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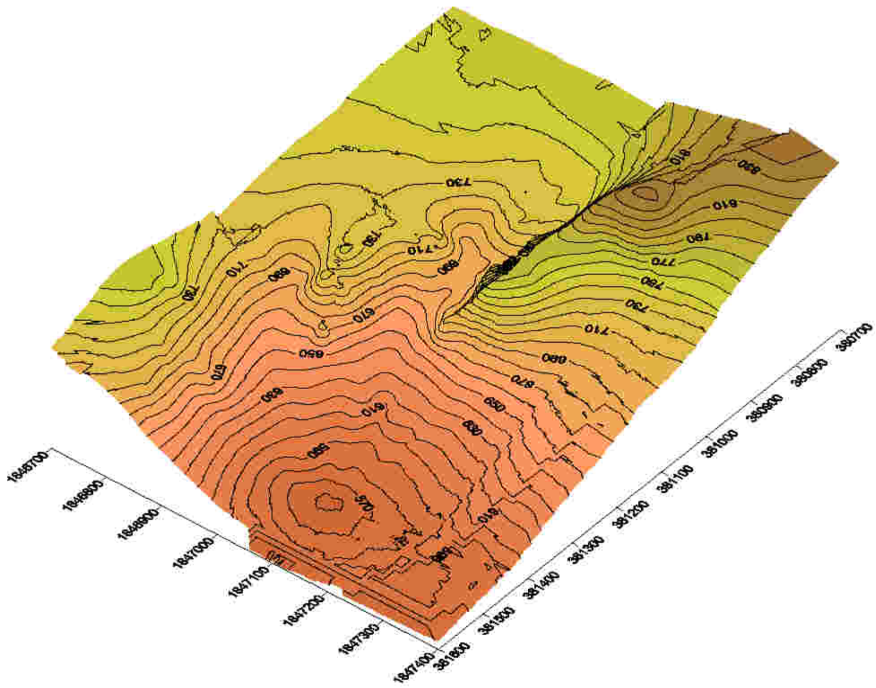
Establishment of a Baseline DEM on the Soufriere Hills Volcano, Montserrat, using Terrestrial LiDAR

Montserrat Volcano Observatory

International Business Development Programme

Physical Hazards Programme

Internal Report IR/05/136



BRITISH GEOLOGICAL SURVEY

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Establishment of a Baseline DEM on the Soufriere Hills Volcano, Montserrat, using Terrestrial LiDAR

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Front cover

Contour map of Soufriere Hills Volcano, colour shaded by relief. View of crater from southeast.

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Executive Summary

This report describe the results of a baseline survey carried out as the initial phase of a monitoring programme to evaluate the nature and instability of the Soufriere Hills Volcano, Montserrat. This programme of work was carried out on behalf of the Montserrat Volcano Observatory (MVO).

The primary aim of this survey was to provide the basis for a future monitoring programme. The survey consisted of a detailed survey of the volcano to establish a 3-Dimensional model at the time of the survey.

Survey data have been analysed to produce a rendition of the crater surface, accurate (in terms of range) to +/- 20 mm, that can be used as a baseline Digital Elevation Model (DEM) of the volcanic crater.

Acknowledgements

A large number of individuals both at the British Geological Survey (BGS), in Keyworth, and at the MVO, in Montserrat, have contributed to the survey. In addition to the collection of data, many individuals have freely given their advice, and provided the local knowledge so important in the completion of this work. Of the many individuals who have contributed to the project I would particularly like to thank the following:

Mr P. Hobbs, Engineering Geologist, BGS

Dr S Loughlin, Director, MVO

Mr M. Strutt, Geologist, MVO

Dr G. Ryan, Volcanologist, MVO

Mr C. Williams, Electronics Technician, MVO

Mr L. Linskey, Helicopter Pilot, Bajan Helicopters

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1 Introduction

1.1 SURVEY BACKGROUND

This report provides the results of a study by the British Geological Survey (BGS). It refers to work carried out on behalf of the Montserrat Volcano Observatory (MVO), under the International Business Development (IBD) and the Physical Hazards Programmes of the BGS.

