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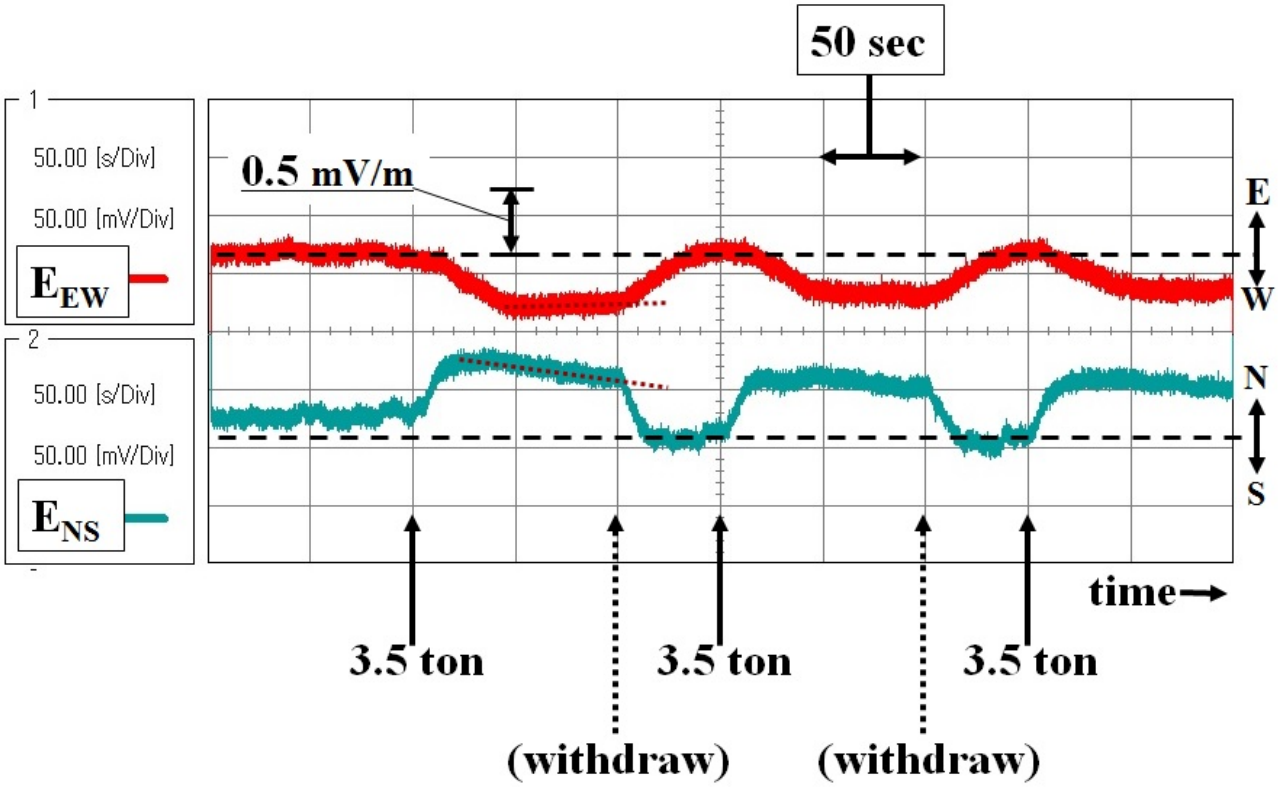
Keywords: Laboratory experiment, Granite under pressure, Radiations of DC electric field



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

Predict the 2016 Kumamoto M7.3 earthquake with satellite clouds data

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Clouds are usually considered as weather phenomenon, while in recent years some reports were published that unusual clouds appeared before strong quakes, and they could be used to predict earthquake. In March 2016, we observed some anomalous clouds over Japan and predict that a M5.8-M6.8 quake will hit east Japan, and the possible date is April 14. This information was published on Researchgate in advance. On April 14 a M6.5 quake hit west Japan and on April 16 a M7.3 quake happened. These facts proved our prediction, and in this paper why the predicted location is wrong is discussed. The predictions about Afghanistan quake and Myanmar quakes which happened in April 2016 are also introduced. Our analysis show that the three consecutive successful predictions are not by coincidence.

