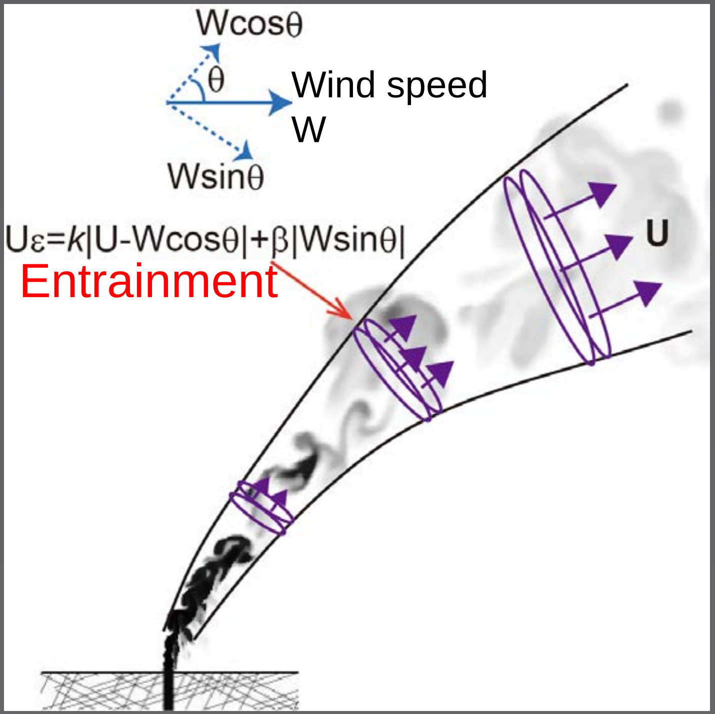
3D numerical simulation of volcanic plume dynamics and ash dispersal

Yujiro J. Suzuki
(Earthquake Research Institute, Univ. Tokyo)

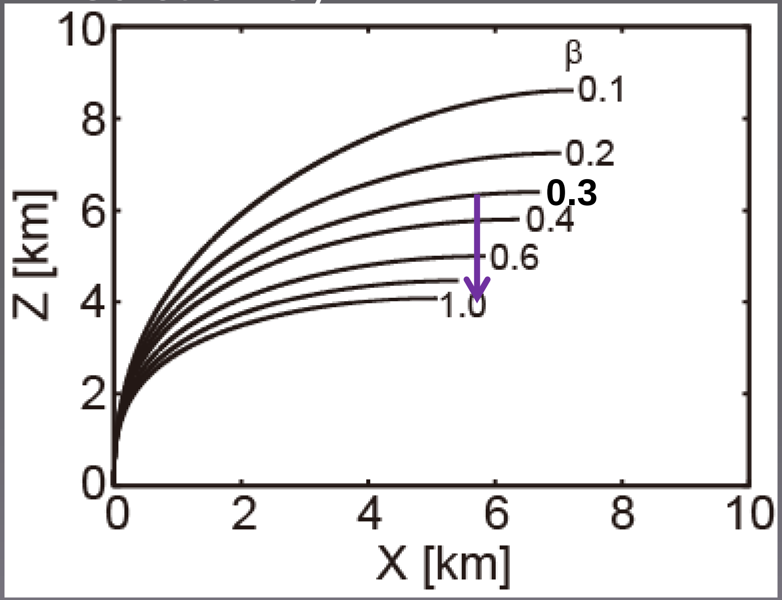
1D model of bent-over plume

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



Laboratory exp. of water and ideal gas
entrainment coefficient, k ~0.10
wind entrainment coefficient, β=0.3-1.0

