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Three-dimensional volcano-acoustic source localization at Karymsky Volcano, Kamchatka, Russia

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ABSTRACT

We test two methods of 3-D acoustic source localization on volcanic explosions and small-scale jetting events at Karymsky Volcano, Kamchatka, Russia. Recent infrasound studies have provided evidence that volcanic jets produce low-frequency aerodynamic sound (jet noise) similar to that from man-made jet engines. For man-made jet noise, noise sources localize along the turbulent jet flow downstream of the nozzle. Discrimination of jet noise sources along the axis of a volcanic jet requires high resolution in the vertical dimension, which is very difficult to achieve with typical volcano-acoustic network geometries. At Karymsky Volcano, an eroded edifice (Dvor Caldera) adjacent to the active cone provided a platform for the deployment of five infrasound sensors in July 2012 with intra-network relief of ~600 m. The network was designed to target large-scale jetting, but unfortunately only small-scale jetting and explosions were recorded during the 12-day experiment. A novel 3-D inverse localization method, srcLoc, is tested and compared against a more common grid-search semblance technique. Simulations using synthetic signals show that srcLoc is capable of determining vertical solutions to within ±150 m or better (for signal-to-noise ratios ≥1) for this network configuration. However, srcLoc locations for explosions and small-scale jetting at Karymsky Volcano show a persistent overestimation of source elevation and underestimation of sound speed. The semblance method provides more realistic source locations, likely because it uses a fixed, realistic sound speed of ~340 m/s. Explosion waveforms exhibit amplitude relationships and waveform distortion strikingly similar to those theorized by modeling studies of wave diffraction around the crater rim. We suggest that the delay of acoustic signals and apparent elevated source locations are due to raypaths altered by topography and/or crater diffraction effects, implying that topography in the vent region must be accounted for when attempting 3-D volcano acoustic source localization. Though the data presented here are insufficient to resolve small-scale jet noise sources, similar techniques may be successfully applied to large volcanic jets in the future.

1. Introduction

Spatio-temporal source location of elastic waves is an important tool in acoustic and seismic studies of geophysical processes. We define an acoustic source as the region in space and time in which a physical process mechanically excites the ambient atmosphere, resulting in the propagation of acoustic waves. This may be the point and time at which a process first excites the atmosphere, or in the case of a distributed source, the region over which mechanical excitation occurs. In volcano studies, the reasons for locating acoustic sources are many: comparing the spatial relationships of acoustic and seismic sources in a volcanic system (Johnson, 2007), differentiating eruptive activity between different vents (Ripepe and Marchetti, 2002; Cannata et al., 2009), tracking of pyroclastic density currents (PDCs) (Ripepe et al., 2010), and long distance monitoring of remote volcanism (Matoza et al., 2011; Fee and Matoza, 2013). One of the challenges in locating acoustic sources from volcanoes is that most microphone deployments lie below the volcanic vent and are restricted to topography that is approximately two-dimensional (Matoza et al., 2013). Such networks are severely restricted in their ability to resolve acoustic sources in the vertical dimension, due to low angular coverage of the source region. Previous volcano acoustic studies have used 3-D spatial information to perform source localization over horizontal or vertical planar source regions (Ripepe and Marchetti, 2002; Ripepe et al., 2007; Jones and Johnson, 2011). We build upon these works by extending our source region to a fully 3-D space.

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Recent research has drawn links between the low-frequency acoustic signals from volcanic jets and the audible sound from man-made jet engines (jet noise), although this relationship has yet to be firmly established due to the complexities in volcanic jets and difficulty in making detailed observations (Woulff and McGetchin, 1976; Matoza et al., 2009a; Fee et al., 2010a,b, 2013; Matoza et al., 2013). A jet is defined as a sustained, momentum-driven, turbulent fluid flow issuing from a nozzle or vent. Jet noise is the acoustic radiation generated aerodynamically by turbulence within the jet flow itself. The acoustics of man-made jet engines are well characterized primarily due to development in the aeronautics industry (e.g. Tam, 1998; Tam et al., 2008; Viswanathan, 2009; Karabasov, 2010). Acoustic localization of man-made jet noise sources is typically done using arrays of microphones at a wide range of receiver angles or using directional and mirrored microphones. Turbulent jet flows have been observed to produce acoustic signals sourced along the edge of the jet, and experimental evidence suggests that turbulent noise sources peak at some distance downstream of the nozzle (Tam et al., 2006, 2008). If volcanic jets produce sound through similar mechanisms to man-made jets, it follows that turbulent sound sources in volcanic jets should peak above (downstream of) the vent (Matoza et al., 2009a; Fee et al., 2013).