This report details the first phase of work carried out to investigate the nature and instability of the Soufriere Hills Volcano, Montserrat, West Indies. The purpose of the monitoring programme is to provide the best possible information to the MVO to assist in decisions about the long-term management of the current volcanic crisis.

This primary aim of the survey was to provide a 'baseline' survey, incorporating a terrestrial LiDAR (Light Distance And Ranging) survey of the volcanic crater to allow a future assessment to be made, based on subsequent periodic 'monitoring' surveys of any changes in the conditions, in particular, the continued growth of a new lava dome or the potential weakening of the crater walls.

1.2 SURVEY LOCATION

The survey was carried out from Perches, on the flanks of the volcanic crater (Figure 1). The survey area covers an 900 m by 700 m (approx.) rectangle between [380700, 1846700] and [381600, 1847400] (Figure 1). The area covers the majority of the crater, especially the area of new dome growth.

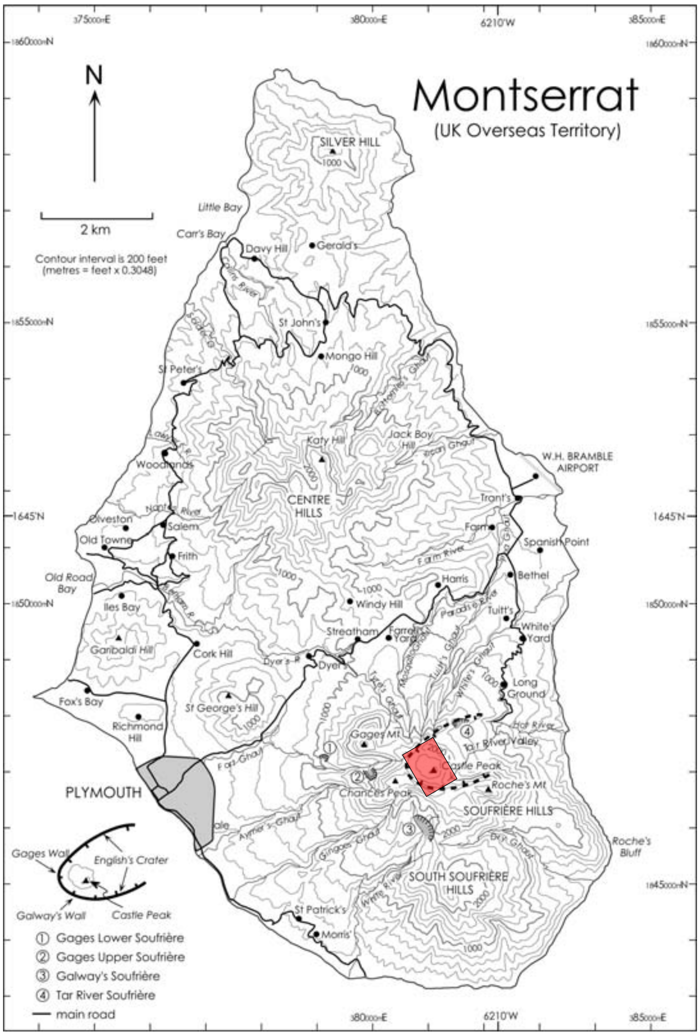

Figure 1 Location of the Soufriere Hills Volcano and extent of the survey area (red box).

1.3 BASELINE SURVEY

The baseline survey was conducted on the 16th of August, 2005 by Lee Jones (Geological Engineer) and Graham Ryan (Volcanologist). The activities and results of this survey are described in this report.

2 Baseline Survey 2005

2.1 INTRODUCTION

The baseline survey consisted of the following:

- Capture of LiDAR data to establish the position of the volcano and the crater, at the time of the survey.
- Establishment of a survey position using a hand-held GPS (Global Positioning System).
- 3-D modelling of the volcano and crater.

The baseline survey was carried out on 16th August, 2005. Weather conditions were good, and two scans from the volcano flanks were carried out, both from the new fixed-camera position at Perches Estate. Approximately 1.5 hours were spent on the flanks scanning, with access and egress via the waiting Bajan helicopter, approximately 30 m from the scanning location. Conditions underfoot were difficult, mainly due to the excessive vegetation between the helicopter landing site and the scanning location. A GPS position was taken at the scanning location and a second GPS position was taken, as a backsight, approximately 10 m southwest of the scanning location, on a large upturned tree-stump.

