Numerical simulations of a two-layer shallow-water model for pyroclastic density current

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During an explosive volcanic eruption, a hot mixture of volcanic particles and gas is continuously ejected from the volcanic vent and develops an eruption column. When the density of the mixture remains higher than that of the ambient air, the eruption column collapses to produce pyroclastic density currents (PDCs). PDCs are characterized by strong density stratification, whereby a dilute current (particle suspension flow) overrides the dense basal current (fluidized granular flow). The dynamics of PDCs is affected by physical processes within each of the dilute and dense parts, such as thermal expansion of ambient air entrained into the dilute part and basal resistance in the dense part. It also depends on the particle transport between the dilute and dense parts. We aim to understand these effects on PDC dynamics and the resulting run-out distance, by using numerical simulations.

We have developed an unsteady two-layer model to describe density currents with strong density stratification. In this model, each of dilute and dense parts is assumed to be uniform in any vertical section and is formulated by shallow-water equations. In the dilute part, the effects of particle settling, entrainment of ambient air, thermal expansion, interfacial drag between the dilute and dense parts, and resistance of ambient at the flow front are taken into account. In the dense part, the effects of basal resistance, sedimentation, and the particle supply from the dilute part are included. The equations are numerically solved by the finite volume method using the HLL scheme. A stationary dilute mixture with its higher density than that of the ambient air is initially (i.e., $t = 0$) set in the rectangular reservoir with a solid backwall, and an additional mixture with the same composition as the initial mixture is supplied to the reservoir at a constant rate at $t > 0$. A density current is produced on a horizontal ground surface by an instantaneous release of the mixture at $t = 0$ and the subsequent steady supply of the mixture in the reservoir.

We calculated time evolution of a PDC (e.g., thicknesses and velocities of dilute and dense parts, and thickness of deposit). The result is divided into two stages. In the first stage (Figure 1a), the dilute part propagates, and the dense part develops. Because the dense part propagates slowly owing to basal resistance, the maximum run-out distance in this stage is determined by the front position of the dilute part (L_1). In the second stage (Figure 1b), the density of the frontal region of the dilute part falls to that of the ambient air owing to particle settling and thermal expansion of entrained air. The mass of this frontal region ascends from the current into a co-PDC plume (i.e., co-ignimbrite ash cloud), whereas the dilute part around the source forms a steady dilute density current. The run-out distance of the steady current (L_S) is much shorter than L_1. Subsequently, the dense part extends beyond L_1, and the run-out distance of the PDC is determined by the front position of the dense part (L_D).

Previously, the run-out distance of PDC was estimated on the basis of a steady one-layer dilute PDC model (Bursik & Woods, 1996). This run-out distance corresponds to L_S, and does not represent L_1 or L_D. Therefore, the run-out distance proposed by the previous study may be underestimated.

Keywords: pyroclastic density current, shallow-water equation, two-layer model, run-out distance, particle suspension flow, granular flow

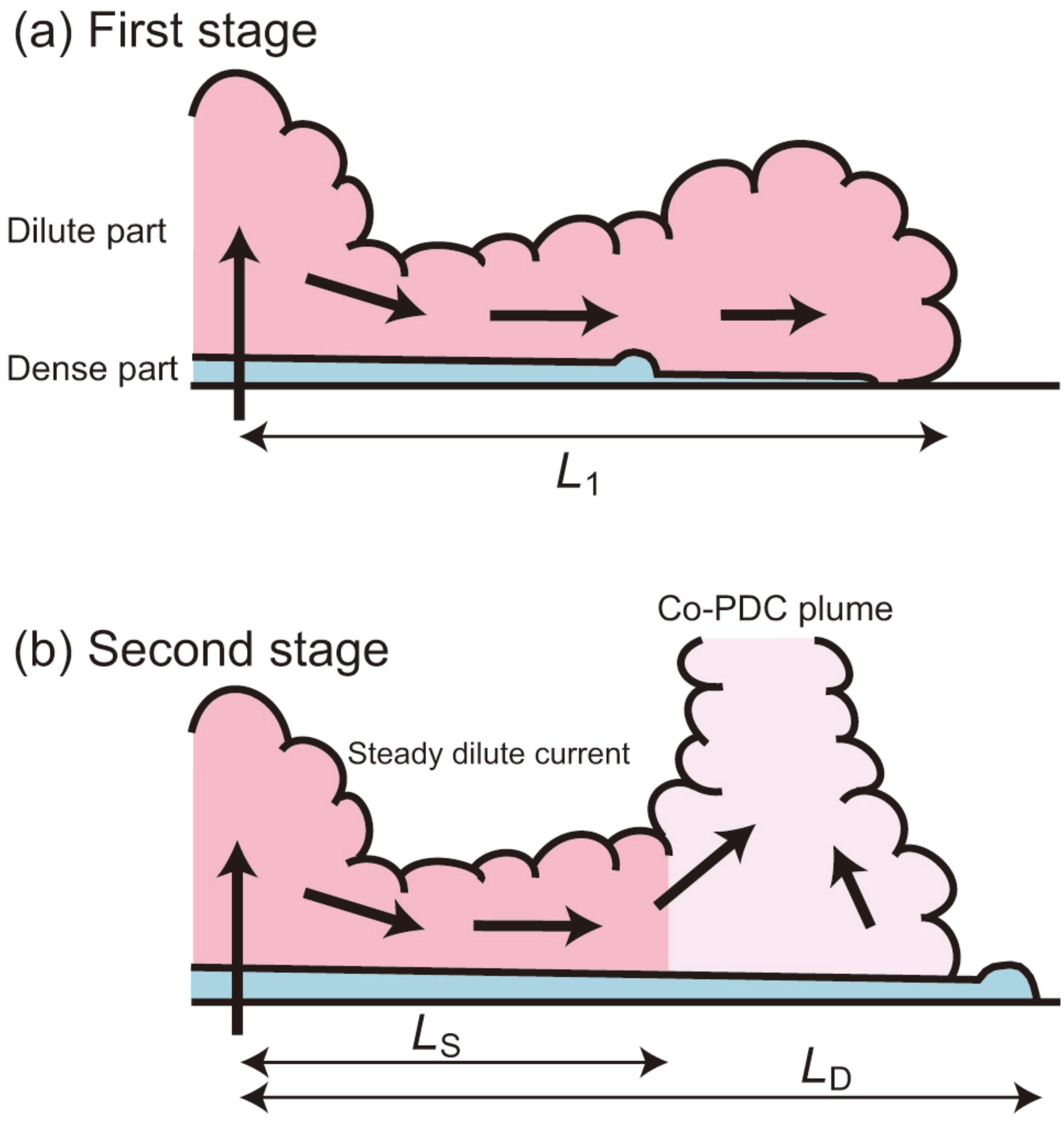

Figure 1 Schematic illustrations showing time evolution of a PDC.