# MONTSERRAT VOLCANO OBSERVATORY

# GOVERNMENT OF MONTSERRAT

## Seismic monitoring and public safety
## June – August 1996

**Glenn Thompson**

**MVO Open File Report 96/30**

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## Executive Summary

This document summarises the seismic monitoring employed at MVO during the June – August 1996 period. It emphasises the role this played in the early warning system, which underpinned the safety of field teams and  general public.

# 1. Introduction

The most important responsibility of the Montserrat Volcano Observatory (MVO) is to alert the authorities (and the public) to escalations in volcano activity. Some hazards develop slowly, as the size of the dome increases. Others, such as a collapse of the a significant part of the dome can occur at any time, and could pose a threat to populated areas, or to aviation, within minutes. On the ground, this is mitigated by having an exclusion zone where people cannot live, though the possibility of a pyroclastic surge reaching populated areas can never be entirely eliminated. The largest the exclusion zone, generally the longer the time there is between an event initially at the dome, and it reaching populated areas.

Hazards to aviation are more difficult to mitigate. Changes in wind direction at different levels mean that there a fixed exclusion zone for aviation would be ineffective. Ash from some volcanic eruptions has travelled thousands of miles. And with long-distance aircraft travelling at typical speeds of 600 mph (10 miles a minute) every minute counts.

A vital requirement of monitoring any volcano is to enable scientists and technicians to make observations, setup and repair instruments and record data at locations within the Exclusion Zone. So the observatory must have a method of warning field teams of sudden, significant changes in volcanic activity, and of logging their locations should it become necessary to send out a search party.

For these reasons, MVO has to provide round-the-clock monitoring of the Soufriere Hills Volcano. The backbone of this operation is the real-time seismic monitoring performed in the hub of the observatory, the Operations Room. Here this whole operation is referred to as the MVO early warning system. In general, an early warning system is a term used to describe a system which alerts personnel to an event as it is happening, but (hopefully) before damage or casualties have been caused.

Even if these needs for real-time seismic monitoring did not exist, seismic monitoring is widely considered to be the most crucial technique for monitoring volcanic activity, on a par with direct visual observations. A variety of earthquake types are observed (VT, LP and hybrid), and can occur in swarms. Explosion signals have been recognised. Tremor (including harmonic and banded tremor) is commonly recorded. Surface processes such as rockfalls, pyroclastic flows and mudflows can be determined by their seismic signals. No other monitoring technique provides as much information as the analysis of the spectral characteristics and spatial-temporal patterns of these different seismic signals.

Given that seismic monitoring is so crucial to MVO operations and understanding this eruption of the Soufriere Hills Volcano, an attempt is made here to provide a snapshot of the status of the seismic monitoring at MVO in the summer of 1996.

# 2. The MVO early warning system

The are several components of the MVO early warning system:

## 2.1 The Analog Seismic Network

There are 10 seismometers in this network; they are located at Bethel, Hermitage, Windy Hill, Long Ground (2), Gages Peak, Chances Peak, St. Georges Hill, St. Patrick and Roches Yard. The voltage signal picked up by the seismometer is used to frequency modulate a carrier frequency which is then radioed back to the MVO via a sequence of transmitters and repeaters.

Each seismic station transmits on a different carrier frequency, and one of these is permanently monitored audially, to give an indication to control room staff of the current level of seismicity. All the radio signals are send to the discriminator, which is essentially a demodulator. Data is then sent to two systems; continuous paper drum records and to a PC-network for digital analysis.

## 2.2 Real-time analysis systems

Available in the Operations Room are three crucial real-time analysis systems.

Helicorders (continuous drum records) display seismic activity at four stations, usually Long Ground, Gages Peak, Chances Peak and Windy Hill. These are a crucial component of the early warning system. In addition, they are a very important record of activity, and are used to help identify triggered events, swarms, and tremor.

