variation of spectral density observed at Kototabang and Biak, and (2) the long distant propagation characteristics based on direction finding analysis. For the latter one, recently Ohta et al. (2006), reported the possibility of long distance propagation of ULF/ELF magnetic signal associated with large earthquakes. In order to verify this phenomenon preceding large earthquakes (the 2004 Sumatra-Andaman earthquake (M9)), data observed at Matsushiro, Nagano, in Japan and Urumqi in China have been investigated. We estimate the direction of arrival using the goniometric approach. The result shows there is a tendency for the signals to come from the epicenter region. It suggests that the possibility of ULF/ELF signal penetration from the source region to the free space and/or atmospheric/ionospheric perturbation creates new electromagnetic signals due to weak discharges.

# SEISMO-ELECTROMAGNETIC SIGNATURES POSSIBLY RELATED TO THE SUMATRA MEGATHRUST EARTHQUAKES OF 26 DECEMBER 2004 AND 28 MARCH 2005

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Electromagnetic phenomena, e.g., ULF, ELF and VLF waves are recognized as useful diagnostic probes of the ionosphere-atmosphere-lithosphere coupled system for prediction of earthquakes. These waves convey information about the dynamics and morphology of the coupled systems. Anomalous ULF geomagnetic field change is one of the most convincing and promising phenomena for earthquake-related electromagnetic studies such as emissions from the crust of the source region. There has been a good deal of accumulated and convincing evidence of ULF magnetic signatures before strong earthquakes as reported in the previous studies. In order to verify these phenomena preceding strong earthquakes and to clarify the relationship between electromagnetic phenomena and possible physical mechanism, we have been investigated on the basis of ULF geomagnetic observation at Kototabang and Biak stations associated with the very powerful Sumatra earthquakes. A case study is carried out in this work to investigate the pre-earthquake ULF geomagnetic anomalies during the Aceh earthquake on December 26, 2004 (magnitude  $M_w=9.0$  and depth = 30 km from USGS catalog), and Nias earthquake of March 28, 2005 ( $M_w=8.7$  and depth = 30 km). For this aim, the polarization analysis and transfer functions analysis based on wavelet transform method have been applied to the observed data. Results of polarization analysis show similar variation of those of amplitude for induction arrow in transfer function analysis. These variations at Kototabang exhibit an anomalous changes a few weeks before the very powerful earthquakes with  $M>6.5$ , while there are no apparent changes in Biak data. This suggests that the anomalous change might be a possible signal related with the earthquake preparation phase of Sumatra earthquakes.

**Keywords:** Seismo-electromagnetic signatures, Prediction of earthquake, Earthquake -related electromagnetic studies, Anomalous ULF geomagnetic field change

## ANOMALOUS GEOMAGNETIC VARIATIONS ASSOCIATED WITH PARKFIELD (MS=6.0, 28-SEP-2004, CALIFORNIA, USA) EARTHQUAKE

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Analysis of the ULF (Ultra Low Frequency) data measured by Parkfield (PRK) magneto-telluric station (fluxgate instrument, 3 magnetic channels + 2 dipoles per 2 electric components) for the period 1 week before – 1 day after the major EQ (Earthquake, Ms=6.0, 28-SEP-2004, 17:15:24) occurred near Parkfield, California, USA, is presented.

Spectral analysis reveals the ULF geomagnetic disturbances observed the day before the event (Sep 27, 15:00-20:00 UT), and at the day of the EQ (Sep 28, 11:00-19:00 UT). Estimations of the perturbed signal amplitudes (frequency band  $f = 0.25-0.5$  Hz) gives following values: up to 20 pT for the magnetic components and 1.5  $\mu\text{V}/\text{km}$  for the telluric ones.

Observed phenomena occurs under quiet geomagnetic conditions ( $|D_{st}| < 20$  nT); revision of the referent stations data situated far away from the EQ epicenter (330 km), does not reveal any similar effect. Moreover, the Quake Finder research group received very similar results (ELF range instrument, situated about 50 km from the EQ epicenter) for the day of the EQ. Comparative analysis with mentioned before results show that we observed the lower-frequency part of the massive ULF-ELF burst, localized in the frequency range 0.25-1 Hz, generated 9 hours before the earthquake. Mentioned above details suggest the localized character of the source, possibly generated in the earthquake preparation area. Original theoretical model for interpretation of the obtained results is presented separately (presentation “A possible mechanism of modulation of intensity of Alfvén resonances at the Earth’s surface before earthquakes”).

## **ON THE COMPLEX REGIONAL EARTHQUAKE PRECURSORS RESEARCH AND PREDICTION NETWORK**

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A project for complex regional NETWORK for prediction the earthquake's time, place (epicenter, depth), magnitude and intensity using reliable precursors is proposed and shortly analyzed. The precursors list includes usual geophysical and seismological monitoring of the region, including hydrochemical monitoring of water sources and their Radon and Helium concentrations, crust temperature, and hydrogeodeformation field, monitoring of the electromagnetic field under, on, and above Earth surface, meteorological monitoring of the atmosphere, including earthquake clouds and electrical charge distributions, near space monitoring aimed to estimate the Sun or Earth origin of variations, and biological precursors. The Project is based on contemporary data acquisition system for preliminary archiving, testing, visualizing, and analyzing the data. The theoretical part of the Project includes wide interdisciplinary research based on the unification of standard Earth sciences and using of nonlinear inverse problem methods for discovering the empirical and hidden dependences between variables. By means of special software the complex environmental and real time analyzed Satellite data shall be used to prepare regional daily risk estimations.

