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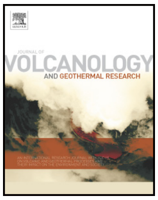

The roar of Yasur: Handheld audio recorder monitoring of Vanuatu volcanic vent activity

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ABSTRACT

We describe how near-field audio recording using a pocket digital sound recorder can usefully document volcanic activity, demonstrating the approach at Yasur, Vanuatu in May 2014. Prominent emissions peak at 263 Hz, interpreted as an organ-pipe mode. High-pass filtering was found to usefully discriminate volcano vent noise from wind noise, and autocorrelation of the high pass acoustic power reveals a prominent peak in exhalation intervals of ~2.5, 4 and 8 s, with a number of larger explosive events at ~200 s intervals. We suggest that this compact and inexpensive audio instrumentation can usefully supplement other field monitoring such as seismic or infrasound. A simple estimate of acoustic power interpreted with a dipole jet noise model yielded vent velocities too low to be compatible with pyroclast emission, suggesting difficulties with this approach at audio frequencies (perhaps due to acoustic absorption by volcanic gases).

1. Introduction

The sound of volcanic eruptions can be usefully diagnostic of conditions in the vent and/or magma conduit (e.g. Woulff and McGetchin, 1958; Johnson et al., 2003; Vergniolle et al., 2004; Johnson and Ripepe, 2011; Fee and Matoza, 2013; Garces et al., 2013). Most recent work, however, has focused on infrasound, since this dominates the output from large volcanoes and is transmitted most effectively over long distances. However, at short range, audible sound is still informative, and can be recorded with very compact consumer recorders.

We explored this approach during a visit to the Yasur volcano on Tanna Island, in Vanuatu. Yasur (Fig. 1) is a small scoria cone volcano (361 m above sea level) at the eastern side of Tanna, has continuous Strombolian to Vulcanian activity, and is responsible for the emission of some several hundred tonnes of SO_2 per day into the atmosphere (e.g. Bani and Lardy, 2007). The volcano currently has three vents, labeled (south to north, A, B and C).

The system used for our acoustic investigation, with a specification typical of many consumer digital audio recorders, is the TEAC VR-10 (TEAC Corporation, Japan). This pocket-sized unit (56 g, 12 × 4 × 1.5 cm) records audio in a range of data formats (e.g. MP3). For maximum fidelity, we recorded data in an uncompressed (PCM) format sampled with 24 bits at 48 kHz; at this sample rate the specification for the unit is of a fairly flat response (+1 dB/−3 dB) over the range 20 Hz–22 kHz (thus no frequency-weighting to compensate for the spectral sensitivity of human hearing, such as A-weighting, is applied) The unit will operate for roughly 2 h, limited in this instance by the life of 2 AAA batteries (other similar products may have better performance in this respect). The 1.5 h of data acquired in our experiment filled about 1.5 GB of the 2GB memory card installed—recording in a compressed format, and/or at a lower sample rate or resolution would require less memory but with some minor loss in quality. While a consumer audio recorder such as this does not record infrasound (which has been extensively used to study volcano dynamics—even from hundreds of kilometers away e.g. Le Pichon et al., 2005) we show in this paper that such equipment can offer a useful record of activity when sited in the immediate vicinity.

The recording was initiated and the recorder was installed on the ground near the rim (Figs. 1, 2) and left in operation for 90 min while near-infrared observations were performed (two 45-minute recordings were made, only the first is analyzed here). Winds of ~6–10 m/s were noted (strong enough to fly a kite), and caused appreciable wind noise. The data, on a micro-SD card, were transferred to a laptop PC. The resultant 500 MB audio file and an accompanying short near-IR video are available at http://www.lpl.arizona.edu/~rlorenz/vanuatu.

2. Spectral analysis and vent velocity

Initial examination of the data was performed with the flexible and powerful freeware software package Audacity (audacity.sourceforge.net). Visual examination of the raw sound waveform was unpromising, with

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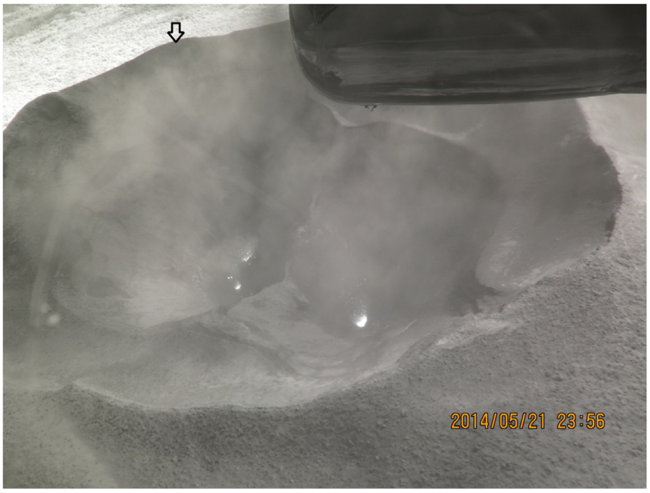

Fig. 1. Yasur observed from the air, thanks to a detour for this purpose by Air Vanuatu at our request. The image is taken with a near-IR camera (Canon G16 with an 830 nm longpass filter), which readily detects the thermal emission from the three vents and cuts effectively through the steam in the crater. The three vents are clearly seen: the image is looking towards the northeast, so the uppermost vent is C, and the rightmost is vent A. The location of Fig. 2 and the audio monitoring station is indicated with an arrow. Note the bright terrain at the upper part of the image—lush vegetation is strongly reflective in the near-IR. Photo: E. Turtle/R. Lorenz.

a strong continuous pseudorandom fluctuation; it was, however, easy to tell on replaying the sound when an eruption occurred (and some short video recordings made at the time confirm the association of the sound with an eruption). Whereas the wind noise, which dominates the waveform, is heard as a low flutter, the eruptions are easy to detect as a whooshing roar, rather similar to a jet aircraft, as noted by Woulff and McGetchin (1958) and also discussed (in an infrasound context) by Matoza et al. (2009) Viewing the audio data as a spectrogram (Fig. 3), it is easy to pick out the explosions, which may feature blast waves (Marchetti et al., 2013). We therefore examined the power spectrum of the audio signal in the intervals between such explosions—see Fig. 4.

