Synthetic Aperture Radar and the Guagua Pichincha Volcano

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Abstract

The Guagua Pichincha volcano close to Quito, Ecuador has been erupting since August 1998. To monitor its behaviour, RADARSAT-1 Fine Mode data were acquired in March, April, October, and November of 1999. Change detection has been carried out using these images. In this study, the capability, utility and limitations of such SAR imagery for monitoring of volcanic activity is being examined.

Introduction

The Guagua Pichincha volcano is located at .171^{o} S and 78.598^{o} W, near Quito, Ecuador in the Cordillera Occidental of the northern Andes [1][2]. Since the volcano is located so close to Quito, the city is at risk from ashfall if winds are blowing to the east during an eruption. A total of a few millimetres of ash were cast over the city in the later months of 1999, and historically, up to 30 cm. have been deposited in the region.

Seismic data in the area of Guagua Pichincha have been collected since 1977. Significant phreatic explosions and seismic events have been noted since August, 1998. These were mainly small volcanic eruptions with lithic ash (i.e. no juvenile magmatic component), during the latter part of 1998 and the first half of 1999.

The Instituto de Geofísico in Quito reported that during July and August 1999, Guagua Pichincha was continuing to emit ash from its vent [3]. (Vents from volcanoes expel gases when pressure builds up beneath the surface.) An elevated hazard status was declared during 1999 which was Yellow from July to September and increased to Orange on 27 September, 1999 [1]. Larger explosive eruptions occurred during the last part of 1999, associated with stages of growth of the lava dome within the caldera. The active crater is shown in Figure 1.

Figure 1a) and b). *Views inside the active crater of Quagua Pichincha. The zone of maximum gas release (on the right) is the area where new domes are growing.*

Although this volcano is in South America, it is along the Pacific Ring of Fire which passes up the spine of North America and then to Asia. Such volcanic behaviour has the potential to occur in many other parts of the world, including areas near the higher population centres on the Pacific Coast of North America. There have been a number of studies examining the uses of spaceborne SAR imagery including radar interferometry in the study of volcanoes e.g. [4][5][6][7][8][9][10] [11] [12]. The method examined for this volcano can be useful for monitoring other regions at risk of volcanic hazard in the Americas and Asia.

To assess the geological changes that have been occurring in the area of Guagua Pichincha, RADARSAT-1 Fine Mode (F3N and F2F) data have been acquired, processed and analyzed. The first of these were obtained on March 25 and April 18 of 1999. Later, following the significant volcanic activity of August, September, and October other data were acquired on October 3 and November 20 of 1999. These data have been processed to imagery.

As processed at CCRS, these RADARSAT Fine Mode images provide a coverage of about 50 km. by 50 km.

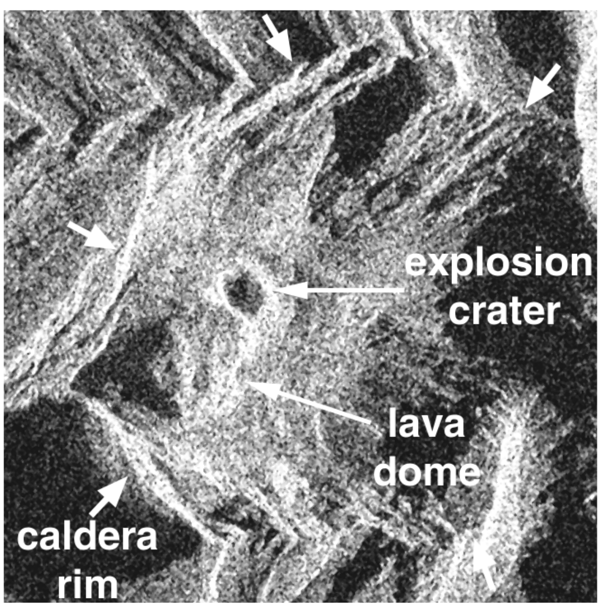

Figure 2. *Subimage of RADARSAT F3N scene acquired on April 18, 1999 in the region of Guagua Pichincha. Major parts of the volcano are indicated including four arrows pointing to the location of the caldera rim. Image size (on ground) approximately 2 km. by 2 km. (Shown in slant range (horizontal)) and azimuth (vertical)) coordinates.)*

Figure 3. *Subimage of RADARSAT F2F scene acquired on October 3, 1999 in the region of Guagua Pichincha.*

Figure 4. *Subimage of RADARSAT F2F scene acquired on November 20, 1999 in the region of Guagua Pichincha.*

with a ground resolution of less than 10 m. in both coordinates. Three such images are shown as Figures 2 to 4.

In comparing the imagery, there is virtually no difference in the morphology of the caldera in the March (not shown here) and April (Figure 2) images. The October (Figure 3) and November (Figure 4) images show that significant change has occurred within the caldera.

This October 3rd image is believed to be the first satellite image revealing growth and change of the lava dome which was first sighted by local observers on October 1. The changes in the lava dome are significant as (1) they signal the presence of new magma within the volcano and (2) dome growth at volcanoes such as Guagua Pichincha is typically accompanied by explosive activity.

Interferometric Processing

Interferometric coherence images have been formed from Single Look Complex images. In particular, March-April, March-November, April-November pairs were formed. Unfortunately, the baselines for interferometric pairs including the October image exceed 3 km which makes it difficult to obtain required coherence [13].

