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# A STOCHASTIC MODEL FOR PREDICTION THE OCCURRENCE OF STRONG EARTHQUAKES (M>7.0) IN THE CHILE SEISMOGENIC AREA

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ABSTRACT. On the basis of preliminary created stochastic model for earthquake prediction, new software is applied about the Chile coastal area. Data about strong earthquakes have been used for the model application. Strong effects of migration of the seismic sources have been discovered in N-S direction. Repeatability and predominant distances of the consecutive events are also result of these investigations. The physical meaning of such effects is dominated by the clear zone of subduction developed there. After the visualization the diagrams about the next expected strong seismic event are presented. The software could be useful to any other applications in the similar regions. The use of the earlier developed stochastic model is based on geometry considerations as well as the statistical distributions of the main parameters of any two consecutive seismic events: temporal and space positions and the magnitude differences. The obtained bi-modal distributions require the consideration of the most probable position of the next expected seismic event. The results obtained show the applicability of the suggested model. The last strong seismic event Mw8.8 occurred on 27$^{th}$ February 2010 is considered as a starting point for the next expected strong earthquake in the area.

## СТОХАСТИЧЕН МОДЕЛ ЗА ПРОГНОЗИРАНЕ НА СИЛНИ ЗЕМЕТРЕСЕНИЯ (M>7.0) В РАЙОНА НА ЧИЛИ

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**РЕЗЮМЕ**. На основата на предварително създаден стохастичен модел за прогноза на силни земетресения, е създадена софтуерна програма за приложение в района на Чилийското крайбрежие. Използувани са данни за силни земетресения с магнитуд над 7.0 за последните няколко века. Установена е миграция в посока север-юг, преобладаващи разстояние между силните земетресения и повторяемост през няколко години. Физическото обяснение за подобно поведение на сеизмичността в района се диктува от ясно изразена зона на субдукцшя, способна да генерира силни земетресения, които често се и източник на цунами. Последното силно земетресение М8.8 от 27 февруари 2010 е използувано акто отправна точка за следващото очаквано силно сеизмично събитие в региона. Визуализирани са получените резултати, като създаденият софтуер може да се използува и за изследвания в други подобни по своята геодинамика региони.

## Introduction

A stochastic prediction of an earthquake occurrence (as well as any other attempt of seismic event prognosis) requires the determination of five elements: two co-ordinates, depth, magnitude and time. It is well known also that predicting the time is the crucial factor for the lack of success in earthquake prediction. The larger the magnitude, the territory and time span of the investigation are the more likely is that the results will be closer to the reality.

Chile subduction area is well known region on the South America continent with a documented history of earthquakes occurrence. But even here, only about 535 years of written documenting is available, and this is a short term as far as seismological prediction is concern. The instrumentally recorded data are limited as well. The magnitudes of the subduction and near subduction zone events in this region are on the highest size of the Richter scale. All these factors are imposing a number of limitations on earthquake prognosis, which may be one of the main reasons for nearly complete lack of studies on this subject.

The idea to make the present attempt was given by the bi-modal distribution of the local seismicity in time (Fig. 1). An attempt to compile a complete set of strong earthquakes in Chile is presented in Table 1 using available data (http://en.wikipedia.org/wiki/List_of_earthquakes_in_Chile).

Then a selection of the most reliable events is done using as main criteria the magnitude threshold of M>7.0. Those 18 events give an average of 22 years time period between the sequential quakes, but one should consider the poor detecting and recording capabilities before and in the beginning of this century.

## Data and Method

Even with a limited amount of information we had to restrict our database to the last 18 events. This is the most homogeneous and reliable part of the presented catalogue. The number of earthquakes with magnitude greater than 6.0 for the same time period is 35 and would give a better basis for statistical study. With such a low magnitude however, it is much more probable that the stochastic distribution is more random and some of the events could be fore or aftershocks of main earthquakes. Their detection as such is not an easy task while the method requires only independent seismic events. The historical part of the catalogue is not complete with those events, that is why we restricted our study to the seismic events with magnitudes greater then 7.0. Such approach has been used in our previous studies and shows good reliability, especially to the stochastic distributions of the different parameters used.

