9th International Workshop on

Earthquake Preparation Process

~ Observation, Validation,

Modeling, Forecasting ~

Program & Abstracts

IWEP9

May 27 – 28, 2025

Chiba University, Chiba, Japan

9th International Workshop on Earthquake Preparation Process

~ Observation, Validation, Modeling, Forecasting ~ (IWEP9)

Sponsor:

- Chiba University, Japan

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- Center for Astronautical Physics and Engineering (CAPE), National Central University, Taiwan
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- Earthquake Prediction Society of Japan
- Electromagnetic Studies of Earthquakes and Volcanoes (EMSEV)
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Date: May 27 – 28, 2025

Venue: Room 101 & 102, the 1st floor of University Library / Academic Link Center Building I, Nishi-Chiba Campus, Chiba University, Chiba, Japan

Contacts: Dr. Katsumi Hattori (Chiba University, Japan)

khattori@faculty.chiba-u.jp +81-43-290-2801

Attention :

・As a general rule, eating and drinking are prohibited at the venue and inside the venue building.

・However, drinks that can be put in a lid, such as plastic bottles or thermoses, are OK.

・Therefore, please note that there will not be a kettle (hot water) provided at the venue.

・Please eat foods at the school cafeteria or other facilities.

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Program

May 27, 2025 Morning

*The building entrance opens at 8:35.

0835-0900 *Registration*

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0910-0940 **Shih-Sian Yang** et al., Exploring the existence of pre-seismic atmospheric gravity wave activity before major shallow earthquakes in Japan and Taiwan: 2024-2025

0940-1010 **Yongxin Gao** et al., Simulation of the acoustic gravity waves generated by a seismic source in the solid earth. (*invited*)

1010-1030 **Zhiqiang Mao** et al., Geomagnetic disturbances of 2024 Hualien earthquake

1030-1050 **Donghua Zhang** et al., Study on Seismic Anomaly Extraction of Swarm Satellite Magnetic Field Data Based on Complex Non-negative Matrix Factorization

1050-1110 **Baiyi Yang** et al., Spatiotemporal evolution characteristics of outgoing longwave radiation (OLR) anomalies before the 2021 Ms7.4 Madoi earthquake

1110-1140 **Hong-Jia Chen**, Investigating the Correlation Between Geoelectric Signals and Seismic Activity: Cases from Hualien and Chiayi, Taiwan

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May 27, 2025 Afternoon

Chair: Dr. Peng Han

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1300-1320 **Yiqun Zhang**, Incorporating Non-Seismic Precursors into Earthquake Probabilistic Forecasting Model

1320-1340 **Wenchao Li** et al., Incorporating Seismo-Magnetic Precursor Anomalies into ETAS Model for Earthquake Forecasting

1340-1440 Poster session 1

Chair: Dr. Peng Han

1440-1510 **Yuanyuan Zhou**, A Multi-Source Precipitation Fusion Model Based on Broad Learning System: A Case Study of Yunnan Province, China

1510-1540 **John B. Rundle**, Nowcasting Earthquakes with QuakeGPT, an AI-Enhanced Model: Methods, Information Content, First Results, Future Directions (*invited*)

1540-1550 *Break Time*

Chair: Dr. Katsumi Hattori

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1620-1650 Yoichi Noda, **Katsumi Hattori** et al., Development of GNSS-based pseudo-strainmeter; preliminary study for the 2016 Kumamoto earthquake (Mj7.3), Japan - temporal and spatial analysis in Kyushu -

1650-1720 **Josaphat Tetuko Sri Sumantyo**, Establishment of an Interdisciplinary Hub for AI Disaster Mitigation and Sustainability (*invited*)

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May 28, 2025 Morning

*The building entrance opens at 8:35.

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0920-0940 **Chinatsu Sasanuma** et al., Statistical significance and Molchan's Error Diagram analyses for long-term Ionosonde data from 1958-2024 at Kokubunji, Japan

0940-1000 **Ting Li** et al., Ionospheric disturbances observed over China after 2022 January 15 Tonga volcano eruption

1000-1030 **Rui Song** et al., The three-dimensional ionospheric electron density disturbances following the 2011 M9.0 Tohoku-Oki earthquake in Japan

1030-1100 **Tiger Jann-Yenq Liu** et al., Lessons learned from ionospheric precursors of the 21 September 1999 M7.7 Chi-Chi Earthquake (*invited*)

1100-1130 **Kosuke Heki** et al., Ionospheric changes immediately before the 2025/3/28 Myanmar Eq. (*invited*)

1130-1210 **Lunch*

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1340-1400 **Nagisa Sone** et al., Fright Model and Mission Concept of the W6U PRELUDE CubeSat for Seismic Ionospheric Disturbance Observation

1400-1420 **Ryoma Miura** et al., Design and Development Status of the Instrument Unit of PRELUDE for Observing Pre-Earthquake Ionospheric Disturbances

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1440-1510 **Yuji Enomoto**, Towards the Forecast and Prevention of Earthquake-Induced Methane Geohazards: A Survey of the Large-Scale Fire in Wajima City following the 2024 Noto Peninsula Earthquake (*invited*) [*online*]

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Posters

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P2: **Shu Kaneko** et al., A development of signal discrimination method using Multi-channel Singular Spectrum Analysis (MSSA) for ULF band electromagnetic data, in Boso, Japan (3)

P3: **Yuichiro Ota** et al., Development of VLF/LF interferometer using capacitive circular flat-plane antenna and signal discrimination / identification by machine learning: Preliminary Result

P4: **Kento Enomoto** et al., Statistical Analysis of GIM-TEC Anomalies Associated with large earthquakes (M>7) during 2000-2024

P5: **Kiyotaka Ninagawa** et al., Continuous radon measurement in atmosphere in Japan

P6: **Shiori Fukunaga** et al., The Fluctuations of the Soil Radon Fluxes at Two Different Depths at Asahi Station, Japan

P7: **Katsumi Hattori** et al., Formation of interdisciplinary hub for AI disaster mitigation and sustainability studies

P8: **Chie Yoshino** et al., Multi-sensor monitoring network for earthquake precursor study near subduction zone at Chiba University, Japan

P9: **Yoichi Noda** et al., Development of GNSS-based pseudo-strainmeter; preliminary study for the 2016 Kumamoto earthquake (Mj7.3), Japan - temporal and spatial analysis in Kyushu -

P10: **Haruki Ariizumi** et al., Monitoring groundwater flows with using 3D self-potential tomography

P11: **Chinatsu Sasanuma** et al., Statistical significance and Molchan's Error Diagram analyses for long-term Ionosonde data from 1958-2024 at Kokubunji, Japan

P12: **Wenchao Li** et al., Incorporating Seismo-Magnetic Precursor Anomalies into ETAS Model for Earthquake Forecasting

P13: **Shuangshuang Li** et al., Development and testing of long-term high stability solid non-polarized electrode

P14: **Shuangshuang Li** et al., Lithological controls on infiltration and failure characteristics of rainfall-induced landslide: experimental study of slopes in northern Guangdong, China

P15: **Xiaocan Liu** et al., North-South asymmetry of Sq variations at geomagnetically conjugate area

P16: **Kuan-Yu Lee** et al., Responses of Seismo-ionospheric Precursors in the Total Electron Content to Earthquake Magnitude and Depth in Taiwan and Japan during 1999–2024

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 27 and 28.

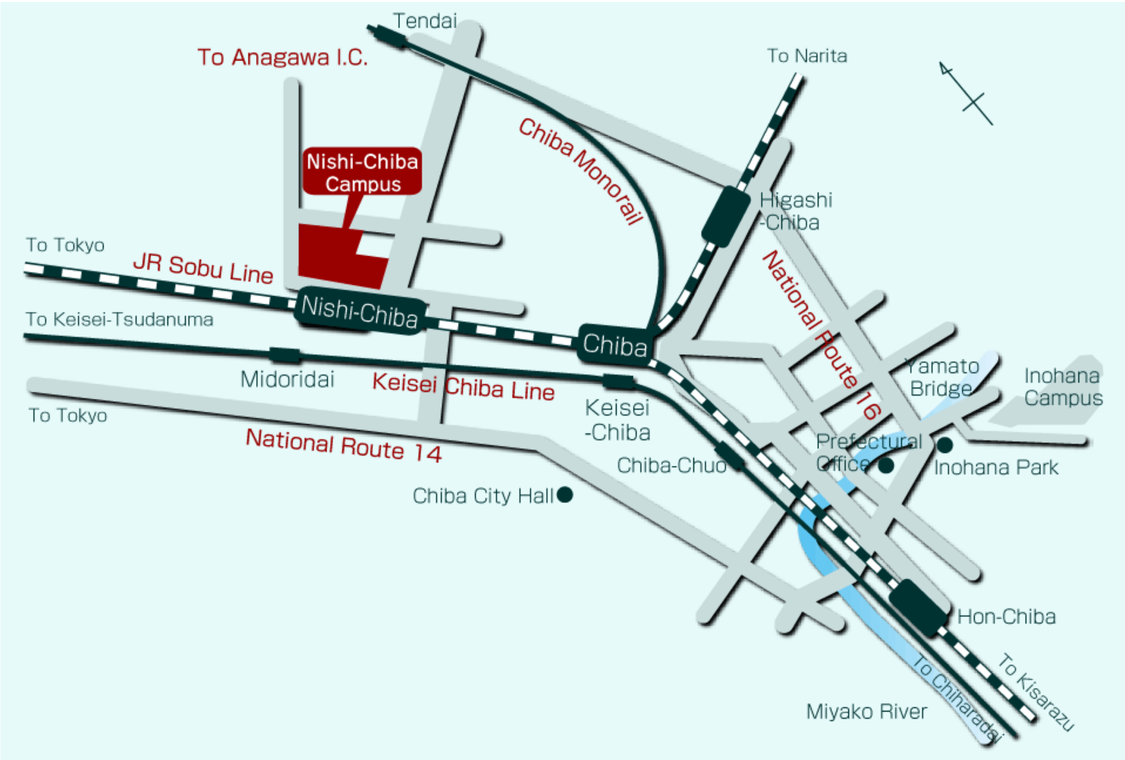
Welcome Party:

Welcome party will be held from 18:30 on May 27, 2025 at " The Italian bar ROMERO at Nishi-Chiba Station ", near JR Nishi-Chiba station (5 minutes by walk). The price will be 8,000 JPY per person (3,000 JPY for a student).

" The Italian bar ROMERO at Nishi-Chiba Station "
https://romero.owst.jp/en/

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



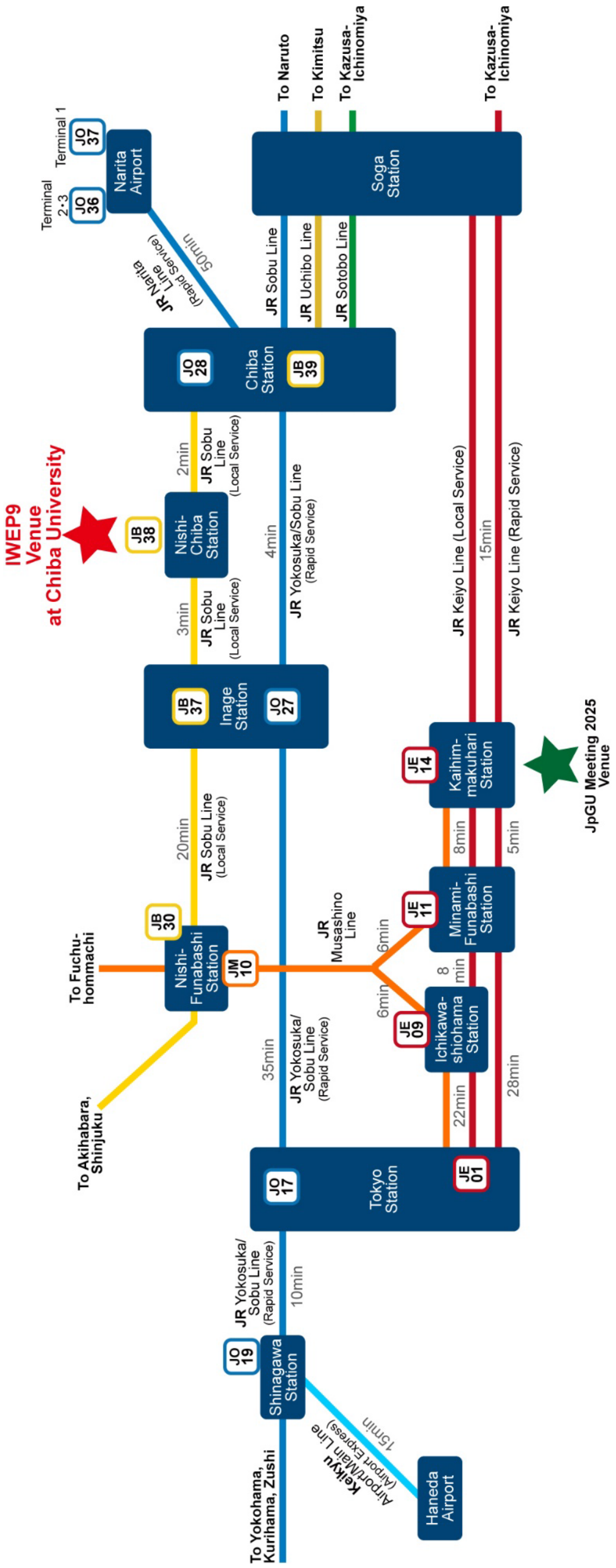
JR Tokyo	35min, 8 Stations, JR Sobu Line (Rapid Service)	JR Inage	3min, 1 Station, Sobu Line (Local Service)	JR Nishi-Chiba

