MERC PhD Project Proposal 2023/2024

Title of the research project:

Improvement of earthquake forecasting modeling and implications in terms of seismic hazard and risk

Keywords (up to five)

earthquake forecasting; seismic risk; model validation

Supervisors (at least two from two different areas):

Supervisor 1: Warner MARZOCCHI, warner.marzocchi@unina.it, +39 335 349759; https://www.docenti.unina.it/warner.marzocchi; geophysics, earthquake and seismic hazard forecasting

Supervisor 2: Mario DI BERNARDO mario.dibernardo@unina.it; https://www.docenti.unina.it/mario.dibernardo; physics of complex systems

Supervisor 3: Iunio IERVOLINO, iunio.iervolino@unina.it; https://www.docenti.unina.it/iunio.iervolino; earthquake engineering, risk modeling

Project description (max 5000 characters)

Earthquakes do not occur completely random. The most striking departure from a full random process is the space-time earthquake clustering, which is particularly pronounced in time windows of days to weeks as in aftershock sequences after large earthquakes, but it may be still relevant for a decade, or even longer. This clustering is usually modeled through Hawkes self-exciting processes, like the Epidemic-Type Aftershock Sequence model (ETAS), which has proved to describe well the evolution of time during complex seismic sequences, like the recent Amatrice-Norcia sequence. One of the most remarkable features of ETAS is the so-called "magnitude-independence" assumption, which represents a major obstacle to enhance the earthquake predictability skill. In fact, this assumption states that the preparatory phase of large and small earthquakes is indistinguishable, implying that the probability of a large earthquake is bounded by the probability of sampling the right tail of an exponential distribution (the so-called Gutenberg-Richter law).

This project aims to improve earthquake forecasting in several ways, and to explore the consequences in terms of seismic hazard and risk at different time horizons. The research will greatly benefit from the ongoing development of innovative high-quality earthquake catalogs. Instead of pursuing the (so far elusive) silver-bullet approach, i.e., the heuristic search for diagnostic precursors to predict with high accuracy large earthquakes in small time-space-magnitude windows, the project will follow the so-called brick-by brick approach, i.e., a systematic improvement of understanding in the physics of the earthquake preparatory phase. Eventually, just increasing our forecasting capability up to a few tens of percent it would be a huge step ahead.

First, the candidate has to explore innovative procedures and/or physical frameworks that are not commonly used in seismology (e.g., physics of the complex systems) to characterize the evolution of the elastic energy release during seismic sequences; the goal is to explore earthquake predictability in general, and to find new physical parameters to describe and characterize seismic sequences, beyond the existing ones. This point is also preparatory to the next.

Second, the candidate has to explore the empirical and/or physical modeling of earthquake sequences through new and cutting-edge approaches (e.g., Deep Learning) to characterize seismic sequences which anticipate large shocks with respect to sequences that end without major events; the findings may allow seismologists to overcome the "magnitude-independence" assumption, increasing markedly earthquake predictability.

Third, any improvement in earthquake predictability has to be translated in new earthquake forecasting software codes that will be submitted for prospective validation in the framework of the international Collaboratory for the Studies of Earthquake Predictability (CSEP; https://cseptesting.org/). Indeed, model testing is the only way to measure the gain in knowledge brought by the new forecasting models.
Furthermore, the candidate is expected to work in synergy with the CSEP team to enhance the testing phase of the earthquake forecasting models.

Fourth, the candidate has to inspect the capability of the earthquake forecasting model to produce synthetic catalogs (Turing-style tests), which mimic realistically the seismicity in quite different time horizons (from days to decades). This is essential for a practical use in terms of long-term seismic hazard and risk.

Fifth, the candidate will use the new earthquake forecasting models in terms of earthquake loss forecasting, i.e., to evaluate the time evolution of the dynamic seismic risk. A comparison with existing models will quantify the impact of the new earthquake forecasting models in terms of seismic risk. Eventually, the candidate has to interact with possible stakeholders to shape the format of the forecasting model for some specific applications.