The imminent "when" earthquake's predictions are based on the correlation between geomagnetic quakes and the incoming minimum (or maximum) of tidal gravitational potential. There is unique correspondence between the geomagnetic quake signal and the maximum of the monitoring point of the energy density of the predicted earthquake. The probability time window for the incoming earthquake is for the tidal minimum approximately  $\pm 1$  day and for the maximum-  $\pm 2$  days.

The statistic evidence for reliability is based on of distributions of the time difference between occurred and predicted earthquakes for the period 2002- 2006 for Sofia region (one component of geomagnetic vector) and 2004- 2006 for Skopje (geomagnetic vector monitoring in variometer mode). The predictions are valid for the earthquakes with magnitude greater then 3 at distance up to some 700- 800 km. The distance dependence of the prediction accuracy on the magnitude is presented.

Some results of collaboration PrEqTiPlaMagInt, which is trying to create the earthquake research and prediction NETWORK in Balkan- Black Sea region are presented: The Sofia and Skopje geomagnetic data and geomagnetic quake as reliable imminent regional earthquake precursor; The preliminary analysis of Kiev and Lvov INTERMAGNET geomagnetic observatories; The preliminary analysis of correlation between Hydrogeodeformation field variations and earthquakes for Georgia; A reliability of predictions made for the 2006 world spectral earthquake numbers; The possibility for systematic of earthquake parameters Richter Magnitude, Seismic Moment, Intensity and Depth; The world statistic of correlations between Earth tides and earthquakes; The correlation between global warming and increasing seismicity on the basis of Sun Spots, Sun Irradiation budget, CO2 anthropogenic production and atmospheric concentration, Ocean level, number and energy of hurricanes is analyzed and the Project for researching the natural or anthropogenic origin of Climate change; The distribution of the World earthquakes with magnitude $>4$  with depth.

## **SESSION I**

### **JOINT SEARCH FOR EARTHQUAKE PRECURSORS BY SATELLITE AND GROUND BASED EM OBSERVATION**

D.Ouzounov, K. Hattori, S.Pulinets, M.Kamogawa, M. Nishihashi, M.Parrot, and J.Y. Liu

Previous studies have shown that there were precursory electromagnetic signals associated with several recent earthquakes observed on the ground and space. Goal of this work is to merge our new approach of recording and analyzing multi-sensor satellite and ground data to our studies of pre-, co- and post-seismic signals. Recent advances in solid earth sciences, GPS/TEC and remote sensing capabilities give us assurance that the scientific understanding and data availability are appropriate at this time to initiate this joint search for the possible earthquake precursors.

Our approach is based on data fusion of satellite data obtained from thermal infrared observations from Terra, Aqua, GOES, POES and space plasma parameters variations from DEMETER, simultaneously with ground based multi parameter continuous measurements of GPS/TEC, ion concentration, Rn, atmospheric electrical field, magnetic array and corona probe from Japan (Iyogatake station, Chiba Univ) and Taiwan (NCU). We use existing satellite sensors and ground observations and the physical link between both measurements are given by Lithosphere-Atmosphere-Ionosphere coupling (LAIC) model. This mechanism is a coupling between the boundary layer of atmosphere and the ionosphere due to increased tectonic activity before strong earthquakes. The simultaneous co-existence of several mechanisms manifesting this coupling enhances the possibility of revealing and tracking future EM seismogenic signals much easier and more reliably. Our first results show that is very unlikely that a single existing method (magnetic field, electric field, thermal infrared (TIR), Surface Latent Heat Flux SLHF, and GPS/TEC) can provide a successful solution for monitoring pre-earthquake phenomena on the global scale. However, simultaneous satellite and ground measurements as an integrated web should provide the necessary information by combing the information provided by multiple sensing sources, both on the ground and from space. The significance of joined satellite and ground based EM precursor search was defined thought analyzing most recent major earthquakes ( $M > 5$ ,  $H < 50\text{km}$ ) in Japan, Taiwan and Sumatra during 2004-2007.



# SEISMO-ELECTROMAGNETIC EMISSIONS AND VHF PULSED RADIO SIGNAL OBSERVED (P-H PULSES) OVER ONE SOLAR ORBIT-MORE QUESTIONS THAN ANSWERS!

