Radiations of DC Electric Field from Granite under Pressure prior to Earthquakes

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Abnormal increases of total electrons contents (TEC) in the ionosphere appeared 1.5 hour ~ few tens of minute prior to large earthquakes were measured by GPS signal [1]. It is considered that the increase of TEC might be caused by deformation of electron density profile in the ionosphere due to DC electric field which would be generated in the earth’s crust under a high pressure and radiated up to the ionosphere at a stage prior to an earthquake. I here present results of a laboratory experiment on DC electric field radiations from granite under pressure.

So far, I have been studying the excitation mechanism and behaviors of co-seismic electromagnetic (EM) waves by detecting EM signals in a deep borehole and above the ground together with the measurement of seismic waves. From the analysis of these data, I found that co-seismic EM waves were basically excited by seismic P-waves due to piezo-electric effect [2], and the EM amplitude was enlarged at arrival of S-waves, via P-wave amplitude largely deformed by seismic S-wave. However, the excited EM wave was easily decayed in the earth’s crust due to its large electrical conductivity [3]. Therefore, it was concluded that co-seismic EM waves can be detected only when the S-wave arrived at the EM observation site. Furthermore, I found EM waves generated at earthquake hypocenters couldn’t be detected at far EM observation sites because the EM waves radiate almost vertically upward by an extremely small critical angle due to the large different dielectric constants between in the earth’s sedimentary layer and in the air. Therefore, EM waves couldn’t become a candidate of precursor of earthquakes [4].

However, from the series of the observational results, I noticed an important point that the piezo-electric effect is very sensitive in the earth’s crust. When we think of electric situation in the earth’s crust loaded by an extremely high pressure before the occurrence of earthquakes, a large electric charge polarization would be formed in the earth’s crust, and a DC electric field would appear above the ground.

I have also noticed an important fact in an experiment. I conducted the laboratory simulation experiment on EM wave excitation in a fragmentation layer in an active fault. The fact was an appearance of DC electric field just before the fracture of small stone in the fragmentation layer. This suggests that DC electric field is expected to be radiated out of the ground whenever extremely high pressure is loaded to the earth’s crust before earthquakes.

Then I conducted another laboratory experiment on high pressure loading to a granite pillar for confirming the radiation of DC electric field from it. A granite pillar (10 cm x 10 cm x 50 cm) and a hydraulic jack with a pressure gauge were straightly arrayed on a wooden bench. A crossed linear electric-dipole-antenna system was set near the side surface of the granite pillar. Figure shows a time-sequence of electric fields of east-west and north-south components when pressure of 3.5 ton were repeatedly loaded to the top of the granite pillar. Both electric field components increased when the pressures were loaded to the granite, and decreased when the pressures were withdrawn from the granite.

This experimental result has manifested that the DC electric field would appear before earthquakes. Therefore the observation of DC electric field above the ground is important for forecasting earthquakes.

