SPATIAL DISTRIBUTION ANALYSIS OF SEISMIC ACTIVITY OCCURRED IN THE COCOS PLATE, MEXICO

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ABSTRACT

Currently, it has not been fully understand the process that generates seismic activity and under what laws it operates, which has led to analysis from different perspectives and approaches to understand the phenomenon, that is why, in this research, the goal is to analyze the spatial distribution of seismic activity occurred in the Cocos Plate, located in Mexico with various techniques and methods among which are Fractal mechanics, some seismic scaling laws and the spatial distances of seismic events occurred in the said plate. That, in order to find some parameters that let define whether there is any relationship between the places of occurrence of the next event with previous events. This would help in moving towards earthquake prediction.

Within the large number of seismic events, it can be observed that even though big events have little statistical weight (10-bM), the radiating energy ($10^{3M/2}$) that they release grows faster than what it decays and although large earthquakes are rare events, they are the ones that determine the energy dissipation in the system, and are therefore those with the greatest destructive potential for populations that are located in seismic areas and therefore are certainly of interest to science.

Keywords: Earthquakes, fractal dimension, time of recurrence, statistical distribution, spatial distribution.

INTRODUCTION

The process of evolution of our planet causes a variety of physical phenomena, among which it can be highlighted hurricanes, floods and earthquakes, among others. These phenomena usually have a large economic political and social impact.

Earthquakes are one of the most devastating and frightening natural disasters, in a few minutes, thousands of people may lose property, health, loved ones and even life. Proof of this is the earthquake in Tang-Shan, China, July 27th, 1976, where there were 655,200 deaths, or the one in Michoacan, Mexico on September 19th, 1985, that caused 20,000 deaths (Nava, 2002).

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On the planet there are definite areas where most of the earthquakes occur, these areas are due to the formation of the outer layer of our planet, which is composed of several plates, and it is precisely the boundaries between these plates where it is developed the largest and most dangerous seismic activity.

Mexico, due to its geographical position, it is located in one of the most seismically active areas of the world. The Mexican territory is divided among five plates (Fig. 1). The relative motion between these plates causes one of the seismic and volcanic hazards highest in the world.

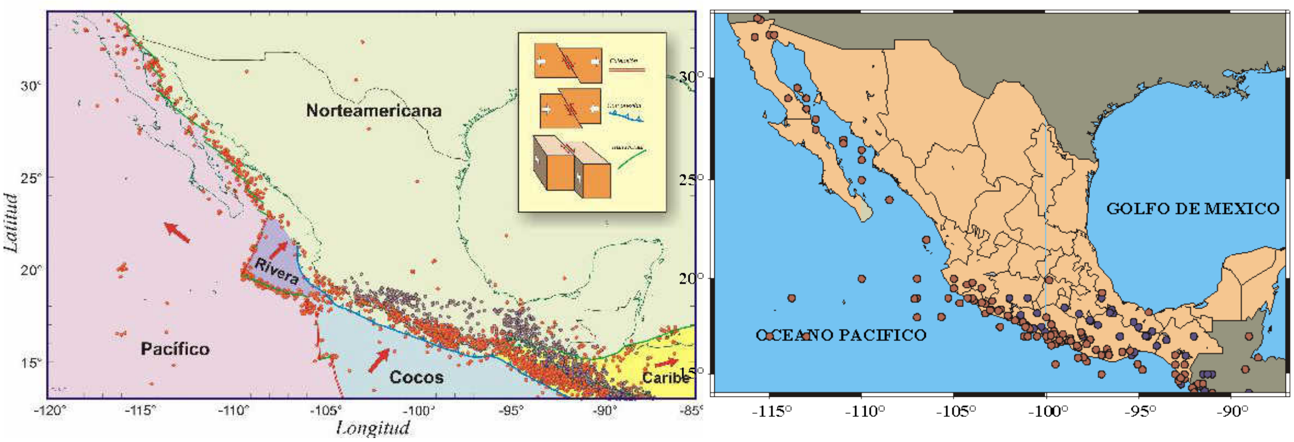

Figure 1. Left: Distribution of the tectonic plates of the Mexican Republic.
Right: The largest century earthquakes (M> 6.5).
Source: Website of the National Seismological Service

As this is undoubtedly a complex phenomenon, it should also be expected a complex answer, so it should be taken into account the diversity of variables involved. That is to say, the seismic observations are often supplemented by other types of observations of physical parameters can be influenced by the stress regime on earth (Nava, 2002).

So far, the most promising techniques that can tackle the problem of earthquakes and when they occur, are the ones that combine the use of several of them and used observational methods in detail, as another problem that can influence strongly the results of methods based on precursory anomalies, is the scale factor, such anomalies may occur in very local areas and losing resolution when considering averages over larger regions.

