Combining focal mechanisms into the ETAS model

蒔田恵理　　総合研究大学院大学　統計科学専攻　博士課程6年

【Abstract】

The epidemic-type aftershock sequence (ETAS) model describes how each earthquake produces subsequent events. Based on the ETAS model, this study explores the possibility of incorporating the focal mechanisms into the original ETAS model which considers only the locations, times, and magnitudes of each event. I hypothesize that the focal mechanism component is independent of all the others. I also test whether the rotation poles are uniformly distributed. Finally, I suggest the following new model;

$$\lambda(x,y,t,\Psi) = \mu(x,y,\Psi) + \sum_{i:t_i<t} \kappa(M_i) g(t-t_i) f(x-x_i, y-y_i \mid M_i) h(\Psi \mid \Psi_i) .$$

This model is helpful for us to understand the mechanism of aftershock triggers and tectonic stress field.

【Introduction】

The widely used space-time ETAS (epidemic-type aftershock sequence) model was developed by Ogata (1998). It has the following conditional intensity;

$$\lambda(t,x,y) = \mu(x,y) + \sum_{i:t_i<t} \kappa(M_i) g(t-t_i) f(x-x_i, y-y_i \mid M_i),$$

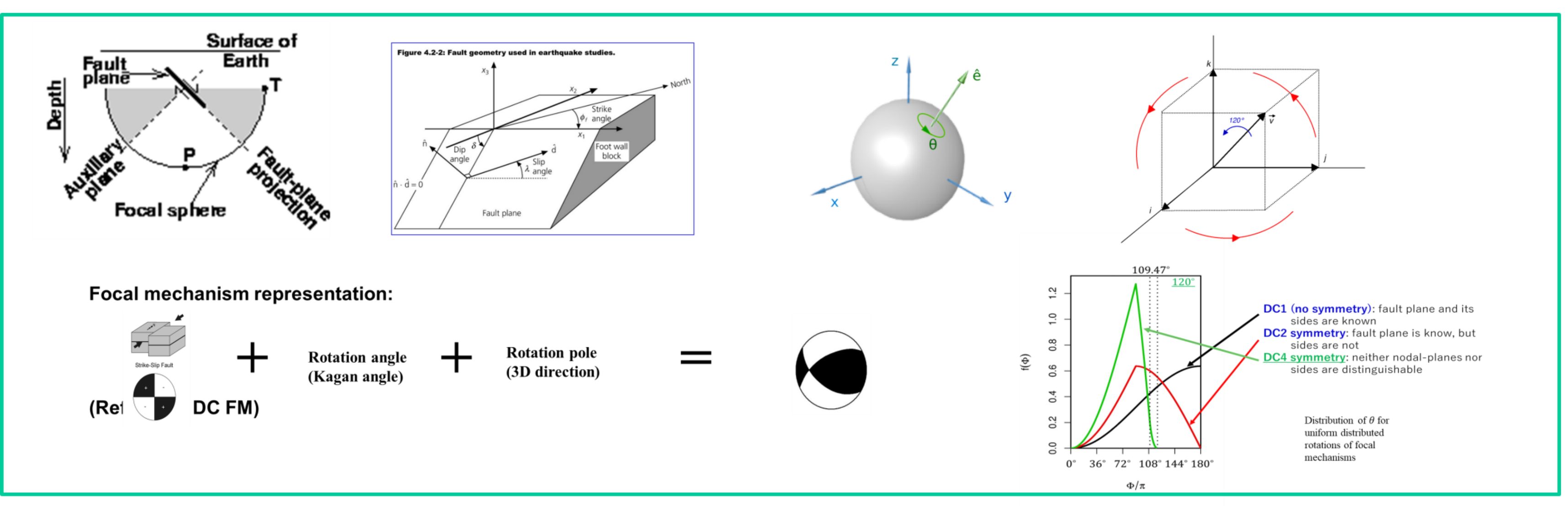
where $\mu(x,y)$ is the background seismicity rate, i runs over all the events in the observatory history, $\kappa(M_i)$ is the expected number of events triggered by an event of magnitude M_i, and the functions $g(t-t_i)$ and $f(x-x_i, y-y_i \mid M_i)$ are normalized time and space probability density functions (pdfs), respectively.