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Electromagnetic radiation has been observed and measured during the deformation/fracture of 'rock' over various scales by many authors for many years (eg. Warwick et al, 1982 to Freund et al, 2007). One form of emission, termed P-H pulses (pulsed VHF radio signals) was originally observed prior to a  $M = 5.9$ , earthquake (EQ) that occurred 10:28, 28 Dec. 1989 (Local Time) at Newcastle, NSW, Australia. At 10:11 (ca. the same time as the anomalous signal), electromagnetic artefacts were noted during routine computed tomography scans by the Radiology Dept., John Hunter Newcastle Hospital, subsequently described by Rowe and Grayson, 1996. The early monitoring equipment and some interpretations and discussions on P-H pulses have been given by Pulinets and Hollis-Watts, 2003 and in Pulinets and Boyarchuk, 2006. In 2006, an improved measurement station was established at Esperance, WA. This station is manually operated which restricts observation frequency and duration but does allow each observation to be checked and confirmed. A systematic assessment began involving measurements at 0.5 hour intervals averaging over 10 hours per day from 20 October 2005 to 20 October 2006 with a hiatus during February and March, 2006. This assessment was conducted over one Earth orbit of the Sun, in an attempt to firstly, determine any daily, monthly, annual variations, secondly to determine any astronomical and atmospheric effects and thirdly to officially record and report any anomalies for comparison to EQs recorded within the Geoscience Australia, 2007 earthquake database. The observations are given in Figure 1. The upper panel of Figure 1 shows the time series for EQ events of magnitude 0 to 9.99 registered in the Geoscience Australia Earthquake Database (Geoscience Australia, 2007) over the period considered for a coordinate range of Lon.  $60^\circ$  to  $180^\circ$  and Lat.  $+40^\circ$  to  $-50^\circ$ . A total of 225 of these events are recorded across continental Australia (proportioned by state with WA: 59%, SA:15%, NSW: 11%, NT: 8%, VIC: 4%, TAS: 2% QLD: 1%). 75 events are also recorded across an Asian arc North of Australia from Pakistan to Fiji. The graph shows a characteristically low magnitude (1 to 4) pattern for continental Australia relative to the significant magnitude events ( $>5$ ) recorded for the chosen Asian arc. It also shows 103 events (or 46% of the total continental occurrence) are recorded in the relatively seismic Yilgarn Craton of WA. It is interesting to note that relatively high principal normal stress magnitudes and ratios of horizontal to vertical stress have been measured in the upper crust within the Yilgarn Craton (Brown and Windsor, 1990). The lower panel of Figure 1 shows P-H pulses per minute monitored from the single Esperance station at two amplitude levels on VHF 148 MHz (data time series and fitted trendlines A and B). An annual reduction in pulses per minute is observed with retreat from the Sun with a daily cycle that peaks at ca. midnight (Local Time). Transformation of time to  $x = \sin(kt)$ , where  $k = (2\pi/\text{LOD})$  and least squares regression with  $y = (\text{P-H pulses /minute})$  visibly indicates a linear relation limited by an  $r^2$  coefficient of ca. 0.56. Also shown is the time series of heliocentric radial range to Esperance, WA at Lon.  $121^\circ 53'$ , Lat.  $33^\circ 51'$ , computed on 23/02/2007 using the Ephemeris Solar System Dynamics Program, NASA/CIT/JPL, 2007 (<http://ssd.jpl.nasa.gov/>). This suggested relation will be tested properly after anomalous spikes have been censored. Two of the many reported anomalies are selected from Figure 1 and are shown in Figures 2 and 3. Figure 2 shows a typical short-lived 'spike' that was reported as a possible EQ precursory event measured on 16 August, 2006 which preceded a magnitude 4.9 EQ that occurred South of Java, Indonesia on the same azimuth some 8 days later on 24 August, 2006. Most anomalous observations appear short lived and are similar to Figure 2. Figure 3 shows a different form of signal which remained persistent for some time and occurred during both 7 and 8 October, 2006. This is co-volcanic with an eruption on Rabaul, Papua and New Guinea and was observed on that azimuth. A similar signal was recorded during eruption of the Merapi volcano, Indonesia, on 26 May, 2006. Fast Fourier Transforms (FFTs) of typical short lived events are indeterminate but during volcanic activity show convex spikes. Work is now concentrating on statistical

analysis of the various time data series in an attempt to test for any correlated effects. At this stage our observations have produced more questions than answers and these will be discussed in the paper proper. At this stage we note:

- Cycles in P-H pulses that appear associated with astronomical geometry.
- No, as of yet, identified effects from severe electrical storms, pressure and precipitation and coronal ejections.
- Consistent measurement (i.e. over 100,000 frames) of more positive than negative spikes indicating a flux which is not a recognised form of electromagnetic interference.
- A short duration anomaly that may precede an EQ and a relatively long duration anomaly that appears to be co-volcanic (with distinctly different FFTs).

The issue of a P-H pulse anomaly representing an EQ precursor requires considerable assessment that has not been attempted here. The rock physics of Freund, 2002 coupled with the ionospheric physics given by Pulnits and Boyarchuk, 2004 indicate lithosphere-ionosphere coupling may be possible through electromagnetic emissions. However, here, we have only reported intermittent observations from a single, manually operated station. Furthermore, we chose an example, thought to be an EQ precursor (Figure 2), that indicates 8 days between the anomaly and the EQ event, while Figure 1 indicates that during an 8 day period several EQ's (albeit of low magnitude) may occur across the relatively seismic Yilgarn Craton. Several automated terrestrial stations with continual measurement and synchronized vectoring of the signal would provide a much better test, (as would a satellite based system). Indeed, the results from this work, once properly assessed, will be used to seek funds for a network of fully automated stations within Australia and a network of deep (> 1.0 km) boreholes instrumented to monitor ion concentrations in the ground water in an attempt to pursue this issue further. Boreholes can be drilled from the many deep underground mines in Australia which also have an interest in predicting seismicity.

