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Multi-dimensional Structures of Turbulent Mixing between Eruption Cloud and Air in Explosive Volcanic Eruption

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Introduction

Plinian eruptions involve the continuous discharge of a mixture of hot gas and solid fragments from volcanic vents. Air is entrained as the mixture rises; the air expands due to heating from the hot pyroclasts, and can cause the mixture in the column to to become buoyant. Therefore, mixing of eruption cloud and air is one of the most important processes for eruption cloud dynamics. The efficiency of this mixing of eruption cloud and air depends on nature of turbulent mixing. Most of the previous models (e.g.1-D model by Woods[1988]) are based on entrainment hypothesis for turbulent jet and/or plume (e.g.Morton et al.[1956]) that the mean inflow velocity across the edge of a turbulent flow is assumed to be proportional to the mean upward velocity. In order to test this hypothesis, the nature of turbulent mixing must be examined by multidimentional numerical models. We developed a numerical multi-dimensional model (Suzuki et al.[2001]) of eruption columns for this purpose.

Model Description

We calculated the motion of an eruption column from a circular vent on the flat surface of the earth. The dynamics of eruption clouds are based on Euler equation of a compressible gas. The partial differential equations are solved numerically by Roe scheme, which is a general TVD (Total Variation Diminishing) scheme for compressible flow and can simulate the generation of shock waves correctly. Supposing that relative velocity of gas and ash particles is sufficiently small, we can treat eruption cloud as a homogeneous gas. Equation of state (EOS) for the mixture of the magmatic component (i.e. volcanic gas plus pyroclasts) and air can be approximated by EOS for an ideal gas, when volume fraction of the gas phase is very large. EOS for the mixture of air and eruption cloud is approximated by changing their ratio of specific heat so that the molecular weight and the specific heat increases as the magmatic component increases.

In order to study mechanism of turbulent mixing, the following three points must be taken into consideration; (1)multi-dimentional and asymmetric structures of flow, (2)non-linear feature of EOS of magma-air system, and (3)energy cascade of turbulence. In general, the nature of turbulent mixing depends mainly on the global features of large-scale vortex ,but not on the subgrid model. We, therefore, employed the Direct Numerical Simulation (DNS) with sufficiently fine mesh-size and confirmed that the global feature do not depend on mesh size.

Result

We focus on the above first effect (i.e. that of multi-dimentional structure) by comparing the numerical results of axisymmetric 2-D and 3-D coordinates in this study.

In 3-D simulation, the results show that the erupted fluid mixes with the ambient fluid due to horizontal fluctuations, and that the radius of jet increases lineally with height. These features are consistent with the entrainment hypothesis. The entrainment coefficient obtained by the 3-D calculation shows good quantitative agreement with experimental measurements [Papanicolaou & List,1988]. On the other hand, in the axisymmetric 2-D simulation, the erupted fluid rises along the central axis and that entrainment coefficient is substantially smaller than in the 3-D simulation. This difference implies that the efficiency of turbulent mixing is largely reduced because of the boundary condition at the centerline in the axisymmetric coordinate. It is suggested that the 3-D effect (e.g. asymmetry and fluctuation of centerline) shoud be taken into account in order to estimate the effects of the turbulent mixing correctly.