Table 1. *List of the 18 events with M>7.0 in Chile*

| Lat S | Long W | Magn. | Year | Month | Day |
|---|---|---|---|---|---|
| -39.80 | -73.20 | 8.5 | 1575 | 12 | 16 |
| -32.50 | -71.50 | 8.7 | 1730 | 7 | 8 |
| -36.83 | -73.03 | 8.5 | 1751 | 5 | 25 |
| -36.83 | -73.03 | 8.5 | 1835 | 2 | 20 |
| -18.50 | -70.58 | 9.0 | 1868 | 8 | 13 |
| -33.00 | -72.00 | 8.2 | 1906 | 5 | 17 |
| -28.50 | -70.00 | 8.5 | 1922 | 11 | 10 |
| -36.20 | -72.20 | 7.8 | 1939 | 1 | 25 |
| -30.75 | -72.00 | 8.2 | 1943 | 4 | 6 |
| -39.50 | -74.50 | 9.5 | 1960 | 5 | 22 |
| -32.41 | -71.10 | 7.1 | 1965 | 3 | 28 |
| -32.51 | -71.20 | 7.5 | 1971 | 7 | 8 |
| -33.24 | -71.85 | 8.0 | 1985 | 3 | 3 |
| -23.36 | -70.31 | 8.0 | 1995 | 7 | 30 |
| -30.93 | -71.22 | 7.1 | 1997 | 10 | 14 |
| -19.89 | -69.12 | 7.9 | 2005 | 6 | 13 |
| -22.19 | -69.84 | 7.7 | 2007 | 11 | 14 |
| -35.82 | -72.67 | 8.8 | 2010 | 2 | 27 |

The strong events in this area are aligned in a relatively narrow strip with slight NW-SE orientation along the Pacific coast of Chile. And again on very few occasions epicenters coincide with the known subduction delineation even if considering an error in location determination of 5-10 km.

The principles of the method applied have been developed by Christoskov et al. (1986; 1989), Christoskov and Ranguelov (1988), Ranguelov (1990), etc. Briefly, for every couple of two sequential events $N_i$ and $N_{i+1}$ with parameters: X, Y, T and M we could create the differences:

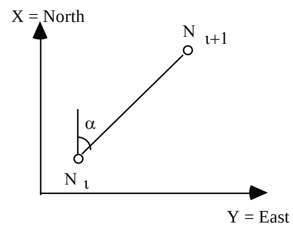
$$\Delta T = T_{i+1} - T_i ; \quad (1)$$

$$\Delta M = M_{i+1} - M_i ; \quad (2)$$

$$\Delta L = [(X_{i+1}-X_i)^2 + (Y_{i+1}-Y_i)^2]^{1/2}, \quad (3)$$

where

$$\alpha = \mathrm{arctg}(\Delta X/\Delta Y); \quad (4)$$




Since the magnitude threshold is strictly limited, magnitude can not be used as a criterion. In such a case the total probability for the next event occurrence will be (if the events are independent in time and space domain):

$$P = P(\Delta T) * P(\Delta L) * P(\alpha); \quad (5)$$

By using the empirical distributions of those parameters and after normalization with the maximum value of each parameter we could produce compatible mutual distributions and even plot the comprehensive results on the map of probabilities. The simple software has been created using this algorithm in MATLAB environment.

## Results and Discussion

The plot of the temporal distribution of the strong earthquakes is presented in Fig. 1. It's a clear left modal shape histogram with a maximum at about 250 months (with "one sigma" interval of about 15 months). The abscise scale is 80 months and the ordinate considers the number of events (integer digit).

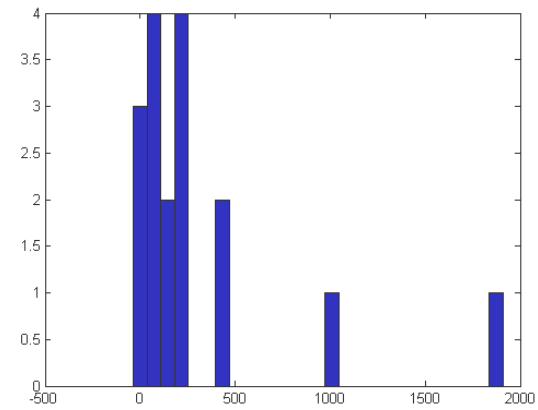



Fig. 1. Time distribution of all events with M>7.0 in the Chile area

The time inconsistency of the historic data could be demonstrated from the right side of the histogram where some events occurred in about 1000 even 2000 months time interval. The time span of nearly 100 years and the increasing number of reported events with the years is making difficult the sensible use of this information for the purposes of the suggested model. It is also possible, especially in the beginning of the period, that earthquakes of that size have not been noticed and/or recorded.

Figure 2 shows the distance distribution of the strong events in the area. The most characteristic feature here again is the uni-modal shape of the histogram. The dominant distance is about 800 km. This could suggest a seismogenic block structure of an average of 400 km (with "one sigma" of about 100 km.) required for accumulation and generation of an event with magnitude greater than 7.0. Even with perhaps incomplete catalogue of seismic data the block structure in the area is well defined, which permitts the creation of a territorial distribution of the probabilities (Ranguelov, Spassov, 2010).