Keywords: Kumamoto Earthquake, Satellite Clouds Data

Statistical analysis of ULF geomagnetic changes related to earthquake activity using transfer function around Kakioka,Japan, during 1997-2015

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Recently, ultra low frequency(ULF, less than 1 Hz) has been considered one of the most prospective bands to detect earthquake precursory signatures because of its larger skin depth. Han et,al., 2014 have performed statistical studies at Kakioka(KAK) station, it is proved that ULF geomagnetic changes preceding earthquake at KAK station has statistical significances. However, we can use only the remote station as a reference which shows a high correlation with KAK station. Therefore, to study use any remote station for investigation the ULF geomagnetic changes related to earthquake, we have performed statistical studies using the geomagnetic transfer function approach using the KAK station, Japan, during 1997-2015. We investigated the energy of ULF geomagnetic signals of the frequency around 0.01 Hz using wavelet transform analysis. To minimize the influences of artificial noisesand to remove global geomagnetic perturbations, we used only the geomagnetic data observed at nighttime (LT01:30 A.M. to 04:30 A.M.) and utilized observations from a remote station, Memambetsu, as a reference. We have computed geomagnetic Z component at KAK station using transfer function, and defined P value (the ratio observed Z component and computed). We have determined threshold for geomagnetic anomaly from P value. Earthquake as Es>10^8 at KAK station have chosen for this study. Statistical results of superposed epoch analysis have indicated that significant correlation between ULF geomagnetic changes and earthquake 21-25 days before the events. Further, we have evaluated the precursory information of ULF geomagnetic changes related to earthquake using Molchan’ s error diagram. The probability Gain(PG) is around 1.3 against a Poisson model. The above results have indicated that it is possible to use any remote station using transfer function. Details will be given in the presentation.

Spatiotemporal Characteristics of b-value and TEC Variations before the Large Earthquakes in Japan

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In recent years, there are many reports on electromagnetic phenomenon preceding large earthquakes. Anomaly of the total electron content (TEC) is one of the most promising anomalies for the short-term earthquake forecast. On the other hand, it is reported that the b-value around the epicenter region decreases prior to the large earthquake. The b-value can compute using the Gutenberg Richter law. The lead time is around few or tens of years. We can’ t discriminate anomalous changes on earthquakes and solar activities easily at the moment. In this paper, we try to develop a method for the earthquake short-term forecast using the b-value and the TEC analysis. We investigate the effectiveness of the integrated analyses on the b-value for the middle-term forecast and TEC analysis for the short-term forecast.
We select the 2003, 2008 Tokachi-oki EQ (M8.0) and the 2011 Tohoku-oki EQ. As results, we found the variation of b-value has a tendency to decrease for M7class EQs in the analyzed regions and the neighbor's area. For the 2003Tokachi-oki EQ, we investigated temporal variation for the b-value with interval of 1day. We found decrease of b-value occurred 16 days and 2-3days before the main shock. On the other hand, for anomaly of the TEC in the Hokkaido-region, we found significant increase of TEC 2 days before the EQ(M>6.0,D<40 km) using the statistical analysis during 1998-2015. That is, the positive anomaly is dominant, In the case of the 2003 Tokachi-oki EQ, TEC anomaly occurred 2 days before main shock. However, immediately after this TEC anomaly , solar activity becomes active, and after that, positive anomaly may be masked from solar activity. From these results, in the 2003 Tokachi-oki EQ,we found that anomaly of b-value occurred 16 days before main shock after that, TEC anomaly occurred. The results for the 2011Tohoku-oki EQ show the similar tendency in b-value and TEC variations.
From above results, we can conclude that simultaneous use of the b-value and the TEC analysis is suggestive of the effectiveness in short-term earthquake forecast for the M7 or higher earthquakes Details will be given in the presentation.

