Improvement of active volcano deformation measurements combining laser altimeter and radar data: the case of the Piton de la Fournaise

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Context

- The Piton de La Fournaise is a very active volcano with an eruption around every 8 months [1].
- Interferometric synthetic aperture radar (InSAR) is a powerful tool to monitor deformation in active volcanoes.
- However, InSAR lacks accuracy over vegetated and pyroclastic surfaces that induce radar phase decorrelation and then errors of pre-eruptive surface displacements [2].
- Light detection and ranging (LiDAR) technology provides more accurate information about topography and vegetation height and allows to generate a high-resolution digital terrain model (DTM) of the volcanic edifice. The information derived from intensity values was recently used to identify and map lava flows [3,4].
- To enhance the calculation of InSAR coherence, we combine normalized airborne LiDAR intensity data with spaceborne InSAR coherence images from ALOS PALSAR L-band acquired over the Piton de la Fournaise in 2008 and 2009.
- This study is focused on different lava flows, vegetated and pyroclastic surfaces.

LiDAR data processing

Datasets (IGN)

- Two high-resolution campaigns performed over the volcano in 2008 and 2009
- Two low-resolution campaigns performed along the island shore in 2008 and over the whole island in 2009

Acquisition system

Wavelength	1064 nm
Vertical accuracy	< 0.15 m
Horizontal accuracy	< 0.40 m
Density	1-5 pt/m^2
Scan angle	5-10°
Measurement rate	50 kHz
Flight height	~1400 m (AGL)

