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A forward test of the Decelerating–Accelerating Seismic Strain model to western south and central America

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ABSTRACT

Global observations show that strong mainshocks are preceded by decelerating preshocks which occur in the focal (seismogenic) region of the ensuing mainshock and by accelerating preshocks which occur in a broader (critical) region of the mainshock. Predictive properties of these preshocks have been expressed by empirical relations supported by theory and form the Decelerating–Accelerating Seismic Strain (D–AS) model. A respective algorithm has been developed which is used to identify the critical and seismogenic region and estimate (predict) the corresponding ensuing mainshock. In the present work a forward test of this model is performed by attempting intermediate-term prediction of future big ($M \geq 7.7$) mainshocks along the western coast of south and central America. Three regions of decelerating shocks and three corresponding regions of accelerating shocks have been identified. The parameters (origin time, magnitude, epicenter coordinates) as well as their uncertainties have been estimated (predicted) for the corresponding probably ensuing three mainshocks. This forward test allows an objective evaluation of the model's ability for an intermediate-term prediction of strong shallow mainshocks.

1. Introduction

Precursory seismic excitation in a broad region accompanied by decreasing seismicity in the focal region of strong mainshocks has been observed some decades ago and was called “doughnut pattern” by Mogi (1969). This general concept, which expresses qualitatively a behavior of precursory seismic activity, has been supported by quantitative investigation of precursory seismic activity. It led to the important conclusion that precursory seismic activity in the broad region is accelerating and in a narrower region is decelerating with the time to the mainshock.

Accelerating seismicity concerns the accelerating generation of intermediate magnitude preshocks with the time to the mainshock and has been extensively investigated (Tocher, 1959; Raleigh et al., 1982; Sykes and Jaumé, 1990; Knopoff et al., 1996; Brehm and Braile, 1999; Papazachos and Papazachos, 2001; Robinson, 2000; Tzanis et al., 2000; Papazachos et al., 2005b; Mignan, 2006, among many others). On the basis of a damage mechanics model, Bufe and Varnes (1993) proposed the following relation for the time variation of the cumulative Benioff strain, $S(t)$ (in Joule$^{1/2}$), released by accelerating preshocks at the time, t:

$$S(t) = A + B(t_c - t)^m \qquad (1)$$

where t_c is the origin time of the mainshock and A, B and m are parameters determined by the available data with $m < 1$. Bowman et al. (1998) suggested the minimization of a curvature parameter, C, which is defined as the ratio of the root-mean-square error of the power–law (relation 1) to the corresponding linear-fit error and used this parameter to identify regions of accelerating preshocks. Accelerating precursory seismicity has been interpreted in terms of the critical point dynamics (Sornette and Sornette, 1990; Sornette and Sammis, 1995; Rundle et al., 2000; 2003) or by the Stress Accumulation Model (Bowman and King, 2001; King and Bowman, 2003).

Decrease of the frequency of small preshocks in the focal region in respect to the background frequency, called “seismic quiescence”, has been also observed by many researchers (Wyss and Habermann, 1988; Jaumé, 1992; Bufe et al., 1994; Zöller et al., 2002, among others) and has been attributed to stress relaxation due to aseismic sliding (Wyss et al., 1981; Kato et al., 1997). Precursory transient seismic excitation followed by continuous decrease of the seismic strain, called “decelerating seismic strain”, has been observed before many mainshocks and its variation with the time to the mainshock is also fitted by a power–law (relation 1) with $m > 1$ (Papazachos et al., 2005a, b). Decelerating seismic strain is attributed to static stress shadow (Papazachos et al., 2006) predicted by the Stress Accumulation Model (Bowman and King, 2001; King and Bowman, 2003).

Papazachos et al. (2006) by taking into consideration the relative published information on decelerating and accelerating seismic strain, and using recent (since 1980) reliable data on such sequences of already occurred strong ($M \geq 6.4$) mainshocks in a variety of seismotectonic

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regimes, developed the "Decelerating–Accelerating Seismic Strain" (D–AS) model and a corresponding algorithm for intermediate term prediction of strong (M>6.0) shallow (h≤100 km) mainshocks. This model is expressed by empirical relations with predictive properties and has been tested by its application on preshock sequences of seven complete samples of 46 strong (M=6.3–8.3) mainshocks which occurred in various seismotectonic regimes (W. Mediterranean, Aegean, Anatolia, Central Asia, Japan, California, S. America). However, this backward procedure is not enough and forward testing, by attempting predictions of future mainshocks, is necessary for a more objective evaluation of the predictive ability of the model. Predictive properties of the accelerating pattern have been already applied (in 2002) for the successful intermediate term prediction of the 8.1.2006 large (M=6.8) earthquake which occurred in the southwestern part of the Aegean (Papazachos et al., 2007). This is encouraging for forward tests of the model like that attempted in the present work.

The purpose of the present work is to apply the D–AS model on data for shocks (preshocks) which occurred up to 1 October 2007 in the western part of south and central America in order to estimate (predict) the basic parameters (origin time, magnitude, epicenter coordinates) of big (M≥7.7) shallow (h≤100 km) mainshocks in this area. We limited our investigation to such big mainshocks because smaller shocks in this region are usually associated shocks (post-shocks, aftershocks) which cannot be predicted by this method. This restriction in the mainshock magnitude and the restriction in the focal depth of the mainshock and of preshocks (h≤100 km) result from a backward test of the method in south and central west America.

