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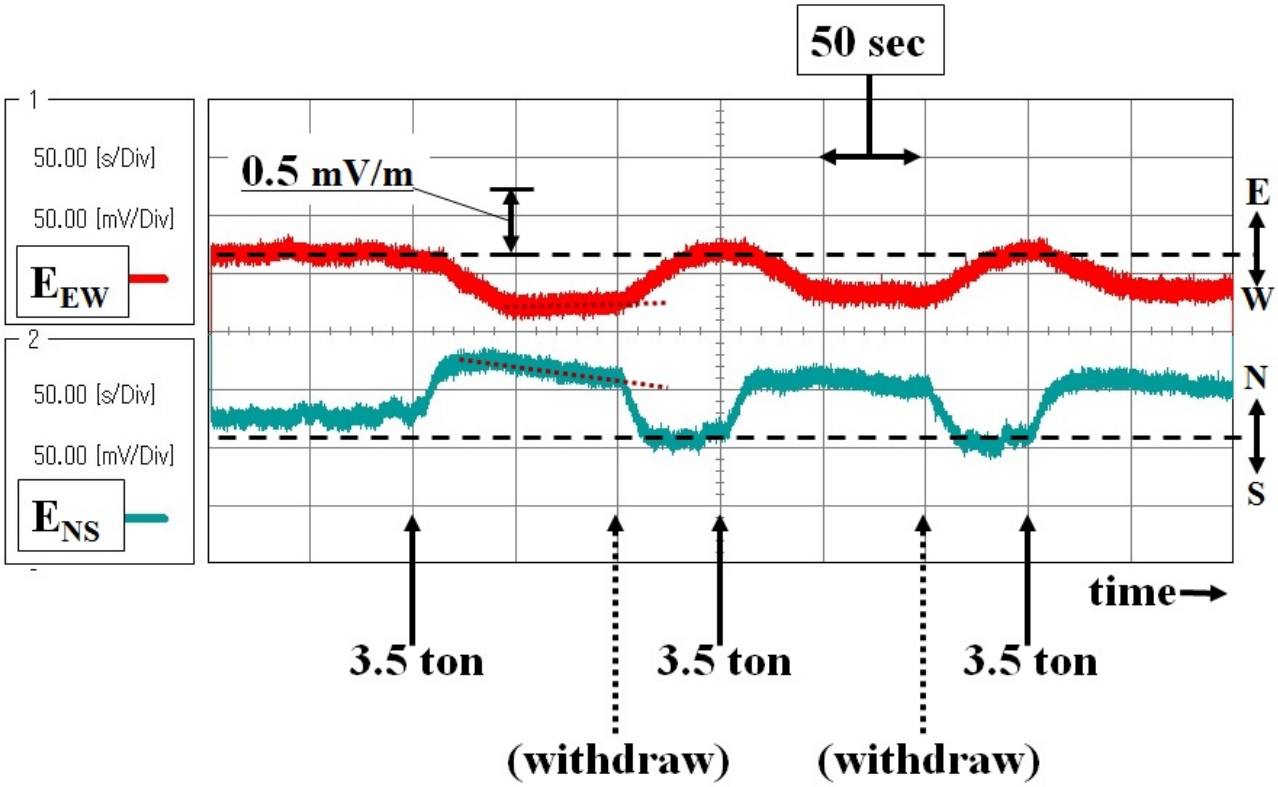
Keywords: Laboratory experiment, Granite under pressure, Radiations of DC electric field



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

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.

キーワード：ULF magnetic data、earthquake precursory information、Molchan’s error diagram、Kanto, Japan
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.

