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Entrainment in dilute pyroclastic density currents

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Pyroclastic density currents (PDCs) can reverse buoyancy as a result of air entrainment and expansion; such reversals result in production of coignimbrite plumes and limit the runout distance of the currents. Understanding air entrainment is thus critical for predicting PDC behavior, but studying this process in natural PDCs is challenging because of their size and hazard. We examine air entrainment in PDCs using scaled laboratory experiments comprising heated particles turbulently suspended in air. Temperature within the experiments is monitored with an array of high-frequency thermocouples, and experiments are illuminated with either fixed laser sheets (for simultaneous observation of multiple, independent 2D planes at 30 Hz) or a swept laser sheet (for measuring the current volume, 3D surface area, and internal structures at <2 Hz). Our results show that entrainment is highly variable with time, and different parts of currents (e.g. nose, head, body) entrain air with different mechanisms and efficiencies. Prior to liftoff, most entrainment occurs at the back of the head; large currents also entrain through lobe and cleft structures at the current nose. Those differences are broadly consistent with other high-Reynolds number density currents. When liftoff begins, entrainment through the lateral current margins dominates; this mode of entrainment is largely unique to PDCs. The entrainment coefficient, ?, is defined as the ratio of entrainment velocity to characteristic current velocity. Density currents are often assigned ? = 0.1, although recent work shows that the value can increase to 0.5 during liftoff and varies through time. Our experiments show that ? can range from ~0 to >1 over timescales comparable to the currents' largest turbulent timescale. This work shows that caution must be used in applying constant values of ? to PDCs, as the actively-entraining portions of currents, and the efficiencies with which they entrain, evolve through time.