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Quantification of L-band InSAR coherence over volcanic areas using LiDAR and in situ measurements

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ABSTRACT

Interferometric Synthetic Aperture Radar (InSAR) is a powerful tool to monitor large-scale ground deformation at active volcanoes. However, vegetation and pyroclastic deposits degrade the radar coherence and therefore the measurement of 3-D surface displacements. In this article, we explore the complementarity between ALOS–PALSAR coherence images, airborne LiDAR data and in situ measurements acquired over the *Piton de La Fournaise* volcano (Reunion Island, France) to determine the sources of errors that may affect repeat-pass InSAR measurements. We investigate three types of surfaces: terrains covered with vegetation, lava flows (a′a, pahoehoe or slabby pahoehoe lava flows) and pyroclastic deposits (lapilli). To explain the loss of coherence observed over the Dolomieu crater between 2008 and 2009, we first use laser altimetry data to map topographic variations. The LiDAR intensity, which depends on surface reflectance, also provides ancillary information about the potential sources of coherence loss. In addition, surface roughness and rock dielectric properties of each terrain have been determined in situ to better understand how electromagnetic waves interact with such media: rough and porous surfaces, such as the a′a lava flows, produce a higher coherence loss than smoother surfaces, such as the pahoehoe lava flows. Variations in dielectric properties suggest a higher penetration depth in pyroclasts than in lava flows at L-band frequency. Decorrelation over the lapilli is hence mainly caused by volumetric effects. Finally, a map of LAI (*Leaf Area Index*) produced using SPOT 5 imagery allows us to quantify the effect of vegetation density: radar coherence is negatively correlated with LAI and is unreliable for values higher than 7.5.

1. Introduction

Surface deformations are key indicators for the earth's crustal dynamics: they are directly linked to natural disasters such as earthquakes, volcanic eruptions or landslides. Understanding the forces that shape our planet requires having accurate topographic data, as well as an adequate spatial and temporal coverage. Over the past years, interferometric synthetic aperture radar (InSAR) proved to be an effective tool to map terrain topography and measure high-resolution and large-scale ground displacements with a vertical accuracy of a few centimeters (Massonnet & Feigl, 1998). The deformations of the *Piton de la Fournaise* (Reunion Island, France) are routinely monitored this way (i.e. Froger et al., 2004; Fukushima, Cayol, & Durand, 2005; Sigmundsson, Durand, & Massonnet, 1999). However, our ability to assess such deformations using SAR interferometry relies on our ability to maintain phase coherence over large areas. The required measurement accuracy may be affected by vegetation that introduces a significant bias by scattering of electromagnetic waves (Slatton, Crawford, & Evans, 2001). Moreover, in case of frequent eruptions, the availability of an accurate and updated digital terrain model (DTM) remains challenging. Those factors lead to spatial–temporal ambiguities that substantially compromise our ability to monitor pre-eruptive displacements. Hence a better knowledge of surface texture and DTM in active volcanic areas is crucial. In the past decade, light detection and ranging (LiDAR) systems emerged as a powerful tool to complete this task. Laser altimetry can be used to collect high-resolution topographic data and generate DTM with decimetric horizontal and centimetric vertical accuracy (Baltsavias, 1999; Wehr & Lohr, 1999). Due to ability of the laser beam to penetrate low-density vegetation, it provides unique information on both surface topography and vegetation structure (Haugerud & Harding, 2001; Nillson, 1996). Aerial surveys, for instance, are widely used in geophysics to obtain information on the geomorphology of active volcanoes (Csatho, Schenk, Kyle, Wilson, & Krabil, 2008; Fornaciai, Bisson, Landi, Mazzarini, & Pareschi, 2010; Mazzarini et al., 2005; Neri et al., 2008; Pyle & Eliott, 2006a,2006b; Webster, Murphy, & Gosse,

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