The authors have developed other analysis, which were presented at the ISSS Congress and others. These analyzes are aimed to contribute to the advancement of models that yield advances in the field of earthquake prediction.

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OBJECTIVE

Analyze and characterize the spatial distribution of seismic activity recorded in Mexico with the techniques and methods of Fractal mechanics, the laws of scaling and spatial distances, in order to know if there is any relationship between the place of occurrence of next event with previous events.

DEVELOPMENT

The first comprehensive statistical studies of seismicity were made by Gutenberg and Richter (Gutenberg & Richter, 1954, 1944) (H. Kanamori & E. Brodsky, 2001, 2004). They studied data from all regions of the Earth and found that the number N of earthquakes greater than magnitude M, which occur in a given time, is a function of magnitude and follows an exponential distribution:

$$\mathbf{Log\ N = a - bM,} \tag{1}$$

which is the law of Gutenberg - Richter (Y. Y. Kagan, 1994), where **a** is a constant that depends on the sampling time and **b** has characteristic values for different regions of the Earth. Therefore, the probability of occurrence of an earthquake is not the same in all regions of the Earth. The relative number of earthquakes against magnitude is different from one region to another. In Mexico, apparently, the relative magnitudes favorite shows, that is, they are more frequent than predicted overall statistic.

The occurrence of a large earthquake in a place does change the probability of occurrence of other earthquakes; a clear case is the occurrence of aftershocks, which are observed after a large earthquake. For a particular point, especially if you are near an active seismic zone it is not appropriate a statistical model such as the Poisson, therefore the adopted process to model the seismicity of the site must have "memory" and be causal (depend on what has happened before) (Esteva, 1976) (Hagiwara, 1974). So certainly it is important to study the statistics of the local seismicity to develop the necessary analysis.

Following the approach proposed by Bak et al (2002), it omits any classification of earthquakes, it does not separate replicas of major events, nor does it isolate specific sequences of replicas. Once more seismicity is considered as a physical phenomenon itself.

The seismic catalog used covers the period from January 1st, 1988 to December 31st, 2004, in a region of southwestern Mexico, covering the latitude between 13 ° N - 19 ° N, and longitude between 89 ° W - 106 ° W. The total number of earthquakes considered is

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15092. The spatial distribution analysis was carried out as follows: the region is covered with a mesh considered with LXL size cells (Figure 3), for L = 1 °, 2 °, 3 °. For each of these cells, were considered only events over threshold magnitude m = 3 and m = 4, respectively (Instituto de geofísica, 2001, 2003) (SSN, 2008).

Having defined the studying window, the coordinates of the epicenters of each event were obtained, which determine the spatial distances between successive epicenters of events given by:

$$\Delta D_i = |d_{i+1} - d_i| \tag{2}$$

with d_i and d_{i+1} in the same cell of linear extension L. where,

$$d_i = \sqrt{\left((Long_2 - Long_1)^2 + (Lat_2 - Lat_1)^2\right)} \tag{3}$$

Concatenating the list of spatial distances obtained for each cell, it is determined the distribution of spatial distances ΔD_i, including earthquakes in the range L whose magnitude is greater than m = 3, 4, which is determined by:

$$P_{m,L}(\Delta D) = \frac{\Pr ob[D \leq D' < D + \Delta D]}{\Delta D} \tag{4}$$

Figure 2 shows the graphs obtained for the distribution $P_{m,L}(\Delta D)$, considering different values for m and L.