日本周辺の地震に先行するb値の時空間変動および電離圏総電子数異常
Spatiotemporal Characteristics of b-value and TEC Variations before the Large Earthquakes in Japan

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近年、地震活動に先行する様々な電磁気現象が報告されており、その中でも電離圏総電子数(Total Electron content: TEC)の異常は、短期地震予測の有力な候補である。一方、地圏では大地震に先行してグーテンベルク・リヒター(G-R)則に従うｂ値が本震付近において本震の数年前(場合によって数十年スケール)から低下する現象がある。TEC変動は宇宙天気など太陽活動による影響も大きく、地震に関連するTEC異常を他の変動から区別することは困難である。

そこで本研究では、電磁気的アプローチ（電離層）に力学的アプローチ（ｂ値解析）を加えることにより予測精度の向上を試みる．つまり、ｂ値解析を用いた地殻変動（応力場の変動）の観測・監視による中期および短期予測方法の開発とTEC変動の観測・監視を統合し、地震短期予測手法の高度化とその観測学的検証を行う．

本研究では、2003年、2008年十勝沖地震、2011年東北沖地震を対象とした．まずは、繰り返してM7クラスの地震が発生している十勝沖や東北沖のb値解析を行った．その結果、解析領域内やその近傍で発生したM7以上の地震に対して、b値が過去の平均値よりも継続して低下する傾向があることがわかった．2003年十勝沖地震（M8.0）に関して1日ごとのｂ値の時間変化を調査した結果、本震発生の16日前と3日前と2日前にb値がステップ状に低下することがわかった．そこで、b値時系列データの異常として、過去のｂ値の平均値を継続的に下回った場合を異常と定義した．一方、北海道地域のTEC異常に関しては、M6.0以上深さ40 km以浅の地震の1-5日前に正の異常が有意であることが統計的に確認された．2003年十勝沖地震（M8.0）に関しては、本震2日前に正のTEC異常が始まることが確認されている．この直後から太陽活動が活発になり、その後の正の異常は太陽活動にマスクされている可能性がある．これらのことから、十勝沖に関しては、b値異常が本震に16日前に先行して発生し、その後TEC異常が続くことがわかる．2011年東北沖地震でも同様な傾向が見られた．

以上のことから、十勝沖地域と東北地域においてはM7以上の地震に対して、TEC異常変動解析にｂ値異常解析による拘束を加えることで地震短期予測精度が向上することがわかった．詳細は講演時に発表する．

キーワード：地震、電磁気、b値
Keywords: Earthquake, Electromagnetics, b-value

ラドン検出器の開発と岡山での観測
Development of Radon Detector and Observation at Okayama

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英文を参照してください。

キーワード：ラドン検出、大気、地震予測
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.