Prediction by BENT



Entrainment velocity, U_ε

* entrainment

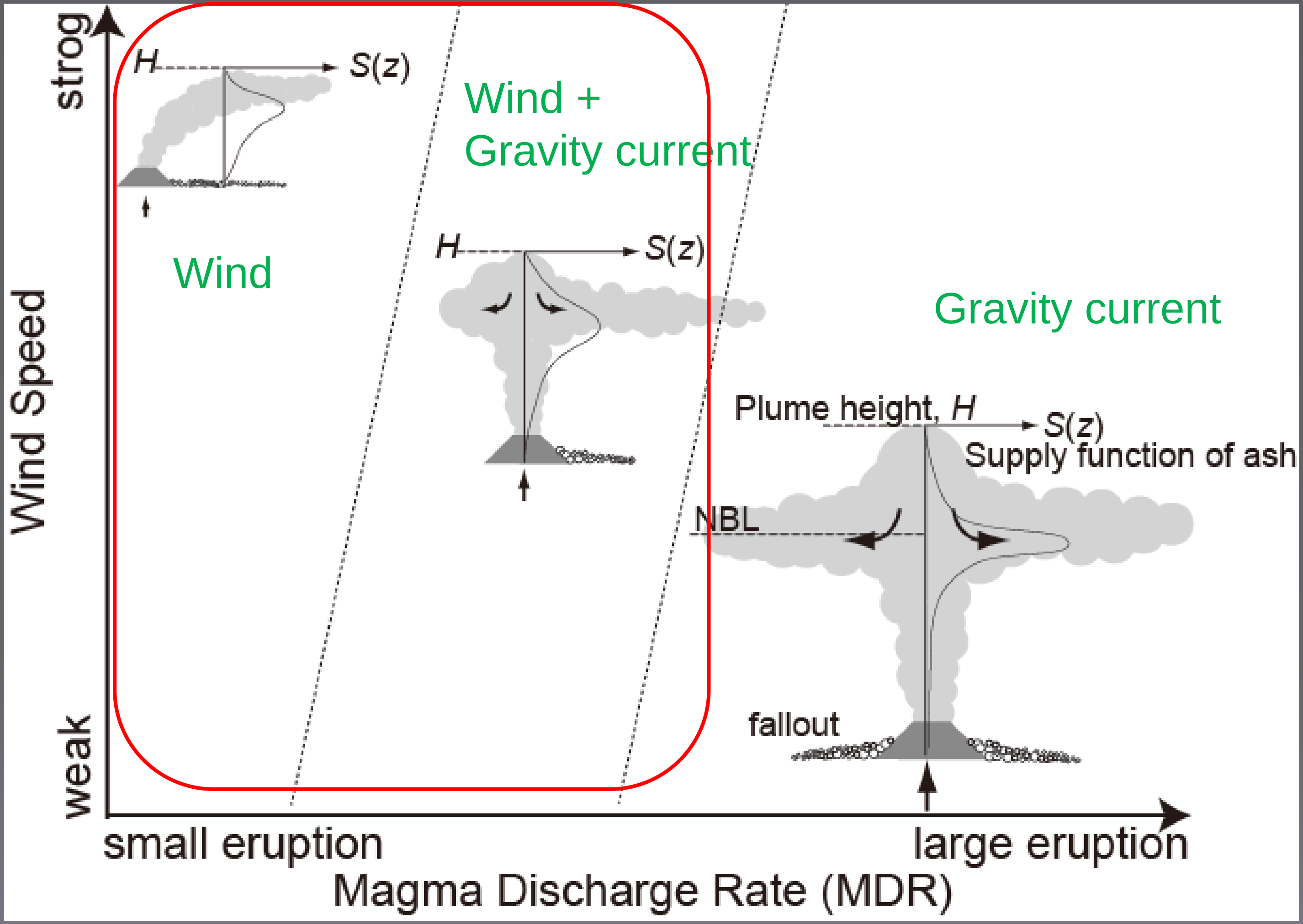
$k|U-W\cos\theta|$

* wind entrainment

$\beta|W\sin\theta|$

We should determine value of β with a narrow range.

