Geophysical Research Abstracts
Vol. 15, EGU2013-11823, 2013
EGU General Assembly 2013

Investigating the fracture non-linear dynamics through multi-spectral time series analysis of fracture-induced electromagnetic emissions

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Electromagnetic (EM) emissions (EME) in a wide frequency spectrum ranging from kHz to MHz are produced by cracks' opening, considered as fracture precursors. Thus, their study constitutes a nondestructive method for the monitoring of the evolution of damage process at the laboratory scale. Earthquakes (EQs) are large-scale fracture phenomena in the Earth's heterogeneous crust. Accordingly, it has been suggested that fracture induced MHz-kHz EME, emerging from a few days up to a few hours before the main seismic shock permit a monitoring of the damage process during the last stages of EQ preparation.

The use of spectral decomposition techniques, namely Singular Spectral Analysis (SSA), Wavelets Analysis (WA) and their Monte Carlo counterparts (MC SSA and MC WA), as well as the revised Multi-Taper Method (MTM) for a reliable discrimination of fracto-EM emissions from the natural geo-EM field is proposed here; the well documented fracture-induced kHz EME time-series associated with the Athens' EQ (M=5.9, 7 September 1999) is employed as a test case. An adequately long time period (> month) prior to the occurrence of the EQ is considered in order to include all different phases of a large-scale fracture, from the "quite" period where only the geo-EM field and its modulation by the ionospheric variations is observed, to the final stages of the EQ preparation process where fracto-EM emissions occur.

The examined time series, recorded at the 10 kHz band and at a high temporal resolution (sampling frequency 1 Hz), is first split into three characteristic excerpts (a) the quiet period well (35 to 25 days) before the event, (b) the first epoch of the candidate pre-seismically active time period (8 to 4 days before the event), and (c) the final epoch of the candidate pre-seismically active time period ($\sim$3 days before the event until short after the event). The Maximum Entropy and Blackman-Tukey FFT methods are initially used for the preliminary evaluation of the time-series excerpts. Then, each of them is studied through the aforementioned spectral decomposition methods. Following standard methodology we attempt to decompose each of the partial time-series into statistically significant non-linear trends, oscillatory modes and noise, by testing each spectral component against red noise and alternatively against locally white noise background. Monte Carlo simulations of AR(1)-process red noise simulations are also utilized in this analysis phase and finally the significant temporal empirical orthogonal functions (T-EOFs) and the associated temporal principal components (T-PCs) are specified. In this way, a non-parametric (and non-empirical) signal to noise resolution is achieved and the reconstruction of the statistically significant signal can be realized by adding the associated Reconstructed Components (RCs).

By applying the aforementioned technique we reveal the significant signal characteristics for each period and try to interpret the underlying dynamics. Given the statistically significant reconstructed signal for each partial time-series we further attempt a comparison between their morphology (also using a spectral cross-correlation study) in order to detect similarities and differences mostly between the quiet and the active periods that could be signify the pre-seismic activity.