Statistical physics of earthquakes: Natural time analysis and Tsallis non-additive entropy

N.V. Sarlis, E.S. Skordas, P.A. Varotsos

Section of Solid State Physics and Solid Earth Physics Institute, Department of Physics, School of Science, National and Kapodistrian University of Athens, Greece.

We shortly review the application of Tsallis non-additive entropy [1] statistical mechanics -in the frame of which kappa distributions arise [2]- to the case of earthquakes. Within this context, a derivation of the fundamental Gutenberg-Richter law of seismicity is discussed and examples from various seismic prone areas, for example Japan and California, are provided. The results obtained when analyzing these seismic data in natural time are also summarized. We show that although some properties of seismicity may be recovered by the non-additive entropy approach, the correlations between successive earthquake magnitudes should be also properly captured by natural time analysis [3] in order to achieve a more accurate description of the experimental data. The importance of such correlations is strengthened by the observation that periods of long range correlated earthquake magnitude time series have been identified [4] a few months before all earthquakes of magnitude 7.6 or larger in the entire Japanese area from 1 January 1984 to 11 March 2011 (the day of the magnitude 9.0 Tohoku-Oki earthquake) almost simultaneously with characteristic variations of seismicity [5]. If geoelectrical and geomagnetic measurements are carried out, these characteristic variations appear approximately when low frequency abnormal changes of the electric and magnetic field of the Earth (less than around 1Hz) preceding strong earthquakes are recorded. The generation of such abnormal changes can be understood in the frame of Thermodynamics of point defects in solids when the gradually increasing stress in the future earthquake focal area reaches a critical value. A typical example is the case of the aforementioned magnitude 9.0 Tohoku-Oki earthquake in Japan in which anomalous geomagnetic field variations have been observed from 4 to 14 January 2011, i.e., almost two months before the main shock occurrence. The simultaneous appearance of precursory phenomena in two independent datasets (geomagnetic measurements, seismicity), which are shown to be also linked in space, is of key importance for understanding the physics of earthquakes.

[l] C. Tsallis, J Stat Phys **52**, 479 (1988).

[2] G. Livadiotis & D. J. McComas, J Geophys Res **114**, A11105 (2009).

[3] N.V. Sarlis et al., Phys Rev E **82**, 021110 (2010).

[4] P.A. Varotsos et al., J Geophys Res Sp Phy **119**, 9192 (2014).

[5] N.V. Sarlis et al., Proc Natl Acad Sci **110**, 13734 (2013).