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The dynamics of turbulent jets with reversing buoyancy rising in a crossflow: Implications for the collapse of explosive volcanic columns in a windy atmosphere

Guillaume Carazzo (1), Audrey Michaud-Dubuy (1), Edouard Kaminski (1), and Frédéric Girault (2)

(1) Institut de Physique du Globe de Paris, Dynamique des Fluides Géologiques, France (carazzo@ipgp.fr), (2) Institut de Physique du Globe de Paris, Physique des Sites Naturels, France

Explosive volcanic columns commonly undergo a transition from a stable Plinian plume to a collapsing fountain regime. A major goal of physical volcanology is to predict quantitatively the limit of the flow regimes as a function of exit conditions at the vent and atmospheric environment. Theoretical models predict that winds can strongly affect the column dynamics causing bending and enhancing turbulent air entrainment in the flow. This phenomenon lowers the plume density and thus tends to promote the formation of a stable plume. In this study, we quantify how the plume/fountain transition is affected by winds using a series of new laboratory experiments on turbulent jets with reversing buoyancy rising in a crossflow. The experiments consist in injecting downwards a mixture of ethanol and ethylene glycol (EEG) in a tank containing fresh water. The density of the EEG-water mixture is a nonlinear function of mixing ratio allowing us to reproduce the convecting and collapsing behavior of explosive volcanic columns. The jet source is towed at a constant speed through the stationary fluid in order to produce a uniform crossflow. According to the range of source and environmental conditions, the turbulent jet forms a collapsing fountain or a stable plume that may be either strong, distorted or bent-over when the wind speed is high. We show that the plume/fountain transition is strongly controlled by the ratio of the horizontal wind speed and vertical plume velocity, and the Richardson number defined at the source. The results are found consistent with theoretical predictions of 1D models of turbulent jets, and provide new constraints on the entrainment coefficient due to wind. The latter parameter is crucial for estimating the critical mass eruption rate feeding a volcanic column before collapse in windy conditions, and hence can be used to improve eruption risk assessment.