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Characterizing complex eruptive activity at Santiaguito, Guatemala using infrasound semblance in networked arrays

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ABSTRACT

We implement an infrasound semblance technique to identify acoustic sources originating from volcanic vents and apply the technique to the generally low-amplitude infrasound (<3 Pa at 1 km) signals produced by Santiaguito dome in Guatemala. Semblance detection is demonstrated with data collected from two-element miniature arrays with ~30 m spacing between elements. The semblance technique is effective at identifying a range of eruptive phenomena, including pyroclastic-laden eruptions, vigorous degassing events, and rockfalls, even during periods of high wind contamination Many of the detected events are low in amplitude (tens of mPa) such that they are observed only by select arrays positioned with proximity and line-of-sight to the source. Larger events, such as the pyroclastic-laden eruptions, which occurred bi-hourly in 2009, were detected by all five arrays and produced an infrasonic signal that was correlated across the network. Network correlated events can be roughly located and map to the summit of the Caliente Vent where pyroclastic-laden eruptions originate. In general, the degree of Santiaguito infrasound event correlation is poor across the network, suggesting that complex source geometry contributes to asymmetric sound radiation.

1. Introduction

Volcano infrasound can provide important constraints on the occurrence and mechanism of a volcanic eruption and the geometry of its vent(s) (e.g. Vergniolle and Brandeis, 1996; Hagerty et al., 2000; Rowe et al., 2000; Ripepe and Marchetti, 2002; Johnson et al., 2003; Petersen and McNutt, 2007; Lees et al., 2008). Compared to seismic elastic waves the characteristic wavelengths of volcano infrasound are short (340 to 17 m for 1 to 20 Hz sound) allowing for relatively high resolution (tens of meters) localization of phenomena occurring at the surface of a volcano. In contrast, ground propagating elastic waves produced by volcanic eruptions are often emergent and incoherent across a network of stations resulting in substantial (>100 s of meters) errors in hypocentral locations (e.g., Lees, 1998).

Higher precision source localization on the order of meters or tens of meters is possible for short wavelength acoustic waves. Such accuracy allows for differentiation of active vents in a multi-vent eruptive system (Johnson, 2005; Ripepe et al., 2007; Jones et al., 2008) and/or tracking of surface flow phenomena such as pyroclastic flows or rock avalanches (Yamasato, 1997; Ripepe and Marchetti, 2002; Moran et al., 2008; Ripepe et al., 2009). When high precision source locations and detection are desired, it is necessary to utilize local (defined here as within 10 km of the source) sensors that are usually deployed on the flanks of the volcano itself. Regional and global distance (greater than 10 km) infrasound arrays are effective for long-term tracking of a volcano's infrasonic activity (e.g., Matoza et al., 2006; Garces et al., 2007), but have inferior source localization capabilities owing to the variability of intervening transverse winds. Even in local and near-local regions, the infrasound amplitude and phase are affected by time-varying winds and temperatures (Fee and Garces, 2007; Marcillo and Johnson, 2010).

For effective implementation, volcano infrasound sensor deployments needs to be tailored to the task(s) at hand, which can include volcano surveillance, scientific study, or a combination of the two. Volcano infrasound deployments are typically deployed in two end-member topologies: network and array distributions. Traditionally infrasound arrays are tight clusters of at least three sensors with inter-sensor spacing less than or equal to the expected infrasonic wavelength (e.g., Garces et al., 2003; Stump et al., 2004). Arrays are generally located greater than a kilometer from the active volcanic vent. For an array aperture that is small (typically tens to hundreds of meters) compared to the transmission distance from an acoustic source the wavefront can be approximated as planar.

Networks of volcano infrasound sensors are analogous to seismic networks in that they usually are distributed at various azimuths and distances encompassing the source area of interest (e.g., Yamasato, 1997; Johnson, 2005; Jones et al., 2008). Local networks can triangulate closely spaced acoustic sources provided they have a

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reasonably high signal-to-noise ratio. Each network station need only have a single transducer and a minimum of three stations to provide a location if source elevation and intrinsic sound velocity are fixed (Jones et al., 2008). Source locations of volcano or other types of infrasound can be achieved using two or more networked arrays of three or more elements (e.g., Arrowsmith et al., 2008). Each array is capable of independent source back-azimuth beaming, where crossed beams can locate an acoustic source.

2. Infrasound at Santiaguito

Previous studies of Santiaguito infrasound were limited to interpretation of data from a single microphone deployed within a couple of kilometers of the active vent. Studies by Johnson et al. (2004a), Sahetapy-Engel et al. (2008), and Marchetti et al. (2009) integrated single station infrasound observations with remote ground-based thermal observations of eruptive activity. Johnson et al. (2009) investigated the audible and infrasonic acoustic signature of a single Santiaguito eruptive event by incorporating broadband seismic and night-time video observations. None of these studies, however, focused on systematic identification and characterization of the various eruptive and surface infrasound source(s). Toward this end, this paper highlights methods for tracking and mapping volcano acoustic radiators at Santiaguito using a hybrid 5-station network of small 2 and 3-element infrasound arrays (Fig. 1). These arrays are used to better understand the occurrence and distribution of explosions and other surface events and to elucidate the mechanisms for infrasound generation.

