Icelandic surface deformation due to earthquakes and volcanoes – visualised by InSAR

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Interferometric combination of synthetic aperture radar images (InSAR) is an efficient method of studying crustal deformation in areas of sparse vegetation, such as Iceland. In Iceland, the technique has been utilized to study the deformation of volcanoes originating from both inflation and deflation of magma chambers, shallow intrusions and cooling of magma bodies at depth. Crustal deformation due to plate movements has also been recorded and a swarm of earthquake events in June 2000 has been well documented.

Two examples from Iceland are discussed. The first is from the Hekla volcano, which had its most recent eruption from February 26 to March 8, 2000. The study covers also the repose period prior to this eruption, after an eruption in 1991. An interferogram series, covering the years 1992-2000, holds both pre-co- and post-eruptive image pairs for the 2000 eruption. The deformation signals arise from several different sources. Subsidence of lava flows due mainly to cooling and compaction is observed in pre-eruptive interferograms. The largest signals originate from the 1991 lava flows, but lava erupted during eruptions in 1980-81 show also considerable subsidence in some interferograms. The amount of subsidence is closely connected to the lava flow thickness and the age (decreasing deformation with time). Widespread volcanic uplift due to magma accumulation in a deep-seated crustal magma chamber is also suggested in pre-eruptive interferograms. The area affected is about 40 km in diameter, but lava subsidence signals are superimposed on the uplift signal, and thereby conceal uplift in the interferograms in a wide area around the Hekla summit. Preliminary inspection of some of the tilt and GPS data appears consistent with this conceptual model. In co-eruptive interferograms asymmetrical deformation in the summit region is seen, due to injection of a feeder dike for the 2000 eruption.

The second example is focused on the two magnitude 6.6 earthquakes which occurred in the South Iceland Seismic Zone (SISZ) in June 2000. The SISZ is a transform zone connecting the western and eastern volcanic zones in Iceland. The SISZ consists of many parallel right-lateral N-S striking faults, that accommodate an overall left-lateral E-W shearing associated with plate spreading, in a "bookshelf tectonics" fashion. The June 2000 earthquakes happened on two of the parallel N-S striking faults.

We have analyzed a series of 21 interferograms of an area in South Iceland. Coseismic deformation originating from the two faults located approximately 20 km apart is observed in the interferogram series. We observe up to 15 cm of range change due to right-lateral strike-slip on these N-S striking faults, although the fault displacement is mainly perpendicular to the satellite look direction. GPS campaign data supplement the interferograms. Modeling of the fault geometry and slip distribution was carried out, assuming finite dislocations buried in an elastic half-space. A two-step joint inversion has been conducted. In the two step inversion we first solve for non-linear model parameters (the fault geometry) using simulated annealing and then estimate the fault slip distribution with linear least squares. With both dislocation-modeling methods we find a best-fitting model that agrees well with aftershock locations and moment magnitudes estimated by U.S. Geological Survey (from seismograms). The fault slip distribution of both events was slightly asymmetric on near vertical faults that extend to approximately 10 km depth and are 15-16 km long. The maximum slip predicted by the inversion depends on the assumed smoothness of the fault slip. The models can explain majority of the observed signals.

One coseismic interferogram indicates that postseismic processes occurred on a part of the June 17 fault, sometime during the time-span of the interferogram from June 19 to July 24, 2000. These processes are thought to consist of a combination of poro-elastic rebound due to large changes in the local water table level, and “back-slip” on part of the fault plane created on June 17. The ”back-slip” was most likely triggered by the June 21 earthquake, which forced the block between the two faults towards south. The “back-slip” amounts to about 10 cm and is minor compared to the co-seismic slip that occurred on this fault plane on June 17. However, we suggest that such minor “back-slip” is sufficient to create fault slicken-sides. This is consistent with geological studies of fault slip (slicken-sides) at other eroded faults in the SISZ that have indicated that both right-lateral and left-lateral slip has occurred on some of the N-S faults in the zone.