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Influence of near-source volcano topography on the acoustic wavefield and implication for source modeling

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ABSTRACT

In near-source conditions (<5 km), the atmosphere is often assumed to be fully transparent to acoustic waves and to have a small effect on the acoustic wavefield. As a consequence, the propagation of the acoustic waves in the atmosphere near the source is often neglected and waveform is compensated only in amplitude by the inverse of the distance from the source. However, the amplitude distribution at five infrasonic stations deployed around the active craters of the Stromboli volcano, reveals anomalous decay up to −11 dB larger than expected, which cannot be explained in terms of energy loss for geometrical spreading. The distribution of amplitude decay changes for different source positions, suggesting a strong relationship with the source-to-receiver path geometry. By using 2D-FDTD modeling, we show that the anomalous amplitude distribution of the acoustic waves at Stromboli is not necessarily due to the source radiation pattern but it is strongly influenced by the topography of the ground–atmosphere interface. Diffraction and reflection of topography contaminate the acoustic wavefield and have a strong effect in reducing the amplitude and altering the waveform. Our work demonstrates that line-of-sight conditions are quite difficult to be achieved in acoustic experiments and that a detailed knowledge of the topography along the crater–receiver path is necessary whenever infrasound waveforms are used to invert for the source process.

1. Introduction

Infrasound on volcanoes is generated by several processes well coupled with the atmosphere. The record of infrasonic activity on open conduit volcanoes like Stromboli indicates that magma is degassing in no-equilibrium condition into the atmosphere. Infrasound is then providing direct information on the explosive dynamics and on the degassing process of magma within the conduit. This makes monitoring the explosive activity more simple and infrasound has rapidly become widely used in volcano monitoring (see Johnson and Ripepe, 2011 for a review).

In terms of the source process, infrasonic studies on volcanoes generally assume that the Green's functions for a fluid atmosphere are far simpler than those for a complex, heterogeneous volcanic edifice (e.g. Johnson, 2003). Unlike seismic waves propagating in the highly scattering ground media, infrasound propagates in the atmosphere, which at a short distance from the source (<5 km) is often assumed as a homogeneous medium with no structures able to modify the acoustic wavefield. The effects of the atmospheric medium are then usually neglected and acoustic waves are considered to be fully representative of the source function and used to invert for the source (e.g. Vergniolle and Brandeis, 1996; Kim and Lees, 2011).

In a spherically propagating sound, absorption of the atmosphere dominates at altitudes above 60 km, and the associated attenuation coefficient (in dB/m) is proportional to the square of the frequency (Sutherland and Bass, 2004). However, the absorption coefficient for infrasonic waves recorded in near source conditions is sufficiently small (~0.001 dB/km) to be neglected (de Groot-Hedlin, 2008a).

Meteorological conditions such as temperature and wind may strongly influence the propagation and the amplitude of sound in the atmosphere. Wind and temperature gradients cause sound to refract either upward or downward, leading to shadow zones or multiple reflections. Fluctuations of wind and temperature by, for example, atmospheric turbulence, may cause sound to be scattered into the acoustic shadow zone.

We show how infrasound measured at the five stations of the Stromboli's permanent network, at distances ranging between 0.29 and 1.1 km from the active craters shows an amplitude distribution which is non-compatible with the generally applied inverse of distance (1/*r*) geometrical attenuation. The amplitude decay of infrasound follows different distributions when generated by different craters. This supports the idea of a non-isotropic source or of an attenuation effect stronger than the simple geometrical spreading.

We here consider the propagation properties of the infrasonic wavefield when it interacts with the topography of the volcano. By

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using a 2D finite-difference time domain (FDTD) modeling, we show how volcano topography contributes to alter acoustic waveforms.

2. Infrasonic network at Stromboli volcano

Volcanic explosions at Stromboli are an efficient source of infrasound. Pressure waves propagating in the atmosphere, are recorded by the permanent infrasonic network of the Department of Earth Sciences of the University of Florence (Ripepe et al., 2004).

Infrasound monitoring consists of 4 seismo-acoustic stations (SAS, STR, ROC, and SCI) and one 5-element infrasonic array. Each seismo-acoustic station is equipped with a differential pressure sensor, Honeywell DC001NDC4, with a pressure range of ±250 Pa and a sensitivity of 0.01 V/Pa in a flat frequency range between 0.01 and 100 Hz. The small aperture array has an L-shape geometry with an internal spacing of ~100 m (Fig. 1), which allows the record of coherent infrasonic waves, in the 1–10 Hz frequency range. The array consists of five pre-amplified electret condenser microphones placed at a mean elevation of 850 m and at 300–450 m away from the summit vents. The acoustic data of the array are recorded with 16 bits acquisition system at a sampling rate of 54.2 Hz. The array was used only to locate the infrasonic source because response function of the electret condenser microphones can be unstable and are thus unsuitable for a detailed waveform analysis (Ripepe et al., 2004).