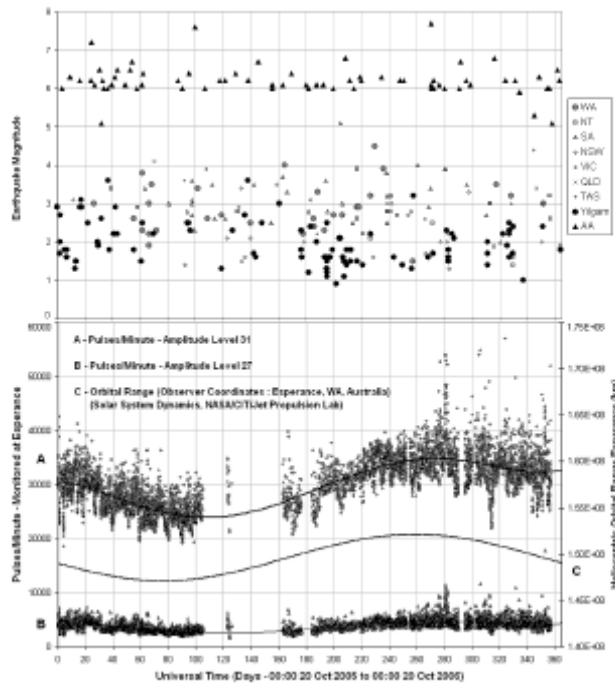


Figure 1. Earthquake events, P-H pulses and heliocentric orbital range over one Earth solar orbit between UT 0:00, 20 October 2005 and UT 0:00, 20 October 2006.

**Upper panel:** earthquake events registered in the Geoscience Australia earthquake database (see: [www.ga.gov.au](http://www.ga.gov.au)) for the six main states of Australia, the Yilgarn Craton of WA and across an arc of Asia (series AA) to the North (coordinate range Lon. 60° to 180° and Lat.+40° to -50°).

**Lower panel:** Pulses per minute monitored from Esperance, WA shown at two amplitude levels (data time series and fitted trend-lines A and B) on VHF 148 MHz compared to the heliocentric radial range to Esperance, WA at Lon. 121° 53', Lat. 33° 51', (data time series C), computed 23/02/2007 using the Ephemeris Solar System Dynamics Program, NASA/CIT/Jet Propulsion Laboratory (see: <http://ssd.jpl.nasa.gov/>).

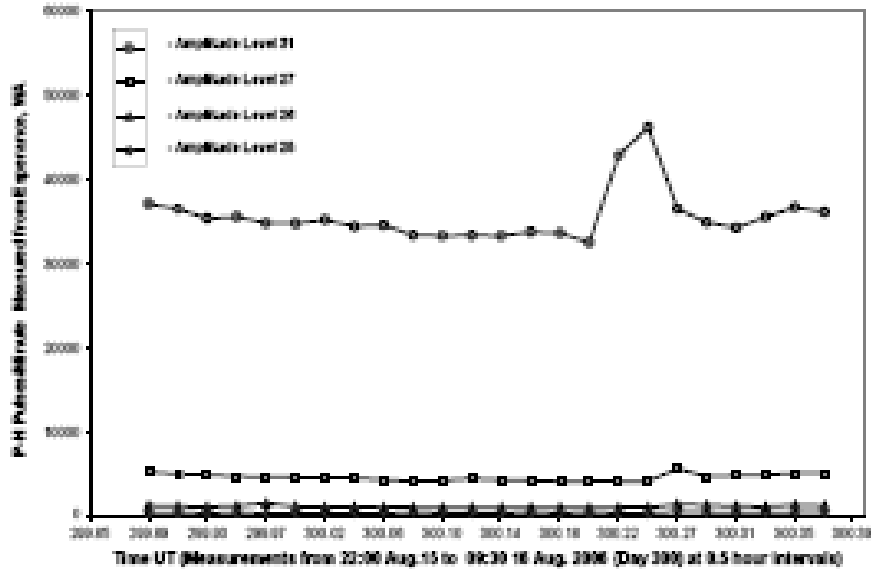


Figure . Graph of time versus P-H pulses/minute measured from Esperance, WA at four different amplitude levels. This ‘spike’ occurred at 06:00 to 06:30 UT on the 16 Aug., 2006 with an azimuth of ca. NW (ie. towards Java, Indonesia). It precedes an EQ of magnitude 4.9 that occurred S of Java, Indonesia at 9.056°S, 108.391°E at UT 22:37:36, Aug. 24, 2006, reported by the US Geological Survey, 2006 (<http://eqint.cr.usgs.gov/neic/>).

