7th International Workshop on Earthquake Preparation Process ~ Observation, Validation, Modeling, Forecasting ~

Program & Abstracts

IWEP7

May 24 – 25, 2023

Chiba University, Chiba, Japan

7th International Workshop on Earthquake Preparation Process

~ Observation, Validation, Modeling, Forecasting ~ (IWEP7)

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Electromagnetic Studies of Earthquakes and Volcanoes (EMSEV)
National Central University, Taiwan
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Southern University of Science and Technology, China
Peking University, China

Date: May 24 – 25, 2023

Venue: Conference Hall, the 1st floor of Sciences and Technology Building No.1, Nishi-Chiba Campus, Chiba University, Chiba, Japan

Contacts: Dr. Katsumi Hattori (Chiba University, Japan)
khattori@faculty.chiba-u.jp +81-43-290-2801

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0930-1000 **Kuniyuki Motojima** et al., Statistical association of earthquakes and MF radio wave propagation anomalies

1000-1020 **Yuichiro Ota** et al., Development of an LF-band broadband interferometer to identify LF-band signals related to earthquakes

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Chair: Dr. Jann-Yenq Tiger Liu

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P5: **Victor Novikov** et al., Physical mechanisms of induced and triggered seismicity: An implication for electromagnetic triggering of earthquakes

P6: **Vyacheslav Pilipenko** et al., Studies of seismo-electromagnetic and seismo-ionospheric effects at Kamchatka

P7: **Stelios M. Potirakis** et al., Criticality analysis of the VLF recordings prior to two strong earthquakes that happened in central Greece on March of 2021

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P16: **Katsumi Hattori** et al., Characteristics of Spatio-Temporal variation of b-values with statistical assessment and GNSS-based strain : Application to the 2016 Kumamoto and the 2011 Tohoku earthquake

Presentation information:

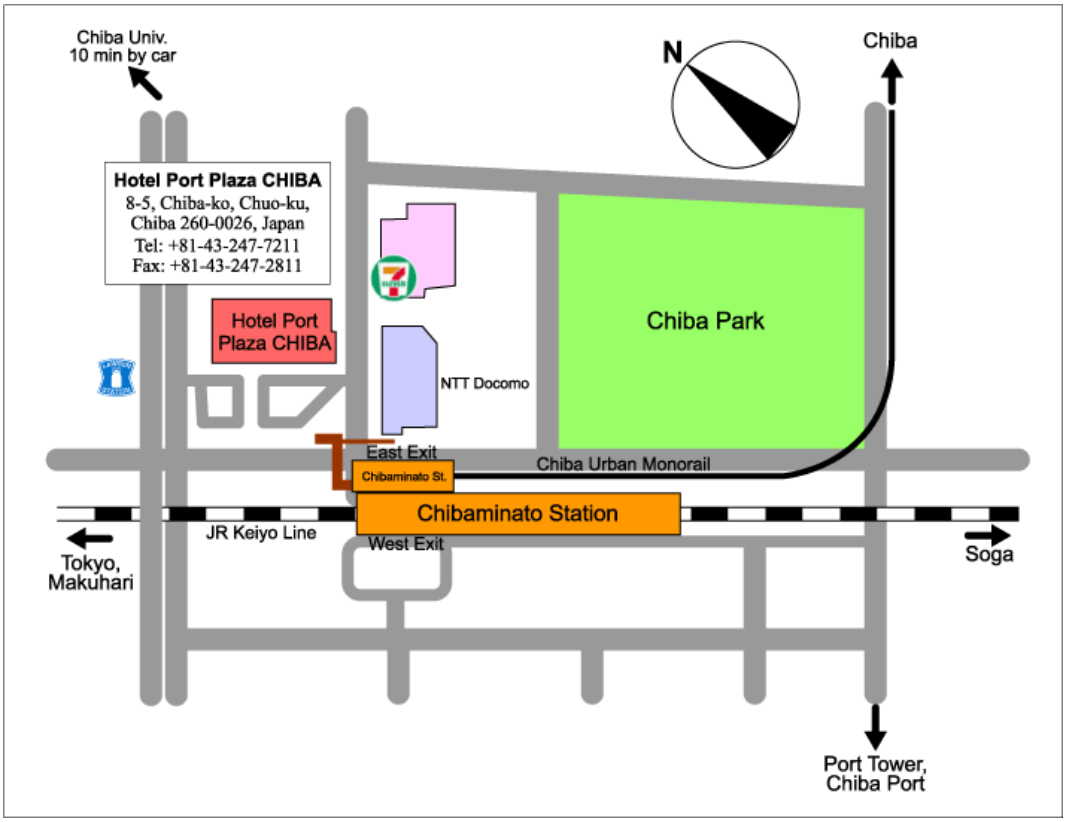
Oral presentation: 30 or 20 minutes including 5 minutes question-and-answer time.

Poster presentation: Poster board size: 90(W) x 180(H) cm

All the posters will be shown in the conference room during May 24 and 25.

Welcome Party:

Welcome party will be held on May 24, 2023 at "Hotel PortPlaza Chiba", near Chibaminato station (10 minutes by car from University). The price will be 8,000 JPY per person (3,000 JPY for a student).



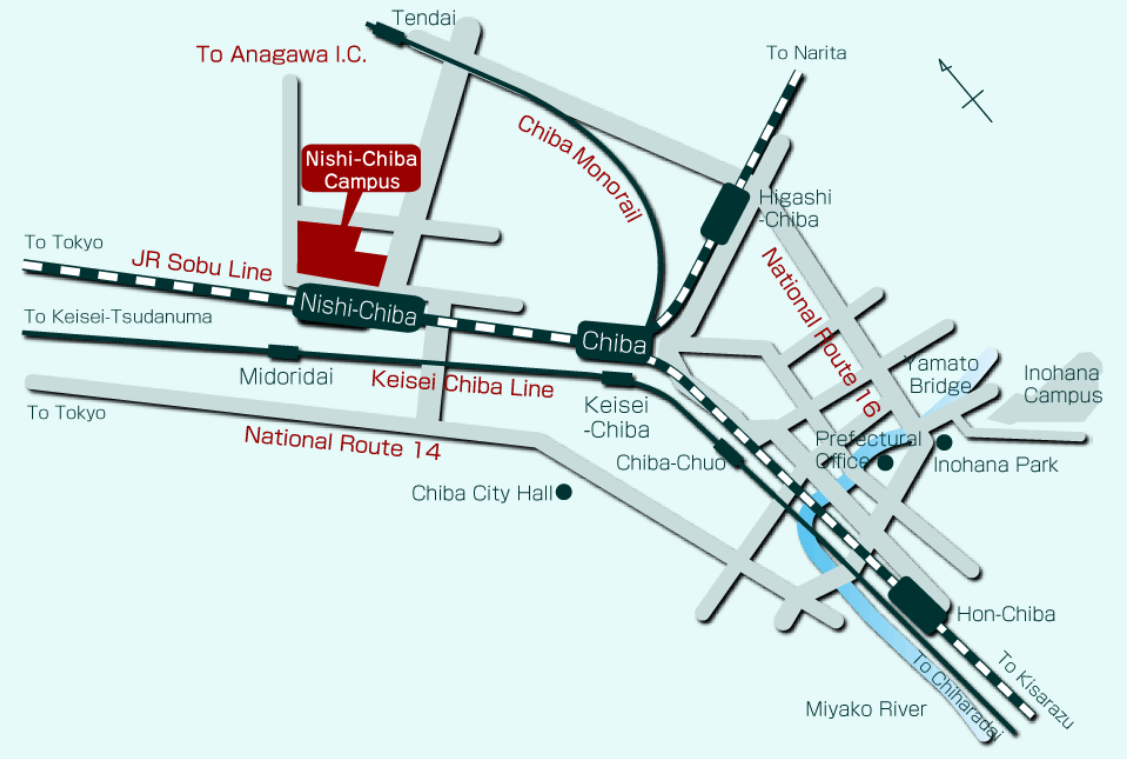
Access:

Access to Nishi-Chiba Campus, Chiba University

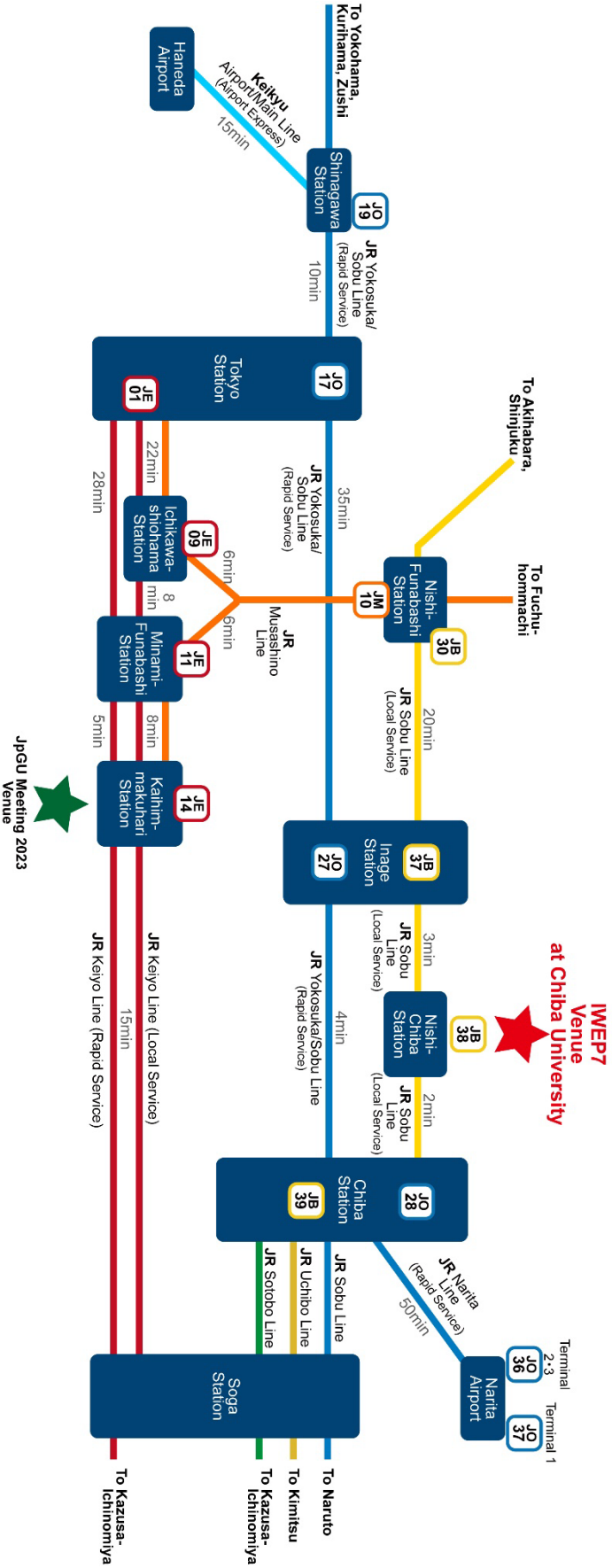
2-min walk from JR Nishi-Chiba Station to the South Gate of Nishi-Chiba Campus

7-min walk from Keisei Midoridai Station to the Center Gate of Nishi-Chiba Campus

10-min walk from Chiba Monorail Tendai Station to the North Gate



JR Tokyo	35min / 8 Stations / JR Sobu Line (Rapid Service)		JR Inage	3min / 1 Station / Sobu Line (Local Service)	JR Nishi-Chiba
Keisei Ueno	35min / 6 Stations / Keisei Line, Limited Express		Keisei Tsudanuma	11min / 5 Stations / Keisei Chiba Line	Keisei Midoridai
Haneda Airport	16 min / 1 Station / Keihin Kyuko Line Airport Rapid Limited Express	JR Shinagawa	45 min / 10 Stations / JR Sobu Line (Rapid Service)	JR Inage	3 min / 1 Station / Sobu Line (Local Service)	JR Nishi-Chiba
Haneda Airport	17 min / 1 Station / Tokyo Monorail Haneda Express	JR Hama-matsucho	6 min / 3 Stations / JR Yamanote Line	JR Tokyo	35 min / 8 Stations / JR Sobu Line (Rapid)	JR Inage	3 min / 1 Station / Sobu Line (Local Service)	JR Nishi-Chiba
Narita Airport	42 min / 8 Stations / JR Sobu Line (Rapid Service)		JR Chiba	3 min / 1 Station / Sobu Line (Local Service)	JR Nishi-Chiba


