ON EVALUATION OF STATISTICAL REGULARITIES IN SEISMIC DATA

V.M. Nedel'ko, T.A. Stupina
Institute of Mathematics SB RAS
Novosibirsk, RUSSIA
e-mail: nedelko@math.nsc.ru, stupina@math.nsc.ru

Abstract

A method for short-term prediction of earthquakes based on Markov time scale is investigated. The results show that the noise added to a signal when sensors are placed on the ground dramatically weakens the predictability. Additionally, a method for testing the statistical dependency between earthquakes on neighbouring regions is proposed. This method uses a certain model of earthquake influence propagation.

1 Introduction

The work[1] is devoted to the problem of earthquakes prediction. First we shall investigate effectiveness of the Markov time scale predictor when it is applied to prediction of seismic events on the data collected by stations of Altai region.

The next goal of this work is to develop a method for testing a statistical dependence between earthquakes on neighbour regions. This needs to construct a model of the propagation of "influence waves" and to build a statistical criterion for testing dependence hypothesis.

2 Short-term prediction of earthquakes

First, we shall consider a task of short-term prediction of earthquakes based on prehistory of seismic waves.

The data to analyze are presented by seismograms being quantitative time series. To illustrate these data a plot of the seismogram of the Altai earthquake in 2003 is shown on the left part of fig. 1.

An interesting method for analyzing precursory seismic data before an earthquake is proposed in the paper [1]. This method gives a prediction for a short time (on the order of several hours) before earthquake with magnitude $M \geq M_c$, where M_c is a threshold. Note, that prediction is local, because it relates to the region of seismic signal registration. We researched applicability of this method to Siberian region data.

The method checks where the seismic data follow a Markov chain and, if so, measures the function t_M. The value t_M is Markov time scale of seismic time series and denotes the step of discretization by which seismic data follow a Markov process. A

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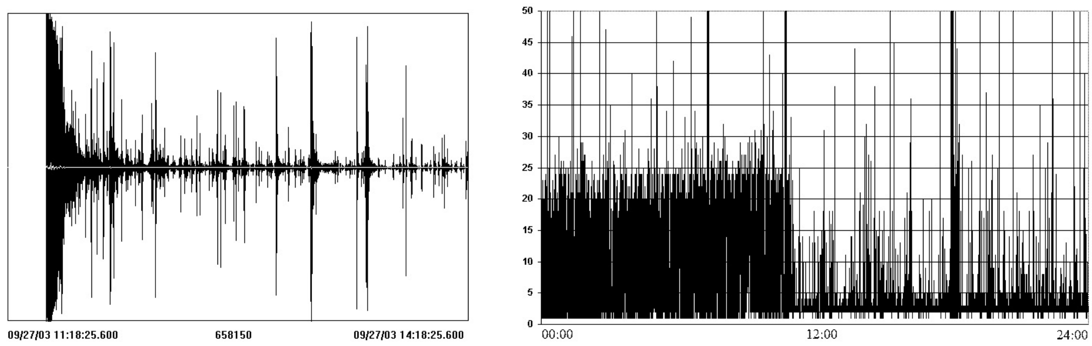

Figure 1: Seismic signal and Markov time scale value for Altai earthquake

short time before an earthquake the value t_M increases sharply, hence providing an alarm for an impending earthquake.

Let us consider the n measured quantities of the stochastic process $x(t)$ and its joint probability distribution function $P_n(x_1, t_1; ...; x_n, t_n)$. The process is a Markov process if $P_n = p(x_1, t_1) \prod_{t=1}^{n-1} p(x_{i+1}, t_{i+1}|x_i, t_i)$. For a Markov process the Chapman-Kolmogorov equation $p(x_2, t_2|x_1, t_1) = \int dx_3 p(x_2, t_2|x_3, t_3)p(x_3, t_3|x_1, t_1)$ holds for any t_3 in interval (t_1, t_2). In order to determinate t_M for the data the value $Q = |p(x_2, t_2|x_1, t_1) - \int dx_3 p(x_2, t_2|x_3, t_3)p(x_3, t_3|x_1, t_1)|$ is computed for given x_1 and x_2. Plotting Q versus $t_1 - t_2$ allows to estimate t_M.

As an additional to t_M predictor the structural function $S_P(\tau) = \langle |x(t+\tau) - x(t)|_p \rangle$ of order p is used. This function characterize a "self-similarity" of seismic data.