RSAM is a program which graphically displays the seismicity at each station on the network over different time periods, making it easy to see if seismicity is increasing or decreasing over periods of minutes, or even crudely estimate the source of an event.

There is also an audible tone, modulated by the amplitude of the seismic signal from one channel – usually Long Ground. This makes it very clear when a rockfall – or pyroclastic flow – signal begins, and alerts whoever is on duty in the Operations Room.

## 2.3 The Operations Room

The Operations Room is manned 24 hours every day. During normal MVO office hours (Monday – Saturday) it is manned by members of the seismic monitoring team (Team Seismic). At other times it is manned on a rota which all MVO staff (including Team Seismic) and visiting scientists partake in.

There are three night shifts: from 6pm – 10pm, 10pm – 2am and 2am to 8am. As no-one is usually in the field during the night, taking care of the helicorder records is the main activity. Occasionally however it may be necessary to alert the MVO Chief Scientist and the authorities if an increase in seismicity/volcanic activity is observed.

Operations Room duties include:

- warning field parties based on current seismic activity seen on drum records/PC-SEIS
- keeping records of the location of field parties
- logging observations made by field parties
- relaying messages between scientists/government officials/media
- helicorder records may need to be 'moved out' every 10 minutes in periods of high activity
- helicorder records must be changed at least every 12 hours and sometimes as often as every 90 minutes
- if there is a significant increase in the level of seismic activity, senior scientific staff must be informed

## 2.4 The Communications Radio Network

A communications radio network links the Operations Room with any MVO teams working within the exclusion zone at all times.

The repeaters for the radios are at Chances Peak (channel 1), Gages Peak (channel 3) and Airport(?) (channel 4). Channel 4 is for use when field teams are out east (Airport, Whites, Long Ground, Tar River). Channel 1 or 3 are superior for field teams out west (Plymouth, Amersham, Gages, Chances, St. Patrick) or north (Windy Hill, Cork Hill, Lees, Dyers, Farrels, Harris).

The most important document at the MVO is the Locations book. Field teams are required to radio in their intended or current locations every time they move to a new location. It is particularly important that they do this if they go east (Whites, Long Ground, Tar River) or up (Chances Peak or Gages Peak). Control room staff then give reports as soon as any significant increase in seismic activity is detected, corresponding to a large rockfall or pyroclastic flow.

Field teams often call for regular updates when entering particularly dangerous are as such as Tar River.

When field teams make important observations, they radio these in and they are recorded in the Observations book. These observations assist the MVO chief in writing the daily reports. They are also a useful reference, particularly for discerning large rockfall signals from pyroclastic flows in the seismic data at a later date.

When a large signal is seen on one or more drum records, field teams are warned by radio that a large rockfall or pyroclastic flow may be in progress. Surface processes such as these may pose an immediate threat to people on the active flanks of the volcano.

The communications radio network underpins the safety of field teams. It means that should a pyroclastic flow or explosion be initiated, speedy notification from the Operations Room will dramatically improve the chances that MVO staff can evacuate themselves (the helicopter is normally present with its engine running at the most proximal field sites) before such an event overtakes them.

### 2.5 Warning the public and the authorities

Given that there is an exclusion zone, there should be a window of at least a few minutes in which MVO can call the Governor and Chief Minister, and sirens can be sounded to alert the public. The public are trained to switch on radio ZJB when the sirens go.

Likewise, its likely there will be a period of at least several minutes before ash reaches altitudes where it can pose a hazard to aviation. This should provide ample opportunity for MVO staff to contact aviation authorities.

## 3. Non-real-time seismic monitoring

After demodulation, seismic data from all 10 stations is fed into the USGS PC-based monitoring system (where it is digitized). This comprises 4 separate computers: PC-SEIS, RSAM, SSAM and BRAINS (a fifth PC is used to acquire data from tiltmeters). These are used for earthquake detection, visualization of real-time seismic amplitudes, visualization of real-time seismic spectra, and data analysis respectively.

