A NEW ANALYTICAL SCALING LAW FOR THE RISE OF BUOYANT JETS IN A CROSSFLOW AND IMPLICATION FOR WIND-BLOWN VOLCANIC PLUMES: COMPARISON WITH EXISTING SCALINGS

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Various scaling relationships relate the height of volcanic plumes to key controls including eruptive source conditions, atmospheric density stratification, turbulent entrainment, and wind stresses (Fig. 1). Existing observational, analog, and numerical studies used to test these scalings capture only a narrow range of eruption source and atmospheric conditions, in particular wind. Accordingly, we develop a new analytical scaling for buoyant plume rising in density-stratified uniform crossflow. We compare this scaling to existing analytical [1, 2] and semi-empirical [3, 4, 5] scalings using an extensive experimental and eruption datasets [5, 6]. We show that our proposed scaling best predicts the height of experimental plumes. A key outcome of this scaling is an improvement over existing constraints on entrainment coefficients: in particular, we show that the ratio of the wind to radial entrainment coefficients is constant through a large span of dynamical regimes. Applied to natural eruptions, our scaling performs comparably well to published semi-empirical scalings typically applied in models. Furthermore, in a comparative analysis, we show that the performance success of tested existing scalings is restricted to the range of eruption magnitudes for which they are calibrated. For moderate to high wind stresses, plume shape evolves over the plume height, violating the self-similarity assumption on which all scalings and integral model results rely. Accordingly, we address why our and published scalings capture the effects of variable wind forcing nevertheless. We discuss consequences for relaxing the self-similarity hypothesis as well as potential improvements for standard integral plume models, in turn.

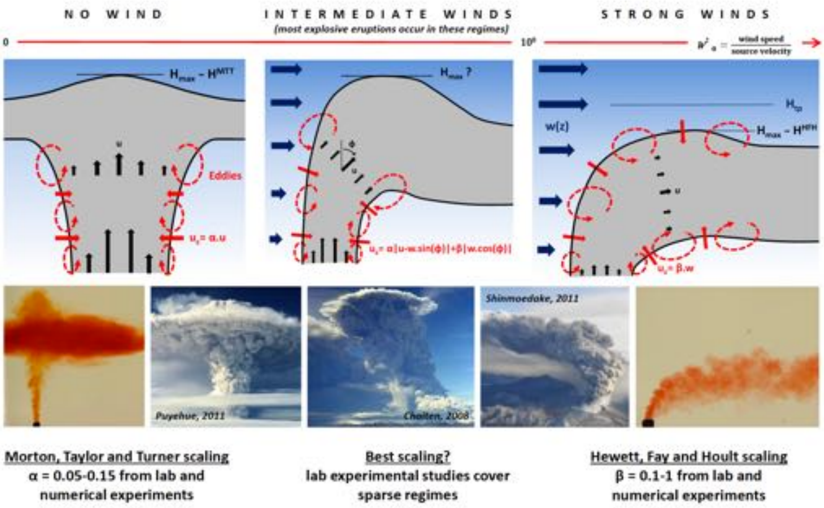

Figure 1. Entrainment hypothesis and scalings for plumes height across different wind regimes: quiescent atmosphere (left), intermediate winds (center), and high winds (right).

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