To Yokohama, Kurihama, Zushi
Haneda Airport
Keikyu Airport/Main Line (Airport Express)
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Shinagawa Station
JO 19
JR Yokosuka/ Sobu Line (Rapid Service)
10min
Tokyo Station
JO 17
JE 01
To Akihabara, Shinjuku
To Fuchu-hommachi
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Nishi-Funabashi Station
JM 10
JB 30
JR Sobu Line (Local Service)
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Terminal 1
JO 37
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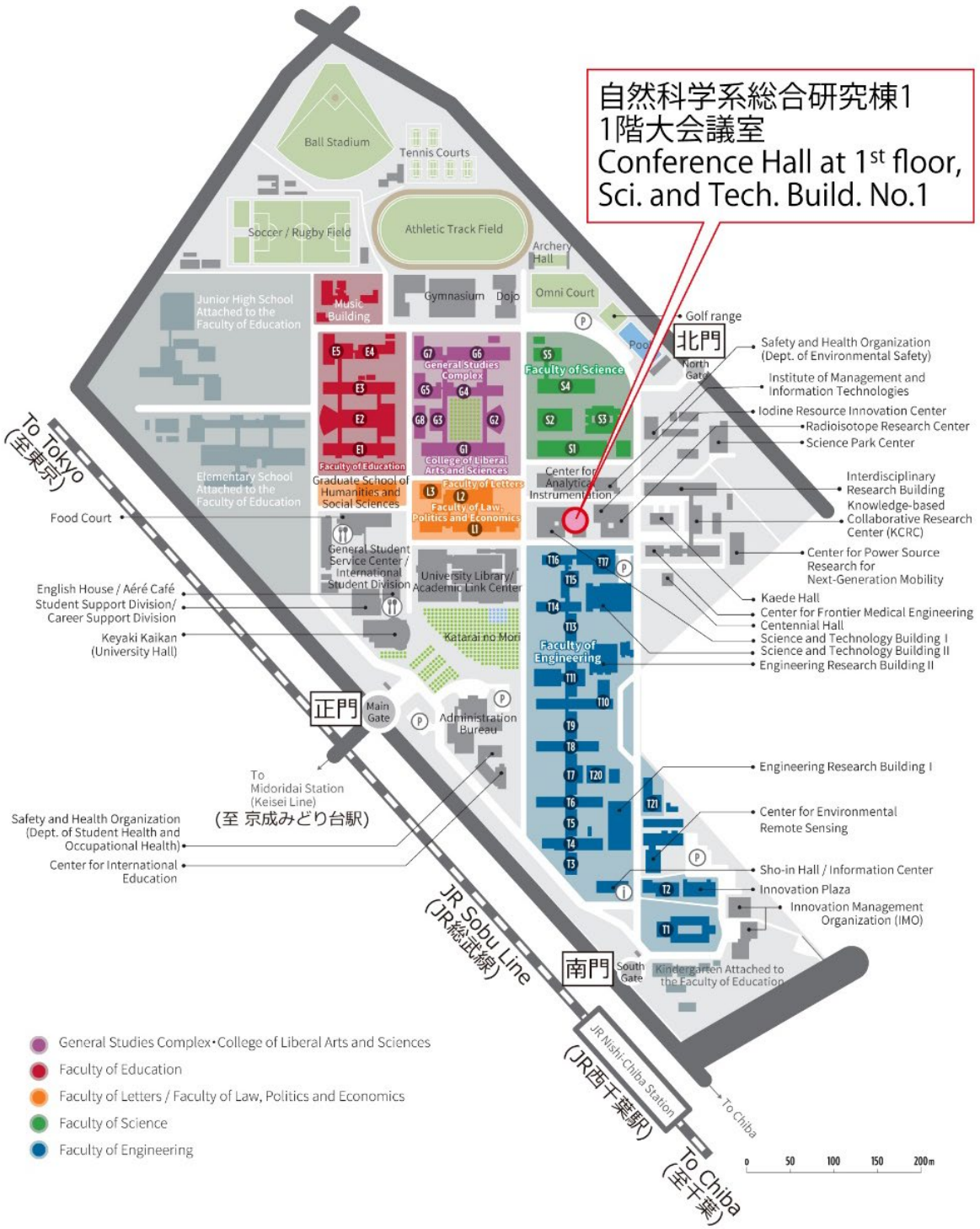

Abstracts of oral presentations

Imminent Precursor of Atmospheric Electric Field Associated with Earthquakes

Yasuhide Hobara (1, 2), Mako Watanabe (1), Hiroshi Kikuchi (2), Takuo Tsuda (1, 2), and Masashi Hayakawa(3, 4)
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(2) Center for Space Science and Radio Engineering, The University of Electro-Communications, Chofu-Tokyo, Japan; e-mail; hkikuchi@uec.ac.jp
(3) Hayakawa Institute of Seismo Electromagnetics, Co. Ltd, Chofu-Tokyo, Japan; e-mail: hayakawa@hi-seismo-em.jp
(4) Advanced Wireless & Communication Research Center, The University of Electro-Communications, Chofu-Tokyo, Japan

In this paper, we report on the near-surface Atmospheric Electric Field (AEF) anomalies immediately before and after earthquakes (EQs) (within 12 hours) in Japan. Using atmospheric electric field data from spatially separated stations in Japan, we demonstrate the results of a case study for several EQs that occurred close to the AEF observation site (within 100-200 km of the epicenter) under relatively fair local weather conditions. We found the common features for different EQs at different field sites e.g. 20~90 min period of clear anomalous signatures in wavelet spectrograms within a few hours around the main shock. This type of anomaly is repeatedly observed for the EQs with relatively small magnitude M ~ 5. Statistical results of the occurrence rate of the AEF anomalies based upon a few hundred EQs support the abovementioned results. We propose the physical mechanism of the observed electric field anomalies attributed to the Internal Gravity Waves (IGW) originating from the epicenter region propagating over the field site and disturbing the local atmospheric electric field.

Statistical association of earthquakes and MF radio wave propagation anomalies

Kuniyuki Motojima, Yuki Goto
(Graduate School of Science and Technology, Gunma University)

Abstract :

Some papers reported about earthquakes and VLF (Very Low Frequency) band propagations have showed existence of relation between the both.

On the other hand, we have been monitored broadcasting waves on MF (Middle Frequency) band over decade at Kiryu, Gunma prefecture in Japan. Propagations on MF band depend on activity of ionosphere in day time and night time. In normally MF band waves become stronger around sunset time. However, we have sometimes experienced anomalous propagations, which have abnormal fluctuations in received waves around sunset time. Moreover, some days later of the anomalous propagation, seismic activities have sometimes observed. They might have shown anomaly of bottom of ionosphere preceding earthquakes. Therefore, we have investigated the relation between occurrence of earthquakes and anomalous propagations in MF band around sunset time. Four broadcasting waves in MF band are targeted for this investigation, NHK Radio 2 from Akita, STV Radio from Sapporo, NHK Radio 1 from Osaka and RCC Chugoku Radio from Hiroshima. Propagation distance range of four waves is from 395 km to 767 km, and they all are domestic radio propagations in JAPAN.

In normal MF band propagation, the received signal strength shows monotonous increase around sunset time. But in propagation with anomaly received signal strengths have fluctuations and consequently have peaks before the sunset time. So, we have focused on the time interval between the peak time of received signal strength and sunset time. Large time intervals were defined as occurrence of anomalous propagation.

In order to evaluate the relation of both, we adopted statistical items of Hit rate, Prediction rate, Probability gain and Molchan's error diagram. As the result of evaluation, it might show some existences between earthquakes and anomalous propagation in MF band broadcasting waves.

However, we have gotten no physical evidence. Getting them is the future works.

Development of an LF-band broadband interferometer to identify LF-band signals related to earthquakes

Yuichiro Ota[1], Kenshin Miura[2], Chie Yoshino[3], Katsumi Hattori[3,4,5], Noriyuki Imazumi[6]

1. Graduate School of Science and Engineering, Chiba University, Japan
2. Faculty of Science, Chiba University, Japan
3. Graduate School of Science, Chiba University, Japan
4. Center for Environmental Remote Sensing, Chiba University, Japan
5. Research Institute of Disaster Medicine, Chiba University, Japan
6. The Institution of Professional Engineers, Chiba Branch, Japan

Recently, there have been reports of earthquake precursor phenomena related to the LF band. To develop an LF-band broadband interferometer capable of spatio-temporal estimation of LF-band electromagnetic wave sources, we started LF-band electromagnetic wave observations using interferometer elements on the rooftop of Chiba University. First, we conducted a waveform and pulse count survey using one interferometer element and detected an increased number of pulses before the earthquake which is unlikely to be caused by cloud to ground discharge and typical waveforms during the time. We also evaluated the performance of three interferometer elements as an interferometer system and found that the synchronization system needs to be improved.

Lithosphere–Atmosphere–Ionosphere Coupling Effects Based on Multiparameter Precursor Observations for February–March 2021 Huge Earthquakes (M~7) in the Offshore of Tohoku Area of Japan

Masashi Hayakawa [1,2]*, Jun Izutsu [3], Alexander Schekotov [4], Shih-Sian Yang [5], Maria Solovieva [4]

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2 Advanced & Wireless Communications Research Center (AWCC), UEC, 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan

3 International Digital Earth Applied Science Research Center, Chubu University, 1200 Matsumoto-cho, Kasugai Aichi, 487-8501, Japan; izutsu@isc.chubu.ac.jp

4 The Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, 10-1 Gruzinskaya, 123242 Moscow, Russia; sasha.schekotov@gmail.com (A.S.); rozhnoi@ifz.ru (M.S.)

5 Department of Space Science and Engineering, National Central University, 300 Jhongha Rd., Jhongli District, Taoyuan 32001, Taiwan; Yang.Sirius.Sian@gmail.com

Abstract:

The purpose of this paper is to discuss the lithosphere–atmosphere–ionosphere coupling (LAIC) effects with the use of multiparameter precursor observations for two successive Japanese huge earthquakes (EQs) (with magnitudes of around 7) in February and March 2021, respectively, considering a seemingly significant difference in seismological and geological hypocenter conditions for those EQs. The second March EQ is very similar to the famous 2011 Tohoku EQ in the sense that those EQs took place at the seabed of the subducting plate, while the first February EQ happened within the subducting plate, not at the seabed. Multiparameter observation is a powerful tool for the study of the LAIC process, and we studied the following observables over a 3-month period (January to March): (i) ULF data (lithospheric radiation and ULF depression phenomenon); (ii) ULF/ELF atmospheric electromagnetic radiation; (iii) atmospheric gravity wave (AGW) activity in the stratosphere, extracted from satellite temperature data; (iv) subionospheric VLF/LF propagation data; and (v) GPS TECs (total electron contents). In contrast to our initial expectation of different responses of anomalies to the two EQs, we found no such conspicuous differences in the occurrence of electromagnetic anomalies between the two EQs, but showed quite similar anomaly responses for the two EQs. It is definite that ULF/ELF radiation happened in the atmosphere and ULF depression as the signature of lower ionospheric perturbation are most obvious phenomena as precursors to both EQs, and most importantly, all electromagnetic anomalies are concentrated in the temporal period of about 1 week–9 days before the EQ to the EQ day. There seems to exist a chain phenomenon of LAIC process (cause-and-effect relationship) for the first EQ, while all of the observed anomalies seem to occur nearly synchronously in time for the send EQ. Even though we tried to discuss possible LAIC channels (chemical AGW channels), we cannot come to any definite conclusion about which coupling channel (or hypothesis) is plausible for each EQ and more information such as Earth's surface and just above the surface for more deepened understanding of LAIC process.

Predicting earthquake precursors: Case study for the 2023 Turkey earthquake

Kosuke Heki[1,2]

1. Shanghai Astronomical Obs., Chinese Acad. Sci., 80 Nandan Rd. 200030, Shanghai, China
2. Dept. Earth Planet. Sci., Hokkaido Univ., N10 W8, Kita-ku, Sapporo, 060-0810, Japan

I first briefly review observations and models of ionospheric electron density changes immediately before large earthquakes. Then I propose a future perspective to validate the series of hypotheses by predicting the attributes (intensity, leading time, locations, etc) of the expected precursors from moment magnitudes of the earthquakes based on their empirical relationships, and by confirming their consistency with observed changes after the occurrences of large earthquakes. This would serve as an objective test of the validity of a model when real-time precursor detections are difficult with the available observing systems.

Since its first observation for the 2011 Tohoku-oki earthquake (Heki, 2011 GRL), ionospheric changes immediately before large earthquakes have been investigated, using ionospheric total electron content (TEC) data from GNSS (global navigation satellite system) receivers, for many earthquakes with moment magnitudes M_w7.3-9.2 (He and Heki, 2017 JGR). These studies revealed a positive correlation between M_w and properties of the anomalies including their leading times and intensities (Fig.1). Based on the 3D structure of positive and negative electron density anomalies in the ionosphere (He and Heki, 2018 JGR), Muafiry and Heki (2020 JGR) proposed a physical model assuming the downward transport of ionospheric electrons along geomagnetic fields to cancel electric fields made by surface positive charges. Despite these advances, the model would need objective tests to draw attention of critical researchers, and I expect this "earthquake precursor prediction" would be effective for the purpose.

Empirical relationship shown in Fig.1 enables us to specify the properties of the precursory change of TEC immediately before a M_w8 event. The intensity of the anomaly would be ~3 percent of the background VTEC, and the leading time would be ~25 minutes before earthquakes. The physical model let us specify the horizontal and vertical positions of the anomalies. The positive and negative electron density anomalies would emerge along the local geomagnetic field. Here, I "predict" the properties of the precursory signals for the 2008 Wenchuan earthquake (M_w7.8) and the 2023 Turkey earthquake (M_w7.9). I will present the analysis results and demonstrate that the observed signals are consistent with the properties prescribed based on their M_w.

