British
Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Charter final operation report

Charter ID 213:

Volcanic eruption of 29th July 2008 on the island of Montserrat

Acknowledgements
We are extremely grateful to: CNES, CSA, DLR, DMCII, ESA and NRSA for the fast provision of EO data following the eruption event at the Soufrière Hills volcano on Montserrat and for the helpfulness of our colleagues within these organisations; M. Eineder and T. Fritz at DLR for rapid production of change difference images; the ESA EO helpdesk for assistance accessing Envisat data; Shailaja Naja for being an effective ECO.

Executive Summary

Charter ID 213 was activated following an eruption event of the Soufrière Hills volcano on the Island of Montserrat on the night of 29 July 2008. The eruption caused fist-sized pumice to fall in some inhabited areas and pumiceous pyroclastic flows which ignited vegetation. In the days prior to the eruption there had been protracted seismic activity at the volcano. The Montserrat Volcano Observatory (MVO) was on high alert for the possibility of a major collapse of the lava dome that has been the source of the main hazard faced by the occupied parts of western Montserrat. Evacuation measures had been put in place and if the event had made the western side of the dome more liable to major collapse in that direction then there could have been the requirement for further evacuation measures. The MVO was under considerable pressure to advise the government on the state of the dome after the explosion.

The source and nature of the explosive activity needed to be determined but could not be properly addressed by scientists at the MVO because cloud obscured the upper slopes of the volcano. The main Earth Observation (EO) requirement was for rapid supply of high-resolution radar images to see through the cloud and determine the source of the event and the state of the lava dome. Low spatial resolution radar data would be able to show if a large part of the pre-existing lava dome had been involved in the event. It was suspected that a smaller explosive vent may also need to be identified to determine the source of the explosive activity, which required higher (1–10 m) resolution radar data. Visible and infrared data of the volcano would also be valuable if a break in the cloud cover made acquisition possible, and would enable the distribution of newly generated volcanic material to be assessed.

TerraSAR-X, RADARSAT, PALSAR, Envisat, SPOT, IRS and TopSat data were provided under the Charter and by DLR and were a significant help in this emergency. The data showed that the lava dome had remained largely intact following the explosion, enabled the source vent for the explosion to be identified, allowed the distribution of newly deposited pumice material to be defined and provided increased understanding of the nature of this type of eruption at the Soufrière Hills volcano. The end user at the MVO was impressed with the EO data, which provided the dominant piece of evidence used in advising government on the post-eruption state of the volcano. As a result people who had been evacuated following the eruption were able to return to their homes.

Front cover image: Montserrat from the air, 4th April 2007.

Report no: CR/08/179

Charter final operation report

Charter ID 213:
Volcanic eruption of 29th July 2008 on the island of Montserrat

Authors: [1]Gisela Ager, [2]Geoff Wadge, [1]Doug Tragheim and [1]Colm Jordan

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Keyworth, Nottingham British Geological Survey 2008

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1 Introduction

1.1 Purpose

The aim of this final report is to document the process that followed the activation of the Charter on Space and Major Disasters Call ID 213. The call was activated as a result of an eruption event of the Soufrière Hills volcano on the island of Montserrat on 29 July 2008.

1.2 Scope

The report documents the background to the activation of the Charter, the acquisition and interpretation of earth observation data, the provision of information to the end-user and recommendations for improving scenarios.

1.3 Applicable documents

The relevant background documents are provided as detailed below:

Appendix A:	General information about the area
Appendix B:	Montserrat Volcano Observatory activity reports of the eruption event
Appendix C:	Media coverage of the eruption
Appendix D:	User Request Form
Appendix E:	Emergency Data Request submission forms for the satellites tasked
Appendix F:	Copy of final value added products delivered

2 Intervention Summary

2.1 Project details

Project:	Volcanic eruption on the island of Montserrat, Charter ID 213
Co-ordinates:	Upper left 16° 46′ 0″ N, 62° 15′ 0″ W Lower right 16° 40′ 0″ N, 62° 08′ 0″ W
Project Manager:	Gisela Ager, British Geological Survey
ECO:	Shailaja Nair, Indian National Remote Sensing Agency (NRSA)
Authorised User/ Requestor:	Cabinet Office Civil Contingencies Secretariat (CCS), UK Government
End Users:	(1) Rod Stewart, Acting Director, MVO – Local volcano hazard end-user (2) Prof. Geoff Wadge, University of Reading – Earth Observation (EO) end-user

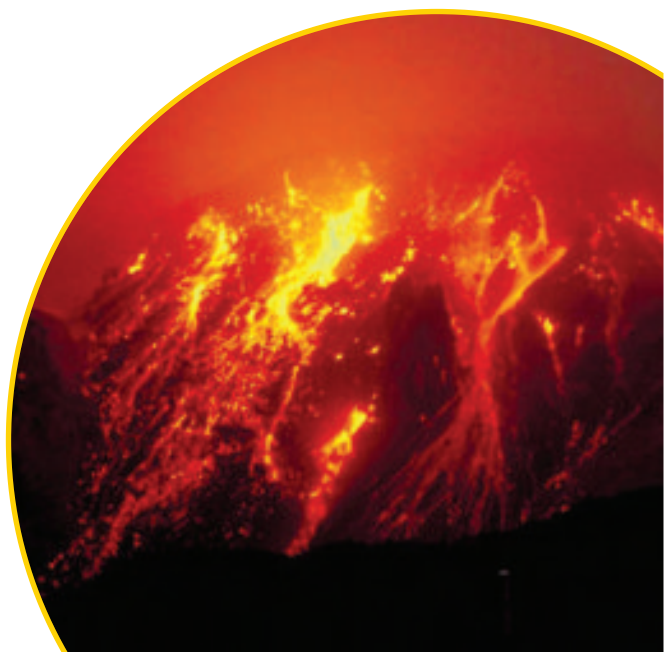
Summary:
Montserrat Volcano Observatory (MVO) recorded an intense swarm of earthquakes during the last week of July 2008, the like of which had not been seen at the Soufrière Hills volcano for several years. This culminated in an explosive event on the night of 28/29 July 2008 that involved fist-sized pumice falling in some inhabited areas and pumiceous pyroclastic flows igniting vegetation. The source and scale of the event could not be properly addressed by the MVO scientists because cloud obscured the upper slopes of the volcano. The issue was vital from a civil protection point of view because if the event had made the western side of the dome more liable to major collapse in that direction then there could have been the requirement for further evacuation measures.

A background to the eruptive activity of the Soufrière Hills volcano is provided in Appendix A.

2.2 Available satellite data

The main requirement for satellite data was for rapid supply of high-resolution radar images to see through the cloud and determine the source of the event and the state of the lava dome. Both new acquisition and reference data were required to conduct the assessment.

The secondary requirement was for new acquisition and reference visible and infrared data to assess the post-eruption appearance of the dome and the surrounding areas. Despite successful acquisition being dependent on cloud-free conditions, the readily accessible information content meant that it was worthwhile requesting the data and hoping for a break in the cloud.



2.3 Chronology of events

A chronological digest of the main events and developments is provided.

28/29 July	Eruption of the Soufrière Hills volcano (03:38 UTC, 29 July; 23:38 local time, 28 July). Explosive event that involved fist-sized pumice falling in some inhabited areas and pumiceous pyroclastic flows igniting vegetation.
29 July	R. Stewart and G. Wadge discuss need for remotely sensed data and for Charter activation. G Wadge independently asked DLR to task TerraSAR-X. Charter activated during the evening and Project Manager (PM) nominated.
30 July	PM contacted by the Emergency On-Call Officer (ECO). ECO Dossier received by PM. Tasked Envisat, RADARSAT and PALSAR overpass and acquisition over Montserrat island. Receipt of Envisat 12 December 2007 reference data.
31 July	Tasked SPOT 5 and 4 overpass and acquisition over Montserrat island. Receipt of quicklooks for SPOT reference data.
1 August	Receipt of PALSAR FBS 8 February 2008 reference data.
2 August	M. Eineder and T. Fritz of DLR produced 2 sets of change difference images from TerraSAR-X 2 August acquisition. Conveyed the initial findings to G. Wadge.
3 August	G. Wadge and R. Stewart made a preliminary interpretation of the change difference images for MVO and for the UK Foreign and Commonwealth Office's Scientific Advisory Committee.
4 August	Preliminary report provided to the authorities in Montserrat. Receipt of RADARSAT-1 F2 descending 10 March 2004 reference data. Requested a further RADARSAT-1 reference image that was closer to the date of the 2008 eruption. Receipt of RADARSAT-1 F2 descending 4 August 2008 acquisition. Receipt of RADARSAT-1 F5N descending 24 June 2008 reference data.
5 August	Receipt of quicklook preview for SPOT 5, 4 August acquisition - there is extensive cloud cover. Receipt of TopSat 1 August and 3 August 2008 acquisitions.
6 August	DLR provided full-resolution/slant range amplitude difference images from TerraSAR-X data following request from G. Wadge. Receipt of quicklook preview for SPOT 5, 5 August 2008 acquisition — there is extensive cloud cover. Receipt of IRS-P6 1 August acquisition. An interim report was provided to MVO based on interpretation of the TerraSAR-X, RADARSAT, TopSat and IRS data.
7 August	Receipt of quicklook preview for SPOT 4, 6 August 2008 acquisition — there is extensive cloud cover.
9 August	Receipt of Envisat 8 August 2008 acquisition.

11 August	Receipt of Envisat 10 August 2008 acquisition. Receipt of PALSAR FBD 10 August 2008 acquisition. Receipt of quicklook preview for SPOT 5, 9 and 10 August 2008 acquisitions.
12 August	Change difference image of the volcano produced from PALSAR data.
18 August	Receipt of quicklooks for SPOT 5, 14 and 15 August 2008 acquisitions and SPOT 4, 16 August 2008 acquisitions.
20 August	Receipt of SPOT 5, 14 August 2008 acquisition and SPOT 5, 24 November 2007 reference data, which was subsequently analysed for changes to the lava and pumice deposits to the west and east of the volcano.

The requests for Earth Observation data are detailed in Appendix D and Appendix E.
Data receipt was via the charter ftp site or an alternative ftp site.

3 Intervention Assessment

3.1 Radar data

The requirement of the intervention was to determine the source and nature of the explosive activity at Soufrière Hills volcano on 29 July. The low-level, ubiquitous cloud cover meant that radar was probably the only type of sensor capable of supplying viable imagery. Whilst relatively low spatial resolution radar (for example, Envisat) would be able to show if a large part of the pre-existing lava dome had been involved in the event, it was considered that only higher resolution radar (10 m resolution and better) would be able to show details of a smaller explosive vent. Fortunately, the first radar (TerraSAR-X) to be tasked (by DLR) to view the volcano was also the optimum for our needs and indeed delivered the form of imagery we sought very quickly.

Radar data from three further satellites were provided under the Charter: RADARSAT, PALSAR and Envisat. These data were acquired at different wavelengths to the TerraSAR-X data and had the potential to refine the findings from that sensor.

A summary of the radar data acquired for the intervention is provided in Table 1 below.

Satellite	Date of image acquisition	Image resolution	Image details	Image format
TerraSAR-X X Band radar Wavelength 2.4-3.75 cm	02 August 2008 02 August 2008 09 October 2007 09 October 2007	2m (approx) 2m (approx) 2m (approx) 2m (approx)	West-looking (descending) East-looking (ascending) West-looking (descending) East-looking (ascending)	GeoTiff GeoTiff GeoTiff GeoTiff
RADARSAT C-band radar Wavelength 3.75-7.5cm	04 August 2008 24 June 2008 10 March 2004	6.25m 6.25m 6.25m	West-looking, Fine 5 Near image geometry West-looking, Fine 2 image geometry West-looking, Fine 2 image geometry	GeoTiff GeoTiff GeoTiff
PALSAR (ALOS) L-band radar Wavelength 15-30 cm	10 August 2008 8 February 2008	12.5m 6.25m	East-looking dual HH-HV polarisation East-looking single HH polarisation	GeoTiff GeoTiff
Envisat C-band radar Wavelength 3.75-7.5cm	10 August 2008 08 August 2008 9 December 2007	30m 30m 30m	East-looking (ascending) West-looking (descending) East-looking (ascending)	N1 N1 N1

Table 1 Details of the radar data acquired for Montserrat.

3.1.1 TerraSAR-X

Two high-resolution (approximately 2m, Spotlight mode) images were acquired by TerraSAR-X on 2 August 2008 from two directions: one looking east and one looking west. Having two viewpoints is generally helpful because of the distorted geometry of radar images in areas of steep terrain. If it is difficult to see a feature from one direction it is often more visible from another.

The exact imaging geometries acquired were the same as had been previously acquired on 9 October 2007. Thus it was possible to directly compare images before and after the 29 July event. Since 9 October 2007 the dome had not changed its shape very much (lava extrusion having stopped on 4 April 2007) and so any major changes in morphology as a result of the explosion should have been obvious.

After acquisition on 2 August, M. Eineder and T. Fritz of DLR produced, on the same day, change difference images from DEM-corrected and geo-referenced images and the first results were conveyed to MVO. Two change difference images were produced, one looking east and one looking west, showing changes between the August 2008 and October 2007 data acquisition. G. Wadge and R. Stewart interpreted these images and provided a preliminary report to the authorities in Montserrat on 4 August. In the images (Figures 1 and 2) yellow represents no change, magenta and cyan represent areas of change (decrease or increase in surface backscatter respectively).

The magenta areas to the east and west of the volcano were recognised to be the surfaces of pumice flows produced during the 29 July explosion and, being below cloud-level,

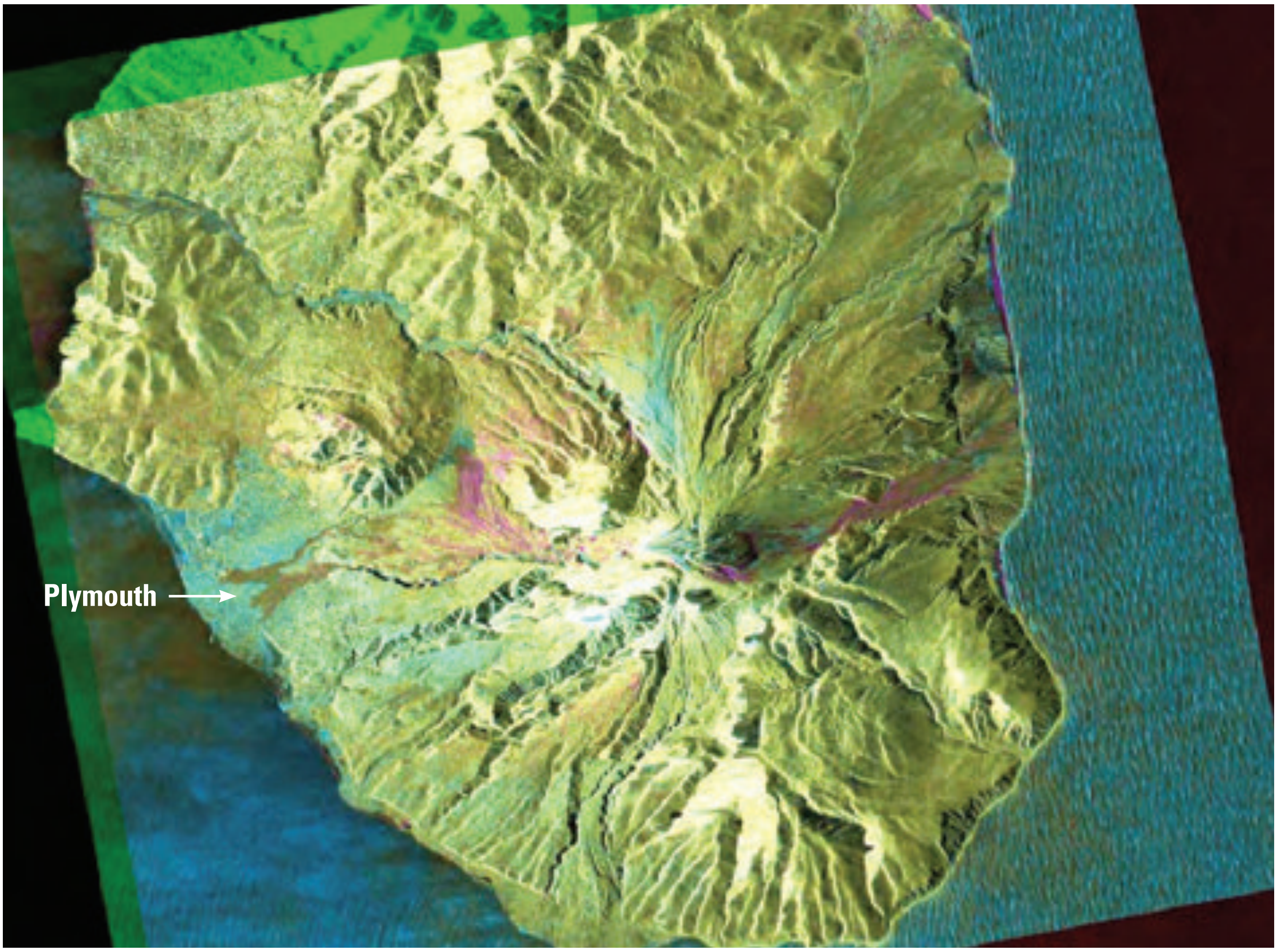


Figure 1 Change difference image of southern Montserrat constructed from two TerraSAR-X images collected in ascending (east-looking), spotlight mode (beam 32, 3 degrees to vertical) on 9 October 2007 and 2 August 2008. The radar data has been corrected for topography except at the dome itself. Red is assigned to the 2007 image, green to the 2008 image and blue to the difference (2007-2008). Areas of no change are yellow, magenta areas scattered more energy back in 2007, cyan areas more in 2008. The areas of pumice flow deposits formed as a result of the explosion are magenta (brown in the Plymouth area). (Image © DLR 2008, annotation G. Wadge).