Relevance to the MERC PhD Program (max 2000 characters)

The planned program is markedly interdisciplinary; the candidate has to have/develop strong skill in probabilistic calculations and statistics, physics of the earth and of complex systems, artificial intelligence, informatic, hazard analysis, engineering.

The planned research lies in the so-called Pasteur's quadrant, because it pursues a fundamental understanding of the earthquake preparatory phase, but with the important practical implication of seismic risk reduction for society. Regarding the scientific impact, the results of the project will be beneficial for the wide global scientific community that explores the earthquake preparatory phase from different research angles. The outcomes of the project earthquakes may have also a significant societal impact, because reliable and skillful earthquake forecasts over different time windows (from days to decades) are essential for establishing rational strategies to reduce the seismic risk and to enhance preparedness and resilience of the society.

Owing to MERC is still in its infancy as well as the interdisciplinary collaboration among MERC colleagues, the candidate and the supervisors will explore the possibility to find collaborations inside MERC on some specific topics.

Key references

C. Meletti, W. Marzocchi, V. D'Amico, G. Lanzano, L. Luzi, F. Martinelli, B. Pace, A. Rovida, M. Taroni, F. Visini (2020). The new Italian seismic hazard model (MPS19). Ann. Geophys., 64 (1), SE112

M. Herrmann, W. Marzocchi (2021). Inconsistencies and Lurking Pitfalls in the Magnitude–Frequency Distribution of High-Resolution Earthquake Catalogs. Seismol. Res. Lett., 92, 909-922.

D. Schorlemmer, M.J. Werner, W. Marzocchi, T.H. Jordan, Y. Ogata, D.D. Jackson, S. Mak, D.A. Rhoades, M.C. Gerstenberger, N. Hirata, M. Liukis, P. Maechling, A. Strader, M. Taroni, S. Wiemer, J.D. Zechar, J. Zhuang (2018). The collaboratory for the study of earthquake predictability: achievements and priorities. Seismol. Res. Lett., 89(4), 1305-1313.

W. Marzocchi, M. Taroni, G. Falcone (2017). Earthquake forecasting during the complex Amatrice-Norcia seismic sequence. Science Adv., 3, e1701239.

I. Iervolino, E. Chioccarelli, M. Giorgio, W. Marzocchi, G. Zuccaro, M. Dolce, G. Manfredi (2015). Operational (short-term) earthquake loss forecasting in Italy. Bull. Seismol. Soc. Am., 105(4), 2286-2298.

W. Marzocchi, A.M. Lombardi, E. Casarotti (2014). The establishment of an operational earthquake forecasting system in Italy. Seismol. Res. Lett., 85(5), 961-969.

Joint supervision arrangements

The supervision will be made through weekly or bi-weekly meetings (depending on the stage of the work), in person or online, to monitor the evolution of the research, to motivate the candidate, to share ideas and thoughts, and to suggest ways to fill the gaps of knowledge that may become evident at different stages of the program.
When needed, the meetings will involve other (MERC) partners of the research to address specific topics of the program.
Flexibility is the key for a successful supervision. Besides the planned meetings, more frequent interactions will be scheduled at critical stages of the proposal.

Location and length of the study period abroad (min 12 months)

The candidate will spend one year or more at the following institutes:

- University of Southern California – Southern California Earthquake Center (prof. Thomas Jordan) to learn and practice the innovative and pilot modeling used for California
- United States Geological Survey to learn and practice the earthquake forecasting system used in United States
- University of Edinburgh, UK (prof. Ian Main)

The exact time schedule will be defined at the beginning of the project

Any other useful information

The results of the project will be taken into consideration to improve the operational earthquake forecasting system at the Istituto Nazionale di Geofisica e Vulcanologia (INGV), which is the official information on earthquake hazard for the Italian Civil Protection.
At the same time, the new models can be used to improve the operational earthquake loss forecasting (OELF) models, which is a worldwide pioneering initiative to forecast the loss caused by earthquakes in a short-term time horizon.

The research has a strong link with the ongoing EU H2020 RISE project, where the supervisors are working package leaders.

Please return this form via email by no later than 9th February 2024 to merc@ssmeridionale.it