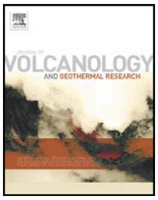
Journal of Volcanology and Geothermal Research 199 (2011) 15–24

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores



Mapping complex vent eruptive activity at Santiaguito, Guatemala using network infrasound semblance

K.R. Jones, J.B. Johnson *

Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, United States

ARTICLE INFO

Article history:
Received 22 December 2009
Accepted 6 August 2010
Available online 19 September 2010

Keywords:
dome volcanism
infrasound
semblance
distributed source

ABSTRACT

Pyroclastic-laden explosive eruptions from Santiaguito Volcano (Guatemala) are vented from the 200-m diameter Caliente Dome summit and result in a superposition of spatially extensive and temporally sustained (tens of seconds to minutes) acoustic sources. A network of infrasonic microphones distributed on various sides of the volcano record distinct waveforms, which are poorly correlated across the network and suggestive of acoustic interference from multiple sources. Presuming the infrasound wavefield is a linear superposition of spatially and temporally distinct sub-events, we introduce a semblance mapping technique to recover the time history of the spatially evolving sources during successive time windows. Coincident high-resolution video footage corroborates that both rapid dome uplift and individual explosive pulses are likely sources of high semblance infrasound that are identifiable during short (2 s) time windows. This study suggests that complex and network-variable infrasound waveforms are produced whenever a volcanic vent source dimension is large compared to the wavelength of the sound being produced. Non-compact infrasound radiators are probably commonplace at silicic volcanic systems, where venting often occurs across a dome surface.

1. Introduction

In January 2009 Santiaguito's Caliente Dome erupted explosively about 15 times per day ejecting pyroclastic-laden columns and buoyant plumes that rose up to 1500 m. Episodic explosive events endured from 1 to 10 min and comprised jetting and discrete explosions from an array of crack and pit craters distributed about the 200 m diameter summit crater. In addition, less vigorous degassing emissions and rock fall events occurred sporadically and often accompanied the explosive eruptions. In general, the 2009 eruptive activity was similar to the activity witnessed during previous field studies both by the authors (e.g., Johnson et al., 2008b; Sanderson et al., 2010) and during campaigns observations by others in recent years (e.g., Bluth and Rose, 2004; Sahetapy-Engel et al., 2008; Yamamoto et al., 2008).

A companion paper by Johnson et al. (2010-this volume) studied the eruption infrasound radiated by Santiaguito in January 2009 and found substantial differences in the infrasound recorded across a local network of pressure transducers for explosion, degassing, and rock fall events. Identical microphones located at a range of distances and azimuths about the eruptive vent, recorded infrasound signals with waveforms that were generally poorly correlated with each other. In contrast, the infrasound recorded at many other volcanoes, e.g., at Stromboli (Ripepe et al., 2007), Etna (Cannata et al., 2009), Erebus (Jones et al., 2008), Karymksy (Johnson and Lees, 2000), and Kilauea (Marcillo and Johnson, 2010) has been found to be similar across networks of microphones.

Some of the variations in infrasound traces recorded at a local network of infrasound microphones could be attributed to second-order effects including: explosive source directivity, near-vent crater morphology (e.g., wall echoes), or site effects resulting from topography near the station (e.g., Johnson et al., 2008a; Jones et al., 2008). Propagation effects, such as non-uniform atmospheric temperatures and/or atmospheric advection due to wind, can also influence the sound radiated in different directions and will be especially pronounced at distances greater than a few kilometers (e.g., Fee and Garces, 2007). Although the relative complexity of the Santiaguito infrasound wavefield might be attributable to a combination of source, site, or propagation effects, the variability in recorded infrasound is considerably greater than for other volcanic systems mentioned previously.

One of the primary differences between the andesite/dacite Santiaguito system and the aforementioned (primarily mafic) eruptive centers is the large dimension of the vent region. Previous studies have observed that pyroclast-laden Santiaguito explosions emanate from an approximate 200 m diameter vent region (Bluth and Rose, 2004; Johnson et al., 2008b; Sahetapy-Engel et al., 2008), which is considerably greater than the 40 m diameter Erebus lava lake

---

* Corresponding author. Tel.: +1 575 835 6398; fax: +1 575 835 6436.
E-mail address: jeff.johnson@ees.nmt.edu (J.B. Johnson).

0377-0273/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.jvolgeores.2010.08.006

(Dibble et al., 1994), or the 10–50 m vents of Stromboli (e.g., Finizola et al., 2003), from which classical Strombolian-style eruptions emanate. For relatively small-vent eruptive systems the infrasound source may be treated as compact because source accelerations occur within a region that is small compared to the radiated infrasound wavelengths (~80–340 m for 0.25 s to 1 s period sound).

At Santiaguito, however, gas emissions and presumed infrasound source loci are distributed over the Caliente Vent summit plateau, the current source of explosive activity since 1967 (Rose, 1987). The infrasound wavefield is complex due to the interference patterns that arise from multiple sources. In this study we consider the source at Santiaguito to be a linear superposition of spatially and temporally distinct sound radiation sources and introduce a technique to map the distribution of these sources in space and time. This technique has application for other silicic systems with active domes, e.g., Chaiten, Montserrat, Mount St. Helens, Merapi, or Colima, where degassing is observed to emanate from relatively large areas. Network infrasound semblance studies might have been useful at Mount St. Helens, for instance, where the infrasound catalogue has been comprised of repetitive "drumbeats", occasional explosion signals, as well as rock fall (Moran et al., 2008; Matoza et al., 2009b). It could also be efficiently applied to distinguish activity at a multi-vent system like Stromboli (Johnson, 2005).