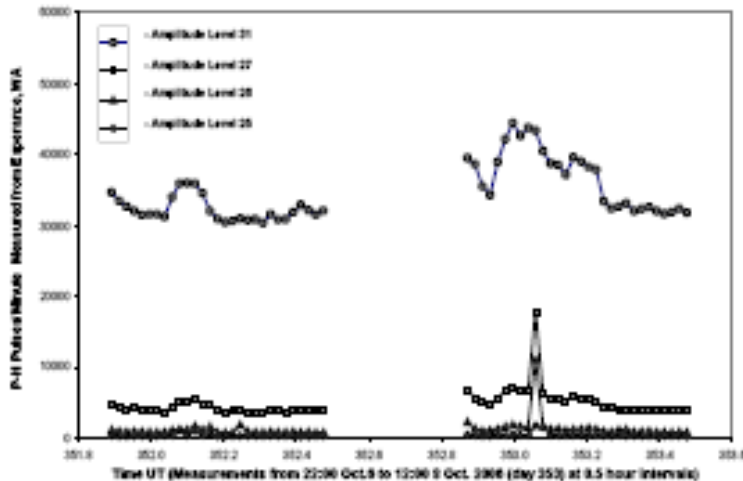


Figure . Graph of time versus P-H pulses/minute measured from Esperance, WA at four different amplitude levels. These ‘spikes’ occurred over 7 and 8 October, 2006 with an azimuth of ca NE (ie. towards Rabaul, Papua and New Guinea). They coincide with volcanic eruptions that occurred on Rabaul, Papua and New Guinea, at ca. 4 °S, 154 °E on UT 07:00, 7 Oct and 8 Oct, 2006 reported by the Rabaul Volcano Observatory, 2006 (<http://www.volcano.si.edu/volcano/cfm>).

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# DEVELOPMENT OF NOAA IMAGERY-BASE AND STUDYING FOR THE CHANGE OF THE EARTH'S SURFACE TEMPERATURE IN SHANGHAI PREFECTURE

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Shanghai is a large city with a developed industry and large population. With quick urbanization, many interference sources produce and cause routine measure difficultly to be used for observing earthquake precursors. At the same time, in Shanghai earthquake menace often comes from Yellow Sea, so far as these known observation measures are concerned, it is scarcely impossible to be used for earthquake precursors' observation in tidal flat and offshore area. Therefore it is difficult to carry through short-term and imminent earthquake prediction in shanghai, especially in tidal flat at present. However, satellite remote sensing technique, because of many special advantages, provides possibility of earthquake monitoring in these special environments. Carrying out study on short-term and immediate earthquake prediction using remote sensing is sufficiently significant in shanghai and its immediate sea area.

In this paper, main study regions include shanghai urban, shanghai suburban and offshore area near shanghai. Yellow Sea, especially South Yellow Sea, is chosen as comparison region. Shanghai locates in 30°40'N—31°53'N, 120°50'E—122°12'E, its north is The Changjiang River, its south is Hangzhou Bay, its east is East China Sea, and its west is near Kiangsu and Chekiang Provinces. Shanghai is of accumulation landform and belongs to alluvial plain. It comes into being land before 6000a and Pudong does before 1300a. In shanghai, apart from scattered isolated hill in west and south area, terrain is flat and average sea level is 4m.

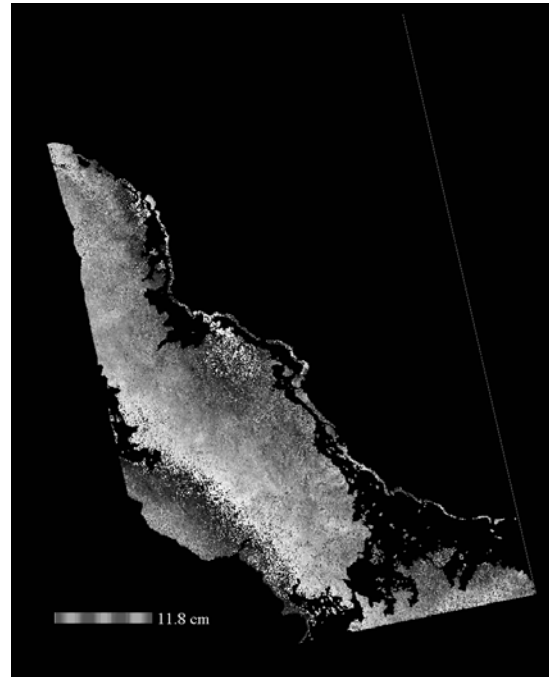
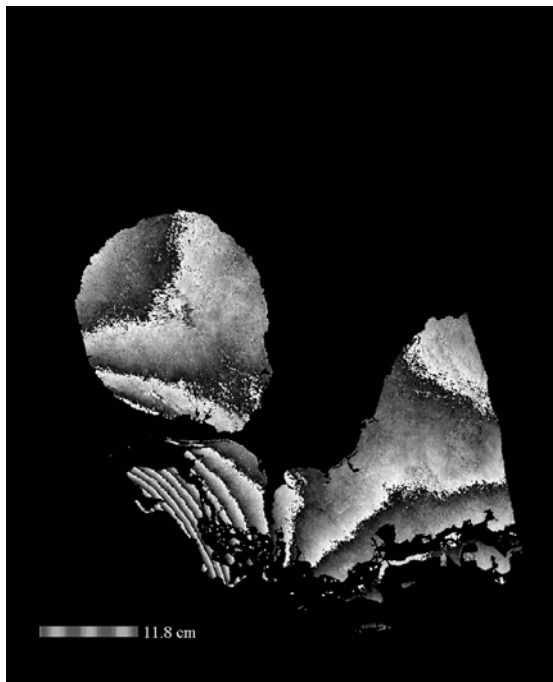
Using NOAA thermal infrared imagery of shanghai region and its neighboring sea area, we carry through statistical analysis the to the brightness temperature mean value of ten days' in the scale of different time and space, then discuss problems about anomaly extraction and relation between thermal infrared anomaly and earthquake occurred. The results indicate as follows: in time scale thermal infrared brightness temperature curve which comes from each experiment point shows same annual change character (it's high in summer and low in winter) as a whole, but concrete change is different. It includes that brightness temperature change is similarity in tendency at four points of shanghai urban, shanghai suburban, the Changjiang River Estuary and South Yellow Sea. The tendency is synchronous in process of temperature rising and falling but amplitude is different. However, in comparison region its amplitude is out sync, despite the curve's annual change shape is analogous to study regions'. From space scale, ten days' brightness temperature variation is 5K at each point in different years. The temperature amplitude is large in land and relatively stable over the sea. This shows brightness temperature of same point waves within some scope in different year but in same date and time phase. Only when the change is beyond the scope, it can be potential anomaly. Integrating geographical environment and weather factors of study region, we discuss cause of the anomaly. The conclusion is the anomaly may be an infrared phenomenon caused by atmospheric inversion, not earthquake precursor's anomaly. It is worth groping to use thermal infrared brightness temperature change of study region to analyze anomaly and to apply on earthquake prediction.

