Volcanic subsidence triggered by the 2011 Mw 9.0 Tohoku earthquake, Japan

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The 2011 Mw 9.0 Tohoku earthquake induced an unprecedented level of seismic activity in eastern Honshu, Japan. How did the volcanoes really respond to the earthquake? Some volcanoes exhibited increased seismic activity, but little is known about the deformation of their edifices.

We performed interferometric synthetic aperture radar (InSAR) analysis using ALOS/PALSAR data acquired before and after the Tohoku earthquake, to investigate the local deformation around volcanoes in the eastern Honshu. The interferograms, after removing the coseismic and early postseismic signals of the Tohoku earthquake, showed subsidence in a few volcanic regions: around Mt. Akitakoma, Mt. Zao, Mt. Kurikoma, Mt. Azuma, and Mt. Nasu. The subsidence reached 5-15 cm and exhibited elliptical shapes with horizontal dimensions of 15-20 x 10-15 km elongated roughly in the direction perpendicular to the axis of maximum coseismic extension. A station of the Global Positioning System (GPS) Earth Observation Network (GEONET) was located within each of the Mt. Zao and Mt. Azuma subsidence areas; the displacement time-series obtained at these sites indicate abrupt surface subsidence whose amount is roughly consistent with the satellite radar observations.

Concentration of Late Cenozoic calderas, high-temperature thermal water, high heat flow data, and borehole sampling of very young and hot granite suggest presence of hot plutonic bodies beneath the subsided regions. We hypothesize that magmatic and surrounding hot rock complexes, having a magma reservoir at the center surrounded by hot pluton and thermally weakened rock, have very small viscosity (effectively no shear strength) as a whole and played a major role in the subsidence. Using a boundary element method, we modeled the weak region as a fluid-filled ellipsoid and investigated how it deforms in response to the stress changes given by the Tohoku earthquake. It was found that such ellipsoids having the longer horizontal axis of 10-20 km and top depth of shallower than a few kilometers can deform to reproduce the observed subsidence signals.

Similar subsidence signals were also observed at several volcanoes in central Chile in association with the 2010 Maule earthquake (Mw 8.8), indicating that such subsidence triggering is ubiquitous for active volcanic chains along subduction zones.