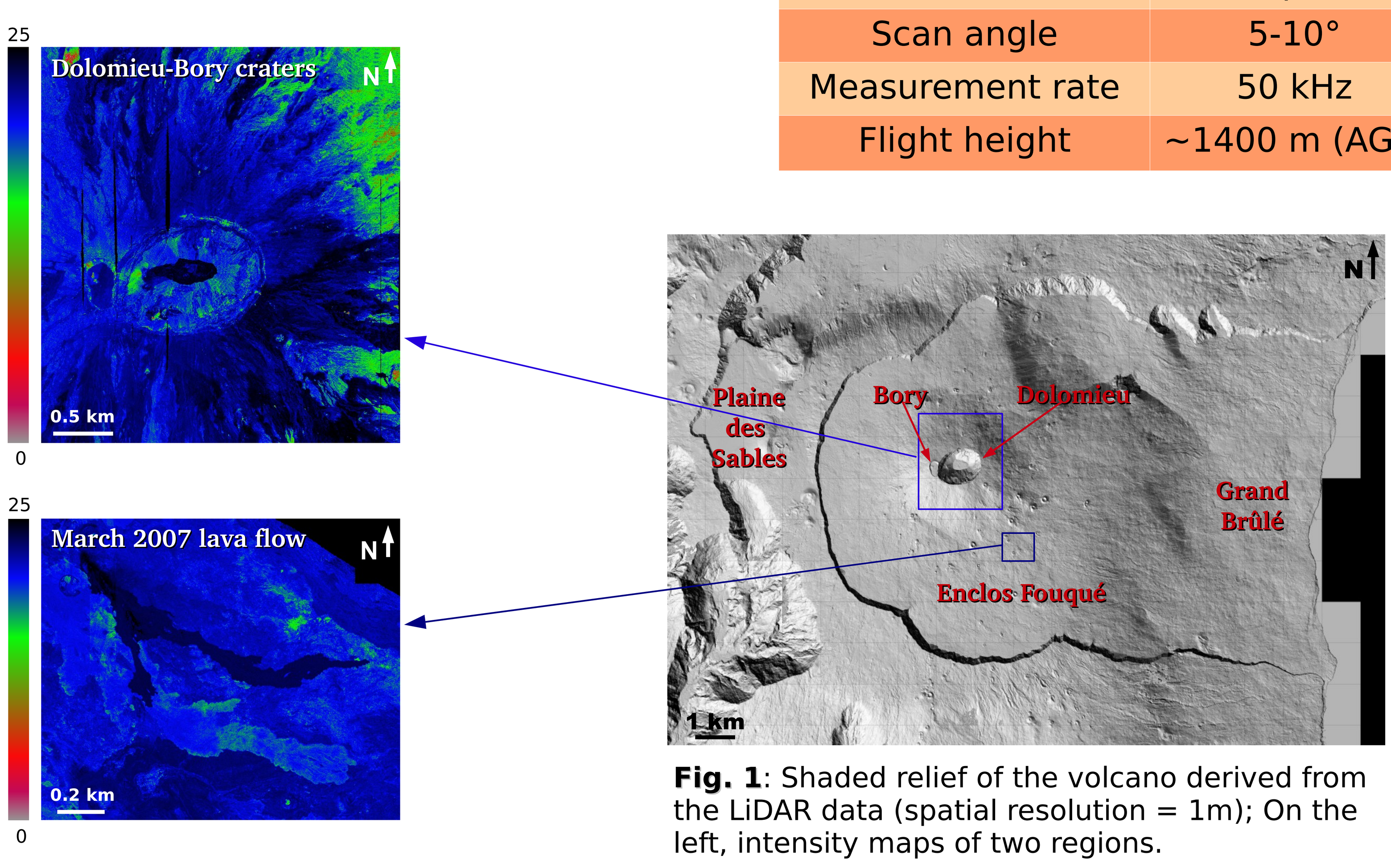

Fig. 1: Shaded relief of the volcano derived from the LiDAR data (spatial resolution = 1m); On the left, intensity maps of two regions.

Generation of a DTM

- Filtering of the point cloud to classify the different types of points (low or high vegetation and ground)
- Triangulation of the ground points to generate a DTM with a 1 m resolution by using the Terrascan software
- Validation of the DTM by comparing the GPS and the LiDAR data acquired over several regions

Generation of normalized intensity images

- Spatial resampling of the intensity values
- Assessment of the main factors influencing the laser intensity [5,6]
  - a) the distance between the sensor and the target
  - b) the topographic and local scan angle effects
  - c) the atmospheric attenuation (considered as constant)
- Validation of the radiometric correction described in [6] to check the first two factors influencing the intensity

$$I_{corrected} = I_{recorded} \times \left(\frac{R}{R_s}\right)^2 \times \frac{1}{cos(\alpha)}$$

- $I_{corrected}$ = corrected intensity
- $I_{recorded}$ = recorded intensity
- R = recorded range
- R_s = standard range
- α = incidence angle

Radar-LiDAR coupling

Radar data specifications

- Sensor: Phased Array type L-band Synthetic Aperture Radar (PALSAR) on-board the ALOS Japanese satellite launched in January 2006
- Wavelength: 23.6 cm (frequency: 1.2 GHz)
- Repeat-pass: 46-day cycle
- Spatial resolution: 18 m
- Polarisation: HH and HV
- Datasets: 9 amplitude images from March 2007 to October 2008 + 8 phase coherence images

Coherence calculation

→ cross-correlation coefficient γ of the SAR image pair, $0 \leqq |\gamma| \leqq 1$

→ γ quantitatively describes the interferogram fringe reliability

$$\gamma = \frac{E\{y_1 y_2{}^*\}}{\sqrt{E\{y_1{}^2\}\, E\{y_2{}^2\}}}$$

where y_1 and y_2 are the phase and amplitude of the radar signal

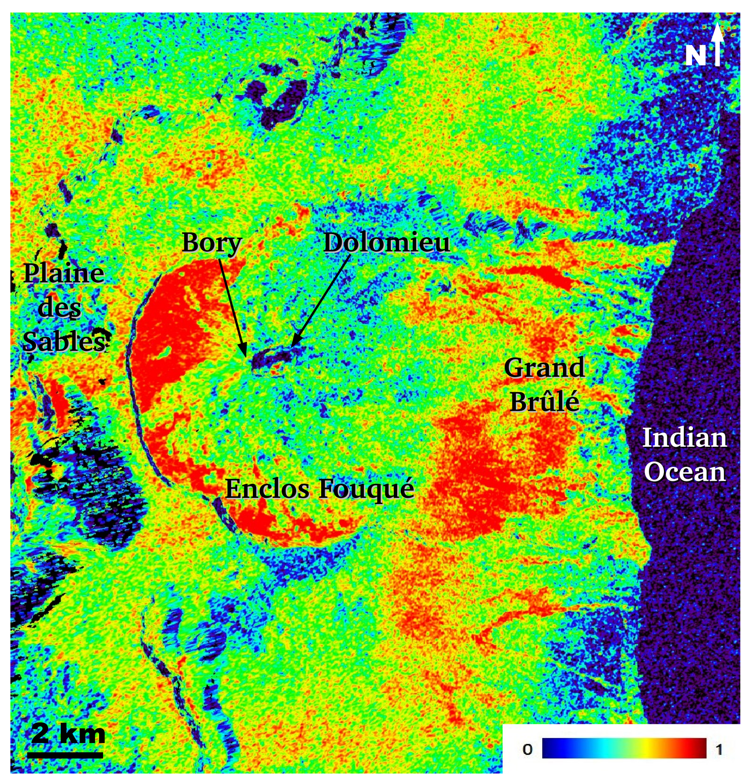

Fig. 2: HH coherence map calculated between two successive images (06 Sept – 22 Oct 2008) acquired over the Piton de La Fournaise.