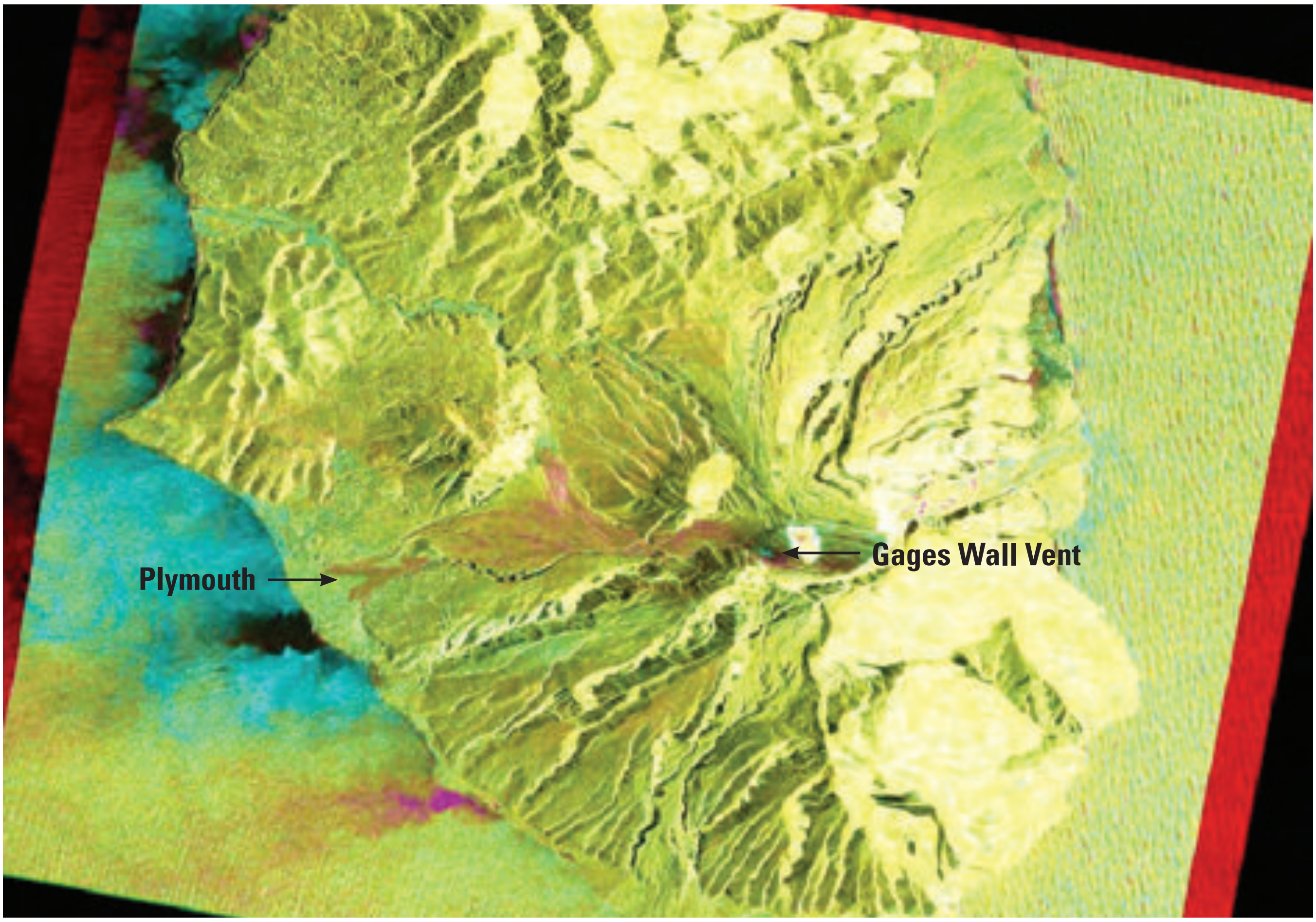


Figure 2 Change difference image of southern Montserrat constructed from two TerraSAR-X images collected in descending (west-looking), spotlight mode (beam 13, 22 degrees to vertical) on 9 October 2007 and 2 August 2008. The radar data has been corrected for topography except at the dome itself. Red is assigned to the 2007 image, green to the 2008 image and blue to the difference (2007-2008). Areas of no change are yellow, magenta areas scattered more energy back in 2007, cyan areas more in 2008. The areas of pumice flow deposits formed in the west as a result of the explosion are magenta, those to the east are poorly represented. The Gages Wall vent, the source of the explosion, is seen as a small cyan patch at the head of the pumice flow. (Image © DLR 2008, annotation G. Wadge).

had been observed via helicopter flights by 2 August. Very minor flows in a deep gulley to the south of the dome could not be detected by the radar because of the angle of view.

These images apparently showed little change to the gross shape of the lava dome indicating that only a small part of the dome had been involved in the explosion. In particular, it appeared that an area of change near to the previous location of the 'Gage's Wall vent', that had been the source of ash and mild explosive activity in May, represented the source vent for the explosion. This is a cyan area west of the dome summit (Figure 2) and appears to be the focus of the pumice flows (magenta areas) to both west and east. However, this judgement was made less certain because the DEM used to correct for terrain effects did not include the most up-to-date shape of the dome and so there was some uncompensated distortion in the key area.

To obtain a clearer picture, G. Wadge requested full-resolution/slant range amplitude difference images (with no terrain correction) (Figures 3 and 4). These gave a clearer, though distorted view of the vent area, particularly from the west (Figure 4).

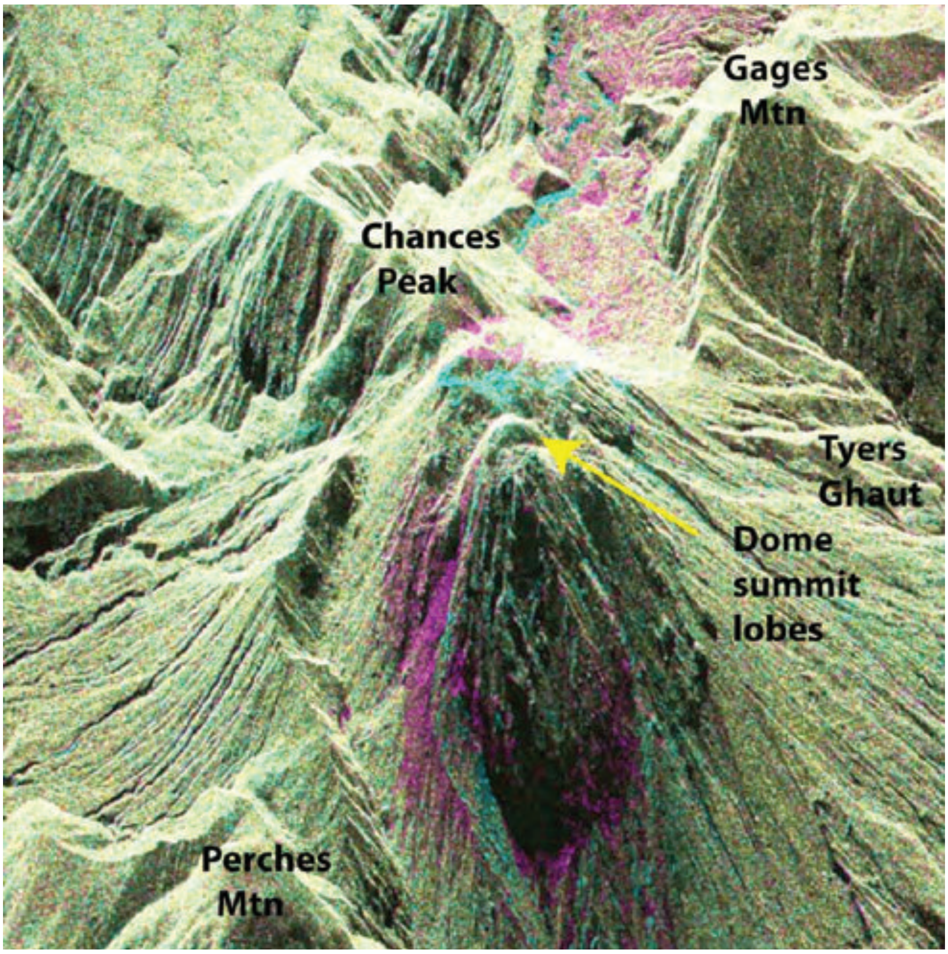


Figure 3 Change difference TerraSAR-X image of Soufrière Hills volcano using full resolution (approximately 2m) slant range data with no topographic correction. This is the equivalent data of Figure 1 with the orientation rotated through 90 degrees (west is up). The colour interpretation is as for figures 1 and 2. (Image © DLR 2008, annotation G. Wadge).

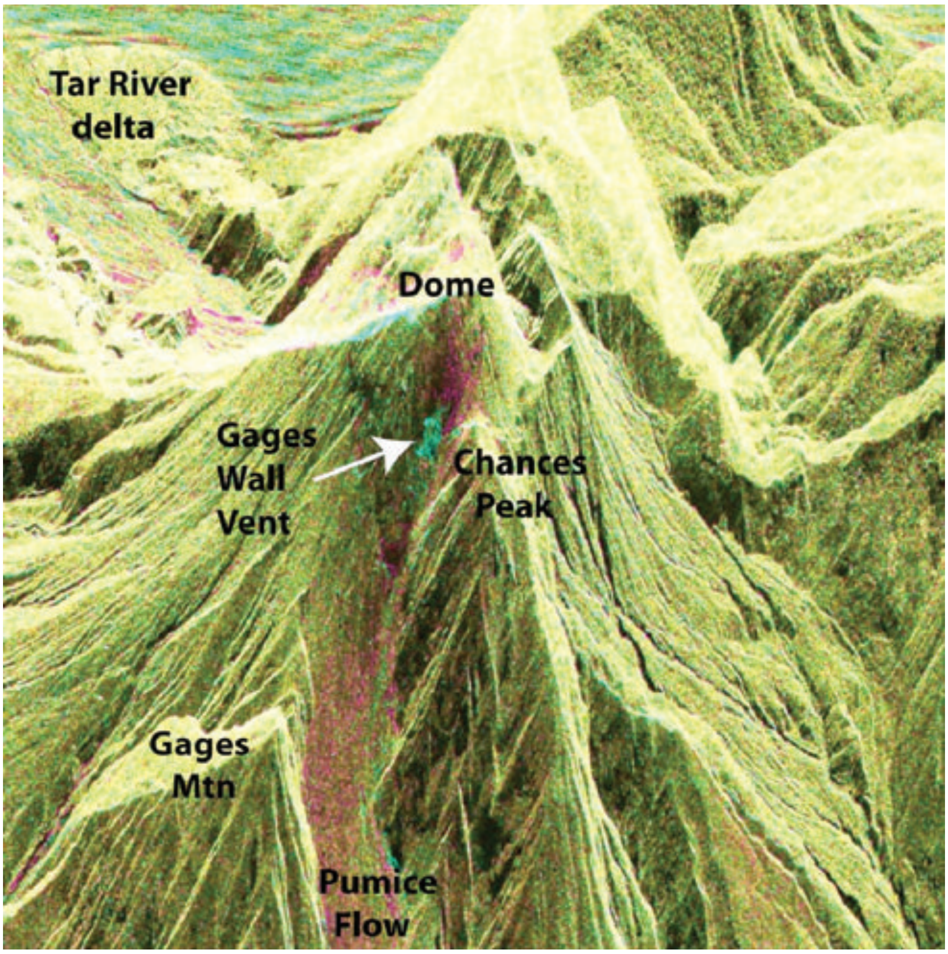


Figure 4 Change difference TerraSAR-X image of Soufrière Hills Volcano using full resolution (approximately 2m), slant range data with no topographic correction. This is the equivalent data of Figure 2 with the orientation rotated through 90 degrees (east is up).The colour interpretation is as for Figures 1 and 2. The cyan area is the Gages Wall vent expanded during the 28/9 July explosion. (Image © DLR 2008, annotation G. Wadge).

They showed that the explosion had modified the former 'Gage's Wall vent' to produce a crater/vent about 100 x 50m in size. There was another, localised, area of change higher on the dome to the north, but the date of this is not known, nor its relevance to the 29 July event.

In addition to the change difference images, M. Eineder also produced differential InSAR images for the two pairs of data. Unsurprisingly, given the relatively long temporal baseline (approximately 6 months) and high rate of surface change on Soufrière Hills there are few areas of coherence in the interferograms, and no useful information content for this study.

In summary, the TerraSAR-X data enabled us to determine the source and nature of the explosive activity. The explosion of 29 July had, almost certainly, involved a Vulcanian explosion from the site of the 'Gage's Wall vent'. This explosion had caused the vent to expand and probably flare during the creation of a magmatic eruption column, which then collapsed back onto the volcano producing pumice flows which reached the sea to the west at Plymouth (approximately 4 km distance) and to the east on the Tar River delta (approximately 3 km distance). The rest of the lava dome away from the vent remained stable. The site of the vent was first observed visually on 8 August 2008. By this time the vent had been partly infilled by new lava extruding through it and producing a chute of talus that descended to the Gages Valley floor (Figure 5).

3.1.2 RADARSAT

The Canadian satellite RADARSAT acquired fine mode (6.25 m resolution), west-looking, C-band radar images on 24 June 2008 and, on request, on 4 August 2008. These data were the next highest resolution radar data available after TerraSAR-X and contained detailed information on the post-eruption state of the lava dome. It was evident from comparison of the 24 June and 4 August 2008 images that the dome had remained largely intact and the vent location was just visible in the 4 August image (Figure 6). However, the two images have different imaging geometries (5N and 2 respectively) and so direct change difference was not possible. An earlier Fine 2 mode image was available from 2004, but the changes since then have been huge and comparison was not useful to this study (Figure 6). If TerraSAR-X data had not been available, we could have enhanced the 24 June and 4 August 2008 RADARSAT data to reveal the landscape change, but the resolution of the TerraSAR-X is superior so there was no need to do so.

3.1.3 PALSAR

Three high resolution L-band PALSAR east-looking images were acquired on 8 February 2008 and 10 August 2008. The February scene is single HH polarisation (6.25 m resolution) and the August scenes are dual HH-HV polarisation (12.5 m resolution). The volcano dome is clearly visible in all three images, showing it had remained largely intact following the explosion (Figure 7). Change difference images were created for the HH-polarisation data (Figure 8). Significant change could be detected from the imagery but not at the detailed level allowed by the TerraSAR-X data as the PALSAR data had coarser spatial resolution. The pumice flow deposits could be detected, but the details of the vent could not.

3.1.4 Envisat

The Envisat satellite acquired two post-explosion C-band ASAR images, one looking west (descending) on 8 August 2008 and one looking east (ascending) on 10 August 2008. An east-looking pre-explosion scene from 9 December 2007 was available as a reference image (Figure 9). The two post-explosion view directions provided a useful perspective on the volcano and it was evident that the volcano dome had remained predominantly intact. Due to the relatively coarse (30m) resolution of the dataset it was not possible to view the detail of the volcano vent. The ESA EO helpdesk provided assistance with the Envisat data. They resolved a difficulty encountered with the decompression of the Envisat data and, as we were not familiar with the N1 data format, guided us to free software to read the data and guided us through use of the software. The helpdesk responded promptly and helpfully to our requests, and conversion of the data from N1 to Tiff format proved to be a simple process.

3.2 Visible and Infrared data

Due to cloud cover and the gas plume, the summit of Soufrière Hills volcano can rarely be observed by satellite sensors in the visible and infrared portions of the spectrum. Nevertheless, due to the potentially valuable information content of optical imagery, three sensors were tasked to view the volcano in the days after the explosion in case of a lucky break in the cloud: SPOT, IRS and TopSat (Table 2). The main area of interest — the lava dome — was hidden by cloud in all three instances. The imagery did provide a detailed view of the pumice flow deposits to the west and east of the volcano that was not obtainable from the radar imagery. The detailed information about the pumice flow deposits has helped to build a better picture of the nature of the eruption.

Figure 5 Photograph of the Gages Wall vent area on 14 August 2008. The vent is partly filled with newly extruded lava which has spilled down the chute between Gages Wall and Chances Peak into the Gages Valley in the foreground. Compare with Figure 4. (Image © MVO).

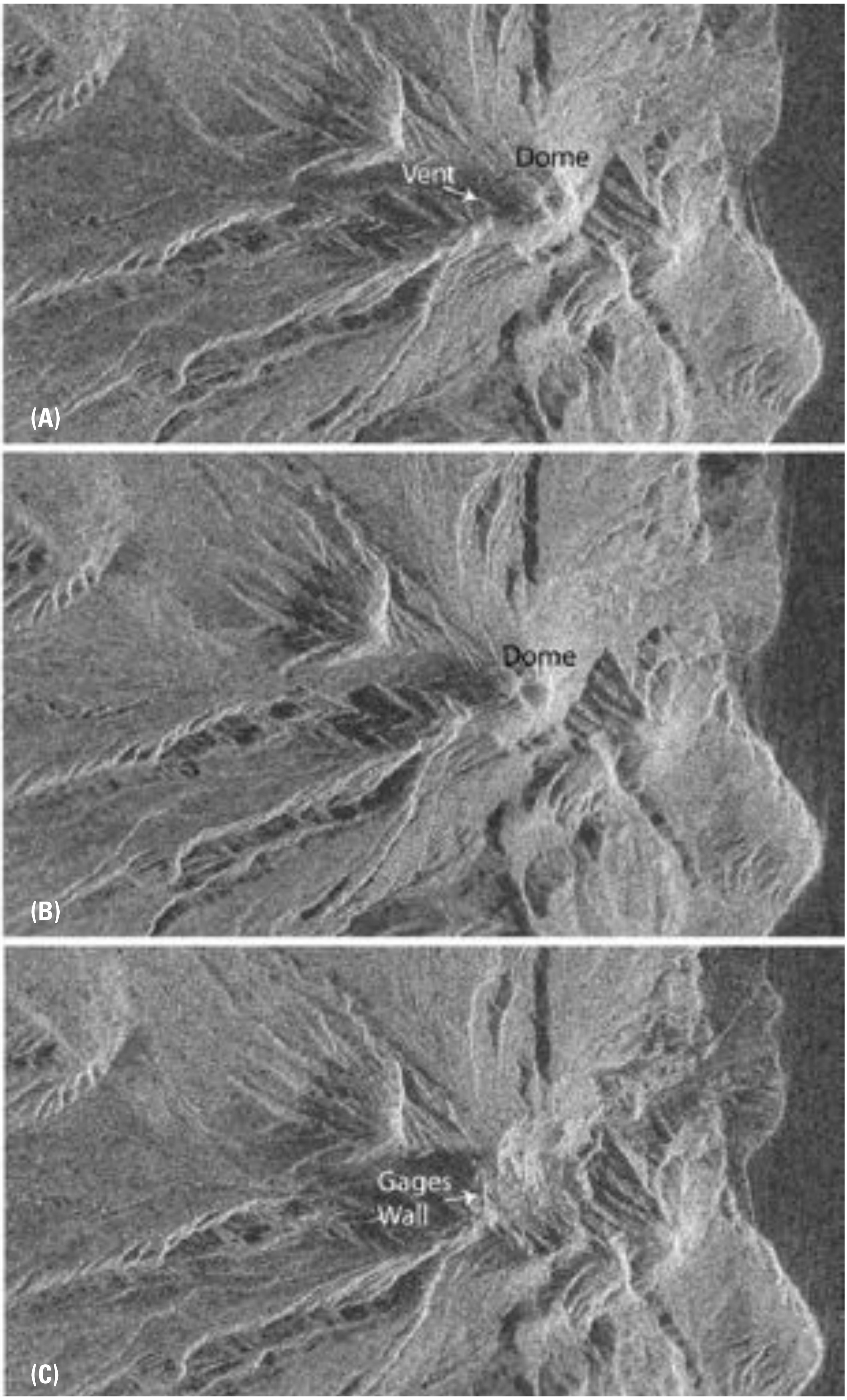


Figure 6 Three RADARSAT fine-mode west-looking amplitude images of Soufrière Hills volcano with 6.25 m spatial resolution. (a) and (c) were taken on 4 August 2008 and 10 March 2004 respectively with the same imaging geometry (F2, 40 degrees from vertical). (b) was taken on 24 June 2008 using a different imaging geometry (F5, 46 degrees from vertical). In the 2004 image there was no dome in the crater. The brightening of the August image around the explosion vent, relative to the June image, (b), can just be discerned. (Imagery Canadian Space Agency/Agence Spatiale Canadienne (2008)).

