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Editorial: Pre-earthquake observations and methods for earthquake forecasting and seismic hazard reduction

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Editorial on the Research Topic
Pre-earthquake observations and methods for earthquake forecasting and seismic hazard reduction

Introduction

Understanding the governing principles, which include long-term tectonic loading, sluggish nucleation, and rapid fracture propagation, enables estimation of the stress level and change during geophysical observations in seismically active locations. The first step in earthquake forecasting is the identification of those factors whose space-time dynamics can be linked to the crustal deformations that precede earthquakes. Significant progresses have been made in analysing earthquake spatial-temporal correlations, clustering, and the development of seismicity patterns, paving the way for the possibility of earthquake prediction. In addition, earthquake physics addresses fundamental questions in seismology, such as how earthquakes form, how seismic rupture begins, propagates, and ends, what role long-term and short-term processes play in earthquake triggering, what role fluids play in earthquake triggering, and what relationship exists between fault dynamics, energy, friction, and other physical parameters of the focal zone. Recent advances in seismological and non-seismological observations have resulted in a variety of data, which have significantly increased our ability to investigate earthquake-related processes at multiple scales. In addition to established earthquake occurrence patterns and probabilistic models, a wealth of newly accessible non-seismological data gathered on a global scale has opened new roads for systematic study and model validation. Ground-based or satellite-based geophysical and geochemical observations, ranging from ground deformation patterns to pre-earthquake changes (geochemical, electromagnetic, hydrogeological, geodetic, etc.), may be related to stress variations in the lithosphere preceding a large earthquake. A critical reevaluation of proposed techniques in

conjunction with state-of-the-art and original observations has been carried out in this volume with the purpose to identify most promising future research directions. The primary objective of the Frontiers in Earth Sciences Research Topic on Pre-Earthquake Observations and Methods for Earthquake Forecasting and Seismic Hazard Reduction is to provide an up-to-date view of the processes preceding earthquake occurrence that can be applied to the design of earthquake forecasting experiments aimed at validating their accuracy in desirable Test Site areas. The growing number of articles and Research Topic devoted to earthquake forecasting, attests to a new attitude towards earthquake forecasting. New observables are constantly proposed, taking advantage from the large amount of data provided by new Earth observation systems and from increased computational power. Nonetheless, efforts to convert such elusive data into precisely defined ones are still limited. Operational earthquake forecasting methods, in particular, should be testable and confirmed by evidence. The set of errors, namely, the rates of failure and the space-time extent of alarms, in comparison to those obtained from the same number of random guess trials, allows for the evaluation of the effectiveness of the forecasting method. A necessary emphasis has been devoted on continuous statistical testing of the relevance and confidence of the precursors in order to evaluate and continue to improve the performance of the forecasts. Observations and physical models suggest that several processes in the lithosphere of the Earth are predictable, but only after extensive averaging and up to a certain limit. Consequently, earthquake forecasting necessitates a holistic approach and should be posed as an integrated, multi-scale process, narrowing the magnitude range, expected territory, and time of occurrence within the constraints imposed by physics and data uncertainties. Understanding governing laws, ranging from long-term tectonic loading and slow nucleation to rapid rupture propagation, can aid in estimating the stress state and temporal evolution of geophysical observables in seismically active regions. Reducing the space-time uncertainty of forecasts requires the use of additional, independent, and trustworthy information, which can be provided by multidisciplinary observations and recording of natural observables at various space-time scales. With this Research Topic, we present the current state of research Pre-Earthquake Observations and Methods for Earthquake Forecasting and Seismic Hazard Reduction, with a particular emphasis on:

a) Systematic analysis, physical interpretation, and modeling of pre-earthquake processes; Yun Zhou, Lisheng Xu, Jianping Wu, Chunlai Li, Lihua Fang, and Pan Pan, Seismicity of the repeating earthquake clusters in the northern Xiaojiang fault zone and its implications.
Jing Zhao, Zhengyi Yuan, Jinwei Ren, Zaisen Jiang, Qi Yao, Zhihua Zhou, Chong Yue, Jun Zhong, and Anfu Niu, Acceleration of deep slip along the Longmenshan fault plane before the 2008 M8.0 Wenchuan earthquake.

b) Model validation and statistical assessment of proposed physical-based precursors; Zhiwei Zhang, Chuntao Liang, Feng Liong, Min Zhao, and Di Wang, Spatiotemporal Variations of Focal Mechanism Solutions and Stress Field of the 2019 Changning Ms6.0 Earthquake Sequence.

c) Statistical methods and issues in earthquake forecast validation; Renata Rotondi and Elisa Varini, Temporal variations of the probability distribution of Voronoi cells generated by earthquake epicenters.
Chong Yue, Ping Ji, Yali Wang, Huaizhong Yu, Jin Cui, Chen Yu, and Yuchuan Ma, Evolution characteristics and mechanism of the Load/Unload Response Ratio based on strain observation before the Jiuzhaigou MS7.0 earthquake.

