Relazione Scientifica

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1.1 Titolo del programma di ricerca:

"Caratterizzazione dinamica con tecniche statistiche avanzate della distribuzione temporale della sismicità dell'isola di El-Hierro (Isole Canarie) durante il fenomeno eruttivo del 2011-2012"

1.2 Keywords : El-Hierro, metodi statistici, sismicità

1.3 Dipartimento: Terra e Ambiente

1.3 Durata: 21 giorni

1.4 Periodo: dal 28/11/2014 al 18/12/2014

2. PERFORMED ACTIVITIES

During the research stay at Instituto de Ciencias de la Tierra Jaume Almera (CSIC), Barcelona, the activity was devoted to the statistical analysis of the time series of the earthquakes recorded from 19/07/2011 to 10/12/2014 at El-Hierro (Canary Islands) (Fig. 1).

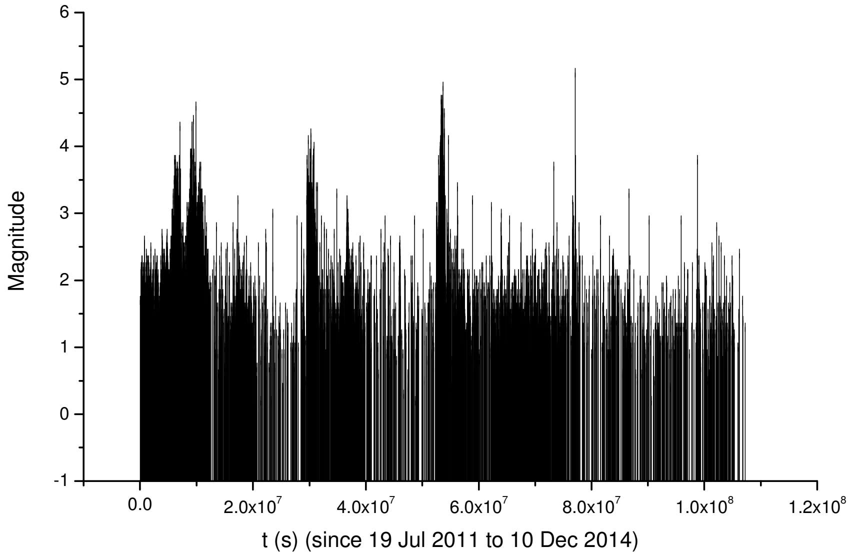

Fig. 1. Time distribution of the seismic activity al El-Hierro

The statistical analyses performed on these data were focused on the time variation of some key parameters that convey information about the complex dynamics of the volcano.

The analysis was performed using a time window sliding over the entire catalogue. The sliding window had a fixed length of one thousand events. The window slides through the entire catalogue with a shift of one hundred events. The length and the shift of the sliding window were chosen respectively to guarantee a sufficient number of earthquakes within each window to perform the statistical analysis and to have a sufficient smoothing among the obtained values.Within the sliding window, the following steps were carried out:

1) The completeness magnitude (Mc) of the subsequence of earthquakes contained in the window was calculated by means of the Maximum curvature-method (MAXC) (Woessner and Wiemer, 2005); this method provides a fast and reliable estimate of Mc as the point of the maximum curvature as magnitude of completeness as that matching the magnitude bin with the highest frequency of events in the non-cumulative frequency-magnitude distribution;

