Detection of spatial variations of earthquake clustering characteristics via weighted likelihood estimators

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The conditional intensity $\lambda(t,x)$ of a spatiotemporal point processes is defined by $\lambda(t,x) = \lim_{\delta\downarrow 0,\epsilon\downarrow 0} \frac{\mathbf{E}\, N[[t,t+\delta)\times B_\epsilon(x)]}{\delta\,\ell(B_\epsilon(x))}$, with $B_\epsilon(x)$ being a ball centered at x with radius ϵ and $\ell(\cdot)$ representing volume. The spatiotemporal ETAS model has been widely used for describing the clustering features of earthquakes in space and time (e.g., Ogata, 1998). Its conditional intensity is

$$\lambda(t,x) \quad = \quad \mu(x) + \sum_{j:t_j<t} \kappa(m_j)\, g(t-t_j)\, f(x-x_j;m_j) \qquad (1)$$

where $t \in \mathbb{R}$, $x \in \mathbb{R}^2$, and $m \in \mathbb{R}^+$ represent the occurrence time, the spatial location and the magnitude of an earthquake, respectively. In the above, m_c is the magnitude threshold, $\mu(x,y)$ represents the stationary spontaneous seismicity rate, $\kappa(m) = A\, e^{\alpha(m-m_c)}, m \geq m_c,$, $g(t) = \frac{p-1}{c}\left(1+\frac{t}{c}\right)^{-p}, t > 0$, and $f(x;m) = \frac{q-1}{\pi D e^{\gamma(m-m_c)}}\left(1+\frac{|x|}{De^{\gamma(m-m_c)}}\right)^{-q}$, $|\cdot|$ representing distance to the origin.

Given a realization $\{(t_i,\, x_i) : i = 1, 2, \cdots, n\}$ of a point process N in a space-time range B, the log-likelihood function is

$$\log L = \sum_{(t_i,x_i)\in B\cap N} \log \lambda(t_i,x_i) - \iint_B \lambda(t,x)\,\mathrm{d}t\,\mathrm{d}x.$$

Zhuang (2006) derived the general form of the weighted likelihood. In this study, for a location x^*, the weighted likelihood is

$$\log WL(x^*) \quad = \sum_{(t_i,x_i,)\in\, N\cap(B)} h(x_i - x^*)\, \log \lambda(t_i,x_i) - \iint_B h(x-x^*)\lambda(t,x)\,\mathrm{d}t\,\mathrm{d}x. \qquad (2)$$

where h is a kernel function only of locations.

The above method is applied to the Japan Meteorological Agency earthquake catalog. The spatial variations of the MWLEs of each ETAS parameter show different features among different tectonic regions. For example, the convergence part among the Eurasian, Philippine and Pacific plates is characterized by low α values.

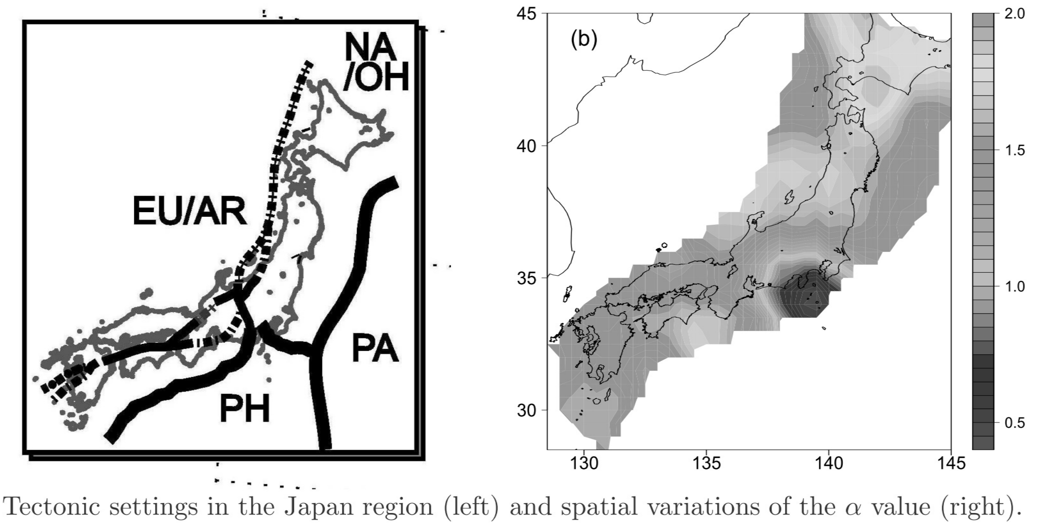

Fig. 1: Tectonic settings in the Japan region (left) and spatial variations of the α value (right).

References

Ogata, Y. (1998). Space-time point-process models for earthquake occurrences. *AISM*, 50:379–402.

Zhuang, J. (2006). Second-order residual analysis of spatiotemporal point processes and applications in model evaluation. *JRSSB*, 68(4):635–653.