SSS01-01 Room:419 Time:May 2 14:15-14:30

Collaboratory for the Study of Earthquake Predictability - Global Activities

SCHORLEMMER, Danijel[1*] ; GERSTENBERGER, Matt[2] ; HIRATA, Naoshi[3] ; JORDAN, Thomas[4] ; LIUKIS, Maria[4] ; MARZOCCHI, Warner[5] ; RHOADES, David[2] ; TSURUOKA, Hiroshi[3] ; WERNER, Maximilian[6] ; ZECHAR, Jeremy[7] ; CSEP WORKING GROUP, The[4]

[1]GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, [2]GNS Science, Avalon, Lower Hutt, New Zealand, [3]Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan, [4]Southern California Earthquake Center, University of Southern California, Los Angeles CA 90089, USA, [5]Istituto Nazionale di Geofisica e Vulcanologia, 00143 Roma, Italy, [6]School of Earth Sciences and Cabot Institute, University of Bristol, Bristol BS8 1RJ, UK, [7]Swiss Seismological Service, ETH Zurich, Zurich, Switzerland

The Collaboratory for the Study of Earthquake Predictability (CSEP) aims to improve our understanding about the physics and predictability of earthquakes through rigorous and prospective testing of earthquake forecast models. The system-science character of earthquake prediction research demands an open and collaborative structure for experimentation in a variety of fault systems and tectonic regions. CSEP Testing Centers in California, New Zealand, Japan, and Europe are being developed to provide adequate infrastructure for predictability research. CSEP is currently running prospective, automated evaluations of more than 350 models in various testing regions, e.g. California, New Zealand, Japan, Italy, and globally. We present the evolution of CSEP since its inception in 2007 and discuss results from several types of CSEP experiments. Finally, we describe how CSEP is expanding into other areas, including the testing of earthquake early warning systems, geodetic transient detectors, intensity prediction equations, ground-motion prediction models, and other types of hazard models.

Keywords: Earthquake forecasting, Seismic hazard, Statistical seismology, Earthquake statistics, Forecast testing

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SSS01-02 Room:419 Time:May 2 14:30-14:45

One-day earthquake forecasting experiment in Japan after the 2011 Tohoku-oki earthquake

HIRATA, Naoshi[1] ; TSURUOKA, Hiroshi[1*]

[1]Earthquake Research Institute, the University of Tokyo

An experiment for earthquake predictability in Japan started in 2009 with a framework of CSEP. We have conducted one-day, three-month, one-year, and three-year forecasting experiments with three different regions of Japanese Islands; all Japan including sea area, main lands without sea area, and Kanto area(Nanjo et al., 2011; Tsuruoka et al., 2012). We currently have 160 modes for three regions and four periods.We conducted a retrospect one-day forecast of aftershocks of the 2011 Tohoku-oki earthquake showing that all proposed models failed in consistency tests immediately after the mainshock but in several days some of the models recovered its performance of forecasting (Nanjo et al., 2012).A current method for short-term forecasting has limitation of a period of one-day, which is arbitrarily determined. A shorter time period may be necessary for very intensive seismicity. Seismic activities in Japan have changed very much after the 2011 Tohoku-oki event, which brought us an idea that current forecasting models should be modified. We will present some new results of one-day forecasting experiments in Japan to discuss how to get information about real time earthquake hazard to mitigate earthquake risk. A new method to test performances of a model is also proposed.

Keywords: Earthquake forecasting, One-day forecasting, seimicity, Tohoku-okiearthquake, Statistical seismology

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Prospective evaluation of 3-month testing class of the CSEP-Japan earthquake forecasts

TSURUOKA, Hiroshi[1*] ; HIRATA, Naoshi[1]

[1]Earthquake Research Institute, University of Tokyo

Collaboratory for the Study of Earthquake Predictability (CSEP) is a global project of earthquake predictability research. The primary purposes of the CSEP is to develop a virtual, distributed laboratory. The final goal of this project is to investigate the intrinsic predictability of earthquake rupture mechanisms.

One major focus of the Japanese earthquake prediction research plan 2009-2013 is testable earthquake forecast models. So, the Earthquake Research Institute joined the CSEP and installed in an international collaboration a testing center as CSEP-Japan for rigorous evaluation of earthquake forecast models.

