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Effects of vertical diffusivity of particles on distribution of deposits calculated by the tephra-tracking model PUFF

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Understanding the process of tephra dispersion is scientifically important in order to estimate eruption conditions from tephra fallout deposits and also socially and economically required to prepare for risks of tephra-fall, such as air traffic disruption and damages to agriculture, infrastructures and buildings. For this reason, advection-diffusion models for tephra transportation have been developed with simplified assumptions (e.g., TEPHRA2). The final goal of this study is development of a new advection-diffusion model which correctly reproduces the physical process of tephra dispersion in the atmosphere.

In TEPHRA2 model, vertical diffusivity of particles is assumed to be negligible. Under this assumption, if the tephra particles of a single grain size are supplied from a point source in the atmosphere, the distribution of the diffused particles is described by a bivariate Gaussian distribution. When the particles with various sizes are released from different heights, the distribution of the entire tephra deposit can be expressed by a simple superposition of bivariate Gaussian distributions. This assumption makes analyses of geological data easier; however, its limitation should be carefully evaluated because the effect of vertical diffusivity on distribution of tephra deposit is not clear. In this study, we systematically investigated the effect using a particle-tracking model (PUFF).

In PUFF model, Lagrangian particles are advected with the local wind velocity and fall with their terminal velocities. The horizontal and vertical diffusions of particles due to atmospheric turbulence are simulated by random walk formulation. In our calculation, single-sized tephra particles are released from a point source above a vent and they are advected and diffused under a uniform wind condition.

In each run, the released particles diffuse and form a ”particle cloud”; the size of cloud increases with time. Because horizontal diffusivity is set to be much larger than vertical diffusivity, the particle cloud has an oblate spheroid shape. The particle cloud moves horizontally with wind speed and fall to the surface at terminal velocity of particles. There is a time lag between depositions of particles at the bottom and those at the top of the particle cloud extending vertically due to the presence of vertical diffusion. Because of the presence of horizontal wind, the particle cloud keeps its horizontal movement until the settlement of its top after the landing of its bottom. As the result, the tephra particles are finally deposited in an area elongated and slightly widening toward downwind; the distribution of particles on the ground deviates from the bivariate Gaussian distribution. To compare the particle distribution with a bivariate Gaussian distribution, variance, skewness and kurtosis of the particle distribution in parallel and cross wind direction are calculated. The particle distribution has larger variance, skewness and kurtosis in parallel wind direction, whereas larger kurtosis in cross wind direction. These deviations from the bivariate Gaussian distribution are more remarkable for finer particles, lower point sources and faster wind speed condition.

The above results suggest that the vertical diffusivity plays an important role in the distribution of tephra fall deposits. The limitations (source height, grain size, wind speed) of the bivariate Gaussian distribution assumption can be determined by the quantitative comparison with tephra deposits calculated with PUFF model.