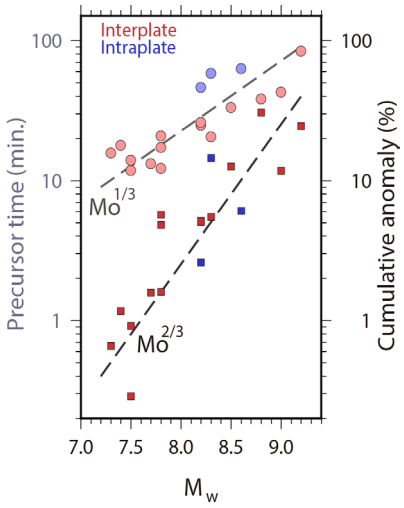

Fig.1. Leading times (circles) and relative intensities (squares) of the TEC anomalies from past cases. They scale with the fault lengths and fault areas, respectively.

Application of earthquake probability prediction model incorporating regional stress evolution to reservoir earthquakes

Rui Wang 1, Peng Han1*,Jiangcang Zhuang2, Miao Miao 1, Ce Zhao 3 , Cuiping Zhao 4 , Renqi Lu 5 , Hongfu Lei6, Mengdi Yao6,

1 Department of Earth and Space Science, Southern University of Science and Technology, Shenzhen 518055, China; 11930870@mail.sustech.edu.cn (R.W.); miaom@sustech.edu.cn (M.M.); 11930855@mail.sustech.edu.cn (Z.Z.); 11930858@mail.sustech.edu.cn (H.C.)
2 The Institute of Statistical Mathematics, Minami-Azabu 4-6-7, Minato-Ku, Tokyo, 106-8569, Japan
3 Institute of Geophysics, China Earthquake Administration, Beijing 100081, China;(C.Z.)
4 Institute of Earthquake Forecasting, China Earthquake Administration, Beijing 100036
5 Institute of Geology, China Earthquake Administration, Beijing 100029
6 China Three Gorges Construction Engineering Corporation, Chengdu 610000
Correspondence: hanp@sustech.edu.cn; Tel.: +86-755-8801-5515

The Epidemic-Type Aftershock Sequence (ETAS) model is one of the most widely used statistical models for earthquake prediction. However, since ETAS and its extensions rely solely on earthquake catalogs, they may ignore physical mechanisms, rendering the method unsuitable for regions with frequent stress changes, such as those near reservoirs, shale gas extraction sites, and wastewater injection wells. In contrast, the Coulomb Rate and State Model (CRSM) is based on the physical mechanisms of stress influence on earthquakes, but wake on earthquakes self-triggering and depending on stress simulation. We propose a novel probability prediction model that integrates regional stress evolution. This model combines the advantages of two existing models and is expected to yield superior results. To validate the efficacy of our proposal, we analyze the seismic activity of three regions near the reservoir. Upon conducting our analysis, we have observed that the seismic activity in two of the three regions cannot be adequately modeled using the stationary ETAS model due to its inability to account for time-dependent background activity. To overcome this limitation, we have applied our proposed probabilistic prediction model that incorporates regional stress evolution. We found that this model was effective in fitting the seismic activity in these two regions. Our findings suggest that the seismicity near the reservoir is a direct consequence of the reservoir filling. Moreover, our proposed model integrating regional stress evolution can be applied to reservoir-induced earthquakes and similar scenarios with a high degree of accuracy.

Title: Polarity correction for microseismic event location using Hilbert transform

Authors: Zhiyi Zeng[1], Peng Han[1]*, Jincheng Xu[1]

[1] Department of Earth and Space Sciences, Southern University of Science and Technology, Shenzhen 518055, China

Abstract

Microseismic events can provide insights into the distribution of faults and fractures in natural and induced earthquakes. Migration diffraction stacking imaging automatically detects and locates microseismic events with low signal-to-noise by implicitly assuming coherent stacking of traveltime-corrected waveforms. However, polarity reversal caused by source radiation patterns can interfere with the coherent stacking. We develop a method that directly correct the polarity to consistency using the Hilbert transform, instead of identifying and correcting the polarity. This method efficiently performs polarity consistency correction in the data domain, while preserving the noise incoherent characteristics and effectively improving source imaging resolution and location accuracy. The method's effectiveness is demonstrated with synthetic data and applies to real data from a coal-bed methane fracturing experiment, locating more microseismic events in practical fracturing depths. Since polarity correction is performed in the data domain before stacking, making this method adaptable to various seismic monitoring projects.

Combining natural time analysis with aspects of non-extensive statistical mechanics to study the seismicity before the 2011 Tohoku M9 earthquake in Japan

- In appreciation of the late Professor Seiya Uyeda's contribution to earthquake prediction research –

T. Nagao[a,b], P. A. Varotsos[c], N.V. Sarlis[c], E.S. Skordas[c] and M. Kamogawa[a,b]

[a]*Natural Disaster Research Section (NaDiR), Global Center for Asian and Regional Research, University of Shizuoka, 3-6-1,Takajo, Aoi-Ku, Shizuoka-City, Shizuoka, 420-0839, Japan*

[b]*Institute of Oceanic Research and Development, Tokai University, 3-20-1, Orido, Shimizu-ku, Shizuoka, 424-0902, Japan*

[c]*Physics Department, National and Kapodistrian University of Athens, Section of Condensed Matter Physics and Solid Earth Physics Institute, Panepistimiopolis, Zografos, Athens, 15784, Greece*

Abstract

Professor Seiya Uyeda passed away on January 19, 2023, at 93. After his retirement from the University of Tokyo, he devoted more than 30 years of his life to research on short-term earthquake prediction. In particular, as the researcher closest to us, he devoted himself to promoting the VAN method. In his later years, he contributed to showing that the Natural time [1,2] analysis discussed in this abstract was very effective for the 2011 Tohoku earthquake.

Natural time, which is based on a new concept of time termed natural time χ introduced in 2001 [3], identifies when the system enters the critical stage before major earthquakes. This occurs when the variance $\kappa_1 = \langle x^2 \rangle - \langle x \rangle^2$ of natural time becomes equal to 0.070 (as has been theoretically shown in Ref. [4]) a few days to around 1 week or so before the mainshock occurrence. For example, by applying natural time analysis to the Japanese seismic data, we have found that this criticality condition (κ_1=0.070) is satisfied upon the occurrence of M=4.2-5.0 earthquakes from 08:36 to 13:14 local time (LT) on 10 March 2011, i.e., almost one day before the M9 Tohoku earthquake on 11 March 2011. Here, and in order to further shorten this time-window, we study also the entropy change ΔS under time reversal of natural time analysis as well as the Tsallis entropy Sq [5] of non-extensive statistical mechanics. We find that, after the aforementioned period from 08:36 at 13:14 LT on 10 March 2011 in which the system entered the critical stage, simultaneous changes appear at 18:00 and 20:00 LT on 10 March 2011 on both quantities ΔS and Sq. These simultaneous changes are evident when computed in the future epicentral region (which can be estimated well in advance by means of the procedure developed in Ref. [6]) but can be also seen ‐but with much difficulty‐ when the computation is made in the entire Japanese region. Finally, a few hours later, and until around 00:00 LT on 11 March 2011 (i.e., several hours before the giant EQ occurrence [6, 7]) precursory changes of the fluctuations of ΔS have been observed.

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Multi-parameter precursory patterns associated with the earthquake sequence in Turkey on February 6th, 2023.

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The most recent M7.8 earthquake on Feb 6, 2023, struck Turkey/Syria at 03:17 LT, and with a more than 100 km rupture, that was one of the deadliest this decade. A second M7.5 earthquake hit the region nine hours later. We study critical lithosphere/atmosphere /ionosphere coupling processes, the modified Earth's EM environment, and precede the earthquake events. We combined observations from different non -correlated ground and space monitoring systems for the first time, such as 1. Vertical static pendulums data from the European network of tiltmeters – vertical static pendulums (Kalenda et al. 2012); /2/ Outgoing long-wavelength radiation (OLR) obtained from NPOESS; 3/ Ionospheric plasma observations from the China/ Italy Seismo-Electromagnetic Satellite (CSES1); and 4/ Atmospheric chemical potential (ACP) obtained from NASA assimilation models. The deformation anomalies started at all European pendulum instruments on January 23, 2023(14 days ahead). The most significant anomaly was recorded in cave No.13, Moravian Karst. This pendulum is directly on the N-S-oriented fault corresponding to the East Anatolian Fault activation (NE-SW), which was in action. NOAA satellite thermal observations of the epicentral show an increase in infrared radiation starting in December 2022 and riches the maximum on January 13 and Feb 1, 2023(24 and 5 days ahead), near the epicenter of the M7.8, compared with the 15 years background level. Increases in OLR from the satellite data coincided with an intensification in the atmospheric chemical potential (Feb 1-4), measured near the epicentral area. The electron density and oxygen ion density from the Ionosphere plasma instrument of the CSES1 satellite showed an abnormal increase on January 27-28 (9 days before the earthquake), which is highly correlated with the earthquake occurrence given the stable space weather index during this period. We show that by combining ground and near-space data accordingly to the physical concept of the Lithosphere-Atmosphere-Ionosphere Coupling (LAIC), we could identify, on a regional basis, abnormal patterns of pre-earthquake-related features.

PRE-SEISMIC GEOMAGNETIC ANOMALOUS SIGNATURE RELATED TO THE BOTH Mw7.8 AND Mw7.5 KAHRAMANMARAS EARTHQUAKES GENERATED IN TURKEY'S SOUTH-EAST ANATOLIA REGION, ON FEBRUARY 6, 2023.

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A very strong earthquake of Mw7.8 struck the Pazarcik, Kahramanmaraş zone in Turkey's South-East Anatolia Region, on February 6, 2023, at 01:17:35UTC. Less than 9 hours later, a second one of magnitude Mw7.5, centered in Elbistan, was generated at 10:24:49UTC. Almost more than 32,670 buildings have collapsed, 35,418 people died and 105,500 were injured. Further on, with the aim to identify any anomalous geomagnetic signature before the onset of the Mw7.8earthquake, we retrospectively analyzed the data collected on the interval January17 – February 7, 2023 at the two geomagnetic observatories Pedeli (PEG)-Greece and Panagjurishte (PAG)-Bulgaria, by using the polarization parameter (BPOL) and the strain effect–related to geomagnetic signal identification. Thus, for the both observation sites (PEG and PAG), the daily mean distribution of the BPOL and its Standard Deviation (SD) have been carried out using a FFT band-pass filtering in the ULF range. Further on, a statistical analysis based on a standardized random variable equation was applied for the following two particular cases: a) to assess on the both time series BPOL*(PEG) and BPOL*(PAG) the anomalous signatures related to the above mentioned earthquakes; b) to differentiate transient local anomaly associated to the both earthquakes, from the internal and external parts of the geomagnetic field by using the PAG Observatory as reference. Finally, on the both ABSBPOL*(PEG) and ABSBPOL*(PAG) time series, carried out on the interval January17–February 07, 2023, a very clear anomaly of maximum, of about **0.9**, was identified in February 01, with 5 days before the onset of the Mw7.8earthquake (Fig.1).

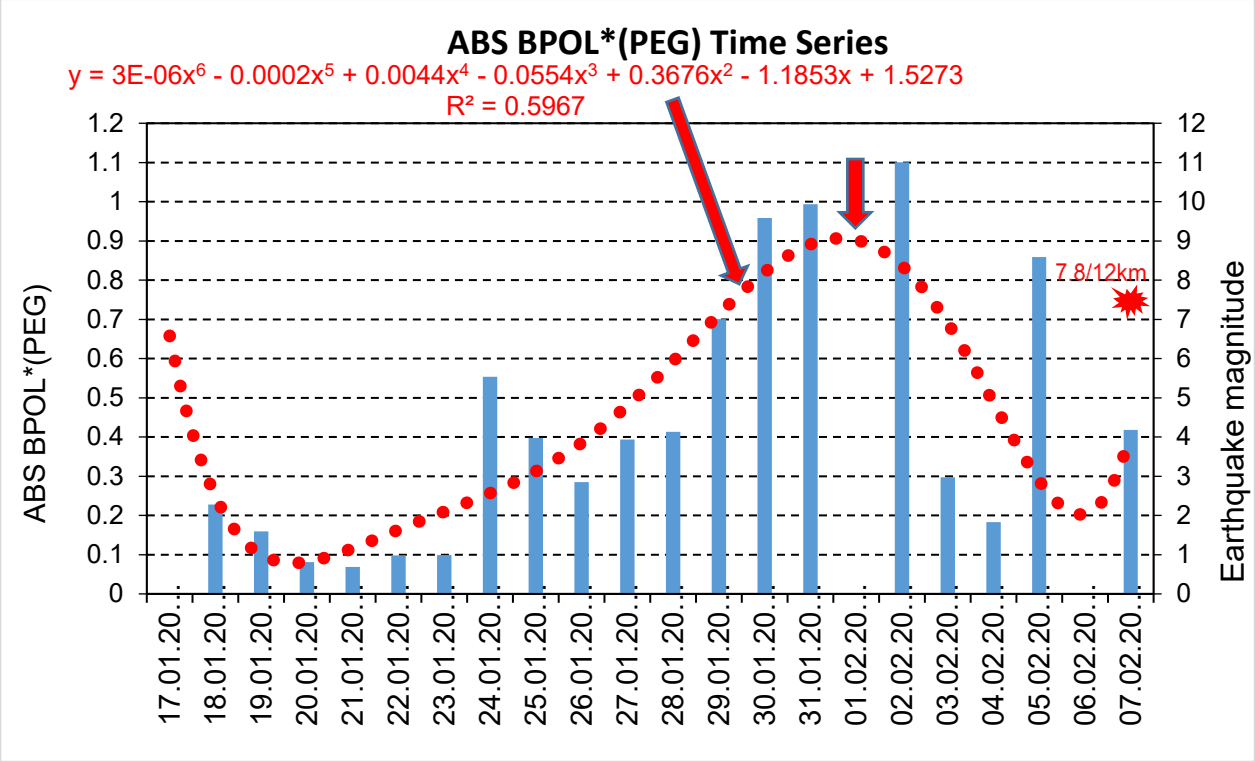

Fig.1. ABSBPOL*(PEG) time series distribution on the interval 17.01-07.02.2023; red dotted line (y) is 6 degrees' polynomial regression (indicated by red arrow); R^2 is root mean square; red star is earthquake; 7.8/12km is earthquake magnitude/depth; vertical red arrow indicates on 01.02.2023 a pre-seismic anomalous signature related to the Mw7.8earthquake.