### 531 Event triggering

The most important part of this computer system is event triggering. PC-SEIS is an earthquake detection program using simple short-term-average versus long-term-average ratios to detect events. When a certain threshold condition is satisfied on at least 4 stations data is archived to discrete event files, until a ‘trigger-off’ condition is satisfied. Not all events identified on the drum records are detected by the triggering algorithm, but this method provides a constant baseline which is independent of human interpretation, which is important for record purposes.

That baseline can however be affected by station outages, changes in the network topology, or quasi-continuous signals such as tremor or storm-related signals, or noise. During episodes of banded tremor the event detection algorithm is particularly poor; the drum records are more reliable. Since event triggering relies on detecting a sharp increase in the seismic signal, earthquake event counts can give a poor representation of seismicity when banded tremor or storm signals are present.

### 3.2 Real time seismic amplitude measurement (RSAM)

The seismic energy is integrated in 10 second, 1 minute and 10 minute bins and displayed on the RSAM computer, giving a continuous visual record showing of the seismicity. This aspect of the RSAM system was mentioned in 2.2 above.

RSAM plots of a few days activity are a good way of detecting periodicities in volcanic phenomenon, and this was the first method to show the banded near harmonic tremor first seen by Rod Stewart on 27 July. The first obvious period of harmonic tremor was not observed until about 23:00 29 July, and it was not identified as banded tremor until 1 or 2 August. Large rockfalls and pyroclastic flows are seen as spikes in this data [Thompson, 1996]. This plotting is done with BOB, described in 3.5.

### 3.3 Spectral seismic amplitude measurement (SSAM)

This is a rather low resolution measurement of the frequency content of the incoming signal. A much better frequency analysis can be performed by loading the data into PITSA.

### 3.4 Event classification (BRAINS)

Files corresponding to events detected by PC-SEIS are transferred to BRAINS using a script called 'transfer'. Operations Room staff (usually, but not always Team Seismic staff) analyse the time series (but not the frequency spectra) of these events, and classify them using the BUDSPICK software. Unfortunately this does not provide any mechanism for logging event classifications and so the event time, classification and analyst initials are written to the Events book (one line per event). The four types of volcano-seismic event are: rockfalls, hybrids, VTs and LPs:

- Rockfall signals are indicative either of rockfalls/landslides or pyroclastic flows. The signal increases fairly rapidly and decays slowly, but there are large variations on this.

- Hybrids swarms appear to correlate with periods of rapid dome growth and so hybrids probably indicate effusion of magma. Hybrids usually begin with a very short high frequency phase which is easy to overlook, then rapidly build to a very low frequency (2-3 Hz) phase which decays approximately exponentially and changes fairly abruptly to a high frequency phase once again.

- VTs correspond to rock fracturing. VTs often appear in swarms; when these events are located they usually are found to originate from a small region some way below the volcano, indicating that magma is rising towards the surface along new or blocked pathways. VTs have a very impulsive start, are very high frequency, and usually decay very rapidly.

- LPs appear to correspond to degassing or gas emission from a vent. They are basically monochromatic, having a dominant frequency between 1 and 2 Hz, and are symmetric, building and decaying slowly. The explanation for their monochromatic nature is most likely that the degassing sets up a resonance within a length of the volcanic conduit.

This classification scheme generally follows that of Lahr et al., [1994]. This is not surprising, as some of the authors of that paper were part of the USGS team that responded to the Montserrat crisis in 1995, and helped train MVO seismic analysts (as well as installing the analog seismic network and PC-based data analysis systems. There was some departure from the Lahr et al., [1994] scheme though, with some events that these authors would classify as an LP even though it had a short high-frequency onset, generally being classified as a hybrid at MVO.

The other type of event seen are regional earthquakes associated with the Caribbean subduction zone.

