Effects of temperature on the run-out distance of large-scale pyroclastic density currents: Numerical simulation of a two-layer depth-averaged model

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During large-scale explosive volcanic eruptions, a mixture of volcanic particles and gas is continuously ejected from the volcanic vent and can flow along the ground surface as a pyroclastic density current (PDC). Understanding the relationship between the run-out distance of PDC (i.e., the extent of PDC deposits) and the eruption conditions (e.g., the magma discharge rate and the temperature of erupted mixture) is desired to mitigate volcanic hazard associated with explosive eruptions. This study aims to clarify the effect of temperature on the run-out distance of large-scale PDCs on the basis of numerical simulations. The effect of temperature is a key issue, because it closely relates to the eruption style; the temperature ranges from less than 500 K for phreatomagmatic eruptions to more than 1000 K for magmatic eruptions.

Generally, the run-out distance of PDC is affected by the vertical stratification of particle concentration in PDC; it is determined by lift-off of the upper dilute part (particle concentrations < 1 vol.%) or deposition of the lower dense part (˜ 10—50 vol.%). To reproduce the run-out distance of a density current with a strong density stratification, we have developed a new two-layer depth-averaged model. In order to evaluate the effects of temperature on the PDC dynamics, our model considers entrainment of ambient air into the upper dilute current, and thermal expansion of the entrained air. We assumed that a homogeneous dilute current is steadily supplied during time > 0 from the source vent on a horizontal ground surface. We performed a parametric study for various temperatures of the dilute current at the source (400—1200 K).

The numerical results show that, as a dilute current spreads radially from the source, the current density decreases through particle settling, air entrainment, and thermal expansion of the entrained air. When the frontal region of the dilute current becomes lighter than the ambient air to reverse buoyancy and lift off, the dilute current stops forward propagation and converges to a steady state (the distance between whose front position and the source position is referred to as $r_{\infty U}$). Particles settling from the base of the dilute current form a thin dense current, which also spreads radially. As the radial mass flux of the dense current at the front balances the basal deposition rate, the dense current stops forward propagation and converges to a steady state (the distance between whose front position and the source position is referred to as $r_{\infty L}$). The result of the parametric study shows that the relative magnitude between $r_{\infty U}$ and $r_{\infty L}$ depends on the temperature: $r_{\infty U}$ is shorter than $r_{\infty L}$ in high-temperature cases (> 600 K) whereas $r_{\infty U}$ is longer than $r_{\infty L}$ in low-temperature cases (< 600 K). This variation comes from the fact that the lift-off distance of the dilute current (i.e., $r_{\infty U}$) significantly increases as the temperature decreases, because thermal expansion of entrained air is suppressed with the decreasing temperature. The results of the low-temperature cases (i.e., $r_{\infty U} > r_{\infty L}$) explain the observation that stratified surge deposits originated from dilute PDCs are widely observed in the deposits of phreatomagmatic eruptions.

Keywords: Pyroclastic density current, Two-layer model, Run-out distance, Temperature of erupted material, Magmatic eruption, Phreatomagmatic eruption