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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JpGU Meeting 2025
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JR Sobu Line
(Local Service)
Inage Station
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8 min
To Fuchu-hommachi
Nishi-Funabashi Station
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JM 10
Ichikawa-shiohama Station
JE 09
To Akihabara, Shinjuku
35min
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22min
28min
Tokyo Station
JO 17
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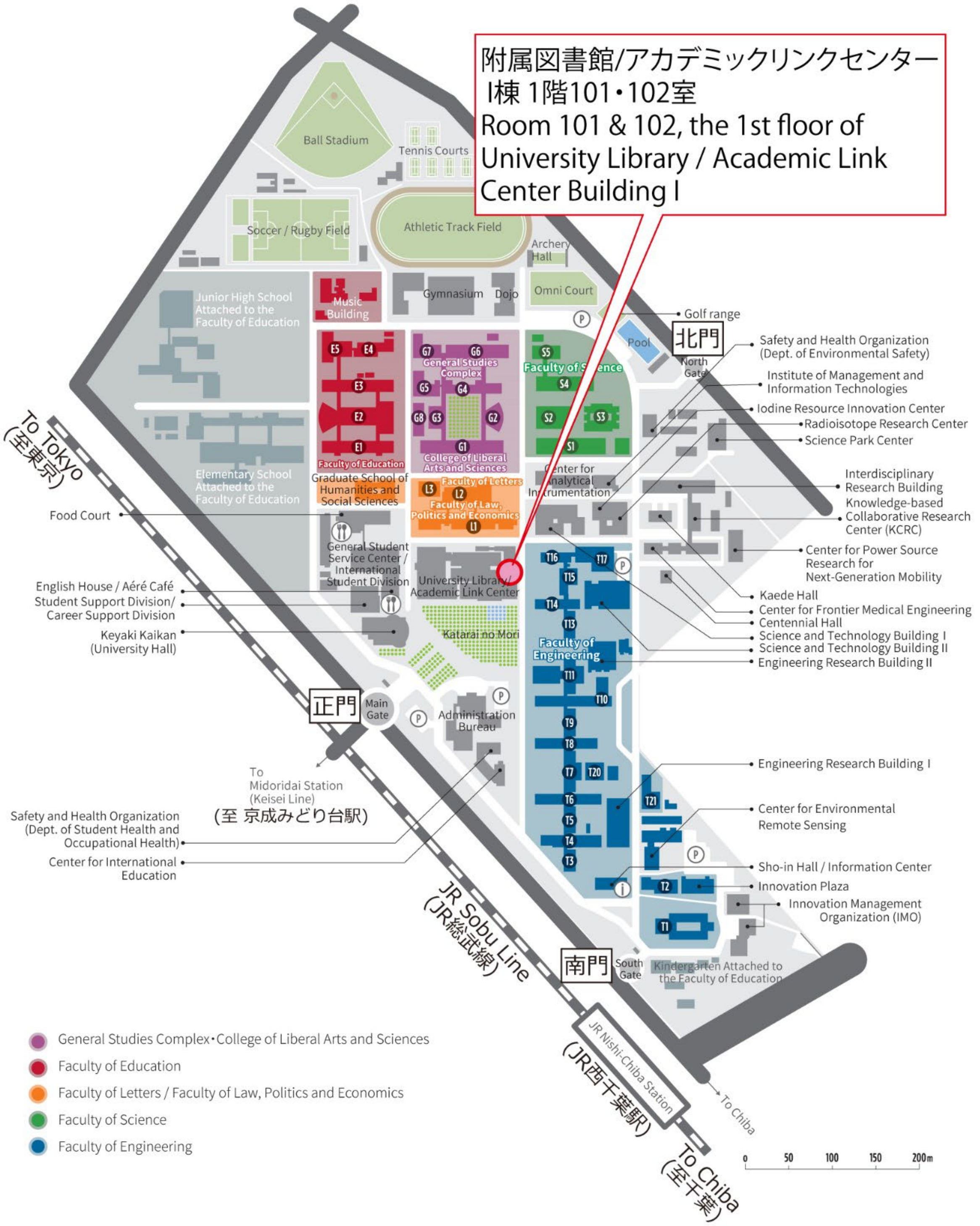

- General Studies Complex・College of Liberal Arts and Sciences
- Faculty of Education
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- Faculty of Engineering

Abstracts of oral presentations

Exploring the existence of pre-seismic atmospheric gravity wave activity before major shallow earthquakes in Japan and Taiwan: 2024–2025

Shih-Sian Yang[1], Sudipta Sasmal[2], Stelios M. Potirakis[3,4], and Masashi Hayakawa[5,6]

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[6] Advanced Wireless and Communications Research Center, UEC, 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan

In the past decades, several hypotheses have been proposed to explain the mechanisms of lithosphere-atmosphere-ionosphere coupling (LAIC) processes, and a promising candidate is the atmospheric gravity wave (AGW) hypothesis. Previously, we found pre-seismic anomalies of AGW activities before the 2016 Kumamoto and 2011 Tohoku earthquakes, supporting the AGW hypothesis of the LAIC processes. However, we also found that the AGW channel was absent during the preparation periods of some major earthquakes. A further survey is needed to determine the possible factors that control the effectiveness of the AGW channel. Therefore, we have initiated a project to routinely explore the existence of the AGW channel before some major shallow (depth ≤ 50 km) earthquakes occurred in Japan and Taiwan, and the progress of this project will be updated in IWEP every year. Our presentation this year surveys four new earthquakes, including the 17 April 2024 Bungo Channel earthquake (Mj 6.6), the 8 August 2024 Hyuga-Nada earthquake (Mj 7.1), the 26 November 2024 Ishikawa Offing earthquake (Mj 6.6), and the 13 January 2025 Hyuga-Nada earthquake (Mj 6.6). The follow-up of two old cases, the 2024 Noto Peninsula earthquake (Mj 7.6) and the 2024 Hualien earthquake (Mw 7.4), will also be presented. A preliminary result of the 2025 Myanmar earthquake, which was the most disastrous earthquake in the world in the past year, will be reported in this presentation as well, though the earthquake did not occur in the Japan–Taiwan region.

Simulation of the acoustic gravity waves generated by a seismic source in the solid earth.

Yongxin Gao[1], Ting Li[1], Junzhe Zhang[2]

1. School of Civil Engineering, Hefei University of Technology, Hefei, 230009, China;

2. Department of Astronautics and Mechanics, Harbin Institute of Technology, Harbin, China

Ground motion generated by seismic source can trigger acoustic gravity waves, which propagate upward to the ionosphere and cause the coseismic ionospheric disturbances, leading to the so called Lithosphere-atmosphere-ionosphere (LAI) coupling phenomenon. Forward modeling is a useful tool to understand the excitation and propagation properties of the acoustic waves. In this study, we present analytical methods to calculate AGWs excited by a seismic source in the stratified lithosphere-atmosphere models, including the horizontally and spherically stratified models. and conduct numerical simulations to investigate characteristics of the AGWs. The results show that Four kinds of AGWs can be generated by the seismic source. One is the head acoustic wave generated by the Rayleigh wave propagating along the surface, which propagates upwards nearly vertically. The second one is the epicenter acoustic generated by the direct seismic waves from the source. Both the head and epicenter acoustic waves are sensitive to the earthquake focal mechanism and are influenced by the structures of the atmosphere and solid earth. The third one is the gravity waves generated at the epicenter. The acoustic waves exist for high frequency while the gravity waves lie in the low frequency. The fourth one is the Lamb wave that propagate along the earth surface. The simulations based on the spherically layered model shows that the Lamb wave can propagate around the earth by several times. We apply our method to a real earthquake event and the Tonga volcano eruption and the synthetic signals agree well with the observed data.

This work is supported by National Natural Science Foundation of China (grants 42174084).

Key Words: Seismic source, Acoustic gravity waves, Lithosphere-atmosphere-ionosphere coupling, analytical simulation

Geomagnetic disturbances of 2024 Hualien earthquake

Zhiqiang Mao[1,2] and Chieh-Hung Chen[2]

1. School of Geophysics and Geomatics, China University of Geosciences
2. State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology

On 2 April 2024, a magnitude 7.4 earthquake struck Hualien, which is the largest seismic event in the Taiwan region since the 1999 Chi-Chi earthquake. This study investigates the geomagnetic responses to the Hualien earthquake across varying epicentral distances. In the near field, simultaneous magnetic perturbations were observed at stations surrounding the epicenter. These disturbances occurred approximately six minutes after the earthquake, consistent with the expected travel time of acoustic waves from the ground to the ionosphere. Furthermore, opposite-phase variations in the Z component suggest the presence of ionospheric electric currents. In the far field, additional magnetic disturbances were detected several minutes after the arrival of Rayleigh waves, with a propagation velocity comparable to that of the Rayleigh waves themselves. These disturbances are attributed to acoustic waves generated by Rayleigh wave, which modulate ionospheric conductivity. Both types of post-seismic geomagnetic variations are linked to acoustic wave propagation, yet they exhibit distinct characteristics: near-field disturbances occur nearly simultaneously at different stations, while far-field responses display time delays. Our findings indicate that different physical processes govern near-field and far-field post-seismic geomagnetic effects, highlighting the importance of distinguishing between them in future studies.

Study on Seismic Anomaly Extraction of Swarm Satellite Magnetic Field Data Based on Complex Non-negative Matrix Factorization

Donghua Zhang[1], Kaiguang Zhu[1], Yiqun Zhang[1], Baiyi Yang[1], Ting Wang[1], Wenqi Chen[1], Pu Wang[1], Yuqi Cheng[1]

1.College of Instrumentation and Electrical Engineering, Jilin University, Changchun, China, 130061

To obtain earthquake-affected signal from the satellite observed data in the ionosphere, it's necessary to avoid the influence of global disturbances in complex space environments of the ionosphere, such as geomagnetic disturbances. However, earthquake-affected signal and global disturbances possibly overlap frequency bands, which makes it difficult to separate them using frequency domain decomposition methods. Therefore, we use the magnetic field data of Swarm Alpha during the M7.8 Ecuador earthquake that occurred on April 16, 2016. Based on the spatial differences between global disturbances and local seismic anomalies, matrix factorization methods are used to obtain the local features that are possibly related to earthquakes from the observation data to avoid the impact of global disturbances. Compared to the traditional solution that only uses observation data from low geomagnetic level periods, this method improves the utilization of data. Meanwhile, as seismic information exists in both the amplitude and phase of the magnetic field, complex nonnegative matrix factorization in matrix factorization methods is selected to separate global disturbances and earthquake-affected signal in complex domain magnetic field data improving the utilization of magnetic field information, thereby enhancing the accuracy of identifying earthquake-affected signal. This method decomposes the observed data into three components, extracts anomalies from the three components, and accumulates the anomalies over time. It is found that the cumulative curve of one component has a strong correlation with the cumulative Benioff strain curve, showing a trend of accelerated growth before the earthquake and slow growth after the earthquake, indicating that this component is likely to be an earthquake-related signal.