Observations during field campaigns by the authors in January 2003, 2007, and 2009 indicated that Santiaguito tends to radiate near-infrasound with relatively low intensity in comparison to the sound typically produced by more open-vent volcanic systems, such as Stromboli, Etna, Villarrica, Erebus, and Kilauea (Johnson et al., 2004b). Although hundreds of eruptive events were recorded during these campaign deployments the highest amplitude pressure signals never exceeded 5 Pa even for sensors located ~500 m from the active vent. Commonly, the Santiaguito eruption infrasound recorded at this distance is registered with peak amplitudes of only a few tenths of a Pa and is often partially obscured by pervasive microbarom signals (occurring at frequencies lower than 0.2 Hz) and/or wind-induced noise, which tends to be relatively broadband (Bowman et al., 2005).

As an example, the seismo-acoustic record in Fig. 2 shows 24 h of trace data from the station CAL, the closest station to the Caliente Vent (~500 m) recorded on 02 January 2009. Microbarom signals have been removed by high-pass filtering the raw acoustic data above 0.25 Hz, but relatively high wind noise remains noticeable on the

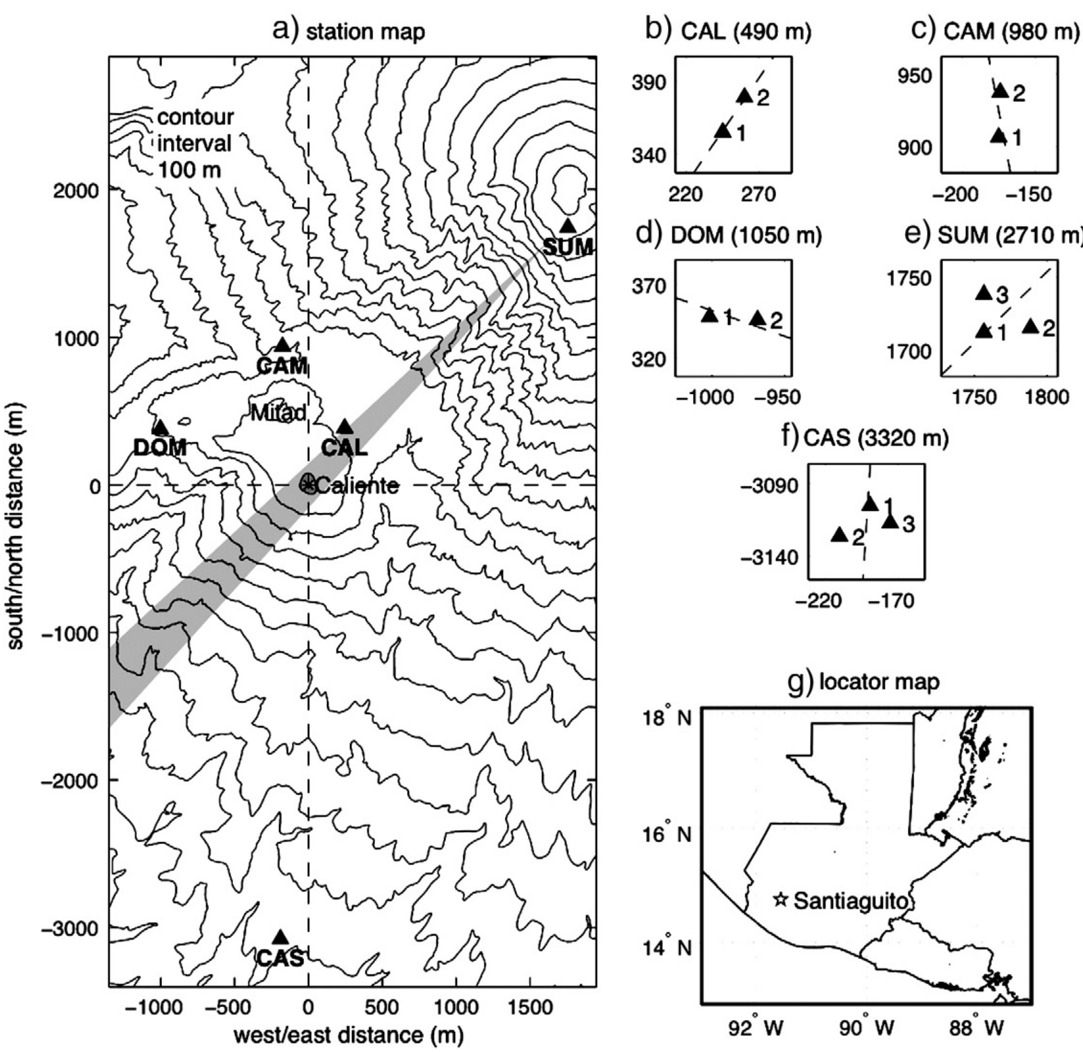

Fig. 1. a) map of Santiaguito network acoustic sites for January 2009 and b–f) detail of mini-array sensor geometry for the five sites with multiple microphones. Station locations are mapped relative to a coordinate origin centered on the Caliente Vent. Slant distances from the vent to the five mini-arrays are noted parenthetically and dashed lines in mini-array detail show radial vent direction. g) locator map for Santiaguito within Guatemala.