Flow patterns of volcanic plume

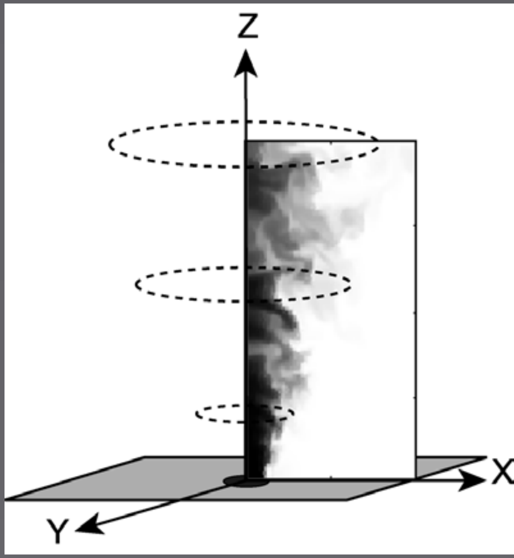


- To directly simulate the plume dynamics by a 3D unsteady model
- To determine the value of β

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 (4ϕ) (-6ϕ)
- Terminal velocity

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

(Re < 6) (6 < Re < 500) (Re > 500)

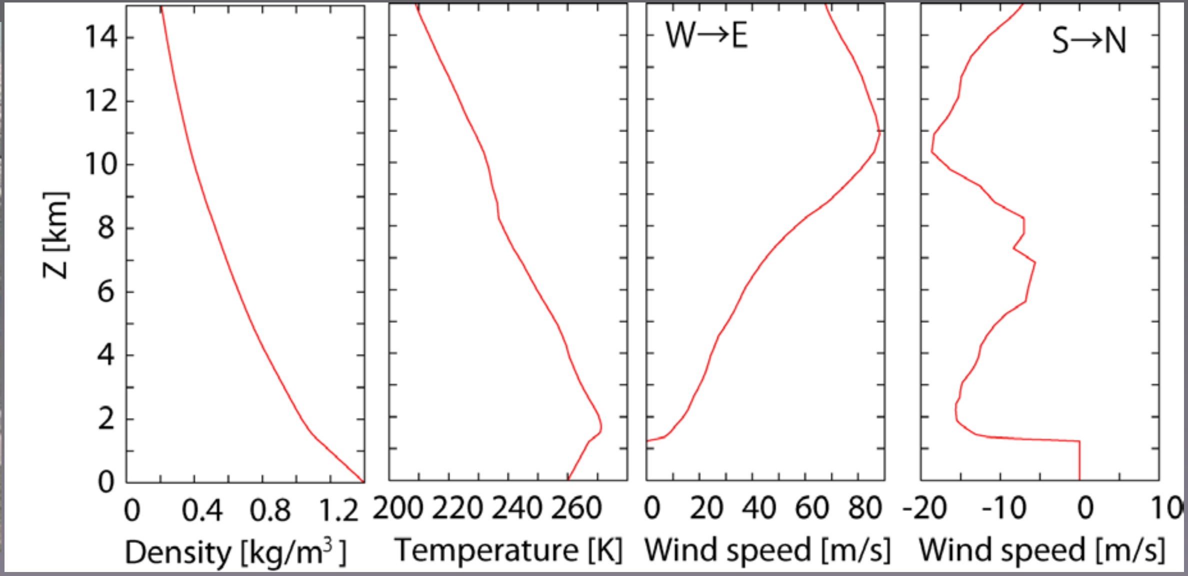
Volcanic Plume in wind field
Shinmoe-dake 2011 eruption

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]