At Karymsky Volcano, Kamchatka, Russia (Fig. 1a), the topography of an eroded edifice adjacent to the volcano, called Dvor Caldera, provides a platform for the deployment of a network of infrasound sensors with high relief adjacent to Karymsky, thereby improving the angular coverage of Karymsky summit. Five infrasound microphones were deployed on this eroded edifice for 11 days in July 2012. Fig. 1 outlines the campaign area with a satellite image of the two edifices (Fig. 1b), a photograph of the Karymsky summit region taken in September 2012 (Fig. 1c), and a perspective view of a digital elevation model (DEM) to highlight the topography of the two edifices. The receiver sites were selected with the specific goal of achieving the maximum possible vertical

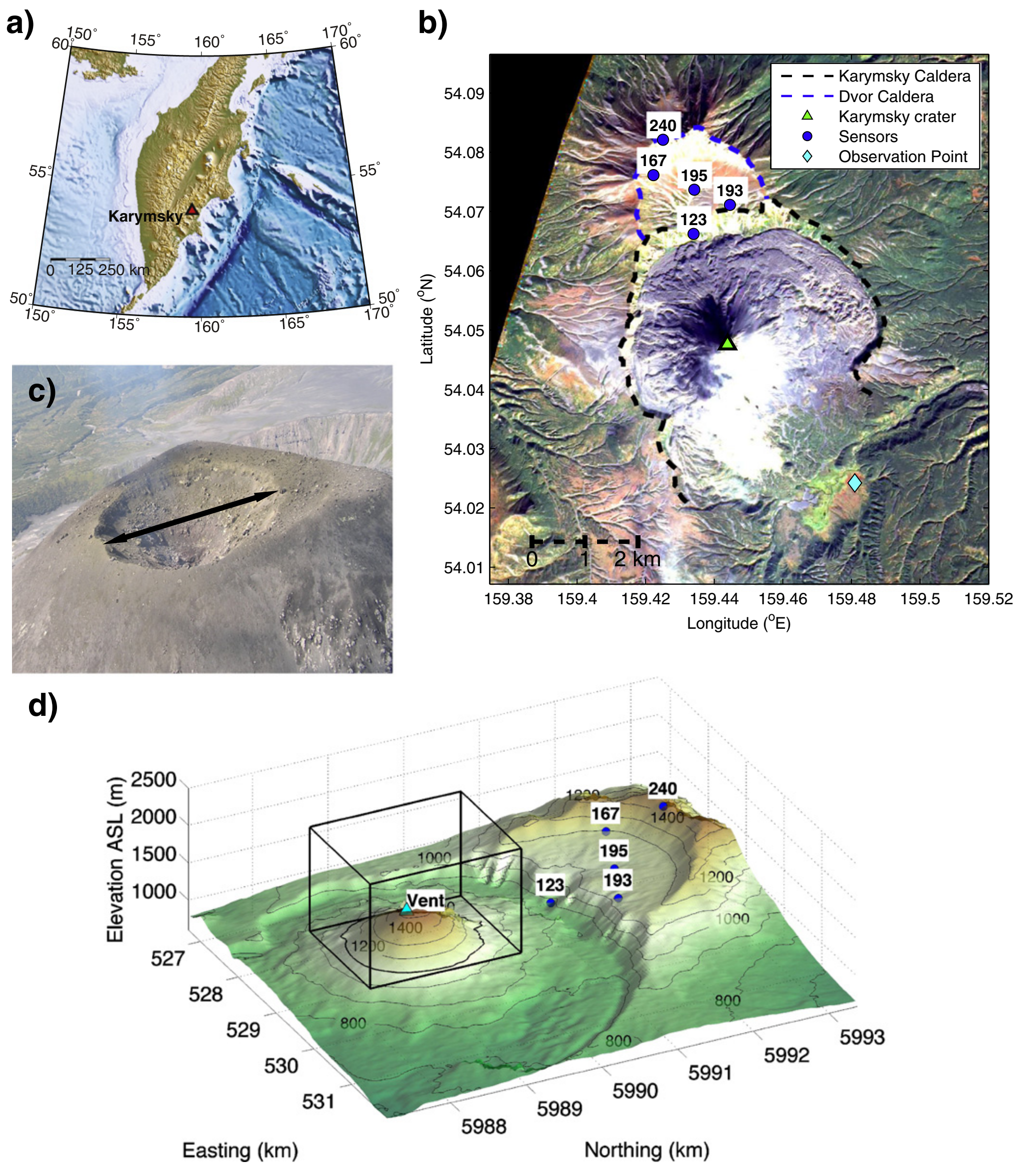

Fig. 1. Location of Karymsky Volcano and geometry of July 2012 field deployment. (a) Map of Kamchatka highlighting the location of Karymsky Volcano. (b) Satellite image of Karymsky Volcano. Acoustic sensor locations are labeled by sensor number. (c) Karymsky vent in September 2012. The crater diameter (black arrow) is estimated at ~150 m. Photo credit: Pavel Firstov. (d) DEM of the Karymsky and Dvor edifices. Sensor locations are labeled as in panel b, and elevation contours are in meters above sea level (ASL). The rectangular space about the Karymsky cone represents the grid space used for the semblance localization method discussed in Sections 4–5.