SSM
Scuola Superiore Meridionale

MERC PhD Project Proposal 2023/2024

Title of the research project:

3D/4D seismic imaging of elastic/anelastic properties of complex geological media

Keywords (up to five)

Seismic imaging, mechanical rock properties, volcanoes, fault structures

Supervisors (at least two from two different areas):

Supervisor 1 Aldo Zollo aldo.zollo@unina.it (Aldo Zollo - Top Italian Scientists Wiki), Seismology

Supervisor 2 Vincenzo Convertito, vincenzo.convertito@ingv.it, Seismology

Supervisor 3 Grazia De Landro, grazia.delandro@unina.it, Seismology
Supervisor 4 Guido Russo, guido.russo2@unina.it, Solid Earth Geophysics

Please include a description of the work to be carried out. State of the art, key research questions and project objectives, workplan and the methodological and application aspects of the project.
[add a page if needed]

Volcanoes and faults, as key players in shaping our planet's topography, harbor secrets within their inner structures that hold the key to understanding geological processes, potential hazards, and the very forces that shape the Earth's crust.
Techniques of seismic tomography imaging use waveform data collected at dense station arrays deployed at the Earth surface to investigate the mechanical properties of shallow crustal rock volumes beneath volcanoes or embedding segmented fault zones.
This PhD thesis project will combine velocity information with the anelastic attenuation properties as retrieved by absolute and double-difference seismic attenuation imaging techniques that adopt linearized, perturbative, or fully nonlinear optimization approaches. Parameter measurement and imaging techniques will be adapted and optimized to benefit of the high spatial waveform correlation resulting from the earthquake recording at dense networks and/or constellation of small-aperture arrays.
The tests sites of the project will be the volcanic area of Campi Flegrei, west of the town of Naples, and the Irpinia Fault systems in southern Apennines where massive seismic waveform data sets are now available form a decade-long monitoring period and provided by observation networks of INGV and UNINA.
The project ambitious goal is to develop and implement new seismic imaging tools, even considering the full waveform information, to gain deep insights into the physical process interaction between fault slip activation, fluid presence/migration and seismicity production in volcanoes and tectonic fault environments.
The project will develop along three main research directions: Observation, Imaging and Numerical modelling. In the Observation part, standard and new techniques will be investigated, tested, and applied to perform reliable and robust measurements of the observed quantities that will allow to estimate the source and attenuation parameters of concern.

The primary data set that will be used in this PhD thesis project are the discrete time signals recorded by dense seismic networks deployed in the volcanic and tectonic fault regions, test-areas of the project to monitor the background seismicity.
During the Imaging part, advanced 3D (space)-4D (space & time) tomographic techniques will be implemented and applied to reconstruct high-definition images of the subsoil structure in the project test areas. These images are represented in terms of spatially variable elastic and anelastic rock properties that will be interpreted according to the rock physical modelling which allows to downscale the microparameter properties to rock microparameters (porosity, consolidation, lithology, permeating fluid species and saturation, etc.).
The refined P and S arrival time readings also using signal processing techniques based on waveform cross-correlation, combined with P and S pulse duration measurements will form the basic observed parameter dataset to be inverted for determining P and S velocity and attenuation images using tomographic approaches. If the observation period is sufficiently long and the data-driven resolution of models in different consecutive observation windows is sufficiently high, the space-time evolution of the crustal volume rock properties under investigation can be inferred and interpreted in terms of possible fluid presence and migration.
The inferred images of the internal Earth structure will finally provide the basic ingredients for deformation, fracture, medium change processes in poro-elastic media using finite-element multiphysics equation solvers.
Numerical simulations for stress-strain-rupture processes in poroelastic heterogeneous media will be developed to study the interplay between medium macro-parameters and rock physical microparameters. The models will be able to combine mechanics and fluid dynamics, by simulating multi-phase fluid motion in porous media and computing the poroelastic response of the medium.

Relevance to the MERC PhD Program (max 2000 characters)

Briefly describe how this project fits within the scope of the MERC PhD program describing its interdisciplinary aspects, relevance in application and beneficiaries.

