Vulcanian Explosion Dynamics in 2008-09 at Soufriere Hills Volcano, Montserrat, from Strainmeter Data

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Vulcanian Explosions on Montserrat

The Soufriere Hills Volcano has been erupting for 14 years, with 3 long periods of extrusion separated by 3 main pauses. The last pause ended on the 29th of July, 2008, when few days of seismic activity was followed by a big explosion. After a period of relatively low activity, there was an explosion on 3 December without precursory activity. Three smaller events occurred on the next days (two events on the 4th and one on the 5th), marking a new period of extrusion. The increase of seismic and visual activity lasted until explosions on 3 January.

figure 1 : Eruption plume of 3 January 2009 as seen from Montserrat Volcano Observatory.

Calipso strainmeter and barometer array

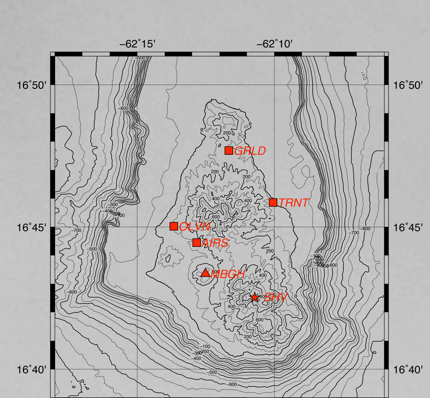

figure 2 : Map of Montserrat with Calipso stations (square) and the broadband seismic station (triangle) used in this study.

The 2008-09 events which occurred in Montserrat were recorded by strainmeters and barometers from the CALIPSO Consortium network. CALIPSO features an integrated array of specialized instruments in four strategically 200 m-deep-boreholes installed to investigate the dynamics of the Soufriere Volcano magmatic system. We present here volumetric strain observations of these explosions from one station (AIRS, located 5.4 km from the lava dome) that we compare to seismic data recorded by the broadband seismic station on nearby St Georges (MBGH).

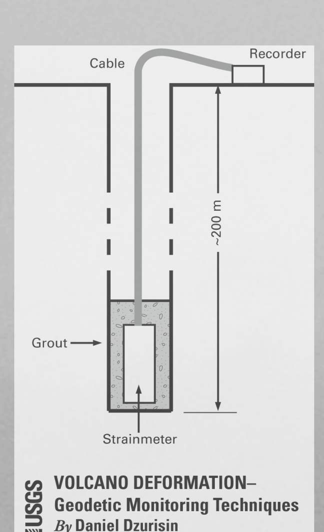

figure 3 : Installation for a borehole strainmeter.

The dilatometers are able to record strain change as small as 1 nanostrain, in periods from DC to about 50 Hz, although our data is limited by the sampling frequency of 50 Hz. The microbarometer is sampled at 1 Hz.

Dynamics of the Explosions

Strainmeter and barometer data present some similarities. The dilatometer is sensitive to variations of atmospheric pressure which propagate down from the surface. In order to have a strainmeter signal reflecting only the underground source effect, we remove the effect of air pressure variation on strainmeter data using a linear relationship in our frequency of interest.

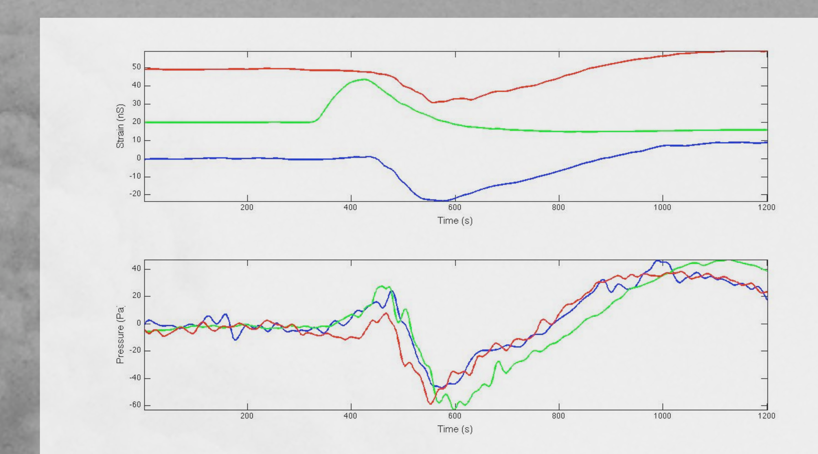

figure 4 : Raw strainmeter and barometer data for the 3 main events of 2008-09 (29 July (red) and 3 December 2008 (green), second event on 3 January 2009 (blue)) recorded at AIRS.

