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Non-linear ground response triggered by volcanic explosions at Etna Volcano, Italy

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Volcanic explosions produce energy that propagates both in the subsurface as seismic waves and in the atmosphere as acoustic waves. We analyse thousands of explosions which occurred at different craters at Etna volcano (Italy) in 2018 and 2019. We recorded signals from infrasound sensors, geophones (GPH), broadband seismometers (BB) and Distributed Acoustic Sensing (DAS) with fibre optic cable. The instruments were deployed at Piano delle Concazze at about 2 to 2.5 km from the active craters, within (or onto) a ~300,000 m^2 scoria layer deposited by recent volcanic eruptions. The DAS interrogator was setup inside the Pizzi Deneri Volcanic Observatory (~2800 m elevation). Infrasonic explosion records span over a large range of pressure amplitudes with the largest one reaching 130 Pa (peak to peak), with an energy of ca. $2.5x10^{11}$ J. In the DAS and the BB records, we find a 4-s long seismic “low frequency” signal (1-2 Hz) corresponding to the seismic waves, followed by a 2-s long “high-frequency” signal (16-21 Hz), induced by the infrasound pressure pulse. The infrasound sensors contain a 1-2 Hz infrasound pulse, but surprisingly no high frequency signal. At locations where the scoria layer is very thin or even non-existent, this high frequency signal is absent from both DAS strain-rate records and BB/GPH velocity seismograms. These observations suggest that the scoria layer is excited by the infrasound pressure pulse, leading to the resonance of lose material above more competent substratum. We relate the high frequency resonance to the layer thickness. Multichannel Analysis of Surface Wave from jumps performed along the fibre optic cable provide the structure of the subsurface, and confirm thicknesses derived from the explosion analysis. As not all captured explosions led to the observation of these high frequency resonance, we systematically analyze the amplitudes of the incident pressure wave versus the recorded strain and find a non-linear relationship between the two. This non-linear behaviour is likely to be found at other explosive volcanoes. Furthermore, our observations suggest it might also be triggered by other atmospheric pressure sources, like thunderstorms. This analysis can lead to a better understanding of acoustic-to-seismic ground coupling and near-surface rock response from natural, but also anthropogenic sources, such as fireworks and gas explosions.