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Review

Inverting the source mechanism of Strombolian explosions at Mt. Yasur, Vanuatu, using a multi-parameter dataset

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ABSTRACT

The source mechanism of Strombolian explosions at Mt. Yasur, Vanuatu, is analyzed using a unique data set which enables us to combine different methodologies. The novelty of the approach presented here lies in the combination of seismic, acoustic and Doppler-radar data. Thus, using infrasound and Doppler radar observations we are able to provide independent estimates of the volume of the eruptive source. In the following, we show that a correlation exists between source volume and the maximum particle velocity of the expelled volcanic products. In order to determine the source location and the associated mechanism and to compare those two methods, we use time reversal imaging and moment tensor inversion. While the first method also applies to extended sources, the latter might be biased by its intrinsic point source approximation. We show that time reversal imaging can deliver an estimate of the source depth without any a priori assumptions even in an unfavorable scenario in terms of topography and receiver setup. The inverted source mechanism retrieved from moment tensor inversion is found to be largely isotropic, with minor deviatoric components. The inverted source location points towards an area to the north-west of the active craters, indicative of a common feeder system of the activity at Mt. Yasur. However, it is also evident, that to fully locate the source of Strombolian activity at Yasur location precision must be enhanced.

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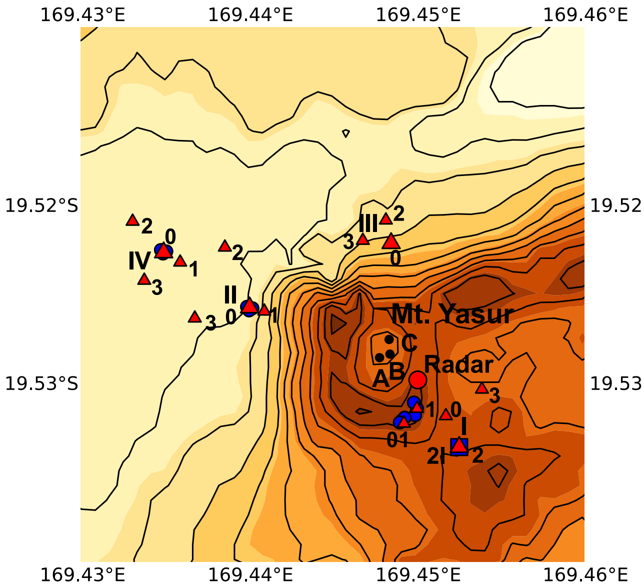

Fig. 1. Station setup at Mt. Yasur. The red triangles give the location of the seismic arrays, called 'I', 'II', 'III' and 'IV'. Large red triangles are seismic broadband stations. The blue spheres show the installed short-period infrasound arrays, the large blue square the acoustic broadband station. The large red sphere gives the location of the Doppler-radars, the infrared - and video camera. The three active craters are denoted as 'A', 'B' and 'C' from south to north, respectively.

1. Introduction

Mt. Yasur is located on Tanna island, which forms part of the subduction related volcanic island chain of Vanuatu. The volcanic activity on Tanna island can be traced back as far as the late Pliocene undergoing a series of major volcanic episodes (Carney and Macfarlane, 1979; Chen et al., 1995). The most recent episode formed the Siwi Group in the easternmost part of the island which is characterized by deposits that are predominantly basaltic to basaltic–andesitic in composition (Robin et al., 1994; Allen, 2005; Bani and Lardy, 2007). Present activity in the Siwi Group is connected to the Mt. Yasur cinder cone, that rises approximately 360 m above sea level. The structure of Mt. Yasur's volcanic edifice is dominated by a complex system of ring faults connected to the collapse of the Siwi caldera that created the Siwi ignimbrite sequence (Carney and Macfarlane, 1979; Robin et al., 1994; Allen, 2005). The post-collapse uplift formed the present Yenhake resurgent block (Chen et al., 1995; Perrier et al., 2011). Since about 1400 years B.C., the eruptive activity has been restricted to Mt. Yasur (Métrich et al., 2011). The analysis of Mt. Yasur's eruptive deposits suggests a continuous activity similar to the presently observed Strombolian to Vulcanian eruptions, interrupted by irregular sub-plinian eruptive phases (Nairn et al., 1988). Mt. Yasur has three small active craters aligned in NE–SW direction (denoted as A, B and C from south to north) that are surrounded by a larger 400-m-diameter crater (Oppenheimer et al., 2006). The three craters show varying styles of activity from ash-venting to strong Strombolian or Vulcanian activity (Carney and Macfarlane, 1979; Oppenheimer et al., 2006; Bani and Lardy, 2007; Métrich et al., 2011; Perrier et al., 2011; Kremers et al., 2012) that now persists for at least 300 years (Simkin et al., 1981).

