Development of a two-dimensional two-layer model for large-scale pyroclastic density currents: Effects of topography and erosion on the deposit distribution

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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 on the ground surface as a pyroclastic density current (PDC). PDCs produce deposits with various characteristics. Clarifying how the characteristics of deposits are related to the dynamical features of PDCs is an important issue for volcanology. The dynamics of PDCs are controlled by eruption conditions, topography, and various physical processes in PDCs (e.g., deposition and erosion). PDCs are generally stratified in terms of their particle concentration. The upper dilute region (particle concentration <1 vol.%) is affected by particle settling, entrainment of ambient air, thermal expansion of the entrained air, and resistance of ambient air at the flow front, whereas the lower dense region (particle concentration ~50 vol.%) is controlled by friction, deposition, and erosion at the base. Our purpose is to clarify the effects of the above factors (especially, topography and erosion) on the distribution of large-scale PDC deposits.

For large-scale PDCs, the thickness of the dilute region is 10^2–10^3 m, and that of the dense region is 10^{-1}–10^0 m. Topography with height differences of less than 10^2 m has little effect on the dilute region, but can significantly change the behavior of the dense region. We developed a numerical two-layer PDC model that applies a one-dimensional axisymmetric depth-averaged equation to the upper dilute region and a two-dimensional depth-averaged equation to the lower dense region. The interaction between the dilute and dense layers is modeled as the mass and momentum transport associated with particle settling from the dilute layer to the dense layer. This presentation shows numerical simulations under the same eruption conditions as those of the eruption at Mt. Pinatubo on June 15, 1991. For generating the surface mesh, we used a digital elevation model for a 40 km square around Mt. Pinatubo, which is based on the measurement in 2006–2011 (ALOS world 3D - 30m). Simulations on a horizontal plane were also performed for comparison.

In the numerical simulations, a dilute layer expands in a steady state radially from the volcanic vent, and the particles settling from its base form a dense layer. The dense layer expands toward the distal area while forming deposits. As the dense layer expands, its horizontal mass flux decreases owing to the basal deposition. When the horizontal mass flux at the flow front is balanced by the basal deposition rate, the front stops expanding and the dense layer converges to a steady state, where the total deposition rate is balanced by the total particle supply rate from the dilute layer.

Our numerical analyses indicate that topography and erosion play an important role in determining the run-out distance of the dense layer (i.e., the distribution of PDC deposits). In the simulations with the Pinatubo topography, the dense layer flows mainly along the valleys and its maximum run-out distance increases. This is because the rate of decrease of the horizontal mass flux for the distance is reduced along the valleys. The simulations with erosion show that the dense layer forms relatively thin deposits due to strong erosion (i.e., re-entrainment of deposits) on the steep slopes near the source and its run-out distance along the valleys further increases compared with the cases without erosion. The strong erosion near the source is caused by the momentum supply associated with particle settling from the upper dilute layer as well as the acceleration due to the steep slopes. The erosion reduces the effective value of the deposition speed, which accounts for the increase in the maximum run-out distance. The above topographic and erosional effects can explain the geological observation that the PDC deposits of the June 15, 1991 eruption of Mt. Pinatubo are thick in the valleys and relatively thin on the steep slopes near the source.

Keywords: Pyroclastic density current (PDC), Run-out distance, Distribution of ignimbrite, Two-dimensional two-layer depth-averaged model, Mt. Pinatubo, Gravity current

