Available online at www.sciencedirect.com

ScienceDirect

Physica A 387 (2008) 3647–3654

PHYSICA A

www.elsevier.com/locate/physa

Analysis of the spatial and temporal distributions between successive earthquakes: Nonextensive statistical mechanics viewpoint

Amir H. Darooneh[a,b,*], Cyruse Dadashinia[a,c]

[a] *Department of Physics, Zanjan University, P.O. Box 45196-313, Zanjan, Iran*
[b] *Sufi Institute, P.O. Box 45195-1547, Zanjan, Iran*
[c] *Iraninan Telecommunication Company, Zanjan Center, P.O. Box 4518613334, Zanjan, Iran*

Received 25 August 2007; received in revised form 16 February 2008
Available online 25 February 2008

Abstract

The spatial and temporal distributions between successive earthquakes are treated in the framework of nonextensive statistical mechanics. We find temporal distributions exhibit the power law behavior; q-exponential with $q > 1$. It means the earthquakes are strongly correlated in time. The spatial distributions obey the q-exponential form with $q < 1$. We also examine the dependence of the q exponent on magnitude range, covering period, time interval and size of the region where data are gathered. The conjecture of Abe et al. [S. Abe, N. Suzuki, Physica A 350 (2005) 588] has been examined for different categories of data. The results show a strange relation between q values of the spatial and temporal distributions.

PACS: 91.30.Dk; 02.50.Ey; 05.45.Tp; 89.75.Da

Keywords: Nonextensive statistical mechanics; Earthquake

1. Introduction and summary

Earthquakes are spatiotemporal phenomena with complex nonlinear dynamics which are not fully understood yet. The sliding of the fault plates on each other creates frictional stress that stores a huge amount of energy in the Earth's crust. When the frictional stress exceeds a threshold value a sudden rupture occurs in the plates, the stored energy is released and seismic waves are radiated through the outermost shell of the Earth [1]. We cannot study the rupture mechanism directly. The simulation of the earthquake occurrence is also inconceivable because we have not complete knowledge about the physical processes which happen in the Earth's solid shell or lithosphere. One of the most important ways for studying earthquakes and the internal structure of the Earth is analyzing the seismic waves. In this way the scientists can assess the earthquakes with some parameters such as magnitude, time of occurrence, depth and epicenter. The time ordered sequence of earthquake parameters may be considered as a time series. We may predict the occurrence of an earthquake if long range memory (correlation) has been seen in the seismic time series. Any long range memory may be expressed by a power law. Any power law exhibits a scaling feature in the time series and can

* Corresponding author at: Department of Physics, Zanjan University, P.O. Box 45196-313, Zanjan, Iran. Tel.: +98 2415152545.
E-mail address: darooneh@gmail.com (A.H. Darooneh).

0378-4371/$ - see front matter
doi:10.1016/j.physa.2008.02.050

be assigned an exponent. The power (scaling) laws are similar to the macroscopic laws in a thermal system which are extracted from the microscopic details of its constituents dynamics. Statistical mechanics enables us to perform such a task. The Omori law for temporal distribution of aftershocks [2] and the Gutenberg–Richter law [3] for magnitude and frequency of earthquakes are well known power laws in seismology.

Recently Christensen et al. [4,5] have shown that the distribution of the waiting time between successive earthquakes obeys a unified scaling law. The logarithmic plot of the rescaled waiting time distribution function in terms of the scaling variable has a linear tail that reveals the power law behavior of the distribution function. In this region the earthquakes appear as a correlated sequence of events therefore the occurrence of an earthquake is predictable. Several scaling laws were reported after this pioneering work [6–10].

Nowadays nonextensive statistical mechanics appears as a suitable framework for studying systems which exhibit the scale free nature [11]. Recently a model for earthquake dynamics was proposed which results in a q-exponential form for the energy distribution function. This form for the energy distribution includes the Guttenberg-Richter law as a particular case [12,13]. The Olami–Feder–Christensen model is one of the most interesting models which resembles real seismicity. Analysis on the dissipative OFC model shows the distribution for the energy difference between successive earthquakes has a q-Gaussian form [14]. Simulation of the two dimensional Burridge–Knopoff model for earthquakes results in a q-exponential form for the temporal distribution between successive earthquakes [15]. Abe et al. [16,17] used nonextensive statistical mechanics to explore the scaling laws in the seismic time series. By analyzing the seismic time series data in California and Japan they found the distribution of distance and time interval between successive earthquakes are nicely fitted by a q-exponential distribution. For the spatial distribution function $0 < q < 1$ whilst for the temporal distribution function $q > 1$. This means the temporal distribution function asymptotically behaves like a power law distribution.

In this work we use the same approach to explore the scaling laws in Iran seismic time series data. We compute the spatial and temporal distributions between successive earthquakes for different restrictive conditions. The results show temporal distributions are described by q-exponential function with $q > 1$ and a strong correlation has been seen among time intervals between successive events but their spatial distances are fitted with the q-exponential function with finite support; $q < 1$ correlated. Our study justifies the conjecture of Abe et al. [16] which states that the sum of the temporal and spatial q values for each data set is approximately equal to 2.

In the following sections we will consider these results in depth. The theoretical preliminary for understanding how we can compute distribution and q exponent is discussed in the second section. In the third section we will describe how we gathered and corrected the data and will explain the results of our analysis.

2. Theoretical preliminary

A new definition for entropy was introduced by Tsallis in 1988,

$$S_q = \left(1 - \sum_{i=1}^{\Omega} p_i^q\right) \Big/ (q-1), \tag{1}$$

where p_i represents the probability for occurrence of the i-th microstate of the system. The total number of microstates is shown by symbol Ω. The parameter q is an intrinsic parameter with a value greater than zero which demonstrates the correlation between the system constituents.

According to this definition the entropy has the nonextensive property when two systems are combined,

$$S(A+B) = S(A) + S(B) \pm (1-q)S(A)S(B). \tag{2}$$

This is the fundamental principle for the nonextensive statistical mechanics. All other quantities which are concerned with thermodynamics may be derived from it and also inherit the nonextensivity (nonintensivity) property. Nonextensive statistical mechanics seems to be a suitable candidate for describing systems with finite degrees of freedom [18,19], complex systems, self organized criticality, long range classical Hamiltonian systems and nonMarkovian processes with long range memory [11,20].

The physical distributions are obtained by maximization of the entropy under appropriate constraints,

$$\delta S^* = \delta\left[S_q - \alpha\left(\sum_{i=1}^{\Omega} p_i - 1\right) - \gamma\xi\right] = 0. \tag{3}$$