A trial to quantify volcanic activities using the JMA unified earthquake catalog and the ETAS model

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To make judgements for bifurcations on volcanic activities based on precursors, a lot of examples of eruptions and precursors need to be evaluated quantitatively with a common approach. A dataset suitable to this type of analysis would be the unified earthquake catalog issued by Japan Meteorological Agency (JMA), which consists of the origin times, locations, and magnitudes of earthquakes all over Japan since 1923 including volcano-seismic events. To quantitatively relate seismic and volcanic activity levels, it seems that the seismicity level needs to be evaluated without explicitly using a time length and the number of earthquakes, since these quantities in precursory periods differ by eruptions. This requirement could be satisfied by using an Epidemic Type Aftershock-Sequences (ETAS) model (Ogata, 1988), which represents the seismicity by the summation of a background activity and aftershocks of all the preceding earthquakes. When the relation between the cumulative earthquake intensity predicted by the model (a transformed time) and the observed cumulative number of earthquakes do not show a single straight line, a change in the slope of the relation would represent a seismicity level change. In this study, we tried to quantify volcano-seismic activity levels using the unified earthquake catalog and ETAS model.

We first evaluated the volcano seismicity in this catalog by comparing it with that in another catalog around Mt. Ontake volcano created by Nagoya University (NU catalog). Although the number of earthquakes in the unified catalog was ~1/7 of that in the NU one, spatiotemporal characteristics of the seismicities in the both catalogs were essentially consistent to each other.

We next tried to develop a common method and criterion to extract volcano seismicities around the active volcanoes all over Japan from the unified catalog. To do this, we grouped the earthquakes within 20 km east, west, south, and north of each volcano at depths less than 15 km into 15 clusters using a mixed normal distribution model for the 3-D spatial distribution of hypocenters. Then volcano-seismic events are extracted as those in the cluster corresponding to a normal distribution for which the weight center was closest and less than 5 km (horizontal) of the volcano (i.e., the location is close enough to the volcano) and the longest radius of one standard deviation ellipsoid was less than 5 km (i.e., the hypocenters are not too widely scattered). The volcano-seismic events were identified successfully at 45 volcanoes, whereas 36 including Aso and Kirishima did not have a cluster which meet the requirements, and 29 volcanoes in island regions had too few earthquakes to perform the clustering.

We investigated ETAS model parameters for the extracted volcano-seismic events. Plots for the cumulative numbers of earthquakes against transformed times of the ETAS model showed elevated seismicities before 2007 and 2014 eruptions at Mt. Ontake, with a more significant activation in the 2014 case consistent with the eruption size. At Sakurajima, an increased seismicity associated with a dike intrusion on 15 August 2015 followed by several stages of calming down were identified. An intensified seismicity at Hakone in 2015 was most clear in the clusters 2nd and 3rd closest to the volcano. Remaining tasks include an improved extraction of the volcano seismicity, evaluations of the ETAS model at the other volcanoes, and a trial to find out a quantitative relation between the seismic and volcanic activity levels.

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