Keywords: Complex non-negative matrix factorization, precursors, Swarm satellite magnetic field data, 2016 Ecuador earthquake

Spatiotemporal evolution characteristics of outgoing longwave radiation (OLR) anomalies before the 2021 Ms7.4 Madoi earthquake

Baiyi Yang, Kaiguang Zhu, *Member, IEEE*, Ting Wang, Donghua Zhang, WenQi Chen, Yiqun Zhang, Pu Wang and Yuqi Cheng

Abstract—OLR anomalies before large earthquakes have been widely detected. In current research, the identification of seismic-related anomalies predominantly relies on uniform thresholds (e.g., $k * \sigma$), which lack adaptability to background variations and sensitivity to subtle anomalies. In this study, we propose a gradient-based adaptive thresholding anomaly extraction method (GAT-AEM) to investigate the spatiotemporal variations of outgoing longwave radiation (OLR) anomalies before the 21 May 2021 Madoi earthquake. First, to establish a stable background field and minimize disturbances from complex surface conditions and weather activities, we constructed a regionally divided sliding monthly mean OLR background field. Then, OLR anomalies spanning the period from 90 days before to 60 days after the seismic event were extracted using the GAT-AEM. The analysis revealed that: spatially, pre-seismic OLR anomalies demonstrated multiple migration processes from the study area periphery toward the epicentral region; temporally, the OLR anomalies exhibited multiple characteristic S-shaped accelerating increase patterns before the earthquake. Furthermore, the comparative spatiotemporal evolution of pre-seismic OLR anomalies with seismic activity revealed that the OLR anomalies correlated well with regional tectonic activity. Additionally, subsurface stress variations were further investigated through a comparison between OLR anomalies and average infrared radiation temperature (ARIT) variations from rock loading experiments. Finally, the possible sources of OLR anomalies and their coupling mechanisms were inferred through the integration of the spatiotemporal characteristics of multi-parameter anomalies before the seismic event.

Investigating the Correlation Between Geoelectric Signals and Seismic Activity : Cases from Hualien and Chiayi, Taiwan

Hong-Jia Chen
Department of Earth and Environmental Sciences, National Chung Cheng University, Taiwan

Seismo-electromagnetic phenomena represent a challenging yet promising frontier in geoscience research. Geoelectric signals have garnered significant attention as potential earthquake precursors. In seismically active regions such as Taiwan and Japan, long-term stable geoelectric monitoring provides a valuable means to explore possible coupling mechanisms between seismic activity and geoelectric variations. This study conducted a comparative analysis of geoelectric signals and seismic energy in two earthquake-prone regions of Taiwan, Hualien and Chiayi, to investigate their temporal and spatial correlations and the underlying physical mechanisms, thereby evaluating the potential application of geoelectric signals in earthquake forecasting.

Hualien, located at the Eurasian and Philippine Sea plate boundary, is characterized by high seismic frequency and intense tectonic activity. Chiayi, situated near the Chi-Chi and Meishan faults, exhibits lower seismic activity but retains considerable seismic risk, notably experiencing a damaging earthquake in 2025. Both regions are equipped with geoelectric monitoring stations, offering nearly a decade of continuous observational data for this study. The datasets utilized include earthquake catalogs from the Central Weather Administration and geoelectric data of north-south (NS) and east-west (EW) components recorded by the monitoring stations from 2014 to 2024.

Preliminary results reveal that in both Hualien and Chiayi, certain monitoring stations observed geoelectric anomalies, such as enhancements in lowfrequency power, and variations in skewness and kurtosis, several days to weeks before the occurrence of M5.0+ earthquakes. This study demonstrates that geoelectric signals under certain conditions may exhibit precursor characteristics, offering valuable insights for developing regional earthquake early warning models and advocating the necessity of long-term monitoring and interdisciplinary integration.

Keywords: Geoelectric signals; Seismic activity; Power spectrum; Statistical moments; Granger causality test

Seismicity Analysis In Yunnan Region And Its Application

Xinle Zhang[1], Rui Wang[1], Peng Han[1,2], Miao Miao[1,2], Ying Chang[3]

1. Southern University of Science and Technology, China;
2. Risks-X, SUSTech Academy for Advanced Interdisciplinary Studies, China;
3. Institute of Mining Engineering, BGRIMM Technology Group, China

Earthquake activity is frequent in Yunnan region, China. To assess the seismic hazard in Yunnan region, the paper applies three methods—Relative Intensity (RI), Pattern Informatics (PI), and Earthquake Nowcasting (EN)—to analyze the earthquake catalog of the region. First, retrospective studies are conducted using these methods to identify historically high-risk zones for destructive earthquakes in Yunnan region. Then, the evaluation results are tested statistically by actual seismic data, and the optimal parameters for each method are refined based on this analysis. Finally, by integrating the results from the three methods, the high-risk areas for large earthquakes in the Yunnan region over the next five years (January 2025–December 2029) are discussed. This study systematically analyzed and comprehensively compared the seismic hazard in Yunnan using three methods—RI, PI, and EN—and explored the high-risk seismic zones in the region over the next five years (January 2025–December 2029). The results of this research can provide technical support for seismic hazard assessment in Yunnan and serve as a reference for identifying large earthquake risk sources and implementing proactive earthquake disaster prevention measures.

Incorporating Non-Seismic Precursors into Earthquake Probabilistic Forecasting Model

Yiqun Zhang
College of Instrumentation and Electrical Engineering, Jilin University, China;
Institute of Statistical Mathematics, Japan

Increasing reports show that various non-seismic anomalies can be observed before strong earthquakes, such as changes in geomagnetic field or gas emission. Many of these anomalies have been statistically linked to earthquakes, suggesting their potential as precursors. However, additional forecasting information provided by non-seismic signals beyond clustering effect in seismicity, which is the most significant predictable component, still needs to be well evaluated. Traditionally, precursors are typically studied separately from seismicity research, despite their potential complementarity. In this study, we develop a probabilistic model by incorporating precursors into temporal Epidemic-Type Aftershock Sequence (ETAS) model, to evaluate earthquake forecasting potential of ultra-low frequency (ULF) magnetic anomaly and carbon monoxide (CO) anomaly. The model is applied to M 4.0+ earthquakes between 2001 and 2010 around the Kakioka (KAK) station, Japan. Results indicate that 15.2% of events originally attributed to the Poisson background in temporal ETAS can be predicted by the external excitation of precursors. The proposed model improves the probability gain by 3.8% compared to ETAS. Although individual precursors may have limited forecasting capability, these findings highlight the potential for enhancing short-term earthquake forecast performance by incorporating precursors. In particular, combining multiple precursors within the model further improves the probability gain of earthquake forecasts.

Incorporating Seismo-Magnetic Precursor Anomalies into ETAS Model for Earthquake Forecasting

Wenchao Li[1)], Chie Yoshino[2)], Katsumi Hattori[2, 3, 4)], Jiancang Zhuang[5)]

1: Graduate School of Science and Engineering, Chiba University, Japan
2: Graduate School of Science, Chiba University, Japan
3: Center for Environmental Remote Sensing, Chiba University, Japan
4: Research Institute of Disaster Medicine, Chiba University, Japan
5: Institute of Statistical Mathematics, Tokyo, Japan

Abstract:

Previous research showed that there was the relationship between the ultralow frequency (ULF, frequency is 0.01Hz) seismo-magnetic phenomena and larger earthquakes in the Kakioka region, Japan. The Epidemic Type Aftershock Sequences (ETAS) model is the most popular stochastic model used to describe earthquake occurrence, to capture earthquake clustering and aftershock sequences. However, it has limitations in distinguishing foreshocks from background seismicity and does not inherently account for non-seismic precursors.

In this study, we investigate seismic activity in the Kanto region of Japan from 2001 to 2010, focusing on earthquakes with magnitudes of 4.0 and above within a 100 km radius of the Kakioka Geomagnetic Observatory. We integrate seismo-magnetic anomaly data recorded at Kakioka with the Self-Exciting and External Exciting Model, an extension of the ETAS model that incorporates external triggering factors. The conditional intensity function of Self-Exciting and External Exciting Model is:

$$\lambda(t) = \mu + \sum_{i:t_i<t} \kappa(m_i) g(t - t_i) + \sum_{j:s_j<t} h(t - s_j)$$

where:

μ is background rate.

$\sum_{i:t_i<t} \kappa(m_i) g(t - t_i)$ is self-exciting rate.

$\sum_{j:s_j<t} h(t - s_j)$ is external exciting rate, here s_j is the date of seismo-magnetic anomaly.

By combining seismo-magnetic anomaly data with the ETAS model, we aim to improve the identification of potential earthquake precursors and explore the relationship between seismic activity and seismo-magnetic anomalies. The results based on the self-exciting and external exciting model, as evaluated through the ROC curve, demonstrate significantly better predictive performance compared to random predictions. This comprehensive model that combines larger earthquake and seismo-magnetic signals has better forecasting ability. Our findings contribute to a better understanding of the feasibility of electromagnetic signals as early-warning indicators and the broader interaction between seismic and seismo-magnetic processes.

Keywords: Point Process, ETAS model, Self-Exciting and External Exciting Model, Earthquake Precursory Information, Seismo-Magnetic Anomaly

A Multi-Source Precipitation Fusion Model Based on Broad Learning System : A Case Study of Yunnan Province, China

Yuanyuan Zhou[1,2]
1. School of Atmospheric Sciences Chengdu University of Information Technology, China
2. Chiba University, Japan

Abstract:

Accurate rainfall estimation remains a critical research focus due to its significant influence on forecasting precipitation-related hazards. In this study, a novel rainfall data fusion approach was developed using the Broad Learning System (BLS) framework to enhance estimation accuracy. Yunnan Province—situated in a low-latitude plateau region of China—served as the study area for constructing a multi-source rainfall fusion model. The model integrates five satellite-based precipitation datasets (namely 3B42V7, IMERG, GSMaP, CMORPH, and PERSIANN) along with spatial coordinates (latitude and longitude) as input features, while ground station measurements were employed as the reference benchmark. The analysis covered the period from April 2014 to December 2017. To validate the model's robustness and generalizability, a leave-one-year-out cross-validation (LOYOCV) strategy was implemented. Performance was assessed using multiple statistical metrics, including Pearson's correlation coefficient (CC), root mean square error (RMSE), mean absolute error (MAE), Nash-Sutcliffe efficiency (NSE), and Kling-Gupta efficiency (KGE), at various temporal and spatial resolutions.

For comparison purposes, alternative fusion models based on Support Vector Machine (SVM) and Deep Neural Network (DNN) were also developed. These helped evaluate the relative performance and efficiency of the BLS approach. Moreover, the added value of incorporating geographic information (i.e., latitude and longitude) was examined in the fusion process.

The results indicate that the BLS-based fusion significantly outperformed the original satellite products, achieving superior daily average accuracy across all statistical measures in the LOYOCV framework. Temporally, the proposed method effectively captured the dynamic patterns of observed rainfall, including accurate estimations during major rainstorm events in 2017. Importantly, BLS-derived rainfall estimates surpassed those of CMORPH—the most accurate among the five satellite sources—during both the wet (May to October) and dry (November to April) seasons. Spatially, the BLS approach produced higher CC and NSE values and lower RMSE and MAE across most of Yunnan Province when compared to the individual satellite datasets.

Comparative analysis among the BLS, SVM, and DNN models further demonstrated that BLS offers stronger mapping capabilities than SVM and is more computationally efficient than DNN. These findings affirm that incorporating geographic context into a BLS-based multi-source fusion framework can substantially improve the accuracy of precipitation estimation in complex terrains such as Yunnan. The proposed methodology offers valuable insights for practical applications in multi-source rainfall assimilation.

Nowcasting Earthquakes with QuakeGPT, an AI-Enhanced Model: Methods, Information Content, First Results, Future Directions

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Key Points

- Interval statistics have been used to conclude that major earthquakes are random events in time and cannot be anticipated or predicted
- AI Enhanced methods combined with machine learning are powerful new techniques that enhance our ability to understand the information content of earthquake catalogs and to track the change in large earthquake potential in real time
- We show that catalogs contain significant information on current hazard and future predictability for large earthquakes, and specifically that there are seismically active regions that can be monitored closely in real time

The question of whether earthquake occurrence is random in time, or perhaps chaotic with order hidden in the chaos, is of major importance to the determination of risk from these events. It was shown many years ago that if aftershocks are removed from the earthquake catalogs, what remains are apparently events that occur at random time intervals, and therefore not predictable in time. We enlist machine learning methods using Receiver Operating Characteristic (ROC) analysis to compute the information value in earthquake catalogs. Here information is defined using Shannon Information Entropy, shown by Claude Shannon (Shannon, 1948) to define the surprise value of a communication such as a string of computer bits. Using stochastic earthquake simulations, we show that significant information in the catalogs arises from the "non-Poisson" power-law aftershock clustering, implying that the practice of de-clustering observed catalogs may remove information that would otherwise be useful in forecasting and nowcasting.