A total of 160 models were submitted from all over the world. And CSEP-Japan started the prospective experiments from 1 November 2009. The models are currently under test in 12 categories, with 3 testing regions and 4 testing classes of different time spans (1day, 3 month, 1 year and 3 years). We evaluate the performance of the models in the official suite of tests defined by the CSEP (L, M, N, S, R, T and W tests) against authorized catalogue compiled by Japan Meteorological Agency.

CSEP-Japan testing center has conducted over 6-12 rounds tests for 3-month testing classes including 2011 Tohoku-oki earthquake. We will discuss these results of evaluation test of the prospective experiments, and checked the performance of the earthquake models.

Keywords: CSEP, Earthquake Predictability, Seismicity

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Does using Coulomb stress change information create quantifiable improvements in earthquake forecast models?

GERSTENBERGER, Matt[1*] ; STEACY, Sandy[2] ; MARZOCCHI, Warner[2] ; RHOADES, David[1]

[1]GNS Science. 1 Fairway Drive, Avalon, Lower Hutt, New Zealand, [2]Environmental Sciences Research Institute, University of Ulster, Coleraine, N. Ireland, [3]Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

The Darfield, New Zealand earthquake sequence has provided an interesting and active sequence for rigorous testing of earthquake forecast models that include Coulomb stress change information. Coulomb forecast models have long been discussed in the scientific literature as providing useful forecast information during aftershock sequences; however, a challenge that has limited our understanding of their ability is the difficulty in specifying such models so that they are prospective and unbiased. With the Darfield sequence we have the opportunity to use the Collaboratory for the Study of Earthquake Predictability (CSEP) earthquake forecast testing centre, that is already in operation in New Zealand, to develop Coulomb models in such a way. By taking advantage of archived data sets to provide all of the necessary inputs into the models, we are able to pseudo-prospectively test the models within the CSEP testing centre. An initial study by Steacy et al (2013) tested several models with Coulomb information. These models include a hybrid model with STEP (Gerstenberger, 2005), a rate-and-state based model, and several non-Coulomb models. Results of this study indicate that adding Coulomb information that was available 10-days after each main event, to a more traditional Omori-based model, provides a statistically improved forecast, even when attempting to test in an unbiased fashion. The experiment also highlighted significant differences when testing models retrospectively and pseudo-prospectively; these differences are driven by the reduced quality of data available to models in pseudo-prospective tests. Following this study, we are now implementing a larger experiment in collaboration with the European Union funded Strategies and Tools for Real Time Earthquake Risk Reduction (REAKT) project. In this experiment we are testing more than 20 Coulomb and non-Coulomb models within the NZ-CSEP testing centre. These models include hybrid statistical-Coulomb models and pure statistical and Coulomb models. We will discuss both experiments and their implications.

Keywords: Earthquake forecasting, New Zealand, CSEP, Coulomb, aftershock model, Christchurch

SSS01-05 Room:419 Time:May 2 15:15-15:30

Test of the argument for remote dynamic triggering by small mainshocks

PENG, Wei[1*]

[1]Wei Peng, [2]Shinji Toda

To understand earthquake interaction and forecast time-dependent seismic hazard, it is essential to determine whether static or dynamic stress change triggers most aftershocks and subsequent mainshocks. Felzer and Brodsky (2006) argued that the observed linear seismic density of small aftershocks with distance from small mainshocks is a product of the decay of seismic wave amplitude. They conclude that even small shocks can dynamically trigger remote earthquakes at distances more than ten source fault dimensions away. Richards-Dinger et al. (2010) counter-argue that the power law decay is an apparent product from independent aftershocks occurring along a large rupture zone or near-simultaneous occurrence in seismic swarms. To test the argument of Richards-Dinger et al. (2010), we use the Taiwanese earthquake catalog of the Central Weather Bureau Seismic Network, whose quality is as good as that in California and Japan. Further, we take an advantage of the absence of major inland earthquakes and significant swarms in the period, 2001-2011.