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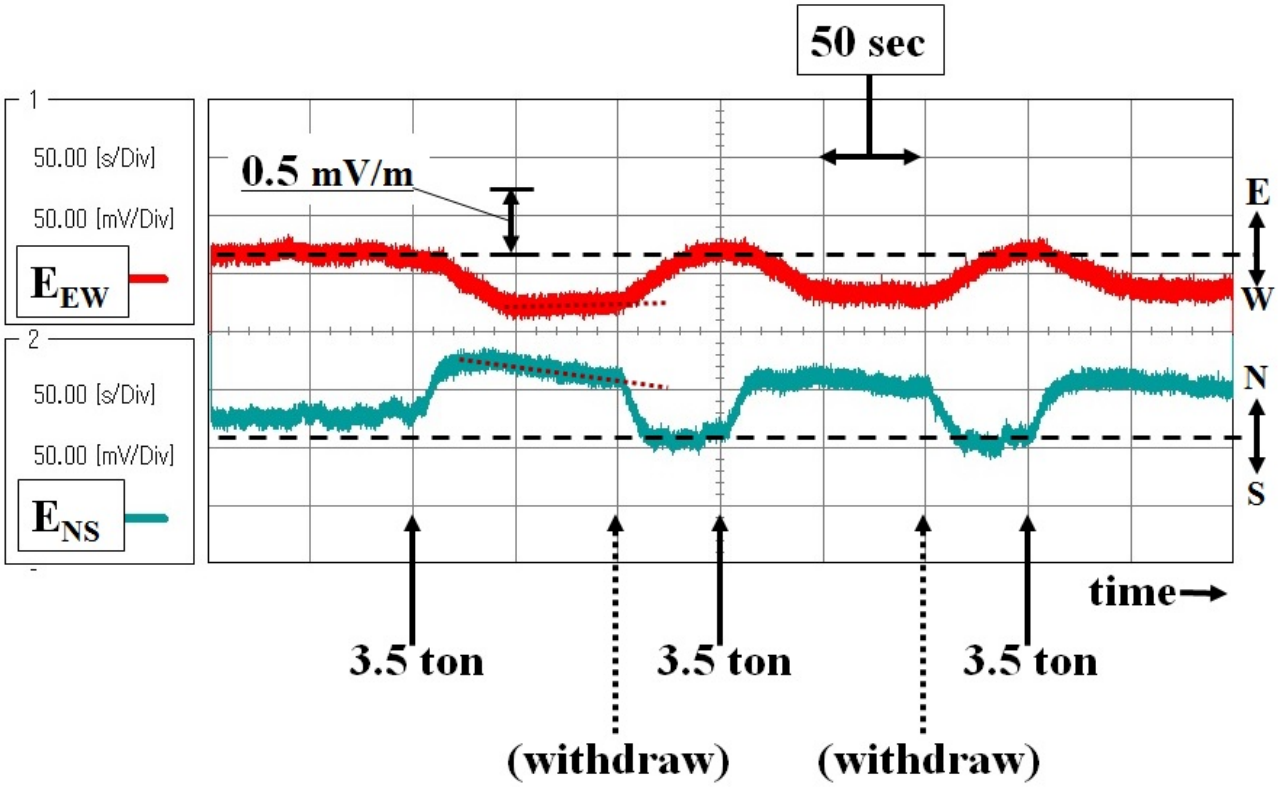
Keywords: Laboratory experiment, Granite under pressure, Radiations of DC electric field



Electromagnetic fields generated by an earthquake due to the motional-induction effect

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When seismic waves propagate in the conducting crust, they make the crust material move and cut the ambient geomagnetic field, and hence product electromotive force and induction electric currents, which give rise to variations of electromagnetic (EM) field. The coupling between the seismic waves and EM disturbances is called motional induction effect and it is a possible mechanism for the anomaly EM disturbances that were observed during earthquake events. In this work, we study the properties of the EM field generated by an earthquake due to such a mechanism. By solving the governing equations that couple the elastodynamic equations with Maxwell equations, we derive the seismoelectromagnetic wavefields excited by a single point force and a double couple source in a full space. Two types of EM disturbances can be generated, i.e., the coseismic EM field accompanying the seismic wave and the independently propagating EM wave which arrives much earlier than the seismic wave. Simulation of an M_w 6 earthquake shows that at a receiving location where the seismic acceleration is on the order of 0.01 m/s^2, the coseismic electric and magnetic fields are on the orders of 1 μV/m and 0.1nT, respectively, agreeing with the EM data observed in the real earthquake, and indicating that the motional induction effect is effective enough to generate observable EM signal. The motional induction effect is compared with the electrokinetic effect, showing the overall conclusion that the former dominates the mechanoelectric conversion under low-frequency and high-conductivity conditions while the latter dominates under high-frequency and low-conductivity conditions.

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Keywords: earthquake, electromagnetic fields, motional induction effect, earth's magnetic field

Probability tomography and wavelet analysis of self-potential data

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Self-potential method is a kind of near-surface geophysical technique, which has been adopted in exploration of metal ore, monitoring of contaminants and natural hazards. This study focuses on the self-potential data processing. The source element occurrence probability tomography can give the probability of the source location and the charge property. In order to improve the limited resolution of the probability tomography for the multiple sources, we combine the charge occurrence probability tomography with the complex wavelet transform method in self-potential data processing. We apply the complex wavelet analysis the synthetic self-potential data obtained from the forward modeling of some given models. We also apply the combined probability tomography and the continuous complex wavelet analysis to the synthetic self-potential data. This study is aiming at providing an effective continuous monitoring method of ground water flow.