We also discuss earthquake nowcasting, which is a relatively new method that employs a simple 2-parameter filter on the observed monthly seismic rate of small earthquakes. Machine learning is used to improve the nowcast filter, and these methods are being actively developed in a variety of new ongoing research projects, which we call "QuakeGPT". This new idea uses stochastic earthquake simulations to train a science transformer model, an attention-based technology similar to that which underlies ChatGPT. As the previous earthquake nowcasting idea generates earthquake probability by optimization using Receiver Operating Characteristic (ROC) methods, the goal of QuakeGPT is to determine with greater accuracy when and where a major earthquake would occur. With respect to the existing earthquake nowcasting technology using ROC machine learning, we show examples that illustrate the advantages of following the change in earthquake risk through time and discuss future directions for this research.

Dual-Parameter Earthquake Forecasting in Yunnan: b-value and Background Seismicity Rate

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Yunnan Province, China, a seismically active and densely populated region, faces substantial earthquake risks and serves as a critical area for seismic forecasting research. Building on our prior study that evaluated the spatial b-value's performance in 5-year earthquake forecasting (2000–2019) and projected M≥5.0 earthquakes for 2020–2024, this work revisits the predictive accuracy of the earlier forecast and incorporates background seismicity rate—a key parameter for long-term hazard assessment—into the forecasting framework. Using a 25-year earthquake catalog, we systematically analyze spatial b-values and background seismicity rates across five temporal windows, validating the model against 86 M≥5.0 earthquakes. The predictive efficacy is rigorously assessed through the Molchan Error Diagram (MED), Probability Gain (PG), and Probability Difference (PD). Our results demonstrate that both b-values and background seismicity rates exhibit utility for 5-year forecasting, with b-value performance positively correlated with target magnitude. Notably, a synergistic effect emerges when combining these two parameters, enhancing predictive capability. Leveraging thresholds optimized for maximum PD, we integrate b-value and background seismicity data to generate a forward forecast for M≥5.0 earthquakes in Yunnan Province from January 2025 to December 2029. This study provides actionable insights for seismic risk mitigation and disaster preparedness in high-risk regions.

Development of GNSS-based pseudo-strainmeter; preliminary study for the 2016 Kumamoto earthquake (Mj7.3), Japan - temporal and spatial analysis in Kyushu -

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An investigation of the relationship between changes in the correlation coefficients of the orthogonal components of four-component borehole strainmeter data and earthquakes in China reported that the correlation coefficients, which are normally close to 1, decreased to 0.2 just before several significant earthquakes. In addition, a study of the relationship between network connectivity and earthquakes using correlation coefficients between stations of multiple borehole strainmeter data reported that anomalies tended to increase 20 days prior to earthquakes. In Japan, 67 strain gauges have been installed, but there is a limit to the number and regional bias. Therefore, using the GNSS continuous observation system (GEONET) deployed by the Geospatial Information Authority of Japan (GSI) at approximately 1,300 locations throughout Japan, we decided to construct a pseudo-strain gauge consisting of four GEONET observation points to index the amount of crustal deformation. Then, we investigated the relationship between the network connectivity calculated from the correlation coefficients among the pseudo-strainmeter stations and earthquakes. In this report, we report the results of our attempts to extract variations before and after the 2016 Kumamoto earthquake (Mw 7.0), the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.0), and the 2024 Noto Peninsula earthquake (Mw 7.5).

Establishment of an Interdisciplinary Hub for AI Disaster Mitigation and Sustainability

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Abstract

Typhoon Faxai on 5 September 2019 made landfall in the Kanto region with one of the highest recorded intensities, causing extensive damage, particularly in Chiba Prefecture (Fudeyasu et.al. 2022 and Tamura et.al 2021). Similarly, the Noto Peninsula Earthquake (M7.6) on 1 January 2024 resulted in severe destruction to buildings, roads, and ports due to ground shaking and terrain changes (Ishikawa et.al. 2024 and Suppasri et.al. 2024). In both cases, the lack of immediate on-site information after the disaster hindered medical emergency response and rapid disaster relief efforts. With concerns about future large-scale typhoons, the Nankai Trough Earthquake, and a potential directly beneath the Tokyo earthquake, this project aims to pioneer the field of AI-based disaster mitigation and sustainability studies. By integrating remote sensing, data science, disaster prevention, meteorology, geophysics, disaster medicine, and social sciences, alongside practical disaster response efforts, the project will leverage satellite big data and spatial AI as its core technologies. This initiative seeks to enhance disaster prediction and prevention functions while establishing an interdisciplinary hub for AI-based disaster mitigation and sustainability studies. By merging scientific disaster forecasting, disaster assessment technologies, and decision-making methods from social sciences, the project aims to develop unprecedented, effective disaster crisis management strategies and technologies. Ultimately, the project envisions the creation of a platform providing pre-disaster prediction data, real-time disaster observation during an event, situational assessments within 24 hours post-disaster, and post-disaster recovery support information. The integration of digital twin-based disaster response science will further contribute to the development of disaster-resilient cities and communities.

Keywords: Disaster, artificial intelligence, prediction, data science, interdisciplinary hub

Author Note

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Monitoring groundwater flows with using 3D self-potential tomography

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In conventional research of the landslide prediction, researchers have considered relationships between slope failure caused by rainfall and hydrological and mechanical phenomena such as incline and ground displacement that occur under slope before landslide. Monitoring this kind of phenomena requires the observation of changes that occur in the groundwater and soil inside the slope. Then, in Chiba university, the self-potential (SP) method has investigated, which has the advantage that the observation of these changes can be performed over a wide range simply and the cost can be reduced. The SP method is a method measuring the potential generated spontaneously caused by fluctuations of charges due to groundwater flows using electrodes installed in the ground. From the results of laboratory experiments to date, it has been confirmed that there is a relationship between water flows and soil layer displacement and SP fluctuation. In sandbox experiment, 2D tomography of charge density and pressure head was created from the observed natural potential values, and the electrokinetic phenomenon was verified by 2D simulation of groundwater flow. In these two-dimensional analyses, the water flow is assumed to be homogeneous across the depth of the sandbox. However, the two-dimensional approximation resulted in a large error between the simulated and measured values of the SP. Then, 3D simulation and SP tomography algorithm has developed.

Then, in this study, we demonstrated the necessity and effectiveness of 3D analysis and models in a rectangular sandbox experiment measuring 200×20×60 cm (width×depth×height). Specifically, actual data from the sandbox experiment was compared with SP generation simulations using forward problems of 2D and 3D flow models, and groundwater flow estimation from self-potentials using 2D and 3D SP tomography was compared with the model and experimental data. In the water injection experiment, the sandbox was laid with homogeneous sand, and water was injected from the lower part of the sandbox, simulating the groundwater flow. Parameters related to the sand of the soil layer, such as the permeability coefficient and the electro-kinetic coefficient, were measured in another experiment and set to be constant in the sandbox. The root mean square (RMS) of the difference between the simulated and observed self-potential values in the water injection experiment was smaller in 3D than in 2D, which was a better result. Next, the difference between the length of the flow velocity of the pressure head tomography obtained by inverse analysis of the SP actual values was smaller in 3D than in 2D compared to the simulation results. It was also found that the flow velocity vector of the 3D reconstruction results had a spread in the depth direction. This shows that the assumption of laminar flow in the 2D approximation is not valid, and it can be said that 3D analysis is essential. Details will be given in the presentation.

Statistical significance and Molchan's Error Diagram analyses for long-term Ionosonde data from 1958-2024 at Kokubunji, Japan

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In recent years, ionospheric disturbances related to earthquakes have been reported and are considered promising for realizing short-term earthquake forecasting.
We therefore investigated the possibility of short-term earthquake prediction by ionospheric disturbances by investigating the significant correlation between earthquakes and ionospheric disturbances and evaluating their precursory properties using ionosonde data.
We defined the threshold of the positive anomaly as the value of median + 1.5IQR of the NmF2 at the same time in the previous 15 days and an anomaly day as ten or more hours of the anomalies appear in one day. We performed Superposed Epoch Analysis (SEA) to investigate the statistical significance of the correlation between NmF2 anomalies and earthquakes. We repeated the random SEA test 100,000 times to evaluate the statistical significance. We also performed Molchan's Error Diagram (MED) analysis to evaluate the efficiency of NmF2 anomalies for earthquake forecasting.
SEA and MED results suggested a causal relationship between NmF2 anomaly and earthquakes.
Since ionospheric anomalies are also caused by geomagnetic disturbances, we attempted to obtain a more reliable precursor evaluation by removing the effects of geomagnetic disturbances. In this analysis, we classified the onset time and the magnitude of the geomagnetic disturbances using the Dst index. We performed a statistical analysis of the ionospheric response for each class and examined the removal period. The details will be given in this presentation.

Ionospheric disturbances observed over China after 2022 January 15 Tonga volcano eruption

Ting Li, Yongxin Gao, Chieh-Hung Chen, Xuemin Zhang, and Yang-Yi Sun

At 04:14:45 UT on 2022 January 15, a powerful eruption of the submarine Hunga Tonga–Hunga Ha'apai volcano occurred at about 30 km south of the Ha'apai Islands in the Kingdom of Tonga (at −20.55 °N, −175.39 °E). This eruption caused atmospheric waves that spread worldwide. In this study, we investigate the total electron content (TEC) variation over China using the BeiDou Navigation Satellite System. The particularly interesting feature of the data set compared to other ground-based TEC data is the exclusive use of the BeiDou geostationary satellites, which monitor the TEC variations for fixed ionospheric piercing points and can provide more accurate calculations of the travelling speed of the disturbance. For comparison, atmospheric pressure records were examined, which show that the Lamb wave passed by the same stations four times with a constant speed of 310 m s^{-1}. However, the TEC results show that the ionospheric disturbances passing over China four times with different speeds within four days after the eruption, two travelling along the short-path direction and two along the long-path direction. The primary front of the first short-path event travels with a speed of 340 m s^{-1}, which is higher than the Lamb wave. The faster speed suggests that the primary front cannot be fully attributed to the Lamb wave, and further studies need to explore its mechanism. The second short-path and first long-path events travel with speeds of 301 and 310 m s^{-1}, respectively, close to the speed of the Lamb wave, and they may be caused by upward energy leakage during the propagation of the Lamb wave. The second long-path event travels with a speed of 264 m s^{-1}, possibly induced by the gravity waves.

Key words: Ionosphere/atmosphere interactions; Acoustic-gravity waves; Wave propagation; Atmospheric effects; Volcano monitoring.

The three-dimensional ionospheric electron density disturbances following the 2011 M9.0 Tohoku-Oki earthquake in Japan

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Abstract

The three-dimensional (3-D) co-seismic ionospheric disturbances (CIDs) caused by the 2011 M9.0 Tohoku earthquake and tsunami in Japan were visualized based on the 3-D computerized ionospheric tomography technique using the total electron content data monitored by the ground-based Global Positioning System. Different types of CIDs, which were related to the Rayleigh waves (RWs), acoustic waves (AWs_{epi}) and gravity waves (GWs_{epi}) caused by the crustal rupture, and the internal gravity waves ($IGWs_{tsu}$) generated by the tsunami waves were identified successively. We studied the 3-D morphological characteristics of electron density (Ne) disturbances and their vertical phase evolution in different wave modes. Further, we investigated the propagation and involution characteristics concerning the AWs_{epi}, GWs_{epi}, RWs and $IGWs_{tsu}$ at the height interval of 190 - 490 km to the southwest, west and north-northwest of the epicenter. We found that the propagation characteristics of these disturbances were greatly affected by the wave properties, medium and geomagnetic field. We determined the propagation characteristics of $AGWs_{epi}$, $IGWs_{tsu}$ and RWs in the ionosphere and discussed the corresponding wave interaction with Ne as well as magnetic field at different altitudes based on the 3-D visualization.The 3-D detection can be utilized to capture CIDs within a framework of multi-parameter early warning system, from the solid Earth to the atmosphere and ionosphere.

