Time series of volcanic deformation in the Galapagos: A perspective from InSAR, GPS, and seismic data
Scott Baker, Marco Bagnardi, Falk Amelung, Dustin Coté, Cynthia Ebingier, and Dennis Geist

ABSTRACT: The Galapagos Islands are home to some of the most active volcanoes in the world, but given their geographic location and difficult working conditions, the volcanoes have gone largely unmonitored until the last 19 years. Interferometric synthetic aperture radar (InSAR) provided surface displacement measurements across the island chain since 1992 and measurements covering six eruptions at three different volcanoes. A continuous GPS network established at Sierra Negra in 2003 provided daily three component surface displacement measurements at the volcano allowing precise measurements during the 2005 eruption and provided a comparison for the InSAR measurements. The temporary broadband seismic network established in 2009 around Sierra Negra and Cerro Azul provided unprecedented measurements of the seismicity at the volcanoes. Using InSAR from ERS-1, ERS-2, Ratsa-1, Envisat, and ALOS satellites from 1992 to 2011, we measured surface displacements at the active volcanoes in the Galapagos Islands and generated time series using the small baseline subset (SBAS) method. A time history of surface displacements was measured at Wolf, Darwin, Alcedo, Sierra Negra, Cerro Azul, and Fernandina volcanoes. Combined with the GPS and seismic data, the InSAR time series allowed us to correlate surface and subsurface activity at individual volcanoes. In addition to activity at individual volcanoes, interactions between neighboring volcanoes were also evident. A brief period of subsidence at Sierra Negra occurred during the 2000 eruption of Cerro Azul seen in both the InSAR and GPS time series. An interaction between Fernandina and Alcedo is also present in the InSAR time series, and the location of seismicity between the two volcanoes provides evidence for a subsurface linkage between them. These interactions are clearly evident in both the geodetic and seismic data, but the recorded seismicity also suggests links between Sierra Negra, Alcedo, and Fernandina further supporting an interconnected magmatic system throughout the island chain. By combining the InSAR, GPS, and seismic datasets, we obtain more details about the time-dependent relationship between what is being measured and the controlling processes beneath.

DISCUSSION: Following the 1998 eruption at Cerro Azul, there was a rapid recharge of the deep magma chamber over the next year, but following the 1998 eruption there was no evidence for rapid recharge. One explanation for this could be the nature of the eruptions. The 2008 eruption had a much larger dike intrusion on the east flank, which possibly resulted in a depleted supply of magma available for rapid post-eruption inflation. The lack of 2008 recharge may also be the result of rapid inflation occurring at Sierra Negra. There is evidence from the time series that inflation at Sierra Negra wanes during the 2008 eruption and continues shortly after, and the deeper supply of magma for these two volcanoes could be going to Sierra Negra. This provides evidence for an interconnected magmatic system between these two volcanoes.

Fernandina and Alcedo also show evidence of inter-volcano interactions. In 2007, earthquakes located between the two coincide with changes and/or increases in the deformation at each volcano. The nature of the earthquakes in this area is still unclear, but these events were large enough to be recorded by the GNS global seismic network and several more events are listed in the catalog. Furthermore, the 2009 eruption at Fernandina brings an abrupt end to the inflation that was occurring at Alcedo since 2007, suggesting a link in the magma supply between the two volcanoes. The earthquakes from August 2009 to January 2011 are concentrated at the summits of Alcedo and Sierra Negra. The earthquakes at Alcedo are located in the southern part of the summit area close to the area that is deforming, providing further insight into the processes beneath the summit. Sierra Negra has the highest amount of earthquakes, and this is not out of the ordinary given the large amount of surface displacement observed in the InSAR and GPS data.