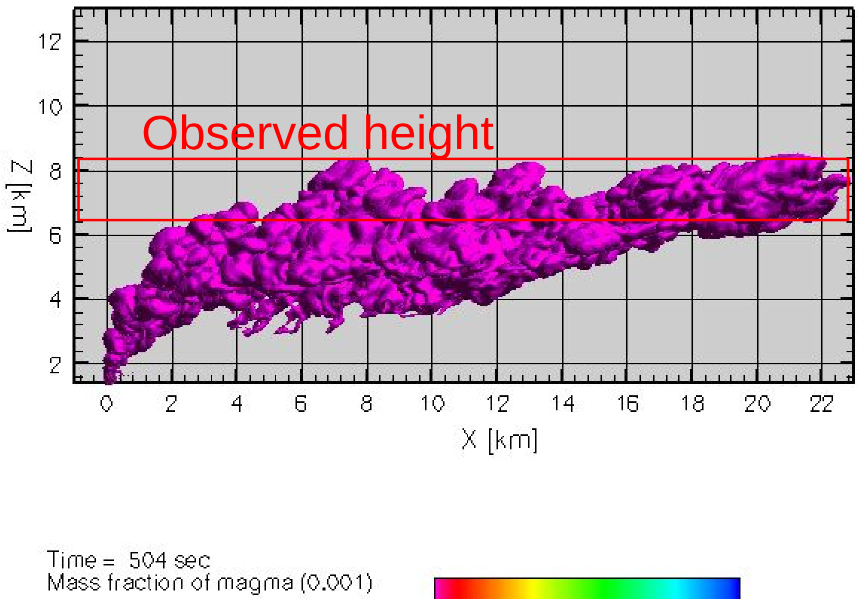


3D Simulation of Shinmoe-dake Eruption

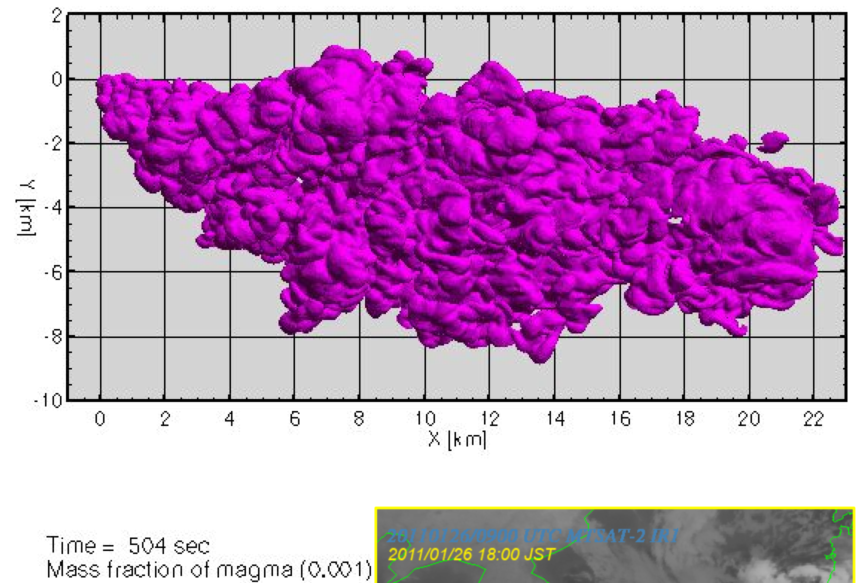
[Suzuki and Koyaguchi, 2013, EPS]