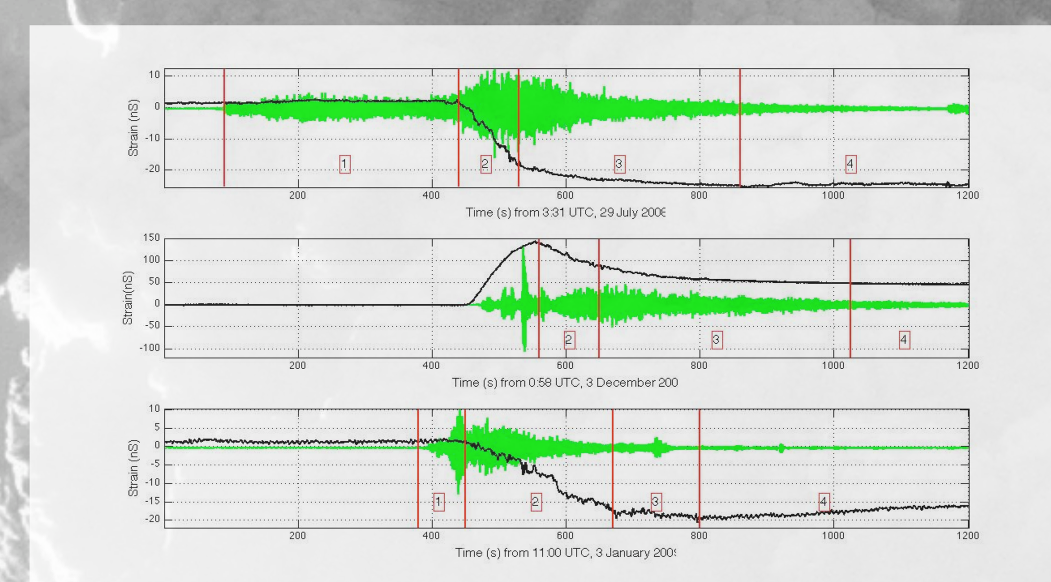

figure 5 : Strain signal recorded at AIRS corrected from variations of air pressure for the three main events of 2008-09 with their respective seismic signal from MBGH, the nearest seismic station. See text for explanation on the different stages.

The three main events which occurred on 2008 and early 2009 (29 July, 3 December, 3 January) allow us to describe typical strainmeter signals associated with Soufriere Hills Volcano explosive activity. The explosion patterns comprise several phases : 1) a short transition between the onset of disturbance and the beginning of a clear strain step ; 2) a quasi-linear step accounting for the majority of strain change ; 3) a continued gradual decline of strain to a minimum value ; and 4) a strain recovery phase. The downwards strain step was caused by the vigorous fragmentation and evacuation of the conduit which led to a contraction of the source recorded by the dilatometer. The 3 December event shows a first upwards step which is interpreted as rapid exsolution-caused pressurization of the conduit magma triggered by decompression from a partial dome collapse. The sudden expansion of the source preceded the explosion itself.

In the past, explosion phases have been interpreted mainly from seismicity, but the strainmeter data reveal new insights and indicate that interpretations based on seismicity alone have pitfalls. Here, we examine the explosion of 29 July 2008, showing low frequency (0.5 - 1.0 Hz) and high frequency (> 2 Hz) filtered seismic data, and compare it to *strain rate* data. The precursory stage reveals an initial burst of low frequency energy for 10-20 s about 5 minutes before the clear explosion strain pulse. The low frequency seismic signal rises gradually accompanied by strain for about 50 s prior to the clear onset of high strain rate and a sharp pulse of low frequency seismicity. There is a suggestion of three pulses of low frequency seismicity, with the second pulse roughly correlating with a second weaker strain rate maximum, and the third accompanying the reduction of strain rate to a base value, with moderate seismicity lasting for another ~100 s after the strain pulse and indicating residual evacuation. Pulsing of low frequency component is attributed to resonance of seismic waves in the conduit. The fragmentation and contraction of conduit walls is completed within the duration of the strain rate pulse. The seismic pattern shows that a longer period of time is required for the eruption mixture to be evacuated. During the second low-frequency pulse, the high frequency signal builds up, indicating ballistic impacts and the generation of pyroclastic flows. The seismic signal is protracted by pyroclastic flow runout.