d) Analysis of input data and requirements for real-time model testing; Jinhan Xie, Shanshan Yong, Xi'an Wang, Zhenyu Bao, Yibin Liu, Xing Zhang, and Chunjiu He, Weekly earthquake prediction in a region of China based on an intensive precursor network AETA.

e) Time-dependent seismic hazard assessment based on space-time characterization of impending earthquakes; Aybige Akinci, Irene Munafò, and Luca Malagnini, S-wave Attenuation Variation and its impact on Ground Motion Amplitudes during 2016–2017 Central Italy Earthquake Sequence.

f) Geophysical interpretation of non-seismological parameters associated with crustal deformation processes Yang Xing, Zhang Tie-bao, Lu Qian, Long Feng, Liang Ming-Jian, Wu Wei-Wei, Gong Yue, Wei Jia-Xi, and Wu Jia, Variation of thermal infrared brightness temperature anomalies in the Madoi earthquake and associated earthquakes in the Tibetan Plateau (China);
Jinhan Xie, Shanshan Yong, Xi'an Wang, Zhenyu Bao, Yibin Liu, Xing Zhang, and Chunjiu He
Mehdi Akhoondzadeh, Angelo De Santis, Dedalo Marchetti, and Xuhui Shen, Swarm-TEC satellite measurements as a potential earthquake precursor together with other Swarm and CSES data: the case of Mw7.6 2019 Papua New Guinea seismic event.
Pan Xiong, Cheng Long, Huiyu Zhou, Roberto Battiston, Angelo De Santis, Dimitar Ouzounov, Xuemin Zhang, and Xuhui Shen, Pre-earthquake ionospheric perturbation identification using CSES data *via* transfer learning.

g) Time series analysis of geophysical and geochemical parameters; Chenhua Li, Xiaocheng Zhou, Jingchao Li, Lei Liu, Hejun Su, Ying Li, Miao He, Jinyuan Dong, Jiao Tian, Huiling Zhou, Gang Gao, Caiyan Zhang, and Zhixin Luo, Hydrogeochemical Characteristics of Thermal Springs in the Qilian-Haiyuan Fault Zone at northeast Tibetan Plateau: Role of fluids and seismic activity.

h) Modeling of pressure fluctuation in deformation processes; Wei Shi, Hanchao Jiang, G. Ian Alsop, and Guo Wu, A continuous 13.3-ka paleoseismic record constrains major earthquake recurrence in the Longmen Shan collision zone.

i) Slow-slip geodetic precursors; Jiangtao Qiu, Lingyun Ji, Liangyu Zhu, and Qingliang Wang, Present-day tectonic deformation partitioning across south Tianshan from satellite geodetic imaging.

j) Modeling of chemical and physical parameter variations in faulted regions; Guo Guangmeng, On the relation between anomalous clouds and earthquakes in Italian land.

k) Spatial and temporal variation of geochemical and hydrogeological features in seismic areas and their relationship to faults and seismic activity Mingbo Yang, Guiping Liu, Zhe Liu, Jingchen Ma, Zhiguo Wang, Peixue Hua, Xiaoru Sun, Kongyan Han, Bowen Cui, and Xiaodong Wu, Geochemical Characteristics of Geothermal and Hot Spring Gases in Beijing and Zhangjiakou-Bohai Fault Zone.

l) How possible scientific results on earthquake forecasting may be provided to decision-makers in a useful way
Xia Chaoxu, Nie Gaozhong, Li Huayue, Fan Xiwei, Zhou Junxue, Yang Rui, and Zeng Xun, Research on lethal levels of buildings based on historical seismic data.

Conclusion

This volume addresses the physical processes that occur in the Earth's crust before the initiation of earthquakes with the purpose to set up methods oriented to earthquake forecasting and to seismic hazard reduction. Numerous newly available seismological and non-seismological data collected on a global scale, present new opportunities for systematic study and model validation. Several geophysical and geochemical measurements obtained by ground-based or satellite-based methods, ranging from ground-associated deformation patterns to pre-seismic alterations, may be associated with stress variations in the lithosphere prior to an eventual large earthquake. We believe that an objective reevaluation of the proposed methods, along with state-of-the-art and novel observations, can aid in elucidating most promising research avenues. The primary objective of the Frontiers in Earth Sciences Research Topic on Pre-Earthquake Observations and Methods for Earthquake Forecasting and Seismic Hazard Reduction is to provide a current view of current knowledge of processes preceding earthquake occurrence, which can be used to set up earthquake forecasting experiments to test their accuracy in large and small Test Site areas.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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