CESE Detections of M7.0 & M6s Earthquakes and the Intense Dst-174 nT Magnetic Storm in August 2018

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The China Seismo-Electromagnetic Satellite (CSES) with a sun-synchronous orbit at 507 km altitude was launched on 2 February 2018 to observe seismo-ionospheric precursors (SIPs) and ionospheric space weather. The CSES probes two manifest longitudinal features of 4-peak plasma density and 3 plasma depletions in the equatorial/low-latitudes as well as mid-latitude troughs. The CSES parameters and total electron content (TEC) of global ionospheric map (GIM) are used to study SIPs associated with a destructive M7.0 earthquake and its following M6.5 and M6.3/M6.9 earthquakes in Indonesia on 5, 17, and 19, August 2018, respectively, as well as to examine ionospheric disturbances induced by an intense storm on 26 August 2018. Anomalous increases (decreases) in the GIM TEC and CSES plasma density (temperature) appear specifically over the epicenter day 1-5 before the M7.0 earthquake and aftershocks, and however similar TEC and CSES anomalies occur globally in the southern hemisphere during the storm days of 26-28 August 2018. Spatial analyses on the CESE plasma discriminate SIPs from magnetic storm effects, and locate the epicenter of possible forthcoming large earthquakes. The CSES ion velocity shows that the seismo-generated electric fields associated with the M7.0 earthquake are 0.06-0.21 mV/m eastward and 0.13-0.14 mV/m downward on 1-3 August 2018, while the penetration electric fields during the storm periods of 26-28 August 2018 are 0.17/0.60 mV/m westward/downward at post-midnight of 02:00 LT and 0.26/0.34 mV/m eastward/upward at post-noon of 14:00 LT. CSES ion velocities are useful to derive SIP and storm related electric fields in the ionosphere.

Nowcasting Earthquakes

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The earthquake cycle of stress accumulation and release is associated with the elastic rebound hypothesis proposed by H.F. Reid following the M7.9 San Francisco earthquake of 1906. However, observing details of the actual values of time- and space-dependent tectonic stress is not possible at the present time. In recent research, we have proposed methods to image the earthquake cycle in California and in other seismically active regions by means of proxy variables. These variables are based on correlations in patterns of small earthquakes that occur nearly continuously in time, as well as on the time varying rate of occurrence of these same small earthquakes. Nowcasting is a term originating from economics, finance, and meteorology. It refers to the process of determining the uncertain state of the economy, markets or the weather at the current time by indirect means. In this paper, we describe a simple two-parameter data analysis that reveals hidden order in otherwise seemingly chaotic earthquake seismicity. One of these parameters relates to a mechanism of seismic quiescence arising from the physics of strain-hardening of the crust prior to major events. We observe an earthquake cycle associated with major earthquakes in California, similar to what has long been postulated. An estimate of the earthquake hazard revealed by this state variable time series can be optimized by the use of machine learning in the form of the Receiver Operating Characteristic skill score. The ROC skill is used here as a loss function in a supervised learning mode. Our analysis is conducted in the region of 5° × 5° in latitude-longitude centered on Los Angeles, a region which we used in previous papers to build similar time series using more involved methods (Rundle & Donnellan, 2020, https://doi.org/10.1029/2020EA001097; Rundle, et al., 2021a, https://doi.org/10.1029/2021EA001757; Rundle, Stein et al., 2021, https://doi.org/10.1088/1361- 6633/abf893). Here we show that not only does the state variable time series have forecast skill, the associated spatial probability densities have skill as well. In addition, use of the standard ROC and Precision (PPV) metrics allow probabilities of current earthquake hazard to be defined in a simple, straightforward, and rigorous way. The workflow for this process is shown in the figure below.

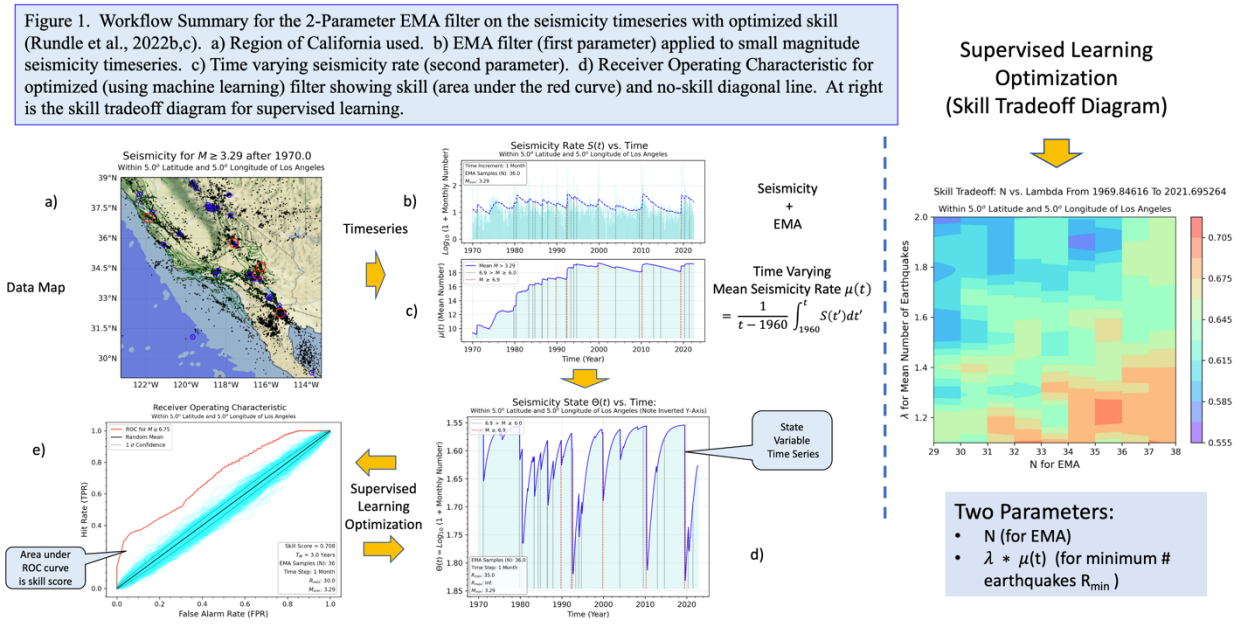

Figure 1. Workflow Summary for the 2-Parameter EMA filter on the seismicity timeseries with optimized skill (Rundle et al., 2022b,c). a) Region of California used. b) EMA filter (first parameter) applied to small magnitude seismicity timeseries. c) Time varying seismicity rate (second parameter). d) Receiver Operating Characteristic for optimized (using machine learning) filter showing skill (area under the red curve) and no-skill diagonal line. At right is the skill tradeoff diagram for supervised learning.

A Study of the ULF seismo-magnetic phenomena in Kakioka, Japan, during 2015-2020

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Abstract:

To mitigate earthquake disasters, the establishment of the short-term earthquake forecast technique is important. To achieve this, the ultra-low frequency (ULF) geomagnetic field changes has been studied and statistical significance in correlation and precursor characteristics in ROC analysis have been presented, It means that the ULF geomagnetic measurement has a potential parameter for the short-term earthquake forecast. In previous studies, the data observed Kakioka station during 2001-2010 operated by JMA has been utilized. In order to clarify ULF seismo-magnetic phenomena, we have studied the geomagnetic data observed at the Kakioka (KAK) station, Kanto, Japan, during 2015-2020. The magnetic data and earthquake catalogs obtained from Japan Meteorological Agency. The same approach with the previous studies have been performed, To select earthquakes, we use the Es parameter which considers the magnitude and distance of an earthquake simultaneously to select statistical samples. As the frequency of original geomagnetic data is 1Hz, the method of wavelet transform was implemented, and extract the signals at the frequency around 0.01Hz. Ground-based ULF geomagnetic data are a superposition of several signals: global magnetic perturbations, artificial noises, and magnetic signals possibly due to underground activities. To minimize artificial noises, we selected the midnight time data (JST 1:30-3:30). And to reduce the influence of global magnetic perturbations, the station Kanoya (KNY) was chosen as reference station. Then the statistical method of superposed epoch analysis (SEA) was adopted to highlight the weak but significant signal from noisy data. Finally, to verify the usefulness of the prediction model compared with random prediction. We evaluated the precursory information of ULF geomagnetic signals for local sizable earthquakes using statistical method receiver operating characteristic (ROC) curve. In ROC curve, the closer to the upper left corner, the better performing for this prediction model.

Keywords: ULF electromagnetic phenomena, Superposed Epoch Analysis(SEA), Molchan's Error Diagram

Evaluating earthquake forecasting models with likelihood based marginal and conditional scores

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Vere-Jones (1998, Computational Geoscience) proposed the general process of earthquake probability forecasting by using point-process models: First, the entire forecasting period is divided into many small time intervals with length Δt. Second, for each time interval seismicity is simulated by using the forecasting model and observations in the past. Then, the probability of earthquake occurrence is the proportion of the simulations with events occurring in all the simulations. He also proposed the likelihood based binary and Poisson scores for evaluating the forecast performance against some reference models.

To evaluate different aspects in the forecasting performance of a model or a method, in CSEP testing centers, the N-, M-, R-, S-, and T-tests have been adopted to test different aspects of the earthquake forecasts in a gridded space-time range. Likelihood based topical scores was proposed by Ogata et al (2015, BSSA) using the Poisson assumptions together with an assumption on each cell of approximation. In this talk, I will show how to use the point-process likelihood directly to evaluate different aspects of the forecast performance: **marginal** and **conditional scores**. These scores include: Numbers, occurrence times, occurrence locations, event magnitudes, correlation among different space-time-magnitude cells.

The results show:
For a fully specified point process model like the ETAS model, the correspondence of N-, T-, L-, and M-tests can be implemented in a rigorous manner according to the likelihood function. We should take special care when calculating the ratio between two small probabilities. Gridding in space, such as in the CSEP tests, unnecessarily increases the complexity of the testing problem. Giving it and evaluating spatial forecasting performance directly the marginal likelihood seems to be a more promising option.

Keywords: point-process model, earthquake forecasting, forecast evaluation, likelihood

To compare to forecast by two models

λ: forecasting model λ^*: reference model

likelihood ratio

$$\frac{L}{L^*} = \frac{p_0}{p_0^*}, \quad \text{when no events}$$

Prob. gain (score) in forecasting Yes/No

Conditional prob. gain in forecasting number given Yes-condition

Conditional prob. gain in forecasting locations given event number

$$\frac{L}{L^*} = \frac{1-p_0}{1-p_0^*} \times \frac{\frac{p_n}{1-p_0}}{\frac{p_n^*}{1-p_0^*}} \times \frac{f_n(x_1,\cdots,x_n)}{f_n^*(x_1,\cdots,x_n)}, \quad \text{when } n \text{ events}$$

$$= \frac{p_n}{p_n^*} \times \frac{L(x_1,\cdots,x_n)/p_n}{L^*(x_1,\cdots,x_n)/p_n^*}$$

Unconditional prob. gain in forecasting number

ULF seismo-magnetic signal extraction and evaluation

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2. Chiba University, Japan

Content: The early research on the anomaly of seismo-magnetic signal mainly focused on the spectrum analysis of the original data of the station, and then PCA and other methods were developed. In recent years, with the application of far reference station, the anomaly index of P value for the ratio of the observed data energy to its model energy has been established, and the anomaly index P value is dimensionless. It is worth thinking whether the actual abnormal waveform can be obtained. However, the seismo-magnetic signal is weak, it is usually mixed with the space sources signal and human noises, so the critical problem is distinguishing the seismo-magnetic signal from the complex environment. It is a potential method to extract the signal of observation stations by using the reference station data based on interstation transfer function. In view of the previous studies, which did not use strict multivariate coherence analysis for the transfer function, this study proposed an interstation transfer function algorithm based on wavelet multivariate coherence to establish the electromagnetic estimated values of observation stations, and the transfer function in the high-frequency part can also be accurately calculated. The phase difference is estimated well and the actual waveform data of the seismo-magnetic signal can be obtained.

