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Large-eddy simulation of eruption column based on multi-fluid approximation - Effects of turbulent model on development

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In the transport of volcanic ash in an explosive eruption, the turbulence is one of the important elements which determine the eruption styles (for example, an eruption column and a pyroclastic flow). The conventional steady one-dimensional eruption column models assume that the effect of turbulent mixing is represented as a constant by a theoretical formula, although it is indicated that the assumption is insufficient in the evaluation of an eruption column near the vent and the estimation of column collapse conditions. In recent years, unsteady three-dimensional eruption column models, which represent the turbulent mixing more directly, have been developed (for example, Neri et al. 2007, Suzuki and Koyaguchi 2010). However, the turbulent modeling of the transports of gas and pyroclastic materials are left unclarified. In this research, the unsteady three-dimensional simulation code of an eruption column based on the multi-fluid approximation is newly built. The effects of the turbulent model are discussed through the comparisons between the simulation results using two kinds of SGS models (sub-models) and the result by the steady one-dimensional model (Woods 1988).

In this code, the model concept of Neri et al. (2007) is adopted, which has advantages in the applicability to various eruption styles and to the transport of the pyroclastic materials of various sizes. The open-source-code FrontFlow/red (Ver.3.0) is used, and the large-eddy simulation (LES) technique based on a sub-grid scale (SGS) model is adopted as expression of turbulence. The gas component and pyroclastic materials of various diameters are classified into two or more phases. The basic equations are the mass, momentum, and energy conservation equations to each phase. The SGS model is a part of the sub-model of the stress term and the diffusion term in the basic equations. As the SGS models of the gas phase, the Smagorinsky model which is generally widely used and the Yuu model which considers the effect of the SGS drag (Yuu et al. 2001) are used, and as the SGS model of the particle phases, the proposal equation of Hinze (1975) considering the relation between the relaxation time of particles and the temporal duration of vortex is used. For the spatial discretization, the third-order TVD scheme is used for the advection terms of the equations of particle phases, and the second-order central difference method for the others. For the time integration, the fractional step method which combined the Euler implicit method and the third-order Adams-Moulton method is applied.

Firstly, the validity of this simulation code was partially estimated in the comparison with the existing experimental data in the simple systems (a single-phase buoyant plume, a gas-particle two-phase jet). As a result, it was confirmed that (1) the simulation values satisfy the similarity law of a buoyant plume, and correspond well with experimental values of the single-phase flow, (2) to the varieties of velocity and turbulent intensities resulting from the velocity difference between the gas phase and the particle phases, the simulation also corresponds well with experiments, (3) and the effects of the SGS model are small in the small-scale laboratory experiment system. Secondly, the simulation results compared with the result of the steady one-dimensional model for an eruption column in a Plinian eruption. As a result, the one-dimensional model and this simulation corresponded well with each other in the style variation of an eruption column according to the velocity at the vent. Moreover, it was suggested that the SGS model considerably affects to simulation results in the real-scale eruption column simulation, since the properties such as the column height varied according to the selection of SGS models.

Keywords: large-eddy simulation, multi-fluid approximation, eruption column, turbulent model