A tephra-dispersal model based on 3-D simulations of eruption clouds and experiments on particle settling in turbulent flow

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During an explosive volcanic eruption, hot volcanic gases and pyroclasts are ejected from the volcanic vent into the atmosphere. The ejected materials mix with ambient air and heat it. As the mixture of the ejected materials and the air becomes buoyant because of expanding air, an eruption column rises. After the eruption column reaches the neutral buoyancy level, it flows horizontally as a gravity current, which forms an umbrella cloud. Pyroclasts generated by the explosive volcanic eruption fall out from the umbrella cloud to the ground surface.

In previous tephra-dispersal models, it is assumed that (1) pyroclasts are homogeneously distributed in the umbrella cloud because of turbulence, and (2) they fall out at their terminal velocity from the bottom of the umbrella cloud where turbulence diminishes [e.g., Koyaguchi and Ohno, 2001]. The first assumption is appropriate only when turbulent intensity is sufficiently strong relative to the terminal velocity of particles. Here, we propose a generalized model in which the relationship between the turbulent intensity and the terminal velocity is rigorously taken into account on the basis of 3-dimensional (3-D) numerical simulations of eruption clouds and a series of laboratory experiments on particle settling in turbulent flow.

The simulation model is designed to reproduce the fluid dynamical features of the eruption cloud, such as column height and laterally spreading umbrella cloud as a function of the conditions at volcanic vent such as vent size and exit velocity and magma properties. Because the dynamics of eruption cloud is determined by the buoyancy in the atmosphere, and because the density of the eruption cloud strongly depends on the mixing ratio between the ejected materials and the air due to turbulent mixing, the simulation model is carefully designed to correctly reproduce the turbulent mixing as well as the density of the eruption cloud as a function of mixing ratio by applying (1) 3-D coordinates, (2) high order accuracy calculation scheme (the modified CIP method), and (3) sufficiently small grid sizes. The results of the present 3-D model are validated by the laboratory experiments on turbulent jets and plumes. From the 3-D simulations of eruption clouds, we determined the turbulent intensity in the eruption clouds.

Laboratory experiments of particle settling in turbulent flow are performed focusing on the effects of turbulent intensity on the process of particle settling. In the experiments spherical glass-bead particles are mixed in stirred water with variable turbulent intensity, and the spatial distribution and the temporal evolution of the particle concentration are measured. The experimental results suggest that, when the turbulent intensity is large relative to the particle terminal velocity, the particles are homogeneously distributed in the fluid, while they settle at their terminal velocity from the bottom of the fluid. On the other hand, when the turbulent intensity is small relative to the particle terminal velocity, the particle concentration increases from the top to the bottom of the fluid during settling process, which substantially increases the rate of particle settling. Through these experiments we establish a relationship between the setting rate and the turbulent intensity.

The above results of numerical simulations and laboratory experiments show that small pyroclasts (less than 1/8 mm in diameter) are distributed homogeneously throughout the umbrella cloud, whereas relatively large pyroclasts (more than a few mm in diameter) tend to concentrate around the bottom of the umbrella cloud. The generalized tephra-dispersal model in which the gradient of particle concentration is taken into consideration better explains the granulometric data of the deposits of Pinatubo 1991 eruption.