COUPLING POLARIMETRIC L-BAND INSAR AND AIRBORNE LIDAR TO CHARACTERIZE THE GEOMORPHOLOGICAL DEFORMATIONS IN THE PITON DE LA FOURNAISE VOLCANO

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Until recently the coarse resolution of topographic mapping acted as a break on understanding the forces and processes that shape the Earth's surface. However, active surface deformation is an important indicator for the earth crustal dynamics since it is directly linked to earthquakes, volcanic eruptions and landslides. Both airborne laser scanning systems (LiDAR) and spaceborne interferometric synthetic aperture radars (InSAR) have provided valuable information for many case studies requiring high-resolution characterization of ground movement in relatively large areas to assess the threat and impact of natural hazards especially for volcanic eruptions.

The Piton de la Fournaise volcano (Réunion Island, France) is one of the most active basaltic shield volcanoes in the world. It has reached an anomalous activity level in the past years with a major eruption occurring in April 2007. InSAR is routinely used to quantitatively monitor its deformations (Sigmundsson et al., 1999; Froger et al., 2004; Fukushima et al., 2005). However multiple eruptive periods have made it a particularly difficult target because of the ambiguities associated with the remote mapping of the extension of the lava flows, the detection of buried source vents, and the assessment of temporal and geographical variability of their textural characteristics (Wada et al., 2010). The burial of flows is a result of the deposition of younger pyroclastics and flows associated with more recent eruptive events. Burial of older flows by younger eruptive events often leads to complex surface geomorphology and subsurface stratigraphy, which in turn leads to substantial ambiguities associated with InSAR monitoring of volcanic activity. Moreover, vegetation on the side of the volcano considerably limits its application because microwave electromagnetic radiations penetrate plant canopies with difficulty: the shorter wavelengths (bands X and C) are backscattered by the upper parts of trees while the longer ones (bands P and L) penetrate profoundly into the forest canopy reaching the surface (El-Rayes and Ulaby, 1987). A last limitation is bound to the availability of accurate and updated Digital Terrain Model (DTM) for multiple eruptive terrains. All these mapping and monitoring limitations, results in a substantial ambiguity in the development of lava flow models which result in a poor understanding of the eruptive history, and hence a failure to address the magma budget in the magma chamber.

LiDAR that allows precise measurement of surface topography even over vegetated areas became in a few years a powerful indispensable tool of cartography of the Earth's surface (Kraus and Pfeifer, 1998; Wehr and Lohr, 1999; Mallet and Bretar, 2009). The calculation of the DTM with a high-vertical accuracy is based on the analysis of the three-dimensional point cloud. The precision of the measurements and the capacity of the electromagnetic waves to penetrate into plant canopies offer the possibility of extracting good quality structural information on the landscape, whatever the cover type. LiDAR is also capable of measuring the intensity of the signal scattered by the surface, which depends on its optical (refractive index) and physical (roughness) properties (Coren and Sterzai, 2006; Höfle and Pfeifer, 2007). This technique has been successfully used in volcanology for geomorphological studies (Mazzarini et al., 2005; Webster et al., 2006; Csatho et al., 2008; Morris et al., 2008), identification and cartography of lava flows of different ages, or the modeling of the distribution of lava flows (Hofton et al., 2006; Mazzarini et al., 2007; Bisson et al., 2009; Favalli et al., 2009; Spinetti et al., 2009). To date, the complementarities of InSAR and LiDAR is more and more explored especially with the aim of correcting topographic models under plant cover to improve the precision of InSAR measured deformations (Slatton et al., 2001; Mougini-Mark and Garbeil 2005; Donnellan et al., 2008). The DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) mission will come to reinforce this urgent need for accurate observation that will improve the monitoring of surface deformations by matching the two above sited methods. In this effort we explore the statistical, spatial and temporal behavior of the L-Band backscattering coefficient at both HH and HV polarizations over different type of terrains in the Fournaise lava field as a function of the LiDAR intensity data. The correlation will be used in setting empirical models to correct for the L-Band phase distortion on ash and rough surfaces in volcanic terrains.