Iso-surface of 1 wt% magma

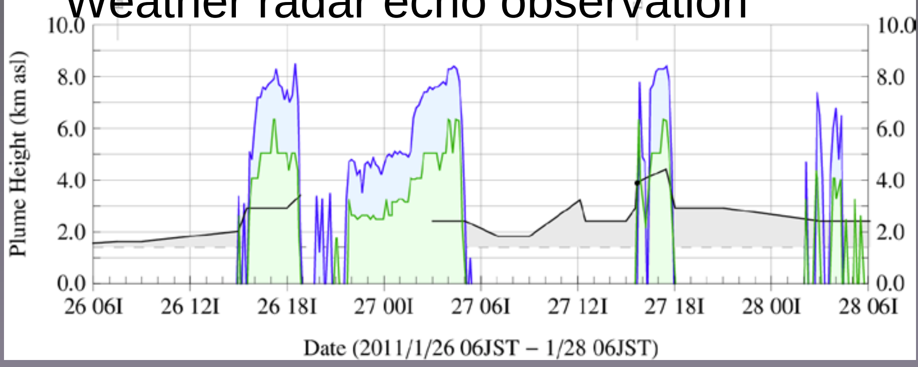
Side view

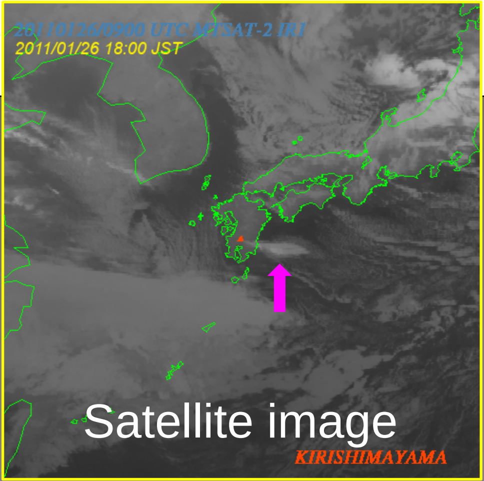


Top view



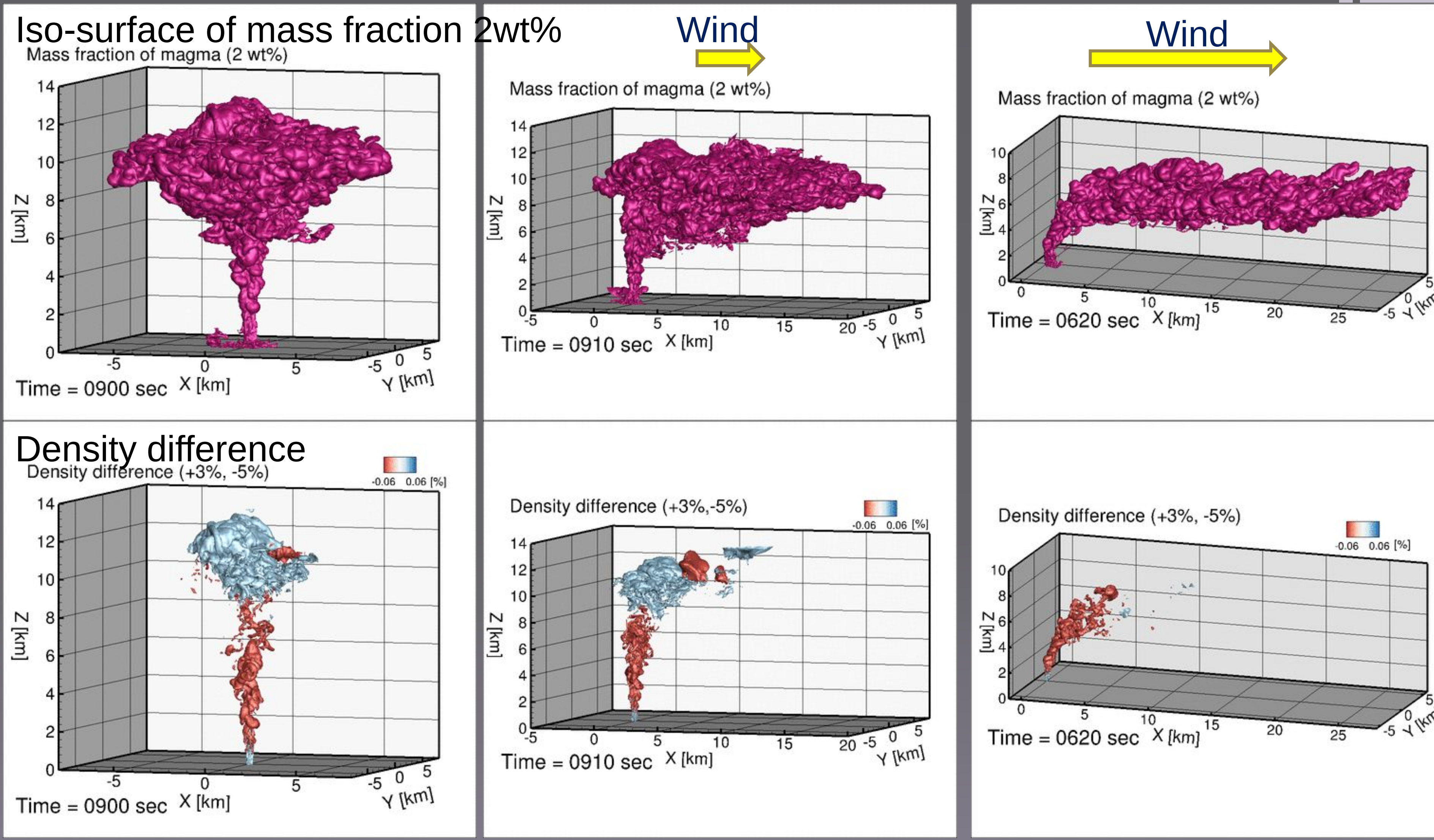
Weather radar echo observation