For Kakioka (KAK) station, the data of KNY and MMB stations are used as reference stations to calculate the interstation transfer function and obtain the estimated values of the three components of the KAK station. By showing the geomagnetic pulsation caused by obvious global disturbance at both the observed and reference stations, the geomagnetic pulsation signal disappears in the residual between the observed and the estimated value. By adopting the SEA method, the anomalies of seismo-magnetic signal before the earthquake show significance. On the basis of correlation analysis, the Molchan diagram was used to evaluate the precursor information in the observed data. The residual values between vertical observed values and estimated values are significantly increased in the total residual, the 50s, 100s, 200s, and 400s periodic of the total residual on 6-15 days before the earthquake. The forecasting efficiency of the above parameters are better than that of the random prediction, and the forecasting efficiency of the total residual and 400s is the best.

Temporal variations of Parkinson vectors in China

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Parkinson vector (or induction vector) is an effective indicator to investigate the underlying conductivity structures and pre-earthquake conductivity anomalies. Typically, the factors influencing Parkinson vectors (PVs) come from underground. Recently, the seasonal effects have been observed in the PVs. However, causal mechanisms of the seasonal effects on the PVs are not fully understood. In this study, we utilize ten years three-component geomagnetic data from 24 stations operated by the Geomagnetic Network of China to study the spatiotemporal characteristics of the PVs through vertical transfer function (VTFs). The analytical results show that the PVs exhibit seasonal variations that the magnitude of PVs reach maximum in summer and winter, which are pronounced in lower frequency bands. In addition, the PVs at all stations consistently exhibit a counterclockwise rotation in June (summer), and a clockwise rotation in December (winter). The Inter-hemispheric field-aligned current in the ionosphere is one of the potential reasons to explain the seasonal variations. This study finds that the PVs are also affected by ionospheric current systems. As a result, the seasonal effect on PVs should be examined when we study the pre-earthquake conductivity anomalies.

Title: Slope surface deformation detection by close-range terrestrial photogrammetry

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Southern University of Science and Technology

Abstract

Landslide monitoring is an important means to prevent the landslide disaster which is one of the most serious geologic hazards that brings great threats and huge losses to society. Among all elements of landslide monitoring, slope surface deformation is a piece of direct evidence to judge whether slope slips, which makes it indispensable in qualitative and quantitative analysis of slope stability. Current mainstream surface monitoring methods using GNSS are difficult to lay out densely on a large scale in a deformation region due to the high cost of equipment, leading to few surface points available for detection. With the rapid development of camera resolution and image processing, photogrammetry based on computer vision has great prospects in the application of slope real-time monitoring.

This paper introduces a low-cost landslide visual monitoring system using close-range terrestrial photogrammetry that deploys fixed cameras to capture the slope surface periodically and calculating the displacement of feature points from sequential slope images to generate the slope surface deformation network. A new machine learning framework is proposed to achieve image recognition, camera calibration and distance mapping altogether. We conduct indoor landslide experiments which verify the high precision, accuracy, and stability of our system.

Keywords:

Landslide, Slope surface, Photogrammetry, Machine learning

Study on Volcanic Activity of Mt. Shinmoedake in 2018 Using Himawari AHI Data

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Ground-based volcano monitoring is not possible for all active volcanoes due to topographical restrictions and cost. On the other hand, volcanic activities that cause lava eruptions or eruptions that cause significant human and economic damage are usually accompanied by an increase in surface temperature, making satellite remote sensing effective for temperature monitoring. Therefore, we have been developing algorithms to detect temperature anomalies associated with volcanic activities (especially for monitoring lava activities that cause serious damage to human lives and predicting pyroclastic flows) by spatiotemporal analysis of ground surface temperature around volcanoes using thermal infrared nighttime data on board artificial satellites. As a result, Noguchi et al. (2004) demonstrated the effectiveness of monitoring volcanic activity in the tropics1 using nighttime infrared data from the MODIS sensor onboard the Aqua/Terra satellites, and Tsutsumi et al. (2020) showed that the appearance of a lava dome on the 2011 eruption of Mt.shinmoe In a similar analysis to Tsutsumi et al. (2020) for the eruptive activity of Mt. Shinmoe in 2018, an anomalous rise in surface temperature associated with the appearance of a lava dome was detected, but the anomalous rise in surface temperature was not detected visually or by SAR data. The reason for this may be that the summit area was covered by clouds at the time of the satellite observations, which prevented observation of the ground surface. There are two possible means of measuring surface temperatures in consideration of cloud effects: using satellite-observed microwave data and increasing the frequency of observations at target locations using geostationary meteorological data to increase the number of cloud-free observations. The former is promising, but requires a large footprint, since microwaves can penetrate clouds. The latter is promising, but the footprint becomes large. The latter is affected by clouds, but the observation frequency is every 10 minutes (2.5 minutes near Japan) (in the case of Himawari No. 8-9).

Therefore, by using thermal infrared data from the Himawari-8 satellite, which has a higher temporal resolution, we conducted a research study to contribute to the detection of surface temperature anomalies associated with magma eruptions and the appearance of lava domes, and to their detection as early as possible. As a result, we were able to confirm the temperature anomaly several hours before the eruption occurred.

Tatun volcano breathing revealed by continuous monitoring of self-potential signals

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In recent years, many studies have suggested that the Tatun Volcanic Group (TVG) may not be a dead volcano, and that there may be a magma reservoir beneath the area, which is a sign of an active volcano. The TVG is located near the Greater Taipei Area, which has a population of nearly 7 million people, accounting for about 30% of Taiwan's population. Due to the potential risks of volcanic activity to the population and critical infrastructure, monitoring and forecasting of volcanoes has always been a major issue. To observe changes in the hydrothermal system beneath the TVG, this study analyzed the continuous self-potential records in the TVG area. The geoelectric method has strong capabilities in imaging petrology, geological discontinuities, and volcanic hydrothermal and conduit systems. Therefore, using the self-potentials for long-term continuous monitoring of volcanoes is very suitable. This study calculated the power spectral densities of self-potentials at the Shrlin station and the Huangzuishan station and compared them with seismic activity at the TVG. The main result found is that the hydrothermal activity during the period from 2014 to 2020 might be divided into three stages. The first stage is a normal period, during which the power spectral density of the self-potentials is stronger, indicating a relatively higher resistivity, and the Gutenberg-Richter b-value of seismic activity is close to 1, with larger cumulative magnitudes. The second stage is an inflation period, during which the power spectral density of the self-potentials weakens, indicating a decrease in resistivity, implying that subsurface thermal flow is moving to shallower layers, and the Gutenberg-Richter b-value of seismic activity is greater than 1, and even greater than 2, with smaller cumulative magnitudes, indicating that there are much more small earthquakes, which also supports the fact that thermal flow causes earthquake triggering. Finally, the third stage is a deflation period, during which the subsurface thermal flow stops surging and instead flows deeper, so the power spectral density of the self-potentials becomes stronger again, indicating an increase in resistivity, and the Gutenberg-Richter b-value of seismic activity returned to 1, with larger cumulative magnitudes. More importantly, a collapse-type earthquake occurs during this stage, which corroborates the fact that subsurface thermal flow no longer surges but dissipates. These three stages are also

observed at the Huangzuishan station from 2020 to 2023. Therefore, we infer that the hydrothermal system beneath the TVG area is undergoing a long-period breathing cycle on an annual basis, causing underground pores to expand and contract, resulting in changes in the power spectral density of self-potentials and seismic activity, and even causing collapse-type earthquakes in the subsurface.

Keywords: Tatun Volcano Group, self-potential signal, collapse-type earthquake

Multidimensional Active fault of Geo-Inclusive observatory - Chihshang (MAGIC) for exploring the earthquake generating process

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Key words: Chihshang fault, multidimensional earthquake observatory, MAGIC, earthquake-generating process

The Chihshang Fault (CSF) located at the boundary between the Eurasian and Philippine Sea plates along the southern Longitudinal Valley in east Taiwan, is a natural experiment field to explore the relationship between surface creeping, subsurface fluid circulation, and seismic activity on the fault. The emission and movement of crustal fluids within the Earth's crust could be triggered by static and dynamic stresses as well as seismic activity. To investigate the origin and migration of the fluids and their relationship to the seismogenic processes around the CSF, this study integrated several geochemical, geophysical, and hydrogeological methodologies to establish a multidimensional earthquake observatory with high temporal-spatial resolutions. The observations of this project (Multidimensional Active fault of Geo-Inclusive observatory – Chihshang, so-called MAGIC) include soil-radon concentration and CO_2 flux on the surface, fluids geochemistry of the fault zone in the borehole, hydrogeological parameters, microseismic observation network, and GNSS array. Furthermore, the optical fiber technology (DAS and DTS) will also be applied for monitoring activities of the CSF near subsurface. The earthquake-generating process will be demonstrated to understand the coupling mode for fissure generation, crustal deformation, and deep fluid migration and circulation through multi-geochemical characteristics, seismic signals, and physical signatures of groundwater at similar spatial scales.

A development of signal discrimination method using Multi-channel Singular Spectrum Analysis (MSSA) for ULF band electromagnetic data, in Boso, Japan

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An electromagnetic phenomenon associated with crustal activity in the ULF band ($f < 10$ Hz) is expected as a method that can detect the signal directly from the intra-crust or plate boundary. However, the observed signal includes not only the earthquake-related signal but also the solar-origin signal and artificial noise, such as the leak current from the DC-driven train. Detection of the signal is difficult because the amplitude of the earthquake-related signal is tiny compared with the other noises, and the waveform of the signal is similar to the artificial noise. Recent analyses were performed in a noiseless environment, such as the region far from the city area, and at night-time to escape this problem. However, by this scheme, we miss detecting the signal that occurs in the daytime. The new signal discrimination method is essential to increase the chance of detecting the signal in the daytime.

We are developing a new signal discrimination method based on Multi-channel Singular Spectrum Analysis (MSSA) to overcome this problem. MSSA is the extension of Singular Spectrum Analysis (SSA), resulting in MSSA can decompose multiple time series to several principal components (PCs). Then, choosing and summing arbitrary PCs with some threshold, such as correlation and contribution ratio of the PCs, the time series can be discriminated into the signal and noise parts.

In the MSSA-based signal discrimination method developed in this study, remove solar-origin signals from 7ch data (target site 5 components (horizontal magnetic field 2ch (Hx and Hy), vertical magnetic field 1ch (Hz), and horizontal electric field 2ch (Ex and Ey)) and reference site 2ch (magnetic field 2ch (Rx and Ry))), then, obtain a local signal. After applying this method to actual data acquired on the Boso Peninsula for signals with a period of less than 400 s, the solar-origin signal was removed, and a local signal of about 1 nT for the magnetic field and about 2 mV/km for the electric field was detected. This presentation will focus on the performance and effectiveness of the method.

Lower Ionospheric Disturbances Induced by the 2022 Hunga Tonga–Hunga Ha'apai Eruption: An Application of the Hilbert-Huang Transform to VLF/LF Data

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The Tongan Hunga Tonga–Hunga Ha'apai (HTHH) volcano (20.6°S 175.4°W) erupted on 15 January 2022. This eruption, with a volcanic explosivity index (VEI) of 5–6, is considered the strongest after the 1991 Pinatubo eruption. Our very low frequency/low frequency (VLF/LF) receiving system in Taiwan, which is used to monitor VLF/LF signals on several propagation paths in the Asia-Pacific region, recorded unusual variations in VLF/LF receiving amplitudes about 7–15 hours after the eruption, suggesting the lower ionosphere was disturbed by oscillations induced by the volcanic eruption. The unusual variations in amplitudes started after the arrival of the so-called "Lamb wave," and the arrival time of the wave can be easily determined by carefully checking the amplitude time series. The fluctuations in VLF/LF amplitudes were sustained for about 8 hours after the passage of the Lamb wave, indicating that the lower ionosphere was continuously disturbed by volcano-induced atmospheric oscillations during this period. Nevertheless, the amplitude time series on the four studied propagation paths present their respective variations. Therefore, it is difficult to coordinate those results and conclude the properties of the atmospheric oscillations using conventional time-frequency analyzing methods, such as Fourier and Wavelet transforms. In such a situation, we used the Hilbert-Huang transform (HHT), which is an algorithmic method for analyzing nonlinear and non-stationary time series and has never been applied to VLF/LF data in previous studies. We successfully decomposed the time series and found modulations of the oscillatory amplitude and period from intrinsic mode functions (IMFs). These modulations are considered to be changes in the properties of atmospheric oscillations, and further, the possible mechanisms of these changes are discussed in this study. It seems the air-sea coupling plays an important role in affecting the amplitude and period of atmospheric oscillations. The present study is the first attempt to employ the HHT to analyze VLF/LF data. As the performance of HHT is well demonstrated in this study, we think that the HHT can be a good tool to detect pre-seismic features hidden in the VLF/LF time series in our feature studies.

