Preliminary results of lava flow mapping using remote sensing in Piton de la Fournaise, La Réunion island

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Abstract—**The use of remote sensing is more and more incontrovertible in volcanic monitoring, especially in INSAR and thermal studies. A comprehensive database of high-resolution multispectral and multitemporal optical satellite imagery exists for Piton de la Fournaise, the active volcano on La Réunion Island. This database, however, remains relatively underexploited in volcanological studies of Piton de la Fournaise.**

Using a large image data set including SPOT 5 and 4, ASTER and aerial photography, we performed cartography of recent lava flows.

Different methods were applied for each sensor in order to extract and map lava flow contours and surface morphology. These methods include photo interpretation as well as fusion of thermal band and optical images. In addition we performed several tests with specific software combining object and spectral based techniques. Subsequently, a simple statistical comparison between different perimeters and areas mapped allowed us to determine a precision ratio. Results show that difficulties in extracting contours arise when the study area is a complex lava flow field where the different lava flows overlap, or have a similar textural and radiometric characteristics.

Keywords- remote sensing ; Piton de la Fournaise; Automatic Mapping; Principal components analysis

I. INTRODUCTION

Piton de la Fournaise (PDF) (Fig.1), on La Réunion Island, is one of the world's most active basaltic volcanoes with an average of one event every 8 months [1]. Between 1980 and 2008, 38 lava flows have been observed. The cartography of lava flows has particularly important implications for the knowledge of the lava emitted by the volcano, and can be very useful to increase the understanding of the PDF.

Even though remote sensing techniques have been used for volcanological studies for many years, there does not currently exist a methodology for automatic cartography that can be applied to all volcanoes.

This fact can be attribute to the poor use of high resolution imagery, the difficulties of timage reatment as applied to complex lava flow fields and the poor use of spectral and object-based automation approaches.

II. LAVA FLOW MAPPING USING OPTICAL DATA

A. *Presentation of the study area*

Most of PDF's recent activity is located in the Fouqué Caldera. Eruptive fissures are mainly situated near the Dolomieu Crater, in the Grandes Pentes (Eastern part) and in the Northem and Southem parts of the caldera. Lava flows furthest from the caldera are easiest to map owing to their isolation.

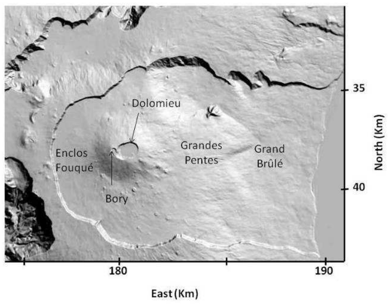

Figure 1: Piton de la Fournaise

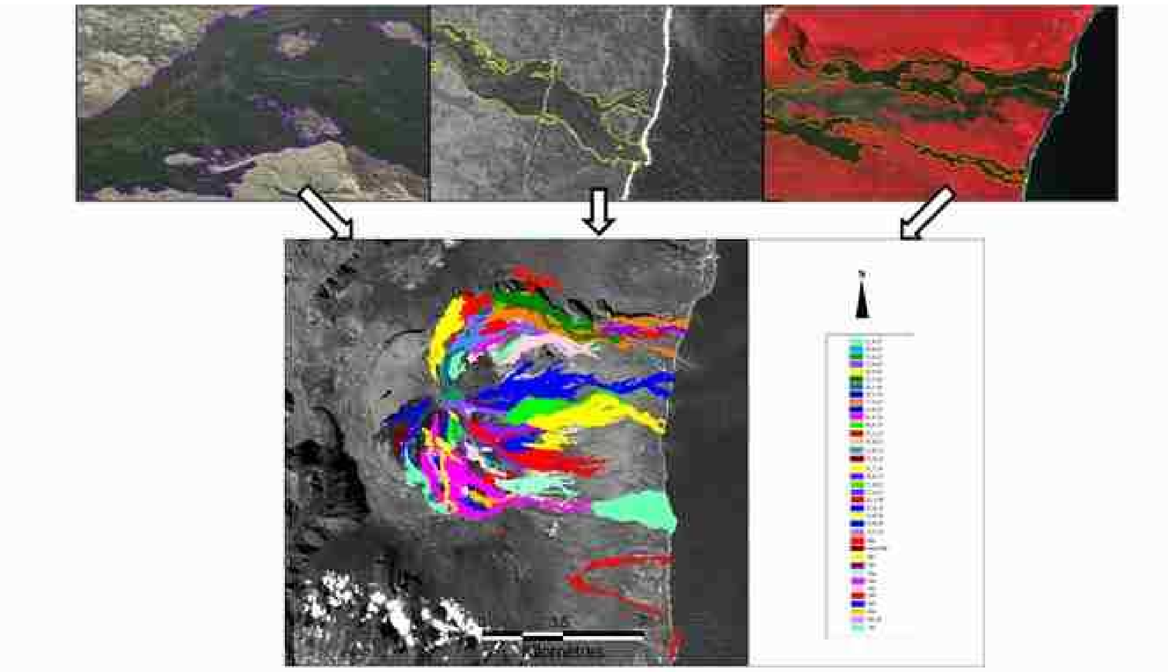

Figure 2 : Lava Flows Cartography between 1980 and 2007

B. *Manual mapping*

A large collection of high resolution multitemporal imagery was used for the manual mapping. This work has been done principally with aerial photography, SPOT 4 and 5 (Kalideos program, CNES, http://kalideos .cnes.fr) and ASTER (Advanced Spaceborne Thermal Emission and reflection Radiometer) data.

