Semi-realtime monitoring of seismicity anomaly around Japan using the ETAS model

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1. Introduction

Detecting and monitoring anomalous seismicity is important for understanding the underlying physics of seismicity. Anomalous swarm-like seismicity, which is different from typical mainshock-aftershock sequences, was often observed during aseismic transients such as slow slip events (Ozawa et al., 2003) and fluid migration (Waite & Smith, 2002). Swarm-like seismicity was also observed a few weeks before the 2011 Tohoku-Oki and 2014 Iquique earthquakes (Kato et al., 2011; Kato et al., 2016). Given these observations, monitoring anomalous seismicity may also be useful for understanding the nucleation process of great earthquakes. Here we constructed a system to monitor seismicity anomaly using the epidemic-type aftershock-sequence (ETAS) model (Ogata, 1988) in semi-realtime. We have operated this system since April 2019.

2. Methods and Data

The ETAS model expresses the seismicity rate as the summation of stationary background seismicity rate and the Omori-Utsu law (Utsu, 1957). We evaluated seismicity anomaly by comparing the number of observed earthquakes with the prediction from the ETAS model. We analyzed seismicity of five subduction zones around Japan (i.e., the Japan Trench, Kurile Trench, Nankai Trough, Ryukyu Trench, and Izu Trench) and divided these subduction zones into eleven study regions (Fig. 1). In addition to the eleven study regions, we also analyzed the source region of two crustal earthquakes, i.e. the 2016 M7.3 Kumamoto and 2019 M6.7 Yamagata-Oki earthquakes.

We extracted M3 or larger earthquakes in each study region from the JMA catalog. We estimated the five ETAS parameters (μ, α, c, K, p) using the maximum likelihood method (Okutani & Ide, 2011). We then obtained the number of events predicted by the ETAS model by integrating the seismicity rate in time (Ogata, 1988). Finally, we compared the number of observed events and predicted events and detected seismic sequences inconsistent with the ETAS model. The detail of the method is as follows:

1. We choose an earthquake which is a target of our judgement of anomalous seismicity activation (target earthquake).
2. For 20 successive earthquakes preceding the target event, we calculate the probability distribution of the number of earthquakes that is realized by the ETAS model within the time period from each earthquake to the target event.
3. We calculate the probability that the ETAS model realizes more earthquakes than we actually observed using the probability distribution in the step 2.
4. We repeat the steps 2 and 3 for all the 20 successive earthquakes preceding the target event. We assign the smallest probability among the 20 probabilities to the target earthquake.
5. We judge the target earthquake as anomalous seismicity activation when the probability is less than 0.1%.
6. We repeat the steps 1-5 for all earthquakes in the study region.

3. Results and Discussion

We detected an earthquake swarm accompanying the

June 2018 Boso-Oki SSE, earthquake swarms off the Okinawa main island in September and October 2018, and doublets of M5.4 earthquakes in Hyuga-Nada in March 2019 as anomalous seismicity activation. We have operated this system since April 2019. We detected an earthquake swarm located to the south of the source region of the 2016 Kumamoto earthquake in June 2019 and one off the Tanega-Shima island in September 2019 in semi-realtime. These results are open on our web page (https://sites.google.com/site/tomoakinishikawahomepage/home/今日の地震活動) and updated every day.

In addition, we applied the above analysis to the foreshock sequences of several past large earthquakes in order to examine whether this system can detect the foreshock sequences as anomalous seismicity activation. As a result, we detected the foreshock sequences of the 1982 and 2008 M7 Ibaraki-Oki, October 1996 M6.9 Hyuga-Nada, 2016 M7.3 Kumamoto earthquakes as anomalous seismicity activation. We also found that the foreshock activity of the 2011 Tohoku-Oki earthquake before 7 March is relatively anomalous, although the assigned probability (0.15%) did not satisfied our detection criterion (0.1%). We may be able to detect similar foreshock sequences in semi-realtime by continuously operating this system.

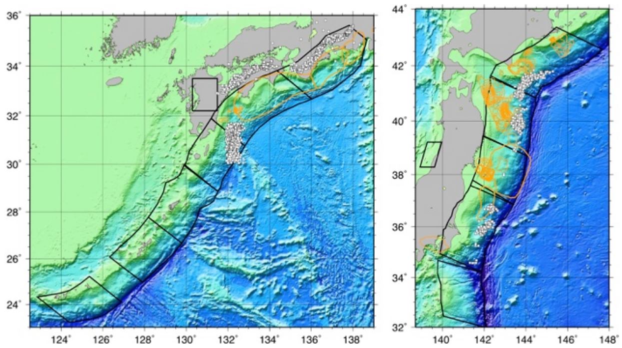

Figure 1. 13 study regions around Japan. Black solid lines indicate the study regions. Orange solid lines indicate slip distributions of past large interplate earthquakes (Yagi et al., 1998; Yagi et al., 1999; Yamanaka & Kikuchi, 2003; Yamanaka & Kikuchi, 2004; Iinuma et al., 2012). White squares represent epicenters of tectonic tremors (Idehara et al., 2014; Yamashita et al., 2015; Nishikawa et al., 2019).