We follow the methodology of Felzer and Brodsky (2006) for selecting mainshocks using their declustering algorithm, and then seek all shocks that occurred within 5 minutes to make a diagram of linear aftershock density as a function of distance from mainshock. First we select as a mainshock any event that is not preceded by a larger shock within 3 days (t1) and 100 km, and that is not followed by a large shock within 12 hr (t2) and 100 km. The mainshocks and aftershocks are 2?M$<$3 and M?2 respectively. This yields 706 declustered mainshocks from the 110,157 candidate shocks, but the number of mainshock-aftershock pairs is just 56. We only find four pairs within 50 km distance range (the maximum considered by Felzer and Brodsky), which precludes any regression, while the others located further than 50 km are regarded as background. We then shorten the time period for both t1 and t2 to be 1.5 days and 0.25 days, which allows us to regress a power law slope of -1.16 ± 0.45 for the 35 pairs within the 50-km distance range. The pairs are located mostly along the northern part of the Longitudinal Valley fault zone where small swarm activity and M˜6 shocks often occur. We conclude that the much fewer ratios of mainshock-aftershock pairs in the Taiwanese catalog, in comparison to California and Japan, are due to lack of any large rupture and the absence of significant swarms in Taiwan, which supports the argument of Richards-Dingers et al. and renders the possibility that these small shocks are dynamically triggered untenable.

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Prediction performance of empirically defined foreshocks in the Izu region

MAEDA, Kenji[1*] ; HIROSE, Fuyuki[1]

[1]Meteorological Research Institute

1. Introduction

Foreshocks have been thought one of the most promising phenomena to predict large earthquakes. However, as the physical mechanism of foreshocks is not clarified yet, it is very difficult to distinguish them deterministically from background seismicity before a mainshock occurs. Therefore, empirical approach is one of the realistic ways to use foreshock activity as a precursor of a mainshock. We investigate probabilistic features of empirically defined foreshocks and search for the best parameters to define foreshocks which present relatively high performance to predict large earthquakes. Maeda (1996) and Maeda and Hirose (2012) proposed a foreshock definition which gives relatively high performance to predict large earthquakes along the Japan trench. In this study we basically apply the same method to the seismicity in the Izu region where swarm activities related with magma movements are frequently observed, and estimate the prediction performance based on empirically defined foreshock activities.

2. Method

The method to search for parameters for foreshocks that present high prediction performance consists of four steps. 1) To eliminate small aftershocks from the original data. 2) To define foreshock candidates as the activities that have number of Nf earthquakes with magnitude >= Mf during the period of Tf days in the segment of the size of D x D degree (latitude x longitude). 3) To set the alarm period of Ta days after a foreshock candidate during which a mainshock is expected to occur. 4) To search for the values of Tf, Mf, D, Nf, and Ta which give high prediction performance by the grid search method. The prediction performance is measured mainly by dAIC, which is defined as the difference of AIC for a stationary Poisson model and a model based on a foreshock activity, and additionally by alarm rate (AR: the fraction of mainshocks alarmed), truth rate (TR: the fraction of foreshock candidates followed by a mainshock), and probability gain (PG: the ratio of mainshock occurrence rate for predicted space-time to background occurrence rate).

3. Data and Results

By applying the above method to the earthquakes cataloged by JMA for the period of 1977 - 2013/06 in the Izu region (33.5N, 138.6E - 35.3N, 139.8E), we obtained the best parameters for foreshocks as Tf=3 days, Mf=3.0 D=0.2 degree, Nf=3, and Ta=5 days for the prediction of mainshocks with M>=5.0. The prediction performance is expressed as dAIC=473, AR=68% (=44/65), TR=23% (=46/196), and PG=225. We also confirmed that the distribution of interval time between foreshocks and mainshocks is better approximated by a power law like the modified Omori's aftershock distribution rather than an exponential distribution. The 26%(=20/77) of mainshocks that occurred within 5 days after the foreshocks have occurred within 4.8 hours after the foreshock. The distance distribution between foreshocks and mainshocks is also found to be better expressed by a power law. If we focus on the specific region of Off Ito (34.8N, 139.0E - 35.1N, 139.3E) where is one of the most active foreshock region, the prediction performance of the same foreshock definition measured by AR and TR, becomes as better as AR= 100% (=18/18) and TR= 37% (=15/41) with dAIC= 166, and PG= 105. As for the Off Ito region, the JMA have been operating an algorithm for predicting the swarm activity basing on the rate increase of volumetric strain observed near the region. When we compare the timing of issuing the prediction information about the swarm activity by the JMA with that of the occurrence of the foreshock defined above, we find that there is not much difference between them. This means that the foreshock activity in this region is strongly related to the crustal deformation before the mainshock.