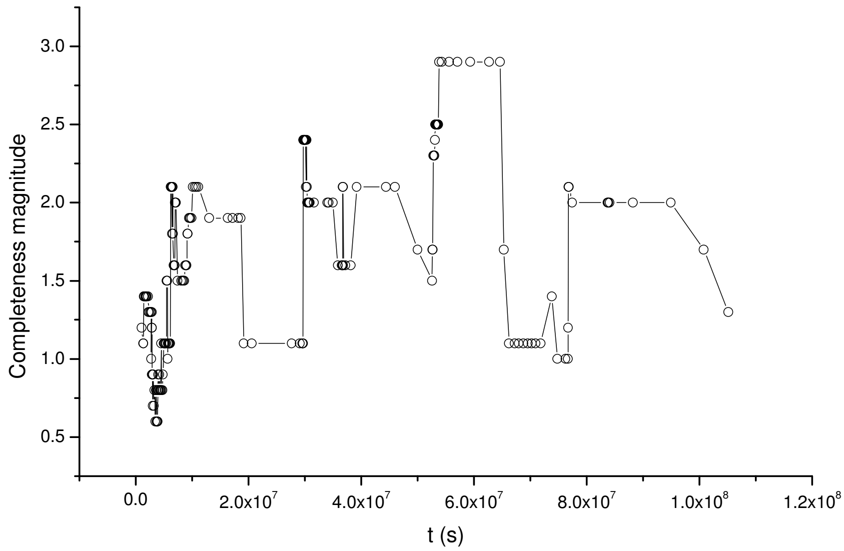

Fig. 2. Time variation of the completeness magnitude. The completeness magnitude ranges 0.6 and 2.9.

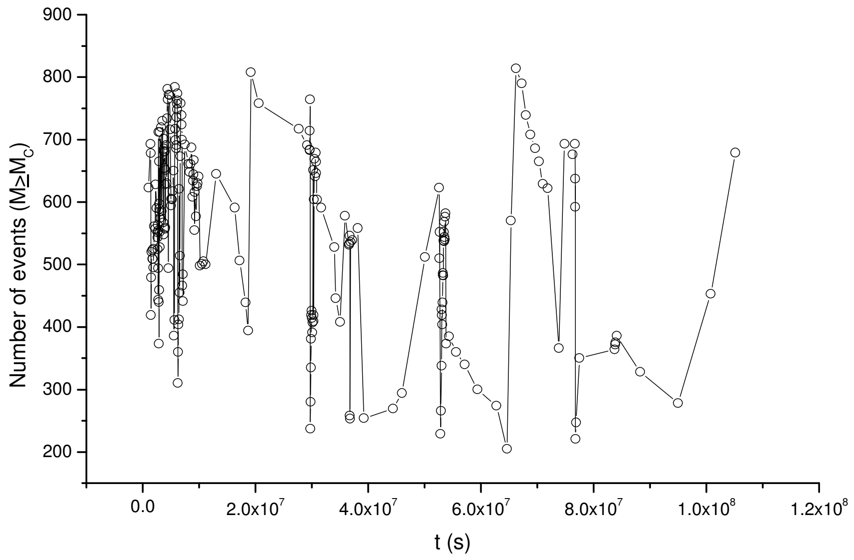

Fig. 3. Number of events with magnitude M larger or equal to Mc per sliding window.

The number of events per sliding window is large enough to guarantee statistical accuracy of the estimated parameters (Fig. 3).

2) The b-value of the Gutenberg-Richter law is estimated by using the maximum likelihood method. Fig. 4 shows the variation of the b-value.

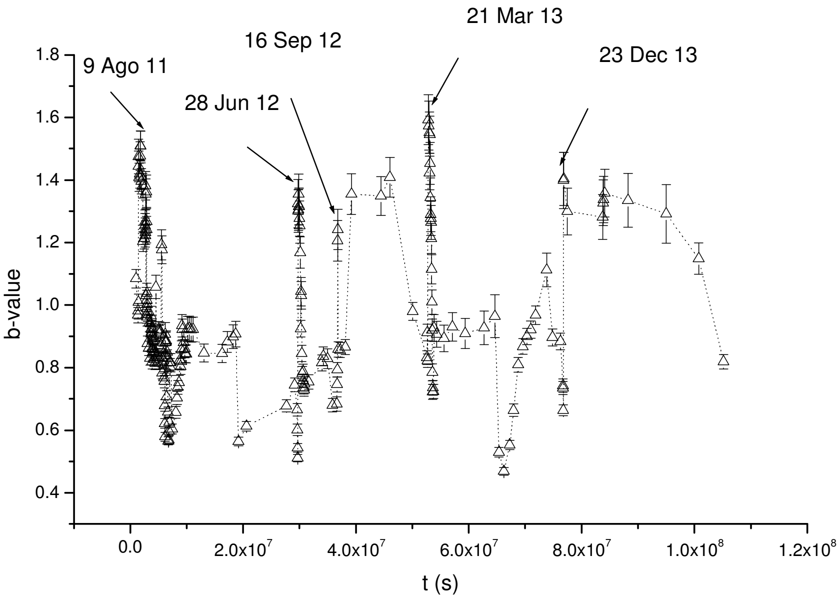

Fig. 4. Time variation of the b-value (and its error). The indicated dates represent the more visible peaks in the variation of b-value.

