P07

Statistical Models for Activity of Low-frequency Earthquakes

○Tomoaki NISHIKAWA

1. Introduction

Slow earthquakes are slow fault slip events (e.g., Ide & Beroza, 2023). Quantifying and monitoring slow earthquake activity characteristics are important because they may change before large earthquakes occur (Matsuzawa et al., 2010; Luo & Liu, 2019).

Statistical seismicity models are useful for quantifying seismicity characteristics. However, no standard statistical model exists for slow earthquake activity. Statistical modeling of low-frequency earthquakes (LFEs), a type of slow earthquake, has only recently begun. LFEs are characterized by low dominant frequencies (1–10 Hz) compared to fast microearthquakes of comparable seismic moment (Shelly et al., 2007; Nishikawa et al., 2023). Constructing a statistical model that successfully describes the LFE activity is important for better characterization and forecasting. However, existing statistical LFE activity models (Lengliné et al., 2017; Tan & Marsan, 2020; Ide & Nomura, 2022) have never been compared, and it is unclear which model best describes LFE activity.

This study applies the existing statistical LFE activity models (Lengliné et al., 2017; Ide & Nomura, 2022) to LFE activity along the Nankai Trough and compare their performances using Akaike's information criterion (AIC; Akaike 1974). Based on the model comparison, I propose a new model that incorporates existing model features.

2. Data and Models

This study used a high-quality LFE catalog in the Nankai subduction zone from April 2004 to August 2015 (Kato & Nakagawa, 2020). I used the goodness-of-fit test (GFT) method (Wiemer & Wyss, 2000; Woessner & Wiemer, 2005) and determined the minimum magnitude of the LFEs to be analyzed (M 0.6).

In the Nankai Trough, LFEs occur in band-like regions downdip of the megathrust seismogenic zones. These band-like regions were divided into subregions in a manner similar to that of Ide and Nomura (2022). In and around the band-like regions, rectangles of 0.2 ° in latitude and longitude were placed at 0.1° intervals to create subregions. Each subregion was required to contain at least 100 $M \geq 0.6$ LFEs, and LFE activity in each subregion was analyzed. Consequently, 43 sub-regions were included in the analysis.

I used two existing LFE activity models. One is proposed by the Lengliné et al. (2017). In their models, the LFE occurrence rate was assumed to be the sum of the stationary background rate and aftershock rates of past LFEs. Furthermore, in this model, the shape of the aftershock rate kernel is not assumed *a priori* but is determined based on the observed data using piecewise constant discretization. In this study, I used 15 piecewise constants to discretize the aftershock rate kernel. I call the above model the L-type model.

Ide and Nomura (2022) proposed a statistical model for tectonic tremors (i.e., LFE swarms) (Shelly et al., 2007). Their model is based on an approach different from that of Lengliné et al. (2017). Ide and Nomura (2022) described the probability distribution of tremor interevent times using a mixture of lognormal and Brownian passage-time (BPT) distributions and forecasted tremor interevent times. Furthermore, their model depends only on the time elapsed since the last event and does not depend on detailed tremor activity history.

Upon applying the Ide and Nomura (2022) model to LFE activity along the Nankai Trough, an additional log-normal distribution was added to the model. This is because short-term LFE clustering often displays two characteristic timescales (tens of seconds and a few hours) as pointed out by Kato and Nakgawa (2020). I call the above model the L-type model.

I also used the epidemic-type aftershock-sequence (ETAS) model (Ogata, 1988), which is the standard statistical seismicity model for fast regular earthquakes. This model is similar to the L-type model. In this model, however, the shape of the aftershock rate kernel is assumed to be a simple power-law decay *a priori.*

The L-type, IN-type, and ETAS models were compared based on AIC (Akaike, 1974). The L-type, IN-type, and ETAS models had 16, 8, and 5 model parameters, respectively. A model with a smaller AIC was considered to be significantly better than a model with a larger AIC when the AIC difference (ΔAIC) between the models was 2 or greater.

3. Results

The IN-type, L-type, and ETAS models were superior in 25, 13, and 1 of the 43 subregions, respectively. The IN- and L-type models were superior in three of the remaining four subregions, with no significant differences between them. In the remaining subregion, the ETAS and L-type models were superior, with no significant difference between them. These results indicate that although there were more subregions in which the IN-type model performed better, the IN- and L-type model performances were competitive. In particular, the L-type model was superior to the IN-type model in several subregions of Shikoku and east of Ise Bay.

In addition, I found that the LFE aftershock rates cannot be described by a simple power-law decay and that there is decay stagnation (1.0×10^{-2} to 2.0×10^{-1} days). This is a general feature of the LFE activity in the Nankai Trough.

The complex shape of the LFE aftershock rate probably explains why the ETAS model, which assumes a simple power-law decay *a priori*, is significantly inferior to the L- and IN-type models.

4. Discussion and Conclusions

Although the IN-type model is superior in more subregions, the IN- and L-type model performances are competitive. Based on these results, I examine whether the incorporation of both IN- and L-type model features results in a superior model. The IN-type model has the characteristic of using a small number of parameters to represent the LFE occurrence rate. The L-type model considers the LFE activity history. I propose a new model incorporating both features. Specifically, a hybrid model was developed in which the L-type aftershock rate kernel was represented by a small number of parameters, similar to the IN-type model.

The AIC was used to compare the model performance. In most subregions (41 of the 43 subregions), the hybrid model was significantly superior to the L-type model.

The hybrid model was superior to the IN-type model in 26 of the 43 subregions. The IN-type model was superior in 15 of the remaining subregions. There were no significant differences in performance between the remaining two subregions. Compared with the previous results, the number of subregions in which the IN-type model performed the best decreased substantially (from 25 to 15).

The above analysis demonstrates that the hybrid model is superior to the L-type model. Furthermore, the hybrid model outperformed the IN-type model in many subregions and could be considered the best model in this study.