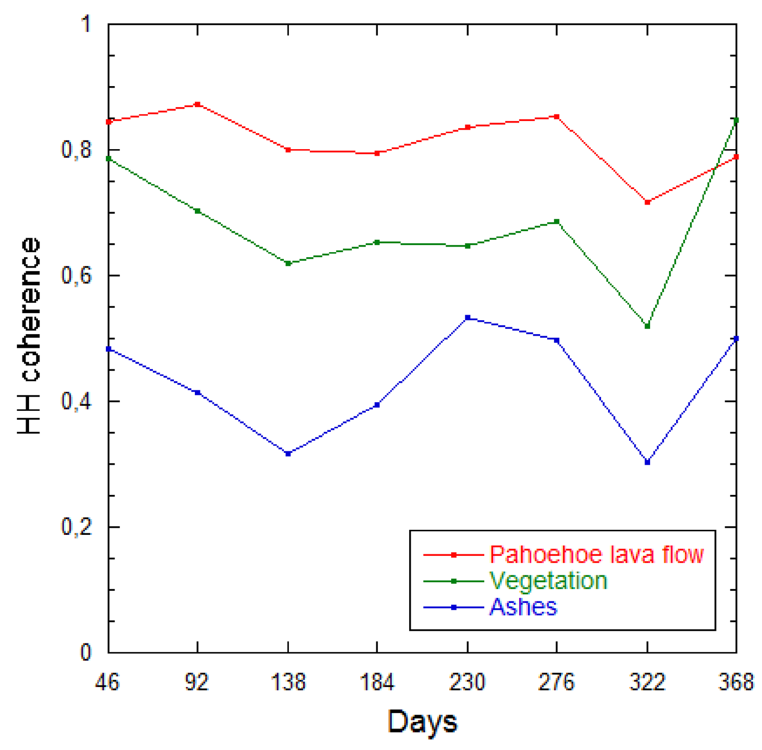

Fig. 3: HH coherence variations for different terrain types.