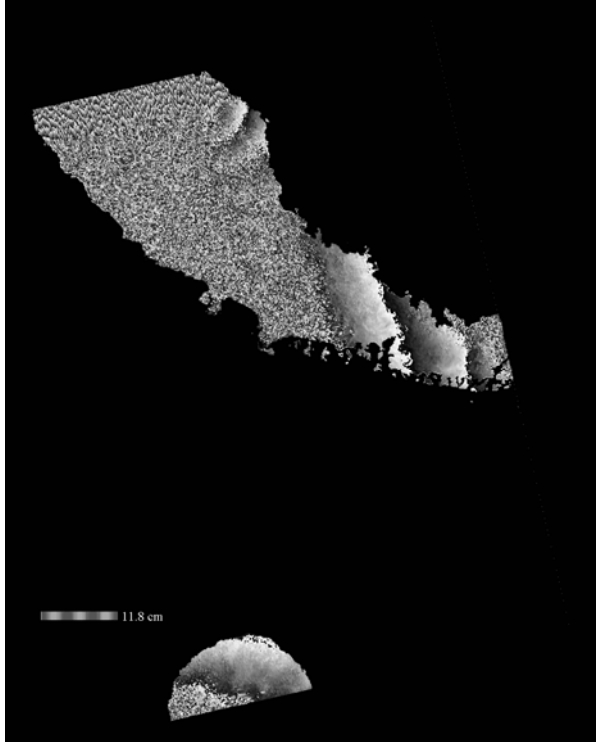
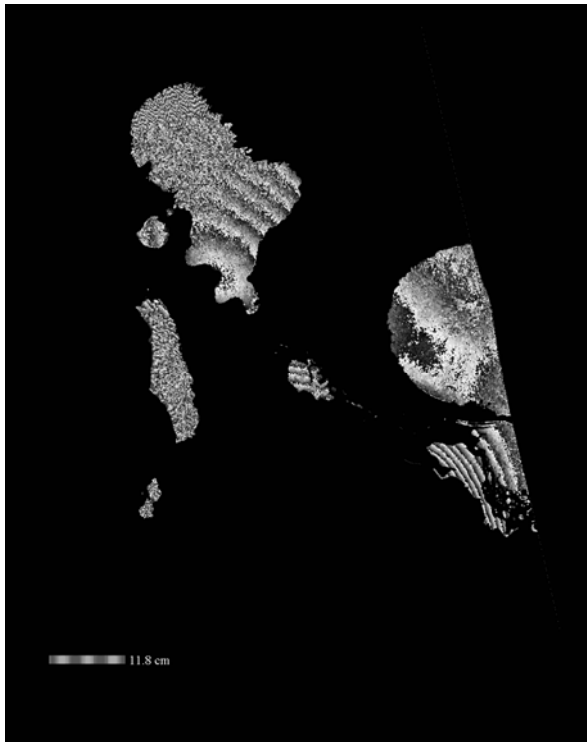
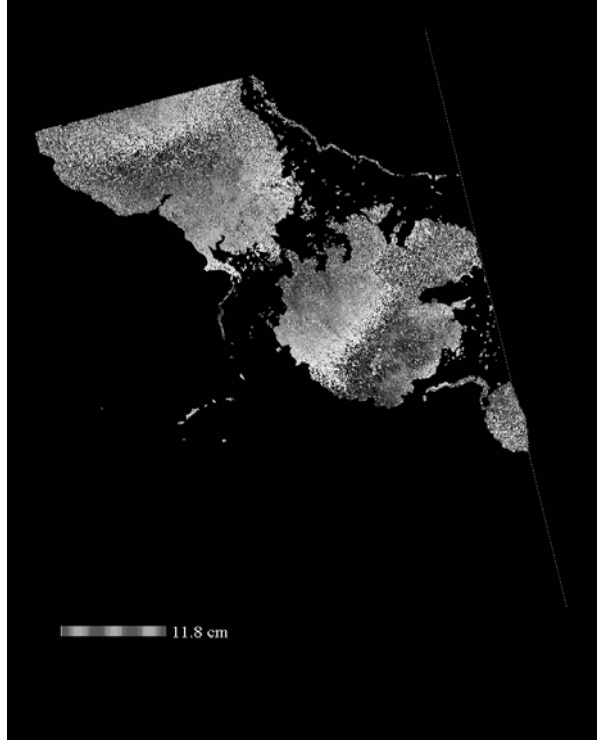
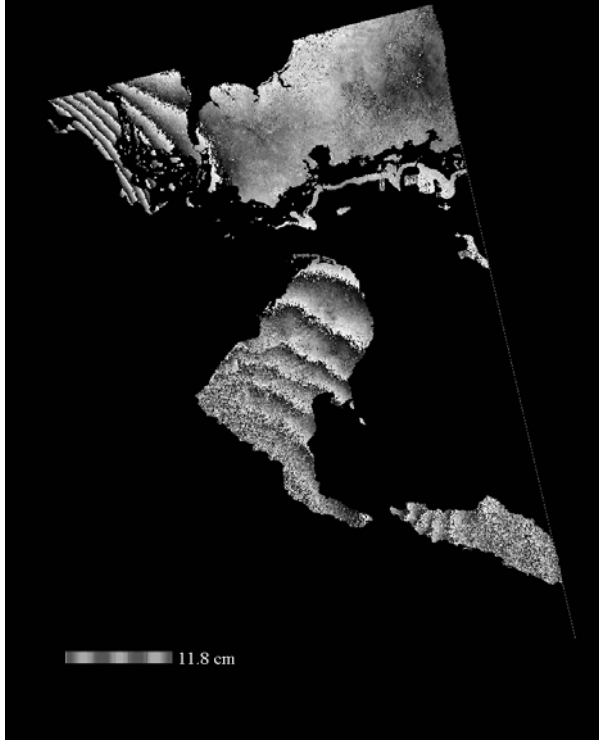
**Key words:** NOAA monitoring imagery, thermal infrared brightness temperature change, sea area seismic monitoring