Volcanic Plumes in wind field

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



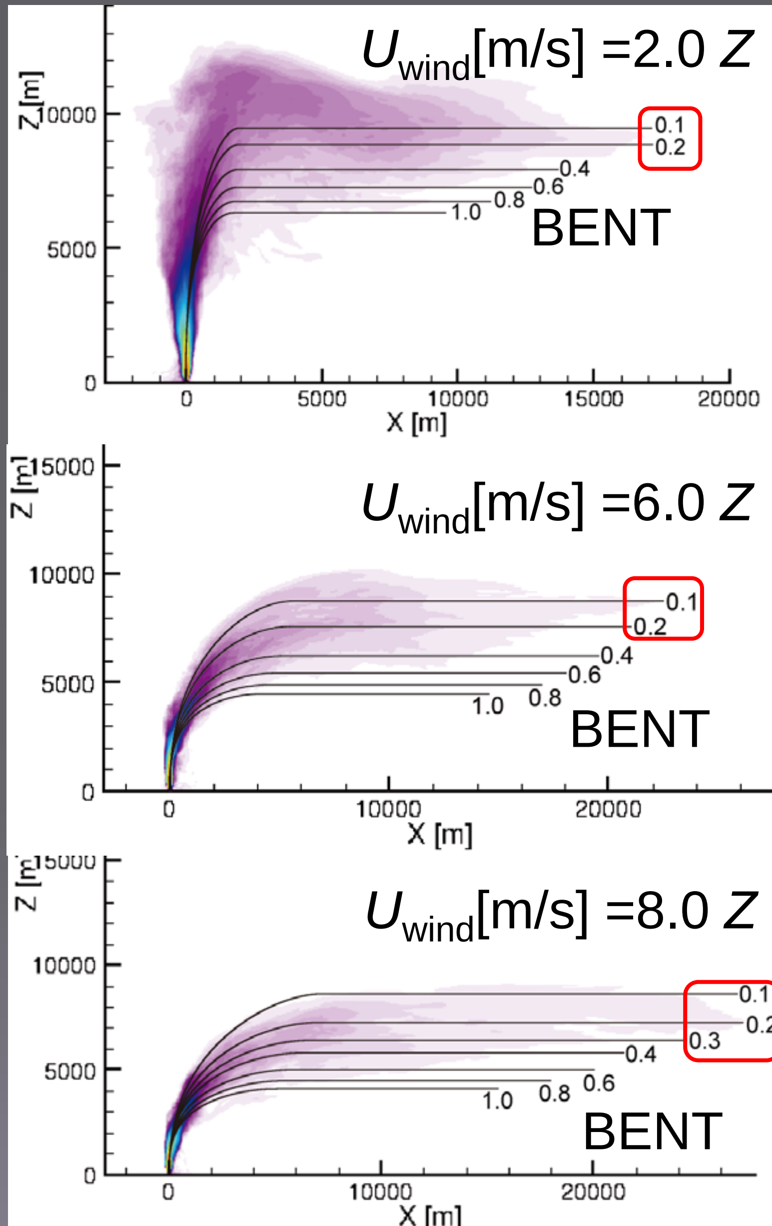
U_{wind}[m/s] = 0 U_{wind}[m/s] =2.0 Z U_{wind}[m/s] =8.0 Z