Key words: Computerized Ionospheric Tomography; Coseismic Ionospheric Disturbances; Total Electron Content; Electron Density.

Lessons learned from ionospheric precursors of the 21 September 1999 M7.7 Chi-Chi Earthquake

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Electromagnetic anomalous variations of the geomagnetic field, lightning activity, ionospheric F2-peak plasma frequency, GPS total electron content (TEC), etc. have been observed around the epicenter few days before the 21 September (local time) 1999 M7.7 Chi-Chi earthquake. The TEC over the epicenter anomalously and significantly decreases in the afternoon period on day 1, 3, and 4 before the Chi-Chi earthquake, which generally agrees with TEC decrease anomalies day 1-5 and day 10-15 appearing prior to M≥5.0 earthquakes in Taiwan during the 6-year period of 1994/1/1-1999/9/20. Temporal and spatial analyses of the global ionospheric map (GIM) shows that TEC anomalously and significantly decrease specifically over the epicenter day 3-4 and day 10-15 before the Chi-Chi earthquake. To find possible physical mechanisms causing the TEC decrease anomalies before the Chi-Chi earthquake, the equatorial ionization anomaly of TEC along the Taiwan longitude during September 1999 and plasma quantities of the ion density, ion temperature, and ion velocity measured by DMSP (Defense Meteorological Satellite Program) satellites are examined. It is found that westward seismo-electric fields around the epicenter area day 3-4 and day 10-15 before the Chi-Chi earthquake are essential.

Ionospheric changes immediately before the 2025/3/28 Myanmar Eq.

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Since the first observation for the 2011 Tohoku-oki earthquake (Heki, 2011), ionospheric changes immediately before large earthquakes have been investigated using ionospheric total electron content (TEC) data from GNSS (global navigation satellite system) receivers, for past earthquakes (Heki, 2021). These studies revealed positive correlations between M_w and the leading times and intensities of the anomalies (Heki et al., 2024). From the 3D structure of positive and negative electron density anomalies, Muafiry and Heki (2020) hypothesized the transport of ionospheric electrons along geomagnetic fields to cancel electric fields made by surface positive charges. Here, we report recent findings from the 2025 March 28 M7.7 earthquake in Myanmar. This earthquake is characterized by high background TEC (~130 TECU), and long fault extending ~400 km. We analyzed TEC data from 7 IGS stations in India, Thailand, and Laos, and 23 stations in Yunnan, China, using GPS, GLONASS, Galileo, BDS, and QZSS. We found positive TEC anomalies of 1-2 TECU occurred above the ruptured fault, which are sandwiched by two negative TEC anomalies to the north and south of them, starting ~30 minutes before the earthquake (**Fig.1**). This structure would reflect south- and northward electron transport to the ionosphere above the fault along the geomagnetic fields.

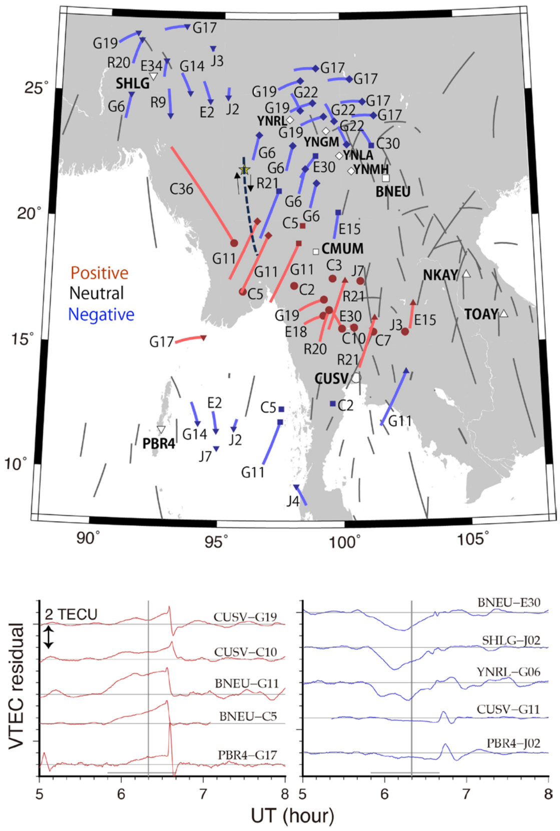

Fig.1. (top) Sub-ionospheric point (300 km altitude) trajectories of GNSS satellites from 11 ground stations showing positive (red), negative (blue), and no (black) anomalies. (bottom)

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Equivalent sunset time delay on MF radio waves propagation prior to earthquakes

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Abstract :

Recently, activity in the ionosphere prior to occurrence of earthquakes is focused. Anomalies in the ionosphere appear as various phenomenon, total electron contents, GNSS waves, VLF band wave propagation, etc.

We have been measuring MF (Middle Frequency) radio waves for long time. In day time MF radio waves fade due to loss in D-layer of the ionosphere. The other hand, D-layer vanishes in night time, then MF radio waves are able to propagate beyond the horizon by reflecting at the bottom of E-layer in the ionosphere. Therefore, sunset is the time of switching from day to night time for the ionosphere too. In observing MF waves, we noticed anomalies in the received signal strength around sunset time prior to occurrence of earthquakes. Usually received signal strength raised monotonically around sunset time. However, in rare cases, it increased non-monotonically caused with anomalous fluctuation. It made a time delay of rising received signal level. This phenomenon results an equivalent sunset time delay.

In this report we have focused to the delay of rising received signal level around sunset time prior to occurrence of earthquakes. The equivalent sunset time delay of the ionosphere appeared occasionally before earthquakes. They were also observed around Kumamoto earthquake in 2016, and prior to Noto earthquake in 2024 too. In order to investigate the relation between the equivalent sunset time delay and occurrence of earthquake, we adopted a statistical estimation method, that is Molchan's diagram. Five MF band waves, Hokkaido STV Radio, Akita NHK 2, Aichi CBC Radio, Osaka NHK 1 and Hiroshima RCC Chugoku, had been performed statistical investigation. As results of them, these statistical diagrams might indicate the existence relation between the equivalent sunset time delay and seismic activity.

This report includes only statistical relation, no physical evidence. Therefore, the physical cause of the equivalent sunset time delay remains unknown. These are the future works.

IWEP9 2025/05

Fright Model and Mission Concept of the W6U PRELUDE CubeSat for Seismic Ionospheric Disturbance Observation

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Although large earthquakes pose a major threat to humanity, no short-term prediction method has yet been established that can forecast earthquake occurrence from several hours to weeks in advance for effective disaster prevention and mitigation. Meanwhile, data from the DEMETER satellite, which was operated between 2004 and 2010, reported a statistically significant phenomenon in which the intensity of VLF (Very Low Frequency) radio waves in the nighttime ionosphere diminished prior to earthquakes (Nemec et al., GRL, 2008; Nemec et al., JGR, 2009; Pisa et al., JGR, 2013). This phenomenon has drawn attention as a promising precursor for earthquake prediction. However, the underlying physical mechanism remains unresolved, and ionospheric observational data that could establish a definitive correlation with earthquakes remains insufficient in both quality and quantity. To address this challenge, our research team is developing the ultra-small satellite PRELUDE designed to CubeSat standards, focusing on electric variations in the ionosphere and building on the achievements of the French satellite DEMETER. PRELUDE has been selected for the 4th JAXA's Innovative Satellite Technology Demonstration Program, and its launch is scheduled for fiscal year 2025. The satellite, which is wide 6 units (W6U) in size and weighs approximately 10 kg, is a CubeSat designed to observe the ionosphere, specifically targeting VLF electric fields. A command-based downlink system will be employed during earthquake events, with a cloudintegrated ground operation system constructed at the ground station. The satellite is designed with expandability in mind, reserving mission space equivalent to 3U, which allows for versatility as a geoelectromagnetic observation platform. In the future, we aim to enhance our data acquisition system by collaborating with multiple ground stations and deploying a satellite constellation, thereby improving data collection of earthquake precursors and the accuracy of predictions. The satellite's payload includes spherical electrodes (40 mm in diameter), which are miniaturized and hybridized versions of the Langmuir and electric field probes used in DEMETER. A 1.5-meter boom is deployed on each side, securing a 3-meter observation span for electric field measurement and reducing noise from onboard equipment. In order to measure the electric field as the potential difference between sensors referenced to satellite potential, the stabilization of satellite potential is essential. To achieve this, an electron emitter (PSEE) developed by LATMOS, France, is installed. Additionally, to ensure high-precision analog signal processing, a dedicated mission processing board is separated from the bus system, and an electrically shielded structure is adopted to minimize noise. This presentation introduces the design, testing, and mission concept of PRELUDE, demonstrating the potential of ultra-small satellites to contribute to clarifying the physical mechanisms of earthquake precursors and advancing earthquake prediction technologies.

IWEP9 2025/05

Design and Development Status of the Instrument Unit of PRELUDE for Observing Pre-Earthquake Ionospheric Disturbances

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CNES (France) launched the DEMETER satellite in 2004 with the aim of investigating the correlation between ionospheric disturbances and seismic activity. Němec conducted a correlation analysis between seismic events and electromagnetic field variations using observational data from the DEMETER satellite. The results revealed a significant decrease in the intensity of 1.7 kHz-band electromagnetic waves approximately four hours prior to earthquakes of magnitude 4.8 or greater, within a radius of about 500 km from the epicenter [Němec et al., GRL, 2008]. Furthermore, Kamogawa et al. reported that the electron density in the ionospheric D-region increased by 20–30% just before earthquakes, coinciding with the observed decrease in radio wave intensity.

Following these findings from the DEMETER satellite, satellite-based observation of electromagnetic precursors to earthquakes has garnered increasing attention in recent years. To verify such phenomena, it is necessary to observe parameters including VLF-band electric field intensity, electron density, electron temperature, ion density, and ion temperature. Satellites for ionospheric observation, such as DEMETER and China's CSES, are therefore equipped with multiple electric field and plasma probes. As a result, such satellites typically exceed 100 kg in mass, making them expensive and time-consuming to develop, and unsuitable for continuous global monitoring.

To address this, Nihon University and the University of Shizuoka have initiated the development of a W6U-sized ultra-small satellite called PRELUDE, with the goal of elucidating the physical mechanisms behind the ionospheric disturbances preceding earthquakes, as reported by Němec et al. PRELUDE is designed to observe electric fields and plasma using a hybrid electric field and plasma sensor mounted at the ends of two 1.5-meter deployable booms.

Due to the size constraints of CubeSats, it is difficult to install deployable mechanisms for electric field measurement in multiple directions. Thus, PRELUDE integrates two instruments—an electric field probe and a Langmuir probe—into a single hybrid unit. As a result, the instrument unit is designed as a 3U hybrid electric field and plasma sensor that can be installed on a 6U CubeSat.

Additionally, in CubeSats, changes in the satellite's electric potential (GND) caused by incoming electrons during electric field and plasma observations can significantly affect measurement accuracy. To minimize this effect, PRELUDE is equipped with a Plasma Source for Electron Emission (PSEE) developed by LATMOS in France.

This paper outlines the design and development status of the instrument unit for observing pre-earthquake ionospheric disturbances.

Multi-rotor unmanned aerial vehicle aeromagnetic survey system

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Unmanned aerial vehicle aeromagnetic surveying offers enhanced operational efficiency and superior safety compared to conventional aeromagnetic surveys, particularly in regions with complex terrain and potential hazards such as cliffs and volcanoes. In this study, we develop a fluxgate-based aeromagnetic system utilizing the DJI M300 RTK drone, integrating an FGM3D/75 fluxgate magnetometer and an LMT70 temperature sensor to enable synchronous acquisition of magnetic anomaly and temperature data. To mitigate the temperature-induced drift of the fluxgate sensor, we propose a temperature-compensated T-L aeromagnetic compensation model, employing a ridge regression algorithm to comprehensively compensate for electromagnetic interference from the flight platform, non-orthogonal errors of the fluxgate, and temperature drift effects. Field experiments demonstrate that this approach improves the compensation enhancement ratio by approximately 40%. The system was deployed for magnetic field measurements in the Yangling Iron Mine, achieving a repeated survey line accuracy of 1.55 nT and providing a high-precision magnetic anomaly distribution of the surveyed area.