Keywords: Probability tomography, wavelet analysis, self-potential

Assessing the potential earthquake precursory information in ULF magnetic data recorded in Kanto, Japan during 2000 –2010

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In order to clarify the ULF seismo-magnetic phenomena, a sensitive geomagnetic network has been installed in Kanto, Japan since 2000. In previous studies, we have verified the correlation between ULF magnetic anomalies and local sizeable earthquakes. In this paper, we use Molchan’s error diagram to evaluate the potential earthquake precursory information in the magnetic data recorded in Kanto, Japan during 2000 –2010. We introduce the probability gain (*PG*) and the probability difference (*D*) to quantify the forecasting performance and to explore the optimal prediction parameters for a given ULF magnetic station. The results show that the earthquake predictions based on magnetic anomalies are significantly better than random guesses, indicating the magnetic data contain potential useful precursory information. Further investigations suggest that the prediction performance depends on the choices of the distance (*R*) and size of the target earthquake events (*Es*). Optimal *R* and *Es* are about (100 km, $10^{8.75}$) and (180 km, $10^{8.75}$) for Seikoshi (SKS) station in Izu and Kiyosumi (KYS) station in Boso, respectively.

Keywords: ULF magnetic data, earthquake precursory information, Molchan’s error diagram, Kanto, Japan

Statistical analyses of *z* test, and ROC curve on anomalies of the ionospheric TEC associated with earthquakes in China during 1998-2015

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In this study, we examine 62 M6.0 earthquakes reported by China Earthquake Networks Center http://www.csndmc.ac.cn/newweb/catalog_direct_link.htm and the ionospheric total electron content (TEC) of the global ionosphere map (GIM) at a fixed location (32.5˚N, 95˚E, the location center of those earthquakes) retreated from CODE (Center for Orbit Determination in Europe, CODE, ftp://ftp.unibe.ch/aiub/CODE/) in China during 1998-2015. The statistical significances of the pre-earthquake ionospheric anomalies (PEIAs) of the GIM TEC associated with the earthquakes are further investigated by z test and ROC curve. Here, we subdivide the earthquakes into three groups, 37 6.0 M<6.5, 18 6.5M<6.9, and 7 M7.0, to avoid a possible confounded effect and find the associated characteristic of the observed PEIA of each group. Meanwhile, we randomize the observed anomalous days to verify the significance of the PEIAs. Statistical results show that the anomaly characteristic of the polarity, appearance local time, duration, lead day, etc. before the earthquakes is essential to detect PEIAs. Three negative anomaly zones (i.e. one for each earthquake group) with significant z test: Zone A (1800-2200 UT (00:20-04:20 LT, post midnight to pre-dawn) 4-5 days before 37 6.0M6.0<6.5 earthquakes), Zone B (0100-0400 UT (07:20-11:20 LT, morning) 3-6 days before 18 6.5M6.5<7.0 earthquakes), and Zone C (0400-1000 UT (10:20-16:20 LT, pre-noon to afternoon) 3-5 days before M7.0 earthquakes). It is found that 59.5% (22 out of 37) of 6.0M6.0<6.5, 72.2% (13 out of 18) of 6.5M6.0<7.0, and 85.7% (6 out of 7) of M7.0.earthquakes are preceded by the PEIA of negative TEC anomalies. This depicts that the greater earthquake have a better chance to be leaded by the PEIAs. ROC curve further confirms that the PEIA is a reliable earthquake precursor. Finally, a logistic regression is applied to find the relationship between earthquake parameters and PEIA strength.

Keywords: z test, ROC curve, logistic regression

A Feature-Based Approach to the Classification of Anomalous Signals in Geomagnetic Data

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QuakeFinder and its international collaborators have installed and currently maintain an array of 165 three-axis induction magnetometer sites in California, Peru, Taiwan, Greece, Chile and Sumatra. Based on research by Bleier *et al.* (2009), Fraser-Smith *et al.* (1990), and Freund (2007), the electromagnetic data from these instruments are being analyzed for pre-earthquake signatures. This analysis consists of both private research by QuakeFinder and institutional collaborators.

QuakeFinder has developed an algorithm framework aimed at isolating anomalous signals (pulses) in the time series. We apply this framework to the magnetometer data and compute features of the isolated pulses. Based on these features, the pulses are then filtered and categorized using a variety of methods. Pulses of interest can then be analyzed with respect to their relationship with seismicity. We map daily pulse-counts to a time series representing the likelihood of a seismic event occurring at some future time. These “pseudo-probabilities” can in turn be represented as Molchan diagrams. The Molchan curve provides an effective cost function for optimization and allows for a rigorous statistical assessment of the validity of pre-earthquake signals in the electromagnetic data.