2.2 SURVEY METHODOLOGY

The baseline survey consisted of setting up a scanning location (Ps1). This scan required at least one sighting on a target at a known location. This ‘backsight’ (Pt1) was located on a large upturned tree stump. The first (general) scan covered an area of the crater approximately 900 m wide (north-south) and 700 m long (east-west) and the second (detailed) scan covered a small area approximately 300 m wide and 150 m long, centred on the area of new dome growth. The general arrangement (not to scale) is shown in Figure 2. Ps1 is located at [382110.496, 1846792.779] and Pt1 at [382110.489, 1846783.561].

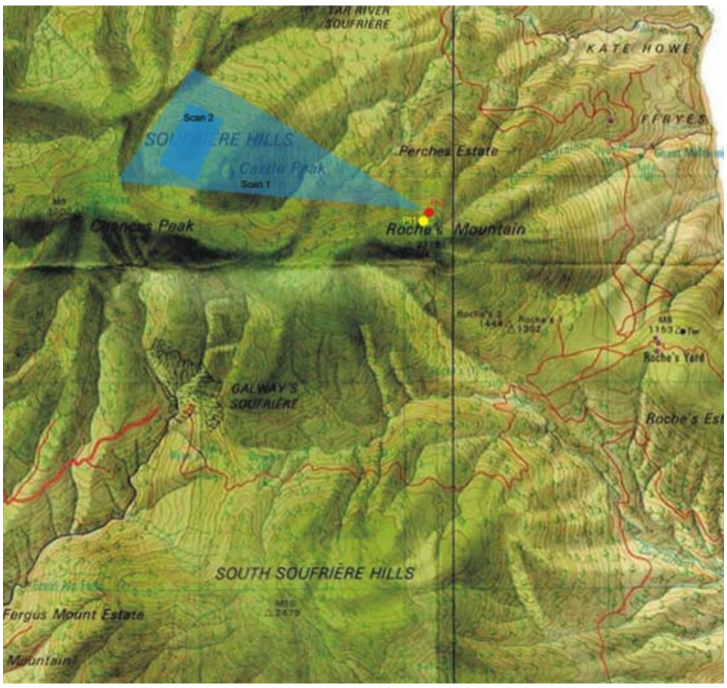

Figure 2 Location of laser scanner (red) and backsight (yellow) positions showing general directions of scans (blue).

2.3 LIDAR SURVEY

The use of terrestrial laser scanning technology, combined with that of a Global Positioning System (GPS), as a method of monitoring landforms is widely used in the BGS. This methodology would allow an accurate digital 3-D model of the volcanic crater to be made. Future surveys can then be compared to this study and differences between survey epochs can be quantified. The scans can be done without the use of targets being placed on the volcano, thus representing a safe, reliable, and responsive method of monitoring, compared with conventional surveying or photogrammetry.

The laser scanner used was a Riegl LPM2K Long-Range Laser Scanner (Figure 3). It is designed to provide digital data for 3D terrain modeling. Unlike some laser devices, it is able to do this in either automatic or manual mode. Thus, in addition to blanket scanning in automatic mode it is able to record individual targets or features in manual mode. This factor, along with its long-range capability and good resolution, gives added flexibility in the field of geoscience mapping. The laser uses 'last-pulse' time-of-flight detection to determine the distance of a reflective surface along with its azimuth and elevation, from the instrument position. By means of back-sighting to a known target in manual mode, or by independent survey (e.g. GPS) the data may be transformed to a grid co-ordinate system using PC software. Using the transformed x, y, z data points 3D contoured models may be created in various CAD and mapping software packages. Reflectivity values are also recorded which may be used to distinguish between rock types. Most rock/soil materials provide a good reflective surface. Typically 8000 points can be data-logged in 1 hour in most weather and light conditions. The scanner has a range of 2.5 km and a resolution of 2.5cm. It is controlled and logged using a ruggedised 'Sunscreen' PC which is powered by two small 12v batteries. Interaction with the PC is carried out via a touch-screen pen directly on to the screen, which is highly visible in direct sunlight.