Towards the Forecast and Prevention of Earthquake-Induced Methane Geohazards: A Survey of the Large-Scale Fire in Wajima City following the 2024 Noto Peninsula Earthquake

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Large-Scale Earthquake-Induced Fire in Wajima City associated with the 2024 Noto Peninsula Earthquake

Approximately 50 minutes after the M7.6 Noto Peninsula Earthquake struck at 16:10 on January 1, 2024, a large-scale earthquake-induced fire broke out in the Asaichi Street area of Kawai Town, Wajima City, Ishikawa Prefecture. The fire burned approximately 49,000 m^2 and damaged around 240 buildings (Fire and Disaster Management Agency, 2024). The agency suggested the possibility of an electrical fire caused by test power transmission conducted about 50 minutes after the earthquake, based on the discovery of melted traces on the indoor electrical wiring of the suspected origin building. However, it is unlikely that copper wires would melt during a test power transmission lasting only 0.3 to 0.4 seconds, and the specific ignition source and combustibles have yet to be identified.

Characteristics of the Fire as Shown in Media Footage

In footage broadcast by Nippon TV NEWS, a vertical jet of flame can be seen erupting from the ground near a parking area to the left of the building identified as the fire's origin, along with a smaller line of flames slightly to its right (**Fig.1**). These flames are unlikely to have been caused by embers scattering from the burning building, as they are confined to paved and unpaved parking lots where no combustible materials are present. Therefore, it is reasonable to conclude that the source of these flames is located underground rather than on the surface.

Geological Environment and Methane Eruption in the Wajima Area

In the vicinity of Wajima, a soft, organic-rich clay layer, formed by the deposition of sediments in a "drowned valley" caused by sea-level rise approximately 10,000 years ago, extends 30 to 40 meters underground. Due to subsequent crustal uplift, this layer now lies beneath the urban area of the city, creating a subsurface environment rich in humic substances. Post-earthquake investigations confirmed methane generation in the shallow strata of Kawai Town, Wajima City. Based on these findings, it is highly likely that the eruption of subterranean methane and its spontaneous ignition were the direct causes of the large-scale fire.

For further details on the above content, please refer to the following paper：

Enomoto, Y., Komatsubara, T. & Kiyashu, S. Ignition of subterranean methane: unveiling a new geohazard in Japan following 2024 Noto Peninsula Earthquake. *npj Nat. Hazards* **2**, 31 (2025). https://doi.org/10.1038/s44304-025-00068-5.

Mechanism of Methane Eruption Induced by the Earthquake

At 17:21, just before the outbreak of the fire, a local M3.5 earthquake was observed at two sites near Kawai Town, Wajima City, recording a seismic intensity of 4(**Fig.2**). Although the hypocenter was located near Amishizaki, 32 km away, no response was recorded at surrounding observation points. It is presumed that this anomalous earthquake acted as the trigger for the subterranean methane eruption and its spontaneous ignition. Furthermore, five subsequent shallow-focus earthquakes (hypocenter depth 0 km) exhibited non-tectonic or quasi-tectonic seismic waveforms. Based on these observations, we hypothesize that degassing of groundwater (the "champagne effect") during aftershock activity caused the gas pressure beneath the viscous clay layer (cap rock) to reach a critical threshold, inducing fracturing and explosive vibrations. From the verification of this hypothesis (**Fig.3**), we propose a chain-reaction model of “gas pressure accumulation → cap rock fracturing upon exceeding the threshold → further fracturing induced along fault zones.

Methane Fire Risk Forecast and Disaster Prevention Strategies

The survey of the Wajima fire incident highlights the necessity of forecasting potential methane fire risks and implementing appropriate disaster prevention strategies in the following ways:

- In regions with underground water-soluble gas reservoirs, it is essential to assess and forecast the risk of methane eruptions and subsequent fires caused by earthquakes.
- In the Wajima fire incident, the fire broke out approximately one hour after the mainshock. This time gap is considered the duration required for methane gas to accumulate inside buildings and reach its lower explosive limit (5 vol%). Recognizing this time lag allows for early evacuation, providing a critical window for risk mitigation.
- It is crucial to identify areas with high methane fire risk, forecast potential hazard zones, and inform residents through hazard maps.
- Investigations into localized methane accumulations, installation of gas venting pipes, deployment of gas monitoring systems, and ventilation devices within buildings are recommended as preventive measures.

Fig.1 Flames erupting form the ground surface.

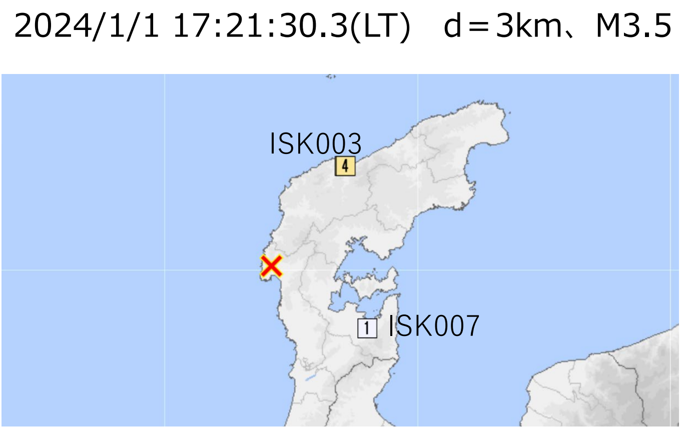

Fig.2 Unusual earthquake presumed to have triggered the earthquake-induced fire.

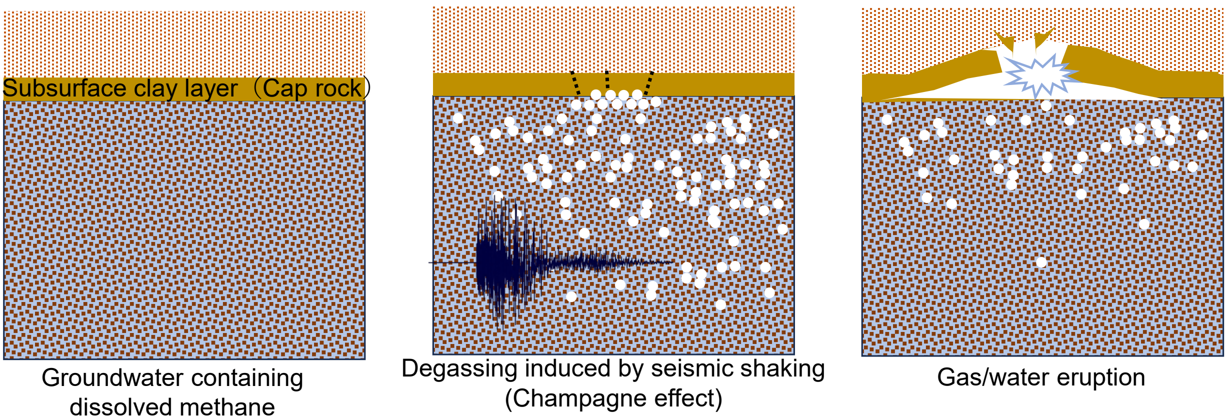

Fig.3. A Seismic vibration model Based on the 'Champagne Effect' — rapid release of bubbles from methane-dissolved groundwater

Identifying Earthquake Precursors in the Western Nepal Himalayas Using Fractal Methods

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Earthquakes in the Himalayan region is entirely tectonic, driven by the continuous collision of the Indian plate subducting beneath the Eurasian plate. This ongoing movement causes slip along fault zones, generating numerous high-magnitude earthquakes. This study focuses on the Western Nepal Himalayas (WNH) and the adjoining region, bounded by latitudes 28.5°N–30.95°N and longitudes 78°E–82.96°E, to analyses seismic activity patterns using the fractal method. To examine variations in the b-value and fractal dimension (Dc) for earthquakes ($m_b \geq 4.0$) occurring between 1964 and 2020, twelve overlapping windows of 100 seismic events each, with a 25-event shift, were analysed. Three consecutive windows from 1991 to 2006 show a b-value variation from 0.80 ± 0.07 to 0.90 ± 0.09, along with a decrease in Dc from 1.24 ± 0.03 to 1.20 ± 0.03. This suggests high earthquake clustering during major seismic events such as the 1991 Uttarkashi earthquake (Mw 6.8) and the 1999 Chamoli earthquake (Mw 6.6). Furthermore, the study highlights a negative correlation between b-value and Dc, influencing the spatial and temporal distribution of earthquakes in the region. These findings emphasize the potential of b-value and Dc as indicators for identifying seismicity patterns before major earthquakes. Continuous monitoring of these parameters could serve as valuable precursors for assessing earthquake hazards in the region.

9th International Workshop on Earthquake Preparation Processes (IWEP9), May 27-28, 2024, Chiba University, Japan

Seismicity response to strong variations in the geomagnetic field as a manifestation of electromagnetic triggering of earthquakes

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In the previous studies [1,2] it was numerically shown that a solar flare (SF) can generate pulsations of geomagnetic field (GMF) and a burst of telluric currents in seismogenic faults comparable in density to electric currents in the Earth's crust generated by an artificial source and resulted in triggering of regional seismicity and its spatiotemporal redistribution [3]. It was shown that after strong SF of X class an increase of the Eart's day-side seismicity up to 40-70% is observed with a delay of 7-8 days. Moreover, a statistical analysis of the strong earthquake (EQ) case (Sumatra-Andaman Islands, M=9.1, 26.12.2004) demonstrated that SF (X7.2 class, 20.01.2005) possibly triggered a seismic surge (an increase in the number of aftershocks by 20 times relative to the background level) with a delay of 7 days after SF in the aftershock zone where the subcritical stress-strain state still existed in some local points during the stress redistribution after the main shock.

The presented study is a continuation of the efforts on verification of the hypothesis of earthquake triggering by natural electromagnetic impacts. The results similar to mentioned above were obtained for aftershock sequence responses of 7 strong EQs of Northern California (M~7) to 24 strong pulsations of the horizontal X-component dB_x of the GMF ($|dB_x/dt| \geq 50$ nT/min) recorded at the Fresno observatory in the period 1991-2024. It was shown that for aftershock areas of strong California EQs the statistically significant increase in aftershock sequence is observed with a similar delay of a few days after strong GMF variation.

The physical mechanism of EM-EQ triggering may be connected with a fluid behavior during EM impact, similarly to dynamic EQ triggering. For verification of this hypothesis a statistical analysis of seismicity was carried out at three geothermal fields in Northern California (Long Valley, Coso, and Geysers) during 24 GMF strong pulsations. A statistically significant increase in regional seismicity of geothermal fields with delay of 2 to 10 days after the GMF pulsation is shown, when the daily number of EQs exceeds the average number of EQs determined for the previous 30 days, plus a threefold value of the standard deviation. This effect indicates not only the presence of an EQ triggering potential for GMF pulsations, but also the possible role of fluids in the process of EM triggering of EQs.

An approach to obtaining additional prognostic information for short-term earthquake forecasting based on the results of reliably recorded seismicity responses to strong external EM impacts under severe space weather conditions is proposed and discussed [4].

The work is supported by RSF (project No. 24-27-00205).

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Do solar flares and sudden storm commencements trigger earthquakes?

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The possibility of a trigger effect of solar activity and related disturbances of the geomagnetic field on the Earth's seismicity is actively discussed in the geophysical literature. In particular, the idea of solar flares and sudden storm commencements (SSCs) as triggers of planetary seismic activity is popular. In this study these hypotheses are statistically validated. The superimposed epoch method has been applied to shallow earthquakes before and after solar flares and SSCs of 2010-2020 in the range of ±2 days and ±1 hour, respectively. A statistically significant increase in the number of earthquakes with epicentral depths less than 60 km after solar flares has been found. This effect is more evident when considering only earthquakes that occurred on the Sun-illuminated side of the Earth. However, a reasonable physical mechanism of solar flare or SSC impact on seismic process has not been established yet.

The influence of geospace weather on earthquake processes: Case study for the M7.7 Myanmar earthquake on March 28, 2025.