During two surveys (July and September 2009) of nearly ten days each we installed at Pizzo one acoustic station (RIF) at a distance of ~290 m and in perfect line-of-sight with the active vents (Fig. 1). The RIF station was equipped with the same differential pressure sensor of the acoustic network with an addition of a second differential pressure sensor with a higher pressure range of ±2500 Pa (Honeywell DC010NDC4). The two sensors at RIF aim to cover the full possible pressure range at near-source conditions and to provide reliable amplitude. Data were recorded by the same acquisition system and at the same sampling rate.

3. Infrasonic activity and amplitude distribution

During the experiment, normal strombolian activity located in two main vents, the SW and NE craters, generated hundreds of acoustic signals per day. The array was used to locate each infrasonic signal using a grid-searching method based on the multichannel semblance of time-delayed signals according to the theoretical travel time (Ripepe and Marchetti, 2002; Ripepe et al., 2007). The source location and signal-to-noise ratio of >15 dB, at the most distant station SCI (Fig. 1), are considered to group acoustic waveforms in two families associated to each active vent (Fig. 2).

Acoustic pressure generated by the SW crater (135 events) ranges at the closest station RIF between 298 Pa and 24 Pa. Waveforms at all the stations (Fig. 2a) are very similar to each other and consisted in a nearly one second long transient characterized by impulsive compression onsets of ~0.12 s followed by a symmetric negative decompression phase (Fig. 3a). The frequency content is peaked around 3.8 Hz (Fig. 3b), which for a sound propagation of 340 m/s results in a wavelength of ~89 m. We used RIF as the reference station to

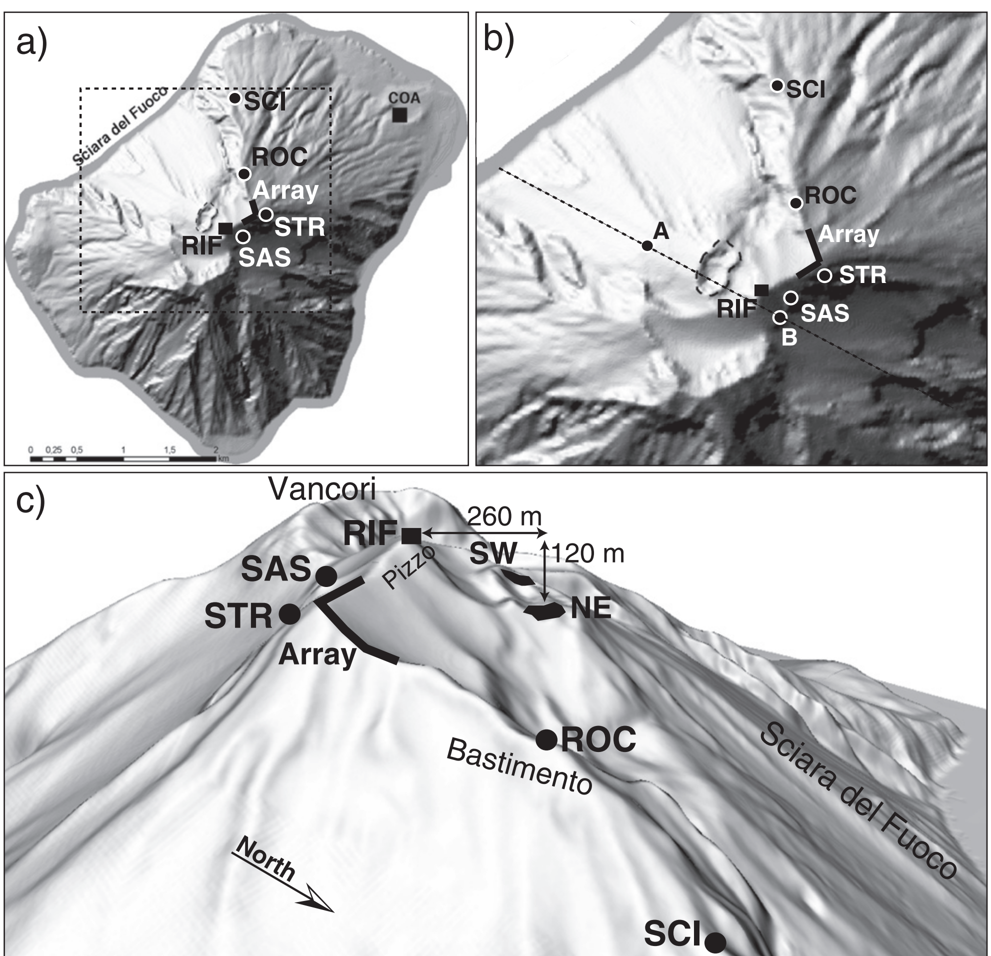

Fig. 1. Map of the Stromboli Island (a, b, c) with the position of acoustic station (dots) and the infrasonic array (bold line) relative to the NE and SW craters (c). The dashed line indicates the topographic section used to calculate the acoustic propagation in Fig. 7.