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Study of Seismic Hazard Anomalies Recognition Possibilities: Strategy of the SHARP Project

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Abstract

The trategy of the newly proposed SHARP project (Study of Seismic Hazard Anomalies Recognition Possibilities) is discussed in relation to development of the natural hazard forecasting methods. The main objective of SHARP is better understanding of the physics of the earthquake precursory phenomena especially of the seismo-electromagnetic origin. Principal aspects of the following topics are introduced: seismotectonic settings of investigated areas; advanced techniques for electromagnetic measurements in seismic active regions; methods of data processing applicable for extraction of the earthquake precursory signatures; modeling of the earthquake preparation processes. Some preliminary results of the SHARP project are presented.

1 Introduction

It is now evident that the earthquake preparation dynamics involves both seismo-tectonic and electromagnetic processes. So the combined seismic-electromagnetic measurements in tectonically active areas are of great importance for seismic hazard assessment. Here we introduce the new collaborative project SHARP (Study of Seismic Hazard Anomalies Recognition Possibilities) is based on joint seismic and electromagnetic observations in tectonically active regions. The principal objective of the SHARP project is to implement experimental, methodological and theoretical framework for identification of earthquake precursory signatures. Schemes for recognizing electromagnetic earthquake precursors are proposed in [1]. These schemes are based on seismotectonic settings, measuring equipment, methods of data processing, and modeling of the earthquake preparation processes. The corresponding technique has to be developed in the context of geological structure of the particular region. So, study of seismotectonic setting of test regions is one of the principal points of the SHARP project.

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2 Seismotectonic setting in the test areas

Two tectonically active areas in Europe are chosen as test regions for the SHARP project: the South front of the Hellenic arc, Crete Island, Greece (see its description in [2]) and the South Apennines chain, Italy (see [3]). Crete is located on the Southern Aegean area that is limited by the continental blocks of the European plate on the north, and by oceanic material of the African plate on the south. The African plate is subducted under the Aegean lithosphere, along the Hellenic arc, where seismic activity is very intense and extends up to a depth of 180 km. The relative motion across the Hellenic trench is NE-SW in this region and greater than 5 cm yr^{-1}. Shallow seismicity ($h < 60$ km) is the highest along the convex side of Hellenic arc but close to the coast of Crete. This location of Crete is the main reason for its complicated geological structure, the high tectonic rates, which become apparent by large active faults and the significant seismicity of the broader area of the island. The prevailing stresses in this area are extensional for shallow earthquakes and compressive for earthquakes of intermediate focal depths.

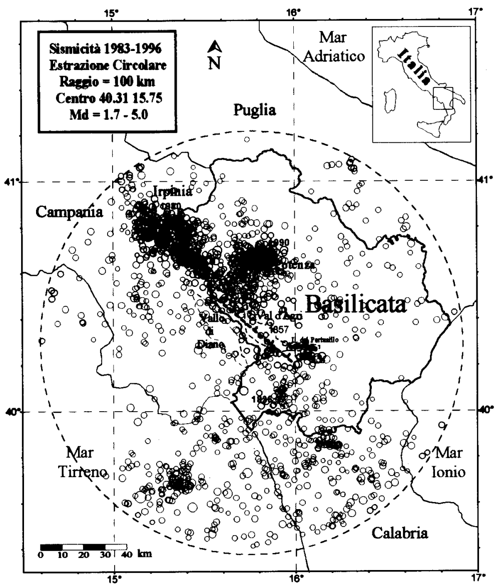

Figure 1: Seismicity distribution in one of the SHARP test regions (Basilicata, Italy, 1983–1996).

The South Apennines chain is an area with tectonic events originated from the collision of Africa and Europe continents. The main features of this region are the low structural and morphological elevation, the presence of the back-arc basin, the 'eastward' polarized coaxial tectonic pair of internal extension and compression to the eastern front, the high heat flow values in the internal parts of the belt, the deep foredeep, etc. The kinematics of W-directed subduction zones can account for these anomalies, and, in particular, it predicts the presence of a shallow asthenospheric wedge underneath the internal western side of the belt. From the seismological point of view, the Southern Apennine chain is one of the most active areas of the Mediterranean region (see Fig. 1). In this area (Irpinia region) a large normal-faulting earthquake occurred on November 23, 1980 ($Ms = 6.9$). The most historically relevant events date back to February 1826 (VIII degree on the MCS scale) and December 16, 1857 (XI MCS). The last one is well-known Val d'Agri earthquake. Seismic activity occurring after Irpinia earthquake of 1980 is characterized by medium intensity events, such as the earthquakes of May 5, 1990 ($M_D = 5.0$) and May 26, 1991 ($M_D = 4.7$), which were followed by intense aftershock activities.

