MULTIFRACTAL ANALYSIS OF THE 1995 ANTOFAGASTA, NORTHERN CHILE EARTHQUAKE

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INTRODUCTION

During the last decades there are several authors showing that the spatial distribution of earthquakes follows multifractal laws (e.g., Hirata and Imoto, 1991; Dongsheng et al., 1994), and the most interesting behaviour observed is the decreasing of the fractal dimensions before the occurrence of a big earthquake, and also before large aftershocks (e.g., Ouchi and Uekawa, 1986; De Rubeis et al., 1993; Legrand et al., 1996).

The 1995 Antofagasta, northern Chile earthquake (Mw=8.0)presented a privileged situation with respect to its location related with a permanent seismological network that was in continuous operation since 1991, permitting to follow the seismicity before, during and after the occurrence of the 1995 earthquake. we use the homogeneous catalogue of the Antofagasta network to study the multifractal analysis of the 1995 earthquake, following the same methodology described by Legrand et al. (1996) for the aftershock sequence of the 1992 Erzincan earthquake.

THE 1995 ANTOFAGASTA EARTHQUAKE

This event is located inside the coverage area of a telemetric seismological network (Figure 1) that is in operation since the end of 1990, through a joint cooperation project between the Institut de Physique du Globe de Strasbourg, Institut de Recherche pour le Développement (IRD, ex-ORSTOM) and the University of Chile for the study of the northern Chile seismic gap located immediately to the north of the 1995 rupture surface (Delouis et al., 1997). The most clear foreshock of the July 30, 1995 Antofagasta earthquake (Mw=8.0) was that occurred on December 10, 1994 (Mw=6.2), which presented the same hypocenter and thrust focal mechanism solution. The 1995 rupture extended over an area of 185x90 km^2 along the subduction interplate contact, between 10 and 50 km in depth. The major events occurred during the first two weeks aftershock sequence were the August 2 (Mw=6.0), the August 3 (Mw=6.4), and the August 9 (Mw=5.5).

The seismic catalogue corresponding to the period of 1992 up to the second week of aftershocks of the 1995 earthquake, has a total of 1467 events with reliable hypocentral locations due to the coverage of the network. In order to work with a complete catalogue in magnitude, it was taken the data associated with the linear part of the Gutenber-Richter law, that is 1286 events with magnitudes greater than 2.8 and less than 6.0 (Figure 2), located inside of the rupture area of the 1995 Antofagasta earthquake (Figure 1).

METHODOLOGY

A full explanation of the theory can be found in Legrand et al. (1997). We will present a brief summary of the main equations used. The generalised correlation function used is defined as:

$$C_q(\varepsilon)=\left\{\frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{N-1}\sum_{i=1,i\neq j}^{N}H\left(\varepsilon-\left\|X_i-X_j\right\|\right)\right]^{(q-1)}\right\}^{1/(q-1)}$$

and the generalised fractal dimension is done by:

$$D_q=\lim_{\varepsilon\to 0}\left(\frac{\log C_q(\varepsilon)}{\log(\varepsilon)}\right)$$

where D_q is the probability of occupation of the i^{th} box with size ε, and q is a positive real number corresponding to the order of the correlation dimension.

Considering that, the coverage of the permanent network of Antofagasta is good enough to obtain reliable hypocenters within the selected area, and that all the events considered in the catalogue have S wave readings, the calculations of spatial distances between earthquakes were done in 3D. We worked with a moving window containing a constant number of events in order to guarantee the preceise estimations of the fractal dimensions. After different trials, we choose 200 for the number of the data points in each windows. Two consecutive windows were shifted by 20 points (Legrand et al., 1996).

RESULTS

The $log_{10}C_q(\varepsilon)$ versus $log_{10}(\varepsilon)$ for each q and for the complete data set is shown in Figure 3. The linear part of the curves, for each q, fall between ε_{min} = 19 km and ε_{max} 89 km: between these two values it can be observed different slopes of the curves suggesting a multifractal structure. The ε_{min} corresponds to the limit of hypocentral resolution of the permanent network, and the ε_{max} is smaller with the dimension of the selected area (km). Figure 4 show the spectrum of the generalised fractal dimension versus q for the complete data set, with the corresponding error bars; it can be observed that an adequate precision of the fractal dimension D_q is obtained for $q=25$ so, the calculations stopped at this value. Figure 5 shows the evolution of the different generalised multifractal dimensions with respect to time. It can be observed that there is a clear increasing of D_q previous to the occurrence of the main foreshock of the 1995 Antofagasta earthquake, followed by a continuous decreasing of D_q up to the moment of the occurrence of the mainshock. The same behaviour is observed for the major aftershocks of the 1995 sequence, and it is also observed for every q value.

DISCUSSION

The multifractal analysis of the Antofagasta earthquake shows that there is a systematic decreasing of the fractal dimension with time before the occurrence of the mainshock and the major aftershocks, that can be observed for every q value. The decrease of the fractal dimension before the occurrence of a big earthquake has been noticed by several authors (e.g., De Rubeis et al., 1993; Legrand et al., 1996). The average amount of the estimated decreasing of the D_q value is almost the same for the 1995, Antofagasta and 1992 Erzincan earthquakes, even though both events are very different in their seismotectonic genesis, magnitude, depth, and number of aftershocks, suggesting that probably the multifractal analysis is independent of these parameters and that the whole processes involved in the nucleation of big earthquakes follow a global law that can be inferred from this kind of analysis.

Following Legrand et al (1996), these results emphasise the importance of applying multifractal analysis in the evolution of the spatio-temporal distribution of seismicity in relation to the occurrence of large earthquakes. However, it is important to point out that it is extremely necessary to have a complete and homogeneous catalogue of seismicity locally recorded in regions where large earthquakes are expected to occur.