キーワード：Lithosphere-Atmosphere-Ionosphere Coupling、atmospheric ion concentration、atmospheric elctric field、radon exhalation quantity
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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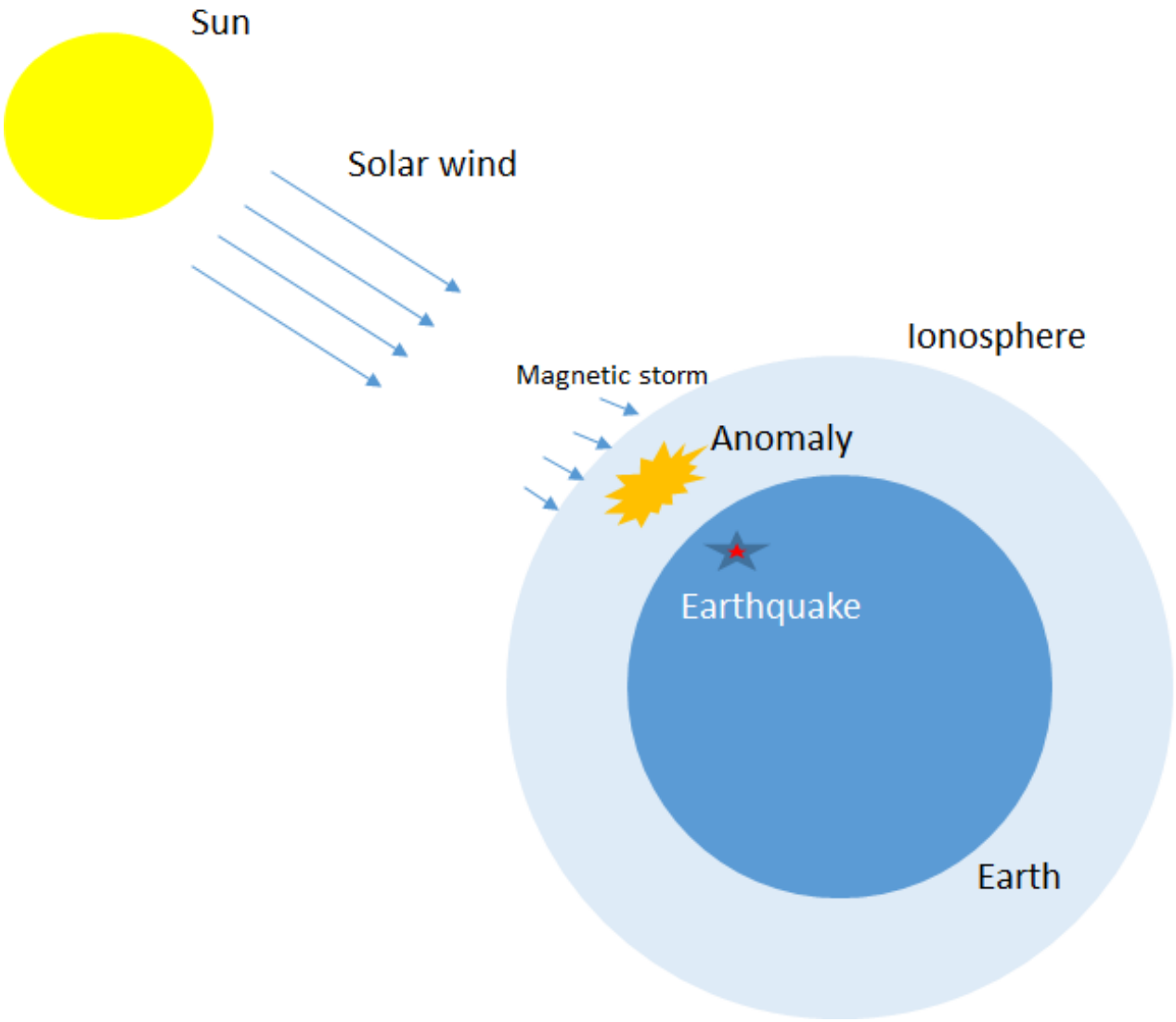
Pre-seismic electron density anomalies have been a widely discussed phenomena in ionospheric studies. However, it is not well-known what causes these anomalies and what is the possible source mechanisms. These are still having not been elucidated questions and more investigations are needed to make clear 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)

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.

キーワード：Geomagnetic Diurnal Variation、the 2011 off the Pacific Coast of Tohoku Earthquake、earthquake monitoring and disaster mitigation
Keywords: Geomagnetic Diurnal Variation, the 2011 off the Pacific Coast of Tohoku Earthquake, earthquake monitoring and disaster mitigation

適切な雲除去を用いたMODISによる地震に関連する温度異常の検知に関する研究

TIR anomaly possibly related to the large earthquake

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本研究は2009年4月6日のL’Aquila地震（6.3）、2016年8月24日のNorcia地震（M6.2）そして2016年10月30日のNorcia地震（M6.2）を対象として、人工衛星Aqua 搭載の赤外センサMODIS の夜間データを用い、雲除去を行った後、時間空間的な統計的な解析を行い、地震に関連する赤外線放射（温度異常）の調査を行った。

解析は地震の震央を中心として経度緯度±10˚の領域で、衛星の特徴から　0.01˚の分解能で抽出し、二次元輝度温度マップを作成した。雲の影響を取り除くために、まずBand20 の輝度温度のヒストグラムから250K以下のピクセルを雲であると判断し、棄却した。次に、残ったピクセルを使用し、各Band 間差分値（Band31-Band32、Band31-Band27、Band31-Band32、Band31-Band20 など）で、平均値（地震のあった時期は除く）や、その標準偏差などを基に、雲ピクセルを棄却した。この雲ピクセルの棄却手法について、その精度を検証するために、人工衛星Calipso 搭載のCALIOP のLidar データを使用し比較を行った。その結果、本研究に用いた4 つのBand 間差分値はうまく雲と雲ではない領域をクラスタリングできている事が分かった。また、雲判別の閾値を決定する際のパラメータであるk の値をLidar データと比較し、調整する事で、より精度の高い閾値を設定する事が出来たと考えられる。