Case studies on Earthquake-related ionospheric anomalies based on CSES observation

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Abstract:

The CSES is the first satellite of the space-based observation platform of China's three-dimensional earthquake observation system. It can carry out real-time monitoring of ionospheric dynamics and tracking of earthquake precursors in China and surrounding regions by acquiring global electromagnetic field, ionospheric plasma and energy particles to make up for the shortage of ground-based observation and open up new ways to explore earthquake monitoring and prediction.

The CSES team has carried out a retrospective study of earthquake cases, including 47 shallow earthquakes with Ms≥7 (depth<100km) and 15 earthquakes with Ms≥6 in Chinese mainland since February 2, 2018. The results show that the Langmuir probe and the electric field have the highest number of anomalously identified earthquake cases, and the anomalously identified rate is more than 70%; Followed by the two instrument, high-energy particle detector and GNSS occultation receiver, with anomaly recognition rate of around 50%. For electromagnetic fields, anomalies mainly are observed in the ULF and ELF frequency range. For plasma, density will show more anomalies than the temperature. The electron flux is the main parameter more sensitive to earthquakes for energy particles. For all instruments, the positive variation is the major variation. The appearing time of the anomalies are mainly focus on the day to 7 days before the earthquake occurring, and during 11~ 15 days before the earthquake occurring, in addition, for the electromagnetic field, the anomalies also appears the 20~25 days before the earthquake occurring. The location of the anomalies generally appears more to the east and south of the epicenter.
Although obvious seismic ionospheric anomalies can be recorded by the CSES, it is still a world scientific problem to achieve accurate prediction of time, position and intensity of earthquakes, especially only using a single satellite. The combination of seismology, electromagnetism, geodesy, geochemistry and other multi-disciplinary means can better promote the research in this field.

Keywords:

CSES, seismic ionospheric anomalies, Electromagnetic fields, plasma, energy particles

Splash of telluric currents generated by solar flare as a possible trigger of earthquakes

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Abstract

The current studies of solar-terrestrial relations and possible impact of space weather on the seismic activity are based on statistical analysis without detailed consideration of possible physical mechanisms that results in contradictory conclusions. We propose to consider a hypothesis of electromagnetic triggering of earthquake by a sharp rise of telluric currents in lithosphere including conductive crust faults due to interaction of solar flare X-ray radiation with "ionosphere-atmosphere-lithosphere" system resulted in a rise of telluric currents in the crust faults. This hypothesis is based on field and laboratory experiments carried out in Russia within the last forty years that clearly demonstrated a possibility of earthquake triggering by electric current injected into the crust fault [1]. We developed a mathematical model and computer code for numerical estimations of telluric currents generated by solar flare radiations [2, 3]. The obtained numerical results show that solar flares can cause variations in the density of telluric currents in the crust faults, comparable to the current densities generated in the Earth's crust by artificial pulsed power sources capable to trigger earthquakes. Based on obtained numerical results, in our opinion, the further correct statistical correlation analysis of solar-terrestrial relations should be carried out in the following sequence: (a) determination of an unstable area (the crust fault section) where the strong earthquake is anticipated based on existing methods of selection of regions with impending strong earthquakes (long- and medium-term predictions); (b) selection of the crust faults in the areas determined in step a) favorable for generation of maximal telluric current density from point of view of their orientation close to direction of the current density vector, as well as their electrical conductivity; (c) sampling the earthquakes from regional seismic catalogs which occurred on the faults selected according to step b); (d) correlation analysis of earthquake occurrence and variations of space weather parameters. Such a statistical approach will provide an estimation of space weather parameters capable to trigger earthquakes in the specific seismic-prone areas sensitive to electromagnetic impact from point of view of orientation of crust faults and their electrical conductivity.

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Critical Dynamics in Stratospheric Potential Energy Variations Prior to Significant (M > 6.7) Earthquakes (AGW hypothesis)

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Abstract:

Lithosphere–atmosphere–ionosphere coupling (LAIC) is studied through various physical or chemical quantities, obtained from different sources, which are observables of the involved complex LAIC processes. LAIC has been proposed to be achieved through three major channels: the chemical, the acoustic (AGW), and the electromagnetic. Accumulated evidence supporting the acoustic (AGW) channel hypothesis has been published, while atmospheric gravity waves (AGWs) play a key role in LAIC as the leading mechanism for the transmission of energy from the lower atmosphere to the stratosphere and mesosphere, associated with atmospheric disturbances observed prior to strong earthquakes (EQs). The seismogenic AGW is the result of temperature disturbances, usually studied through stratospheric potential energy (EP). In this work, we examined 11 cases of significant EQs (M > 6.7) that occurred during the last 10 years at different geographic areas by analyzing the temperature profile at the wider location of each one of the examined EQs. The "Sounding of the Atmosphere using Broadband Emission Radiometry" (SABER) instrument, a part of the "Thermosphere Ionosphere Mesosphere Energetics Dynamics (TIMED)" satellite, data were employed to compute the potential energy (EP) of the AGW. Using the temperature profile, we first calculated EP and determined the range of altitudes for which prominent pre-seismic disturbances were observed. Subsequently, the EP time series at specific altitudes, within the determined "disturbed" range, were for the first time analyzed using the criticality analysis method termed the "natural time" (NT) method in order to find any evidence of an approach to a critical state (during a phase transition from a symmetric phase to a low symmetry phase) prior to the EQ occurrence. Our results show criticality indications in the fluctuation of EP a few days (1 to 15 days) prior to the examined EQs, except from one case. In our study, we also examined all of the temperature-related extreme phenomena that have occurred near the examined geographic areas, in order to take into account any possible non-seismic influence on the obtained results.

Atmospheric Waves, role of ionosphere modification before large earthquakes

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We reported that all ionosphere disturbance which is seen before large earthquake is explained by "enhanced dynamo electric field". (Oyama et al., 2019). The process to the enhanced electric field is: 1. Enhanced dynamo electric field is caused by the increased electric resistivity of the dynamo region, 2. which is generated by the enhanced plasma irregularities. 3. The enhanced plasma irregularities is generated as the existence of neutral density irregularities, 4. which is produced as the breaking of the atmospheric waves. The paper concentrates to discussed the role of the waves, and the origin of the waves.

Our study on the possible candidate to modify the ionosphere starts from the finding of the good correlation between NmF2 and variation of neutral temperature, Tn. Tn were observed by TIDI (TIMED Doppler Interferometer) instrument onboard US satellite,TIMED (Thermosphere、Ionosphere, Mesosphere Energetics and Dynamics Mission) (Sun et al., 2015). The wavy structure of large amplitude and small-scale neutral irregularities was studied. Tn around the height of 100-110 Km for Sechuan earthquake, which occurred in 12 May 2008 (31.02° N,103.367°E, Ms8.0, Mw7.9, 31D19 km) shows the increase of NmF2 corresponding to the increase of the amplitude of Tn variation. The Tn variation of vertical wave length less than 20 km shows the broad peak around 100 km. The irregularities thus produced contributes to the reduction of the electric conductivity (Prakash,1999). We conclude that this irregularity finally enhances the dynamo electric field.

Study on the role of atmospheric waves which we conducted for Sechuan earth quake was applied to the Tohoku-Oki earth quake which occurred on 11 March 2011(38.297°N,142.373°E, Mw=9.1, D29 km). We confirmed that atmospheric wave is the main player to modify the ionosphere. Although we do not exclude other mechanism for ionosphere disturbance, two days oscillation of NmF2(considered to be possible interaction between atmospheric waves) appears, for one week before earth quake both for Tohoku-Oki and Kumamoto earthquake, which occurred at 21:26 on 14April 2016 (JST), at 32°44.5'N /130°48.5'E, Mj6.5, Mw6.2, D11 km), and 1:25 on 16 April (32.782N,130.726E, Mj7.3Mw7.06D12Km. The two days oscillation suggests the possible role of atmospheric waves. The two days oscillation might be generrated as a result of the interaction between the earthquake triggered wave and existing waves (Pancheva et al., 2006). The origin of the atmospheric wave will be discussed in detail in another time.

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Towards a closer cooperation between space and seismology communities

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The space physicists and the earthquake prediction community exploit the same instruments – magnetometers, but for different tasks: space physicists are trying to comprehend the global electrodynamics of the near-Earth space on various time scales, whereas the seismic community develops electromagnetic methods of short-term earthquake prediction. However, the lack of deep collaboration between those communities may result sometimes in misleading conclusions. In this talk we demonstrate some incorrect results caused by a neglect of specifics of geomagnetic field evolution during space weather activation. Specific examples comprise:

- Magnetic storms as a trigger of earthquakes;
- Global ULF waves occurring several tens of mins before strong earthquakes;
- Immediate (several minutes) geomagnetic impulses before seismic shocks;
- Long-period geomagnetic disturbances generated by strong earthquakes;
- Discrimination of underground ULF sources by amplitude-phase gradients;
- Depression of ULF power as a short-term (several days) earthquake precursor.

To verify the reliability of the above phenomena, we have used data from the PWING network of induction magnetometers in the Far East, augmented by data from world-wide array of fluxgate magnetometers. In these events, the ULF behaviour can be explained by global geomagnetic activity, and it is apparently not associated with seismic activity. We suggest that both communities must cooperate their studies more tightly (data exchange, combined usage of magnetometer networks, CDAW of unique events, etc.).

The Three-dimensional Ionospheric Disturbances Caused by the M9.0 Tohoku-Oki Earthquake in Japan

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In this study, we reconstructed the three-dimensional (3-D) ionospheric disturbances of electron density (Ne) induced by the M9.0 Tohoku Earthquake in 2011 using the computerized ionospheric tomography technique. The reproduced Ne distributions around 06:00 - 06:10 UT exhibited significant uplift with a displacement of ~30 km in the F layer along the longitude of 138° - 141°E, which corresponded to a sudden depletion of Ne when Rayleigh wave-induced traveling ionospheric disturbances (TIDs) was passing through. At 06:12 UT, abrupt uplift of the F layer with sharp slope was detected in 137.5°E. Then, it propagated away from the epicenter and appeared in 136°E at 06:24 UT. From then on, the Rayleigh wave-induced ionospheric disturbances became dispersive, and the tsunami-induced disturbed structures became prominent. During 06:34 - 06:52 UT, the mesoscale TIDs associated with tsunami gradually came out from 06:34 UT with a remarkable sinusoidal waveform in 250 - 400 km. The distribution of detrended Ne presented several prominent negative and positive bands, which were closely following along 132° - 141°E in a similar height interval. Further, the downward phase progression with increasing time was significantly detected in the time-height distribution of the filtered Ne related to the tsunami waves generated by offshore earthquake, which strongly indicated the signature of the upward propagation of the atmospheric gravity waves in accord with the numerical simulated results. Finally, by virtue of the reproduced vertical wavelength and dispersion equation, we estimated a background neutral wind of -49.3 m/s for the tsunami case (negative values represent northward propagation). The estimated neutral wind velocity is consistent with the usual values ranging from -100 m/s to 100 m/s.

The relationship between geomagnetic field observations and ionospheric perturbations around strong earthquakes in China

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Abstract: As proposed concepts in LAIC processes, three channels have been suggested, one for chemical channel or named overlapped electric field channel, one for acoustic gravity wave channel, and the last one for ULF electromagnetic wave channel, where the first channel is widely accepted to explain the ionospheric plasma perturbations, especially for their magnetic conjugate characteristics. But due to the low conductivity of the air, the strength of electric field up to the lower ionosphere is limited or quite small. Here on the basis of ground-based geomagnetic field observations, we collected the multi parameters in ionosphere from ionosonde or satellites. The signals around a few strong earthquakes in China have been analyzed, including Mani in 1997, Kunlunshan in 2001, Wenchuan in 2008, Yangbi in 2021, and it is found that when the significant perturbations occurred in ionosphere, the geomagnetic field observations always exhibited simultaneous disturbances, including their amplitude and phase in its diurnal variations. We try to construct their intrinsic correlation, and the occurrence of new current system under the seismic preparation region is recommended to overlapped on the internal source current system to cause the increasing or reducing of the geomagnetic field in vertical component or directly to change the diurnal variation phase such as the lowest point time displacement or double low points in one day. After separating of equivalent current system for external and internal sources from Sq in geomagnetic field, underground current in seismic region is illustrated for the lithosphere and ionosphere coupling, especially for the origin of long period disturbances more than 1h in lithosphere and ionosphere.

Statistical correlation between DEMETER satellite electronic perturbations and global earthquakes with M⩾4.8

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Upon obtaining a relatively low false discovery rate (FDR) of alarms and a low false negative rate (FNR) of earthquakes, several previous long-term statistical researches concluded that ionospheric perturbations recorded by satellites are statistically related to earthquakes. However, overly large time-space windows for correlating perturbations with earthquakes will also contribute to low FDR and FNR. In this study, a new score - the number of non-randomly successful alarms - is used to quantitatively describe the sensitivity of Electron Density Perturbations (EDPs) recorded by the DEMETER satellite to global earthquakes with $M \geq 4.8$. Results show that the EDPs are significantly related to global medium-to-strong earthquakes and that optimal parameters for removing EDPs which are non-related to earthquakes and the optimal time-space windows for correlating earthquakes and EDPs are variable in space. Moreover, our results show that the intensity of EDPs makes little contribution to distinguishing the perturbations related to earthquakes with different magnitudes and perturbations non-related to earthquakes, while the K_p index is effective for improving the Signal/Noise ratio of our model, where Signal/Noise refers to the EDPs related/non-related to earthquakes. Finally, using the optimal time-space windows for correlating EDPs and earthquake, we construct several earthquake prediction models and quantitatively evaluate their power. We find that these EDP-based earthquake predictions are better than the spatially variable Poisson model showing the great potential of predicting earthquakes based on satellite-based Earth observation techniques. However, the spatio-temporal accuracy of these models for predicting earthquakes is not satisfactory, as the alerted time-space volume is big.

