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A numerical study of pyroclastic flow dynamics: Development of a two-layer model based on Shallow-Water equations

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Pyroclastic flows are density currents of mixtures of volcanic particles and gas that flow on the ground surface. They are characterized by wide ranges of density ratio $\rho/\rho_a(\sim 10^0\text{-}10^3)$, where ρ and ρ_a are the densities of current and ambient, respectively. The dynamics of pyroclastic flows are affected by many physical factors such as settling of particles and entrainment of ambient air. In order to understand these effects on the dynamics of pyroclastic flows with wide ranges of ρ/ρ_a, we have developed a new numerical model based on shallow-water equations. The model has been verified by applying it to the dam-break problem, for which analytical solutions of different fluid dynamical stages are available.

In order to calculate the dynamics of pyroclastic flows with wide ranges of ρ/ρ_a using the shallow-water equations, the balance between the driving force and the dynamic reaction at the flow front (i.e., front condition) should be correctly taken into account. In previous works, two types of numerical models have been proposed to express the front condition: Boundary-Condition (BC) type model and Artificial-Bed (AB) type model. BC type model is a numerical method in which the front condition is applied to the boundary condition at the flow front. In AB type model, the front condition is calculated by setting a thin artificial bed ahead of the front. We have revealed that AB type model is applicable to the currents of $\rho/\rho_a \geq 100$, whereas BC type model should be used for the currents of $\rho/\rho_a \leq 100$. We have also developed a rigorous algorithm calculating the front condition using BC type model.

Our numerical method enables us to investigate the effects of the settling of particles and the entrainment of ambient air on the flow dynamics for wide ranges of ρ/ρ_a. Particle settling decelerates the front speed and enhances the formation of "jump" that separates the current into head and tail parts. Entrainment of ambient air also decelerates the front speed and suppresses the formation of the jump between the head and the tail of the current. Our results also suggested that the rate of entrainment tends to increase as ρ/ρ_a increases. When both the effects of particle settling and entrainment are present, the competition between these two effects is considered to result in diverse flow patterns.

Pyroclastic flows with large density gradients are generally divided into a dilute overriding part ($10^0 \leq \rho/\rho_a \leq 10^1$) and a dense basal part ($\rho/\rho_a \sim 10^3$). In order to simulate the dynamics of such realistic pyroclastic flows, we have developed a two-layer model where the dynamics of the dilute overriding part is solved by BC type model and that of the dense basal part is solved by AB type model. In the dilute overriding part, the effects of the settling of particles and the entrainment of ambient air are taken into account. In the dense basal part, the effects of the settling of particles and the basal friction are taken into account. We present some preliminary results showing temporal evolutions of the dilute overriding part, the dense basal part and the deposits.

Keywords: pyroclastic flows, density currents, gravity currents, Shallow-Water equations, two-layer model