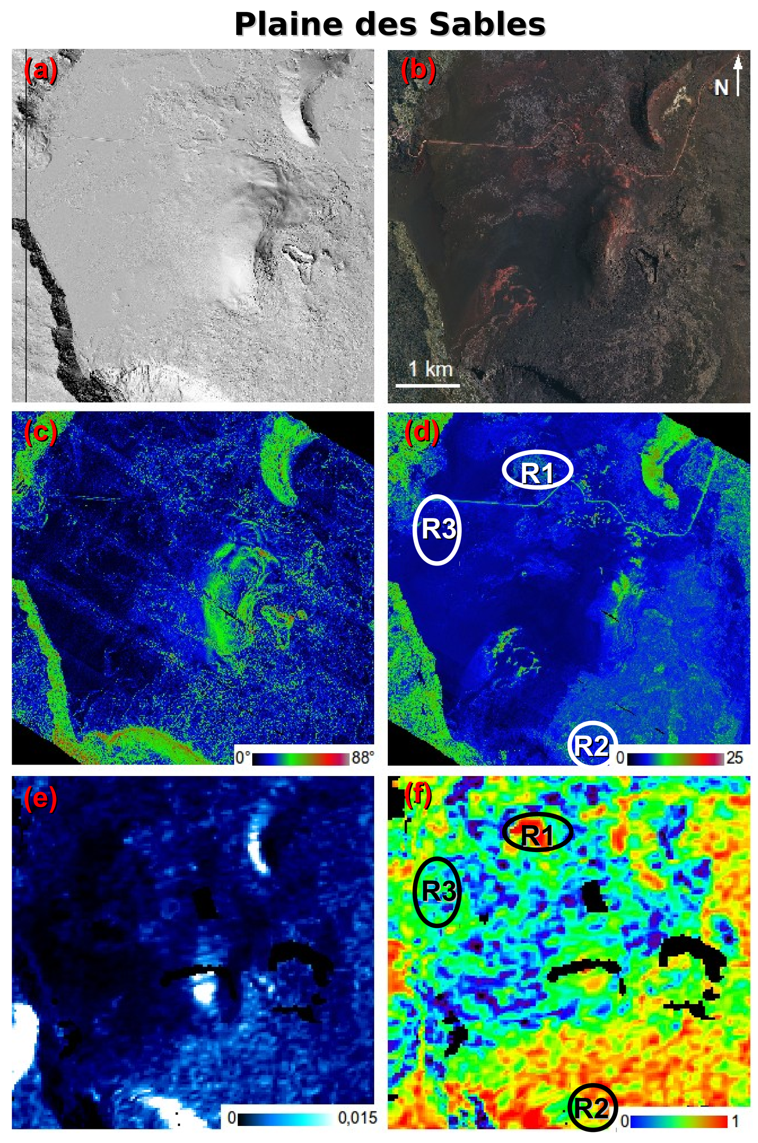

Fig. 4: LiDAR and SAR maps of the NW flank of the edifice. (a) Shaded relief representation derived from the LiDAR data; (b) visible image; (c) slope map derived from the LiDAR data; (d) LiDAR intensity image; (e) HH amplitude map (22 Oct 2008); (f) HH coherence map (06 Sept – 22 Oct 2008).

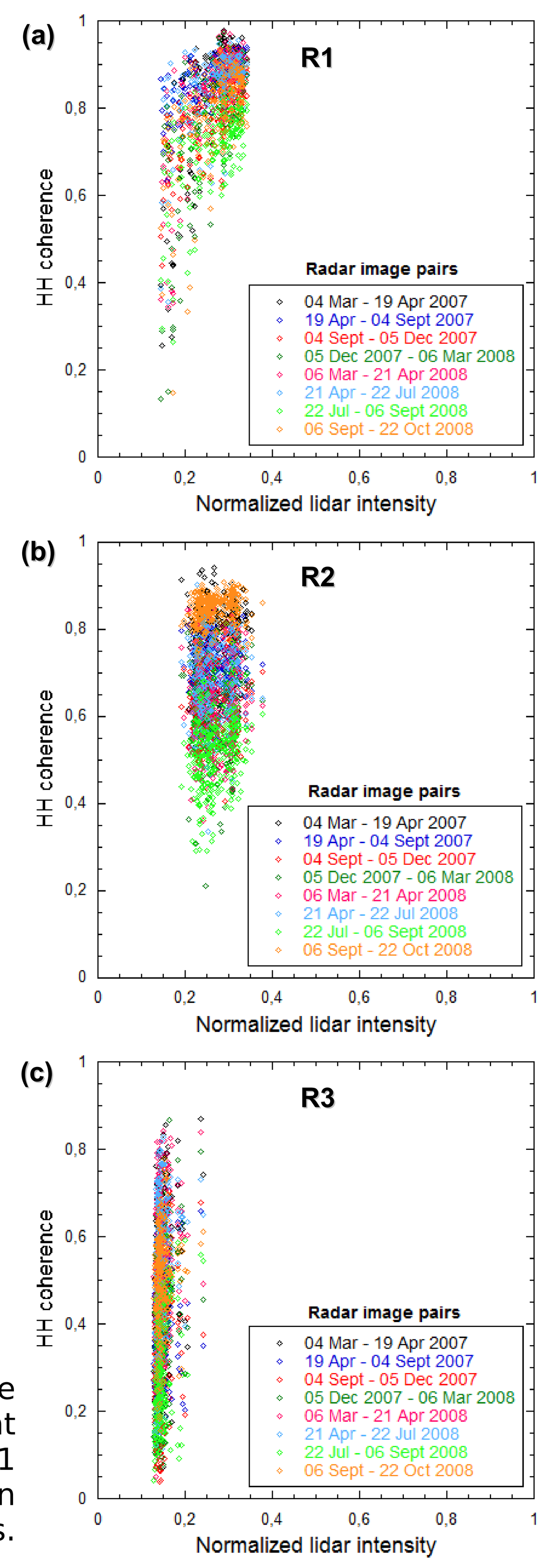

Fig. 5: Correlation between HH coherence and normalized lidar intensity for different terrain types shown in Fig.6(d)-(f). (a) R1 = pahoehoe lava flow; R2 = vegetation (bushes); R3 = volcanic ashes.

Preliminary conclusion

- SAR coherence variations are caused by the dielectric property modifications of pyroclastics and vegetation growth.
- L-band polarimetric data is expected to minimize temporal decorrelation effects.
- The correlation between InSAR coherence and LiDAR intensity should enhance the analysis of the coherence over vegetated and pyroclastic active terrains in order to enhance the accuracy of early phase displacement maps.

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