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Information entropy of earthquake populations in northeastern Italy and western Slovenia

G. Bressan [a], C. Barnaba [a], S. Gentili [a,*], G. Rossi [b]

[a] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – Centro Ricerche Sismologiche, Via Treviso 55, 33100 Udine, Italy
[b] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – Centro Ricerche Sismologiche, Borgo Grotta Gigante, 42/c, 34010 Trieste, Italy

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ABSTRACT

The spatio-temporal evolution of eight seismicity populations, preceding and following moderate earthquake sequences occurred in NE-Italy and W-Slovenia, are investigated by means of the normalized Shannon entropy and the fractal dimension. Three phases are recognized in the temporal seismic series. The period preceding the mainshock is characterized by oscillations of the Shannon entropy around a nearly constant level and by fluctuations of the fractal dimension. The phase of mainshock and aftershock sequences is characterized by a significant decrease of the Shannon entropy. A simultaneous marked decrease of the fractal dimension is observed in five cases. After the sequence, the entropy recovers the nearly constant trend before the mainshock and the fractal dimension is characterized by fluctuations. We interpreted the fluctuations of the normalized Shannon entropy and the fractal dimension caused by the coupling between the stress field and the mechanical heterogeneities of the crust that results in spatial and temporal fluctuations of the strain energy.

1. Introduction

The aim of the present work is to analyze the seismic sequences induced by moderate events in northeastern Italy and western Slovenia as a dynamic system by means of information entropy.

The spatial and temporal pattern of the seismicity in northeastern Italy and western Slovenia is rather complex. The time occurrence of seismicity appears random without clear regular trends, and most of the spatial pattern of seismicity cannot be resolved on well-defined fault planes. Peresan and Gentili (2016) applied the "nearest-neighbours" method of Zaliapin and Ben-Zion (2013) to the Istituto Nazionale di Oceanografia e Geofisica Sperimentale – OGS/CRS seismic catalog from 1977 to 2015. They found that the seismicity in the northeastern Italy and western Slovenia is characterized by a dominant Poissonian component and a limited clustering component consisting of seismic sequences. Bressan et al. (2016) emphasized that the seismicity spatial occurrence appears closely related to the variation of the mechanical properties of the crust, and its spatial organization is complex. The fractal analysis of the spatial distribution of the hypocentres (Correlation integral method) evidenced that the regional seismicity pattern, in general, fills only partially a plane, with the most common fractal dimensions comprised between 1 and 2. The Principal Component Analysis (PCA) of the same hypocentres evidenced planes with variable orientations. Gentili and Bressan (2007) investigated the spatio-temporal pattern of seismicity preceding moderate-sized earthquakes (coda-duration magnitude $M_D \geq 4.1$), with the Region-Time-Length (RTL) (Sobolev and Tyupkin, 1996) and Pattern Informatics Technique (PI) (Tiampo et al., 2002) algorithms. The seismicity appears distributed irregularly in space and time around the future mainshock epicenter, revealing more or less evident quiescences and anomalies in the earthquake rate. Furthermore, in correspondence of most of the aftershock sequences, and the local increase of events, a gap in the regional seismicity if observed, within a radius of about 30 km from the aftershock cluster, and lasting from about 1 to 6 months (Gentili and Bressan, 2008).

The spatio-temporal variability of the seismicity reflects the effect of the tectonic stress field applied to a crustal volume and can be represented as a physical system characterized by chaotic processes, whose level of organization can be quantified by the physical quantity entropy. The spatio-temporal evolution of the seismicity can be investigated with the Shannon's information entropy (1948) in order to characterize the complex dynamics of an earthquake population (Main and Al-Kindy, 2002).

* Corresponding author.
E-mail address: sgentili@inogs.it (S. Gentili).

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The Shannon's entropy calculates the probability of occurrence of different states during the evolution of a system. Within the wide literature regarding the application of the entropy concept to seismicity, Shannon's information entropy was applied to earthquake sequences by Matcharashvili et al. (2002), Telesca et al. (2004), Padhy (2004) and De Santis et al. (2011). The seismicity can be viewed as a process of damage evolution and fractal analysis can provide a quantitative measure of the pattern of the seismicity spatial distribution. The Shannon's information entropy and the fractal dimension are calculated for eight temporal seismic series, preceding and following moderate earthquake sequences (M_D of the mainshocks between 4.1 and 5.6) in northeastern Italy and western Slovenia regions during the period 1988–2015.

2. Data

We analyzed the seismicity preceding and following the moderate shocks here listed: 1988 February 1 M_D 4.1 (Mena88) (Fig. 1), 1996 April 13 M_D 4.3 (Claut96) (Fig. 2), 1998 April 12 M_D 5.6 (Kob98) (Fig. 3), 2002 February 14 M_D 4.9 (Sernio02) (Fig. 4), 2004 July 12 M_D 5.1 (Kob04) (Fig. 5), 2012 June 9 M_D 4.3 (Alp12) (Fig. 6), 2015 January 30 M_D 4.1 (Moggio15) (Fig. 7), 2015 August 29 M_D 4.3 (Kob15) (Fig. 8). The seismicity was recorded by the local seismic networks operated by the OGS and by the seismological survey of Slovenia, covering NE-Italy and W-Slovenia.

