Potential density and T-S diagram for volcanic ash clouds

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Volcanic gas suspending numerous fine particles is discharged from a volcanic vent during explosive volcanic eruptions. The gas-particle mixture mixes with the ambient air owing to vigorous turbulence. This mixture consisting of volcanic gas, fine particles and the air is a volcanic ash cloud. The solid particles are so fine that a volcanic ash cloud can be regarded as a homogeneous fluid. Besides, the solid particles are hot and dense, because they are generated by the fragmentation of magma (molten rocks). Thus, the motion of a volcanic ash cloud is significantly affected by the particles.

The bulk density of the gas-particle mixture at a volcanic vent is considered to be much larger than the density of the ambient air, because solid particles of large density are highly concentrated. On the other hand, the solid particles in volcanic ash clouds behave as heat reservoirs, because they are hot and dense. Thus, the added air into a volcanic ash cloud is heated and expands, and as a result, the bulk density of the mixture decreases while the ash clouds remains hot. If the supplied thermal energy is large enough to make the bulk density smaller than the ambient density, the ash cloud rises high into the atmosphere owing to the buoyancy. Otherwise, the bulk density remains larger than the ambient air and the ash cloud spreads along the ground surface resulting in a hazardous pyroclastic flow.

For the reason described above, the quantitative method to evaluate the dependences of the bulk density on the temperature and solid particles concentration are desirable. Therefore, we introduce powerful variables, potential density and potential temperature, which describe the state of volcanic ash clouds. The variables are derived by modifying the potential temperature and potential density that are often used in meteorology to consider the stability of the atmosphere. The modified potential temperature and modified potential density include the effect of suspended fine particles, which are incompressible.

Since the modified potential density excludes the effect of pressure change due to atmospheric stratification, the modified potential density depend only on the modified potential temperature and the mass fraction of solid particles in volcanic a ash cloud. Thus, we can introduce a diagram on which the contours of constant modified potential density are drawn on the plane of the modified potential temperature and the mass fraction of solid particles. We call it T-S diagram. T-S diagram is useful to evaluate the buoyancy forces acting on a volcanic ash cloud. The discussion with T-S diagram indicates that the initial temperature of pyroclastic surges observed during the Unzen eruption in 1991 is higher than 600K. We demonstrate the usefulness of T-S diagram by using the results obtained from a numerical simulation for a pyroclastic surge.