This time, I incorporate focal mechanism into the original ETAS model. To find a proper mathematical form of the new model, I used the stochastic reconstruction method developed by Zhuang et al. (2004).

【Theory and Methodologies】

The focal mechanism calculated from seismic waves is typically displayed on maps as a "beach ball" symbol. In the beach ball (focal sphere), a line represents the fault plane or auxiliary plane that is perpendicular to the fault plane. The beach ball also depicts the stress orientation and can be characterized by 3 patterns: normal, reverse, and strike-slip faults. In my notations, I first select a reference focal mechanism, and then use a rotation angle and a rotation pole to represent an arbitrary focal mechanism. Such notations can be described by normalized quaternions. Since double couple focal mechanism (DC FM) has 3 kinds of symmetries: DC1, DC2 and DC4. Only DC4 are recorded in earthquake catalogues. DC4 has 4 possibilities where neither the fault plane nor sides are known and symmetric. In the research, we deal with θ distribution in DC4.

Before the investigation of θ distribution, we use the declustering method to separate the background seismicity and different aftershock branches for weighing each earthquake for constructing the empirical pdf of the rotation angle. The original ETAS model provides the weight of any jth aftershock event triggered by the previous ith events: $\rho_{ij} = \frac{\kappa(M_i) g(t_j - t_i) f(x_j, y_j; M_i)}{\lambda(x_j, y_j)}$. We can do the same procedure for each background event and the density of jth background event is φ_j. We apply the above methods to the F-net catalogue (1997 ~ 2017) with more than 4.2 magnitude.