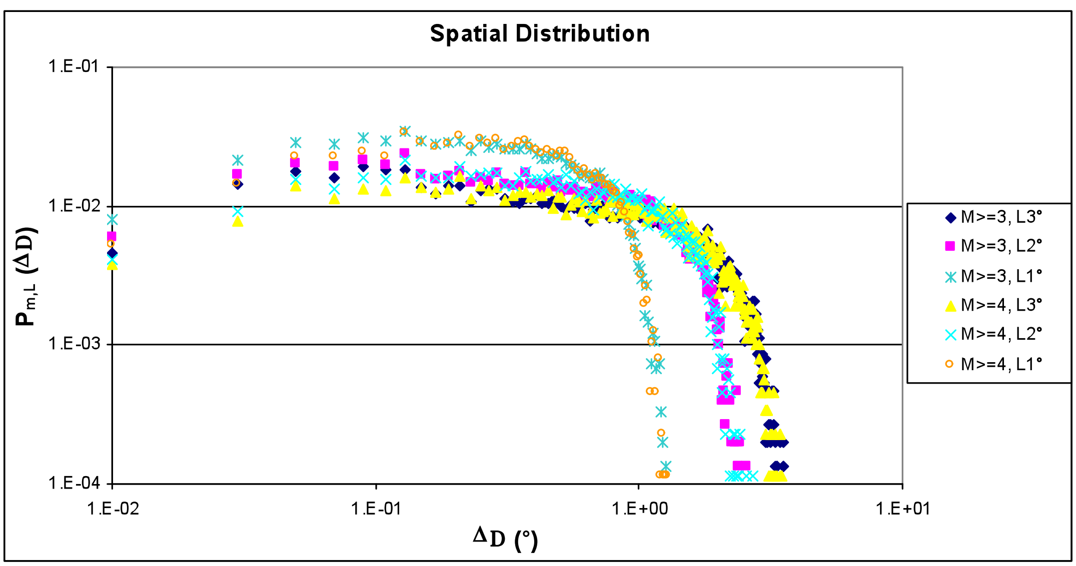

Figure 2. Distribution $P_{m,L}$ (Δ D) of the spatial distances Δ D between earthquake epicenters with magnitude m within an area of linear size L.

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It can be seen from Figure 1 that considering the spatial distances, as in the recurrence time, there is similarity in the curves. Which once more it shows a linear regime, indicating a power law distribution.

The above result suggests that the curves can be transformed into coordinates rescaled back now as follows:

The x axis is divided by L and the y axis is multiplied by L, i.e.

$$x = \Delta D / L \tag{5}$$

$$y = L * P_{m,L}(\Delta D) \tag{6}$$

The rescaling causes a change in the curves of Figure 1, which are presented in Figure 3.

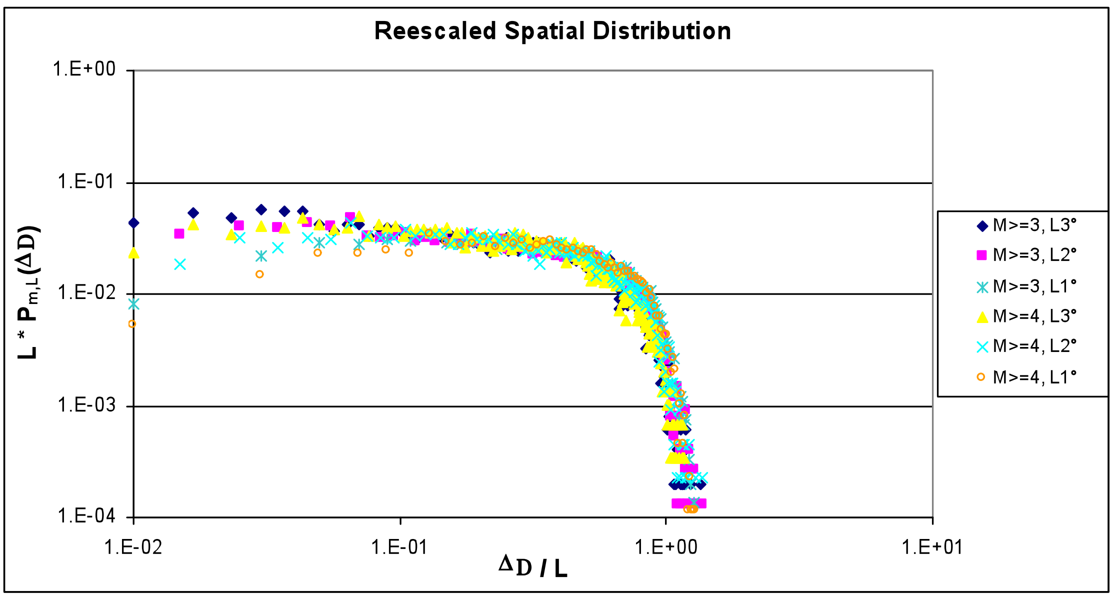

Figure 3. Rescaled data for the variables x = Δ D / L y = L * $P_{m,L}$ (Δ D). The collapse of the data is indicative of scaling.

It can be seen that considering the spatial variables, the data also collapse when rescaled. Therefore, it can also be set a scaling law seismicity in the Cocos Plate to the spatial distributions in the period considered, which is given by (Davidsen & Paczuski, 2005):

$$P_{m,L}(\Delta D) = \frac{f(\Delta D / L)}{L} \tag{7}$$

The collapse of the data for distances and also for the times as a result of rescaling of the respective values suggests a relationship between distance and time in the seismic activity in question. Recalling that the formula in which the above variables relate the speed, then this can be expressed as follows:

$$v = \frac{\Delta D_i}{\Delta t_i} \tag{8}$$

Speeds are considered subsequent events saw between each cell to above the threshold magnitude m, where ΔD_i is the distance from epicenters of two consecutive events in the Δt_i considered cell and you is the time between two consecutive events also within the same cell. It determines the probability density of vi, which is given by:

$$P_{m,L}(v) = \frac{\Pr ob[v \leq v' < v + dv]}{dv} \tag{9}$$

Figure 4 shows the graphs obtained for the distribution $P_{m,L}$ (v), considering different values for m and L.

