Temporal changes in the distinct scattered wave packets and their origin associated with triggered earthquake swarm beneath the Moriyoshi-zan volcano, northeastern Japan

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We investigated temporal changes in the waveform of wave packets in S-coda associated with a swarm-like earthquake sequence, and estimated the original location of the wave packets via an array analysis. The earthquakes are located around the Moriyoshi-zan volcano in northeastern Japan, and were triggered by the 2011 off the Pacific coast of Tohoku earthquake, forming the largest cluster to the north of the volcano. A notable feature of seismograms from the triggered earthquakes is the appearance of the distinct scattered wave-packets (DSW) that are S-to-S scattered waves from the localized strong heterogeneity in the mid-crust. The DSW appear about 2–3 s after the onset of S-wave with a dominant frequency of 8–24 Hz and with a duration of around 1 s. Furthermore, the DSW show the variation in their shapes even in the roughly near events.

To investigated the variation of DSW in detail, we first grouped events in the largest cluster with short inter-event distances and high cross-correlation coefficients (CC) in the time window of direct waves. Then we focused on the DSW part. Even in the same group, DSW showed temporal changes in their amplitudes and shapes. The change occurred gradually in some cases, but temporal variation were much more complicated in many cases. For example, the shapes of DSW changed from unclear peak to clear double peaks and suddenly back to the unclear. We also found that the shape of DSW changed in a very short time interval, for example, within ~ 12 h.

Next, we estimated the location of DSW origin by applying the semblance analysis to the data of the temporary small-aperture array deployed to the north of the largest cluster. The DSW origin is located between the largest cluster within which hypocentral migration had occurred and the low-velocity zone depicted by a previous tomographic study. These observations imply the existence of crustal fluid and the DSW origin was composed of crustal fluid accumulated midway in the upward fluid pathway from the low-velocity zone to the earthquake cluster.

Though we could not entirely exclude the possibility of the effect of the event location and focal mechanisms, the remarkable temporal changes in DSW waveforms possibly reflect the temporal changes in and/or near the origin. The short term change in DSW implies that fast movement of crustal fluid can occur at the depth of the mid-crust.