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3-D numerical simulations of eruption clouds: Effects of the environmental wind on column height

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During an explosive volcanic eruption, an eruption cloud which is ejected from volcanic vent with a high temperature becomes buoyant to generate an eruption column. The heights of eruption column are key observable data for understanding the dynamics of eruption cloud and estimating the eruption conditions at the vent. Therefore, to clarify the relationship between the column height and eruption conditions has been one of the most important issues from the viewpoint of disaster prevention as well as volcanology. Woods [1988] proposed a steady vertical 1-D model of eruption column in a calm environment. This model predicts the column height ($H_{no-wind,1D}$) when the atmospheric condition, the magma properties (temperature and water content), and the eruption conditions (mass discharge rate and exit velocity) are given. Bursik [2001] proposed a steady 1-D model in which the effect of environmental wind is taken into account. This model predicts that the column height in the wind field ($H_{wind,1D}$) is lower than those without the wind ($H_{no-wind,1D}$). In the Shinmoe-Dake 2011 eruption, the column heights in a wind field were accurately measured by means of the weather radar system. The observed column heights are inconsistent with the predictions by the 1-D models ($H_{no-wind,1D}$, $H_{wind,1D}$). In this study, we aim to develop a 3-D numerical model that can quantitatively reproduce column heights in a wind field, and to study the effects of wind on column height.

Using a 3-D unsteady model of eruption cloud [Suzuki et al., 2005], we carried out a numerical simulation of Shinmoe-Dake 2011 26-27th Jan eruptions. The wind velocity, density, pressure, and temperature on the basis of the NHM model [JMA] are applied to the atmospheric condition. On the basis of the petrological data, the magma temperature and water content are assumed to be 1000 K and 3 wt.%, respectively. The average mass discharge rate can be estimated to be 10^6 kg/s from the observation by the tilt-meter. The 3-D model successfully reproduces the eruption column which is strongly bent-over by the environmental wind. The total height of eruption column shows quantitative agreement with the observation.

In order to investigate the effects of wind on column height, we carried out some simulations for variable wind profiles and compared the 3-D simulation results with the 1-D predictions (i.e., $H_{wind,1D}$). The results show that the total height of eruption column in all the cases of the 3-D simulations are higher than $H_{wind,1D}$. Some cases show that the central axes of horizontal flows are consistent with $H_{wind,1D}$, whereas others show that the central axes are higher than Hwind,1D. These results indicate that the column height depends not only on the average wind speed but also on the wind profile. It is suggested that the basic physics of eruption column dynamics (e.g., the effect of wind on entrainment coefficient) should be systematically studied in order to quantitatively predict the column height in a wind field.

Keywords: volcano, eruption cloud, numerical simulation, turbulent mixing