As an example, we show the interferogram (originally in colour) formed of the March-April pair which was the pair with the smallest time separation between images. In this image (Figure 5) and an enlargement (Figure 6), well defined fringes showing good coherence are seen only in a small area on the side of the caldera. The effects of steep slopes, shadow areas and foreshortening combined with the impact of a perpendicular baseline of almost 1400 m. contribute to difficulties in creating images of useful coherence. Areas of low coherence appear dark in the interferometric image.

Although low coherence can be due to a number of inherent sources including steep topographic slopes, vegetation, and low backscatter, it can also be caused by volcanic related factors such as a buildup of ash deposits and surface changes due to ground deformation. Unfortunately, in the case of this volcano, which is covered with significant vegetation except in the regions of the caldera (both on the inside and outside), it is not possible to distinguish these causes of decorrelation from one another. Furthermore, due to the dangerous level of volcanic activity, it is not possible to obtain ground truth within the caldera which would be useful for further interpretation of local variations appearing in the interferometric imagery.

The parallel fringes on the floor of the crater indicate a quite stable region with almost linear boundaries (discontinuities) between these fringes and the chaotic interferograms of the adjacent areas. It is possible that these boundaries could possibly represent fault lines along which dome growth can be accommodated. On one side of the fault, little movement of the ground surface is occurring, whereas on the other side of the fault block, we have deformation due to lava dome growth. The fault represents the boundary at which the strain stops and where slip may occur. Two sets of arrows have been drawn in Figure 6. Two pairs parallel to one another show the lower left to upper right trend; a second pair indicates a possible minor fault trace from left to right.

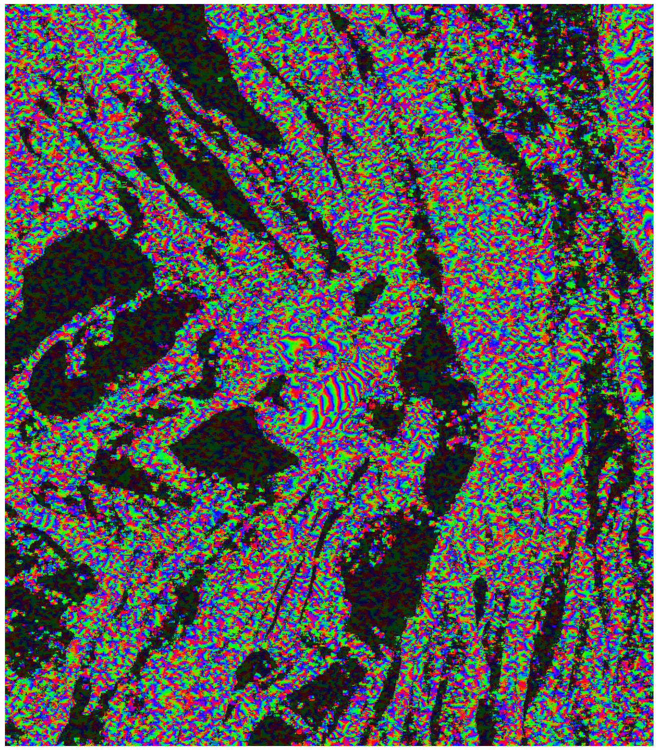

Figure 5. *Interferogram of images of March 25, 1999 and April 18, 1999 in the region of Guagua Pichincha.*

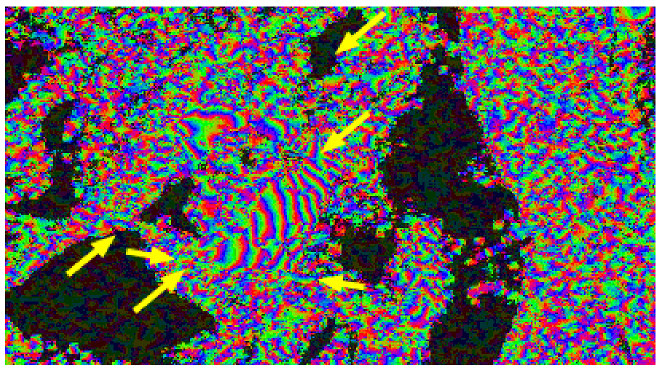

Figure 6. *Enlargement of interferogram of images of March 25, 1999 and April 18, 1999 in the region of Guagua Pichincha.*

Since differences have been noted in the detected imagery (as shown in Figures 2 to 4), it had been hoped that changes in this volcano could be tracked by interferometric methods. Ongoing change in the volcano has clearly made it difficult to obtain a sufficiently steady state of the volcano over the time period required to obtain coherence images with RADARSAT-1 (a minimum of 24 days). Further studies using interferometric methods are continuing.

Conclusions

This phase of the study of the Guagua Pichincha Volcano has again shown the utility of SAR imagery in the monitoring of volcanoes, in particular in remote areas. The ability of spaceborne synthetic aperture radar systems to look at the behaviour and changes occurring at such volcanoes makes possible the monitoring of such phenomena even in the presence of clouds of ash. Observation of detail, in particular using interferometric coherence appears to be difficult for this RADARSAT-1 case for several reasons including the impact of vegetation at the wavelength of this system. It is clear, however, that there are a number of cases such as more arid regions where these techniques would be particularly well adapted. Further studies on this volcano are ongoing.

Acknowledgements

RADARSAT-1 images are ©Canadian Space Agency, 1999.

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