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A method to identify clusters of seismic events

G. Adelfio (1), M. Chiodi (1), L. De Luca (2), D. Luzio (2)

(1) Dipartimento di Scienze Statistiche e Matematiche "S. Vianelli" (DSSM), Università di Palermo,
(2) Dipartimento di Chimica e Fisica della Terra (CFTA), Università di Palermo

To describe the seismicity of an area in space, time and magnitude domains, it could be useful to study, by using the parameter estimates of a number of phenomenological laws, characteristics of independent events and strongly correlated ones, separately. The two different kinds of events give different information on the seismicity of an area. For this purpose the preliminary subdivision of catalog in background seismicity and clustered events is required. At this regard, a seismic sequences detection technique is presented; it is based on maximization of likelihood function defined from a model that describe seismic activity as a clustering-process.

Statistical predictive models based on identification of the two distinguished components (main-shocks and aftershocks) are diffused: the most popular is ETAS model (Ogata *et al*. (2002)).

Models proposed to describe seismicity are numerous, but most of them describe seismic events as the realization of a point process. A *space-temporal point process* can be considered as a random collection of points and each represents time and localization of every single event. *Homogeneous Poisson process* is the basis of the point process theory. It is the generator process of main seismic events in time, being characterized by absence of memory or complete temporal independence. Its simplest generalization is the *non-homogeneous Poisson process*, in which the intensity function is not constant.

The cluster detection technique introduced here allows us to define a predictive model for seismicity. This technique has been realized by software R and is based on estimation methods of the intensity components.

This approach is based on local maximization of a part of contributions to likelihood and returns an estimation of the intensity function of the point process that generated seismic events in spatial, temporal and magnitude domain.

It is based on ETAS model hypotheses: distinction between background seismicity and clusters of events, conditioned independence between spatial and temporal distributions, independence of magnitude distribution of clustered events from background seismicity one. It is important to note that strong assumptions about shape of components of intensity function in time and space are not formulated.

The algorithm proposed starts from an initial guest on clustering of events in the catalog and, examining iteratively points in temporal sequence, looks for the best aggregation, finding for every event E_j (with coordinates x_j, y_j, t_j) the main-shock (with coordinates x_i, y_i, t_i, M_i) that maximizes the product:

$$f(x_j - x_i, y_j - y_i)g(t_j - t_i)\kappa(M_i) \tag{1}$$

Then, according to the model supposed, this approach allows to find the event E_j for which the contribution to the intensity function is maximum.

In the intensity function, $\kappa(\cdot)$ describes the number of offspring that each main-shock independently produces as a function of its magnitude M_i. Density functions $g(\cdot)$ and $f(\cdot)$ are been estimated by non-parametric methods (Silverman (1986)).

Density estimation is based on events that belong to the cluster considered at current iteration. For events without offspring the density is that estimated for isolated events. At the end of each iteration this procedure returns the events classified in main-shocks, aftershocks (correspondent to each main-shock), isolated events.

This clustering technique has been conducted on a catalog containing seismic events occurred in the Southern Tyrrhenian Sea between 1988 and October 2002.

Starting from this new classification, it could be interesting to carry out an analysis on independent events, to verify, with a fixed confidence level, the hypothesis that the main-shocks have been generated by a Poisson homogeneous time process.

In point process residuals are the realization of a homogeneous Poisson process with unitary intensity named *residuals process* (Cox and Isham (1980), Ogata (1988)):

$$\tau = \int_0^t \lambda(s)ds \tag{2}$$

For spatial process residuals have been computed by different methods (Baddeley *et al*. (2004)).

The analysis of the characteristics of these processes and of the hypothesis below them, represents an useful tool to evaluate the goodness of the model. A distortion of residual distribution from expected characteristics could advise the necessity of investigating the effective independence of spatial component from temporal one, and the validity of assumptions made for the model definition.

References

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