Physica A 465 (2017) 62–65

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

A new physical model for earthquake time interval distribution

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HIGHLIGHTS

- This paper reports a new physical model for earthquake time interval distribution.
- For the earthquakes with magnitude $\geq M$, there existed $\lg N(>t) = c - dt$.
- The value d decreased with M.

ARTICLE INFO

Article history:
Received 16 May 2016
Received in revised form 2 August 2016
Available online 12 August 2016

Keywords:
Earthquake
Time records model
Log-linear distribution
Sand-dust storm
China

ABSTRACT

This paper reports a new physical model for time interval distribution of earthquakes, which was obtained by borrowing the idea from the research in the time interval distribution of sand-dust storms. Of the model, it was hypothesized that the earthquakes were induced by the magma movement inside the earth, and if the speed of magma $\geq$ threshold value U_t, the earthquakes with magnitude $\geq M$ occurred. With this model, it was obtained that for the earthquakes with magnitude $\geq M$ there existed $\lg N(>t) = c - dt$, where N was the number of time intervals longer than t; the value d decreased with M. This result was also verified by analyzing the earthquake data from the China Earthquake Networks Center (CENC).

1. Introduction

Statistical properties of time interval distribution of earthquakes have been frequently studied [1–16]. However, there is no uniform time interval distribution function and the most appropriate distribution function still remains under debate and open.

In our previous paper [17], a physical model was introduced in studying the duration of sand-dust storms. In the model, X represents the random signals of a normal Gaussian distribution with zero mean and variance of one; Xr is the threshold value. Events occur only when $X \geq Xr$. It was also proven that this model could be used in studying the time interval distribution [18]. From this model, while the threshold value Xr did not vary with time, the time interval distribution of log-linear type

$$\lg N(>t) = c - \mathrm{d}t \tag{1}$$

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http://dx.doi.org/10.1016/j.physa.2016.08.006
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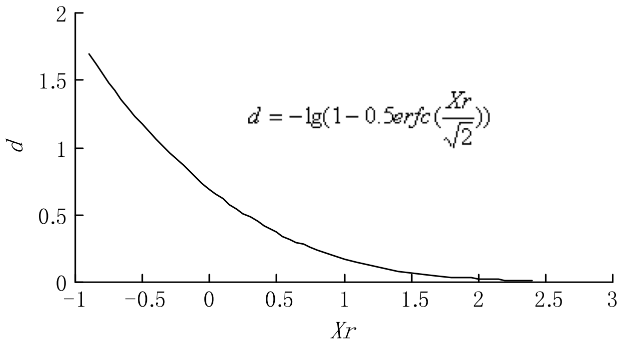

Fig. 1. Relationship between d and Xr given in Eq. (2).

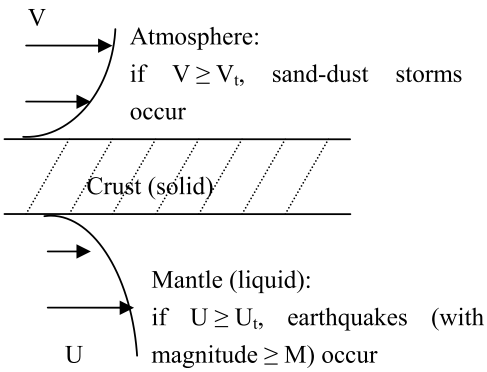

Fig. 2. Instruction chart for the similarity of earthquake and sand-dust storm.

could be deduced in theory, where N was the number of time intervals longer than t. The value of d decreased with Xr and

$$d = -\lg\left(1 - 0.5erfc\left(\frac{Xr}{\sqrt{2}}\right)\right), \tag{2}$$

where $erfc(x)$ was the complementary error function. The relationship described in Eq. (2) is shown in Fig. 1.

Borrowing the idea from above researches [17,18], the time interval distribution of earthquakes was studied in this paper. This work may provide a new idea to study the time interval distribution of earthquakes.

2. Model

From the knowledge about the structure of the interior of the earth, the earth is composed of multiple layers, which can be defined by earth crust, earth mantle, and the core. The earth crust is solid, while the earth mantle is liquid. The earthquakes occur as a result of fracture and a frictional slip of fault, which is induced by the liquid (magma) movement of the earth mantle.

Fig. 2 is the instruction chart describing the similarity of the earthquake and the sand-dust storm. The sand-dust storms are caused by movement of the atmosphere. It is supposed that while the wind speed $V \geq$ threshold value V_t, the sand-dust storms occur [17]. Analogously, if the magma speed $U \geq$ threshold value U_t, the earthquakes with magnitude $\geq M$ occur. The U represents the speed of magma near the crust. The U_t is the threshold value for earthquake with magnitude M. While the dynamo action within the Earth' Liquid is the generation source of the geomagnetic field [19], it can be supposed that the U is related with the geomagnetic field.