Figure 3 Riegl LPM-2K Long-range Terrestrial laser scanner.

A detailed procedure could only be made after the initial site visit, to assess ground control requirements and scan point requirements. An outline methodology is presented here, based on the site at Perches.

1. The Riegl LPM-2K laser scanner was sited as close to the crater as possible, on Perches, enabling as much of the crater as possible to be scanned (Figure 4). A GPS position was recorded for the scanning location and a backsight location.
2. The scanner was then programmed to measure the distance, direction and azimuth of points within the defined window the scanning head rotates at a specified angular increment after each measurement). A spacing of 2'2" (giving a point spacing of 10 m at a distance of 2 km) was used, and a denser measurement cloud was also produced of the new dome growth area.

3. Besides a second, more detailed, scan of the new dome area specific marker locations within the crater were sighted to individually.
4. Data was processed by BGS to produce an elevation model compliant with WGS84 and the local Montserrat grid.
5. Data from successive surveys can be processed to calculate various useful parameters such as elevation change, volume distribution, and movement vectors.
6. On completion of the survey and after initial processing and orientation, using the GPS results, the data was exported in ASCII format.

Figure 4 Setting-up of scanner on Perches.

2.4 3-D COMPUTER MODEL

The terrestrial LiDAR data produced by the oriented laser scan and GPS survey was processed to develop a 3D computer model of the crater. Firstly, the raw data produced by the RiPROFILE™ program consisted of 'point-clouds' of approximately 3000 *xyz* points (Figure 5). This data was oriented using the relative GPS positions of both the scanner and the backsight and output as an ASCII file, made up of x, y, z and intensity values. The data was imported into Surfer™ (a surface mapping program) and manipulated using a geostatistical gridding method (Kriging) that produces visually appealing maps from irregular spaced data. Figure 6 shows a contour map, colour shaded by relief and Figure 7 shows a surface model of the gridded data.