In order to perform this task we started in 2006 an intensive SAR polarimetric mapping campaign of the Piton de la Fournaise volcano using Advanced Land Observing Satellite (ALOS) L-Band images with parallel and cross polarizations to avoid the phase decorolation caused by dense vegetation. The full ALOS polarimetric modes, allow a better identification of deformations that occur in the vegetated areas inside and surrounding the volcano. This analysis enabled us to visualize and monitor the evolution of the deformations between June 2006 and October 2007, before, during, and after the eruption (Wada et al., 2010). Four months after the end of the eruption, we performed a heliported radar sounding of several sections of the volcano using a high power 40 MHz antenna that allows penetration of 50-80 m and we have observed decimetric topographic deformations in the InSAR maps. The aim of this investigation was to correlate the topographic deformations to the variations of the structural rigidity of the subsurface. We observed that the deformed zones are correlated with the occurrence of subsurface fractures, suggesting occurrence of collapsing zones at the caldera.

In September 2008 and September 2009, we complemented our analysis with airborne LiDAR scans acquired by the Institut Géographique National, in order to obtain a high-resolution DTM of the most active sections of the volcano. The total LiDAR points were distributed in 44 strips covering the summit of the volcano and parts of its eastern, western and northern flanks, i.e ground area of 80 km2, which corresponds to a point density of about 5pt/m2. In particular, we surveyed the Dolomieux crater, which shows substantial correlation between the inSAR observed anomalies and the collapsing zones, suggesting additional enlargement of the crater in the upcoming eruptions. Four locations in the great slopes area East of the caldera also showed similar significant fracturing and will have to be monitored closely as potential eruption locations. We finally generated LiDAR normalized intensity images to assess the roughness and textural variances of the lava flows. Normalized LiDAR reflectivity where correlated to the L-Band coherence images as shown in figure 1.

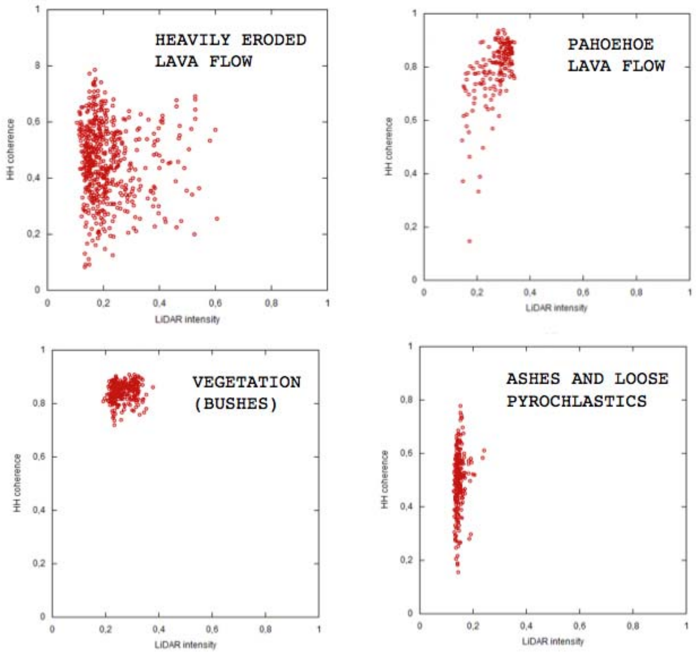

Fig.1. Preliminary results showing the HH L-Band 46-days coherence values as function of normalized LiDAR intensity for the four main textural variances of the Fournaise volcano: (1) Heavily eroded lava flows, (2) vegetation, (3) Pahoehoe lava flow and (4) ash and loose pyrochlastics. Smooth surfaces where coherence is preserved show a distinguished agglomerate pattern as observed in (2) and (3). As LiDAR penetrate through vegetation to the surface, surfaces covered with small bushes maintain the L-Band coherence. In Heavily eroded lava flows and ashes the coherence is low due the decorolation caused by multiple

More discussion of the implication of the variation of the Radar L-Band coherence as a function of the LiDAR intensity to improve the inSAR coherence will be discussed in the conference.

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