Characteristics of Geomagnetic and Pre-Seismic Changes in Ionospheric Electron Density over Japan Area

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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 mechanism. These are still having not been elucidated questions and more investigations are needed to make clear that phenomena.

On the other hand, the another natural 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. To overcome this problem, a characterization and classification of magnetic storm and earthquake signatures is necessary. For this purposes, in this study, we mainly focused on similar and differing effects of magnetic storms and earthquake preparation period on the ionospheric composition.

In this study, the time period after magnetic storms and before earthquakes were investigated. The selection of earthquake cases was carried out between 1998 to 2013 with M>6 and depth<30 km. Under these criteria, 53 earthquakes were extracted. To determine the anomalous behaviour before each, we examined the TEC responses against each earthquake both in temporal and spatial ways by using GIM TEC data. Thus, we found that 28 earthquakes had caused anomalous condition in the ionosphere. We further examined these earthquake cases with tomography method to investigate their 3D distribution and encountered with that 13 of those had also shown similar anomalous behaviour. Meanwhile, magnetic storms were also selected between 1998 to 2013 within the intense storm category in which Dst < -100 nT. The onset time was in daytime hours from 06:00 AM to 06:00 PM. Hereby, 42 geomagnetic storms were obtained. Among these, we have chosen arbitrarily 10 different magnetic storm case days and same analysis steps for earthquakes was followed again to determine the anomalous changes of ionospheric electron content.

The TEC data sets were extracted from both local receivers (GPS-TEC) and global receivers (GIM-TEC). In tomography process, GPS-TEC data was inverted to the electron density (Ne) quantities by using Neural Network non-linear function approximation method. This process was carried out for each ionospheric sample point (altitude) to examine 3D electron density distribution in the ionosphere. On the other hand, since TEC is usually slower to respond the compositional changes in the ionosphere, ionospheric foEs and NmF2 parameters which are obtained from ionosondes were also employed as complementary data. There, the time series plots of these parameters were prepared. For pre-seismic period, ionospheric NmF2 had mainly shown an enhancing characteristic even at night time, while for the storm cases, fluctuation was usual response after around few hours of storm onset time. Besides that, foEs values have found as changed suddenly over stations near the epicentre, however, for the storms foEs responses were irregular and was not so distinctive. The hmF2 values have increased, while before earthquakes it was not as much as affected. Moreover, the another observed difference was disturbance characteristic that after magnetic storms the ionosphere has been disturbed both negatively and positively, while before earthquakes positive disturbances and quiet weak negative disturbances were usually effective around the epicentre.

Abstracts of poster presentations

Current status of the Prelude: Precursory electric field observation cubesat demonstrator

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Abstract

Small satellites have already been used for earthquake precursory phenomena observation in other countries, but CubeSat-class satellite has not existed yet. The French seismo-electromagnetic satellite DEMETER reported statistically the reduction of the radio wave intensity 4 hours before earthquakes, but its mechanism and dependence on local time is unknown.

The 6U CubeSat "Prelude" under development is aimed at verifying the reduction of radio wave intensity 4 hours before earthquakes by installing only one pair of electric field probes which is already proven by DEMETER in the vertical direction, constructing the satellite constellation in a low cost.

In February 2023, a probable earthquake prediction demonstration CubeSat based on the detection of pre-earthquake phenomena, was additionally selected for the "Innovative Satellite Technology Demonstration Unit 4 theme open call".

The Innovative Satellite Technology Demonstration Unit 4 is scheduled to launch in 2024.

Study of Atmospheric Precursor Anomalies Associated with Earthquake Events: Role of Machine Learning

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Abstract

Prior to an earthquake, physical and chemical interactions in the earth's crust may induce abnormalities in latent heat flux, air and surface temperature. As the energy accumulated in rocks is released, earthquakes occur. Sometimes, ground movements generate rifts in the earth's surface, and occasionally, two sides of an existing fault shift towards one another.

Several remote sensing techniques, such as satellites and various ground-based instruments, are used to detect the increases in latent heat; It record the surface air temperature, the surface latent heat flux, the relative humidity, and other atmospheric variables. In order to explore the phenomenon of earthquake precursors, we utilized satellite data for an atmospheric component known as surface latent heat flow. Here, it is determined if there is a relationship between the atypical behavior of surface latent heat flux and the devastating earthquakes that occurred west of Kathmandu, Nepal, on January 24, 2023, with a magnitude of 5.6, and on the Turky-Seria Border on February 6, 2023, with a magnitude of 7.7, causing significant loss of life and property. Seismicity is induced by the release of energy in fault zones hundreds of kilometers wide in a structurally complex and inhomogeneous collision region such as the Anatolian Plate, where the East Anatolian Fault and Transform Fault are located. To the south and southwest is the African Plate. In addition, the Eurasian Plate is located in the north of Turkey. These plates revolve in a counter-clockwise manner.

Keywords: Latent Surface Temperature, Radon emissions, low frequency emissions, earthquakes, solar flares, magnetic storms, precursors etc.

Continuous radon measurement in atmosphere at Okayama and Kiyosumi

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Abstract.

We designed radon detection system utilizing a PIN photodiode, as known as a high sensitive alpha ray detector in Super Kamiokande, and conducted to measure the radon concentration in atmosphere. Our system consists of a Si PIN photodiode (S3204-09, unsealed, Hamamatsu Photonics K.K.), aluminum pot as an atmosphere accumulator, a charge amplifier (H4083, Hamamatsu), a high voltage power supply module (C4900-01, Hamamatsu), a pulse shaped amplifier with time constant of 10 ms, a multi channel analyzer (MCA-LiteN), and a PC for data acquisition. We found the four components of alpha ray originated from ^{218}Po, ^{214}Po and ^{210}Po of U series, and ^{212}Po of Th series, respectively.

We measured the radon concentration in atmosphere at domestic two measurement points at Okayama since 2022 and Kiyosumi since 2017, respectively. This time we investigated inhalation height dependence of air, and the relations between radon variation and weather (typhoon and precipitation). We tried to find relations between radon variation and nearby earthquakes. We also report some troubles, motor stop and sudden rise of radon intensity in observing radon variation.

We thank to Akitsugu Kitade, Kazuhide Nemoto, Haruna Kojima and Jyunpei Ohmura of Graduate school of Science, Chiba University for data collection at Kiyosumi.

Relationship between catfish activities and geophysical changes. (a preliminary report)

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The macroscopic anomaly associated with earthquakes is the natural unusual phenomenon that can be noticed without scientific instruments but by a naked eye or by an ordinary human sense, such as land deformation, rumbling, unusual behavior of wild animals, natural lightening, and so on. There have been a number of reports on such phenomena from all over the world. However, sufficient scientific research is not going on them. In this study, we deal with the behaviors of a catfish for the research target, because a lot of reports on them have been published in the past as related with seismic events. There is required to be more research based on comprehensive zoological aspects such as animal behavior, ecology, physiology, psychology, and so on. The relationship between physical and chemical changes in earthquake precursor phenomena and the susceptibility of animals requires to be clarified. Therefore, we developed a method to quantify catfish behavior using a special aquarium and CCD camera system. Secondly, Catfish behavior was classified as a behavior pattern composed of four elements: swimming trajectory, swimming time, swimming distance, and average swimming speed. As a result, we succeeded in comparing changes between detailed behavioral information and geophysical changes. We introduce very preliminary results of our observation and consider the future directions of the current work.

Physical mechanisms of induced and triggered seismicity: An implication for electromagnetic triggering of earthquakes

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Abstract

A new type of earthquake triggering has been discovered during the field experiments on electromagnetic monitoring of the Earth crust resistance at the Pamir and Northern Tien-Shan regions where DC current of 0.6-3.5 kA has been injected into the crust through the grounded dipole of 4.2 km length. The spatiotemporal variation of regional seismicity just after the DC current injection has been found, that may be explained by triggering of weak earthquakes around the dipole due to interaction of electromagnetic field with stressed rocks [1]. The observed field data were confirmed in laboratory experiments at the press and shear machines, when it was demonstrated that DC current injection into the tested rock sample is resulted in sharp increase of acoustic emission (crack formation) followed by the sample failure, as well as in triggering of laboratory "earthquakes" at the spring-block models of seismogenic fault. Nevertheless, the mechanism of electromagnetic earthquake triggering is still poorly understood that prevents the practical application of obtained results to earthquake hazard mitigation based on earthquake control or short-term prediction.

In this connection we analyze various physical mechanisms of well-studied cases of induced and triggered seismicity for their possible application to explain the electromagnetic phenomena of earthquake triggering. As a possible candidate of a mechanism of electromagnetic/electric triggering of earthquakes we consider the Joule heating of porous fluid-saturated rocks during DC current flow through the rocks resulted in increase of fluid pore pressure and corresponding decrease of efficient rock strength followed by a rupture of the fault when it is in subcritical strain-stress state. For verification of this hypothesis, we carried out the laboratory experiments at the specialized press, where the increase of the sample deformation rate is observed during electrical processing of the sample. The experimental results are compared with numerical data calculated by COMSOL Multiphysics© software, which indicate the clear pore pressure increase due to DC current impact.

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Studies of seismo-electromagnetic and seismo-ionospheric effects at Kamchatka

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According to the threat of natural disasters, Kamchatka is one of the most dangerous regions of the world. Only during the lifetime of the current generation, many strongest earthquakes with M=6.6-9.1 occurred in this region. There is no doubt that natural disasters in Kamchatka will continue to occur with a high frequency. The Geophysical Survey of the Russian Academy of Sciences operates >40 years on the territory of Kamchatka (http://www.emsd.ru). The system of real-time observations includes: 80 seismic stations; 27 stations for measuring deformations of the earth's crust using GPS receivers; 13 wells and bore-holes equipped with automatic systems for recording pressure, temperature, electrical conductivity of groundwater; 6 sites for registration of subsoil gases and meteorological parameters; 6 points for measuring the atmospheric electric field; amplitude-phase characteristics of VLF signals from 10 radiopaths; and 2 stations of electromagnetic observations. By the breadth and complexity of geophysical observations in a seismically active region, the Kamchatka testing ground is one of the leading in the world. Work at the testing ground is carried out by seismologists, specialists in hydrogeochemistry and fluid dynamics, experts in radioactive emanations, atmospheric electricity, atmospheric and ionospheric physics, and electromagnetic ULF-ELF emissions. In addition, leading researchers of the Institute of Physics of the Earth (https://ifz.ru/) are involved in the work. This allows one to set the fundamental problems of the physics of the lithosphere-atmosphere-ionosphere interactions during catastrophic events using data from this international prognostic testing ground. A synergistic approach is used, including both theoretical modeling and analysis of long-term multi-instrumental observational data. There are not so many places in the world where forecasting polygons are deployed. But no matter how well these polygons are equipped, there are no guarantees that these observations will enable us to assess the reliability of forecasting methods in the foreseeable future because no one can guess where and when a seismic event will occur. In this talk we present a brief review of recent observational and theoretical results obtained at Kamchatka testing ground.

Criticality analysis of the VLF recordings prior to two strong earthquakes that happened in central Greece on March of 2021

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Abstract

In this paper we investigate two strong earthquakes (EQs) which sequentially occurred on 3 and 4 March of 2021 in Central Greece, the epicenters of which were located on land [M6.3 occurred on 3 March 2021, 10:16:09 (UT), depth 8.0 km, at (39.755°N, 22.176°E), and M5.8 occurred on 4 March 2021, 18:38:19 (UT), depth 10.0 km, at (39.787°N, 22.116°E)]. We present the criticality analysis of the very low frequency (VLF) subionospheric propagation data acquired by a recently installed VLF receiver which is located at the University of West Attica in Athens (Greece). Specifically, we applied the method of critical fluctuations (MCF) analysis to the raw nighttime amplitude recordings from multiple transmitters, detecting power-law behavior for the laminar lengths' distributions of specific time windows recorded prior to each of the abovementioned EQs, with power law exponent values that imply criticality. Further analysis of the specific time windows, with the use of the autocorrelation function (ACF), proved that these time windows are also characterized by high ACF values persisting for long time. Our findings reveal that the ionosphere was indeed in critical state before each of the studied EQs.

The Response of Geomagnetic Daily Variation and Ionospheric Currents to the Annular Solar Eclipse on 21 June 2020

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According to the ampere's law, the geomagnetic variations caused by the ionosphere current can detect the ionosphere electrodynamic process during a solar eclipse. Due to the lack of observation, the previous research on the geomagnetic effect of solar eclipse focused on the range of one or several geomagnetic stations, which makes the latitude and local variation characteristics of the geomagnetic effect and the corresponding ionosphere electrodynamics process are not totally studied. The annular solar eclipse on June 21,2020 passed through China during the daytime, and the regional high density observation of the Geomagnetic Network Center of China, Institute of Geophysics, China Earthquake Administration and International Real-time Magnetic Observatory Network provides a good opportunity for the study of this issue.

