Eruptions from UV to TIR: multispectral high-speed imaging of explosive volcanic activity

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Abstract: Explosive volcanic eruptions eject a mixture of rock/magma fragments and gases. Ground-based eruption imaging, combining thermal infrared, high-speed visible, and ultraviolet videos, can parameterize ejection dynamics and gas/fragment ratios at the seconds and centimeter scales.
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1. Explosive volcanic eruptions

Explosive volcanic eruptions are global phenomena threatening life and society but also contributing to the life cycle of the planet. Ranging in scale from less than one to thousands of kilometers and from a few seconds to years, the processes involved in explosive volcanism share the same fundamental dynamics at all volcanoes. Key to the development of an eruption is the release of pressurized volatiles – magmatic gases plus water from the surrounding environment – that drive the dispersal of solid and molten fragments. The physical characteristics of the fragments, primarily their size, and eruption characteristics, primarily the mass eruption rate, i.e., the mass flux of gas and fragments over the time unit, determine the emplacement modes of the eruption products:1) the ballistic launch of boulders, 2) the fallout of ash particles from wind-advected plumes, and 3) the mass emplacement of ground-hugging pyroclastic density currents, or 'glowing avalanches'.

Quantitative parameterization of explosive eruptions is at the base of eruption modeling and hazard mitigation, but explosive processes are intrinsically fast and dangerous. A well-established approach in eruption studies is that of using so-called 'laboratory volcanoes', i.e., volcanoes featuring persistent and mild explosive activity that can be approached relatively safely with a variety of measuring instruments and techniques. One of the techniques that is currently gaining momentum is eruption imaging (Fig. 1). Taking advantage of recent progress in both hardware (e.g., CMOS, CCD, solid-state memories) and software (e.g., particle image velocimetry, optical flow) evolution, ground-based remote sensing of explosive eruptions is opening new perspectives in eruption parameterization.

Fig. 1. Multiparametric deployment at Stromboli volcano (Italy) in 2017. Several high-speed and thermal cameras are pointing towards the active volcanic vents, which are located to the right (north) and below the ridge hosting the instruments and researchers (aerial picture courtesy of Ulrich Kueppers, LMU University of Munich).

2. Eruption imaging

Portable thermal infrared cameras made of uncooled microbolometer arrays have been used in volcanology since more than ten years. These instruments can detect thermal anomalies with a time and space resolution unachievable from satellite, and are an important component of many volcano monitoring networks, as well as key tools for the characterization of explosive volcanic activity [1]. More recently, ultraviolet cameras (CCD- or CMOS-based cameras with specific lenses and filters) have been developed to image the sulfur dioxide (SO_2) gas released by volcanoes [2]. These measurements are crucial for determining the degassing budget of volcanoes but also to estimate the amount of volcanic gases driving explosions [3]. Finally, visible-light sensors recording at frame rates > 500 frames per second, coupled to large telelenses, are now being used to parameterize explosive volcanic activity with an unprecedented temporal and spatial resolution, better than 2 mm/pixel at a distance of about 300 m. Applications include measurements of the size and ejection velocity and angle of the fragments [4], but also the direct visualization of volcanic jet dynamics, plume growth, particles sedimentation, and acoustic waves emission.

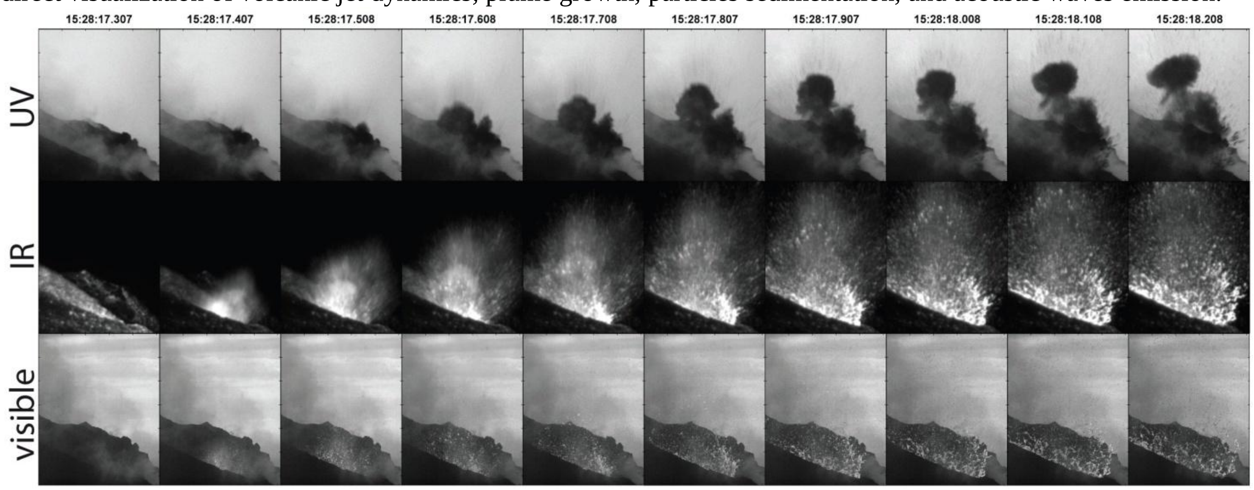

Fig. 2. Synchronized still frames of the initial phase of a Strombolian-style volcanic explosion at Stromboli volcano in 2013 (at the image top, the Coordinated Universal Time of each frame). In the top row, images from a UV camera highlighting the gas (SO_2 only) component of the volcanic ejecta. In the central row, TIR images displaying the strong thermal contrast between the magma fragments at eruptive temperature (>1200 K, bright tones) and the surrounding background at ambient temperature (<300 K, dark background). In the bottom row, still frames from the high-speed camera displaying the eruption in the visible wavelength and with a resolution more than double that of the other cameras. All the images cover the same 40 m high by 32 m wide field of view.

A combination of the different imaging system mentioned above has been attempted recently in what is, in effect, the first, filed-based, high-resolution multispectral eruption imaging experiment [5]. Thermal infrared, UV and high-speed cameras have been deployed simultaneously at Stromboli volcano (Italy) to provide the most complete parameterization of a single explosive volcanic event so far (Fig. 2). In particular, UV and high-speed cameras have been used to measure, respectively, the mass flux of gas and fragments released by the explosion. A subsequent comparison of these measurements with FLIR data show that the latter, adequately filtered, can provide a robust proxy for both the flux of gas and fragments.

3. References

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