Wind entrainment coefficient, β

weak

wind

Strong



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

0.1

Increase in wind speed

Increase in efficiency of entrainment

Decrease in plume height

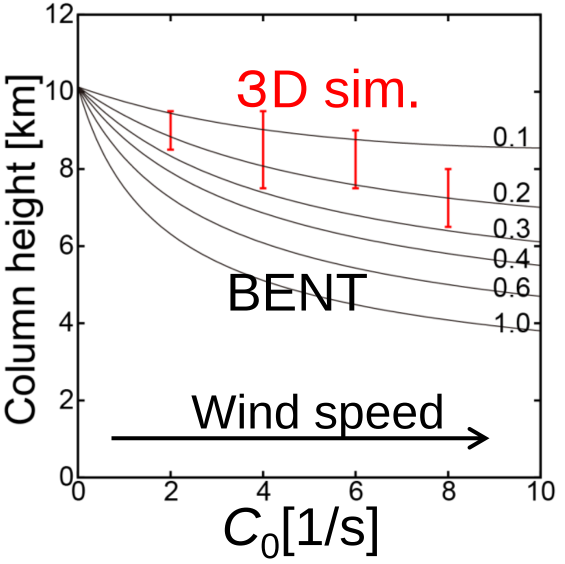
$\beta = 0.1\sim0.3$

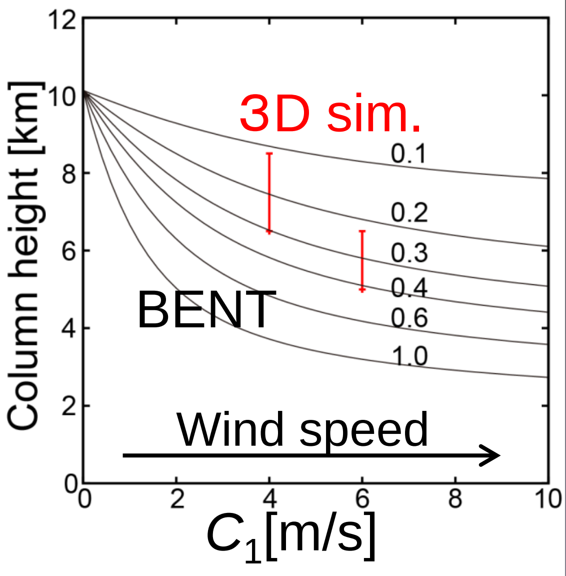
Parametric study for β

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

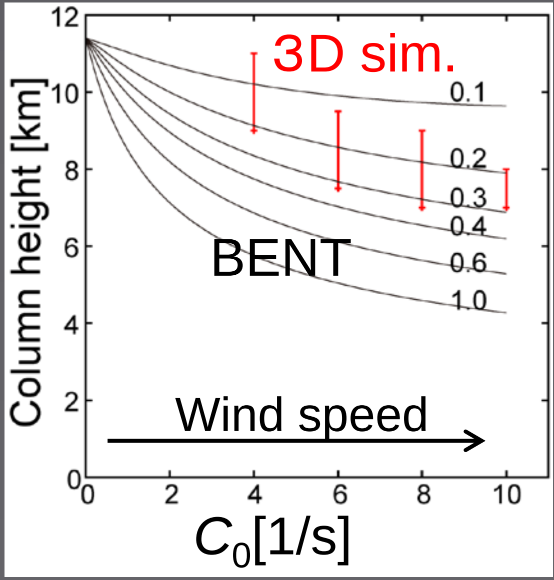
U_{wind}[m/s] $=C_1 \tanh(Z/1\text{km})$

MDR=$10^{6.4}$ kg/s





MDR=$10^{6.6}$ kg/s



β=0.1~0.3
Robust value

Recommended model:
BENT with k=0.1, β~0.2

Summary

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