The D–AS model has been developed by data of earthquakes which occurred in the Mediterranean, California, central Asia, south and central west America and Japan. For the first three areas forward tests of the model have been already attempted. In these three areas, however, no broad subduction zones and no big (M>8.0) earthquakes occur while such zones and earthquakes occur in the last two areas. This is the main reason for which such test is performed in the present paper for south and central west America. We are now preparing a forward test for Japan too.

Papazachos et al. (1997) have developed the "regional time and magnitude predictable model" (R-TM), which can also contribute to intermediate term earthquake prediction. The basic relations of this model are:

$$\log T = 0.19M_{\min} + 0.33M_p + q \quad (2)$$

$$M_f = 0.73M_{\min} - 0.28M_p + m \quad (3)$$

where, T is the interevent time between the mainshocks of a region, $M_{\min}$ is the minimum mainshock magnitude, M_p is the magnitude of the previous mainshock, M_f is the magnitude of the following mainshock and q, m are parameters which are calculated by the available data of the region. This is a time-dependent model since the time of the following mainshock in a region depends on the magnitude, M_p, of the previous mainshock and can be used for intermediate term prediction. Thus, in the present work, relation (3) is used to calculate an additional value for the magnitude of the predicted mainshock.

The investigated area is formed of two long seismic zones. The first one extends along the western coast of south America, has an almost north–south direction (45° S–5° N, 65° W–84° W) and is a result of convergence of the south American lithosphere with the Nazca lithospheric plate. The second one is a narrow seismic zone which has a SE–NW direction and is defined by the geographic points (5° N, 65° W), (5° N, 84° W), (16° N, 106° W), (24° N, 106° W). This seismic zone is a result of convergence of the north American and Caribbean lithospheric plates with the Cocos lithospheric plate. Fig. 1 shows the epicentres of the shallow (h≤100 km) earthquakes which occurred during the period 1900–2007 in the investigated area (along the western coast of south and central America) and have moment magnitudes M≥7.7.

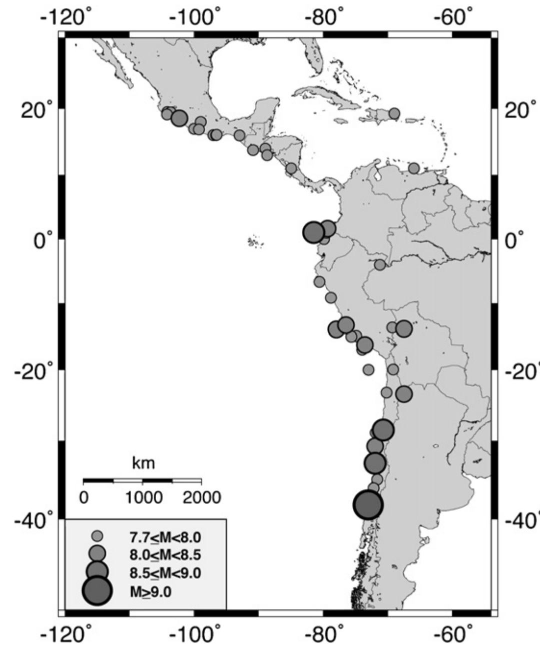

Fig. 1. Distribution of epicenters of the shallow (h≤100 km) earthquakes with M≥7.7 which occurred along the west coast of south and central America during the period 1900–2007.

2. The Decelerating–Accelerating Seismic Strain (D–AS) Model

The D–AS model is formed of relations with predictive properties which can be separated in three categories. The first category includes relation (1) and other relations, which concern accelerating preshocks and are used for the estimation (prediction) of the origin time and the magnitude of the ensuing mainshock. The second category of relations includes also relation (1) and other relations which concern decelerating preshocks and are used to estimate (predict) another value for the origin time of the mainshock and another value for its magnitude. The relations of the third category are based on properties of both accelerating and decelerating shocks (preshocks) and are used to estimate (predict) the epicenter coordinates of the ensuing mainshock. All these relations are based on global observations but most of them have been derived theoretically and/or interpreted physically (Papazachos et al., 2006).

2.1. Accelerating preshocks

An accelerating preshock sequence follows relation (1) with m<1 and the relations:

$$\log R = 0.42M - 0.30 \log s_a + 1.25, \qquad \sigma = 0.15 \quad (4)$$

$$\log(t_c - t_{sa}) = 4.60 - 0.57\log s_a, \qquad \sigma = 0.10 \quad (5)$$

$$M = M_{13} + 0.60, \qquad \sigma = 0.20 \quad (6)$$

$$\log(t_c - t_a) = 3.11 - 0.36\log s_a \quad (7)$$

where R (in km) is the radius of the circular (critical) region, s_a (in Joule$^{1/2}$/yr 10^4 km^2) is the rate of the long-term seismic strain, t_{sa} (in yr) is the start time of the accelerating sequence, t_c is the origin time of the mainshock, M is the magnitude of the mainshock, M_{13} is the mean magnitude of the three largest preshocks and t_a is the mean origin time of the accelerating preshocks.

A "quality index", q_a, is defined by the relation:

$$q_a = \frac{P_a}{mC} \quad (8)$$