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We have discussed the influence of solar wind energy and geomagnetic storms on intra-terrestrial processes that manifest as earthquakes. Strong earthquakes follow geomagnetic storms in longitudinal regions located beneath the polar cusp at the onset of the storm. The efficiency of solar wind energy penetration into Earth's environment varies with the season and time; thus, the pattern of seismic response to different geomagnetic storms may differ. One might suggest that it could be similar for analogous geomagnetic storms, which is the case here. The strong (SYM/H = −132 nT) and powerful (SYM/H = −234 nT) geomagnetic storms started on 17 March in 2013 and 2015 (St. Patrick's Day Geomagnetic Storms) at relatively close times of 06:04 UTC and 04:48 UTC, respectively. At an interval of approximately 2.5 months after the storms' onset, a similar pattern of global seismicity occurred. In 2013, a crustal M7.7 earthquake took place in Iran on 16 April with a time delay of 30 days, followed by a deep-focused M8.3 earthquake beneath the Sea of Okhotsk (Russia) on 24 May with a time delay of 68 days. In 2015, a crustal M7.8 earthquake occurred in Nepal on 25 April with a time delay of 39 days, and then a deep-focused M7.8 earthquake occurred in the Pacific Ocean (Japan) on 30 May with a time delay of 74 days.

In the case of the 2025 M7.7 Myanmar earthquake, a powerful geomagnetic storm (SYM/H = -239 nT) began on December 31, 2024, at 16:37 UTC. During this time, the American longitudinal region was beneath the cusp. On February 8, 2025, the M7.6 Cayman Islands earthquake (17.651°N, 82.395°W) occurred with a delay of 39 days. Another CME erupted from the Sun on January 1, 2025, and impacted the Earth on January 4. A strong geomagnetic storm (SYM/H=-112 nT) commenced on January 4, 2025, at 02:55 UTC. At that time, the longitudinal region from 750E to 1950E was under the polar cusp. The M7.7 Myanmar earthquake (22.013°N, 95.922°E) occurred on March 28, 2025, with a delay of 83 days. The revealed association between strong earthquake occurrences and geomagnetic storms, along with polar cusp geometry, may clarify the longitudinal variation in seismic activity, particularly its elevated levels in the regions where the American and Asian branches of the Pacific Ring of Fire are situated.

Abstracts of poster presentations

Seismo-geomagnetic precursor signal recognition based on a novel high-precision interstation transfer function method

Hongyan Chen, Peng Han, Katsumi Hattori

The analysis of electromagnetic disturbances prior to fault rupture is considered an effective method for monitoring crustal activity and is regarded as one of the promising approaches for short-term earthquake prediction. However, due to the typically weaker intensity of seismic geomagnetic precursor signals compared to spatial field source disturbances, the separation and extraction of seismic geomagnetic signals from actual observational data present significant challenges. The use of interstation transfer functions based on reference stations has emerged as a viable method for estimating spatial field source signals at target stations. However, existing methods for calculating inter-station transfer functions suffer from computational inaccuracies and low precision. Previous research has not yet achieved the extraction of seismic geomagnetic precursor signal waveforms, nor has it systematically analyzed the characteristics, particularly the waveform features, of these precursor signals. In recent years, advancements in signal processing techniques have led to the development of accurate wavelet-based multivariate coherence calculation methods, offering new opportunities for seismic geomagnetic research. This progress has made the precise extraction of weak seismic geomagnetic precursor signals feasible.

In light of these developments, this study integrates multivariate coherence calculation methods to enhance the accuracy of inter-station transfer function calculations across different frequency bands through rigorous coherence analysis and more refined computations for various periods. By establishing high-precision inter-station transfer functions, we aim to estimate the background geomagnetic field at observation stations and extract local geomagnetic signal waveforms. This will enable the development of a robust method for accurately extracting seismic geomagnetic precursor signals. Furthermore, we will evaluate the predictive efficacy of the waveform characteristics of these precursor signals. The findings of this research are expected to provide critical data for the quantitative analysis of the mechanisms underlying seismic geomagnetic precursor signals. Additionally, the study will offer a novel analytical approach for geomagnetic observation data recorded in the earthquake experimental area. This will enhance the application of observational data in earthquake prevention and disaster mitigation, contributing valuable insights to the field of seismic geomagnetic research.

A development of signal discrimination method using Multi-channel Singular Spectrum Analysis (MSSA) for ULF band electromagnetic data, in Boso, Japan (3)

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The electromagnetic phenomena suspected to be related to earthquakes in the ULF band (f<10 Hz) are reported because the skin depth (more than a few km) corresponds to the interior of the crust of the plate boundary. However, the observed data include seismo-electromagnetic signals, natural electromagnetic field variations caused by solar-terrestrial coupling, and artificial noise caused by leak currents from DC-driven railways and power transmission lines. Since the amplitude of seismo-electromagnetic signals is smaller than that of natural magnetic field fluctuations and artificial noise, and especially similar to train noise, analysis has focused on nighttime (e.g., LT 2:30~4:00) when human activities are calm. Therefore, conventional analysis methods may miss seismic EM signals during most of the day. Thus, a method that can discriminate seismo-electromagnetic signals sufficiently, even if the signal-to-noise ratio is poor, is indispensable to extracting seismo-electromagnetic signals buried in other signal components. Therefore, we are developing a signal discrimination method based on Multi-channel Singular Spectrum Analysis (MSSA), which can decompose non-stationary time series.

In the past, a wavelet transform-based method was developed to discriminate the ULF band electromagnetic signal. The method decomposes the time series into wavelet coefficients and estimates the vertical magnetic and horizontal electric fields based on Inter Station Transfer Function (ISTF), then reconstructs by summing the Inverse wavelet transformed estimated wavelet coefficients of target bands. Therefore, once the well-defined ISTF is obtained, the method will be a powerful tool.

In this presentation, we will suggest the appropriate signal discrimination method for noisy data by looking into the performance of relatively clean data (Kakioka (Japan Meteorological Agency) data sets) and noisy data at the Boso peninsula, through the difference of the procedures.

Development of VLF/LF interferometer using capacitive circular flat-plane antenna and signal discrimination / identification by machine learning: Preliminary Result

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Japan is frequently hit by major earthquakes, such as the 2011 off the Pacific coast of Tohoku Earthquake and the 2024 Noto Peninsula Earthquake, which cause enormous human and economic losses. Short-term forecast of earthquakes is effective for mitigating such damage, but this has not been achieved to date. On the other hand, there have been reports of electromagnetic phenomena preceding major earthquakes in various frequency bands, including precursor phenomena in the VLF/LF band (3-300 kHz). In this study, we investigated earthquake-related VLF/LF signals, which has strong electromagnetic emissions due to lightning activity, and it is important to discriminate the VLF/LF signals from those due to lightning activity. In this study, two approaches were attempted: (1) development of a source localization method using VLF/LF broadband interferometry and (2) removal of signals caused by lightning discharges using machine learning.

The first approach is expected to spatially discriminate between VLF/LF signals related to earthquakes (which are located near the epicenter and do not move) and signals related to lightning activity (which move with fronts and thunderclouds). The second is to utilize machine learning technology, which has been rapidly developed in recent years, for detection and removal of lightning discharge signals. For example, Wu et al. at Gifu University have succeeded in classifying lightning discharge waveforms in the thunderstorm activity process with an accuracy of approximately 99% using a machine learning technique called Random Forest. In this study, machine learning is expected to efficiently discriminate and eliminate known lightning discharge signals from a large amount of observation data with high accuracy, and analyze the remaining unknown signals to efficiently investigate the relationship between lightning and earthquakes. In this paper, we will describe the specific methods and results of the above two approaches.

Statistical Analysis of GIM-TEC Anomalies Associated with large earthquakes (M>7) during 2000-2024

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Short-term forecast is important for mitigating damage from earthquakes, and electromagnetic phenomena related to earthquakes are attracting attention as an indicator of such phenomena. Among them, the study of anomalies of TEC before earthquakes is considered to be promising. The number of earthquakes per region is too small to cover large earthquakes (For example, earthquakes of M>7.0 that occurred between 2000 and 2024, 369 in the world and 26 in Japan). Therefore, the purpose of this study is to investigate ionospheric anomalies preceding earthquakes by case/statistical analysis for earthquakes of M>7.0, D<60 km that occurred in the world during 2000-2024. Earthquake catalogs were from the USGS (United States Geological Survey). GIM, a global grid of TEC data published by CODE (Center for Orbit Determination in Europe), was used for the analysis. As a indicator of anomaly, GIM-TEC** was defined by normalizing GIM-TEC at a given time by the median of the same time over the previous 15 days. Values exceeding the median +1.5 IQR were considered anomalies, and days with anomalies exceeding 10 hours per day were considered anomalous days. In the statistical analysis, using the SEA (Superposed Epoch Analysis) method, anomalous days were accumulated for 45 days before and after the earthquake occurrence day. To verify the significance of the anomalies, the same number of days as the earthquake occurrence was randomly selected from the analysis period 10000 times (random SEA), and the process was performed on the grid including the epicenter and the surrounding. details of the results will be given in the presentation.

Continuous radon measurement in atmosphere in Japan

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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 μs, a multi channel analyzer (MCA-LiteN), and a PC for data acquisition. We detected the four components of alpha rays originated from ^{210}Po (peak1), ^{218}Po (peak2), and ^{214}Po (peak3) of U series, and ^{212}Po (peak4) of Th series, respectively.

We have measured these concentrations in atmosphere at domestic five measurement stations at Choshi, Kiyosumi, Kochi, Susai, and Okayama in Japan.

This time, we tried to installed a suction port near the ground surface to get high peak4 intensity at three stations, Choshi, Kiyosumi and Okayama. We reports the measurement results.

The Fluctuations of the Soil Radon Fluxes at Two Different Depths at Asahi Station, Japan

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Short-term earthquake forecast is important for mitigating the damage caused by major earthquakes such as the 2011 Tohoku earthquake and the 2024 Noto Peninsula earthquake, but it has not yet been achieved. There have been reports that the radon concentration in the atmosphere and the radon concentration in groundwater showed abnormal levels prior to the 1995 Hyogo-ken Nanbu earthquake, and the relationship between changes in radon concentration and major earthquakes has attracted attention. However, there are problems with the time resolution and sensitivity of the measuring equipment, and it has not yet been possible to show a statistically significant correlation with earthquakes. Therefore, we have developed a radon observation device that can measure the soil radon concentration in the ground near the surface with high sensitivity, and we are using this device in this study. This device is a radon monitor made by OHYO KOKEN KOGYO Co., Ltd. and is a device that detects alpha rays. In a previous study, the soil radon concentration in the ground was measured using a radon monitor, and the atmospheric tides were removed from the data by using atmospheric pressure and temperature data and MSSA (multichannel spectral singular value analysis) to estimate the soil radon flux in the ground near the surface. However, it was also found that in the case of heavy rain (more than 20 mm of precipitation per hour), the effect of precipitation was indicated. In order to realize earthquake forecast using radon observation, it is necessary to remove these fluctuations. Therefore, in this study, radon monitors were installed at different depths of 60 cm and 100 cm, and the soil radon flux was estimated using MSSA, as in previous studies, to examine the differences in flux intensity according to depth and the differences in the effects of precipitation due to heavy rain.

Formation of interdisciplinary hub for AI disaster mitigation and sustainability studies

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For weather disasters such as torrential rains and typhoons, information on rainfall amounts, wind speeds, etc. is disclosed in advance, albeit with some uncertainty, to encourage society to respond to such disasters, and society has developed countermeasures in advance, taking into account the uncertainty of the forecasts. On the other hand, all information on earthquakes and tsunamis is currently available only after they occur, with little or no advance information available. Even in the case of a massive earthquake event of magnitude 7 or greater, it is expected that individuals and companies will be able to smoothly prepare in advance and take actions to mitigate damage if they have predictive (advance) information at normal times, one week, three days, one day, several hours, one hour, just before the arrival of seismic waves (Earthquake Early Warning), and 20 minutes before the arrival of tsunami It is also expected to facilitate individuals and businesses to prepare in advance and take actions to mitigate damage. In addition, as seen in the case of the Boso typhoon and Noto earthquake, there is a lack of information on the disaster during and immediately after the disaster (access to the disaster area by roads, ports, etc., and the situation of hospitals and other emergency response centers). Especially at night or when bad weather, power outages, the spread of infectious diseases, or nuclear accidents occur, information is even more scarce, making it difficult to conduct appropriate disaster response activities. In addition to conventional meteorological information and earthquake early warning systems, it would be expected to further reduce economic and human losses if accurate forecasting and disaster monitoring information could be utilized. This led to the conception of a world-first attempt to develop a system for extracting information from earth observation big data that contributes to disaster forecasting and monitoring and reconstruction assistance, and a crisis response navigator that uses this information, which will be refined and upgraded on a spatial AI platform and implemented in society. The creation of an AI disaster mitigation sustainable science that contributes to the realization of a disaster resilient society through collaboration and fusion of various fields of mathematical sciences such as remote sensing, disaster science, meteorology, and geophysics, social sciences that determine behavioral patterns, and various fields of disaster medicine and emergency response on the frontlines.