A total of 37 lava flows, between 1980 and 2007, have been digitized (Fig. 2). The accuracy with which each flow was digitized depends on the resolution of the imagery available. Is Lava flows mapped from aerial photography with resolution of 50cm do not have the same precision as those mapped from 20mSPOT 4 imagery.

C. *Accuracy*

Statistics have been gathered to compare the perimeters and areas of different digitized lava flows , depending on the data used to create the outline.

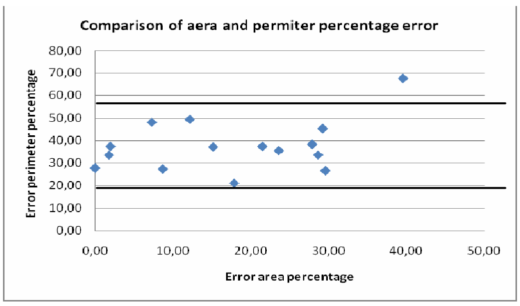

Figure 3: Comparison of area and perimeter percentage error

It was found that the perimeter of a lava flow digitized from SPOT 5 data can differ with up to 37.84% from the perimeter of that same lava flow when digitized from aerial photography. Similarly the area of lava flows can differ with up to 17.68%, depending on the data used as input. This would indicate that the perimeter obtained from the digitized lava flows cannot be used with certainty, but that the area can be used as a rough estimation.

Furthermore the relative perimeter and area errors are not correlated: the relative perimeter error does not influence the area error. The larger variation in perimeter than area, as well as the lack correlation between the errors in these variables is consistent with the behaviour of fractal shapes, which have fixed areas, but perimeters that increase with increasing detail (zoom) level.

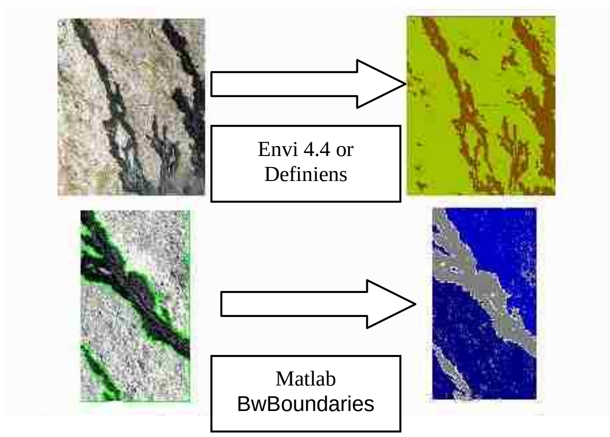

Figure 4: Isolated lava flows automatic cartography

III. AUTOMATIC CARTOGRAPHY

The aim is to produce an automatic cartography using a data treatment sequence not only for the visible surface information [2,3] but a complete one capable of obtaining the complete lava flow. During a first iteration a delimitation of the volcano influence area should be done. Different image processing methods can subsequently be used, depending on the lava flow type. The processing involved in extracting an isolated lava flow is significantly less complex than for overlapping flows. As a result, the processing of these two flow types are discussed separately.

A. Isolated lava flows

In the case of an isolated lava flow covering a vegetated area or a recent lava flow overlapping with older ones, the use of automatic classification or edge detection techniques allow us to obtain an automatic cartography using different software (Envi 4.4, Ecognition, Matlab…) as shown in Fig.4.

In these examples the spectral contrast of the lava flow with its surrounding material is sharp and the extraction of lava flows are relatively simple. When the spectral reflectance of the flow is similar to its surroundings, however, the treatment becomes more complicated.

B. Automatic cartography

To obtain an accurate automatic cartography, different image treatment processes have been used in Envi 4.4 (Fig. 5):

- a layer stacking of thermal and optical imagery;
- a principal component analysis;
- a decision tree classification;
- a classification to vector transformation.

Layer stacking was used to build a new multiband file from georeferenced data. During this process, thermal and optical imagery was resampled and reprojected to a common output image where all the data extents overlap. Using the thermal band allowed us to focus on one complete lava flow. This is an automatic discrimination by thermal wavelengths that correspond to an active area compared to its immediate environment.