Considering only the subset of events whose magnitude is larger or equal to the completeness magnitude Mc, the following further steps are carried out:

3) The coefficient of variation Cv is calculated as the ratio between the standard deviation and the mean of the interevent times. The Cv furnishes a global information of the time-clustering of the seismic subsequence, which is Poissonian or time-clusterized if Cv is equal or larger than 1 respectively. Fig. 5 shows the time variation of the Cv.

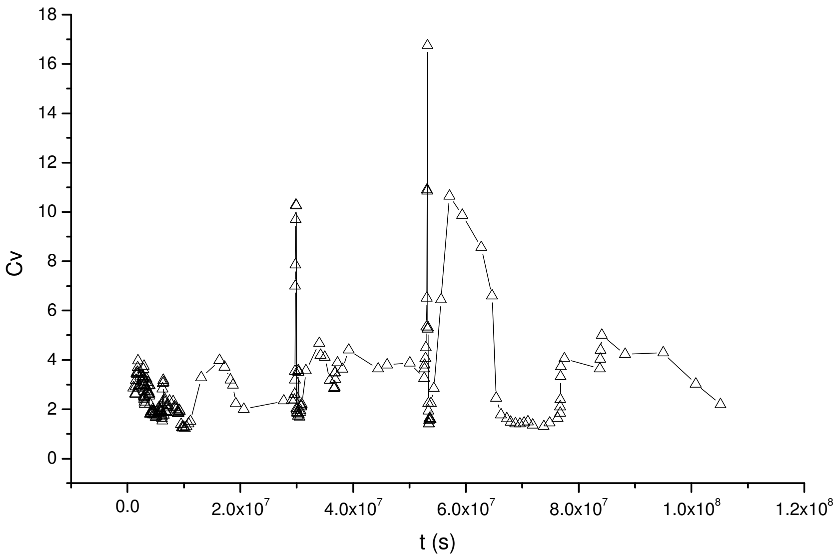

Fig. 5. Coefficient of variation. Two peaks are clearly corresponding to the 28 Jun 12 and 21 Mar 13. However, the Cv indicates the seismic sequence is time clusterized at any time.

4) The AF curve is computed by using the method described in Telesca et al. (2004). Regarding the estimation of the power-law exponent of the curve (which is simply given by the slope of the line fitting by the curve plotted in log-log scales by means of a least square method), attention is focused on the selection of the range of scales, over which the AF curve is linear in bilogarithmic scales. We applied the algorithm developed by Gulich and Zunino (Physica A 397, 17-30, 2014) for the selection of the dominant scale range over which the AF is linear in log-log scales. The exponent of the AF curve is then estimated on such range of scales. Theoretically, if the AF exponent is equal to 1, the sequence is Poissonian and uncorrelated, while if it is larger than 1 the sequence is time-clusterized. However, the analysis of the scaling exponent of surrogate seismic sequences is necessary to check the significance of the obtained values of the AF

exponent.There are two methods to generate surrogates of seismic sequences: by Poissonian simulation and by random shuffling of the interevent times. Therefore, our methodological procedure follows the next two steps:

5) The 95th percentile of AF exponents is calculated for one hundred surrogate seismic sequences drawn from a Poisson distribution having the same mean interevent time of the original subsequence of earthquakes (with magnitude larger or equal to Mc) contained in the sliding window. Comparing the 95th percentile of the AF exponents of these Possianian surrogates with the AF exponent of the original subsequence gives information on how significantly different from a Poissnian process is the seismic subsequence: if the AF exponent of the original subsequence is higher than the 95th percentile of the AF exponents of the Poissonian surrogates, it indicates that the original sequence is significantly not Poissonian but time-clusterized. Fig. 6 shows the comparison between the AF of the original sequence and the 95% confidence curve by Poissonian surrogates.