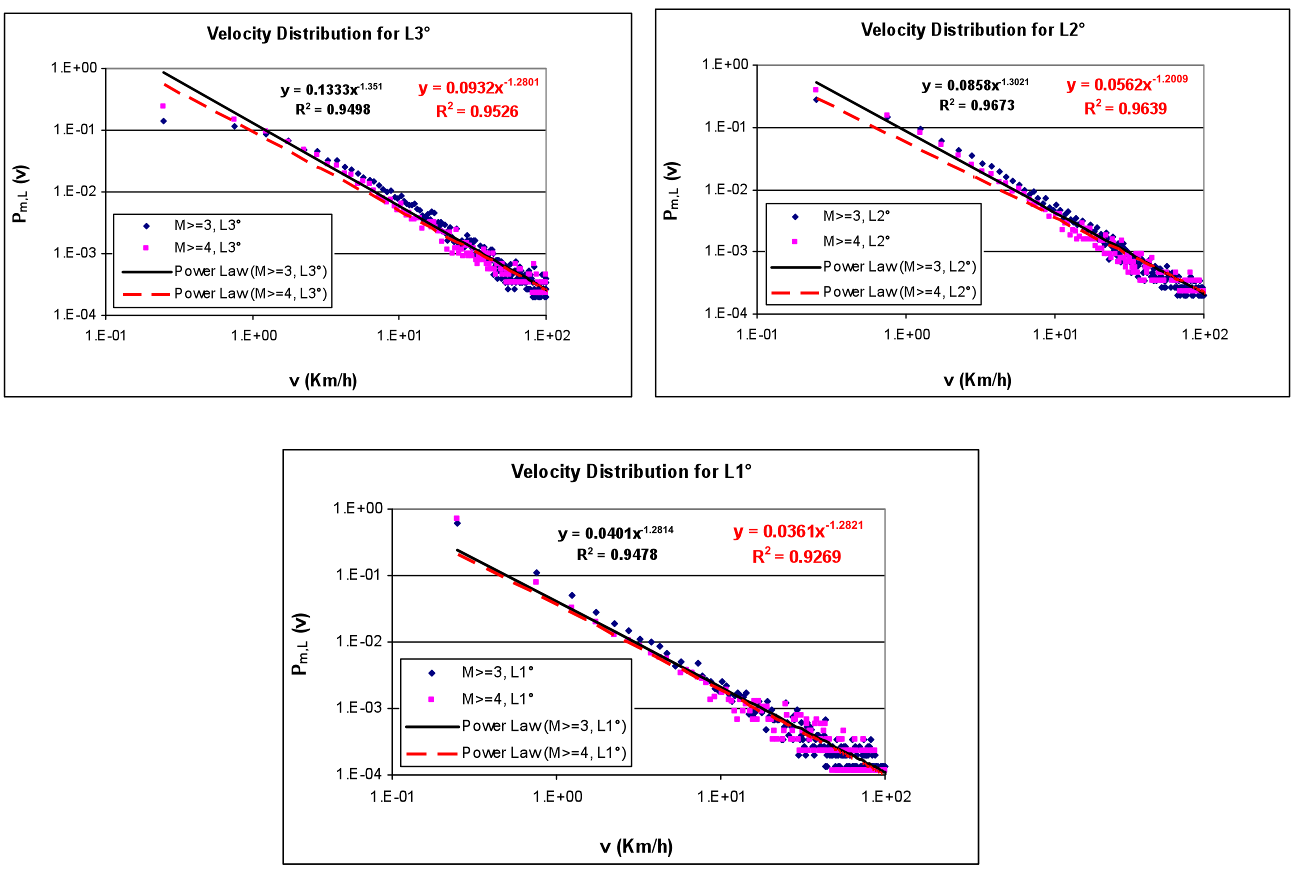

Figure 4. P_{mL} distribution, L (v) of the velocities v between earthquakes with magnitude m within an area of size L. linear.