3 Measuring technique

The combined seismic-electromagnetic measurements are planned to be carried out in the SHARP test regions. Particular emphasis will be put on the ultra-low frequency ($f = 0.001 - 10$ Hz) range — so-called ULF seismo-electromagnetic precursors of earthquakes. The ULF signals are expected to be extremely sensitive to structural changes in earthquake hazard systems during the preparation phase of strong events (see [1, 4, 5] for supporting arguments). The special measurement system LEMI 009 is developed for that purpose [6]. Methodology of seismic-electromagnetic tomography experiments covering fault zones is proposed on the basis of diffraction tomography method [7, 8].

4 Methods of data processing

The advanced mathematical methods are developed and applied to investigate the stochastic, subcritical, critical and supercritical stages in the evolution of the earthquake hazard systems. Among them, fractal and multifractal approaches appear to be the most promising ones. Application of those methods to regional seismicity distribution [9, 10] and ULF geomagnetic variations in seismic active regions [11] allowed us to reveal definite regularities in the behaviour of scaling (fractal and multifractal) characteristics of ULF time series and spatio-temporal distributions of seismicity on the preparation phase of strong seismic events. The most important regularities are clustering of seismicity and appearance of the flicker noise in the ULF frequency range. Those methods will be developed and complemented with contemporary methods of non-linear dynamics (construction of attractors, analysis of low-dimensional chaos via Lyapunov exponents, application of the Takens procedure, Kolmogorov entropy estimation), methods of neural networks, topological dynamics and Minkowski functionals [12, 13]. Geophysical diffraction tomography methods [7, 8] will be of the first priority for creation of optimal monitoring networks in the particular hazard zone of the SHARP test regions.

5 Modelling of the earthquake preparation processes

In the SHARP project, essential attention is given to creation of physical models of the tectonic processes responsible for generation of electromagnetic precursors of strong seismic events. Simulation of the crack network development in elastic body under external stresses has been recently performed in [9, 10]. It is shown that the crack network evolves from the state with random (chaotic) distributions of cracks and seismicity to the state with fractal clustered patterns. The results of simulations are supported by the results of case studies of regional seismicity dynamics before strong worldwide earthquakes. It is shown that variations of the multifractal characteristics of the seismicity distribution manifest certain tendencies in the process of evolution of the hazard system towards the main rupture. Modeling of the physical processes in the earthquake focal zone is implementing on the basis of the SOC (self-organized criticality) theory taking into account phenomenological model of the large-scale evolutionary processes between two violent earthquake suggested in [8]. A possibility of using the non-Abelian sandpile model for studying coupling effects between seismic activity and the multiscale spatial structure of faults has been recently analyzed [14]. It is shown that conductivity fluctuations of the model exhibit long-range correlations carrying useful information on system's stability. The shape of the simulated conductivity signals in the vicinity of global critical point has been found to be reminiscent of pre-seismic ULF electromagnetic emissions. This promising result is a good support for the subsequent development of the non-Abelian SOC model in the frame of the SHARP project.

6 Preliminary results of the SHARP project

As SHARP preliminary results, we describe the results of simulation of the crack network evolution and the solution of 2D problem of elastic waves propagation in elastic media containing multiple cracks. It is shown that the fractal dimension of synthetic seismograms of scattered waves decreases as the crack network evolves to pre-rupture state. It is also found that the spectrum of scattered waves undergos a transition from the multiscale to almost monoscale form. This indicates a transition of the crack network from random distribution to fractal ordered state with pronounced scaling dependencies. Thus, the realization of the SHARP project will help us understand better the earthquake preparation dynamics and physics of seismo-electromagnetic precursors of earthquakes. It will also provide a possibility to estimate perspectives of seismic-electromagnetic tomography experiments in tectonically active regions for creating the optimal monitoring networks in particular hazard zones.

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