Keywords: Earthquake, Electromagnetics, b-value

Development of Radon Detector and Observation at Okayama

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An increase of the radon in underground water at Nishinomiya City[1] and an increase of the radon in atmosphere[2] at the southern part of Hyogo Prefecture earthquake in 1995 were reported. Moreover, in the case of Tohoku Region Pacific Coast Earthquake, the data of the exhaust air monitor in the radiation facility of Fukushima Medical College (Fukushima) has been reported that the peak duration was long, and the peak decreased rapidly before the earthquake[3].
We had measured radon in a pit of Kurashiki mine, and in the atmosphere in Chiba Prefecture, Chiba. We used a Radon Monitor of SUN NUCLEAR Corporation, Model 1028 in the Kurashiki, and Pylon Trace Environmental Level Radon Gas Detectors (abbreviated to TEL) in Chiba. The TEL is composed of ZnS(Ag) scintillator and a Photomultiplier. However, its count rate decreased due to unknown causes, and stopped in the end.
On the other hand PIN photodiode have been developed for high sensitive radon detector, and used in Super-Kamiokande[4]. Last year we made a detector to measure atmospheric radon, using PIN photodiode. We use a Si PIN photodiode as detector, S3204-09 (Unsealed), supplied by Hamamatsu Photonics K.K. We constructed a radon detection system, using a stainless pot as air container, H4083 as charge amplifier, C4900-01 as High voltage power supply module, a pulse shape amplifier, a Multi-Channel Analyzer, and a Personal computer as data analysis. Output of the multi-channel analyzer showed clear alpha peaks of ^{218}Po and ^{214}Po of radon daughters from Uranite.
This time we have measured the radon in the atmosphere by the system, for one year at Okayama University of Science, and observed daily variation. We also measured the radon by the system in the pit of Kurashiki mine for about 1 week, and got sensitive data comparing with those by the Radon Monitor, Model 1028. We also plan to substitute the system for the TEL to measure the radon density in the atmosphere in Chiba Prefecture, Chiba.

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Keywords: Radon detection, atmosphere, earthquake prediction

Experimental Study for Lithosphere-Atmosphere-Ionosphere Coupling : Observation of Atmospheric Parameters at Asahi Station, Chiba, Japan

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The Ionospheric anomaly is one of the most promising precursory phenomena for large earthquakes. Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model has been proposed to explain these phenomena. To examine the possibility of chemical channel of LAIC through the monitoring of atmospheric electricity parameters, we have installed sensors for the atmospheric electric field (AEF), atmospheric ion concentration (AIC), radon concentration, radon exhalation quantity (REQ), and weather elements. We will report the properties of variation in atmospheric electricity parameters observed at Asahi station (ASA), Japan to identify earthquake-related signals in these parameters.
We found that the variation of radon exhalation quantity shows a clear negative correlation with 3 hours delay to the air pressure variation in clear days. Each season differs in daily pattern. AIC and AEF variations show lag correlation with radon exhalation quantity variation. To extract anomalous radon variation related to earthquakes, we should set a network of Radon monitoring and establish a model of radon variation for the future detailed analysis. We also observed cases that AEF has showed a spike-like increase at the same time as the time when AIC has largely increased. It must be going to be checked whether AEF data was taken in fair-weather period, however, it is suggested that change in local charge distribution may have influenced AEF.

Keywords: Lithosphere-Atmosphere-Ionosphere Coupling, atmospheric ion concentration, atmospheric elctric field, radon exhalation quantity

Co-seismic signatures observed by QuakeFinder systems during the 6 February 2016 M6.6 Meinong Earthquake in Taiwan

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At 03:57 local time (19:57 UTC) on 6 February 2016, an earthquake with a moment magnitude of 6.6 struck in the Meinong District of Kaohsiung in Taiwan. The earthquake struck at a depth of around 23 km. This comparatively shallow depth caused more intense reverberations on the surface, and resulted in widespread damage and 117 deaths. The earthquake is the deadliest earthquake in Taiwan since the 921 earthquake in 1999. In this paper, seismograms of the free field strong earthquake observation network published by Center Weather Bureau are used as a reference. Concurrent/co-located measurements of seismometer and QuakeFinder systems together with infrasound systems are employed to study seismic waves and disturbances in the neutral atmosphere near the Earth’ s surface of the Meinong Earthquake. Each QuakeFinder system consists of a 3-axes induction magnetometer, an air conductivity sensor, a geophone, and temperature/relative humidity sensors. There are no obvious charges in the positive/negative ions, the temperature, and the humidity, while the magnetometer, the geophone, and infrasound data show clear co-seismic signatures, similar to seismic waves recorded by seismograms. The magnetometers register high-frequency pulsations, like seismic waves and superimpose with low-frequency variations, which could be caused by the magnetometer tilting and the underground water level change, respectively, during the arrival of seismic waves. The overall power spectrum of the geophones is similar to that of the seismometers, and however, the geophone (also magnetometer) power yields an exponential decay to the distance to the epicenter, while the seismic wave power is inversely proportional to the square of the distance. This suggests that the mechanisms detecting seismic waves of the QuakeFinder system and seismometers are different. In general, the geophone and magnetometer/infrasound system are useful to record high- and low-frequency seismic waves, respectively. Finally, some latest progresses in pre-earthquake signals probed by QuakeFinder systems in Taiwan are reported.