Keywords: foreshocks, probabilistic prediction, prediction performance, alarm rate, truth rate, Izu region

Foreshocks and short-term forecasting: comparisons between real seismicity and synthetic catalogs

OGATA, Yosihiko[1*]

[1]The Institute of Statistical Mathematics

Some of the statistical characteristics of foreshocks in the Japan Meteorological Agency (JMA) earthquake catalog are similar to those in synthetic catalogs simulated by the space-time epidemic-type aftershock sequence (ETAS) model or even the space-time nonhomogeneous Poisson process. However, they are quantitatively different from each other. Also, the information gain of a foreshock probability forecasting for real seismicity is significantly larger in comparison with that of synthetic catalogs. We discuss the reasons for such differences between the JMA and the synthetic catalogs.

Keywords: Foreshocks, short-term forecasting, JMA earthquake catalog, synthetic catalogs simulated by ETAS model, statistical characteristics of foreshocks, foreshock probability forecasting

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Modelling the effect of fault geometry on earthquake triggering

GUO, Yicun[2] ; ZHUANG, Jiancang[1*] ; ZHOU, Shiyong[2]

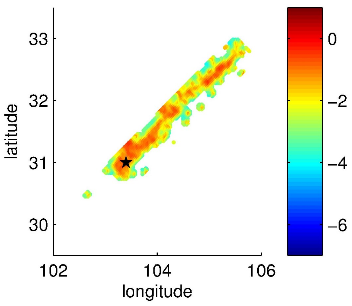
[1]Institute of Statistical Mathematics, [2]School of Earth and Space Sciences, Peking University

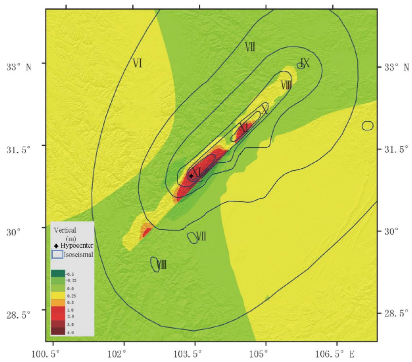
This study incorporates the rupture extensions of big earthquakes in the formulation of the Epidemic Type Aftershock Sequence model (ETAS) model, which is a point process model widely applied in the studies of spatiotemporal seismicity, rather than regarding every earthquake as a point in space and time. We apply the new model to the catalog from Sichuan province, China between 1990 and 2013, during which the Wenchuan Mw7.9 earthquake occurred in May 2008. Our results show that the modified model has better performance in both data fitting and aftershock simulation, confirming that the elliptical aftershock zone is caused by the superposition of isotropic triggering effects from each patch of the rapture extension. Also, using the technique of stochastic reconstruction, we found that the direct productivities of aftershocks from each patch on the mainshock fault are positively correlated to the slip distribution. We also confirm that the elliptical aftershock zone is caused by the superposition of isotropic triggering effects from each patch of the rapture extension.

Figure: (Left panel) Reconstruction results of aftershock productivity from each patch of Wenchuan mainshock fault based on the new ETAS model, which considers the rupture extension of large earthquakes instead of regarding all the earthquakes as point source. The values are in the logarithm scale. The Wechuan mainshock is marked by the black pentagon.

(Right panel) Contour image of the vertical component of the coseismic displacement distribution and isoseismal lines caused by Wenchuan mainshock.

