論文の内容の要旨

Detection and statistical analysis of earthquake swarms at subduction zones globally: Implications to slow slip activity
（全世界沈み込み帯における群発地震活動解析とスロースリップ活動への示唆）

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Slow earthquakes, which are slip phenomena with longer time scales than ordinary earthquakes, occur in the vicinity of locked regions in subduction zones and are speculated to be related with occurrence of large earthquakes. Furthermore, slow slip events (SSEs), which are slip phenomena with a time scale of days to years, were reported to have preceded some large earthquakes. Therefore, revealing SSE activity in subduction zones globally is indispensable to understand large earthquake activity worldwide. However, currently, there are many areas where geodetic observation networks have not been well developed, such as offshore ocean areas, and it is difficult to elucidate SSE activity in subduction zones globally only from current geodetic observation networks. On the other hand, two kinds of ordinary earthquakes are known to closely related to SSE activity in subduction zones. One is an earthquake swarm. An earthquake swarm is a seismic sequence without a distinguished mainshock, and swarms triggered by SSEs have been observed in subduction zones

such as Boso-Oki, Japan and the Hikurangi trench, New Zealand. The other one is a repeating earthquake. Repeating earthquakes are repetitive rupture of almost the same area on the plate interface and can be used as a creep meter on the plate interface. By using these two kinds of ordinary earthquakes as potential indicators of SSEs, we can infer the occurrence of SSEs even in areas where geodetic observation networks have not been well developed. In this study, by investigating earthquake swarms and repeating earthquake, we aim to obtain implications for global SSE activity and the mechanism of large earthquake occurrences.

We make a global catalog of earthquake swarms in subduction zones. We present a method for detecting earthquake swarms using the space-time epidemic-type aftershock-sequence (ETAS) model. We applied this method to seismicity ($M \geq 4.5$) in the Advanced National Seismic System catalog at subduction zones during the period of 1995–2009. As a result, we detected 453 swarm sequences. Subduction zones such as Kermadec and Vanuatu are characterized by especially high swarm activity. Moreover, in some subduction zones such as Ibaraki-Oki, Japan, foreshock sequences of large earthquakes are also detected as earthquake swarms. In these regions, the large earthquakes may have been preceded by SSEs. We then compare the swarm activity and tectonic properties of subduction zones, finding that the swarm activity is positively correlated with curvature of the incoming plate before subduction. This correlation implies that swarm activity is controlled by hydration of the incoming plate and/or by heterogeneity on the plate interface due to fracturing related to slab bending.

We then further explore the possibility of occurrence of SSEs in Ibaraki-Oki, Japan by examining the space-time distribution of earthquake swarms and foreshocks of large earthquakes. We use the space-time ETAS model, the matched filter technique, and the repeating earthquake analysis to

reveal a more detailed history of swarm activity, restore small events missing from the earthquake catalog, and estimate the amount of interplate fault slip in Ibaraki-Oki. We found that 19 swarm sequences repeatedly occur during 1982–2009 at almost the same location as foreshock sequences preceding the 1982 and 2008 *M* 7 Ibaraki-Oki earthquakes. Both the foreshock and swarm sequences contain repeating earthquakes and have anomalously high seismicity rates inexplicable by the ETAS model, suggesting recurrence of SSEs in the source of the 1982 and 2008 *M* 7 Ibaraki-Oki earthquakes. The foreshock sequences in 1982 and 2008 have a larger number of events inexplicable by the ETAS model than the swarm sequences. The amount of slip of repeating earthquakes in the foreshock sequence in 2008 is also larger than those of the swarm sequences, and the slip rate increased 12 hours before the 2008 *M* 7 event. These results imply that the SSEs that preceded the 1982 and 2008 *M* 7 Ibaraki-Oki earthquakes have larger seismic moments than the other SSEs that triggered the swarm sequences. These large SSEs might be related to the nucleation phase of the *M* 7 Ibaraki-Oki earthquakes.

Our study reveals earthquake swarm activity in subduction zones worldwide, tectonic controls on earthquake swarm activity, and the relationship between the *M* 7 Ibaraki-Oki earthquakes and recurring SSEs in their source region. Our results and insights may be useful for future global investigations of SSE activity and studies on the mechanism of large earthquake occurrence in subduction zones.