The proposed PhD projects fits different aspects of the MERC program. The project is focused on natural hazard risk evaluation linked to the presence of fluids in the Earth crust. It is already well known that fluid injected in the subsoil during exploitation activities may increase seismic risk. But fluids in the subsoil are also spontaneously produced by natural sources located at different depths in the crust. The impact of these fluids on risk is then an important research topic. The PhD project then focuses on the volcanic area of Campi Flegrei. The role of fluids in determining the now occurring bradyseismic crisis is widely recognized. Less clear is how the presence of fluids is related to different kind of hazards (seismic, for example). The proposed multidisciplinary approach that will be used to tackle the problem will give the student the possibility to manage both theoretical and practical aspects of scientific investigation relevant for risk assessment. The student will deepen his knowledge about many of the different problems involved in this research, giving him at the end of the project a superior qualification in the interdisciplinary study of complex systems. His acquired skills may be applied in the second proposed test area: Irpinia. In this tectonic environment the presence of natural fluids is recognized, but its link with the background seismicity (and hence with seismic risk) is only partly understood. It is worth underlining the practical and social impact the the results of the project may have on risk mitigation of densely populated areas.

Key references

- Amoroso, O., Russo, G., De Landro, G., Zollo, A., Garambois, S., Mazzoli, S., ... & Virieux, J. (2017). From velocity and attenuation tomography to rock physical modeling: Inferences on fluid-driven earthquake processes at the Irpinia fault system in southern Italy. Geophysical Research Letters, 44(13), 6752-6760.
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- D'Agostino, N., Silverii, F., Amoroso, O., Convertito, V., Fiorillo, F., Ventafridda, G., & Zollo, A. (2018). Crustal deformation and seismicity modulated by groundwater recharge of karst aquifers. Geophysical Research Letters, 45(22), 12-253.
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- di Uccio, F. S., Lomax, A., Natale, J., Muzellec, T., Festa, G., Nazeri, S., Convertito, V., Bobbio, A., Strumia, C., & Zollo, A. (2023). Delineation and Fine-Scale Structure of Active Fault Zones during the 2014-2023 unrest at the Campi Flegrei Caldera (Southern Italy) from High-Precision Earthquake Locations. Authorea Preprints (Under review)
- Guo, H., & Thurber, C. (2021). Double-difference seismic attenuation tomography method and its application to The Geysers geothermal field, California. Geophysical Journal International, 225(2), 926-949.
- Pride, S. R. (2005), Relationships between seismic and hydrological properties, in Hydrogeophysics, pp. 253–290, Springer, Netherlands.
- Schaff, D. P., & Waldhauser, F. (2005). Waveform cross-correlation-based differential travel-time measurements at the Northern California Seismic Network. Bulletin of the Seismological Society of America, 95(6), 2446-2461.
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- Virieux, J., & Operto, S. (2009). An overview of full-waveform inversion in exploration geophysics. Geophysics, 74(6).
- Zhang, H., and C. H. Thurber (2003), Double-difference tomography: The method and its application to the Hayward Fault, California, Bull. Seismol. Soc. Am., 93, 1875–1889, doi:10.1785/0120020190

Joint supervision arrangements

Describe joint supervision arrangements, e.g. weekly/monthly meetings with one or both supervisors, how will the joint supervision be split etc

The student's work will be structured around achieving the research objectives through a well-organized schedule of appointments. Updates will be provided through presentations highlighting key findings (weekly), or by scheduling meetings with one or more supervisors (at least monthly), depending on the topic, to discuss progress, address any challenges, and seek guidance as needed. Collaboration will be encouraged to foster a supportive and productive research environment.

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

Give details of the foreign research institution where the student will be host together with the full name and contacts of the foreign host. Please indicate if the foreign institution has already agreed to host the student and when the student is expected to travel abroad.

To be defined during the first year. Here several possibilities to be checked:

ISTERRE Université de Grenoble (FRA) - Ludovic Métivier (ludovic.metivier@univ-grenoble-alpes.fr) (researcher)

GFZ Potsdam (Germany) – Simone Cesca (simone.cesca@gfz-potsdam.de)

Any other useful information

E.g. involvement of stakeholders, industrial partners, other research institutions etc, funded research projects related to the proposed activity etc

INGV Osservatorio Vesuviano – Dr. Vincenzo Convertito

Please return this form via email by no later than 24th February 2023