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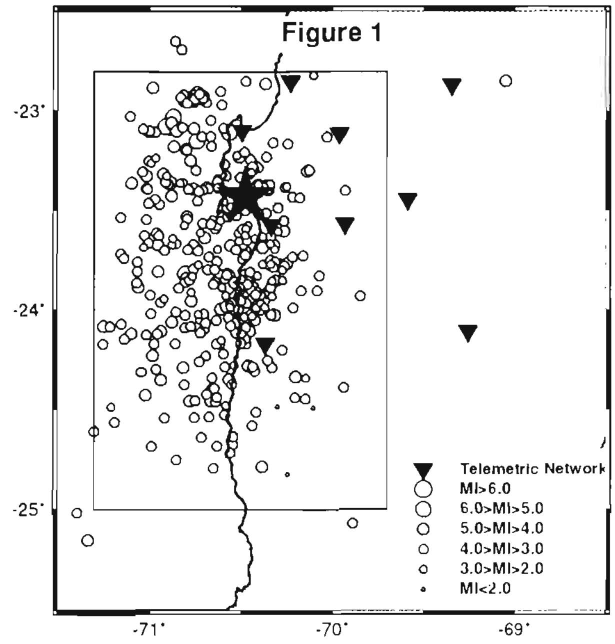
Figure 1
-23°
-24°
-25°
-71°
-70°
-69°
Telemetric Network
Ml>6.0
6.0>Ml>5.0
5.0>Ml>4.0
4.0>Ml>3.0
3.0>Ml>2.0
Ml<2.0

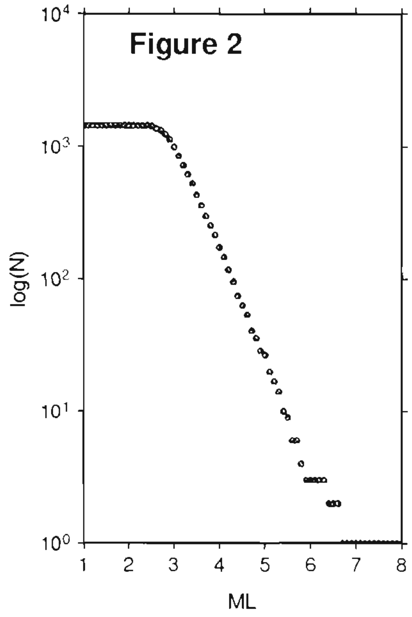
Figure 2
log(N)
10^4
10^3
10^2
10^1
10^0
1
2
3
4
5
6
7
8
ML

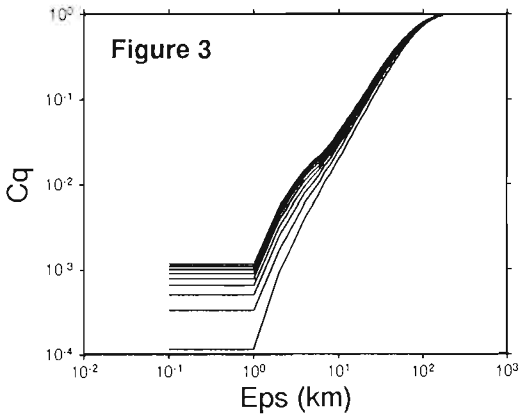
Figure 3
Cq
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
Eps (km)

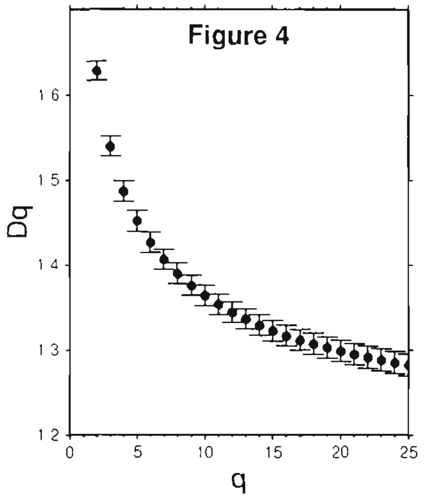
Figure 4
Dq
1.6
1.5
1.4
1.3
1.2
0
5
10
15
20
25
q

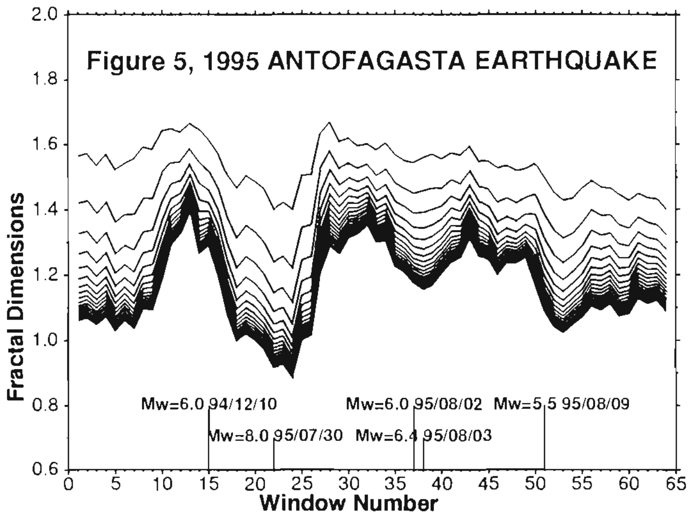
Figure 5, 1995 ANTOFAGASTA EARTHQUAKE
Fractal Dimensions
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Mw=6.0 94/12/10
Mw=8.0 95/07/30
Mw=6.0 95/08/02
Mw=6.4 95/08/03
Mw=5.5 95/08/09
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Window Number