3D numerical simulations of eruption cloud in the 2022 Tonga eruption

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On January 15, 2022, the Hunga Tonga - Hunga Ha'apai volcano caused an explosive eruption. It was reported that a large amount of volcanic eruption rose, and its maximum altitude exceeded 50 km (NASA, 2022), which was the highest eruption altitude ever observed. The radius of the horizontally expanded eruption called an umbrella cloud reached about 260 km 80 minutes after the eruption onset, which was larger than the umbrella cloud radius of the 1991 eruption of Mount Pinatubo at the same elapsed time from the eruption onset. In addition, a pressure change of several hPa was observed in Japan, which is 8000 km away from the volcano, and a tide level change, which is thought to be excited by the pressure wave caused by the eruption, was also observed in Japan. These observations suggest that the eruption was substantially intense. In this study, we performed a numerical simulation of an eruption cloud to understand this eruption phenomenon.
A two-fluid model, SK-3D (Suzuki et al., 2005 JGR), was used for the numerical calculation. Assuming a computational region filled with a standard tropical atmosphere, the lower surface is the sea level with slip conditions. A circular volcanic vent was in the center of the lower surface. A mixture of magmatic pyroclasts, volcanic gas, and seawater was ejected for 1 hour. It is assumed that the pyroclastic materials are sufficiently small and are in dynamically and thermally equilibrium with the gas phase. The exit velocity was the sound speed of the ejected mixture.
As a result of preliminary calculations, it was found that the behavior of the eruption cloud and its altitude changed significantly depending on the amount of seawater mixed with magmatic material at the vent. When the mass fraction of mixed seawater in the ejecta was 0 wt.%, that is, in the case of a magmatic eruption, a part of the eruption collapsed, and a pyroclastic flow was generated. In this case, the maximum altitude of the eruption was 30-40km. When 10 wt.% of mixed seawater was contained, the pyroclastic flow was not generated, and it became a strong buoyant flow. The altitude of the eruption column exceeded 50 km. Furthermore, when the proportion of mixed seawater was high (20 wt.%), a stable eruption column was formed, but the eruption altitude remained at about 40 km. We also conducted a parametric study of mass eruption rate, which is representative of the eruption intensity. The umbrella cloud radii observed could be explained when the eruption rate was $2-3 \times 10^9$ kg/s.

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