According to Eq. (1) it can be obtained that while the threshold value U_t does not vary with time, in a region for earthquakes with magnitude $\geq M$, there should exist $\lg N(>t) = c - dt$, where N is the number of earthquake time intervals longer than t, and d decreases with M, which is similar to Eq. (2) (i.e., d decreases with Xr).

3. Testimony

The earthquake data were analyzed to verify this result. The earthquake catalogs were downloaded from the China Earthquake Networks Center (CENC).

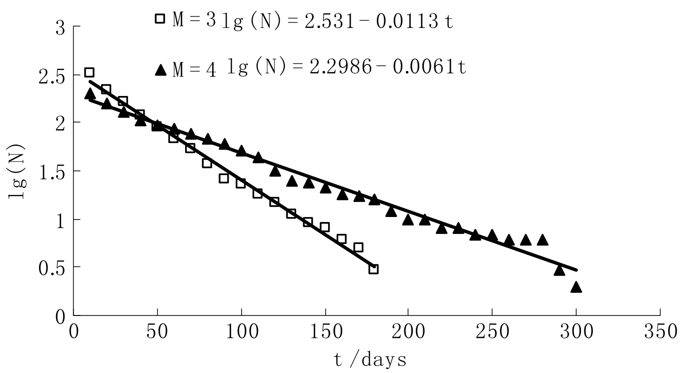

Fig. 3. lg(N) versus t for earthquakes with magnitude greater than M (3 and 4), where N is the number of the time intervals between two successive earthquakes with length longer than t. The earthquake data are between January 1, 1970 and October 31, 2010 in the region spanning 28°–33° N latitude and 100°–105° E longitude.

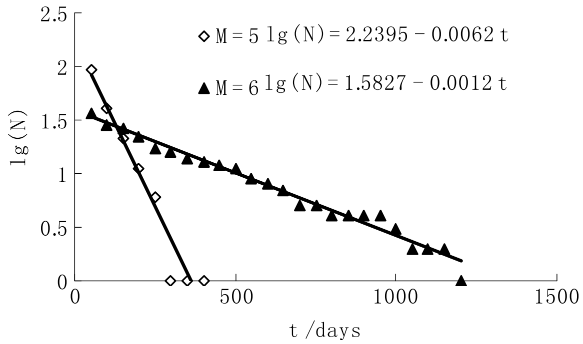

Fig. 4. Same as Fig. 3 except for $M(= 5, 6)$ and a bigger region (25°–40° N latitude and 95°–110° E longitude).

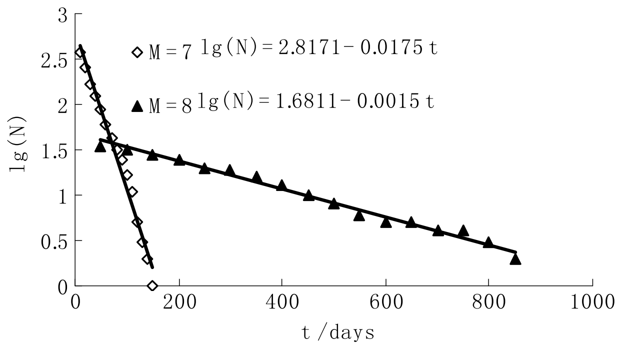

Fig. 5. Same as Fig. 3 except for $M(= 7, 8)$ and a bigger region (all global).

Fig. 3 shows the analysis results of the earthquake data covering the period between January 1, 1970 and October 31, 2010 in the region spanning 28°–33° N latitude and 100°–105° E longitude. For earthquakes with magnitude greater than $M(=3$ and 4), the pattern of N versus t is well described by Eq. (1) with d value of 0.0113 day^{-1} and 0.0061 day^{-1}, respectively.

Figs. 4 and 5 show the other two examples. The earthquake data of them also cover the period between January 1, 1970 and October 31, 2010 but in different regions. Fig. 4 shows the analysis results of the earthquake data in the region spanning 25°–40° N latitude and 95°–110° E longitude. The pattern of N versus t is also well described by Eq. (1) with d value of 0.0062 day^{-1} and 0.0012 day^{-1} for M value of 5 and 6, respectively. Fig. 5 shows the analysis results of the earthquake data in the region of all global. The pattern of N versus t is also well described by Eq. (1) with d value of 0.0175 day^{-1} and 0.0015 day^{-1} for M value of 7 and 8, respectively. All of them also agree well with the conclusion in Section 2, i.e., "in a region for earthquakes with magnitude $\geq M$, there exists lg$N(> t) = c - dt$, where N is the number of earthquake time intervals longer than t, and d decreases with M".