Keywords: earthquake fault, ETAS model, earthquake forecast, aftershock





SSS01-09 Room:419 Time:May 2 16:30-16:45

History of network detection completeness in Japan

SCHORLEMMER, Danijel[1*] ; HIRATA, Naoshi[2] ; ISHIGAKI, Yuzo[3] ; NANJO, Kazuyoshi[2] ; TSURUOKA, Hiroshi[2] ; BEUTIN, Thomas[1] ; EUCHNER, Fabian[4]

[1]GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, [2]Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan, [3]Seismological and Volcanological Department, Japan Meteorological Agency, Tokyo 100-8122, Japan, [4]Institute of Geophysics, ETH Zurich, Zurich, Switzerland

An important characteristic of any seismic network is its detection completeness, which should be considered a function of space and time. Many researchers rely on robust estimates of detection completeness, especially when investigating statistical parameters of earthquake occurrence like earthquake rates. Contrary to traditional approaches, we do not estimate completeness using methods in which the completeness magnitude is defined as the deviation of the frequency-magnitude distribution from the linear Gutenberg-Richter relation. Here, we present a method based on empirical data only: phase data, station information, and the network-specific attenuation relation. For each station of the network we estimate a time-dependent distribution function describing the detection capability depending on magnitude and distance to the earthquake. For each point in time, maps of detection probabilities for certain magnitudes or overall completeness levels are compiled based on these distributions. Therefore, this method allows for inspection of station performances and their evolution as well as investigations on local detection probabilities even in regions without seismic activity.

We present a full history of network detection completeness for Japan and discuss details of this evolution. These results are compared with estimated completeness levels of other methods and with completeness levels in other regions of the World. We present scenario computations showing the impact of different possible network failures. All presented results are published on the CompletenessWeb (www.completenessweb.org) from which the user can download completeness data from all investigated regions, software codes for reproducing the results, and publication-ready and customizable figures.

Keywords: catalog completeness, earthquake recording, statistical seismology, earthquake statistics, earthquake forecasting, seismic hazard

SSS01-10 Room:419 Time:May 2 16:45-17:00

Collaboratory for the Study of Earthquake Predictability & Global Earthquake Model - Testing Center Software Development

BEUTIN, Thomas[1*] ; LIUKIS, Maria[2] ; MAECHLING, Philip[2] ; MAK, Sum[1] ; SCHORLEMMER, Danijel[1] ; YU, John[2]

[1]GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, [2]Southern California Earthquake Center, University of Southern California, Los Angeles CA 90089, USA

The Collaboratory for the Study of Earthquake Predictability (CSEP) aims to improve our understanding about the physics and predictability of earthquakes through rigorous and prospective testing of earthquake forecast models. CSEP operates four testing centers in California, New Zealand, Japan, and Europe running prospective, automated evaluations of more than 350 models. These testing centers are the technical infrastructure of CSEP and implement all procedures and protocols for rigorous testing and evaluation of earthquake prediction experiments. These experiments run in various testing regions and comprise forecast periods of one day to many years.

The CSEP testing center software system is the general infrastructure of all CSEP testing centers and is now being used for earthquake early warning systems, geodetic transient detectors, intensity prediction equations, and ground-motion prediction equations. We present the recent developments and introduce the structure of the software system.

Keywords: Earthquake forecasting, Seismic hazard, Statistical seismology, Earthquake statistics, Forecast testing, Software

SSS01-11 Room:419 Time:May 2 17:00-17:15

Lithospheric stress and deformation, and megathrust prediction

HONG, Tae-kyung[1*] ; LEE, Junhyung[1]

[1]Yonsei University, Department of Earth System Sciences, Seoul 120-749, South Korea

Lithospheres respond to stress load that is a major cause of earthquakes. Thus, understanding the lithospheric response before and during the megathrusts may allow us to find a way to predict megathrusts. We investigate the lithospheric responses for megathrusts with magnitudes greater than 8.7 since 2000 from precursory and coseismic events. The seismicity presents the cumulation or release of stress before and after megathrust, and discriminative spatial distribution of stress. Normal-faulting earthquakes were increased particularly around large slip regions at shallow depths after the megathrusts, which may be associated with lithospheric rebound and splay-fault development. The earthquake occurrence rate (b value) displays a characteristic slip-dependent feature. The earthquake occurrence rates were decreased with slip amount by forthcoming megathrust due to continuous accumulation of plate-driven stress and tectonic loading around the future rupture planes on slab

surface. The slip dependency of earthquake occurrence rates is enhanced with time until the occurrence of megathrust. The level of seismicity after megathrust is inversely proportional to that before megathrust, yielding the compatible average seismicity before and after megathrust over rupture regions regardless the slip amount of each subregion due to difference of accumulated stress depending the rock properties. It was also observed that the dynamic lithospheric response is highly associated with slip distribution on the rupture plane. Temporal changes of slip-amount-dependent b values are fitted well with an exponential function, suggesting an exponential increase of normal stress with time on locked region until the occurrence of megathrust.