10 August 2008
HV

10 August 2008
HH

8 February 2008
HH

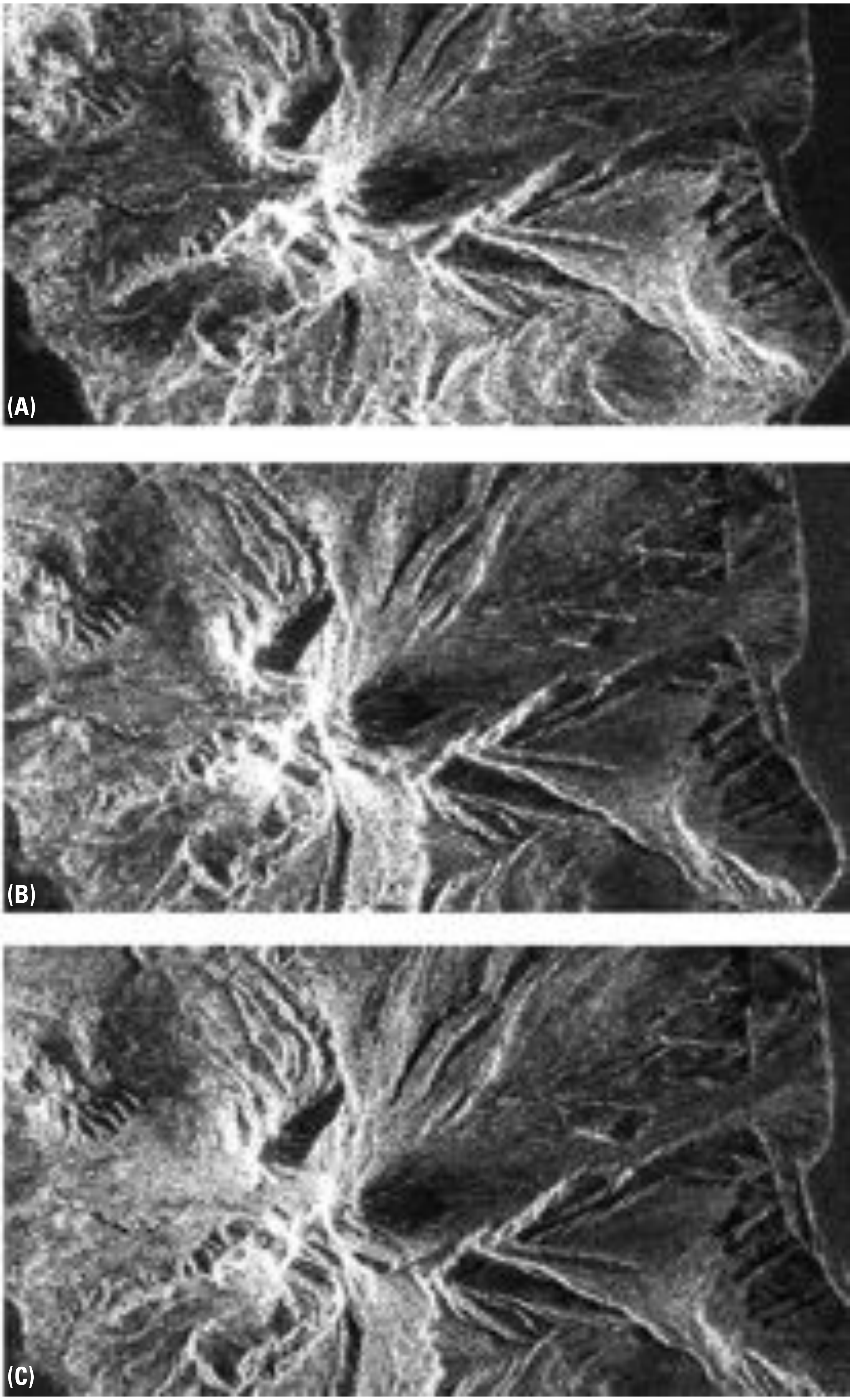


Figure 7 PALSAR east-looking images of Soufrière Hills volcano. (a) and (b) were acquired on 10 August 2008 at dual HV and HH polarisation respectively at 12.5m resolution. (c) was acquired on 8 February 2008 at single HH polarisation at 6.25m resolution. The dome is in the centre of the images. (Imagery © JAXA, METI 2008).

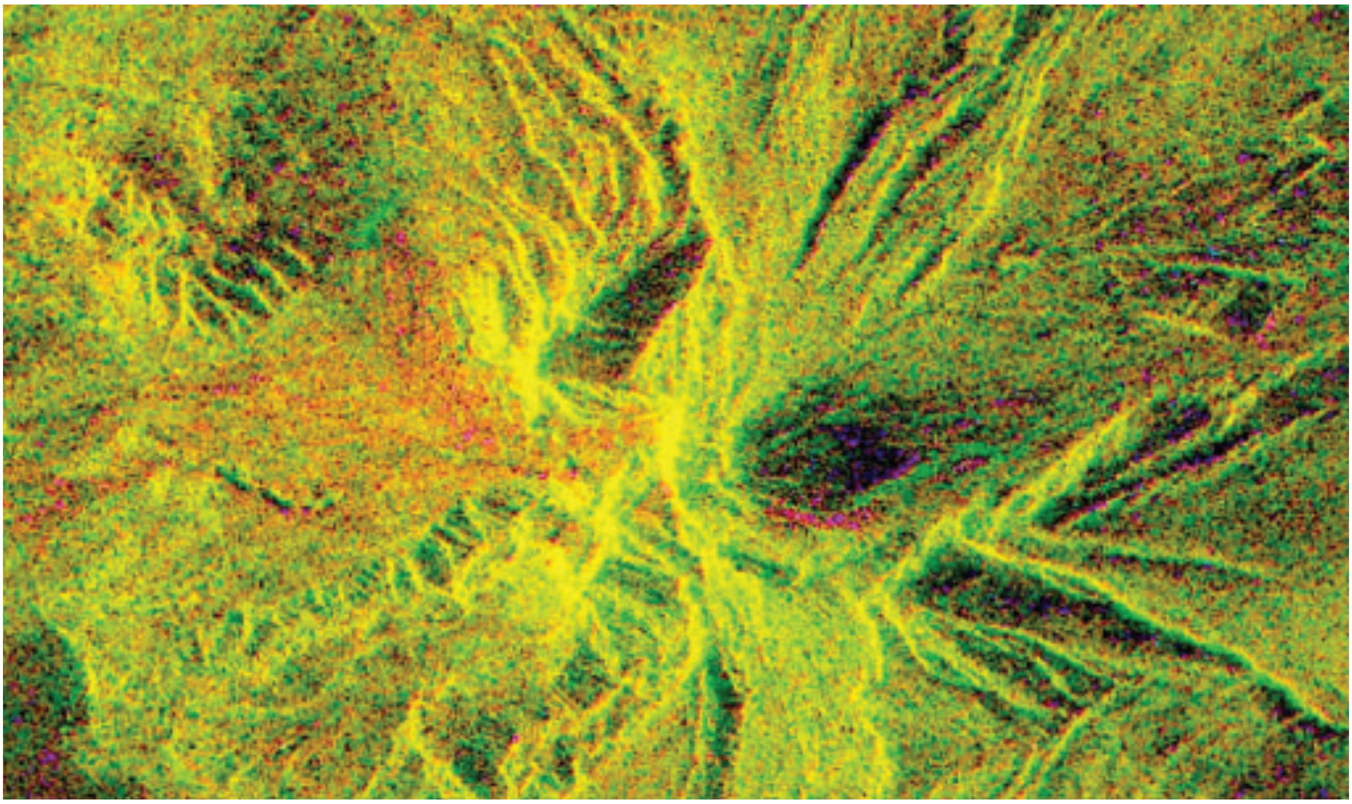


Figure 8 Change difference image constructed using two east-looking (34 degrees from vertical) PALSAR images of Soufrière Hills Volcano acquired on 8 February 2008 and 10 August 2008. The dome is in the centre of the image and is in a similar viewing geometry and change difference colour scheme to that of the TerraSAR-X image of Figure 1. (Original data © JAXA, METI 2008).

3.2.1 TopSat

Two pairs of TopSat imagery (5 m resolution colour and 2.5 m panchromatic) were acquired on 1 and 3 August 2008 in visible wavelengths (Figure 10). Cloud covers the summit and much of the volcano. The pumice flow deposits to the east of the volcano are clearly visible in the images.

3.2.2 IRS

This 3-band scanner with a resolution of 5.8 m acquired an image on 1 August 2008 in the green, red and near infrared part of the spectrum. The freshly deposited pumice flow material is visible to the east and the west of the volcano (Figure 11). The summit and much of the volcano is obscured by cloud.

3.2.3 SPOT

The SPOT satellite acquired an image on 14 August 2008 that was relatively cloud-free on the western side of the volcano. There was cloud over the summit and to the east of the volcano, with a cloud free view further to the east. A 10m-pixel, 3-band composite image shows the distribution of the pumice flow deposits, particularly on the western side (Figure 12). The deposits are clearly visible, albeit somewhat eroded/buried after two weeks. The cloud/shadow obscures the dome. A 2.5 m-pixel panchromatic image allowed even finer mapping of the deposit (Figure 13). A pre-explosion image from 24 November 2007 has much less, though some, cloud and allowed comparison with later deposits (Figure 14). The distribution of the recently deposited pumice flow material visible in the SPOT imagery has been mapped in Figures 15 and 16 (see section 3.3).

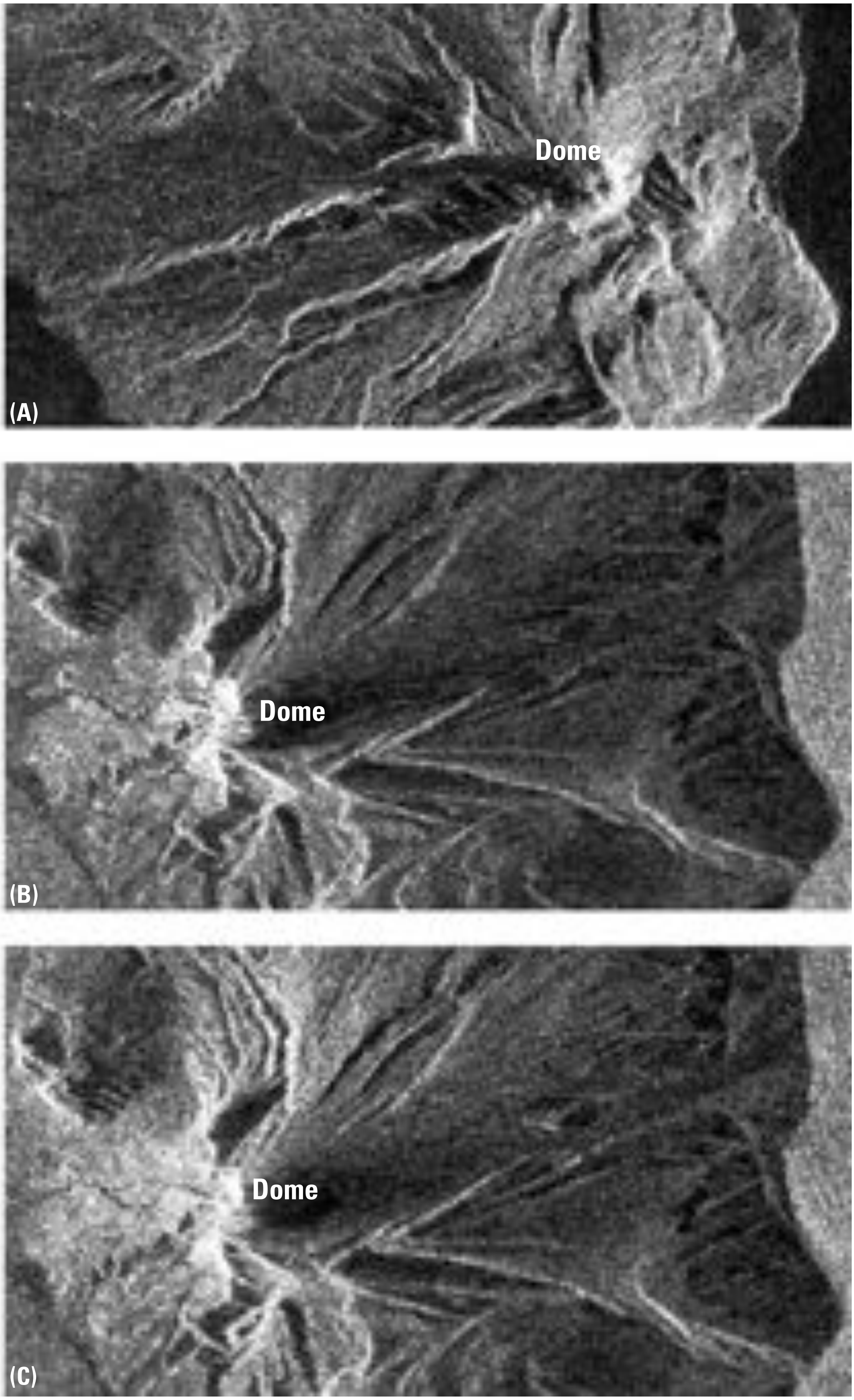


Figure 9 ENVISAT data of Soufrière Hills volcano acquired at 30 m resolution. (a) and (b) were acquired post-29 July 2008 eruption, on 8 August looking west and on 10 August looking east respectively. (c) is an east-looking image acquired on 9 December 2007. (Imagery © ESA, 2008).

Satellite	Date of image acquisition	Image resolution	Image details	Image format
SPOT 5 Band 1 (green) 0.49-0.61um Band 2 (red) 0.61-0.68um Band 3 (near IR) 0.78-0.89um Band 4 (mid IR) 1.58-1.75um Panchromatic Band: 0.49-0.69um	14 August 2008 14 August 2008 24 November 2007 24 November 2007	10m 2.5m 10m 5m	Multispectral Panchromatic Multispectral Panchromatic	GeoTiff GeoTiff GeoTiff GeoTiff
IRS Band 2 (green) 0.52-0.59um Band 3 (red) 0.62-0.680um Band 4 (near IR) 0.77-0.86um	1 August 2008	5.8m	Multispectral	GeoTiff
TopSat Band 1 (blue) 0.45-0..5um Band 2 (green) 0.5-0.6um Band 3 (red) 0.6-0.7um	3 August 2008 3 August 2008 1 August 2008 1 August 2008	5m 2.5m 5m 2.5m	Multispectral Panchromatic Multispectral Panchromatic	Tiff Tiff Tiff Tiff

Table 2 Details of the visible and infrared data acquired for Montserrat.

3.3 User Feedback

The end user, Montserrat Volcano Observatory (MVO), was pleased with the outcome. The Acting Director, R. Stewart, said on 4 August 'I am really impressed with these results, and am excited about the other images that might come'. In the days prior to the explosion there had been a protracted seismic crisis at the volcano and MVO was on high alert for the possibility of a major collapse of the lava dome that has been the source of the main hazard faced by the occupied parts of western Montserrat. Thus MVO was under considerable pressure to be able to advise government on the state of the dome after the explosion.

For seventeen days, from before 28 July until14 August, the dome could not be observed visibly, therefore it was not known if the explosion had destabilised a large part of the western and northern sides of the dome. Within days of Charter activation, analyses of primarily the radar data provided the MVO with the information they required.

Armed with the initial interpretation of August 3, R. Stewart was able to inform the Montserrat government civil protection committee (NDPRAC) who met on 5 August. As a result of this the people that had been evacuated following the event were allowed to return to their homes (see the MVO activity reports of the eruption in Appendix B and the Press Statement in Appendix C).

Scientists at MVO/Institut de Physique du Globe de Paris (IPGP) (Y. Legendre and J-C Komorowski) were later able to use the terrain-corrected TerraSAR-X change difference images and the SPOT panchromatic data of 14 August 2008 to map the pumiceous pyroclastic flows that were deposited to the west and east of the lava dome. They were able to validate the high accuracy of this mapping with GPS measurements in the field. Figure 15 shows the deposit field (generalised, with no 'holes' or kipukas) superimposed on a TerraSAR-X image and Figure 16 shows the same field superimposed on a SPOT image.

3.4 Conclusions of the project

1. Earth Observation data provided the dominant piece of evidence used by scientists in advising government on the post-eruption state of the Soufrière Hills volcano on Montserrat. As a result people who had been evacuated following the eruption were able to return to their homes.
2. The new acquisition radar data from the TerraSAR-X, RADARSAT, PALSAR and Envisat satellites showed little change to the overall shape of the lava dome indicating that only a small part of the dome had been involved in the explosion.
3. For the nature of the hazardous event to be understood the relatively small new volcanic vent, the source of the eruption, needed to be located. This was achieved with best effect from the TerraSAR-X data and the vent was also visible in the RADARSAT data.
4. The key factors in the fast provision of detailed change detection information from the TerraSAR-X data were: the ability to acquire both ascending and descending pass images rapidly; the availability of equivalent archival imagery to the new acquisition data; the availability of experts at DLR who were able to rapidly add value to the data.
5. Further understanding of the nature of the eruption was provided by observation of pumice flows in the change difference images generated from the TerraSAR-X and PALSAR data. The SPOT data provided a more detailed view of the pumice flow deposits where there was no cloud cover.
6. The EO data as a whole has provided increased understanding of the nature of this type of eruption at the Soufrière Hills volcano.
7. TerraSAR-X, with a resolution of up to 1 m, is the sensor of choice for detailed change detection targets, particularly on volcanoes under cloud.
8. RADARSAT and PALSAR, operating in fine mode and single polarisation respectively with spatial resolution of 6.25 m, are the next sensors of choice for detailed change detection targets under cloud.
9. Two factors helped speed the activation of this Call to the Charter that might have otherwise been delayed. Firstly, R. Stewart of MVO had been on a remote sensing workshop 'Space-based solutions for disaster management in the Caribbean region' run from 8 to 11 July 2008 by UN-SPIDER, and so was alert to the role of the Charter. Secondly, G. Wadge who is an expert in volcano remote sensing (and had initiated the only previous Montserrat call to the Charter in 2003) had previous experience with imagery from the TerraSAR series of satellites. Thus as early as 29 July they were able to both recognise the need to initiate a call to the Charter and to get in touch directly with contacts at DLR in Germany to enquire about tasking TerraSAR-X. Thus continuing education and networking played a role here!
10. Almost a day elapsed between the end-user (MVO) taking the initiative and activation of the Charter by the UK government. It is not obvious from a cold start with web-based resources (at Charter or BNSC) who to contact and how the process should proceed. The process of communication between BNSC, FCO and the Cabinet Office to evaluate the request worked but should be reviewed to increase its speed for future calls.
11. The data requested were received in good time and good order. Putting the data on the ESA Charter ftp site works well.

3.5 Recommendations for improving scenarios

This volcanic crisis was characterised by three main requirements. The first one, speed of action, is common to most crises. The second was the ability to see through cloud, which could only be met with radar sensors. The third was for high-resolution radar imagery. It is not obvious when this may be required. In this case it was the suspicion that a relatively small (approximately 100 m) feature had developed and needed to be positively identified to enable the nature of the hazardous event to be understood. Images with pixels coarser than 10 m are not able to satisfactorily resolve such objects. Thus a cloud-covered volcano with explosive activity underway requires the sort of resources as the rapid deployment of a high-resolution radar. Ideally, TerraSAR-X data would be available under the Charter.

To answer the question posed by this event required construction of very high resolution change difference radar amplitude images. This was only made possible by the availability of archived data with the same viewing geometry. Fortunately this was available — it might not have been. On the volcanology side we could have been better prepared for this by asking ourselves what we might need by way of archival data to be able to respond to the scenario we faced on 29 July. The MVO will now seek to become better prepared in this regard.