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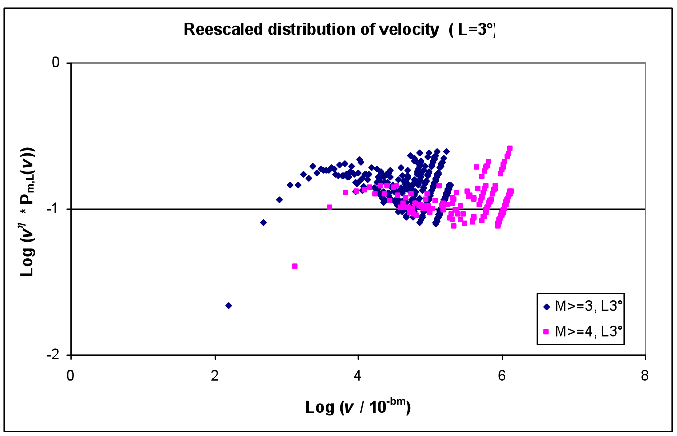
Again, there was similarity among the graphs obtained, which can rescale the graphs obtained for the velocity distribution, are now rescaled axes values as follows:

$$x = Log(v/10^{-bm}) \qquad (10)$$

$$y = Log(v^{\eta} * P_{m;L}(v)) \qquad (11)$$

The result also causes a change in the graphs, as seen in Figure 5. In the graphs of Figure 4 show the trend of the data with the value of the slope (η) of the power function, which is used for the rescaling of the data on the y axis, when considering a linear size L = 3 °, it is obtained an average value of η = 1.31, if L = 2 ° is obtained η = 1.25 and L = 1 ° is obtained η = 1.28.



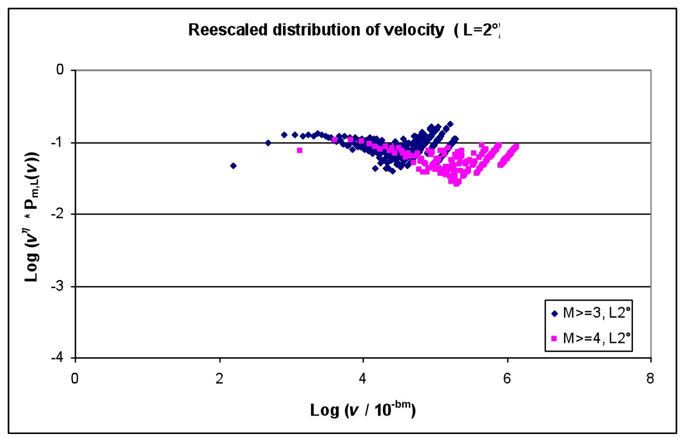


Figure 5. Rescaled data for the variables x = Log (v / 10^{-bm}) and y = Log (v^{η} * $P_{m,L}$ (v)).

The value of b = 0.9338 is used for the rescaling of the axis x, which had been obtained in the statistical analysis.

CONCLUSIONS

It was found that considering the spatial variables, the data collapse in Figure 3, is indicative of a critical process, since only these exhibit this type of collapse, which is known as scaling in critical phenomena. This analysis shows that earthquakes are a phenomenon of Auto Review Organization (SOC) (Yeomans, 1992) (Bak, 1987, 1997) (Kanamori & Brodsky, 2007).

Is also shown in the graphs obtained for the rescaling of the probability distribution of the velocities which are presented in Figure 5 the graphs offsets for rescaling the values considered, this is because the graphs of the distribution of the velocities (Figure 4) almost collapse to such securities, and then, when resizing the x axis is considered the value of m = 4, this causes a considerable increase in the term 10-bm and since the probability distributions of the velocities are very similar, this causes the phase shift of the graphs for different values of m in an area of linear size L.

It was found that the values obtained in the various analyzes for seismicity Cocos Plate in Mexico, they behave as presented in other seismic zones of the world seems to obey the relations proposed previously, but when considered some real parameters, for example, the 3D fractal dimension (instead of epicenters hypocenters), the unified scaling law proposed by Bak et. al., no longer satisfied.

On the other hand, we see that in the search for scaling laws that define the behavior and self-similarity of the earthquake, we can return the reflections of Dr. Álvaro Corral, in the sense that: It's interesting to go beyond the law of Gutenberg - Richter (1), asking whether the simple ratio contained in this Act (about 100 earthquakes with $M \geq 5$ for every 10 with $M \geq 6$ and each with $M \geq 7$, etc..) is not a reflection a deeper self-similarity in the structure of seismicity. That is, in a given region is it equivalent 1 year of earthquakes with $M \geq 5$ to 10 years with $M \geq 6$, or 100 years with $M \geq 7$? The answer to this question would have important implications for seismic hazard studies (Corral, 2005, 2006, 2007), as for prediction.

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