## CRUSTAL DISPLACEMENT OF THE 2 APRIL 2007 SOLOMON EARTHQUAKE MW 8.1 OBSERVED BY DIFFERENTIAL SAR INTERFEROMETRY

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The Solomon Islands earthquake, about 40 km south-southeast (SSE) of Gizo, New Georgia Islands, Solomon Islands, occurred on April 2, 2007 at 7:39 AM local time. The magnitude of the earthquake was 8.1 on the moment magnitude scale. We use the benefit tools of Interferometric Synthetic Aperture Radar (InSAR) to make a rough estimation of crustal displacement associated with this earthquake. Eight interferograms from 16 L-band synthetic aperture radar (SAR) images acquired by ALOS PALSAR synthetic aperture radar instrument on January 31, 2007, February 12, 2007, March 1, 2007, April 16, 2007, May 3, 2007 and May 15, 2007 are analyzed. The SIGMA SAR packed software produced by JAXA Japan was applied to produce SLC (Single Look Complex) and interferometry patterns. In order to remove the effect of topographic phase, we used conventional digital elevation data, a 3-arcsecond SRTM digital elevation model. We found the maximum displacement in Ranongga Island of the [New Georgia Islands](#). Moreover, we estimated that uplift about 1.2 meters on Vonavona Island. In general, our result agrees well with in situ observations which were performed by Japanese scientists just few weeks after the earthquake.





## A PROPOSAL FOR SMALL SATELLITE MISSION FOR EARTHQUAKE STUDY

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Possible effect of the earthquake on the ionosphere has been reported many times in the past (Liu et al., 2001; Dvi et al, 2004). However as the manuscripts, which have been reported so far, are not convincing enough for most scientists to believe the effect, and the physical mechanism was not proposed, almost all ionospheric scientists are suspicious about the existence of the effect. One of the authors (Oyama) was also suspicious about the effects about 10 years ago. However we tried to find the effect by using data, which was obtained by Japanese satellite. Electron temperature ( $T_e$ ) at the height of 600km was studied in detail. We first examined three big earthquake occurred near Philippine in 1981 November and 1982 January. Oyama found that  $T_e$  in the afternoon overshoot reduces or disappears about 5 days prior to and after the earthquakes. The quality of the satellite data is accurate enough for us to believe the findings. We conclude that the westward electric field, which is generated associated with earthquake, modifies the behavior of  $T_e$  at the height of 600km.

However there are cases where the effect of the earthquake on the ionosphere is not detectable. It appears that the degree of the effects on the ionosphere depends on the magnitude of the earthquake, the depth, the latitude, and the electrical features of the fault. Land /sea earthquake might give different effect on the ionosphere. As a first step toward earthquake prediction, we need to study more cases, at least for the earthquake of magnitude greater than 7. The earthquake of the magnitude  $>7$  occurs about 10 times per year in the world.

With this background, we propose mini satellites armada. Each satellite should have the same electron temperature probe and electron density probe as a common instrument. The probes should be an impedance probe and electron temperature probe which have been developed in Japan (Oyama 1970, 1999; Oya 1965). The weight of the satellite would be about 30kg—100kg. One of the requirements to the satellite system for accurate electron temperature measurement is that the electrode of the electron temperature probe should point ram direction. It is desirable for the probe point ram direction all the time, to avoid the measurement inside the satellite wake. One  $T_e$  sampling about every 10-20 seconds is still acceptable. The circular electrode should not point the sun in order to avoid the secondary electrons from the electrode surface. The satellite should be designed to meet the requirement above.