Principal component analysis produce an image with spectrally uncorrelated output bands using a linear transformation to maximize the variance of the data. This transformation allows for an increase the optical reflectance variation in the area of high thermal activity.

The decision tree classification is a type of multilevel classifier. It is made up of a series of binary decisions that determine the classification of each pixel. For example, the use of a thermal threshold can delimit if a certain pixel falls inside the thermally active area or not. Inside the thermally active group a differentiation can be done between low and high thermal emission. The resulting classification yields the lava flow of interest as a specific class.

The classification to vector transform is executed to isolate and export the target class to a vector file.

C. Result accuracy

The total area obtained shows a variation of 11.5% of overestimation with the referenced one, and 13.1% for the perimeter. So the automatic mapping result obtain a good accuracy result. The aim of automatic cartography.

IV. OBJECT ORIENTED APPROACH

The use of object-oriented methods in classification automation is currently underexploited in volcanological studies [3, 4, 5, 6] .

A. Using image objects

In object-oriented segmentation, an image is divided into objects. An object is a group of similar, connected pixels that represent a region of relative homogeneity in an image. Regions in the image provide much more information than single pixels since the regions contain the spectral information of their constituent pixels, but can be analyzed further, based on color, shape, and texture.

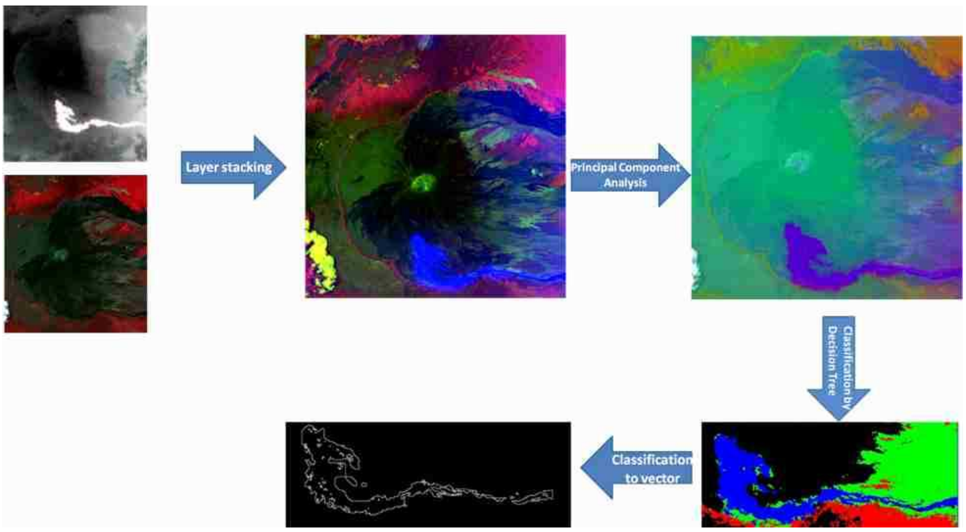

Figure 3: Automatic cartography treatment sequence

B. Analysis

The object-oriented classification automation was found to work only on isolated flows, the lava flow fields in Piton de la Fournaise being too complex for the segmentation when lava flows overlap. Newer flows overlying ancient ones can, however, be differentiated successfully (Fig.6).

Fissures on the volcano exhibit a strong contrast with characteristic reflectance, which makes it possible for them to be distinguished using object-oriented classification.. In this case the linearity of the fissures allow them to be identified using functions of shape and length of the image objects. Only some shadows can cause trouble in the automation. (Fig.6).

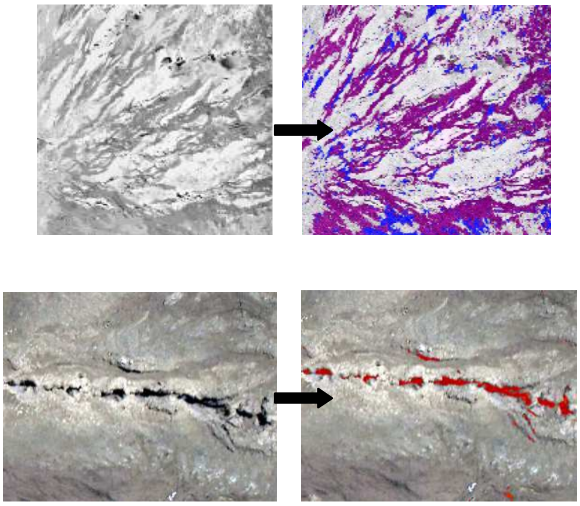

Figure 4: Recent lava flows and fissure cartography with Definiens

V. CONCLUSION

It is a cartographic objective that brings this automatic study. The aim to create an automated image processing chain is achieved. However the creation of a complete lava flow cartography using this technique is currently not feasible, because of the limited temporal frequency of available optical imagery, and the lack of sufficient thermal imagery.

ACKNOWLEDGMENT

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