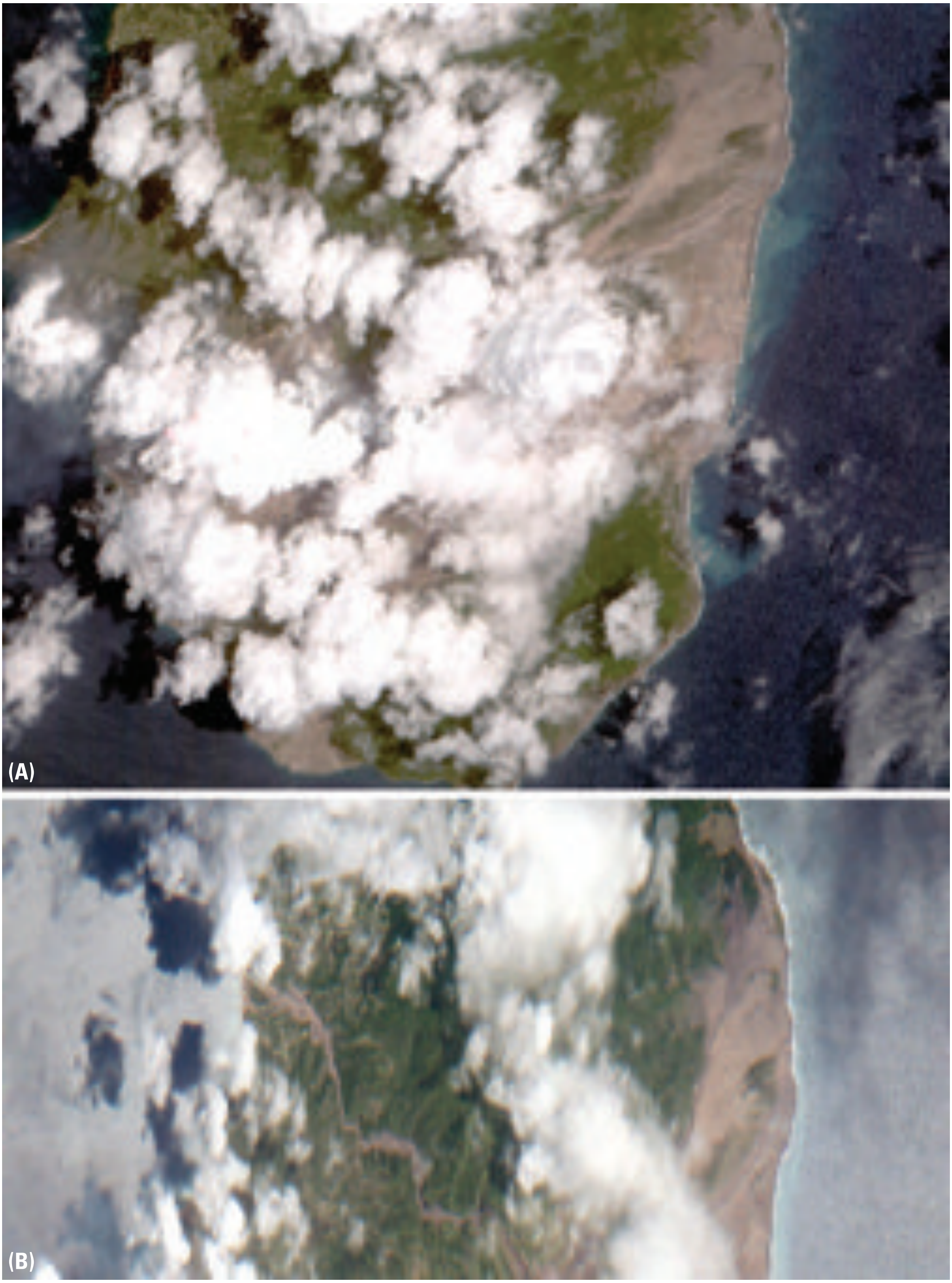


Figure 10 True colour 5m pixel TopSat images of southern Montserrat, (a) acquired on 1 August 2008, (b) acquired on 3 August 2008. (Imagery courtesy of TopSat consortium © QinetiQ Limited, 2008, distribution Infoterra Ltd all rights reserved).

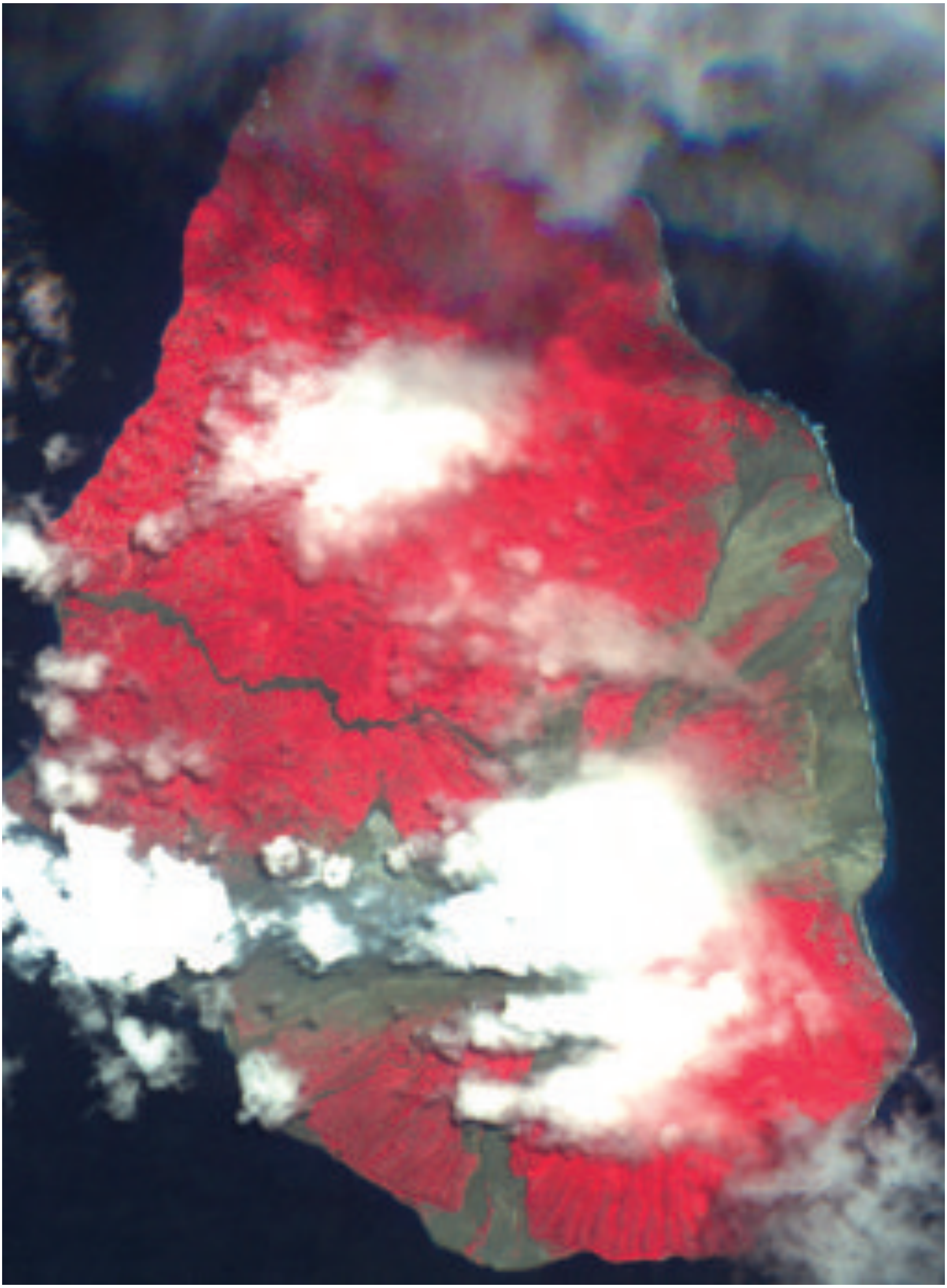


Figure 11 False colour composite IRS image of southern Montserrat acquired on 1 August 2008 (Bands 2,3,4 in R,G,B)) with spatial resolution of 5.8 m. Note the pale pumice deposits to the west and east of the volcano. (Image © Courtesy National Remote Sensing Agency, Govt. of India).

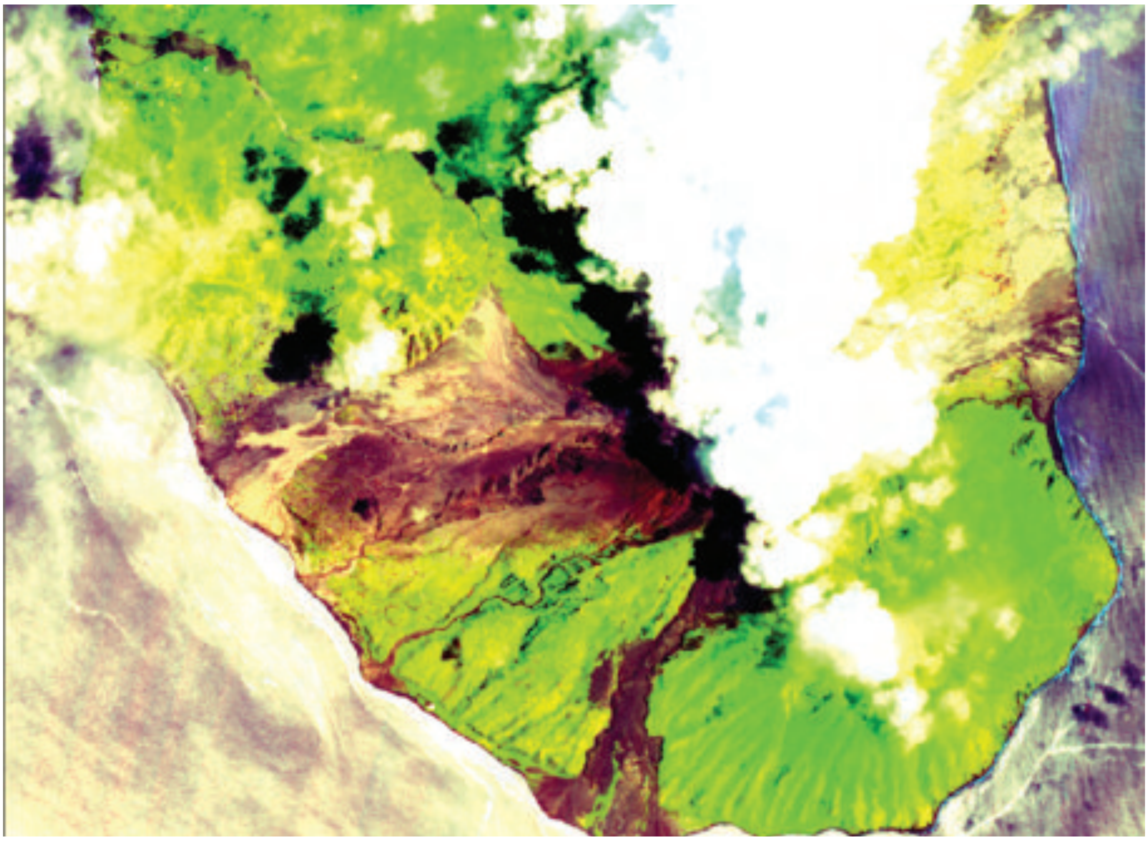


Figure 12 SPOT 10m pixel colour composite (4,1,3 in R,G,B) image of southern Montserrat taken on 14 August 2008. Note the pale pumice deposits to the west and east of the volcano, in particular the more extensive distribution of the deposits that reach the coast at Plymouth compared to the TerraSAR-X images of 1 August 2008 in Figures 1 and 2. (Image © CNES 2008, distribution Spot Image S.A., all rights reserved).

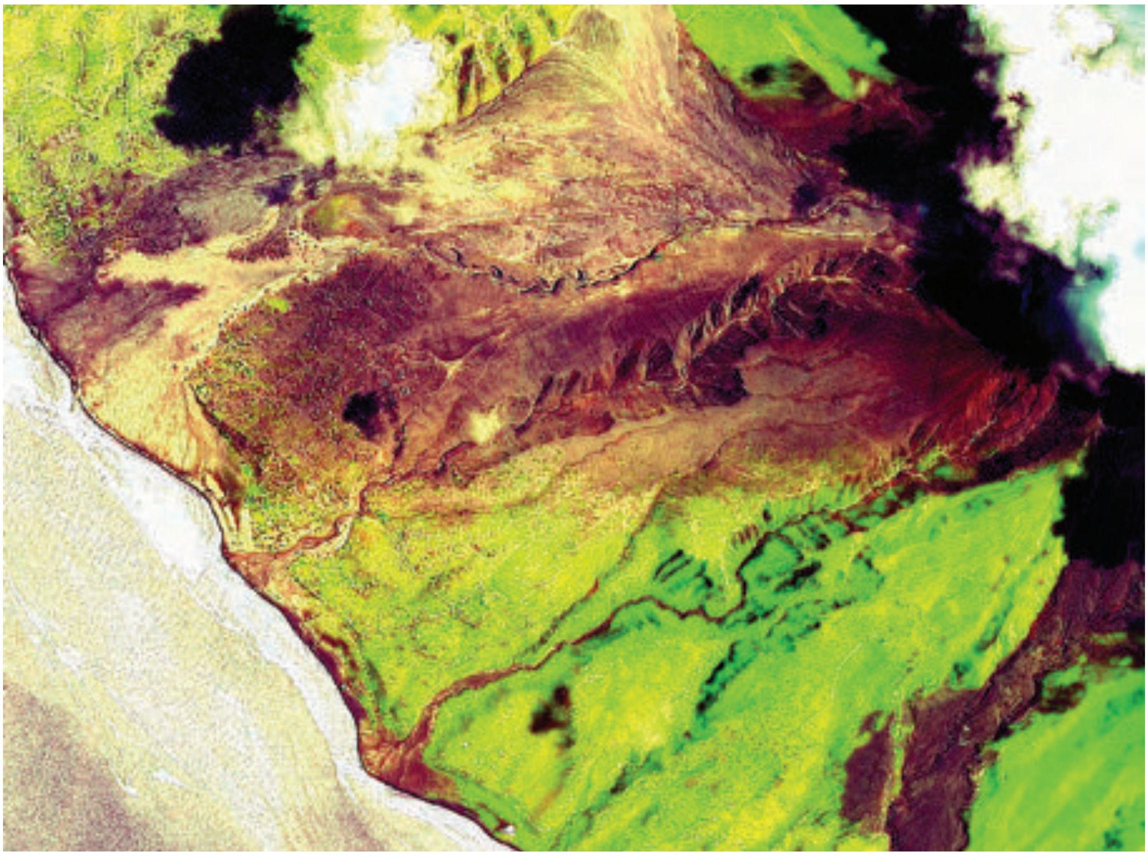


Figure 13 2.5m pixel SPOT resolution merge colour composite (4,1,3 in R,G,B) image of the area to west of the Soufrière Hills volcano taken on 14 August 2008. (Image © CNES 2008, distribution Spot Image S.A., all rights reserved).

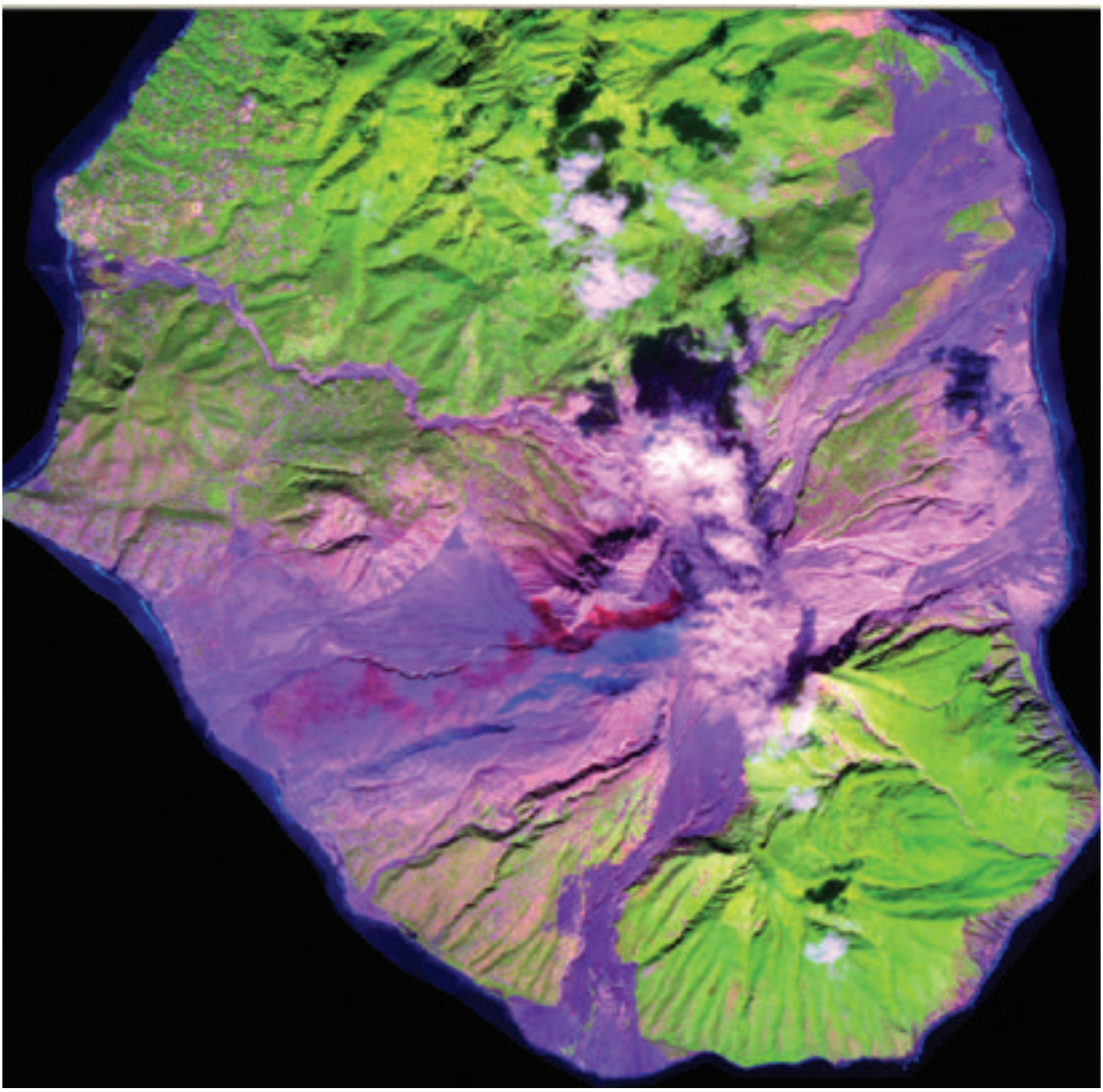


Figure 14 SPOT 10m pixel colour composite (4,1,3 in R,G,B) image of southern Montserrat taken on 24 November 2007. Note the absence of the pumice flow deposits seen in Figures 10-13 and also how the WSW directed plume casts a maroon coloured shadow. (Image © CNES 2008, distribution Spot Image S.A., all rights reserved).