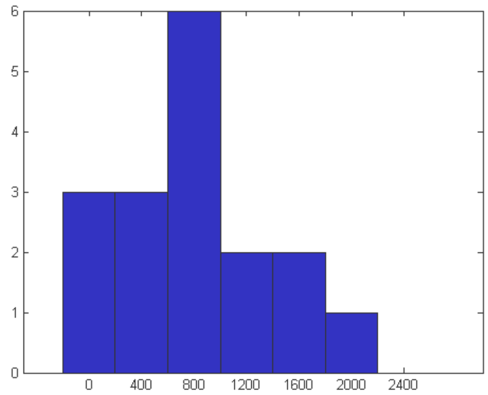



Fig. 2. Distance distribution of the strong events in the area

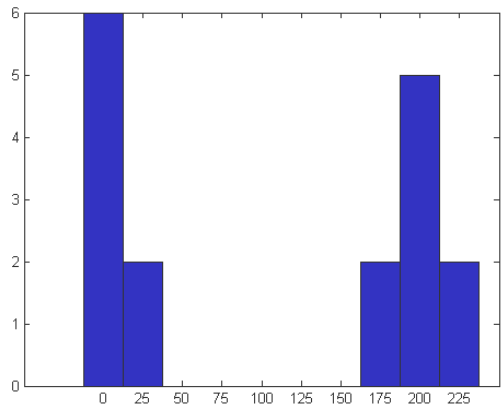



Fig. 3. Probability map based on the stochastic model described in the text

The azimuthal distribution of the main events for this study is investigated. The orientation of its maximums could easily be expected from the space distribution of the events (Fig. 3). The dominant N-S direction of migration of the epicentres is so clearly expressed that could be used without doubt about the high probability expectation of the next seismic event position. Clearly explained remains the minimum in the opposite direction E-W, which could be assigned to the main seismotectonic fiture of the subduction zone which is clearly elongated in N-S direction. Probably the most real representation of the azimuthal preferences of the strong events migration could be obtained from such distribution of all events with M>7.0.

The normalization of the values and their comprehensive consideration allows a construction of a probability nomogram shown in Fig. 4. Each of its circular segments contains the percentage probability of an earthquake occurring in the sector if the centre of the nomogram is placed over the location of the epicentre of the last strong event – Mw8.8 strong earthquake occurred on the 27th of February 2011. Similar graph could be more useful in a more rapidly changing seismicity or for planning some long term investigations.

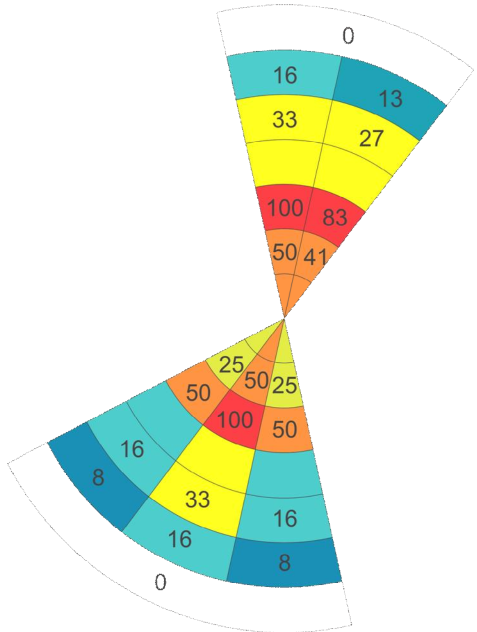



Fig. 4. Probability nomogram after normalization of the values and their comprehensive consideration

Probably the most important effect of the suggested model is that it is giving the opportunity to transfer the result on to the territory of study. Dividing the area into individual cells (in this case in 1 by 1 geographical degrees dimensions) one could calculate the total probability of occurrence for each cell. The interpolation of the data then would give a probability for this particular set of data. The maximum in the distance distribution (Fig. 2) is marked here by a 70% margin, but the overall probability is greatest in the respective coloured area.

A retrospective analysis of the data has been performed in order to evaluate the reliability of the method and the results using the new created software. A retrospective check of all couples gives an average success rate of nearly 70%, while on two occasions the success rate is 90%. Another estimate shows that in 76% of the retro-analyses the success is 65% or more.

## Conclusions

The midterm stochastic model for studying the earthquakes with magnitude greater than 70 in South America Chile coast defined uni-modal distributions of both time and distance. A clear bi-modal distribution is expressed about the azimuth which gives real opportunity of successful next strong earthquake probabilistic prediction. A software created is used about probabilistic nomogram generation (Fig. 4), which shows the maximum probability of the next strong earthquake occurrence within the time interval of 120-250 months (10-20 years) and distance of about 800-1000 km in the direction of North (or South) of the last very strong earthquake happened on 27 February 2010. The 100 value just shows that this is the maximum maximorum value about the stochastic model, which is normalised to be able quantitatively to assess other segments values as parts of 100. This could give some grounds for expecting the next strong earthquake in a certain confidence interval (+/- "one sigma"). Although the historic data of the seismic events with such size may not be complete, a block structure of the territory and a predominant azimuthal orientation of the quake occurrence are likely to be distinct features of the seismicity in South America Chile coast.

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