We explore different methods to isolate these pulses in the data, features to characterize them, and ways to determine their source. Specifically we emphasize the usage of clustering algorithms applied to principle components in feature space and algorithms that identify simultaneous pulses at more than one station where typical station distance is approximately 32km. By integrating these new techniques into our algorithm, we can compare the Molchan curves and fairly assess their performance.

Keywords: magnetic field, earthquake, algorithm

An Integrated Approach to Observations of Pre-earthquake Signals. Why Geospace observations still need ground data?

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This work is part of international project to study the complex chain of interactions lithosphere –atmosphere -ionosphere (LAI) and is supported by International Space Science Institute (ISSI) in Bern and Beijing.

We are applying a scheme requiring interdisciplinary use of latest geospace and remote sensing technology based on multi platform data observations. This multi sensory approach utilizes atmospheric and ionospheric signals needed for the search of pre-earthquake signals in atmosphere. The proposed methodology uses existing satellite thermal observations (LEO, GEO) in conjunction with GPS/TEC (GNSS), atmospheric assimilation models and ground multi parameter continuous measurements to study physical processes described by the Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) concept. We present results of analyzing five physical parameters- radon, seismicity, temperature of the atmosphere boundary layer, outgoing earth infrared radiation and GPS/TEC and their temporal and spatial variations several days before the onset of the following recent earthquakes: (1) 2016 M6.6 in California; (2) 2016 M6.4 of Feb 06 in Taiwan and (3) 2016 M7.0 of Nov 21 in Japan. Our preliminary results of simultaneous analysis of multi-parameter data suggest that pre-earthquake phase follows a general temporal-spatial evolution pattern, which plays a critical role in the understanding of LAI coupling associated with earthquake processes. This pattern could be reviled only with multi instruments observations from space and ground and been seen and in other large earthquakes worldwide.

Keywords: earthquake, geospace, precursor

The new application research related to CSES

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China CSES satellite will be launched in 2017. There are eight scientific payloads onboard, to detect the electric field with frequency band of DC-10MHz, magnetic field to 20kHz, in-situ plasma parameters including electron density, electron temperature, ion composition, ion density and ion temperature, high energy particle of electrons and protons, electron density profiles and tomography. In order to bring them into full play, new research has been carried out in data processing and application. The main progress has been concluded as following.
By receiving the TBB signals, about 30 stations will be set up to construct two profiles in south-north direction in China mainland. The ionospheric tomography technology has been developed by employing the methods of Truncated Singular Value Decomposition, Spherical Function and Empirical Orthogonal Function (EOF). On the basis of beacon receiver data in China, the Ne profiles along the observing links have been built up, and their temporal features have been studied.
Based on the constellation observation, and taken COSMIC data as an example, the assimilation model of ionosphere on electron density has been developed by using EOF method. Considering the inversion accuracy at different layers, E and F layer have been calculated separately under different coordinate systems. Furthermore, the Hall and Pederson conductivity have been obtained at the altitude of 90-500km, which can be an input for computing the current system in ionosphere.
The full wave propagation model of VLF radio waves has been improved, and the two-dimensional calculating results are displayed to reveal the spatial distribution features of these radio waves. The actual observation on DEMETER satellite of ground transmitters is compared with the 2D theoretical results, and their consistence verifies the reliability of the model.
By emitting the high power HF signals into the space, one can disturb and cause the heating phenomena in lower and topside ionosphere. Three heating events have been chosen out in SURA-DEMETER experiments. Based on the Ohmic heating theory, a 3D model has been constructed to simulate the heating process, in which the disturbed amplitudes in Ne are close to the actual observing under different ionospheric state.
In the LAIC model related to earthquake research, the DC electric field coupling model has been paid more attention in recent years. Some simultaneous variation phenomena have been obtained around earthquakes. To explain these disturbances, the electric field model is suggested and improved, in which the additional current at the ground surface is considered. It is found that, vertical electric field is more obvious at low latitude and the horizontal electric field does not change with the height at high latitudes. The penetration height of LAI electric field in ionosphere is lower at low latitude than that at high latitude.