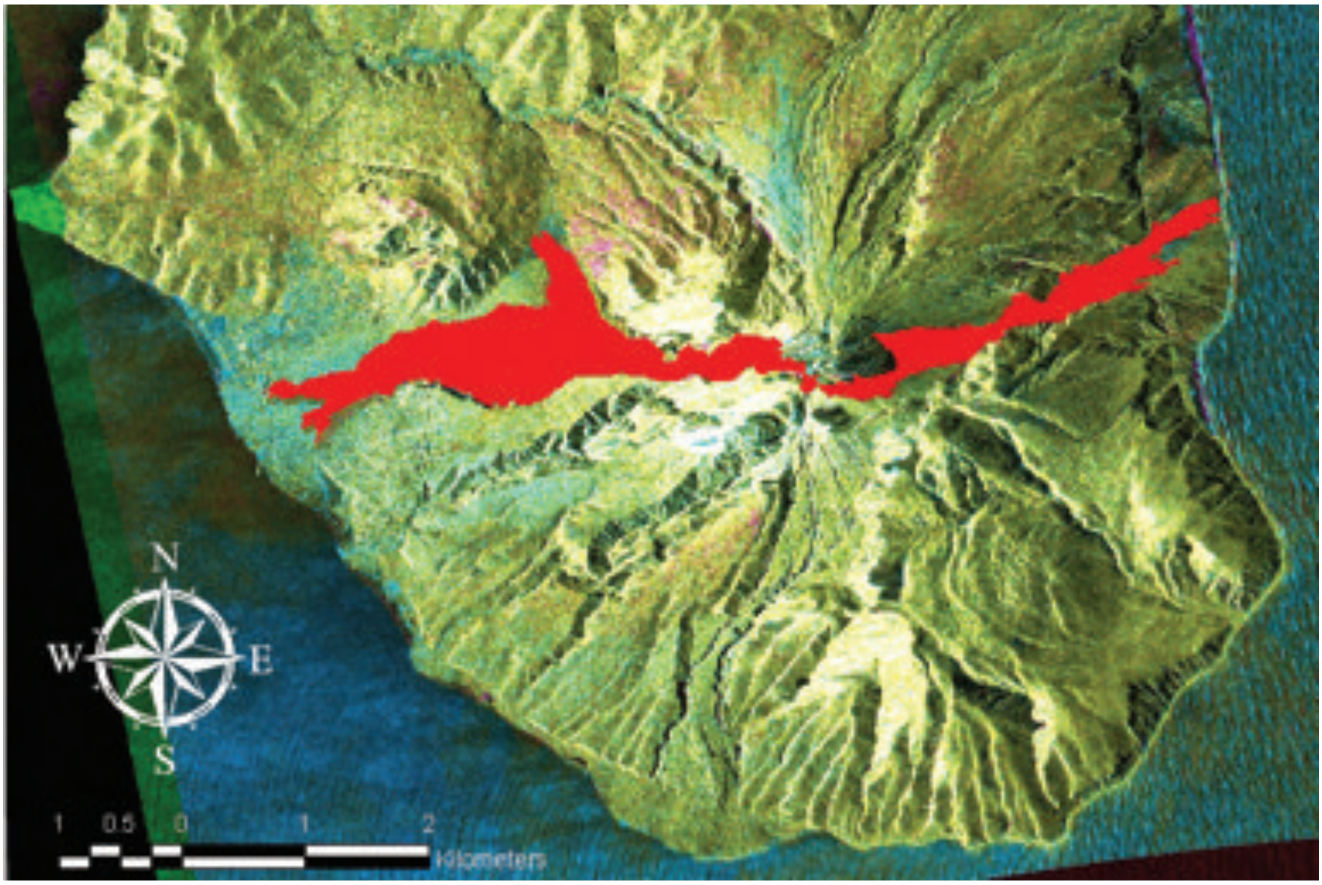


Figure 15 Mapped outline (red) of the column collapse pumiceous pyroclastic flow deposits of 29 July 2008 based on joint mapping using the TerraSAR-X change difference and SPOT imagery and superimposed on the TerraSAR-X image (courtesy of Y Legendre and J-C Komorowski). (TerraSAR-X image © DLR 2008.)

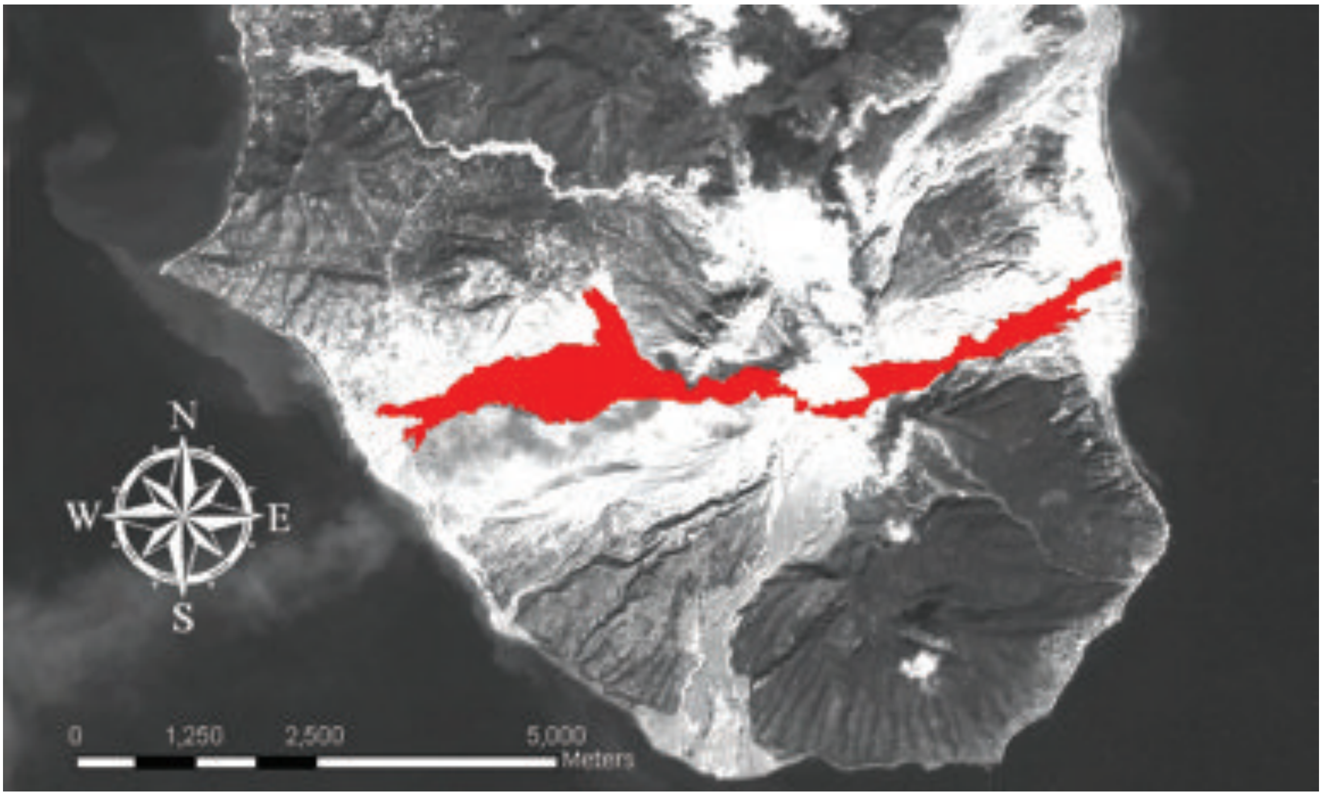


Figure 16 Mapped outline (red) of the column collapse pumiceous pyroclastic flow deposits of 29 July 2008 based on joint mapping using the TerraSAR-X change difference and SPOT imagery and superimposed on a panchromatic SPOT image (courtesy of Y Legendre and J-C Komorowski). (SPOT image © CNES 2008, distribution spot Image S.A., all rights reserved.)

Appendix A. General information about the area

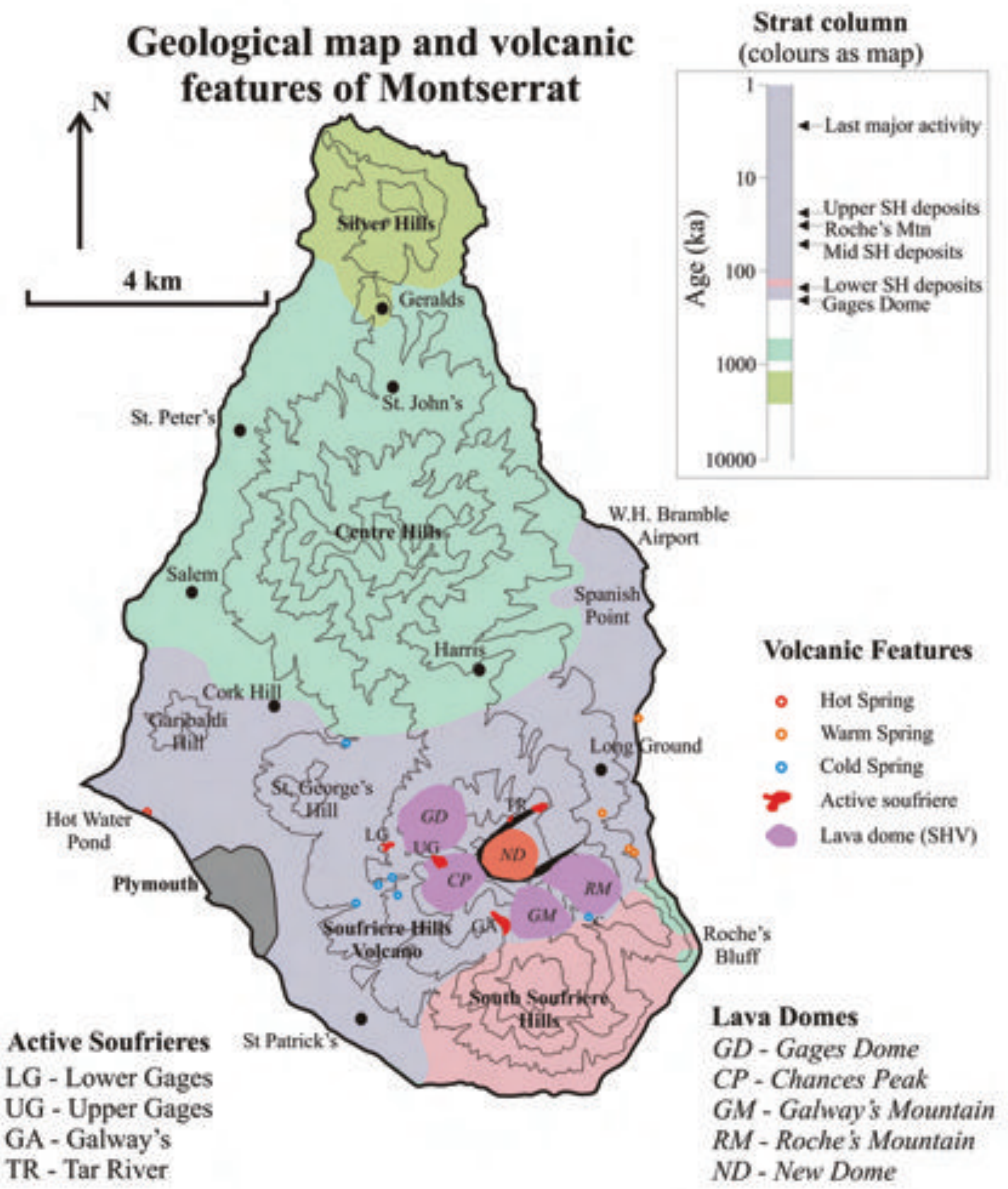


Figure A1 Map of Montserrat showing volcanic features and simplified geology. (From Norton et. al., 2004 based on Harford et. al. 2002).

Figure A2 Photo of Montserrat, with the Soufrière Hills volcano towards the top of the photo. (© NERC/GOM).

Soufrière Hills Volcano: background information

Country:	United Kingdom
Subregion:	West Indies
Volcano Number:	1600-05
Volcano Type:	Stratovolcano
Volcano Status:	Active
Summit Elevation:	915m (3002 feet)
Latitude:	16.72deg N (16 43 0 N)
Longitude	62.18 deg W (62 11 0 W)

Geological and eruption history of the Soufrière Hills volcano, Montserrat

Montserrat is situated in the northern part of the Lesser Antilles, which is a volcanic island arc formed along the junction where the Atlantic tectonic plate is subducted beneath the Caribbean plate. Nearly all the islands along the arc are the result of subduction related volcanism. Most have andesitic stratovolcanoes, which have been produced by explosive eruptions, coupled with the growth of lava domes and associated pyroclastic flows, and the occasional extrusion of lava flows.

Montserrat is only 16 km long (north–south) and 10 km wide (east–west), and is built almost exclusively of volcanic rocks. The island comprises three volcanic centres or massifs of differing age. These are, from oldest to youngest: the Silver Hills in the north; the Centre Hills in the centre; and the active volcano of the Soufrière Hills and South Soufrière Hills in the south. In addition, Garibaldi Hill and St George's Hill form two smaller, isolated topographic highs. The island's interior is densely vegetated, with the exception of areas affected by the recent eruption. Rock exposures are thus largely limited to coastal cliffs, road cuttings, and inland cliffs.

The island is mainly composed of andesitic lavas and volcaniclastic rocks produced by dome-forming eruptions; although the South Soufrière Hills are of basaltic to basaltic-andesite composition. The main products consist of the remnants of andesite lava domes; andesitic breccias representing the talus of previous lava domes; pyroclastic flow deposits formed by the collapse of lava domes; lahar and debris avalanche deposits; and subordinate tephra fall deposits. There are zones of hydrothermally altered rocks, and active fumarole fields (known locally as Soufrières) occur on the Soufrière Hills volcano.

During the last 100 years, there have been several earthquake crises associated with the Soufrière Hills volcano. These occurred in the 1890's, the 1930's and the 1960's and were accompanied by increased fumarolic activity at the Soufrières on the flanks of the volcano. These crises are interpreted as failed eruption, produced by magma rising beneath the volcano, but failing to reach the surface.

The current eruption of the Soufrière Hills Volcano began in 1995, following a three-year period of precursor seismic activity.

The eruption has been characterised by the growth of an andesite lava dome with associated pyroclastic flows, vulcanian explosion and debris flows, similar to the activity that produced the ancient deposits making up the rest of the island. There have been five distinct phases to the eruption so far. These include a period of extrusion from 1995 to early 1998, during which the dome grew and collapsed on a number of occasions. This was followed by a period of residual activity, from early 1998 to late 1999, when there was no extrusion of lava, but several collapses of the dome occurred, as well as small to moderate size explosions. The third phase began in November 1999, with the renewed extrusion and growth of a large lava dome, and which continued until July 2003. There were three major collapses during this second phase of dome growth: in March 2000, July 2001 and July 2003. There then followed a period of quiescence, with three main phases of elevated activity: in March-May 2004, April 2005 and June-July 2005. These phases of activity include ash and steam venting, occasional pyroclastic flows and explosive eruptions. In August 2005 the fifth phase of the eruption, the third phase of dome growth, began with renewed extrusive activity. There was a dome collapse event on 20 May 2006, after which dome growth continued.

2007 saw significant activity at the Soufrière Hills Volcano. At the beginning of January, a period of especially elevated growth rates saw the NW sector of the dome bulk up to a similar height to the eastern and south-western lobes giving the dome a more symmetric mass. An unprecedented level of pyroclastic activity occurred in Tyres Ghaut during this time. The most significant event of the period was a partial collapse (est. 5 Mm3) into Tyres Ghaut on 8 January 2007, including pyroclastic flow with a run out of c.5.5 km down the Belham River Valley reaching Cork Hill. The dome growth rate decreased during mid to late January before refocusing to the SW. During February the focus switched to the east, back to the SW and to the east again, before focusing on the NE in early March. During mid to late March dome growth rates reduced and all signs of activity were low, limited to small rockfalls and intermittent pyroclastic flows predominantly in the Tar River Valley. Lava extrusion and dome growth ceased in early April. This marked the start of phase 6 of the eruption, a phase of residual activity. The final volume reached by the dome was measured at 203 Mm3, which is the second largest to date (Figure A3). Since then there has been very little change in the dome morphology excepting slow erosion of the eastern sector of the dome above the Tar River Valley by ongoing minor rockfall and pyroclastic activity.

Summary of the eruption:

- 1995: Initial phreatic activity
- 1995–1998: Dome growth (Phase 1 of the eruption, Phase 1 of dome growth), the so-called 'volcanic crisis' years when population was displaced and the Capital lost
- 1998–1999: Residual activity, no dome growth (Phase 2 of the eruption)
- 1999–2003: Dome growth (Phase 3 of the eruption, Phase 2 of dome growth)
- 2003–2005: Residual activity, no dome growth (Phase 4 of the eruption)
- 2005–April 2007: Dome growth (Phase 5 of the eruption, Phase 3 of dome growth)
- April 2007–present: Residual activity (Phase 6 of the eruption).

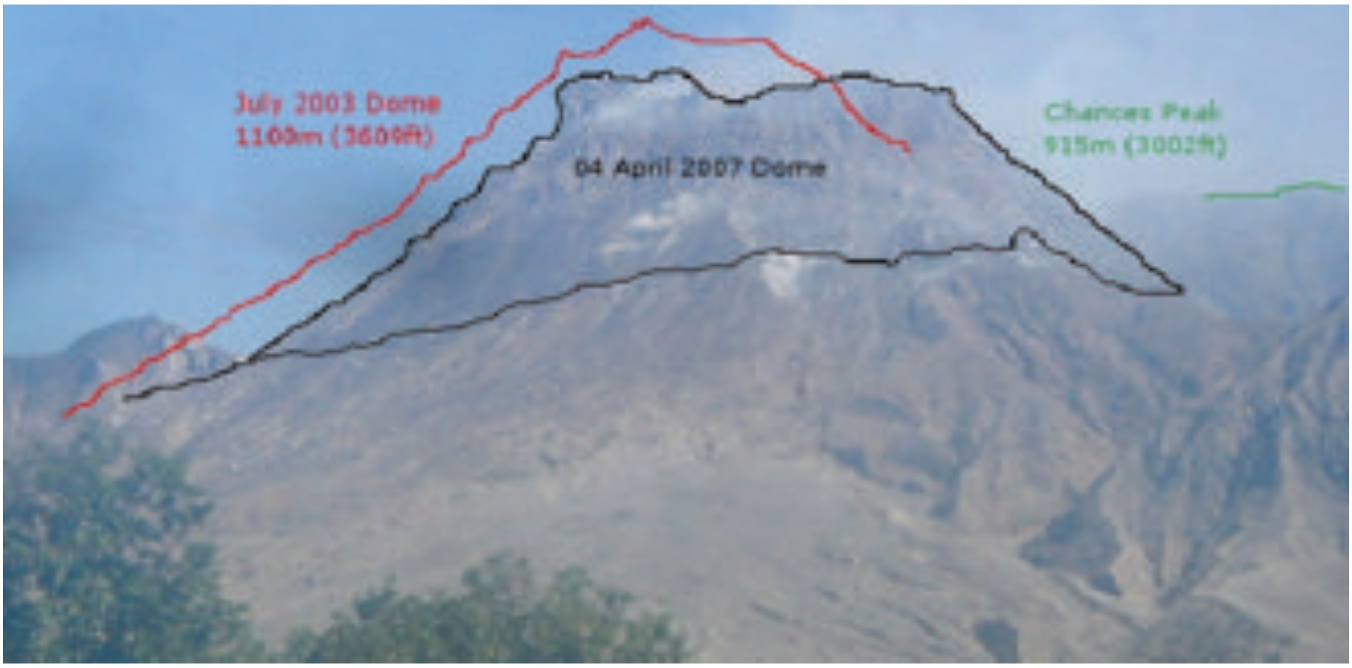


Figure A3 April 2007 appearance of the Montserrat lava dome compared to that in July 2003. (© NERC/GOM).