In general, Strombolian eruptions are agreed to be caused by the rise and burst of large gas slugs, i.e. bubbles in the range of several meters in diameter that have decoupled from the melt phase at the top of a magma column (e.g., Blackburn et al., 1976; Seyfried, 1997; Chouet, 2003; Johnson, 2003; James et al., 2004). The mechanism responsible for generation of these large gas pockets is still under debate, proposed models are a slug formation enhanced by structural barriers at depth that allow for a development of a foam layer (Jaupart and Vergniolle, 1989; Vergniolle and Jaupart, 1990; Vergniolle, 1996) or by inclined dipping feeder systems (Chouet, 2003). The rising gas slugs, that can easily reach lengths up to several tens of meters (e.g., Chouet et al., 2003; Gerst, 2010) fill most of the conduit horizontally (Vergniolle, 1996; Seyfried and Freundt, 2000; Vergniolle et al., 2004).

Seismic signals that are thought to be generated by fluid mass transport (Chouet, 1994; Ripepe and Gordeev, 1999; Konstantinou, 2002; O'Brien and Bean, 2008) have been observed at, among others, Stromboli (Italy) in the long to very-long-period (LP–VLP, 3–30 s, Neuberg et al., 1994) and ultra-long-period (ULP, 100–1000 s, Dreier et al., 1994; Wassermann, 1997; Kirchdörfer, 1999) range. Aster et al. (2003) demonstrated the excitation of a resonator as source of VLP events at Mt. Erebus (Antarctica). James et al. (2006) showed experimentally that the interaction of a rising slug with the conduit geometry can create pressure oscillations that are recorded as seismic signals in the VLP to LP range. Other authors attributed these signals more generally to resonance effects caused by pressure fluctuations in a fluid filled conduit (Chouet, 1996; Ripepe, 1996; Wassermann, 1997; Neuberg et al., 2000; McNutt, 2005; Neuberg et al., 2006; Bean et al., 2008). As low-frequency signals at volcanoes often show emergent onsets, conventional approaches for localization based on first arrivals cannot be applied. Techniques that have among others been used to localize the source of LP and VLP events include beam-forming on diffraction hyperbolids (Wassermann, 1997), a waveform semblance method (Kawakatsu et al., 2000), a method based on seismic amplitudes corrected for station site effects (Battaglia and Aki, 2003), moment tensor inversion (e.g., Chouet et al., 2003; O'Brien and Bean, 2008; Bean et al., 2008) and time reversal (O'Brien et al., 2011).

This study aims to enhance the understanding of Strombolian eruptions in general and in detail the rise and burst of gas slugs at Mt. Yasur (Tanna, Vanuatu) in particular, which is besides Mt. Erebus (Antarctica) the only Strombolian-type volcano that allows a persistent observation of the processes acting at the magma–air interface. In this unique setup, we carried out a multi-disciplinary field experiment combining seismic, acoustic and radar monitoring techniques. This combination of the monitored parameters allows us to define the slug rise time and length, correlate seismic amplitudes with particle velocities and recorded acoustic pressures, and to validate or falsify proposed models for Strombolian type activity. Using the velocity model of Perrier et al. (2011) which is independently tested using frequency-wavenumber analysis and the corresponding numerical mesh, we perform moment tensor (MT) inversion and time reversal (TR) simulations to locate the source of LP to VLP signals (>2 s) that are recorded a few seconds before the manifestation of surface activity. For a stability test of the MT inversion on the Mt. Yasur data we computed Green's functions (GF) including a superficial low-velocity layer. Although this layer is small compared to the used wavelengths it can have a strong influence on the inverted source mechanism (Lokmer et al., 2007; Bean et al., 2008). MT inversion is performed in the Fourier domain using an algorithm developed by van Driel et al. (in preparation). The algorithm searches over a large grid of possible source positions, using a misfit criterion for the selection of the best source location. This technique represents the source as a point, i.e. the source extent is small compared to the used wavelength. This assumption might be violated by the fact that we only have stations in the near-field.

Assuming that a rising slug in the conduit acts as source of the LP signal the source position will only be represented as a centroid. In contrast, TR is a promising approach to invert for an extended time-variant source. When applying this method, the recorded seismic signals are reversed in time and re-injected in the model domain. Wave propagation is implemented via a high-order accurate