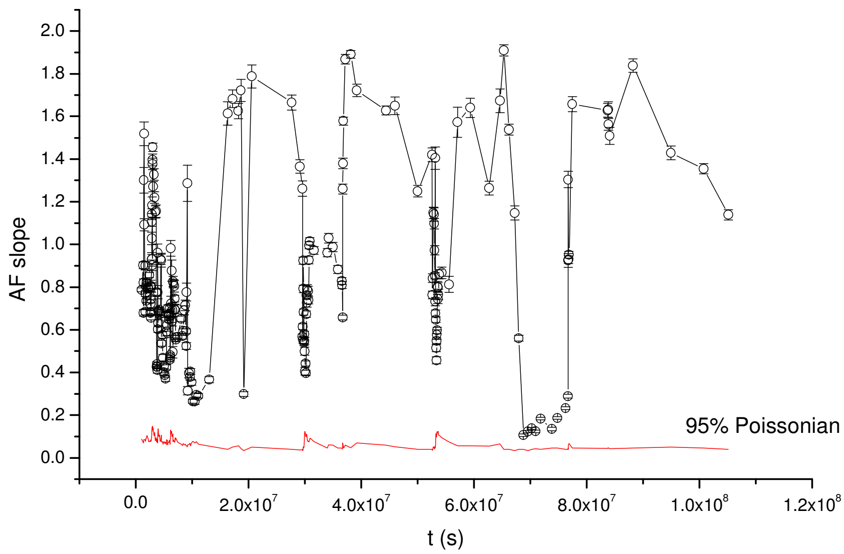

Fig. 6. Time variation of the slope of the AF curve along with its error and the comparison with the 95% of the slopes of Poissonian surrogates. The AF slope gives the quantitative information about

the time clustering of the seismic sequence. The AF slope ranges between about 0.2 and 2.0; this range is consistent with what has already been found in other seismo-tectonic environments. The comparison with the 95^{th} of the AF slopes calculated on Poissonian surrogates indicates that the AF slope of the original sequence is significantly higher than that could be obtained by a Poissoonian sequence with same mean interevent time. The comparison assesses the robustness of the found AF value.

6) The 95^{th} percentile of the AF exponents is calculated for one hundred surrogate seismic sequences obtained by shuffling the interevent times of the original seismic subsequence. This method produces sequences that have the same probability density function of the interevent times (PDFIT) of the original sequence but with all the time correlation destroyed. Comparing the 95^{th} percentile of the AF exponents of these shuffled surrogates with the AF exponent of the original subsequence gives information on how significantly different from a uncorrelated process is the seismic subsequence: if the AF exponent of the original subsequence is higher than the 95^{th} percentile of the AF exponents of the shuffled surrogates, it indicates that the original sequence is significantly correlated and that its time-clustering is due to ordering among the interevent intervals and not to the shape of the PDFIT. Fig. 7 shows the comparison between the AF of the original sequence and the 95% confidence curve by shuffled surrogates.