Annex B. Montserrat Volcano Observatory activity reports

Montserrat Volcano Observatory
Weekly Report for the period 25 July – 1 August 2008

Following a period of intense seismic activity at the Soufrière Hills Volcano, there was an eruptive event on the night of Monday 28th July 2008 which generated a large ash column, pyroclastic flows and falls of airborne pumice in some inhabited areas. Due to cloud cover, the dome has not been seen since the event and may be less stable than it was prior to this event.

Last week, seismic activity had been at an increased level with intermittent swarms of hybrid earthquakes. Seismic activity started to increase further at approximately 1am on Saturday 26th July 2008 with the onset of hybrid and long-period earthquake activity. The number and size of the earthquakes slowly increased and peaked at about 9 pm on the same day, with a rate of around 15 events per hour. Seismic activity decreased over the next few hours, before starting to increase again at approximately 1 am on Sunday 27th July. The activity peaked at around 3 am, at a rate of more than one event per minute, and continued at a high level until 9:35 am on the same day.

There was then a short series of eruptive events. The first and largest event started at approximately 9:35 am and vented ash for about 15 minutes. The source of the ash could not be seen due to cloud cover, but was probably the Gages vent. This first event generated a non-energetic ash column which rose to about 2.5 kilometres (8000 feet) above sea level. The ash cloud was blown to the west and north-west, and there was ashfall in Plymouth and St George's Hill. There were no pyroclastic flows.

There were two other eruptive events in the following 45 minutes. These were much smaller, with ash clouds below 1.5 kilometres (5000 feet) above sea level.

Seismic activity continued at a slightly reduced level following these eruptive events. Seismic activity started to decline noticeably at approximately 10 am on Monday 28th July and had returned to the levels of last week by approximately 3:30 pm on the same day.

There were two small rockfalls between then and the eruptive event at approximately 11:30 pm.

The eruptive event started without any warning at 11:27 pm on Monday 28th July. The seismic signals show that the start of the event built up gradually over a period of a few minutes, consistent with a dome collapse rather than explosive activity. Seismic activity then shows a series of sharp peaks starting at 11:32 pm, consistent with explosive activity. The seismic signal shows that the activity was over within about one hour.

An infrasound sensor on St Georges Hill, which records low frequency sound waves, recorded a clear explosion signal at 11:38 pm, which coincides with the largest peak in the seismic signal.

The eruptive event generated a large ash column, pyroclastic flows and the fallout of airborne pumice.

The ash column was reported to reach a maximum height of about 12 kilometres (40 000 feet) above sea level. Satellite imagery shows that the ash was blown mainly to the north-west. There were reports of ashfall from St Croix, Puerto Rico and Guadeloupe.

There were three pyroclastic flows on the flanks of the volcano. The largest flow was from the Gages area which then split into two and travelled into Lee's Yard and

Plymouth. The flow into Plymouth also split into two around Round Hill, with a pyroclastic surge travelling over the top of the hill. The two lobes of this flow travelled almost to the sea, with one reaching the old Police headquarters and the other reaching the Pentecostal Church and the old Government House. This flow set light to trees and vegetation on Gages Mountain and the lower flank of St George's Hill. It also set fire to some buildings in Plymouth.

Another flow was in the Tar River Valley. This came from the channel that has been created by erosion on the south-east flank of the dome. This flow travelled as far as the old Montserrat coastline.

The other flow was much smaller, and was confined to an erosion gully in the volcanic material that has now filled in White River. This flow travelled no more than about two kilometres (1.5 miles) from the dome.

Examination of the flows, and of rock samples, show that the Plymouth and White River flows were mainly pumice; new lava as opposed to existing dome material. It is most likely that these flows were generated by collapse of material from the eruption column. The Tar River flow appears to have a larger proportion of old dome material, which would be consistent with partial dome collapse.

The first report of the fall of airborne pumice was at 11:40 pm. In the inhabited areas, the largest fallout was in the Iles Bay area, where hand-sized pumice fragments were reported. In Salem and Olveston, the pumice fragments were up to a centimetre in diameter. Crystal-sized pumice was reported as far north as Runaway Ghaut and Palm Loop.

There was almost no ashfall in inhabited areas.

Satellite sensors showed that at least 2-3000 tons of Sulphur Dioxide (SO_2) was released by this event.

There were at least two minor eruptive events at approximately 4 and 8 am on Tuesday 29th July. These generated small ash clouds. There has been very little activity, both visual and seismic since then.

This week, the MVO recorded 25 rockfalls, 1271 long period, 355 hybrid and 68 volcano-tectonic events. Almost all of the long-period and hybrid earthquakes occurred during the intense activity from 26th–28th July.

There are no estimates of Sulphur Dioxide (SO_2) flux for the week.

The eruptive event on Monday 28th July 2008 is interpreted as being caused by a vertical explosion in new magma which had been relatively quickly emplaced into the dome. The trigger for the explosion may have been a partial collapse of existing dome material. It has not yet been possible to establish the amount of material involved. Due to cloud cover, it has not been possible to establish how much of the dome has collapsed and if the dome has been made less stable by this eruptive event.

Until the stability of the dome can be established, it has to be assumed that there is an increased risk of collapses on all sides of the dome. There is an attendant increased risk of a pyroclastic flow travelling down to the Belham Valley and access restrictions have been imposed in the areas south of and immediately north of the Belham Valley as a precaution.

The alert level remains at 4.

Montserrat Volcano Observatory
Activity Report – 29 July 2008

There has been a partial dome collapse on the west side of the Soufrière Hills Volcano.

The collapse started at 11:27 pm local time on Monday 28th July 2008 without any precursory activity. Part of the western side of the lava dome collapsed generating pyroclastic flows that reached Plymouth and the sea.

There were also a few explosions from the dome during the collapse, with the largest at approximately 11:32 pm

The height of the ash column was estimated at 12 kilometres (40 000 feet) above sea level.

MVO: weekly Report for the period 1–8 August 2008

The Soufrière Hills Volcano has been relatively quiet following the event which occurred on Monday 28 July, with one or two small ash clouds and seismic activity at low levels. There has been a significant increase in the sulphur-dioxide flux.

A small ash cloud was observed at around 1 pm on Thursday 7 August. There are unconfirmed reports of a similar ash cloud between 3 and 4 pm on Sunday 3 August. There were no seismic signals associated with either of these.

Seismic activity was relatively low this week. The MVO recorded 16 rockfalls, 30 long period, 8 hybrid and 14 volcano-tectonic events. There were no swarms of seismic activity, with the events occurring throughout the week.

The average sulphur dioxide (SO_2) flux for the week was 1121 tons per day (t/d) with a minimum of 671 t/d on August 5 and a maximum of 2069 t/d on August 3. These values are significantly higher than the values before the event on 28 July.

Further investigation of the event on Monday 28 July has confirmed that it was a vertical explosion, with a small amount of dome collapse. The total amount of material involved was probably around 200 000–300 000 cubic metres. Cloud cover has prevented any clear views of the dome since the event, but satellite radar images indicate that the vent above Gages Wall has been enlarged by the explosion and now has dimensions of about 150 by 60 metres, elongated east-west. Most of the ejected material would have come from this vent.

All indications are that the explosion on 28 July cleared a blockage from the Gages Wall vent. The increase in gas flux and the non-seismic generation of small ash clouds suggest that the vent is more open than before.

The satellite data also showed that the stability of the dome was not affected by the explosion. In consequence, the precautionary access restrictions for areas in and around the Belham Valley have been lifted. A new Hazard Level System has been designed by the Montserrat Volcano Observatory and DMCA in consultation with the Government of Montserrat and community groups. The Hazard Level System divides the southern two-thirds of Montserrat into six zones along with two Maritime Exclusion Zones. Access permission for each of these zones is dependent on the Hazard Level. The Hazard Level, which ranges from 1 to 5, is set by NDPRAC on the advice of the MVO.

The Hazard Level is not related to the Alert Level used before. Leaflets and posters explaining the system are available from DMCA, MVO and several other locations on Montserrat. The new Hazard Level System takes immediate effect. The current Hazard Level is 3. Current access restrictions are unchanged.

MVO: activity Report – 6 August 2008

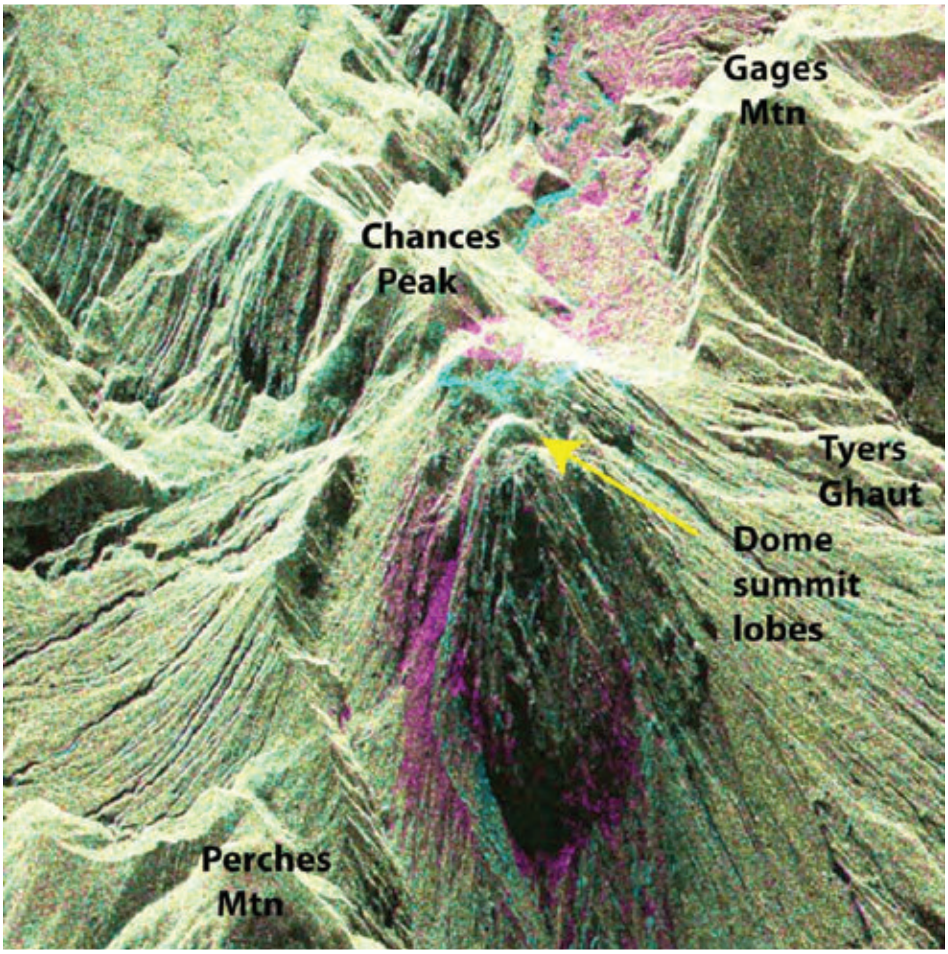
Following the activity on 28 July 2008, MVO obtained satellite imagery, particularly radar imagery, so that the condition of the lava dome could be established. A request was made using the United Nations' International Charter (http://www.disasterscharter.org/). Additional images from the German TerraSAR-X satellite (http://en.wikipedia.org/wiki/TerraSAR-X) were obtained through the efforts of Prof. Geoff Wadge, Reading University.

The topography of the dome has been largely unchanged by the explosion. The only significant change is in the area of the Gage's Wall vent that has been the source of ash and mild explosive activity in the last few months. The radar data indicates that this vent has been enlarged by the explosion, is probably now a crater, and has dimensions of approximately 150 by 60 metres, elongated in an east-west direction.

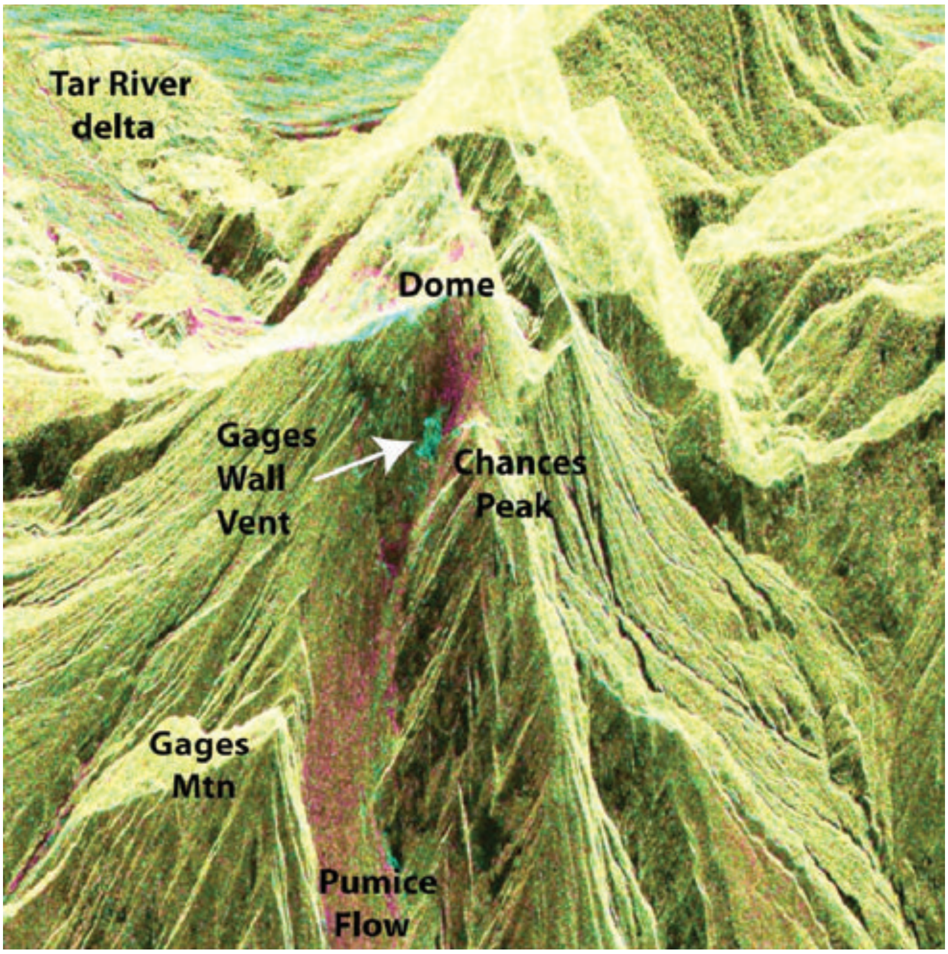
Given the lack of other changes to the dome, and the lack of any significant rockfall activity since the explosion, MVO conclude that the dome is no less stable than it was before the explosion.

Two satellite images are shown below - one each from the east and from the west. They are false-colour images combining TerraSAR-X data from 9 October 2007 and 1 August 2008. Although these images appear to be realistic, some of the features are not real but are artefacts of the data processing, particularly for the image from the west. Radar is sensitive to the roughness of the ground and areas that have changed in roughness show up as magenta or cyan in colour.

The magenta areas in these images show the pumice deposits from the pyroclastic flows on 28 July 2008. The enlarged Gages Wall vent, which is best seen in the view from the west, shows as a cyan area.



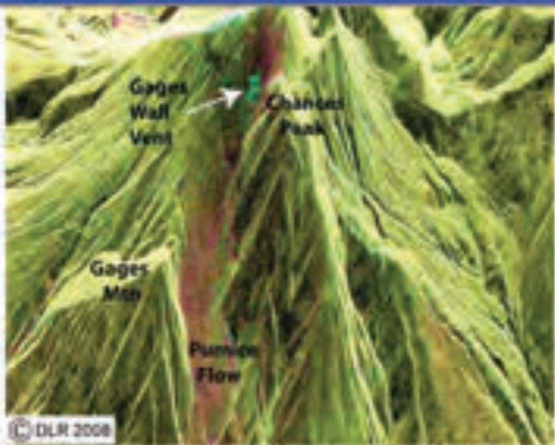
False-colour satellite radar image of the dome from the east. The resolution of the data is 2-3 metres. Image © DLR 2008.



False-colour satellite radar image of the dome from the west. The resolution of the data is 2-3 metres. Image © DLR 2008.

Annex C. Media coverage of the eruption

http://www.themontserratreporter.com/?id=1913980 - The Montserrat Reporter - Windows Internet Explorer



Satellite radar image showing changes caused by the explosion on 28 July 2008. Copyright (c) 2008, DLR. courtesy MVO

Scientists at the Montserrat Volcano Observatory (MVO) as well as the government and disaster preparedness authorities must be breathing easier at the volcanic activity which took place at the Soufriere Hills volcano early this week.

Residents on the flanks nearest to the volcano were given warnings early Monday morning. A Joint statement by H.E. THE Ating Governor and Honourable CHief Minister said: "We advise the evacuation of areas from Isles Bay Hill, Belham, Water Works, Happy Hill, Lower Friths, and parts of Old Town south of Loblolly Lane."

It was explained in the release as follows: "Scientists at the Montserrat Volcano Observatory (MVO) reported that a partial collapse of the dome at 11:30 pm on Monday July 28, 2008 sent pyroclastic flows down over Plymouth and into the sea, on the western side of the volcano."
The release which was issued about 4.00 a.m. Tuesday, said also that small explosions sent ash several thousands of feet into the air and that the eruptive episode lasted between 45 minutes and one hour.

Meanwhile the MVO acting director issued a brief report which confirmed: "There has been a partial dome collapse on the west side of the Soufriere Hills Volcano.

The collapse started at 11:27 pm local time on Monday 28th July 2008 without any precursory activity. Part of the western side of the lava dome collapsed generating pyroclastic flows that reached Plymouth and the sea.

There were also a few explosions from the dome during the collapse, with the largest at approximately 11:32 pm."

Some residents expressed concern as to the statement "without any precursory activity," finding it confusing since during the previous week there had been reports of some increase in activity at the Volcano. The MVO acting Director Roderick Stewart responded to the question. He said the statement is made in the context where: The activity takes places over a period of an hour or less before the event, i.e The time period can be more than an hour, up to several hours. The important thing is that there is no gap between the activity and the event; The activity increases in size over time; and there is no gap between the activity and the ensuing event, which could be the collapse, an explosion or a pyroclastic flow.

Later in the authorities reported that all emergency operations had been called off and since then the volcano has been relatively quiet.
However the MVO in its weekend report said: It has not yet been possible to establish the amount of material involved. Due to cloud cover, it has not been possible to establish how much of the dome has collapsed and if the dome has been made less stable by this eruptive event.

Until the stability of the dome can be established, it has to be assumed that there is an increased risk of collapses on all sides of the dome. There is an attendant increased risk of a pyroclastic flow traveling down to the Belham Valley and access restrictions have been imposed in the areas south of and immediately north of the Belham Valley as a precaution.

