# 3D numerical simulations of volcanic jets inside a crater during explosive volcanic eruptions

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During explosive volcanic eruptions an eruption column forms a buoyant plume or collapses to generate a pyroclastic flow. Since the impact and type of volcanic hazards are largely different between these two eruption styles, it is important to predict the condition where an eruption column collapses (i.e., the column collapse condition). One of the main quantities determining the column collapse condition is the initial upward momentum. The initial upward momentum depends on the mass flow rate at the crater base and the crater shape. The presence of a crater causes the formation of expansion and/or shock waves inside and/or just above the crater, which leads to a transition between supersonic and subsonic eruptions. The influence of crater shape on eruption column dynamics was recently investigated by Koyaguchi et al. (2018) on the basis of a quasi-1D steady model for the flow inside crater. Their model implicitly assumes that pressure is uniform in each horizontal slice along the flow inside the crater. However, Ogden (2011) showed that this assumption is valid only for small open angles. If $\theta > 30º$, the pressure distribution is distorted, because 2D waves are generated around convex corners (Prandtl-Meyer expansion). As a result, the quasi-1D approach is no longer valid. In this study, we investigate the whole range of possible crater open angles using 3D simulations inside the crater. We conducted 3D simulations of flow inside and just above the crater under uniform pressure distributions at the crater base for different open angles ($\theta$ = 15º, 30º, 45º, 55º, 75º) . The representative results are as follows.

For given mass flow rate at the crater base, the flow inside and just above the crater depends on ratio of cross-sectional area at the top and the base of crater (*At/Ab*) and open angle of the crater ($\theta$). For all the investigated cases, when $\theta$ is sufficiently, the physical quantities at the crater top are approximately uniform. In this case, the 3D simulations are consistent with what are predicted by the quasi-1D approach. When *At/Ab* is small, an underexpanded flow occurs at the crater top. A jet from the underexpanded flow has a large momentum flux after the decompression processes just above the crater. As *At/Ab* increases, an overexpanded flow occurs. A jet from an overexpanded flow with relatively large *At/Ab* can have a small momentum flux due to the deceleration by shock waves just above the crater. As *At/Ab* further increases, a shock wave forms inside the crater. The flow strongly decelerates due to this shock wave so that it erupts as a subsonic jet from the crater top. As $\theta$ increases (the depth of the crater decreases for given *At/Ab*), a pressure bulge at the crater base caused by Prandtl-Meyer expansion starts affecting flow in the upper part of the crater. As a result, the physical quantities at the crater top substantially deviate from the quasi-1D results. Because of this deviation from the quasi-1D results, the momentum flux of jet after the decompression/compression processes just above the crater decreases with the increasing $\theta$. As $\theta$ further increases and exceeds a certain value, a detachment of the flow from the crater wall occurs. This detachment leads to a qualitative change in flow structure inside and just above the crater; the flow erupts as an underexpanded flow directly from the crater base. The transition associated with the flow detachment results in a significant increase in momentum flux after the decompression/compression processes just above the crater particularly for overexpanded and subsonic flows with large *At/Ab*. It is suggested that the eruption style can change from a pyroclastic flow to a buoyant plume as $\theta$ increases for the explosive eruption from a crater with large *At/Ab*, and vice versa.

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