Keywords: co-seismic signature, earthquake

Characteristics of Ionospheric Electron Density Anomalies related to Geomagnetic Storms and large Earthquakes

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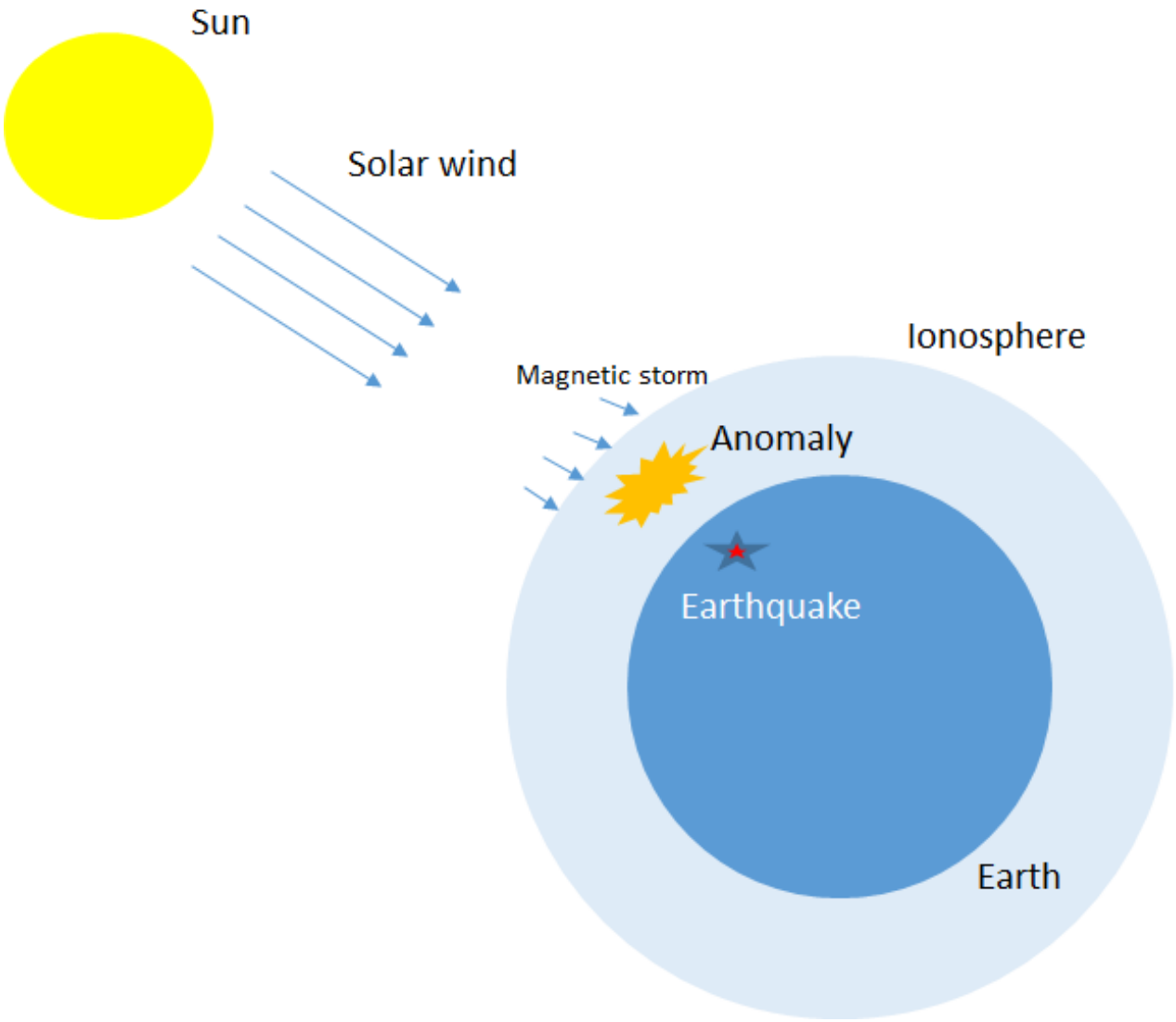
Pre-seismic electron density anomalies have been a widely discussed phenomena in ionospheric studies. However, it is not well-known what causes these anomalies and what is the possible source mechanisms. These are still having not been elucidated questions and more investigations are needed to make clear that phenomena. The another question is how to distinguish ionospheric anomalies from other disturbances such as geomagnetic storms. In many cases, simultaneous geomagnetic activities make it difficult to detect an earthquake precursor effect in the ionosphere. Therefore, a characterization and classification of magnetic storm and earthquake signatures is necessary to make reliable forecasting. For this purpose, in this study, we investigated the similar and differing effects of magnetic storms and earthquakes on the ionospheric composition.
Int this study, the time period after magnetic storms and before earthquakes were mainly investigated. The selection of earthquakes was carried out between 1998 to 2013 with M>6 and depth<30 km. Following this, to detect the anomalous behaviour, we examined the temporal and spatial distribution of TEC values of those cases by using GIM-TEC data. Thus, we found that 28 earthquakes had caused anomalous changes in the ionosphere. We further examined these earthquakes with tomography method to investigate their 3D distributions. There we found that 13 of them had also shown the similar anomalous effect. Meanwhile, magnetic storm cases were chosen between 1998 to 2013 within the intense storm category in which Dst < -100 nT. And the onset time was selected in daytime hours from 6 am to 6 pm. By applying this criteria, 42 magnetic storms were extracted. Among them, we selected arbitrarily 10 different storm cases and same analysis steps was followed to determine the anomalous changes. For TEC analysis, we mainly made use of TEC data from both local receivers (GPS-TEC) and global receivers (GIM-TEC). The GPS-TEC data sets were inverted to electron density form (Ne) in the tomography process with neural networks to examine the 3D electron density distribution of the ionosphere. On the other hand, since the TEC is sometimes slower to respond to compositional changes in the ionosphere, we further employed the ionospheric foEs, NmF2 and hmF2 quantities as complementary data. There, we prepared time series figures of these parameters and compared their responses against storm and earthquake effects. Results will be presented in the presentation.