[CLOSE WINDOW]

Done Internet 100%

Annex C. Media coverage of the eruption

GOVERNMENT HOUSE PRESS RELEASE

NATIONAL DISASTER PREPAREDNESS, RESPONSE AND ADVISORY COMMITTEE

NDPRAC met on 5 August to review the level of volcanic activity following last week's eruptive event and to be informed of the status of emergency preparedness should there be further elevated volcano activity.

Chaired by HE the Governor, NDPRAC was informed by the MVO's Acting Director that radar satellite imagery indicated no significant deterioration in the stability of the dome since last week's event. However, there was an enlargement of the vent above Gages Wall. The Acting Director informed NDPRAC that the worst-case scenario in the near future is for another event similar in intensity to the one that occurred last Monday. More vigorous volcanic activity would be likely to be signalled by seismic activity.

Taking account of the scientific advice, NDPRAC decided that those people evacuated last week are now able to return to their homes.

James White, Director (Ag) of the DMCA presented the NDPRAC with an overview of emergency preparedness. To ensure an operational state of readiness, all components of the volcano emergency response plan are being reviewed; from warning cascade and evacuation to shelter and search and rescue. The review includes provisions already in place to deal with the demands of a potential large-scale evacuation, for example housing, education and social welfare. These will result in strategies and action plans to address deficiencies and immediate priorities.

Government House
Wednesday 6 August 2008

Annex C. Media coverage of the eruption

UNITED NATIONS
Office for Outer Space Affairs

United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER)

UN-SPIDER July 2008 Updates

Please forward this **UN-SPIDER Updates** to colleagues who might benefit from receiving the information.

If you would like to subscribe to this list please visit the following website:
http://www.ungiwg.org/cgi-bin/mailman/listinfo/unspider

1. Caribbean Region Taking Advantage of Space-based Solutions

A direct result of the recent "United Nations Regional UN-SPIDER Workshop: Building Upon Regional Space-based Solutions for Disaster Management and Emergency Response for the Caribbean" which was held in Barbados, from 8 to 11 July 2008, was the request for activation of the International Charter Space and Major Disasters to monitor the recent activity of the volcano in Montserrat (16.715N, 62.176W) on 29 July 2008. Mr. Rod Stewart, Acting Director of the Montserrat Volcano Observatory participated in the Caribbean workshop where he shared his expertise and learnt of the opportunities available for the Caribbean region. On his return he immediately had the opportunity to take advantage of what he learnt and to contact the people he met in Barbados to help Montserrat to deal with this new potential threat.

Information on the workshop can be accessed at:
http://www.unoosa.org/oosa/en/unspider/recentworkshops.html

2. UN-SPIDER Support to Wenchuan Earthquake Relief Efforts

UN-SPIDER received thanks from the China National Committee for Disaster Reduction (CNCDR) and the National Disaster Reduction Centre of China (NDRCC) for providing support to China during the recent catastrophic Wenchuan Earthquake which occurred on 12 May 2008. The thank-you letter specifically recognised that the support received from UN-SPIDER helped China "coordinate with international agencies to provide to us satellite images of the earthquake areas" and that this was "very helpful in our timely acquirement of first hand information for the disaster assessment." In particular they thanked UN-SPIDER Programme Coordinator, David Stevens, "who came to Beijing and provided useful suggestions about our work". The support received "played a unique role in assisting our estimation about the magnitude of damage and greatly empowered the rescue and relief efforts to reduce the casualties and damage. While expressing our gratitude to your institution for your timely and most needed support, I wish that we continue our close cooperation in application for space technologies in disaster prevention and reduction for benefiting the people."

Full story at:
http://www.unoosa.org/oosa/en/unspider/index.html

3. Visual Tools for BP's Crisis Managers

A Web-based tool combining 3-D satellite imagery and real-time weather data helps crisis managers at energy company BP make improved decisions. For years, Brian Audio, BP's geospatial team lead for the Gulf of Mexico, used a mishmash of tools, from satellite images to paper wall maps dotted with pushpins, to accomplish his work. There was room for improvement. "It's just a very intense process, and it lends itself perfectly to technology," Audio said. He and his colleagues now have a more advanced system to help them do their jobs. BP's Crisis Management System uses 3-D satellite imagery, real-time weather data, and a visual representation of the company's workers, their homes and corporate assets to deliver a visual assessment of what's happening where.

Full story at:
http://www.computerworld.com/action/article.do?command=viewArticleBasic&taxonomyName=networking_and_internet&articleId=320316&taxonomyId=16&intsrc=kc_feat

www.unspider.org

Annex D. User request form

User Request Form
(Affected area information)

To be filled by ODO Call ID 213	
1. Date and time of the call	**DAY 29 MONTH (Spell) JULY YEAR 2008** **TIME 04:45 LOCAL TIME ZONE UTC-4 UTC TIME08:45**
2. Name of the organization and caller Phone Fax Cellular phone E-mail to be used for call back	Montserrat Volcano Observatory, Mr Roderic Stewart 6644915647 Ext. 6644912423 Ext. Roderick Stewart [rod@mvo.ms]

3. Type of disaster

☐ flood	☐ storm/hurricane	☐ earthquake
☐ landslide	☐ fire	☐ oil spill
☒ volcano	☐ ice	☐ other (specify)

4. Geographical location	**5. Geographical Coordinates in Degrees, minutes, seconds**	
Region/Country name, approximate geographical location and surface extent. Region/country name:Montserrat Location From To Extent (km2) 50	a) Center Point Lat 16° 42' 54" N Long 62° 10' 33" W	b) Upper left Lat 16° 40' " N Long 62° 15' " W Lower right Lat 16° 46' " N Long 63° 8' " W

6. Approximate date/time of occurrence or predicted occurrence	03:28 UTC on 29 July 2008
7. Additional information on the disaster	Partial collapse of lava dome at Soufriere Hills Volcano, Montserrat. Pyroclastic flows affected Plymouth (evacuated for several years). Instability of the rest of the dome may cause further collapses which have the potential to impact on inhabited areas. Imagery is required for two purposes. 1) There is a need for imagery to assess the extent of the damage. 2) The observatory needs to know the topography of the lava dome to assess the source of this collapse and the likelihood of further collapses. Given the cloud cover, there is a need for frequent radar images.
8. Additional instructions (shipping instructions)	Mr. R Stewart, Acting Director, MVO is the end user. MVO has limited in-house SO expertise. Prof. G Wadge, ESSC, Univ. or Reading, will act as liason for data ordering and product suitability checking prior to delivery to MVO. Prof Wadge is chairman of the government Scientific Advisory Comitte and has EO expertise. email: gw@mail.nerc-essc.ac.uk tel: +44 118 378 6412

2/2

To be filled by ODO **Authorized User** ☐ **Cooperating Body** ☐ **Other** ☒ NOT AUTHORIZED

Authorized User/Cooperating Body: Fill the form as indicated above and fax it to +39-06-94-180 202. A completed form may additionally be sent as a backup via email to: charterops@disasterscharter.org

Annex E. Emergency Data Request Submission forms for the satellites tasked

International Charter Space and Major Disasters:
Emergency On-Call Officer Procedure

EMERGENCY REQUEST FORM – (common part)	
Date (dd/mm/yyyy) :29-JUL-2008	**Call_ID :213**

ECO on-duty	
Name	V.SHAILAJA NAIR
Agency	NRSA,ISRO
Phone	+91-040-23884461/+91-040-23088491
Fax	+91-040-23884424
Mail	shailajanair_v@nrsa.gov.in, vshaila@yahoo.com

Authorized User / Cooperating Body	
Name / Organization	
Address	
Phone	
Fax	
Mail	

End User / Agent	
Name / Organization	Mr. Roderic Stewart,
Address	Monteserrat Volcano Observatory
Phone	6644915647
Fax	6644912423
Mail	rod@mvo.ms

Type of disaster		
☐ flood	☐ storm/hurricane	☐ earthquake
☐ landslide	☐ fire	☐ oil spill
☒ volcano	☐ ice	☐ other (specify) _______

Affected area details		
Geographical location	**Geographical Coordinates in Degrees, minutes, seconds**	
Approximate geographical location and surface extent Location From To Extent (km2)	a) Center Point Lat …16……°…42…' 54….” (N) Long …62….° 10… ‘ …33” (W)	b) Upper left Lat …16°46' 0.” N Long …62° 15 ‘ 0” W) Lower right Lat… 16°40' 0” N Long 62° 08' 0” W

Comments or Special instructions
Due to the cloud cover over the area user requests for Radar data

Annex E. Emergency Data Request Submission forms for the satellites tasked

ESA Emergency Request Form (specific part)

ESA Emergency Request	Id	213
Date/time received at ESA		

ERS Scenes detail

Mission	Orbit	Track	Frame	Date (dd-mmm-yyyy)	New ? (Y/N)

ERS Product details

O RAW	O SLCI	O PRI	O Other

ENVISAT ASAR Scenes detail

Mission	Orbit	Swath (WS, 1-7)	Polarization (*)	Centr. Lat (N/S deg:min)	Centr. Long (E/W deg:min)	Date (dd-mmm-yyyy)
ES	33553		V	16:51N	62:07W	31-JUL-
ES	33674		V	16:29N	62:04W	08-AUG-
Archives						
requested						

(*) Polarizations: VV, HH (WS & IM Mode), HH/VV, HH/HV, VV/VH (AP Mode only).

Product details ENVISAT ASAR Narrow Swath (Compatible with archives data)

O IMS/APS (SLC)	O IMP/APP (PRI)	O IMM WSM (Medium res)

Delivery details

Target delivery date:			
Medium	O CD	O EXABYTE	☑ FTP pick

Recipient details (PM details are attached)

Destination	O AUTHORIZED USER	O END USER
or FTP pick up only * **PM e-mail gjag@bgs.ac.uk**		
User e-mail rod@mvo.ms		

Annex E. Emergency Data Request Submission forms for the satellites tasked

JAXA EMERGENCY REQUEST FORM (Specific Part)

International Charter on 'Space and Major Disasters'

Date and Time of Request	29 /07 /08 (MM/DD/YYYY) : 8:45 (UTC)

ALOS Data Request

New Acquisition

Sensor	Mode	AcquisitionDate (MM/DD/YYYY)	Path	Remarks
□PRISM	□OB1 □OB3			Pointing Angle (deg.)
□AVNIR-2	OBS			Pointing Angle (deg.)
☑PALSAR	□FBS □FBD □PLR □WB1	**07/30/2008 to 08/07/2008**		Off-nadir Angle (deg.) Polarization: □HH □VV (FBS/WB1) □HH+HV □VV+VH (FBD)

Archive Data

Sensor	Mode	Acquisition Date (MM/DD/YYYY)	Path	Frame	Remarks

Processing Level: All products will be processed at the Level 1B2 for AVNIR-2/PRISM and Level 1.5 for PALSAR unless specified below.

□AVNIR-2, PRISM: ______ ☑PALSAR:

Delivery Details: □Upload to the recipient's FTP server

FTP address:

Username: __________ Password:

□Download from JAXA FTP server

□Other:

Annex E. Emergency Data Request Submission forms for the satellites tasked

RADARSAT EMERGENCY REQUEST FORM (specific part)

Charter Space and Major Disasters

Date/Time received at CSA:	
CSA On-Call Officer:	**OCP:**

CSA Internal Use Only

Call_ID #: 213

Number of Acquisitions Requested:
Maximum 5 image frames)

First Frame: ☒ New Acquisition ☐ Archive Data

Cycle:1932 71.45335 | Relative Orbit Start Time:17:57:30.08 | Duration:14.82 | Beam:F2N

Gain Control: ☐ Automatic Gain Control ☐ Fixed Gain

Date & Time of Image (UTC): 04-Aug-2008

Second Frame: ☒ New Acquisition ☐ Archive Data

Cycle:1932 93.04434 | Relative Orbit Start Time:06:12:58.01 | Duration:14.80 | Beam:S2

Gain Control: ☐ Automatic Gain Control ☐ Fixed Gain

Date & Time of Image (UTC):06-Aug-2008

Third Frame: ☐ New Acquisition ☒ Archive Data **compatible archives requested**

Cycle: | Relative Orbit Start Time: | Duration: | Beam:

Gain Control: ☐ Automatic Gain Control ☐ Fixed Gain

Date & Time of Image (UTC):

Fourth Frame: ☐ New Acquisition ☐ Archive Data

Cycle: | Relative Orbit Start Time: | Duration: | Beam:

Gain Control: ☐ Automatic Gain Control ☐ Fixed Gain

Date & Time of Image (UTC):

Fifth Frame: ☐ New Acquisition ☐ Archive Data

Cycle: | Relative Orbit Start Time: | Duration: | Beam:

Gain Control: ☐ Automatic Gain Control ☐ Fixed Gain

Date & Time of Image (UTC):

Annex E. Emergency Data Request Submission forms for the satellites tasked

Call_ID# : 213

PROCESSING DETAILS:

Product: ☒ Path Image (SGF) ☐ Path Image Plus (SGX) ☐ Single Look Complex (SLC)

☐ ScanSAR Narrow (SCN) ☐ ScanSAR Wide (SCW) ☐ Signal (RAW)

Processing Remarks:

Media: ☐ CD-ROM ☐ Exabyte (2GB) ☐ Exabyte (5GB) ☒ Electronic - ITN

Data Format: ☐ CEOS ☐ MrSID ☐ TIFF ☐ GeoTIFF ☐ JPEG

Application: ☐ Geology ☐ Forestry ☐ Oceans ☐ Agriculture ☐ Ice

☐ Hydrology ☐ Other - specify:

DELIVERY DETAILS:

Who is to receive the data: ☐ Authorized User ☐ End User **PM will decide**

Type of delivery: ☒ FTP ☐ Courrier ☐ Other

FTP IP address: **PM will inform**

Login: Password:

Courrier special instructions:

Target Delivery Date:

Approved by CSA: **Date / Time:**

Comments:

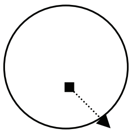
CSA Internal Use Only

Annex E. Emergency Data Request Submission forms for the satellites tasked

EMERGENCY **R**EQUEST **F**ORM FOR **SPOT** DATA (specific part)
International Charter on Space and Major Disasters

Requested image location details: <u>mandatory</u>

Area Name / Country :	Coordinates of image center point : (ONLY in Degrees, Minutes, seconds)
Montserrat	Latitude : 16 ° **42 '54" N** Longitude : **62° 10' 33" E / W** (Radius = 30 km)



New acquisition request (*):

First acquisition date : / / (d/m/y)
or ☒ As soon as possible

N.B. : the programming on this area will be activated for one week nominally

Requested image(s) :

Resolution/Mode	B&W (Panchromatic)	Colour (Multispectral)	Colour + SWIR band
2.5 m		✓	Not available
≤ 5 m			Not available
≤ 10 m			
≤ 20 m	Not available		

Pre-processing level : ☐ 1A or ☒ 1B or ☐ 2A

Additional instructions :

Archive data request (*):

Image identifier(s) : - 1: …latest archived date……………………………………………
(Sirius code + Shift along the tracl

Pre-processing level : ☐ 1A or ☒ 1B or ☐ 2A

Additional instructions :

(*) CAUTION: a maximum of 2 images in total (for example one archive plus one new acquisition) shall be ordered by the ECO, on the same area (If more images or extension of the target area, or extension of the programming period are needed, an agreement must be requested to CNES via SPOT IMAGE : **charter.disasters@spotimage.fr)**

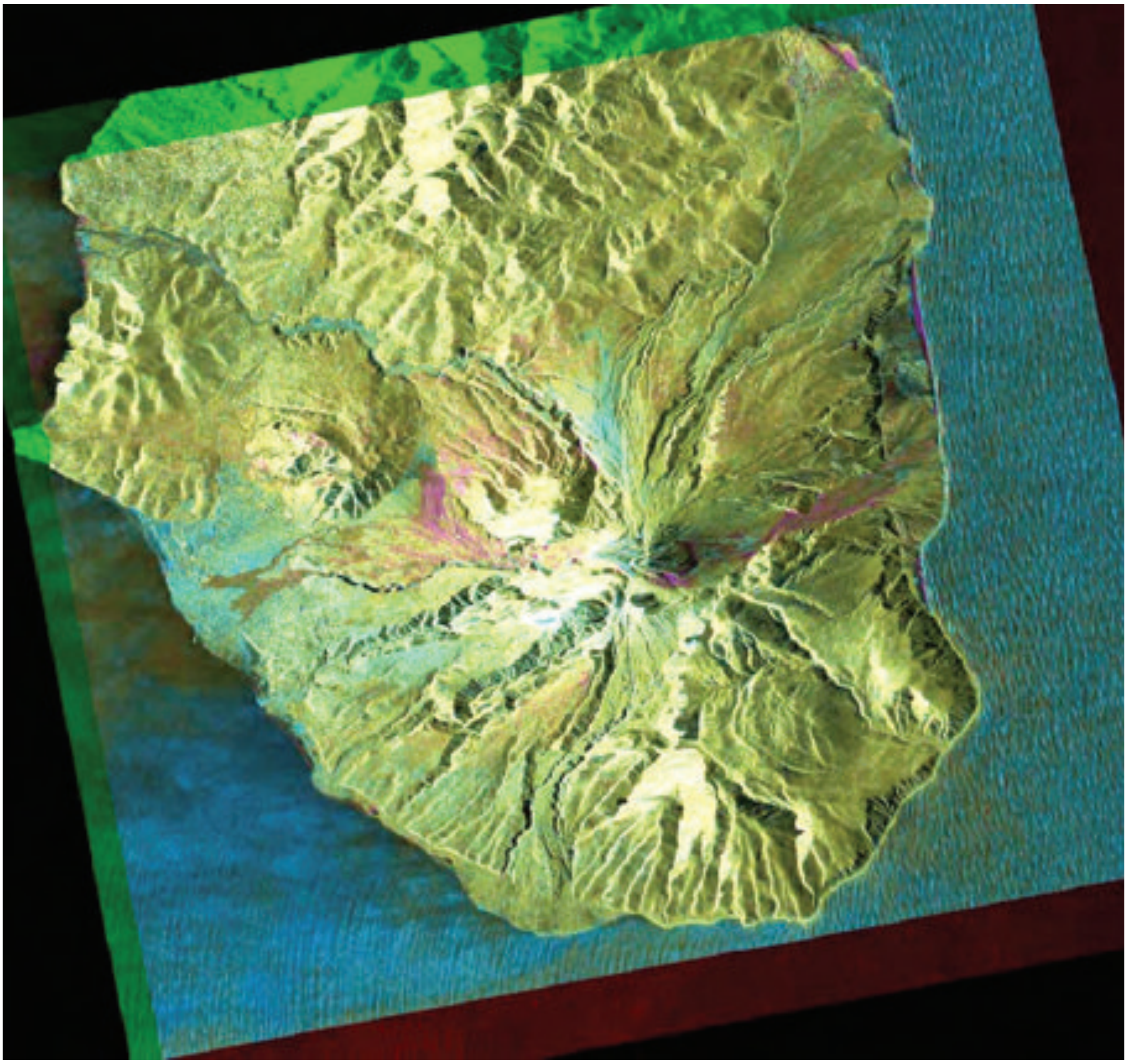
Media : Will be issued through FTP

Shipping to:

☐ Authorized User ☐ End User ☒ : (Other) **PM**
Gisela Ager (gjag@bgs.ac.uk)

