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Special issue

Developments in Earthquake Precursors Studies

Preface

This Special Issue of Annals of Geophysics is dedicated to present recent developments in the field of earthquake (EQ) precursors. Due to their potentially catastrophic nature, EQs have early attracted the attention of humans. During the last decades, a considerable amount of scientific effort has been devoted to the study of EQ precursors, aiming at EQ forecast. Prediction of large EQs, especially in the short-term, is of outmost importance for our society, since it could prevent, or at least restrict, their disastrous consequences, both in terms of infrastructure/material damages and in terms of casualties. It is clear that EQ preparation processes are complex and multifaceted, which call for a multidisciplinary approach. Many possible precursors have been reported and studied during the last decades, which include (just to mention some): foreshock activity, pre-slip effect, surface deformation, seismic electric signals (SES), ultra-low frequency (ULF) magnetic field anomalies, fracture-induced electromagnetic emissions (FEME) (fracture-induced electromagnetic radiation, FEMR), ULF/ELF (extremely low frequency) atmospheric electromagnetic radiation, atmospheric anomalies (such as SLHF, OLR etc.) and ionospheric (lower and upper regions) anomalies, lithosphere-atmosphere-ionosphere (LAI) coupling, even abnormal animal behavior.

However, EQ precursor studies are still considered a challenging research topic, even a controversial one according to part of the scientific community. The very existence of EQ precursors has been criticized by some scientists. Despite the accumulated evidence that have been published, even for the statistical correlation of some EQ precursors, sometimes the arguments have been extended to the extreme claim that any precursory activity is impossible. However, short-term EQ prediction is too important to humanity to be simply discredited. Therefore, the research focusing on possible EQ precursors should be continued, with the aim of building up a solid ground for EQ prediction, convincing even for the most reluctant.

Considering the difficulties associated with such factors as the highly complex, multifaceted nature, and rarity of large EQs, as well as subtleties of possible pre-seismic signatures, the multidisciplinary research related to EQ precursors is calling for extensive efforts and synergies. In this direction, it is considered very important to: (a) Develop both ground-based and space-borne instrumentation for observables which are EQ precursors or can provide information about EQ precursors. (b) Deploy and maintain networks of ground-based stations, as well as satellite missions for EQ precursor monitoring. (c) Continuously record any possible precursor to large EQs to accumulate sufficient amount of data, appropriate for different kinds of analysis. (d) Analyze precursors' data in a multidisciplinary and combinatory way to find any evidence of their association to EQs. (e) Study the possible mechanisms involved in the generation of different precursors. (f) Find possible relations among different precursors. (g) Beyond case-studies, perform statistical studies concerning individual precursors' as well as multi-precursors' presence before large EQs, even though this is difficult due to rarity of large EQs and/or rarity of long-term datasets. (h) Suggest multi-precursor schemes for the short-term prediction of large EQs. The articles included in this Special Issue cover most of the above aspects of the specific research field, as evidenced by the following brief description of them.

Apostol and Cune [2023] suggest a methodology (i) for the estimation of the time of occurrence of a main EQ event, based on the fitting of a previously published time-magnitude relationship, which indicates the presence of an abrupt magnitude-decreasing sequence of correlated foreshocks in the proximity of a mainshock, and (ii) for the estimation of the mainshock's magnitude based on the parameters of the background seismicity of the seismic region of interest. The application of the proposed methodology is demonstrated for six EQ cases, whereas its limitations are discussed.

Kiria et al. [2023] present a data-driven, machine learning binary classification, approach to EQ forecast. As inputs to their classifier, they use the variations of the statistical characteristics of geomagnetic field components, seismic activity, water level in deep boreholes and tides, whereas they compensate for imbalanced data. They apply the specific approach to five regions of Georgia and discuss the results.

In Wang [2023] a new method of predicting the magnitude M and failure time of a forthcoming EQ is proposed, based on observation data of two different precursors that obey a relation of the form $\log T = a + bM$, where T is the so-called precursor time (measured from the occurrence time of a precursor to the failure time of the forthcoming EQ). The article investigates the physics of the aforementioned relation and explains the constraints and requirements on the two such relationships (of two different precursors) in order to be usable for prediction. Preseismic radon concentration anomalies and gamma-ray emission changes observed at respective monitoring stations in Taiwan are used in a test example.

Malkotsis et al. [2023] focus on FEME/FEMR precursors. In this article they present in detail all information about the the hELlenic Seismo-ElectroMagnetics Network (ELSEM-Net), a telemetric stations network spanning all over Greece for the monitoring of FEME/FEMR, which counts almost 30 years of continuous operation. Specifically, after presenting the research incentive, the theoretical background, and information on the history of deployment of the network, they give detailed information about the specially developed instrumentation and the management of the network. Moreover, they present the analysis of selected observations associated with recent strong EQs that hit Greece, using a most recently introduced time series analysis method based on wavelet analysis to achieve a coarse-graining that permits the extraction of dynamics information from noisy data.

Kachakhidze et al. [2023] present a suggestion on the source of electromagnetic anomalies at different wavelengths in relation to the fault length of the upcoming EQ as inferred from its magnitude, further focusing on VLF/LF and ULF anomalies as possible EQ precursors.

