Project Title: Development of an Operational Earthquake Forecasting System using the simplETAS Model

1. Introduction

Earthquake forecasting is a critical undertaking in seismology. It is essential for quantifying and better understanding earthquake risks, which ultimately improves disaster preparedness. This project aims to develop an **operational earthquake forecasting system** (Marzocchi et al. 2014) using the **simplETAS (Simplified Epidemic-Type Aftershock Sequence) model** (Mancini and Marzocchi 2023) to forecast seismicity in the next few hours/days in real-time based on recently observed seismicity. The target area will be the Italian territory.

ETAS is a widely used statistical model class for earthquake forecasting, which simulates the occurrence of earthquakes based on the size, time, and spatial distribution of prior earthquakes. This model is capable of capturing the clustering effect of earthquakes that drive foreshock-mainshock-aftershock sequences, making it ideal for real-time forecasting applications.

The system will be developed in Matlab or **Python**, with a focus on making it both operational and scalable for use in earthquake-prone regions in Italy.

2. Project Objectives

- **Objective 1**: Create an interface to download, on request, an updated seismic catalog of the target region.
- **Objective 2**: Provide a short-term forecast for the selected area, calculated with simplETAS using the updated seismic catalog.
- **Objective 3**: Create an interface to display real-time forecasts, including event probability for different magnitudes and ground motion forecasts.

3. Method

3.1 Data Collection and Preprocessing

The first step in developing the forecasting system is to gather historical earthquake data. This data can be sourced from the INGV earthquake catalog. The data will include:

- Earthquake magnitudes (Ml or Mw)
- Epicenter locations (latitude, longitude)
- Time of occurrence

This data will be preprocessed to remove inconsistencies and outliers, to evaluate completeness, and to convert it into a format suitable for the model.

3.2 simplETAS Model Implementation

The project will make use of the available simplETAS model, presently developed in Matlab. The project will convert this code to Python, apply it to the target area, and post-process the results to produce quantitative forecasts. In particular, the model's parameters will be optimized using local historical earthquake data, and the parameterized model will be used to produce the synthetic catalogs, which will be post-processed to produce the final forecasts. The key components of this procedure includes:

- **Test the spatial invariance of the parameters**: The downloaded catalog will be used to estimate the model's parameters and to test possible spatial variations.
- **Generating synthetic catalogs**: The parameterized model is used to generate a large number of synthetic catalogs simulating the potential evolution of seismicity.
- **Earthquake forecasts**: The synthetic catalogs will be post-processed to quantify the occurrence probability of future seismicity, for the target area and for different magnitude thresholds.
- **Short-term hazard (optional)**: The earthquake forecasts will be translated in forecast of (short-term) ground shaking using Ground Motion Models developed for the target area.

3.3 User Interface

A user-friendly interface will be developed to showcase the workflow, which will include visualizations such as:

- **Target area selection:** an interactive selection of the area of interest.
- **Past seismicity:** a spatial and temporal visualization of the downloaded seismicity in the target area.
- **Earthquake forecasts:** maps reporting the spatial distribution of the forecasts (i.e., indicating where earthquakes are most likely to occur) and timelines reporting the evolution the provided forecasts (i.e., indicating how the forecasts change in time); both visualizations for different magnitude ranges.
- **Short-term hazard:** hazard maps for different ground motion intensities/thresholds.

4. Expected Outcomes

By the end of the project, we expect to have:

1. A fully functional **earthquake forecasting system** capable of real-time forecasting of earthquake sequences, to be executed on demand.
2. A **user-friendly interface** for visualizing real-time forecasts.

5. Work Plan

The project will be carried out over a 3-month period, and involves a total workload of 150 hours (6 CFU) for 3 students, for a total of 450 hours.

The work will be divided into the following phases:

1. **Phase 1 (25 hours)**: Lecture-style teaching to introduce to the project and to assign individual tasks (group work)
2. **Phase 2 (90 hours)**: Implementing the codes, adapting the simplETAS model, and create a real-time forecasting system (individual work with interactions)
3. **Phase 3 (35 hours)**: Group work for integrating and testing the different components (group work)

The project will involve prof. Jacopo Selva, prof. Warner Marzocchi, and Dr. Marcus Herrmann.

References

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Marzocchi W., Lombardi A.M., Casarotti E., 2014. The establishment of an operational earthquake forecasting system in Italy, Seismol. Res. Lett., 85(5), 961–969..10.1785/0220130219