V230-007 Room: Ocean B Time: May 27 15:30-15:45

Numerical experiments of a volcanic eruption cloud: Efficiency of turbulent mixing in an eruption column

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Plinian eruptions involve continuous discharge of a mixture of hot gas and solid fragments from volcanic vents. As the mixture rises, surrounding air is entrained due to turbulence; the air expands due to heating from the hot pyroclasts, which can cause the mixture in the column to become buoyant. Therefore, turbulent mixing of eruption clouds and air is one of the most important processes for eruption cloud dynamics. The classical approach to turbulent entrainment of Morton et al. [1956] assumes that the mean inflow velocity across the edge of a turbulent jet and/or plume in a uniform environment is proportional to the mean upward velocity. In this hypothesis, the proportionality constant (i.e., entrainment coefficient, k) represents the efficiency of entrainment and its value is constant (0.07 for jets; 0.10 for plumes). Recent experimental study (Carazzo et al., 2006) and numerical study (Pham et al., 2006) report that the value of k varies with the downstream distance from the source. In this study, we aim to numerically reproduce the development of eruption columns and to capture the evolution of k in an eruption column because the efficiency of turbulent mixing, k, largely controls the dynamics of eruption clouds such as a height of eruption column and a condition of a generation of pyroclastic flow.

The numerical model is designed to describe the injection of a mixture of solid pyroclasts and volcanic gas from a circular vent above a flat surface of the earth in a stationary atmosphere (Suzuki et al., 2005). We apply a pseudo-gas model because the relative velocity of gas and ash particles is sufficiently small, and employ the Euler equations of a compressible gas. The nonlinear density change of the mixture of the ejected material and air is reproduced by changing the effective gas constant of the mixture in the equation of state for ideal gases. We apply a third-order accuracy scheme with fine grid sizes in order to satisfy the condition where the efficiency of turbulent mixing no longer depends on the grid size.

In this study, we have estimated the value of k as a function of the downstream distance from the volcanic vent (referred to as 'local k'). For the case of small Plinian eruption columns (mass discharge rate of 10^6-10^7 kg/s), local k can be calculated on the basis of the local measurement of the fluxes of volume ($V=UL^2$), velocity ($W=U^2L^2$), mass ($Q=mUL^2$) , and momentum ($M=mU^2 L^2$), where m, U and L are the mean density, vertical velocity, and characteristic length scale, respectively. Substituting U, L, and Q determined from these fluxes in the mass conservation equation (Morton et al., 1956), local k is directly obtained. The results of the preliminary studies show that the entrainment coefficient is small near the vent (k˜0.05) and approaches to 0.1 with increasing distance. This result is consistent with the conclusion of the previous numerical study (Suzuki et al., 2005) and experimental study (Kaminski et al., 2005) that the effective value of k determined from the global features of eruption column varies with height; the effective value of k determined from the condition of the generation of pyroclastic flow is smaller than the one determined from the total height of eruption column.