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Vortex rings and acoustic signatures from volcanic jets at Stromboli volcano (Italy)

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Volcanic jets are frequent among a variety of explosive activity styles, including the Strombolian one. Despite this acknowledged role, jet dynamics and their consequences on volcanic eruptions are still largely unexplored. In 2018 we used high-speed imaging and acoustic recordings to document volcanic jets at Stromboli volcano (Italy), with particular focus on the formation of vortex rings at the onset of the jets.
Vortex rings are toroidal vortices generated at the noozle of a jet (in this case the gas-pyroclast mixture) entering into a still fluid (in this case the Earth atmosphere), and play an important role in many jet-related processes. Vortex rings have already been shown to affect the velocity field of pyroclasts in Strombolian explosions, but they may play other roles in the eruption dynamics, including, e.g., momentum transfer from the jet to the surrounding fluid, entrainment, and acoustic signature of the jets.
We documented the jet-forming explosions by using: 1) a high-speed camera zooming on the vent and filming at 500 frames per second in the visible light; 2) a camera recording a broader field of view at 200 frames per second in the thermal infrared; 3) a microphone recording at a rate of 20 kHz in the audible to infrasonic wavelengths; 4) multiple acoustic arrays recording at 200 Hz as well as 10-10kHz. These sensors were used to characterize the jets, the vortex rings, and the associated acoustic signatures.
All explosions were characterized by the formation of at least one vortex ring at their begin, and most of the observed explosions formed two distinct jets, each with its initial vortex ring. In a few cases, more than one vortex ring formed in rapid succession. The rise and expansion rates of the vortex rings are in agreement with literature experiments and theory. The emergence from the vent of each vortex ring was accompanied by an acoustic wave, rings and waves displaying similar emergence times and rates. The amplitude of the acoustic waves scales linearly with the rise velocity of the vortex rings, and exponentially with the delay time between the formation of the vortex rings and the appearance of pyroclasts at the vent.
We suggest that vortex rings may play a significant role in the origin of volcanic acoustic signals, and that they hold information on the dynamics (depth, gas velocity) of the source explosions.