Impact of wind on the condition for column collapse of volcanic plumes

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Collapse of volcanic plumes has significant implications for eruption dynamics and associated hazards. We show how eruptive columns can collapse and generate pyroclastic density currents (PDCs) as a result of not only the source conditions, but also of the atmospheric environment. The ratio of the potential energy and the kinetic energy at the source quantified by the Richardson number, and the entrainment efficiency quantified by the radial entrainment coefficient have already been identified as key parameters in controlling the transition between a buoyant and collapsing plume. Here we quantify how this transition is affected by wind using scaling arguments in combination with a one-dimensional plume model. Air entrainment due to wind causes a volcanic plume to lower its density at a faster rate and therefore to favor buoyancy. We identify the conditions when wind entrainment becomes dominant over radial entrainment and quantify the effect of wind on column collapse. We propose a generalized regime diagram based upon (i) the ratio of the Richardson number and the radial entrainment coefficient and (ii) the ratio of the wind entrainment rate and the radial entrainment rate. Previously used diagrams under the condition of choked flow can be considered as a special case within this diagram. The mass flow rate is shown to be an ambiguous parameter to assess column collapse as both an increase and decrease can lead to collapse. Rather the effects of its independent constituents (density, exit velocity, and vent radius) should be considered.

Wind significantly affects eruption dynamics as it can (i) reduce the final height of the plume, (ii) be the dominant entrainment mechanism, and (iii) prevent a plume from collapsing. Therefore, strong winds are natural allies in reducing hazards present at volcanoes both on a proximal (less PDCs) and regional scale (reduced height). Observations of several eruptions qualitatively confirm this behavior. In particular, the parameter range derived for the 2010 Eyjafjallajokull eruption suggests the wind enhanced the buoyancy of the plume, where in a still environment this plume would have probably collapsed.