The continuous background signal includes volcanic tremor, ocean microseismic noise and electronic noise. Banded tremor has been observed at this volcano and it is the most important seismic phenomenon yet observed [Thompson, 1996]. This banded tremor has been observed to correlate with intense periods of degassing, but appears as the merging of hybrid events. There also appears to be a correlation between high level tremor and large rockfalls or pyroclastic flows. Unfortunately because it is a slowly varying signal, banded tremor rarely 'triggers' the PC-SEIS event detection algorithm. Since there is no archival of the raw continuous seismic data from the analog seismic network, no recordings of banded tremor have been available for analysis except for helicorder records, making spectral analysis impossible.

Classifying events is an art and nothing beats experience. However some general rules are:

- Concentrate on stations where the magnification is close to 1.00x. This indicates a strong signal and it is therefore more likely that the signal to noise ratio will be high, and so the recorded waveform is more accurate. Any stations with magnifications above 3.00x should be totally disregarded. If all magnifications are high, the 'event' is probably just noise.

- Always check against drum records if in doubt. The waveform is usually recorded more faithfully on the drum records: computer data has been modified by analog to digital conversion and filtering, which alters the waveform.

- Check the arrival times! If the 'event' occurs on different stations at times different by more than a few seconds, then there must be more than 1 event, unless it is an air-wave.

- Make sure the event is recorded on more than 1 station. Telemetry noise is a particular problem with the analog network telemetry. Signals are often recorded which look like VTs, but are in fact just short bursts of telemetry noise. There are also the as yet unidentified 'plinks', which Graham Ryan has been studying.

**3.5 Integrated Data Analysis (BOB)**

Logged events (recorded in the Events book) are counted daily and recorded in paper records and in a computer file (quakes.dat). A separate record of triggered rockfalls is kept, again on paper and on computer (rockfall.dat), with the duration and amplitude measured from the Long Ground drum record. The daily event count records is continuous from January 3rd, and the rockfall logging record is continuous since May 10, though in periods of high activity it is difficult to keep these records up to date. However, the effort is worthwhile since these data, complemented by the RSAM data, provide the most quantitative measure of volcanic activity.

The BOB software, which is also on the BRAINS PC, is simple tool for analysing tabular data, and is the main tool for graphing daily earthquake counts (from the quakes.dat file) and rockfall durations (rockfall.dat). It can also read the binary files produced by RSAM, and thereby is the main tool for analysing continuous seismicity. Furthermore, it is common practice at MVO for other datasets, for example from COSPEC, or from estimates of dome volume, to be stored as tabular data files on BRAINS. BOB commands allow scripts to be developed by non-programmers, and these can be linked to icons stored on the desktop which when double-clicked, will then display the latest version of a particular plot, which may include, for example the rockfall counts compared with the COSPEC measurements for the last 4 months. BOB therefore is a limited but effective integrated monitoring software.

# 4. Discussion

Overall, the USGS PC-based seismic analysis system provides a simple but effective 'off-the-shelf' monitoring system which can rapidly be installed at any volcano observatory. It principle drawbacks are probably: (1) the lack of a spectral analysis tool, to assist in event classification, (2) the lack of a relational database, or indeed any computer-based logging of event classifications, (3) the lack of an effective data archival module. Nevertheless, it is an excellent tool for real-time monitoring (an alarm program is also included, but not used presently at MVO since the Operations Room is always staffed, and thus it is not discussed here).

Probably the biggest factor affecting the effectiveness of the early warning system is the rapid turnover of MVO staff. MVO still feels like it is in crisis mode, with a team from the Seismic Research Unit, local technicians, and a continual flow of scientists and students from universities in the UK and elsewhere hired by the British Geological Survey. The Chief Scientist changes every few weeks. And different groups seem to not entirely accept the presence or viewpoints of others at certain times. The lack of continuity might mean that some of the individuals who participate in the Operations Room rosta are not comfortable with that responsibility. Nevetheless, there did not appear to be any problems which in any way compromised safety at any time.

## References

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