Inversion of envelope widths of volcano-seismic events to estimate 3D scattering structures: application at Taal volcano, Philippines

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Estimating heterogeneous structures beneath volcanoes is important to understand and to monitor various volcanic activities. Seismic heterogeneities or scattering structures are described by the scattering mean free path (l_0) and the quality factor for medium attenuation (Q_i) for *S* waves. Kumagai et al. (JGR, 2018) estimated a one-dimension (1D) layered scattering model by a grid search with respect to l_0, Q_i, and depth in each layer at Taal volcano, Philippines. The surface layer in the 1D model is highly heterogeneous (l_0 = 690 m) and attenuative (Q_i = 110) with a thickness of 1 km. This model was estimated by fitting observed envelope widths of volcano-tectonic (VT) earthquakes to those calculated from envelope waveforms synthesized with the Monte Carlo method (Yoshimoto, JGR, 2000). However, it is difficult to estimate more complex scattering models practically in this way because computational time for the envelope simulation rapidly increases with complexity of models. In this study, we developed a new method with inversion of envelope widths to estimate three-dimension (3D) scattering structures, and we applied it to observed envelope widths at Taal.

In this method, we assumed anomaly regions in the 1D model, and estimated deviations (dl_0 and dQ_i) from the 1D model values in the anomalies by performing inversion of envelope widths with the damped least squares method. Here, the envelope width is defined by the ratio of the peak amplitude to the amplitude integrated over time in a high-frequency (5-10 Hz) envelope waveform. We first synthesized envelope waveforms with the Monte Carlo method to calculate envelope widths for 3D models with l_0 and Q_i in each anomaly perturbed from the 1D model. Using the envelope widths of the perturbed models, we calculated the partial derivatives of envelope widths with respect to l_0 and Q_i in each anomaly for our inversion. We analyzed VT earthquakes that occurred between November 2011 and May 2013 at Taal. We set two anomaly regions in our inversion based on previous studies at Taal. One (Anomaly 1) is the high seismic attenuation region beneath the eastern flank of Volcano Island (Kumagai et al., GRL, 2014), and the other (Anomaly 2) is a high electronic resistivity region beneath Main Crater (MC) (Yamaya et al., BV, 2013). Niino and Kumagai (AGU Fall Meeting, 2018) estimated temporal changes in l_0 and Q_i in Anomaly 1 by envelope waveform fitting of three VT earthquakes (May 15, June 25, and November 25, 2012) that occurred almost same hypocenters and source mechanisms but showed different high-frequency envelope waveforms.

We performed inversion of envelope widths using VT events strongly affected by the two anomalies simultaneously. Our inversion results show that estimated Q_i values in the two anomalies were almost same as the value in the surface layer of the 1D model. The estimated values of l_0 = 980 m and 400 m in Anomalies 1 and 2 were smaller and larger than that of the surface layer, respectively. This indicates the existence of weaker and stronger heterogeneities in Anomalies 1 and 2, respectively. For the three events exhibiting temporal variations, we estimated l_0 and Q_i in Anomaly 1 by inversion of observed envelope widths of each event. The estimated Q_i values were almost constant around 80, but the estimated l_0 values were 1300 m in May 15, 660 m in June 25, and 1320 m in November 25, 2012, indicating temporal variations in l_0 in Anomaly 1.

We suggest that the stronger heterogeneity in Anomaly 2 was caused by cracks in solidified magma conduits. As suggested by Niino and Kumagai (2018), the short-term temporal variations in I_0 in Anomaly 1 is reasonably explained by ascends of magma with different initial water contents, which varied scattering characteristics in magma due to degassed bubbles. Our inversion results are consistent with the interpretations presented by the previous studies at Taal, and our approach using inversion of envelope widths is useful to quantify 3D scattering structures.