Keywords: lithospheric stress, lithospheric deformation, megathrust, prediction, seismicity

SSS01-12 Room:419 Time:May 2 17:15-17:30

Global distribution of the earthquake-induced Schumann resonance anomalies

ZHOU, Hongjuan[1*] ; CAO, Bingxia[1] ; YU, Haiyan[1] ; QIAO, Xiaolin[1]

[1]Harbin Institute of Technology at Weihai, China

Schumann resonance (SR) is a global electromagnetic resonance phenomenon. Recently, SR anomalies before some earthquakes (EQs), which are considered to be concerned with the irregular disturbance of the lower ionosphere above the epicenters, are discovered. Although the examples are limited, we can see that the SR anomalies are usually different for different EQs. This paper concerns with the distinctions of SR anomalies observed at different locations for the same EQ, with the 2011 Magnitude 9.0 Tohoku-Oki EQ in Japan, before which significant SR anomalies have been observed in China, as an example.

Zhou et al. (2013) have found an anomalous SR affect observed at YS and AJ stations of China, associated with the Tohoku-Oki EQ. The anomalies were characterized by an increase in the intensity at frequencies from the first mode to the fourth mode in both magnetic field components, and the abnormal behaviors of the north-south magnetic field component primarily appeared at 0000-0900 UT 3 days prior to the main shock, about 2 h ahead of east-west magnetic field component. The above phenomena are shown in Figures 1 and 2. Figure 1 shows the deviations of the magnetic field amplitudes from the monthly averaged values observed at YS and QJ stations from 1 to 11 March 2011. Figure 2 shows the comparison of the amplitude differences of both magnetic fields on 8 March observed at YS station with 2 standard deviations which is calculated by the spectra over $\mp$15 days around 8 March, and the areas where the amplitudes are stronger than 2 standard deviations are marked with white. After the comparative analysis of the disturbed phenomena produced by the selected 10 sites shown in Figure 3 by numerical method with a locally EQ-induced disturbance model of the atmospheric conductivity in the day-night asymmetric Earth-ionosphere cavity, it is concluded that the SR anomalous phenomena before the Tohoku-Oki EQ have much to do with the excited sources located at South America and Asia marked with red circles in Figure 3.

Another 2 observing sites, with Sites 1 and 2 located at (N35^o, E137^o) and (N0^o, E110^o) respectively, are selected besides YS in order to compare the abnormal variations of SR magnetic fields observed at different locations under the same disturbance situation. The same simulation model and method as those in Zhou et al. (2013) are used, and the abnormal variations of both magnetic field spectra of SR observed at 3 sites are shown in Figures 4 and 5, with the source located at SA2 and AS4 as shown in Figure 3 respectively. It is obvious that the differences of the abnormal variations observed at different sites are distinct.

Further, Figures 6 and 7 show the global distributions of the anomalies for the first 3 modes of both SR magnetic field components under the excitation of the source SA2 and AS4 respectively. The color codes stand for the ratio of disturbed amplitude to the regular one, and the regions with green color represent the disturbed ratio lower than 1 and also include the possible nodal points which are the results of the simple model of point sources, while white to dark red colors represent the appearance of SR anomalies. It can be seen that the distribution of SR anomalies is very complicated, and is related to the relative locations of EQ epicenter, lightning currents and the observatories, and of course the EQ-induced disturbance of atmospheric conductivities.

The present simulations are done under the simple models of lightning and disturbed conductivity, which will be improved in the next studies.

Keywords: Schumann resonance, Tohoku-Oki earthquake, earthquake-induced Schumann resonance anomalies, day-night asymmetric Earth-ionosphere cavity

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