Hayakawa et al. [2023] deal with the study of Schumann resonance anomalies related with two successive EQs (M~7) occurred on 2021 offshore Tohoku, Japan, as observed from a relatively close distance (~500 km) at stations of the Chubu University ULF/ELF network. By comparative analysis of modeling results and observational data, they show that the observed anomalies might be attributed to two types of seismogenic modifications in the lower ionospheric profile: the compression or the expansion of the vertical profiles of mesospheric conductivity over the EQ epicenter

Chen et al. [2023], using data from a multi-instrument array (referred to as the Monitoring Vibrations and Perturbations in Lithosphere Atmosphere and Ionosphere –MVP-LAI– system) and the BeiDou navigation system geostationary satellites, observed that enhancements in ground vibrations, air pressure, geomagnetic data, and total electron content (TEC) occur at common frequencies of ~5 mHz a few days before EQ occurrence (for the successively occurred, within 4 h, 21 May 2021 M6.4 Yangbi EQ, that occurred in Yunnan, southwest China, and M7.4 Maduo EQ, occurred in northwest China, approximately 1000 km away from the Yangbi EQ). Based on the fact that this frequency roughly agrees with the resonance frequency (~4 mHz) from the surface to the upper atmosphere, they suggest that two resonance systems control the observed responses from multiple geophysical parameters (lithosphere resonance before the failure of the crust and atmospheric resonance, which affects multiple geophysical parameters), further enhancing the understanding of LAI coupling.

Sorokin and Novikov [2023], starting from the observation that an injection of charged aerosols into the atmosphere in the epicentral EQ area has been detected before main EQs, suggest a model for the explanation of preseismic TEC perturbations. Their model is based on the idea that the spatial distribution of TEC arises as a result of the combined action of two factors, and its nature depends on the relationship between them. One factor is an electro motive force in the surface layer of the atmosphere, resulting from the aforementioned injection of charged aerosols, which initiates a perturbation of the electric current in the global circuit and the electric field appearance in the ionosphere and the other factor is the already established fact that TEC disturbance arises as a result of the heating of the ionosphere by electric current and the plasma drift in the electric field of this current. Based on the proposed model, the numerical study of the spatial distribution of TEC in the ionosphere is possible for a given horizontal distribution of the concentration of charged aerosols in the atmosphere near the Earth's surface.

Tachema et al. [2023] present a case study of seismogenic ionospheric anomalies. Specifically, they used selected data from many GPS/GNSS stations to compute local vertical TEC measurements and, using spherical harmonic analysis, to produce a sequence of high (temporal and spatial) resolution grid-based maps of the electron content of the ionospheric F2 region over the epicentral zone of the 2016 Mw = 6.4 Al Hoceima, Morocco, EQ. By means of statistical and wavelet analysis, they identified ionospheric TEC irregularities a few days before the aforementioned EQ.

Contadakis et al. [2023] investigate a time period of intense seismic activity in Greece during October 2020 using TEC data from GNSS stations closer to the epicenters of the 6 considered EQs. Applying both spectral and statistical analysis on the TEC variations they report increase in the TEC turbulence band upper limit f_0 as approaching the occurrence time of the EQ and statistical anomalies in TEC variations exceeding $+3\sigma$ a few days before the EQ.

Politis et al. [2023] present a multi-method analysis of VLF sub-ionospheric propagation data recorded by a receiver in Athens, Greece, before two strong EQs that occurred in north-central mainland Greece sequentially, on 3 and 4 March 2021, with very close epicenters, to investigate for possible EQ-related anomalies of the lower ionosphere. Specifically, they applied the "nighttime fluctuation method" (NFM), as well as, the "terminator time method" (TTM) in order to reveal any statistical anomaly in the nighttime amplitude recordings within 15 days before each one examined EQs, as well as Morlet wavelet scalogram analysis of the same nighttime data searching for possible imprints of wave-like structures during the same time period, and finally criticality analysis by applying the "natural time" (NT) analysis method to the daily-valued NFM VLF propagation quantities, and subsequently applied the "method of critical fluctuations" (MCF) to the raw nighttime amplitude VLF recordings, to check for any criticality signatures up to two weeks before the examined EQs. They found multiple indications that the lower ionosphere was indeed disturbed due to the preparation processes of the above-mentioned EQs, offering different types of seismogenic indications.

Sasmal et al. [2023] focus on the acoustic and electromagnetic channel of LAI coupling, using ground- and satellite-based data, in a multi-parametric study of seismogenic anomalies during the 2021 Crete, Greece, EQ (M = 6.0). Specifically, they present the Atmospheric Gravity Wave (AGW) in the acoustic channel using the temperature profile computed from the SABER/TIMED instrument, they analyze the ionospheric TEC recorded by the GNSS-IGS station DYNG in Greece in terms of the electromagnetic channel, as well as the acoustic channel anomaly by computing the wave-like structures in the small-scale fluctuation of the TEC profile. They also compute energetic (30 to 100 keV) electron precipitation in the inner radiation belt from the NOAA satellite and compute the magnetic field and electron density profile using SWARM satellite data. All the parameters show significant seismogenic anomalies (mostly enhancement) before the EQ. Finally, they present a comparison using the anomalies in each studied parameter to show each parameter's temporal and spatial sensitivity.

Ouzounov et al. [2023] report anomalies in the UHF and SHF bands (specifically at 1.8 and 3.5 GHz) signals received by receivers located in SW Bulgaria, while the transmitted signals (Bulgaria's standard cellular communication network) were of constant level, days/hours before EQs, even far from the observation region. Specifically, they present observations before four significant EQs in the area: (1) M5.6 on May 22, 2012, in Bulgaria, (2) M6.9 on May 24, 2014, in the Aegean Sea, Greece, (3) M6.5 on Nov 17, 2015, Lefkada, Greece, and (4) M6.3 of May 12, 2017, in Western Turkey. The origin of the observed anomalies is examined within the LAI coupling framework.

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