The whooshing/roaring sound is dominated by sound around 263 Hz, with a distinct second tone at 514 Hz. Contrary to the monitoring of some volcanoes, where it has been reported that infrasound monitoring was most effective with low-pass filtered acoustic signals (e.g. Johnson et al., 2003), we find that in the presence of wind noise while being relatively close to the vent, in fact high-pass filtering is most effective at isolating the vent sound. Note that our instrumentation, covering ~20 Hz to ~20 kHz, is not sensitive to infrasound of a few Hz, which may dominate the acoustic emission overall and may be controlled by the vibration of a bubble in the magma conduit—see Vergniolle et al. (2004). Further discussion of the audio spectrum of volcano sound is presented in Fig. 2 of Matoza et al. (2010) and in Fig. 2 of Fee and Garcés (2007). The red spectrum of wind noise is discussed by Raspet et al. (2008) who note the strong roll-off towards higher frequencies.

Fig. 2. Observing the easternmost vent (C) in Yasur near sunset. The sound recorder is visible at the bottom of the photo. Photo: R. Lorenz.

Our first hypothesis was that the dominant audible frequency of 263 Hz is an aeolian tone (in essence, a whistle) determined by the vent diameter and velocity (see also Matoza et al., 2010). Crudely, we estimate the vent velocity as follows: we assume that the peak emission frequency f has a Strouhal number St = fD/U, in common with other aeroacoustic situations, of ~0.2, and thus f ~ 0.2U/D where D is the vent diameter in m and U is the flow speed. It follows, then that the vent velocity (m/s) here is ~5*263D. Assuming a vent constriction diameter of ~0.5–1 m, the exhaust velocity would be 500–1000 m/s. This seems implausibly high as it is strongly supersonic (indeed, the vortex shedding characteristic of aeolian tones may not occur in supersonic flow). While supersonic flow leading to blast or shock waves are encountered in volcanic explosions (including at Yasur—Marchetti et al., 2013), it seems unlikely that such flow can be sustained at a small vent. Further, no shock diamonds or other flow features (seen in supersonic jet engine exhausts) were observable. An additional acoustic feature associated with supersonic flow is a 'crackle' noise, most obvious as a strong positive skew (Fee and Matoza, 2013) in the waveform (lots of high, narrow positive peaks in the pressure signal, offset by wider, shallow troughs). We did not see evidence of such skew in the waveforms, nor indeed did the noise seem 'crackly' to the ear (we are familiar with such sound from several space rocket launches and jet fighter displays at airshows).

Although we are not aware of any in-situ measurement of vent velocities at Yasur, small pyroclasts advected in the vent flow do serve as tracers which establish a minimum gas speed (larger clasts accelerate too slowly in the flow). Since we observed bombs thrown to heights of 20–40 m, it follows that the exhaust velocity must be at least 30 m/s. We acquired visible and near-infrared video records, typically a minute in length but at conventional frame rates (24 frames per second): an example is at http://pirlwww.lpl.arizona.edu/~turtle/photos/PortVila-TannaYasur1405/index.html. While no formal analysis of the video record was made, the length of streaks in some frames suggests launch velocities reaching 70 m/s. Examination of the video suggested an interval between exhalations of 1–4 s (median 2.4 s) and a duration of each of 0.5–2 s (median 1 s). Thus the vent flow was active about 25–33% of the time. Recently, Gaudin et al. (2014) have used particle tracking velocimetry—i.e. analysis of high speed (500 frame per second, 14 s long) video acquired in 2011 to measure pyroclast velocities from the Yasur vents—their velocity histograms show a modal velocity of ~20 m/s, a median of ~40 m/s and a maximum of perhaps 150 m/s. Thus evidently the gas speed at least occasionally exceeds this value, but there is no evidence of it being supersonic except during the explosions noted by Marchetti et al. (2013).

We might expect an exhalation, associated with the burst of a gas bubble that has ascended in the magma column, to produce an initially high flow that decays as the pressure in the vent decreases. In such a model, the initial gas flow, and the pyroclasts embedded in it, would tend to have a higher velocity than those at the end of the exhalation, which is exactly what is observed (Gaudin et al., 2014; their Figs. 1 & 4). If the simple aeolian tone model of acoustic emission is correct, then the sound frequency should also fall towards the end of an exhalation, which was not noticed.

An alternative model of the sound source is where a resonant cavity is excited by the flow, as encountered in an organ pipe, for example. Here, for an open pipe resonance, the frequency f is simply related to the length L and sound speed c as f = c/2 L. Note that the relevant sound speed here is that in the volcanic gas itself, not the ambient air. For a water-vapor dominated gas composition (e.g. Metrich et al., 2011) and temperatures of ~1000 K, the sound speed is of the order of 700 m/s, about double that in the ambient air. A 263 Hz emission

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