Keywords: Geomagnetic Storm, Earthquake,TEC(Total Electron Content), Tomography, foEs, NmF2, hmF2



Inner and external geomagnetic Sq current system associated with the 2011 Tohoku earthquake (Mw 9.0)

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Han et al. (2016) have reported unusual behaviors of geomagnetic diurnal variation (GDV) in the vertical component prior to the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.0). Spatiotemporal characteristics of the GDV anomalies and the possible coupling of multiple pre-earthquake phenomena have been demonstrated. To make a further understanding of the reported geomagnetic anomalies, spherical cap harmonic analysis method is applied to reveal the inner and external geomagnetic Sq current system. The inner Sq current, which is an induced field, may reflect possible conductivity structure changes related to the Tohoku earthquake. We calculate three-component Sq variations of 17 geomagnetic observatories. The detailed results will be shown in our presentation.

Keywords: Sq variation, Inner and external geomagnetic field, Tohoku earhquake

VLF radio signal propagation anomaly associated with strong earthquakes from joint observations from the ground and space based observations

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The VLF radio signals recorded both from the ground based VLF radio wave monitoring network and the DEMETER is investigated during the 2010 Ms 7.1 Yushu earthquake. The ground-based observations show that the disturbance intensity of VLF wave’ s amplitude relative to the background gets an enhancement over 22% at 11.9 kHz, 27% at 12.6 kHz and 62% at 14.9 kHz VLF radio wave along the path from Novosibirsk - TH one day before the main shock, as compared to the maximum 20% observed during non-earthquake events. The space based observations indicate that there is a decrease of the signal to noise ratio (SNR) for the power spectral density data of 14.9 kHz VLF radio signal at electric field four days before the main shock, with disturbance intensity exceeding the background by over 5% as compared to the maximum 3% observed during non-earthquake events. The geoelectric field observations in the epicenter region also show that a sharp enhancement from ~ 340 to 430 mV/km simultaneously appeared at two monitors 14 days before main shock. The comparative analysis from the ground and space based observations during the earthquake and non-earthquake time provides us convincible evidences that there are seismic anomalies from the VLF radio wave propagation before the 2010 Ms 7.1 Yushu earthquake. The possible mechanism for VLF radio signal propagation anomaly during 2010 Yushu earthquake maybe related to the change of the geoelectric field nearby the earthquake zone.

