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Surface loading affects internal pressure source characteristics derived from volcano deformation signals

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Deformation of the Earth's surface provides critical information about the migration of material beneath a volcano. The resulting displacements, recorded by geodetic techniques such as GPS or InSAR, are used to infer characteristics of the volcanic plumbing system which are critical for hazard mitigation in volcanic regions. Given some deformation data, we search for the source model that explains the data best. Discussions of the results usually focus on the validity of the chosen model and the underlying assumptions regarding crustal composition, e.g. the level of inhomogeneity, elastic versus plastic deformation, thermal effects, depth vs. volume trade offs of the applied analytical models, or the (in-)compressibility of materials.

Surface loads such as lava flows, however, provide an additional source of deformation. The initial elastic response due to a load on the surface of the Earth is followed by a visco-elastic response of the ductile crust below the uppermost elastic layer. Thus, a deformation signal recorded in the vicinity of a volcano is often composed of at least two contributors: an internal pressure source (the magma chamber) and a surface load (e.g., a composition of previously erupted lava flows) – at the extreme the volcanic edifice and its glaciers.

A test case for a circular lava flow on top of a deflating magma chamber shows that the crust will adjust to the load towards final relaxed response. During this relaxation process gradual subsidence occurs that may mistakenly be interpreted as due to pressure decrease in a magma chamber since the deformation pattern of both processes are very similar. This poses a problem when characteristics of a magma chamber are to be derived.

Based on the ratio of horizontal and vertical displacement and a combination of model results (Green's functions and Mogi model), we can estimate the composition of observed deformation signals. This method is applied to the Icelandic volcano Mt. Hekla where we investigate InSAR observations prior to the Hekla 2000 eruption that show circular pattern of near field subsidence and far field inflation. We compare these data to the deformation pattern expected from pressure changes in a hypothetical, shallow magma reservoir. We estimate surface loading at the volcano to account for a displacement of $13.5\, mm/yr$ based on a comparison of expected Mogi source and observed InSAR line of sight velocity. From this we estimate an effective relaxation time of $t_r = 100\, yrs$ for this region. We infer an elastic plate thickness of $H = 3.5\, km$ which controls the $15 - 20\, km$ radius of subsidence.

We find that surface load signals in volcanic regions affect magmatic source model estimates significantly ; to the point of changing the preferred source model. This effect should be considered in virtually any volcanic region that shows lava flow emplacement, glacier dynamics, or sudden load removal (i.e., lateral blasts). Deformation data that remains uncorrected will most likely result in an overestimation of depth and volume of a magma reservoir. We find that the ratio of displacements aids the identification of composite signals and suggest that the ratio for GPS data be employed more rigorously in future studies since this allows volume independent source depth estimates.