The seismic events were located by the HYPO71 program (Lee and Lahr, 1975). The crustal model used for the earthquake location consists of two layers and a half-space (depth 0–22 km with Vp = 5.85 km/s; depth 22–39.5 km with Vp = 6.8 km/s; depth > 39.5 km with Vp = 8.0 km/s; Vp/Vs = 1.78). We selected the earthquakes with GAP less than 180°. Table 1 shows the average horizontal (errh) and vertical errors (errv) of location. The values of magnitude are given in coda-duration magnitude M_D (Rebez and Renner, 1991).

The seismic events plotted in the maps of Figs. 1–8 are marked with different colours corresponding to different periods preceding and after the mainshock. The vertical sections show the spatial distribution of seismicity preceding the mainshock within ±10 km from the trace of cross-sections. Fig. 9a–h show the temporal evolution of earthquake magnitude.

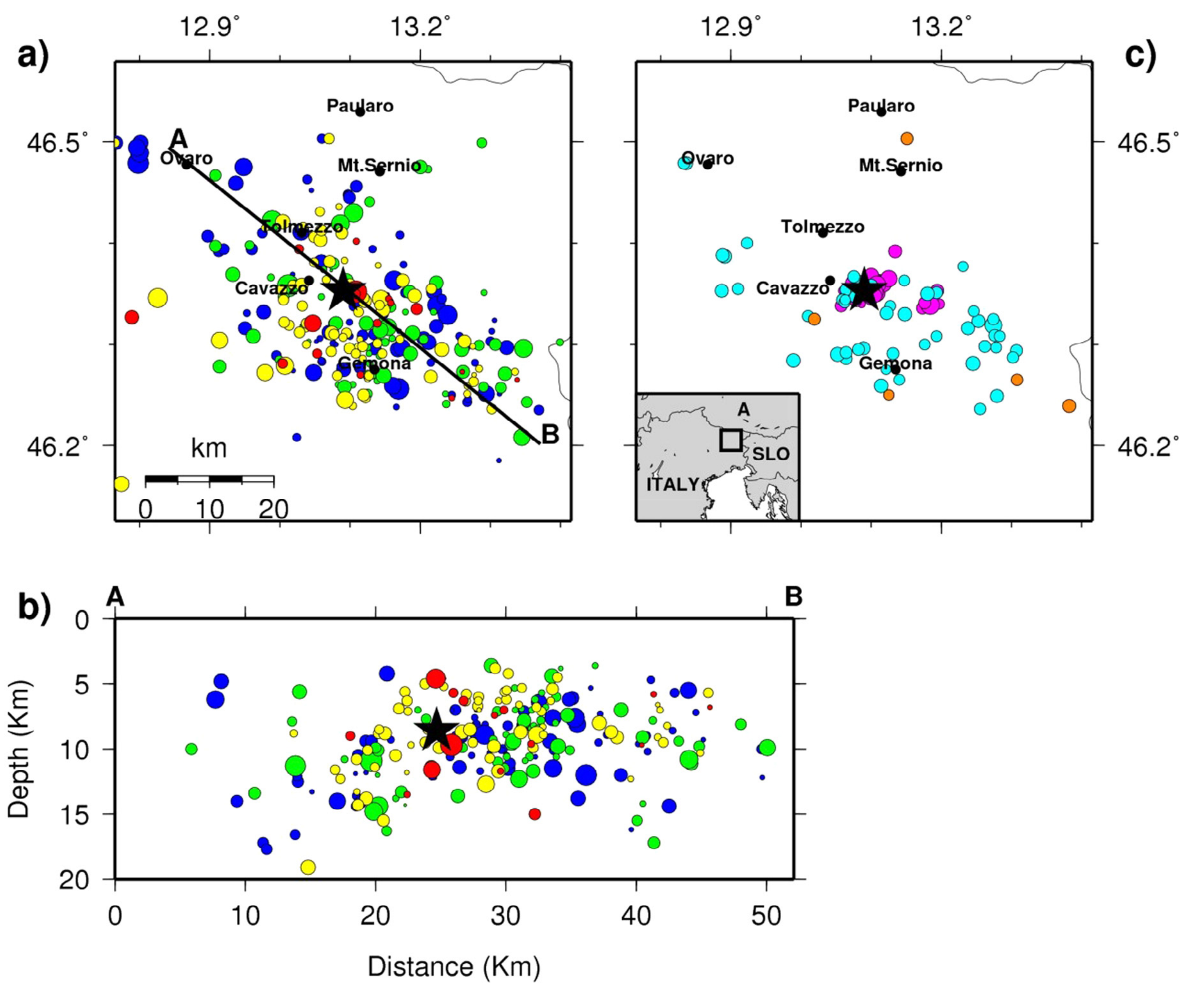

Fig. 1. Map (a) and cross-section (b) of the seismic events (dots) preceding the 1988 February 1 M_D 4.1 (Mena88) mainshock (black star). Blue: 1985 events, green: 1986 events, yellow: 1987 events, red: 1988 events. The earthquakes are plotted within ±10 km from the trace of the section. Map (c) of the seismic events following the mainshock. Fuchsia: aftershocks, orange: events occurred during the aftershock sequence, fair blue: events occurred later. Symbol dimensions are proportional to earthquake magnitude. The inset shows the location of the study area. A: Austria, Slo: Slovenia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)