In this work, we studied the latitude and local time dependences of the geomagnetic-solar eclipse effect of the June 21,2020 annular eclipse event in China and the neighbour areas, and analyzed the electrodynamics process of the ionosphere. The results are as follows:

1. The eclipse weakens the intensity of three components for the geomagnetic daily variations. Amongthem, the effect of the north-south component ΔX has a clear latitude dependence, that is, the decrease of intensity significantly below the center of the Sq current vortex and is slightly weaker above the focus, while the eclipse effect of ΔX near the center of the current vortex is almost absent. In addition, the effect of the east-west component ΔY increases as latitude decreases and the eclipse obscuration rate increases .
2. The eclipse effect of ΔY along the totality from noon to afternoon shows a local time dependent, whilethe eclipse effect of ΔX component is not so regular like ΔY, it is roughly stronger from early afternoon to early afternoon than that in the late afternoon. The eclipse effect of the vertical component ΔZ was weak, mainly in the early afternoon period on the totality path.
3. The eclipse effects of the geomagnetic daily variation simulated by the TIEGCM are generally consistentwith those by the ground magnetometer data. It was demonstrated that the ionospheric current system caused by the eclipse has a counter-Sq pattern and thus weakens the background Sq current system.

Keywords: Geomagnetic Daily Variation, Ionospheric Currents, Solar Eclipse

Multi-sensor monitoring network for earthquake precursor study near subduction zone at Boso, Japan

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New observations from ground and space have provided multiple evidences of pre-earthquake signals and the latest studies show their statistical significance, repeatability, and universality. In this project, to understand the preparation process of large earthquakes and slow-slip events in subduction zone, especially to clarify the nucleation stage of the earthquake cycle, we plan to establish a dense observation network in Boso, Japan, where large subduction earthquakes are expected soon. Since the subsurface fluid flow may play an important role in the preparation process of subduction activities, we intend to employ electromagnetic approaches including oceanic and continental MT survey to monitor the underground resistivity structure which is sensitive to the dynamics of fluid. Other geophysical monitoring such as ULF geomagnetic and geoelectrical observations, radon measurements, and inland GPS movements, TIR, and OLR will be incorporated to help to understand the preparation process and evaluate the applicability of various pre-earthquake signals towards short term earthquake forecasting. We call this idea “sensor WEB”. We will show the state of the art and some results in our presentation.

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ROC Analyses to Assess Pre-earthquake Information in Ionospheric Electron Density Data Observed by Ionosonde, at Kokubunji, Japan

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Recently, ionospheric anomalies related to earthquakes have been reported and are considered promising for short-term earthquake forecast. In Japan region, the previous statistical studies on GNSS-TEC and Ionosonde show a statistically significant correlation between sizable earthquake and TEC anomaly about 0-5 days before the earthquake. Similarly, regarding the NmF2 by ionosonde, there is a significant correlation between them on 1-10 days before the earthquakes with M<6, depth D<40 km, epicenter distance R<350 km. Here, NmF2 indicates the maximum electron density in Ionosphere.

In this paper, we assess the effectiveness in short-term earthquake forecast using the NmF2 data during 1958-2019. In this study, we used ionosonde data observed at Kokubunji (35.71N, 139.49N), Japan, operated by the National Institute of Information and Communications Technology (NICT).

We defined the anomaly of NmF2 as the value in excess of 15 days backward median + 1.5 IQR of the NmF2 at the same time hour in the previous 15 days. And we define the anomalous day as ten or more hours of the anomalies appear in one day.

Then, we performed Molchan's Error Diagram (MED) analysis to evaluate the efficiency of NmF2 anomalies for earthquake forecasting. MED analysis is very similar to ROC (receivers operation characteristic curve) approach. The MED results show that NmF2 anomalies contains a precursor information and the tendency is clearer for the shallower, the larger, and the closer earthquakes. Using MED analysis, we can estimate the optimum parameters of earthquake detection; lead time T, alarm window L, earthquake magnitude, hypocenter depth, epocentral distance from the ionosonde. The result indicated that the forecast is most efficient when M>6.4, D<20 km, R<200 km, T=10, L=1.Using these parameters, it is found that about 46% of targeted earthquakes can be successfully detected.

Soil radon concentration analysis by multi-channel singular spectrum

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Recently, there are many papers on electromagnetic pre-earthquake phenomena such as geomagnetic, ionospheric, and atmospheric anomalous changes. Ionospheric anomaly preceding large earthquakes is one of the most promising phenomena. Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model has been proposed to explain these phenomena. In this study, to evaluate the possibility of chemical channel of LAIC by observation, we are developing soil and atmospheric Rn observations using an α-ray detector in Chiba-Ibaraki area to investigate the relationship between earthquakes and Rn emissions from the ground. We have installed sensors for atmospheric electric field, atmospheric ion concentration, atmospheric Rn concentration, soil radon Rn concentration (SRC), and weather elements, Since the atmospheric electricity parameters are very much influenced by weather factors, it is necessary to remove these effects as much as possible. In this aim, we apply the MSSA (Multi-channel Singular Spectral Analysis) to remove these influences from the variation of SRC and estimate the soil Rn flux (SRF). We investigated the correlations (1) between SRF and precipitation and (2) between SRF and the local seismic activity around Asahi station. The preliminary results show that SRF was significantly increased by heavy precipitations of 20 mm or more in total for 2 hours. We proposed two types of models, a rainwater load model and a rainwater infiltration model, and it is appropriate for both models to work and (2) between SRF and local seismicity within an epicenter distance of 50 km from the station.

A development of signal discrimination method using Multi-channel Singular Spectrum Analysis (MSSA) for ULF band electromagnetic data, in Boso, Japan

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An electromagnetic phenomenon associated with crustal activity in the ULF band ($f < 10$ Hz) is expected as a method that can detect the signal directly from the intra-crust or plate boundary. However, the observed signal includes not only the earthquake-related signal but also the solar-origin signal and artificial noise, such as the leak current from the DC-driven train. Detection of the signal is difficult because the amplitude of the earthquake-related signal is tiny compared with the other noises, and the waveform of the signal is similar to the artificial noise. Recent analyses were performed in a noiseless environment, such as the region far from the city area, and at night-time to escape this problem. However, by this scheme, we miss detecting the signal that occurs in the daytime. The new signal discrimination method is essential to increase the chance of detecting the signal in the daytime.

We are developing a new signal discrimination method based on Multi-channel Singular Spectrum Analysis (MSSA) to overcome this problem. MSSA is the extension of Singular Spectrum Analysis (SSA), resulting in MSSA can decompose multiple time series to several principal components (PCs). Then, choosing and summing arbitrary PCs with some threshold, such as correlation and contribution ratio of the PCs, the time series can be discriminated into the signal and noise parts.

In the MSSA-based signal discrimination method developed in this study, remove solar-origin signals from 7ch data (target site 5 components (horizontal magnetic field 2ch (Hx and Hy), vertical magnetic field 1ch (Hz), and horizontal electric field 2ch (Ex and Ey)) and reference site 2ch (magnetic field 2ch (Rx and Ry))), then, obtain a local signal. After applying this method to actual data acquired on the Boso Peninsula for signals with a period of less than 400 s, the solar-origin signal was removed, and a local signal of about 1 nT for the magnetic field and about 2 mV/km for the electric field was detected. This presentation will focus on the performance and effectiveness of the method.

A Study of the ULF seismo-magnetic phenomena in Kakioka, Japan, during 2015-2020

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Abstract:

To mitigate earthquake disasters, the establishment of the short-term earthquake forecast technique is important. To achieve this, the ultra-low frequency (ULF) geomagnetic field changes has been studied and statistical significance in correlation and precursor characteristics in ROC analysis have been presented, It means that the ULF geomagnetic measurement has a potential parameter for the short-term earthquake forecast. In previous studies, the data observed Kakioka station during 2001-2010 operated by JMA has been utilized. In order to clarify ULF seismo-magnetic phenomena, we have studied the geomagnetic data observed at the Kakioka (KAK) station, Kanto, Japan, during 2015-2020. The magnetic data and earthquake catalogs obtained from Japan Meteorological Agency. The same approach with the previous studies have been performed, To select earthquakes, we use the Es parameter which considers the magnitude and distance of an earthquake simultaneously to select statistical samples. As the frequency of original geomagnetic data is 1Hz, the method of wavelet transform was implemented, and extract the signals at the frequency around 0.01Hz. Ground-based ULF geomagnetic data are a superposition of several signals: global magnetic perturbations, artificial noises, and magnetic signals possibly due to underground activities. To minimize artificial noises, we selected the midnight time data (JST 1:30-3:30). And to reduce the influence of global magnetic perturbations, the station Kanoya (KNY) was chosen as reference station. Then the statistical method of superposed epoch analysis (SEA) was adopted to highlight the weak but significant signal from noisy data. Finally, to verify the usefulness of the prediction model compared with random prediction. We evaluated the precursory information of ULF geomagnetic signals for local sizable earthquakes using statistical method receiver operating characteristic (ROC) curve. In ROC curve, the closer to the upper left corner, the better performing for this prediction model.

Keywords: ULF electromagnetic phenomena, Superposed Epoch Analysis(SEA), Molchan's Error Diagram

Development of an LF-band broadband interferometer to identify LF-band signals related to earthquakes

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Recently, there have been reports of earthquake precursor phenomena related to the LF band. To develop an LF-band broadband interferometer capable of spatio-temporal estimation of LF-band electromagnetic wave sources, we started LF-band electromagnetic wave observations using interferometer elements on the rooftop of Chiba University. First, we conducted a waveform and pulse count survey using one interferometer element and detected an increased number of pulses before the earthquake which is unlikely to be caused by cloud to ground discharge and typical waveforms during the time. We also evaluated the performance of three interferometer elements as an interferometer system and found that the synchronization system needs to be improved.

Study on Volcanic Activity of Mt. Shinmoedake in 2018 Using Himawari AHI Data

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Ground-based volcano monitoring is not possible for all active volcanoes due to topographical restrictions and cost. On the other hand, volcanic activities that cause lava eruptions or eruptions that cause significant human and economic damage are usually accompanied by an increase in surface temperature, making satellite remote sensing effective for temperature monitoring. Therefore, we have been developing algorithms to detect temperature anomalies associated with volcanic activities (especially for monitoring lava activities that cause serious damage to human lives and predicting pyroclastic flows) by spatiotemporal analysis of ground surface temperature around volcanoes using thermal infrared nighttime data on board artificial satellites. As a result, Noguchi et al. (2004) demonstrated the effectiveness of monitoring volcanic activity in the tropics1 using nighttime infrared data from the MODIS sensor onboard the Aqua/Terra satellites, and Tsutsumi et al. (2020) showed that the appearance of a lava dome on the 2011 eruption of Mt.shinmoe In a similar analysis to Tsutsumi et al. (2020) for the eruptive activity of Mt. Shinmoe in 2018, an anomalous rise in surface temperature associated with the appearance of a lava dome was detected, but the anomalous rise in surface temperature was not detected visually or by SAR data. The reason for this may be that the summit area was covered by clouds at the time of the satellite observations, which prevented observation of the ground surface. There are two possible means of measuring surface temperatures in consideration of cloud effects: using satellite-observed microwave data and increasing the frequency of observations at target locations using geostationary meteorological data to increase the number of cloud-free observations. The former is promising, but requires a large footprint, since microwaves can penetrate clouds. The latter is promising, but the footprint becomes large. The latter is affected by clouds, but the observation frequency is every 10 minutes (2.5 minutes near Japan) (in the case of Himawari No. 8-9).

Therefore, by using thermal infrared data from the Himawari-8 satellite, which has a higher temporal resolution, we conducted a research study to contribute to the detection of surface temperature anomalies associated with magma eruptions and the appearance of lava domes, and to their detection as early as possible. As a result, we were able to confirm the temperature anomaly several hours before the eruption occurred.

Characteristics of Spatio-Temporal variation of b-values with statistical assessment and GNSS-based strain : Application to the 2016 Kumamoto and the 2011 Tohoku earthquake

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The frequency-magnitude distribution of earthquakes is expressed by the Gutenberg-Richter Law, in which a critical parameter is the b-value. The results of previous studies show that the b-value portrays not only the quantitation relationship between different earthquakes but also its magnitude negatively correlates with the regional stress level. In particular, the b-values show apparent precursor anomalies before some large earthquakes. But objectively judging their relevance to earthquakes is difficult. In order overcome this, we are developing evaluation methods that introduced the Akaike information criterion (AIC) and GNSS-based strain. Regarding the former, AIC, we investigate the difference dAIC between AIC over reference period and that of studied period. For the latter, GNSS-based strain, the correlation between monitoring strain anomalies and major local earthquakes has been verified in recent years.

Therefore, this paper analyzes the characteristics of the b-value and GNSS-based strain network related to the 2016 Kumamoto and the 2011 Tohoku earthquakes to examine whether there are any anomalies in the occurrence of large earthquakes. The results will be shown in the presentation.