4. Conclusion

We borrowed the idea from the research in the time interval distribution of sand-dust storms [18] and introduced a physical model for earthquake time interval distribution. From this model, it was deduced that for the earthquakes with magnitude $\geq M$, there existed $\mathrm{lg}N\ (> t) = c - \mathrm{d}t$, where N was the number of time intervals longer than t; the value d decreased with M. This result also gets supports from the earthquake data of CENC.

References

[1] B.C. Papazachos, E.E. Papadimitriou, A.A. Kiratzi, C.A. Papaioannou, G.F. Karakaisis, Probabilities of occurrence of large earthquakes in the Aegean and surrounding area during the period 1986–2006, Phys. Earth Planet. Inter. 125 (4) (1987) 597–612.
[2] G.A. Papadopoulos, An alternative view of the Bayesian probabilistic prediction of strong shocks in the Hellenic arc, Tectonophysics 132 (1987) 311–320.
[3] D.D. Dionysiou, G.A. Papadopoulos, Poissonian and negative binomial modeling of earthquake time series in the Aegean area, Phys. Earth Planet. Inter. 71 (1992) 154–165.
[4] J.H. Wang, C.H. Kuo, On the frequency distribution of inter-occurrence times of earthquakes, J. Seismol. 2 (1998) 351–358.
[5] P. Bak, K. Christensen, L. Danon, T. Scanlon, Unified scaling law for earthquakes, Phys. Rev. Lett. 88 (2002) 178501.
[6] M.V. Matthews, W.L Ellsworth, A.P. Reasenberg, A Brownian model for recurrent earthquakes, Bull. Seismol. Soc. Am. 92 (2002) 2233–2250.
[7] A. Corral, Long-term clustering, scaling, and universality in the temporal occurrence of earthquakes, Phys. Rev. Lett. 92 (2004) 108501.
[8] J. Davidsen, C. Goltz, Are seismic waiting time distributions universal? Geophys. Res. Lett. 31 (2004) L21612.
[9] S. Abe, N. Suzuki, Scale-free statistics of time interval between successive earthquakes, Physica A 350 (2005) 588–596.
[10] R. Shcherbakov, G. Yakovlev, D.L. Turcotte, J.B. Rundle, Model for the distribution of aftershock interoccurrence times, Phys. Rev. Lett. 95 (2005) 218501.
[11] A. Corral, Statistical features of earthquake temporal occurrence, Lecture Notes in Phys. 705 (2007) 191–221.
[12] S.G. Abaimov, D.L. Turcotte, R. Shcherbakov, J.B. Rundle, G. Yakovlev, C. Goltz, W.I. Newman, Earthquakes: recurrence and interoccurrence times, Pure Appl. Geophys. 165 (2008) 777–795.
[13] B. Enescu, Z. Struzik, K. Kiyoto, On the recurrence time of earthquakes: insight from Vrancea (Romania) intermediate-depth events, Geophys. J. Int. 172 (2008) 395–404.
[14] T. Hasumi, C. Chen, T. Akimoto, Y. Aizawa, The Weibull-log Weibull transition of interoccurrence time for synthetic and natural earthquakes, Tectonophysics 485 (2010) 9–16.
[15] M. Erisoglu, N. Calis, T. Servi, U. Erisoglu, M. Topaksu, The mixture distribution models for interoccurence times of earthquakes, Russ. Geol. Geophys. 52 (2011) 737–744.
[16] C. Tsallis, Inter-occurrence times and universal laws in finance, earthquakes and genomes, Chaos Solitons Fractals (2016). http://dx.doi.org/10.1016/j.chaos.2015.12.025.
[17] G.-L. Liu, S.-U. Park, The logarithm-linear relationship of the occurrence frequency to the duration of Sand-dust storms: evidence from observational data in China, J. Arid Environ. 71 (2007) 243–249.
[18] G.-L. Liu, L.-Z. Hao, F. Zhang, Time interval distribution of sand-dust storms in theory: test with observational data in Yanchi, China, J. Stat. Mech. Theory Exp. 11 (2012) P11015.
[19] F. Vallianatos, A non-extensive statistical physics approach to the polarity reversals of the geomagnetic field, Physica A 390 (2011) 1773–1778.