次に空間的な変動要素の影響を取り除くために、ある観測点（A：Focal Point）の輝度温度(T_FP）を測定し、そして観察できたA点以外すべての観察点（RP：Reference Point）の輝度温度（T_RP）を測定し、A点以外すべての観察点（RP）の測定値の平均値（μ_RP）をTとして計算した。次に、TのMulti-Year(2006～2016年、ただし、地震のあった2009と2016年を除く)±15日平均および±15日標準偏差をピクセル毎に算出した。最後にcurrentTの値から±15日平均を引き、±15日標準偏差で割った値をRSTと定義した。このRSTの値が1.5より高いところを温度異常であると定義した。

MT法による房総半島の地下比抵抗構造探査に関する研究
MT Survey and its preliminary result at Boso Peninsula, Japan (3)

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本研究では、地磁気地電流法(MT法）による房総半島全域の地下比抵抗構造探査を試みた。本研究の目的は以下のとおりである。(1)電磁気学的に房総半島全域の地下比抵抗構造を推定することである。特にプレート境界等の地下比抵抗構造を推定することが地学的なテーマである。(2) ULF帯等の地震電磁気現象が観測された場合、波の発生および伝播機構を調査するための基礎資料を得ることである。波の発生および伝播機構の解明には、波動の伝播シミュレーションが必要不可欠である。伝播シミュレーションには地下の比抵抗構造が重要であり、現実的な結果を得るためには観測データに基づくデータが必要である。(3)人工雑音が多く含まれる地域でMT探査が可能になる、新たな信号処理手法の開発である。関東地域では堆積層が厚く、また、直流電車や工場等からの漏洩電流の影響で、観測されるデータに雑音が多い。そのため、従来MT探査が敬遠されてきた。これらの雑音はどの周波数にも乗るため、周波数領域で行うMT解析では除去することが困難であった。時間領域において雑音を除去する新たな取り組みが必要であり、今回取得するデータを用いてその手法と効果について述べる。

以上の目的のため、2014年11月から2015年3月にかけて房総半島の北部を対象とし、2015年11月から2016年1月にかけて房総半島の南部を対象としてMT探査を実施した。観測点は緯度経度ごとに41箇所設けた。全観測点においてPhoenix Geophysics社のMTU-5, 5A, netを用い、サンプリング周波数15, 150, 2400 Hzのデータを観測した。これらのデータから約0.003 s –3,000 sのMTインピーダンスを推定する。41箇所の観測点の内12箇所ではテラテクニカ社のU-43も用い、サンプリング周波数1 Hzのデータを観測した。これらのデータから約20 s –15,000 sのMTインピーダンスを推定する。

MT法により房総半島全域の地下比抵抗を推定するためには、電磁場に影響するコヒーレント/インコヒーレントノイズを除去する手法が必要となる。ノイズを除去するため、まず従来の周波数領域の手法であるリモートリファレンス法を試みたところ、房総南部のMTインピーダンスは多少の改善が見られたものの、北部のMTインピーダンスは改善が見られなかった。そこで、時間領域で処理を行うマルチチャンネル特異スペクトル解析 (Multichannel-Singular Spectrum Analysis: MSSA) を長期観測点と参照点のMTデータに適用し、S/N比を改善する新たな試みを行った。MSSAによって元の時系列を特異値分解し、観測点と参照点の水平磁場で相対的に高い相関係数を示す主成分を用いて時系列を再構成したところ、リモートリファレンス法で見られる異常値を抑制できることがわかった。このことは、時間領域におけるMTデータの前処理の有効性および有望性を示すと考えられる。

長期観測点の再構成時系列にリモートリファレンス法を用いて房総半島の南西から北東方向の地下比抵抗断面を算出したところ、地下約1-2 kmには0.1-10 Ωmの低比抵抗領域が存在した。これは房総半島の地表の大部分を覆う堆積層に含まれる流体の影響と考えられる。南西方向の地下では最深部で約10 kmまで0.1-10 Ωmの低比抵抗領域が存在するが、超苦鉄質岩類または沈み込む海山によって押し上げられた付加体の影響を反映した領域である可能性がある。

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.

キーワード：MT データ処理
Keywords: MT data processing

