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Fractal analysis: A new tool in transient volcanic ash plume characterization.

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Transient volcanic plumes are time-dependent features generated by unstable eruptive sources. They represent a threat to human health and infrastructures, and a challenge to characterize due to their intrinsic instability. Plumes have been investigated through physical (e.g. visible, thermal, UV, radar imagery), experimental and numerical studies in order to provide new insights about their dynamics and better anticipate their behavior. It has been shown experimentally that plume dynamics is strongly dependent to source conditions and that plume shape evolution holds key to retrieve these conditions. In this study, a shape evolution analysis is performed on thermal high-speed videos of volcanic plumes from three different volcanoes Sakurajima (Japan), Stromboli (Italy) and Fuego (Guatemala), recorded with a FLIR SC655 thermal camera during several field campaigns between 2012 and 2016. To complete this dataset, three numerical gas-jet simulations at different Reynolds number (2000, 5000 and 10000) have been used in order to set reference values to the natural cases. Turbulent flow shapes are well known to feature scale-invariant structures and a high degree of complexity. For this reason we characterized the bi-dimensional shape of natural and synthetic plumes by using a fractal descriptor. Such method has been applied in other studies on experimental turbulent jets as well as on atmospheric clouds and have shown promising results. At each time-step plume contour has been manually outlined and measured using the box-counting method. This method consists in covering the image with squares of variable sizes and counting the number of squares containing the plume outline. The negative slope of the number of squares in function of their size in a log-log plot gives the fractal dimension of the plume at a given time. Preliminary results show an increase over time of the fractal dimension for natural volcanic plume as well as for the numerically simulated ones, but at varying rates. Increasing fractal dimension correspond to an increase in the overall complexity of plume shape and thus to an increase in flow turbulence over time. Accordingly, numerical simulations show that, fractal dimension increases faster with increasing Reynolds number. However, other parameters seem to play a role in volcanic plumes evolution. The features of the eruption source (e.g. vent number, size and shape, ejection duration, number and time interval between the different ejection pulses that characterize unsteady eruptions) seem also to have an effect on this time evolution with for example a single vent source generating a faster increase of the fractal dimension than in the case of a plume fed by several vents over time. This first attempt to use fractal analysis on volcanic plume could be the starting point towards a new kind of tools for volcanic plume characterization potentially giving an access to parameters so far unreachable by only using more traditional techniques. Fractal dimension analysis applied on volcanic plumes could directly link a shape evolution to source conditions and thus help to constrain uncertainties existing on such parameters.