Keywords: CSES, LAI coupling mechanism, ionospheric tomography

Integrated observations of earthquake precursors in Taiwan

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The integrated observational project of earthquake precursors in the Taiwan area consists of continuous measurements of the geomagnetic perturbation, crustal deformation, ionospheric disturbance, ground water level, and leaky gas (Radon) from the crust in the past two decades. Since 2010, the gamma-ray sensors, downhole strainmeters, telluric electric field measurements and thermal infrared ray analysis are further established. An electric coupling model for the lithosphere-atmosphere-ionosphere was also developed. In this talk, some recent results from the integrated observations and theoretical model for earthquake precursors will be presented.

Keywords: earthquake precursors, electric coupling model

Implications of radon and gamma rays anomalies in northern Taiwan

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Taiwan is tectonically situated in a terrain resulting from the oblique collision between the Philippine Sea plate (PHS) and the Eurasian plate (EU). The continuous observations of soil radon for earthquake studies at the Tapingti station (TPT) have been recorded and are compared with the data from gamma rays observations at the Taiwan Volcano Observation station(YMSG), located north to the TPT station. Some anomalous high radon concentrations and gamma-ray counts at certain times can be identified. It is noted that the significant increase of soil radon concentrations were observed and followed by the increase in gamma-ray counts several days before the earthquakes, which occurred in northeastern Taiwan. Many of these earthquakes are located within the subducting PHS beneath the EU to the north along the Ryukyu trench in northern Taiwan (e.g., M_L=6.3 April 20, 2015). It is suggested that the pre-earthquake activities may be associated with slow geodynamic processes at the subduction interface, leading to the PHS movement to trigger radon enhancements at TPT station. Furthermore, the further movement of PHS may be locked by EU and accumulate elastic stress resulting in the increase of gamma rays due to an increase in the porosity and fractures below the YMSG station. The continuous monitoring on the multiple parameters can improve our understanding of the relationship between the observed radon and gamma-ray variations and the regional crustal stress/strain in the area.

Keywords: radon, gamma ray, earthquake, subduction

Progresses on Theoretical Simulations of Electric Current Effects on the Ionospheric Plasma Structure

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Recent studies show ionospheric plasma density modifications due to lithosphere and atmosphere activities. One of the possible mechanisms for the ionosphere modifications might be direct current transmission effect to the ionospheric dynamo region. On the other hand, the disturbances could also affect the ionosphere by generating atmospheric disturbance waves that modify the neutral winds and thus affect the ionospheric dynamo and electron density. In this study, we report recent progresses on simulations of the direct current and disturbance wind dynamo effects using a coupled three-dimensional global ionosphere electrodynamic model. Simulations carried out by inclusion of the upward/downward transmission of direct electric current at 85 km altitude with various areas of current injections, indicate negative/positive TEC effects. The simulations for different local time sectors are also carried out showing that the effect is most prominent at dusk followed by that of at afternoon and noon periods. The simulations will also be compared with observations of pre-seismic ionospheric anomalies.

Keywords: Pre-seismic ionosphere disturbances, ionospheric electrodynamics

Possible disturbing mechansim of ionosphere before large earthquakes

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Electric field seems to be a main driver which disturbs ionosphere prior to large earthquake. The problem is where and how the electric field is generated. First part of this paper, we present data observed with US satellite, Dynamic Explorer 2 (DE-2) which is used to discuss our idea on the generation of electric field. We propose here that electric field is originally dynamo field which appears around 100 km. It only enhances around the epicenter region. That is, during daytime the eastward electric field is enhanced, while during nigh time, westward electric field is enhanced. As a result of enhanced eastward/westward electric field, plasma density over the geomagnetic equator increases both day and night time. During day time, plasma is lifted to higher altitude, causing plasma density increase because of its less recombination with neutral particles. At the same time, magnetic flux tube is filled by the plasma. During night time plasma which is lifted up during daytime is pushed down. This process causes increase of plasma density around F region and topside ionosphere. In high latitude, night time enhancement of F region plasma density is more clearly observed because plasma which is stored in the large magnetic flux tube is continuously supplied. Although the mechanism of the enhanced dynamo field is not so clear, we suggest that internal gravity wave of small amplitude which is generated before large earthquake nonlinearly interacts with planetary scale wave, and is amplified. The internal gravity thus amplified enhances the dynamo electric field and /or neutral density at dynamo region as well as F region.

Keywords: Satellite , Earthquake, Electric field