The most difficulty in the implementation of this method is estimating conditional probabilities. While applying the method to Altai region seismic data we used empirical distributions.

The right part of fig. 1 shows a 24 hours plot of t_M in the day of the Altai earthquake. There is no rising of the value before the event. The plot for $S_P(\tau)$ was also built and like the previous predictor showed no alarm.

This difference in behavior of predictors on data of Iran and Altai stations may be explained by that Altai stations record ground signal that includes a noise.

3 Structural waves hypothesis testing

There is known a hypothesis that suppose an existence of structural waves. These waves represents changing of rock structure. Their velocity is expected to be about 1 km per day.

An indirect evidence of such waves might be statistical correlations between earthquakes on neighbour areas.

The problem of finding spatio-temporal correlations between earthquakes is widely investigated now (see for example [2]). Our statement differs in that we has a goal to find very weak and lagged statistical correlations between seismic activities on neighbour areas.

Since two territories fixed, the time required for a wave to arrive will have certain expectation but will not be constant because of velocity fluctuations.

So we have the following mathematical model.

Let two time series presented by events be given. Need to test a hypothesis whether these time series are statistically dependent.

Let $\omega = \{(x_j, t_j)|i = \overline{1, N}\}$ – two-dimension time serie, where x_j – the magnitude of j-th event (earthquake), t_j – the time of the event, and there are two series of such kind.

Need to determine whether these series are dependent.

The simplest characteristic of dependence is a correlation coefficient. But in the considered case it is not appropriate. So we shall construct some criterion of test of hypothesis.

Let us consider also more simple form of time serie when the magnitude is not taken into account: $v = \{t_j|i = \overline{1, N}\}$.

Let there are two different regions A and B for those one need to test an existence of dependence between events occurring on them. We need to construct a statistical criterion that allows to test hypothesis of whether events on the region A influence on events on the region B.

Suppose we are interested in investigation events over certain period T. After appropriate rescaling one may always assume $T = [0, 1]$.

Assume that all events on B are a sample from the same distribution with density $\rho(y)$.

Suppose that the probability of occurring an event on region B is comprised by the probability of its spontaneous arising and the probability of that the event is triggered by some event on the region A.

This idea is represented by the model:

$$\rho(y) = (1 - p) + p\frac{1}{N}\sum_{i=1}^{N}\frac{1}{\sigma\sqrt{1\pi}}e^{-\frac{(y-x_i-\tau)^2}{1\sigma^2}}.$$

This model assumes that the time for that a signal comes from A to B is distributed normally with parameters τ and σ. The parameter p characterizes a force of the influence. Fig. 2 shows the function $\rho(y)$ built by real earthquakes data.

The plausibility function will be $\phi = \frac{1}{M}\sum\limits_{i=1}^{M}\ln(\rho(y_i))$.

As a measure of dependence may be used a difference between the maximum of ϕ over all parameters values and the value of plausibility by $p = 0$. To test the dependence hypothesis some kind of plausibility ratio criterion may be used.

The simulation on modeled data illustrated that this criterion is applicable for estimating statistical dependence between time series, but because of the using of fitting procedure some problem like overfitting problem in classification is emerged [3].

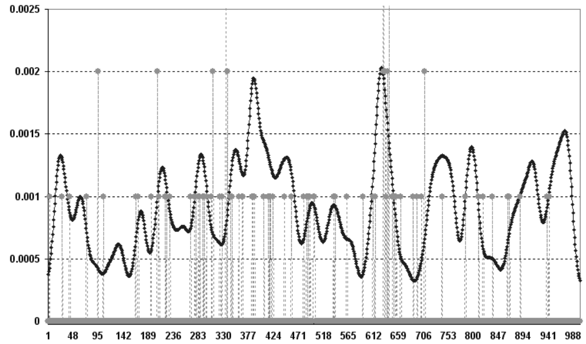

Figure 2: Model density for some earthquakes

4 Conclusions

In this work the results of applying the method for short-term earthquakes prediction based on Markov time scale was presented. This results showed that the noise added to a signal when sensors are placed on the ground dramatically weakens predictability.

A method for testing the statistical dependence between earthquakes on neighbour regions was proposed. This method uses a certain model of earthquake influence propagation.

References

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