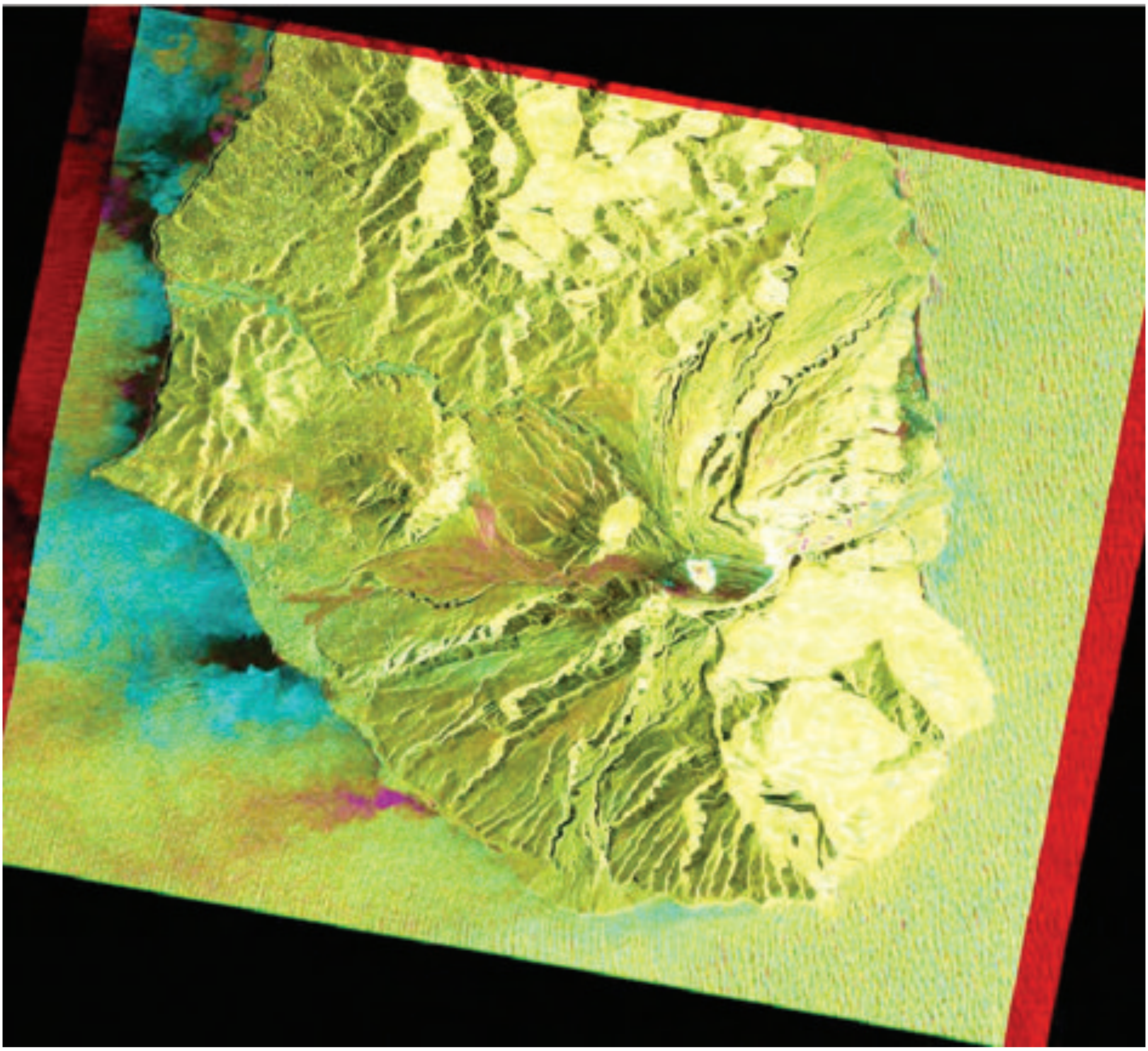
Additional information :

Annex F. Copy of final value added products



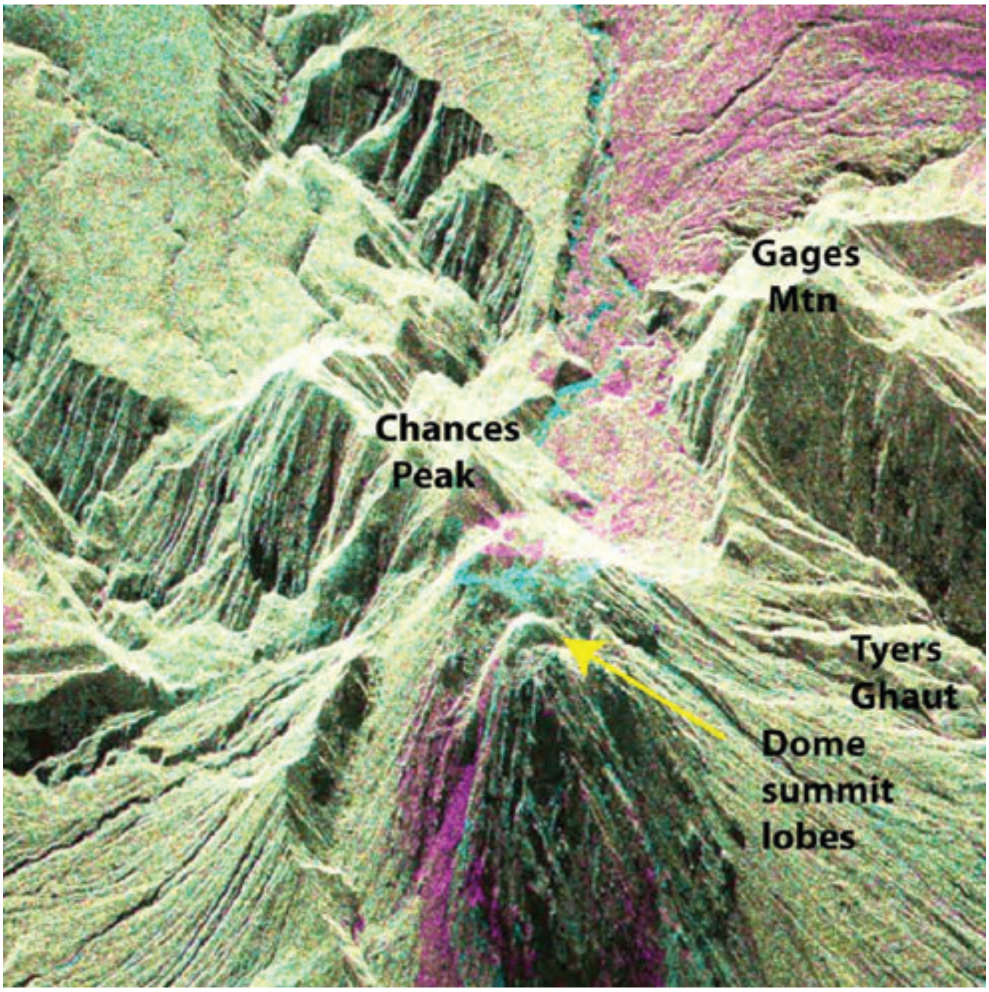
Change difference image of southern Montserrat constructed from two TerraSAR-X images collected in ascending (east-looking), spotlight mode on 9 October 2007 and 2 August 2008. (Image © DLR 2008).

Annex F. Copy of final value added products



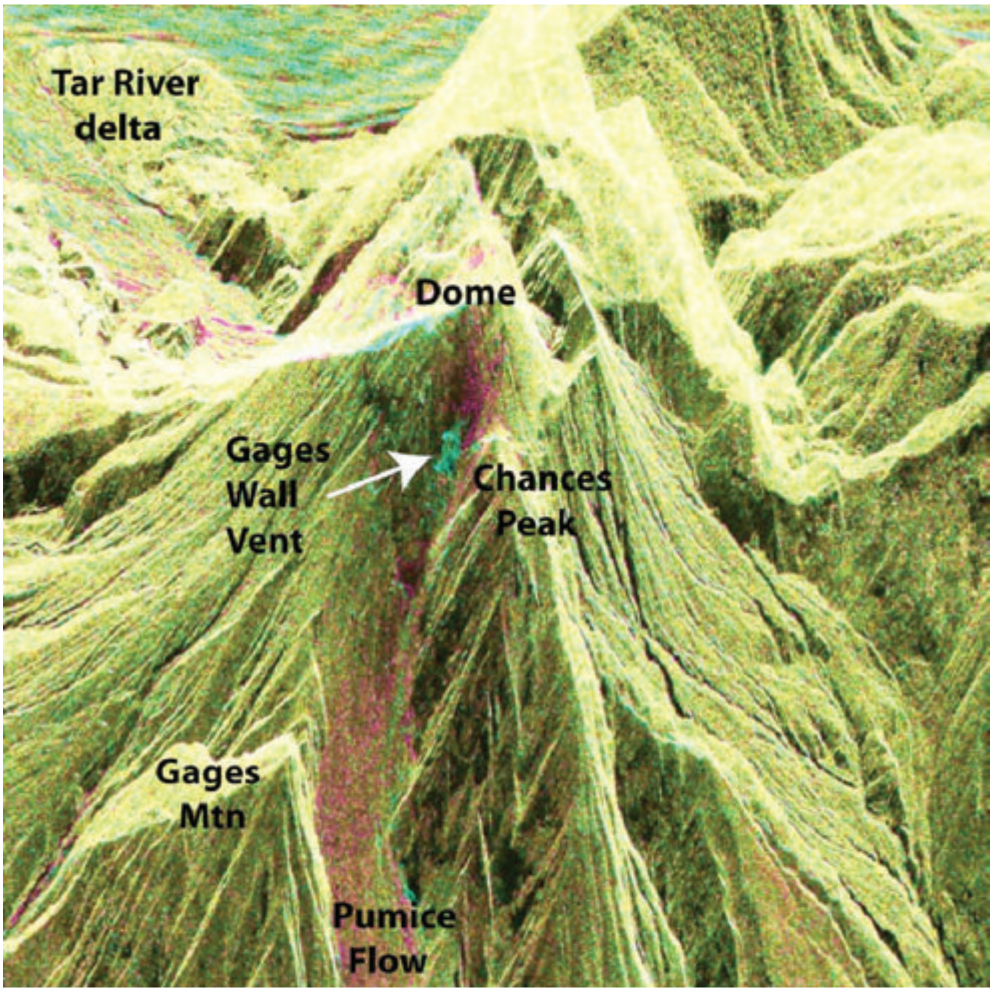
Change difference image of southern Montserrat constructed from two TerraSAR-X images collected in descending (west-looking), spotlight mode on 9 October 2007 and 2 August 2008. (Image © DLR 2008).

Annex F. Copy of final value added products



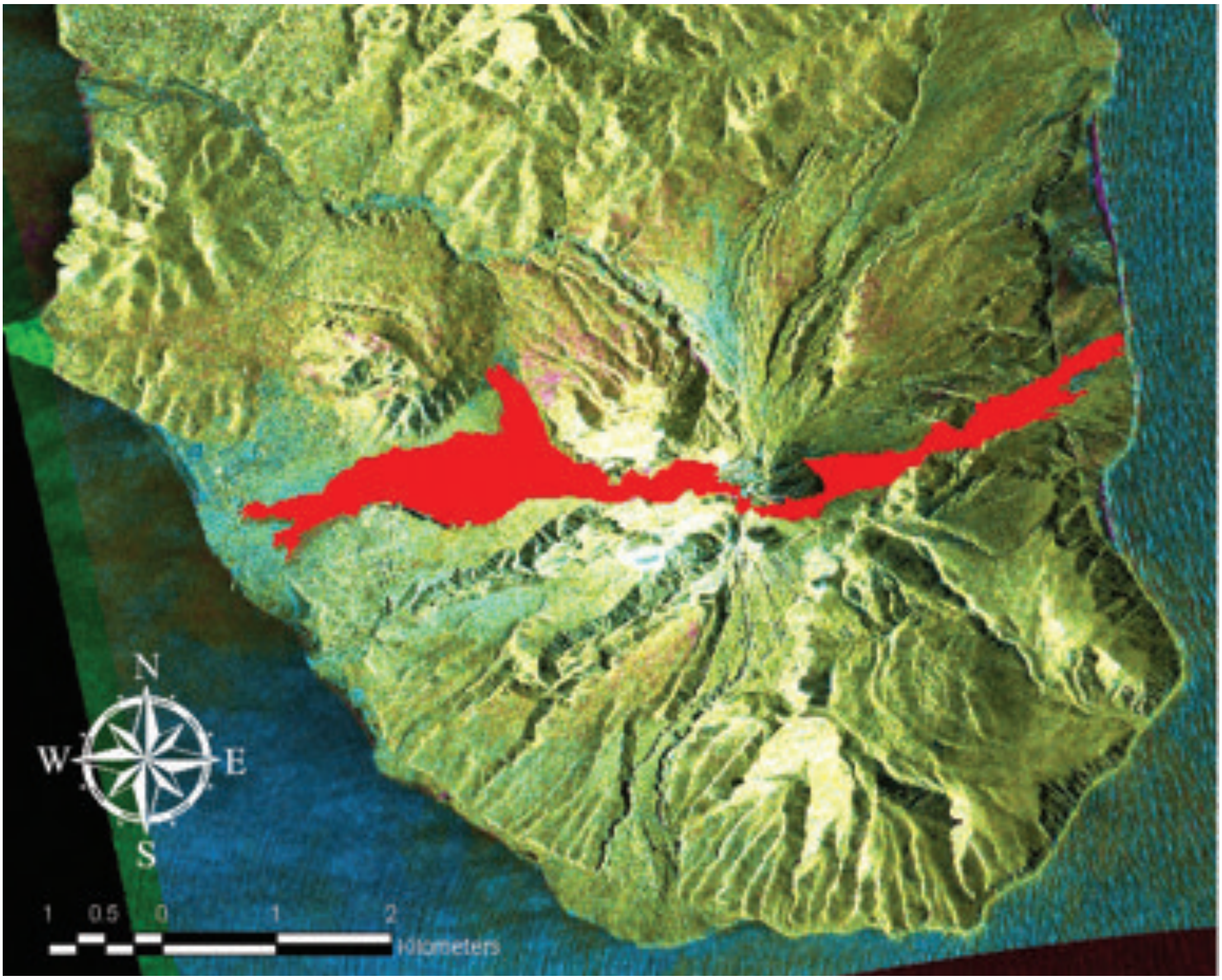
Change difference image of the volcano dome from the east. (Image © DLR 2008).

Annex F. Copy of final value added products



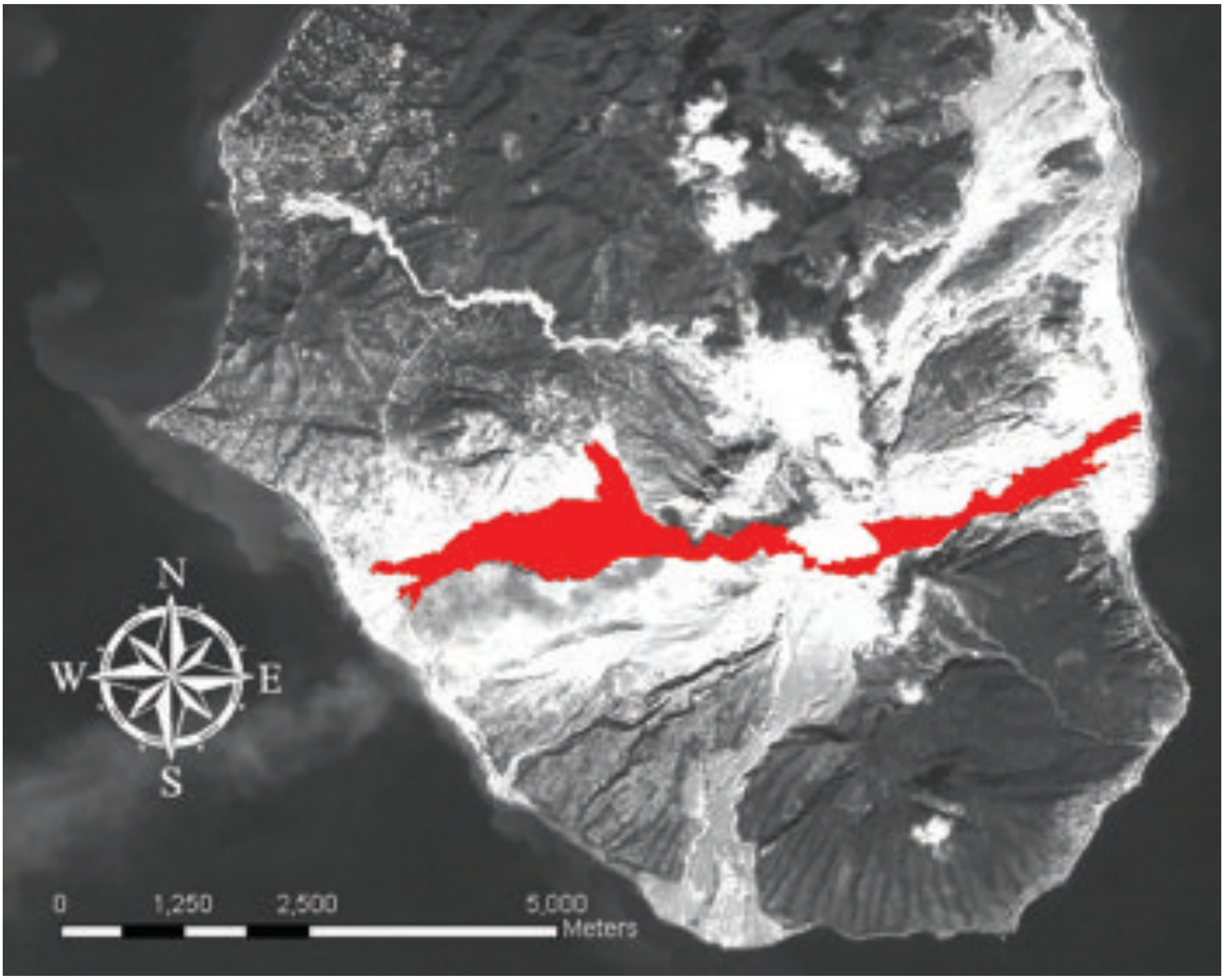
Change difference image of the volcano dome from the west. (Image © DLR 2008).

Annex F. Copy of final value added products



Mapped outline (red) of the column collapse pumiceous pyroclastic flow deposits of 29 July 2008 based on joint mapping using the TerraSAR-X change difference and SPOT imagery and superimposed on the TerraSAR-X image (courtesy of Y Legendre and J-C Komorowski). (TerraSAR-X image © DLR 2008.)

Annex F. Copy of final value added products



Mapped outline (red) of the column collapse pumiceous pyroclastic flow deposits of 29 July 2008 based on joint mapping using the TerraSAR-X change difference and SPOT imagery and superimposed on a panchromatic SPOT image (courtesy of Y Legendre and J-C Komorowski). (TerraSAR-X image © DLR 2008.)

References

HARFORD, C.L., PRINGLE, M.S., SPARKS, R.S.J. and YOUNG, S.R., 2002. *The volcanic evolution of Montserrat using 40 Ar/ 39 Ar geochronology.* In: Druitt, T.H. and Kokelaar, B.P. (eds) The eruption of the Soufrière Hills Volcano, Montserrat 1995 to 1999. Geological Society, London . Memoir 21, p. 93–113.

NORTON, G., HARFORD, C. and YOUNG, S. 2004. *Volcanic Geology of Montserrat, West Indies.* Field Guide. Montserrat Volcano Observatory, Montserrat, WI.

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