The height and inclination of the orbit are about 500-600km and less than 30 degrees. If the inclination is higher than 30 degrees, the effect of the electric field upon downward/upward drifting plasma reduces and the detection of the earthquake effect, which might be caused by electric field, becomes more difficult.

Format of the data acquired from satellite armada should be the same in order to ease the data analysis and to save energy of software programming. Depending on the availability of the space in the satellite, several instruments can be added. Those are photometer (630nm), energetic particle detector, and VLF receiver. In the past, these instruments have reported abnormal phenomena, which are assumed to be associated with earthquakes. For the smallest satellite such as of 30kg weight, about 10 kg weight can be used for the science payload accommodation, as the total weight for the science payload would be about 30 % of the satellite. This means that several science payloads are possible to be accommodated except electron temperature probe and impedance probe for 30kg satellite..

We propose that each country, which is suffering from earthquake, launch one or two satellites under the coordination of scientists group. The satellites should use commercially available parts, which can reduce the cost of the satellite. The data obtained by these satellites will be analyzed with common



computer program. Receiving of the satellite data and/or the distribution of the data to university students as well as high school students should be planned as a series of space education program.

Together with the mini-satellite, which mentioned above, a small satellite (200kg), which accommodates more instruments, should be also proposed to study physics of the effect of the earthquake on the ionosphere. Possible candidate instruments are : 1. Direction finding VLF receiver, 2. Energetic particle analyzer, 3. Photometer and/or. Camera with several wave lengths, 4. Topside sounder, 5. Ion massspectrometer, 6. Plasma drift meter (which needs precise satellite attitude). The numbers in front of the instrument are in priority order. Emission of VLF radio wave is already confirmed, by DEMETER satellite (Parrot, 2004). Precipitation of energetic particle, enhanced intensity of nightglow has been once reported, which should be verified. Topside sounder provides information on the topside ionosphere, which might be deformed by the electric field associated with earthquake if it exists. Ion-mass spectrometer might help the variation of composition of the ionosphere caused by upward and down ward plasma drift.

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**SESSION J**

**PRECURSOR AND CO-SEISMIC SIGNATURES IN THE IONOSPHERE ASSOCIATED WITH  
THE 2004 M9.3 SUMATERA EARTHQUAKE**

**Jann-Yenq Liu (National Central University)**

## THE ATMOSPHERE VHF RADIO EMISSION AS PRECURSOR OF EARTHQUAKES

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As result of our analysis of a number of continuous VHF observations on a network of Crete island we show, that in an atmosphere above the sea on the eve of earthquake at heights of 0.1-10km electrically active clouds are produced and the conditions for electrical discharges in an atmosphere are created which can serve a source of VHF radio-emission registered on Crete.

We propose the model of pre lightning electricity generation. It is the model of convection transport that is started in an atmosphere by a horizontal gradient of temperature. It is proposed that the occurrence of electrical charges on a surface of the sea and their transportation further on heights up to 10 km in our model occurs due to pollution energy allocated within bottom of the sea as gases and heat injection.

The average flux density and power estimations of VHF precursors were made for Crete net situation to compare with published VHF data and radio stars sources. The average anomaly of the VHF flux density is comparable with the radio stars emission or is to be more than  $10^{-19} \text{ Wm}^{-2}\text{Hz}^{-1}$ . The space monitoring by occultation method will be useful to confirm the atmosphere nature of VHF precursors. The payload COMPASS-1 mission included the 41/53 MHz receivers to study global distribution of electromagnetic emissions in VHF range.

# **IONOSPHERIC TOTAL ELECTRON CONTENT VARIATIONS OBSERVED BEFORE EARTHQUAKES: POSSIBLE PHYSICAL MECHANISM AND MODELING**

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The numerous studies of the ionospheric earthquake precursors in the GPS TEC (Total Electron Content) measurements carried out in the last years show that for strong mid-latitudinal earthquakes the seismo-ionospheric anomaly looks like local TEC increase situated in the vicinity of the earthquake epicenter area. The zone of the anomaly maximum manifestation (TEC enhancement more than 35%) has a spatial scale of some thousands km in longitude and about 1000 km in latitude. In the case of strong low-latitudinal earthquakes there are effects related with modification of the equatorial anomaly: deepening or filling of the ionospheric electron density trough over the magnetic equator.

We consider that the very probable reason of the observed NmF2 and TEC disturbances observed before the earthquakes is the vertical drift of the F2-region ionospheric plasma under the influence of zonal electric field of seismogenic origin. To check this hypothesis, the model calculations were carried out with use of the UAM (Upper Atmosphere Model) - the global numerical model of the Earth's upper atmosphere. The upper atmosphere state, presumably foregone a strong earthquake, was modeled by means of switching-on of additional sources of the electric field in the UAM electric potential equation which was solved numerically jointly with all other UAM equations (continuity, momentum and heat balance) for neutral and ionized gases. Results of the model calculations have revealed a fine agreement with TEC anomalies observed before strong earthquakes in the middle and low latitudes both in spatial scales and in amplitude characteristics.