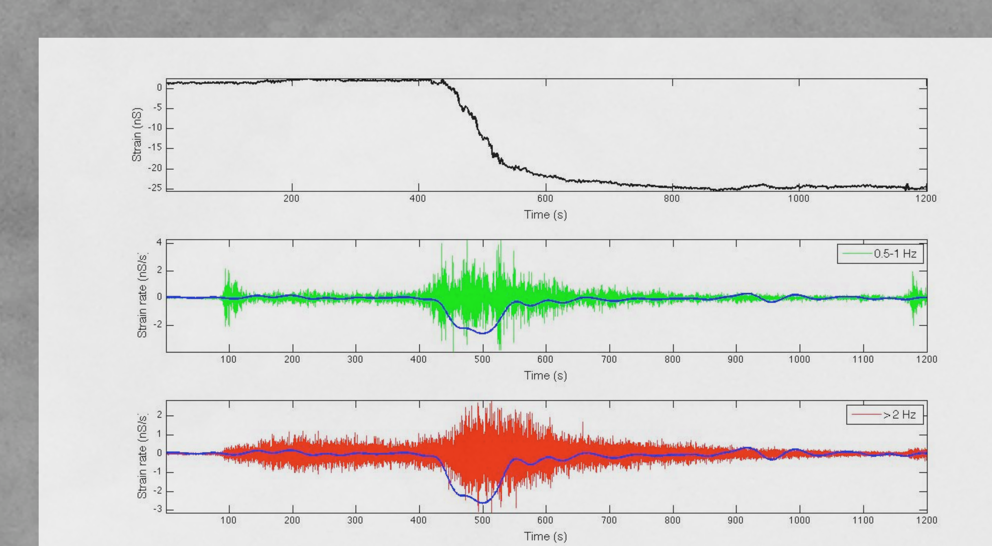

figure 6 : Strain step at AIRS for 29 July explosion (upper panel). Corresponding strain rate plus filtered low frequency seismicity (middle panel) and high frequency seismicity (lower panel).

Discussion - Conclusion

Activity at Soufriere Hills Volcano in 2008 and early 2009 was divided in two types of events with typical strainmeter signals. All of them were explosions with the same waveform in their barometer signal but the 3 December event was certainly triggered by a small dome collapse clearly visible on the strain signal. When seismic data are difficult to interpret, as it is the case for 29 July because of an intense period of seismic activity preceding the explosion, studying strain data may help to understand the dynamics of such big events.

Strain data may also help to ameliorate hazards for aviation if we find a relationship between strain and plume height. We studied then the smaller events of 4 and 5 December 2008, an early event on 3 January 2009, and three other events on 13, 14 and 15 July 2003 (just after a major dome collapse).

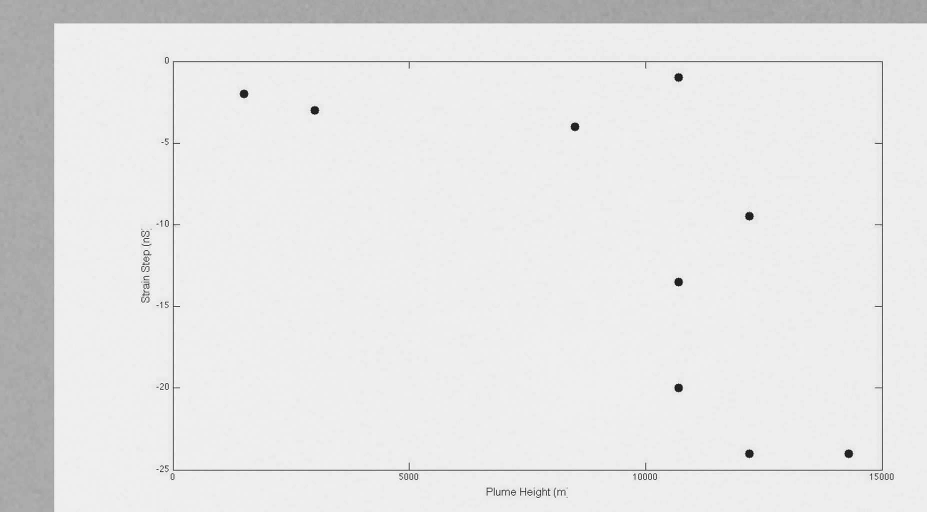

figure 7 : Corrected strain step recorded at AIRS against plume height for the 2003 and 2008-09 explosions. The 3 December event is omitted because of its complicated mechanism.

Then, we use plume heights estimated by NOAA and there is a logical trend indicating that events with high plumes in general have also a big strain step, but there is a caveat. Several explosions were also accompanied by column collapse and generation of pyroclastic flows, contributing to the strain step recorded. Then, not only we will understand the dynamics of the events, but also we will be able to improve estimates of pyroclastic flows if we find an empirical relationship between the volume of ejected material and the strain step recorded.

References

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