Keywords: VLF radio signal, ground based observation, space based observation, earthquake

Geomagnetic Diurnal Variations Analysis in Space and Time Associated with the 2011 off the Pacific Coast of Tohoku Earthquake (Mw9.0)

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Recent studies have reported unusual behaviors of geomagnetic diurnal variation (GDV) in the vertical component prior to the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.0). To make a better understanding of this phenomenon, time-spatial analysis of GDV has been applied in this study. Geomagnetic data of long term observations at 17 stations in Japan have been analyzed using the same method in Han et al. 2015. Ratios of diurnal variation range between the target station and the reference station KAK have been computed. After removing seasonal variations revealed by wavelet transform analysis, the 15-day mean values of the ratios in the vertical component shows a clear anomaly exceeding the statistical threshold about 2 months before the mega event in both ESA and MIZ stations in the Tohoku Region. Similar results could not be found in other regions of Japan. Spatial distributions of the ratios show a good agreement between the location of the anomalies and the epicenter of Mw 9.0 earthquake. These time-spatial results seem to be consistent with independent results obtained from other observations such as radon density, seismicity, and GPS displacements, which suggest the geomagnetic data might be useful in earthquake monitoring and disaster mitigation.

Keywords: Geomagnetic Diurnal Variation, the 2011 off the Pacific Coast of Tohoku Earthquake, earthquake monitoring and disaster mitigation

TIR anomaly possibly related to the large earthquake

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MT Survey and its preliminary result at Boso Peninsula, Japan (3)

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A magnetotelluric (MT) survey is one of the methods to understand the underground electric properties. In Boso area, Japan, there are three main topics to perform the MT survey; (1) to estimate underground resistivity structures related to the plate boundaries, seamount, asperities, and slow slip events; (2) to obtain a regional realistic resistivity structure for the numerical simulation in generation and propagation mechanisms of electromagnetic precursors, and (3) to develop a new MT technique to reduce the cultivated noises such as DC-driven train system and factories. For challenges to solve them, we decided to carry out the MT survey in Boso area, Japan during 2014 - 2016. Due to sensing down to 100 km depth, we used induction and fluxgate magnetometers. We set 41 and 12 sites for induction and fluxgate type magnetometers, respectively.

To remove noises from MT data, we attempted remote reference method that is conventional MT method in frequency domain. Hereupon, MT impedance at southern Boso area is improved to a certain degree. In other hand, the one at northern Boso are is not very improved. Therefore, we attempted MSSA (Multi-channel Singular Spectrum Analysis) for MT data in time domain to improve MT impedance. We performed SVD (Singular Value Decomposition) of original time series in MSSA, and reconstructed time series by using the principal components that indicate relatively high correlation in horizontal geomagnetic field between observation site and remote reference site. Then, unexpected MT impedance seen after remote reference method is tend to be restrained. It supposedly indicates that preprocessing MT data in time domain is effective and promise.

We calculated underground resistivity structure from southwest to northeast by using long period sites' data, there is low resistivity region (0.1 −10 ohm-m) around 1 - 2 km depth. This region possibly indicates fluid in sediment layers overlying large amount of surface at Boso area. There is low resistivity region (0.1 −10 ohm-m) under about 3 −10 km depth at southwest site, which possibly indicates ultramafic rock or accretionary prism pushed up by subducting seamount.

Magnetotelluric data progressing with U-43 data beneath the Boso Peninsula

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In Boso Peninsula, we have several stations to study seismo-electromagnetics. Among of them we had very interesting phenomena to show the fluid flows under the ground related to slow slip event. In addition, we have observed geomagnetic anomalies before sizeable earthquakes. In order to understand generation and propagation mechanisms of earthquake-related ULF electromagnetic signatures, we need the computer simulation on electromagnetic waves using FDTD or FEM. Due to this aim, we carried out the MT survey in BOSO area, Japan during 2014-2016.

Keywords: MT data processing