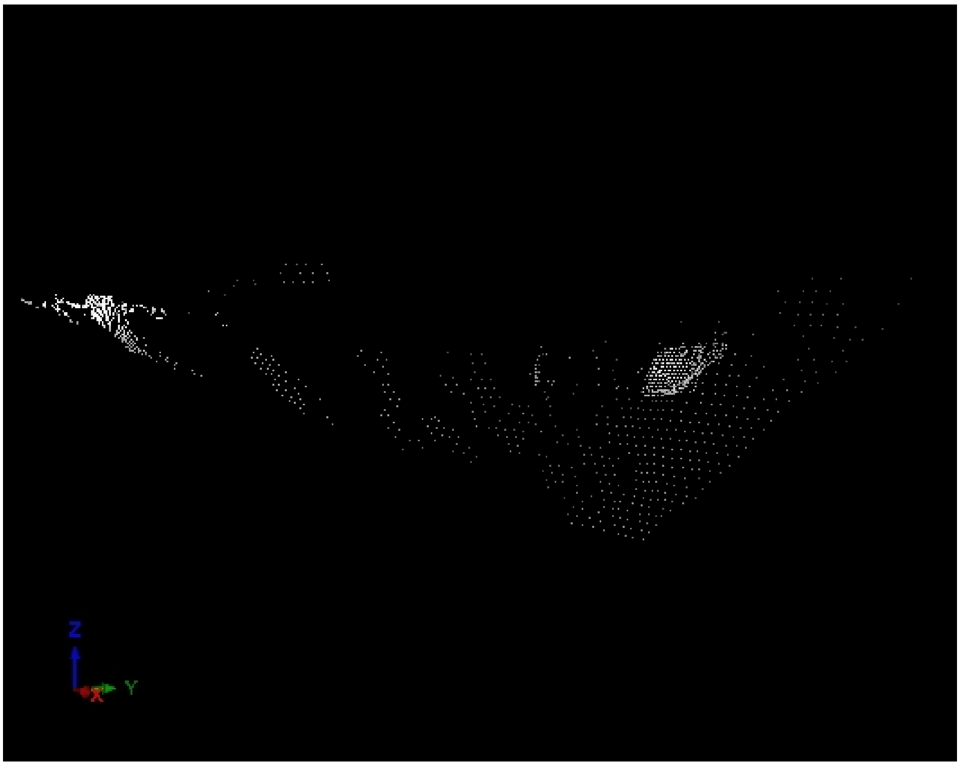

Figure 5 Point-cloud model (3-D), viewed from east

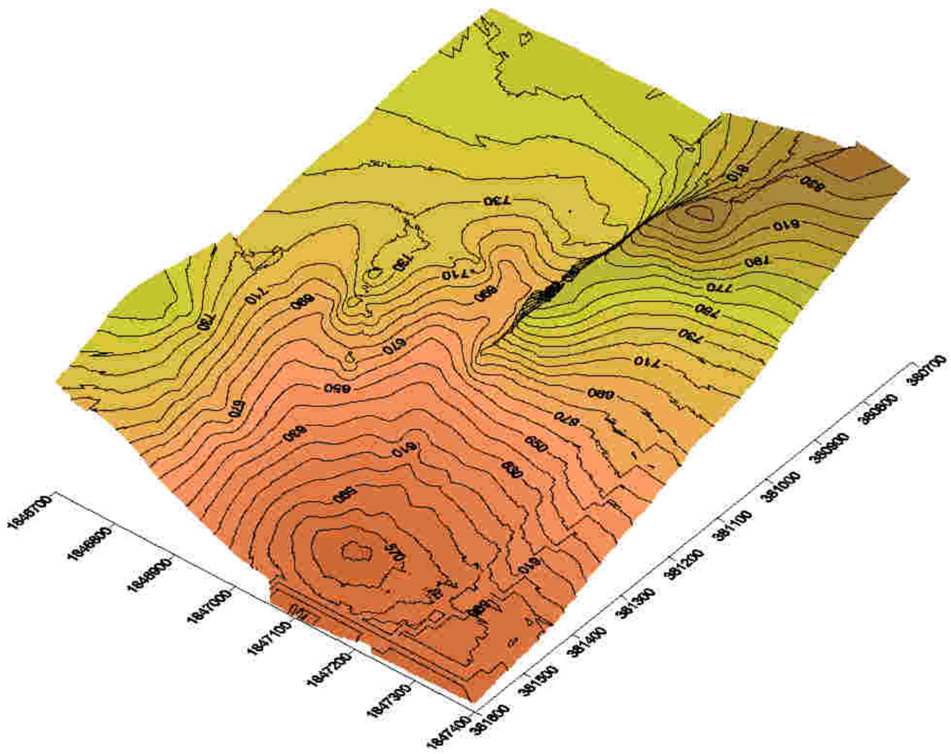

Figure 6 Contour map (3-D), viewed from southeast

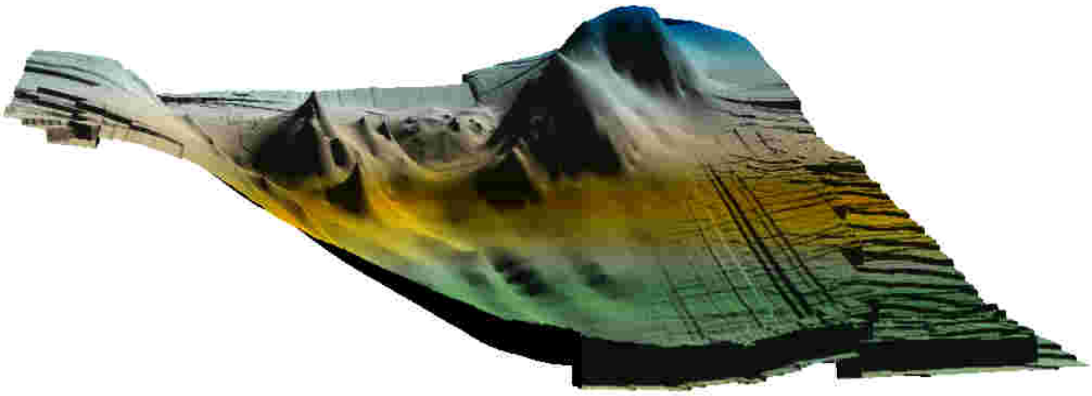

Figure 7 Surface model (3-D), viewed from southeast [Surfer]

The data was also imported into GoCAD™ (a digital 3D drawing program) and 'surfaced' using a triangulation method to produce a solid 3-D model (Figure 8) that can be viewed from any orientation.

