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Numerical simulation of medium-scale volcanic eruption clouds: Inner structures and turbulent mixing

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During an explosive volcanic eruption, hot volcanic gases and pyroclasts are ejected from a volcanic vent into the atmosphere, and the ejected materials mix with air due to turbulence. The mixture buoyantly rises because the entrained air expands by heating from the hot solid pyroclasts. The critical condition for column collapse and the dimensions of eruption clouds such as the total height of eruption column are controlled by the turbulent mixing which governs the efficiency of entrainment of ambient air, and they also depend on the phase change of vapor and the separation of solid pyroclasts from the cloud. The effects of the vapor phase change and the solid separation become significant particularly for the medium to small scale eruptions (the mass discharge rate is smaller than 10^7kg/s). In order to systematically investigate these effects, we are developing a numerical model of eruption clouds in the relatively small eruptions. In this presentation, we focus on the features of turbulent mixing in the eruption column for a medium-scale eruption. Using a generalized coordinate system, we have a new 3-D code which can reproduce both of the small structures near the vent and the global features of eruption column in the medium-scale eruptions.

Generally speaking, the mean inflow velocity across the edge of turbulent jet and/or plume is proportional to the mean vertical velocity (Morton et al., 1956). The proportionality constant represents the efficiency of entrainment of the ambient fluid and it is called the entrainment coefficient, k. In the case of the turbulent jet and/or plume into a uniform environment, the value of k is constant (0.07 for the jet and 0.1 for the plume). In the case of eruption cloud, on the other hand, the value of k is not always constant because of the atmospheric stratification and the nonlinear change of eruption cloud density. There are three methods to estimate value of k from the simulation results; (1) the effective value of k is calculated on the basis of the global features of eruption cloud such as the column height and the critical condition for column collapse (Suzuki et al., 2005), (2) the effective value of k as a function of downstream distance from the vent (local k) is calculated using the vertical fluxes (e.g., mass flux, Q) and the vertical change of flux (dQ/dz) (Suzuki and Koyaguchi, 2008, JPGU), and (3) the value of k is calculated from the direct measurement of the mass inflow from the ambient (m_{in}). Since the third method is the most accurate, we have estimated the values of k using (3) and compared them with those using (1) and (2).

Simulation results indicate that the radial profile of the vertical velocity can be approximated by the Gaussian profile (the standard deviation L~0.1). It is also indicated that m_{in} remains at a constant level sufficiently far from the axis and its value is almost same as that of dQ/dz. On the basis of the local measurement of m_{in}, wide variation in the value of k is detected; the value of k is small near the vent (~0.04) and it approaches to 0.1 as the distance increases. The accurate estimations in this study are consistent with the estimations by (1) and (2) in the previous studies and they support the idea that the efficiency of entrainment for the flow of eruption clouds vary with height.