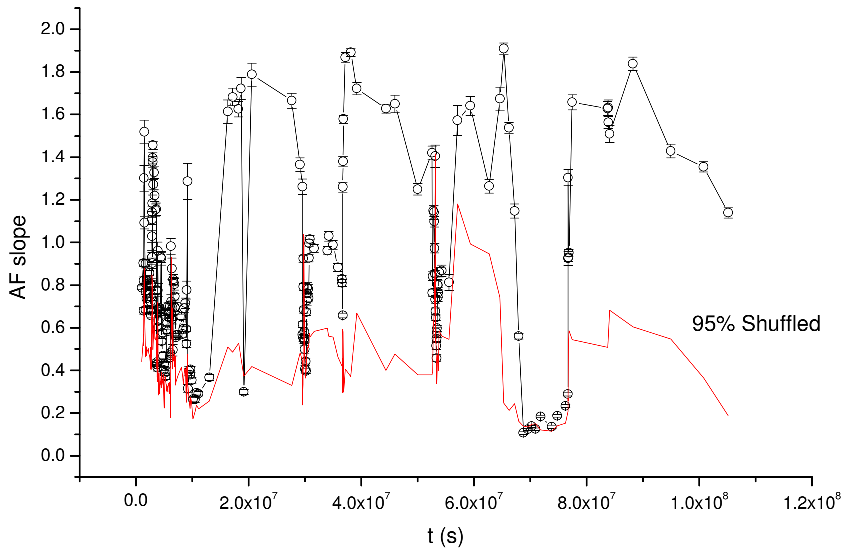

Fig. 7. Time variation of the slope of the AF curve along with its error and the comparison with the 95% of the slopes of shuffled surrogates. The comparison with the 95th percentile of the AF slopes calculated for AF curves obtained by random shuffles of the interevent times of the seismic sequence shows that there are phases in which clustering behavior depends on the probability density function (pdf) of the interevent times (when the 95% red curve is over or very close to the black curve) and phases in which the clustering depends on the ordering of the interevent times but not on the pdf (when the 95% red curve is lower the black one).

7) The further analysis is the estimation of dominant periodicity of the sub-sequence contained in the sliding window by using the method of Schuster (Ader and Avouac, EPSL, 2013). Fig. 8 shows the results.

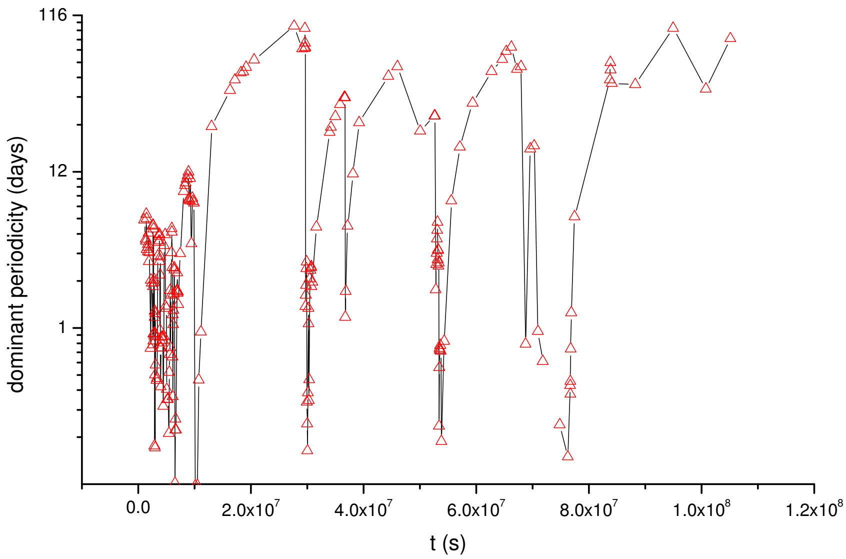

Fig. 8. Time variation of the dominant periodicity. This is the dominant significant (at 99%) periodicity, calculated by using the Schuster's method. By visual inspection it seems to me that the lowest periodicities (higher frequencies) are during the eruptive phases while the higher periodicities (lower frequencies) during the phase in which the volcano is "quiet".

2. CONCLUSIONS

On the basis of the obtained results, the following conclusions can be drawn:

1) the seismic process generated at El Hierro volcano is extremely nonstationary and nonhomogenous, as revealed by the changing completeness magnitude through time and the changing of all the key parameters that were investigated;

2) the ionset of each eruptive phenomenon is signalled by an anomalous peak of the b-value;

3) the clustering behaviour of the seismic process is extremely varying, and shows a quasi-periodical pattern through time; the clustering behaviour is significant against random chance (checked by using Poissonian and shuffled surrogates);

4) it seems that there is a tendency of the seismic process to increase the high frequency fluctuations during the eruptive phases and to enhance the low frequency fluctuations during the "quiet" phases.

3. CRITICAL EVALUATION OF THE PROJECT

The research activity performed during my stay at Instituto de Ciencias de la Tierra Jaume Almera (CSIC) was successful and the objectives of the STM project were fully reached.

In particular:

1) It was planned to submit one paper at scientific International journals with the citation of the STM 2014 CNR Program;

2) The scientific collaboration was strengthened not only with the ICTJA-CSIC in Barcelona, but also with the IGN in Madrid

4. ACKNOWLEDGEMENTS

I acknowledge:

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22/12/2014 Dr. Luciano Telesca