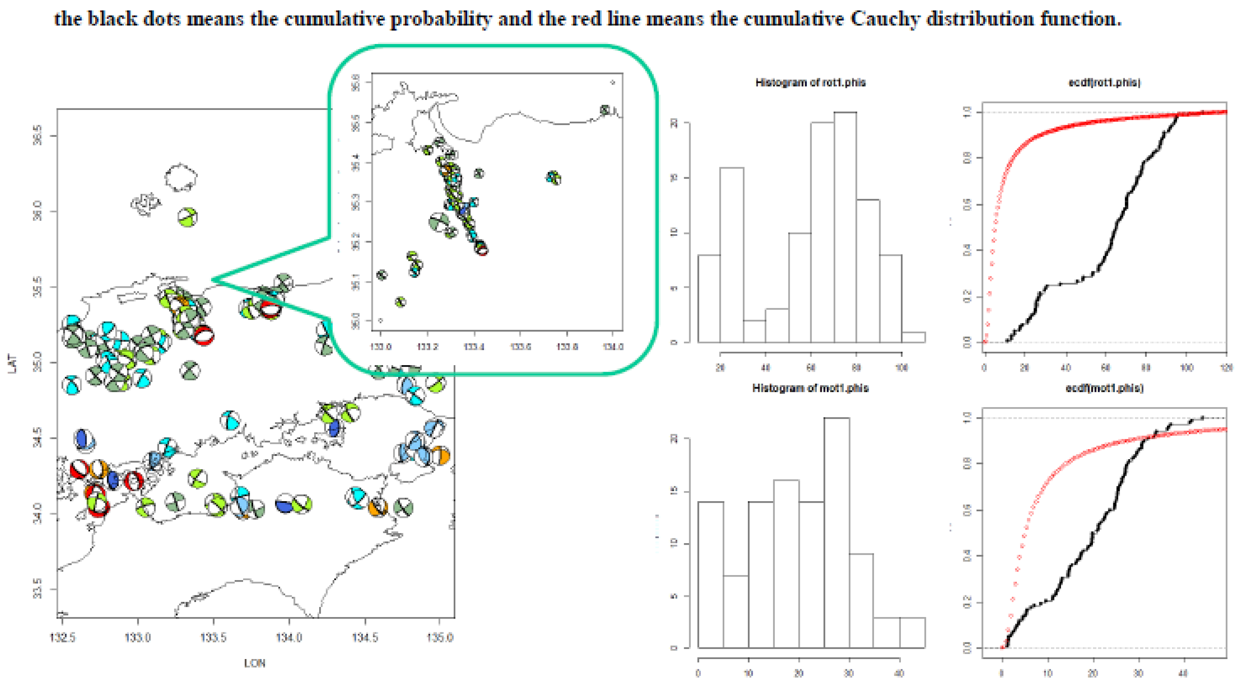
【New Extended Model】

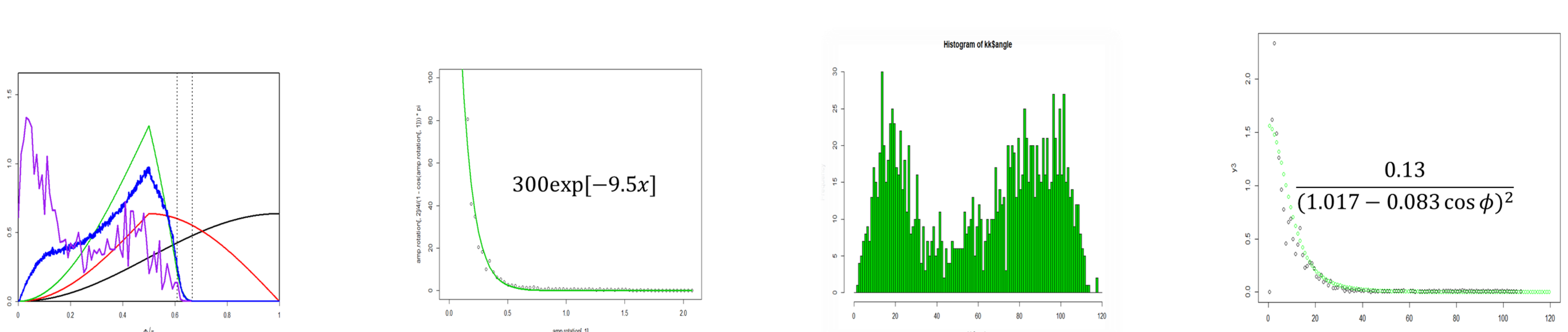
$$\lambda(t,x,y,\phi) = \mu(x,y)\boldsymbol{\zeta}(\boldsymbol{\Delta}(\boldsymbol{\phi},\boldsymbol{\phi}_0)) + \sum_{i:t_i<t} \kappa(m_i)\, g(t-t_i)\, f(x-x_i, y-y_i; m_i)\, \boldsymbol{\xi}(\boldsymbol{\Delta}(\boldsymbol{\phi},\boldsymbol{\phi}_i)),$$

$$\zeta(\Delta) = \frac{\kappa}{(1+\kappa^2+(1-\kappa^2)\cos\phi)^2}\zeta_0(\Delta) \quad \text{and} \quad \xi(\Delta) = \exp\left[Ae^{-B\Delta}\right]\xi_0(\Delta) .$$

【Resion:Tottori in Japan】

- The upper left figure :
  Small focal mechanisms are each event and the large one is the mean focal mechanism.
- The upper right figure:
  Kagan angels between the mean one and each event.
- The lower left figure:
  the black dots means the cumulative probability and the red line means the cumulative Cauchy distribution function.





(a) (b) (c) (d)

[Results]

The new model obtained through stochastic reconstruction has the following form, where the rotation poles for focal mechanisms are uniformly distributed.

Figure (a) $\boldsymbol{\xi}(\boldsymbol{\Delta})$ (purple curve) and and $\xi_0(\Delta)$ (green curve) (b) Ratio $\boldsymbol{\xi}(\boldsymbol{\Delta})/\xi_0(\Delta)$ (c) Empirical $\zeta(\Delta)$ (d)) Ratio $\zeta(\boldsymbol{\Delta})/\xi_0(\Delta)$ (e) Simulation of focal mechanism in Tohoku area

[Conclusions]

Using stochastic reconstruction, a proper form of new ETAS model which incorporates the correction between focal mechanisms is built.