Multi-sensor monitoring network for earthquake precursor study near subduction zone at Chiba University, 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.

Development of GNSS-based pseudo-strainmeter; preliminary study for the 2016 Kumamoto earthquake (Mj7.3), Japan - temporal and spatial analysis in Kyushu -

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An investigation of the relationship between changes in the correlation coefficients of the orthogonal components of four-component borehole strainmeter data and earthquakes in China reported that the correlation coefficients, which are normally close to 1, decreased to 0.2 just before several significant earthquakes. In addition, a study of the relationship between network connectivity and earthquakes using correlation coefficients between stations of multiple borehole strainmeter data reported that anomalies tended to increase 20 days prior to earthquakes. In Japan, 67 strain gauges have been installed, but there is a limit to the number and regional bias. Therefore, using the GNSS continuous observation system (GEONET) deployed by the Geospatial Information Authority of Japan (GSI) at approximately 1,300 locations throughout Japan, we decided to construct a pseudo-strain gauge consisting of four GEONET observation points to index the amount of crustal deformation. Then, we investigated the relationship between the network connectivity calculated from the correlation coefficients among the pseudo-strainmeter stations and earthquakes. In this report, we report the results of our attempts to extract variations before and after the 2016 Kumamoto earthquake (Mw 7.0), the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.0), and the 2024 Noto Peninsula earthquake (Mw 7.5).

Monitoring groundwater flows with using 3D self-potential tomography

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In conventional research of the landslide prediction, researchers have considered relationships between slope failure caused by rainfall and hydrological and mechanical phenomena such as incline and ground displacement that occur under slope before landslide. Monitoring this kind of phenomena requires the observation of changes that occur in the groundwater and soil inside the slope. Then, in Chiba university, the self-potential (SP) method has investigated, which has the advantage that the observation of these changes can be performed over a wide range simply and the cost can be reduced. The SP method is a method measuring the potential generated spontaneously caused by fluctuations of charges due to groundwater flows using electrodes installed in the ground. From the results of laboratory experiments to date, it has been confirmed that there is a relationship between water flows and soil layer displacement and SP fluctuation. In sandbox experiment, 2D tomography of charge density and pressure head was created from the observed natural potential values, and the electrokinetic phenomenon was verified by 2D simulation of groundwater flow. In these two-dimensional analyses, the water flow is assumed to be homogeneous across the depth of the sandbox. However, the two-dimensional approximation resulted in a large error between the simulated and measured values of the SP. Then, 3D simulation and SP tomography algorithm has developed.

Then, in this study, we demonstrated the necessity and effectiveness of 3D analysis and models in a rectangular sandbox experiment measuring 200×20×60 cm (width×depth×height). Specifically, actual data from the sandbox experiment was compared with SP generation simulations using forward problems of 2D and 3D flow models, and groundwater flow estimation from self-potentials using 2D and 3D SP tomography was compared with the model and experimental data. In the water injection experiment, the sandbox was laid with homogeneous sand, and water was injected from the lower part of the sandbox, simulating the groundwater flow. Parameters related to the sand of the soil layer, such as the permeability coefficient and the electro-kinetic coefficient, were measured in another experiment and set to be constant in the sandbox. The root mean square (RMS) of the difference between the simulated and observed self-potential values in the water injection experiment was smaller in 3D than in 2D, which was a better result. Next, the difference between the length of the flow velocity of the pressure head tomography obtained by inverse analysis of the SP actual values was smaller in 3D than in 2D compared to the simulation results. It was also found that the flow velocity vector of the 3D reconstruction results had a spread in the depth direction. This shows that the assumption of laminar flow in the 2D approximation is not valid, and it can be said that 3D analysis is essential. Details will be given in the presentation.

Statistical significance and Molchan's Error Diagram analyses for long-term Ionosonde data from 1958-2024 at Kokubunji, Japan

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In recent years, ionospheric disturbances related to earthquakes have been reported and are considered promising for realizing short-term earthquake forecasting.
We therefore investigated the possibility of short-term earthquake prediction by ionospheric disturbances by investigating the significant correlation between earthquakes and ionospheric disturbances and evaluating their precursory properties using ionosonde data.
We defined the threshold of the positive anomaly as the value of median + 1.5IQR of the NmF2 at the same time in the previous 15 days and an anomaly day as ten or more hours of the anomalies appear in one day. We performed Superposed Epoch Analysis (SEA) to investigate the statistical significance of the correlation between NmF2 anomalies and earthquakes. We repeated the random SEA test 100,000 times to evaluate the statistical significance. We also performed Molchan's Error Diagram (MED) analysis to evaluate the efficiency of NmF2 anomalies for earthquake forecasting.
SEA and MED results suggested a causal relationship between NmF2 anomaly and earthquakes.
Since ionospheric anomalies are also caused by geomagnetic disturbances, we attempted to obtain a more reliable precursor evaluation by removing the effects of geomagnetic disturbances. In this analysis, we classified the onset time and the magnitude of the geomagnetic disturbances using the Dst index. We performed a statistical analysis of the ionospheric response for each class and examined the removal period. The details will be given in this presentation.

Incorporating Seismo-Magnetic Precursor Anomalies into ETAS Model for Earthquake Forecasting

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Abstract:

Previous research showed that there was the relationship between the ultralow frequency (ULF, frequency is 0.01Hz) seismo-magnetic phenomena and larger earthquakes in the Kakioka region, Japan. The Epidemic Type Aftershock Sequences (ETAS) model is the most popular stochastic model used to describe earthquake occurrence, to capture earthquake clustering and aftershock sequences. However, it has limitations in distinguishing foreshocks from background seismicity and does not inherently account for non-seismic precursors.

In this study, we investigate seismic activity in the Kanto region of Japan from 2001 to 2010, focusing on earthquakes with magnitudes of 4.0 and above within a 100 km radius of the Kakioka Geomagnetic Observatory. We integrate seismo-magnetic anomaly data recorded at Kakioka with the Self-Exciting and External Exciting Model, an extension of the ETAS model that incorporates external triggering factors. The conditional intensity function of Self-Exciting and External Exciting Model is:

$$\lambda(t) = \mu + \sum_{i:t_i<t} \kappa(m_i) g(t - t_i) + \sum_{j:s_j<t} h(t - s_j)$$

where:

μ is background rate.

$\sum_{i:t_i<t} \kappa(m_i) g(t - t_i)$ is self-exciting rate.

$\sum_{j:s_j<t} h(t - s_j)$ is external exciting rate, here s_j is the date of seismo-magnetic anomaly.

By combining seismo-magnetic anomaly data with the ETAS model, we aim to improve the identification of potential earthquake precursors and explore the relationship between seismic activity and seismo-magnetic anomalies. The results based on the self-exciting and external exciting model, as evaluated through the ROC curve, demonstrate significantly better predictive performance compared to random predictions. This comprehensive model that combines larger earthquake and seismo-magnetic signals has better forecasting ability. Our findings contribute to a better understanding of the feasibility of electromagnetic signals as early-warning indicators and the broader interaction between seismic and seismo-magnetic processes.

Keywords: Point Process, ETAS model, Self-Exciting and External Exciting Model, Earthquake Precursory Information, Seismo-Magnetic Anomaly

Development and testing of long-term high stability solid non-polarized electrode

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Geoelectric field measurement plays a crucial role in geophysical exploration techniques such as magnetotelluric and spontaneous potential (SP) exploration, and a solid non-polarized solid electrode (NPE) with long term high stability is the basis of achieving high precision geoelectric field observation. In practical applications, the performance of these electrodes significantly impacts the accuracy of observations and exploration results. Therefore, how to maintain long-term high stability poses a challenge. Based on the reaction principle of electrodes, this paper enhances the stability of the NPE by enhancing the water retention and homogeneity of electrolyte through the addition of a trace of nano-fumed silica to prepare a gel. Then, improvements have been made to the size and position of the small channels within the internal cavity of the electrode to further enhance its stability and lifespan. Additionally, a removable maintenance cylinder is introduced to cater to harsh environmental conditions. Through repeated tests, the long-term high-stability NPE series, solid NPE, has been developed. The internal resistance, polarization potential difference, stability, self-noise level, temperature and frequency response of the electrode are tested, the test results show that the main performance indexes have reached the international level. This research provides an innovative domestic sensor solution for high-precision geoelectric field measurements.

Lithological controls on infiltration and failure characteristics of rainfall-induced landslide: experimental study of slopes in northern Guangdong, China

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Rainfall-triggered landslides in northern Guangdong Province, China result in substantial annual economic losses and pose significant risks to human safety. Comprehensive statistical analyses demonstrate clear lithological controls on failure mechanisms: granitic residual soils predominantly develop retrogressive failure surfaces, while sedimentary formations exhibit preferential shallow sliding along weak structural planes. This study combines X-ray diffraction (XRD) analysis with controlled flume experiments to systematically examine how lithology governs hydrological response and failure initiation processes. Experimental results reveal that granitic residual soils (classified as sandy clays and clayey sands) contain 40-48% coarse particles and are quartz-rich (>60%), leading to rapid strength degradation through particle detachment and intergranular weakening during infiltration. This mechanism results in retrogressive failure patterns, with critical shear strength reductions exceeding 40% controlling failure initiation. In contrast, weathered shale-derived soils display elevated clay mineral content (montmorillonite-illite-kaolinite assemblages constituting 37.1-54.6% of total composition), promoting shallow translational movements along hydro-mechanically weakened bedding planes with pore pressure buildup. The study establishes a predictive lithological framework for rainfall-induced slope failures, emphasizing the fundamental role of mineralogical composition in determining failure modes. These findings provide quantitative benchmarks for improving regional landslide early-warning systems, particularly in distinguishing hazard potential between igneous and sedimentary geological units.

North-South asymmetry of Sq variations at geomagnetically conjugate area

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Abstract Asymmetry in the northern and southern hemispheres of Sq variations at the middle and low latitudes (within ±50°) is examined by analyzing observations from five pairs of geomagnetically conjugate stations of SuperMAG during quiet days. The results indicate that the asymmetries of the horizontal components of Sq variations (ASYM-X/Y) significantly vary with season and depend on latitude. First, ASYM-X of the three pairs of conjugate stations on the polar-side (44°) of and near (33° and 25°) the Sq focus are stronger from May through October than in the other seasons. ASYM-X of the two pairs of conjugate stations on the equatorial-side of focus (14° and 8°) is weak even in the June solstice. The intensity of ASYM-X on the polar-side is as strong as that of near focus from May through September and becomes as weak as that of the equatorial-side in other seasons. Second, the pattern of ASYM-Y on the polar-side is different from that at other latitudes, which basically consists of two parts. At other latitudes, ASYM-Y from April to October has a three-part pattern. The intensities of ASYM-Y in 06–10 LT and 14–18 LT decrease with increasing latitude from April to September. Finally, by using the empirical model data for the horizontal winds associated with diurnal, semidiurnal, and terdiurnal tides from TIMED satellites Doppler meteor radar (TIDI) observations, it is found that the north-south hemisphere asymmetry of the Sq variations is mainly caused by the asymmetry of the neutral winds. The seasonal and latitudinal variations of the asymmetry of the migrating tides, especially the zonal component, are essentially consistent with those of the Sq variations.

Keywords: Sq variations, geomagnetically conjugate area, north and south hemispheric asymmetry, seasonal variations, latitudinal dependence, neutral winds

Responses of Seismo-ionospheric Precursors in the Total Electron Content to Earthquake Magnitude and Depth in Taiwan and Japan during 1999–2024

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The median base is employed to identify anomalies in the total electron content (TEC) on the Global Ionosphere Map (GIM) associated with earthquakes in Japan and Taiwan during 1999–2024. Z values of the one-sample test are used to find the characteristics of seismo-ionospheric precursors (SIPs) in the polarity of anomalous GIM TEC increases or decreases, lead days, durations, etc. for various earthquakes. The statistical significance of the SIP characteristics is further confirmed by the Receiver Operating Characteristic (ROC) curve analysis. Odds with SIPs versus earthquake magnitudes and depths are further computed to have a better understanding on the relationship between SIP occurrences and the preparation energy of earthquake preparation processes and underground structure.