2. Experiment

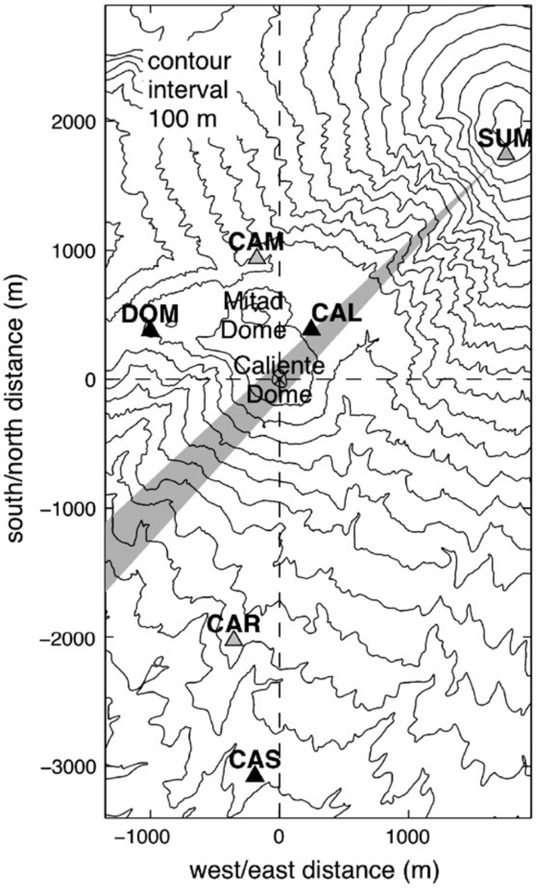
In January 2009 Santiaguito exploded frequently (tens of times per day) producing pyroclastic-laden eruption columns that reached more than a kilometer above the Caliente Vent. These eruptions radiated complex seismicity and infrasound, which was well recorded across a network of six stations deployed between 400 m and 3300 m from the active vent (see Fig. 1). During the course of four days the network recorded more than 60 explosion events along with a variety of vigorous degassing signals and rock fall. The corresponding infrasound signals and method of semblance identification are described in a companion paper (Johnson et al., 2010-this volume).

Each of the 6 seismo-acoustic stations consisted of 1, 2, or 3 identical microphones linked to a central datalogger by cables up to 30 m in the length. The microphone transducers were All Sensors™ MEMS differential pressure transducers fitted with 2-cm-long 50 μm diameter capillary tubes to allow pressure equilibration on one of the pressure ports. The shunt generated an effective high-pass corner frequency at ~40 s, well beneath the targeted in-band frequency range of 0.25 to 20 Hz. In-band response of the microphones is flat and RMS electronic noise levels between 1 and 10 Hz band is measured at 5.5 mPa, nearly three orders of magnitude lower than the typical peak-to-peak excess pressures (~5 Pa) recorded during large explosive eruptions. In this study the signals from an individual array were appropriately time shifted, corresponding to correlated signal moveout from the Caliente vent, and then stacked to increase the signal-to-noise. At each station infrasound and seismic signals were collected continuously at 100 Hz with 24-bit Reftek 130 digitizers using GPS time synchronization. Broadband seismometers, including both Güralp CMG 40 T (30 s corner) and Güralp CMG 3ESP (60 s corner) sensors, were co-located at each infrasound station.

We map the evolving infrasonic sources from explosive eruptions using pressure records from three azimuthally distributed infrasound stations, DOM (1100 m distant at 290°), CAL (450 m distant at 35°), and CAS (3300 m distant at 185°). These sites provide a well-spaced geometry in terms of azimuthal coverage that is suitable for triangulating acoustic sources. Although the method outlined in this paper could easily be extended to a network with more than three stations, we chose not to use infrasound from stations SUM, CAM, or CAR. The reasons for their exclusion included: 1) pervasive microbarom and wind turbulence noise at SUM, 2) low signal-to-noise at CAM due to its position behind the Mitad Dome (Johnson et al., 2010-this volume), which serves as a physical barrier to propagating sound, and 3) redundant azimuth and distance for station CAR, which is located close to CAS.

A high-definition Casio EX-F1 video camera was sited at the summit of Santa Maria (2700 m from the vent) to provide visual observations of the explosive eruptions that were mapped through infrasound semblance. This camera was directed at 225° (from N) and tilted downward at 25° (from horizontal) and was zoomed in to focus on the summit of Caliente, a region about 250 m in horizontal extent (field of view is shown in Fig. 1). Camera timing was calibrated with a handheld GPS to an accuracy of +/− 0.5 s.

a) Santiaguito map detail



b) locator map

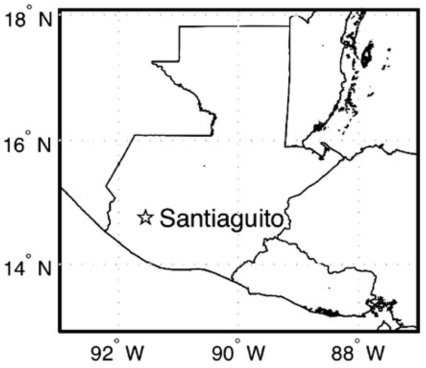


Fig. 1. a) Map of Santiaguito acoustic network deployed in January 2009. Those sites indicated by filled triangles correspond to stations used in this study for network semblance mapping. b) Locator map of Santiaguito within Guatemala.