3D numerical simulation of volcanic plume dynamics and ash dispersal

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1D model of bent-over plume

Entrainment velocity, $U_\varepsilon$

* entrainment $k|U-W\cos\theta|$

* wind entrainment $\beta|W\sin\theta|$

We should determine value of $\beta$ with a narrow range.

[Bursik, 2001; Woodhouse et al., 2013]

Laboratory exp. of water and ideal gas

entrainment coefficient, $k \sim 0.10$

wind entrainment coefficient, $\beta = 0.3-1.0$

Prediction by BENT
Flow patterns of volcanic plume

- To directly simulate the plume dynamics by a 3D unsteady model
- To determine the value of $\beta$
3D Numerical Model

Fluid motion: pseudo-gas model [Suzuki et al., 2005]
- reproduction of entrainment process
- the mixture of gas phases and pyroclasts is treated as a single gas
- mixture density is calculated from mixing ratio

Particle motion: Lagrangian model
- Lagrangian marker particles of ideal sphere
- 200 particles every 1 or 10 sec.
- Grain sizes are randomly selected within 0.0625 – 64 mm
- Terminal velocity

\[ V_t = \frac{g \sigma d^2}{18 \mu} \quad , \quad V_t = d \left( \frac{4d^2 \sigma^2}{225 \mu \rho_a} \right)^{1/3} \quad , \quad V_t = \left( \frac{3.1g \sigma d^2}{\rho_a} \right)^2 \]

(Re < 6) \quad (6 < \text{Re} < 500) \quad (\text{Re} > 500)
Volcanic Plume in wind field
Shinmoe-dake 2011 eruption

1/26-27: three sub-Plinian eruptions

$MDR = 1.5 \times 10^6$ kg s$^{-1}$ [Kozono et al., 2013] (tiltmeter + SAR)

$T_0 = 1273$ K, $n_{g0} = 3$ wt% [Yuki Suzuki et al., 2013]

Atmospheric conditions were calculated using the Japan Meteorological Agency’s Non-Hydrostatic Model [Hashimoto et al., 2012]
3D Simulation of Shinmoe-dake Eruption

[Suzuki and Koyaguchi, 2013, EPS]

Iso-surface of 1 wt% magma

Side view

Top view

Observed height

Weather radar echo observation

Satellite image
Volcanic Plumes in wind field

MDR: $2.5 \times 10^6$ kg/s, $n_0$: 2.84 wt%, $T_0$: 1000 K, Atmosphere: mid-latitude

 Iso-surface of mass fraction 2wt%

Density difference

$U_{\text{wind}} [\text{m/s}] = 0$

$U_{\text{wind}} [\text{m/s}] = 2.0 \ Z$

$U_{\text{wind}} [\text{m/s}] = 8.0 \ Z$
Wind entrainment coefficient, $\beta$

Wind speed, $U_{\text{wind}}$ [m/s]:
- $U_{\text{wind}} = 2.0$ Z
- $U_{\text{wind}} = 6.0$ Z
- $U_{\text{wind}} = 8.0$ Z

$U_{\varepsilon} = k|U - W\cos\theta| + \beta|W\sin\theta|$

- $\beta = 0.1 \sim 0.3$

Increase in wind speed
Increase in efficiency of entrainment
Decrease in plume height
Parametric study for $\beta$

$U_{\text{wind}}[\text{m/s}] = C_0 \ Z$

$U_{\text{wind}}[\text{m/s}] = C_1 \ \tanh(Z/1\text{km})$

$\beta = 0.1 \sim 0.3$

Recommended model: BENT with $k=0.1$, $\beta \sim 0.2$
Summary

- The simulation results of the 3D model suggest BENT model with $\beta = 0.2$ provides plume shape and height if $k = 0.1$.
- The 3D model can directly simulate the ash dispersal.