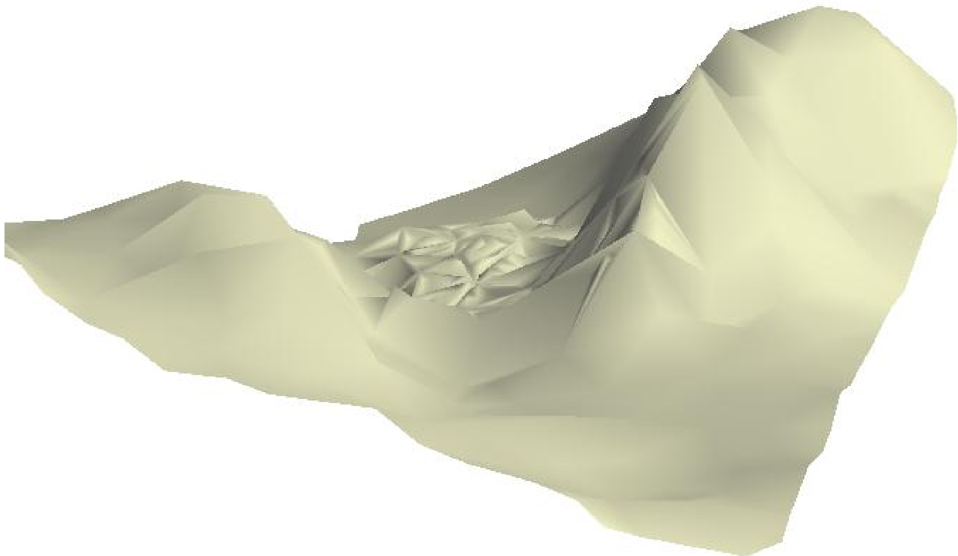

Figure 8 Surface model (3-D), viewed from southeast [GoCAD]

Intensity plots, range plots and, after further surveys, change plots can also be shown using these surface models. It will also be possible to extract cross-sections and calculate volumes. The surface models compare well with the photographs taken from the same location, during the scans (Figure 9).

Figure 9 Comparative photograph of volcanic crater.

3 Conclusions

The principal aim of the study was to provide a ‘baseline’ survey of the volcanic crater and the new dome growth at the Soufriere Hills Volcano, Montserrat, to establish the starting point for a stability monitoring programme in order to assess future potential instability of the volcano walls and dome. The aim of the baseline survey was fulfilled, albeit with less detail than would have been hoped for due to the time constraints at the scanning location.

The survey was carried out remotely by laser scanning. Approximately 80% of the intended survey area was completed using a total of two scans, combined and oriented by means of GPS. Accurate 3-D models were produced of the crater and the new dome growth within it.

The results of this baseline survey cannot be used to comment on likely failure modes or the scale of future failure events. Such comment will only be attempted following comparative monitoring, the first stage of which is proposed for February 2006. For the same reason, it is not possible to make recommendations regarding the stability of the volcano walls and associated slopes at present.

A summary of the key conclusions is as follows:

- Survey and backsight positions were located using GPS. These positions were marked and should be easy to relocate.
- Both the general scan of the crater and the more detailed scan of the new dome growth area were successfully completed. Had time allowed a third scan of the lower part of the crater would also have been carried out.
- The models generated by both Surfer™ and GoCAD™ are excellent and show aspects of both the crater surface and the volcano flanks, in good detail. The area of new dome growth is also picked out very well. The photographs taken, from the scanning location, at the time of the survey compare favourably with the scans and the subsequent models.
- The oriented scans need to be overlaid on an existing DEM in order to form a true comparison of the volcano as it was in 1995, pre-eruption, and as it is now.
- In addition to establishing changes from the baseline survey, Phase 2 will take scans of the outer flanks of the volcano from Harris, St. George’s Hill, Gages and Fergus Mountain. If time allows the flows at Trant’s, Tar River, White River and Belham Valley will also be scanned.