Numerical simulation of air entrainment by three dimensional pyroclastic surge flow model

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Research background

<u>Pyroclastic surge</u>

- Solid-gas multiphase flow composed by ejected materials (ex. Volcanic gas, particles, and ash)
- Due to the high temperature and high velocity, pyroclastic surge is one of the hazardous flows in volcanic event.
- Fully turbulent characteristics and large temperature difference between ambient air cause air entrainment and volume expansion.
- The understating of entrainment process and its influence in high temperature particle-laden current is not fully revealed yet.

Research objectives

In this study, we focus on following points;

1. Development of numerical model and validation with experimental dataset (Cerminara et al., 2021).
2. Examination of the effect of topography under two settings.
3. Investigation of entrainment by changing turbulent effect.

Method

Governing Equation (Y. Ishimine, 2005)

$$\frac{D\phi_s}{Dt} = -\phi_s \mathrm{div}\boldsymbol{u} - \frac{\partial}{\partial z}(\omega\phi) + F_\phi$$

$$\frac{D\boldsymbol{u}}{Dt} = -\frac{1}{\rho_m}\nabla P + \boldsymbol{g} + F_{\boldsymbol{u}}$$

$$\frac{DT}{Dt} = -\frac{P}{C'_V \rho_m}\mathrm{div}\boldsymbol{u} + F_T$$

$$\frac{DP'}{Dt} = -\gamma^* P \mathrm{div}\boldsymbol{u}$$

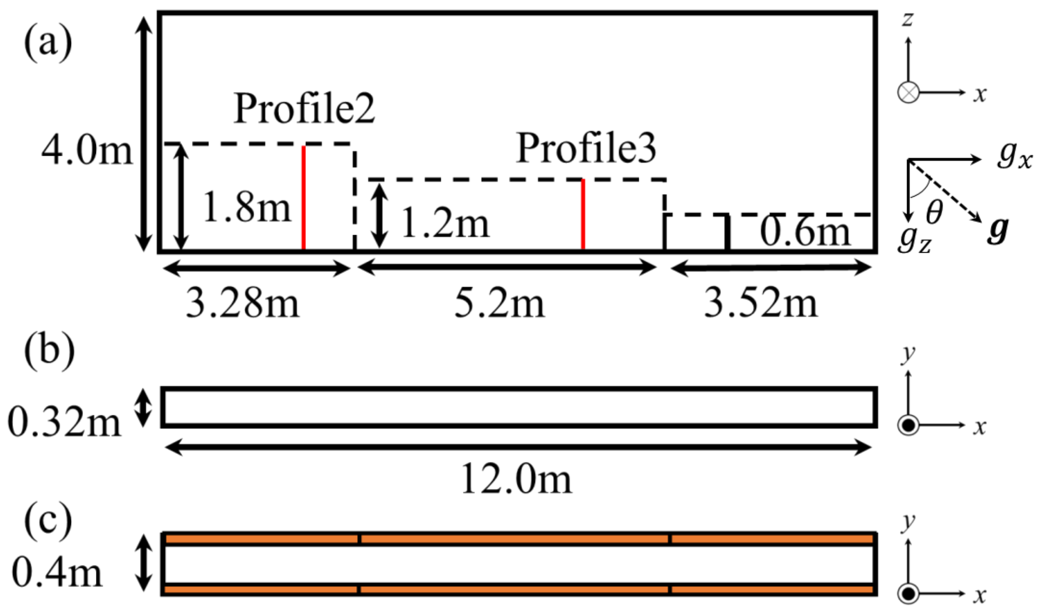
$$F_T = K_T \nabla^2 T$$
$$F_\phi = K_\phi \nabla^2 \phi$$

$$K_T = K_\phi = (C_s\Delta)^2 \sqrt{\overline{D}_{ij}\overline{D}_{ij}}$$
$$\left(\Delta = \alpha \sqrt[3]{\Delta x \Delta y \Delta z}\right)$$

ϕ_s:	Volume fraction of particles
$\boldsymbol{u}$:	Velocity [m/s]
P:	Pressure [Pa]
P':	Pressure deviation from ambient
ρ_m:	Bulk density of mixture [kg/m3]
T:	Temperature [K]
γ^*:	Modified specific heat
ω:	Settling velocity [m/s]
F_x:	Turbulent diffusion term in x

In this study, filter width, Δ, is treated as the geometric mean of the grid width as α-multiplied, and examine their influence under α=1.0~2.0, 3.0. Mesh size is 1.0cm.

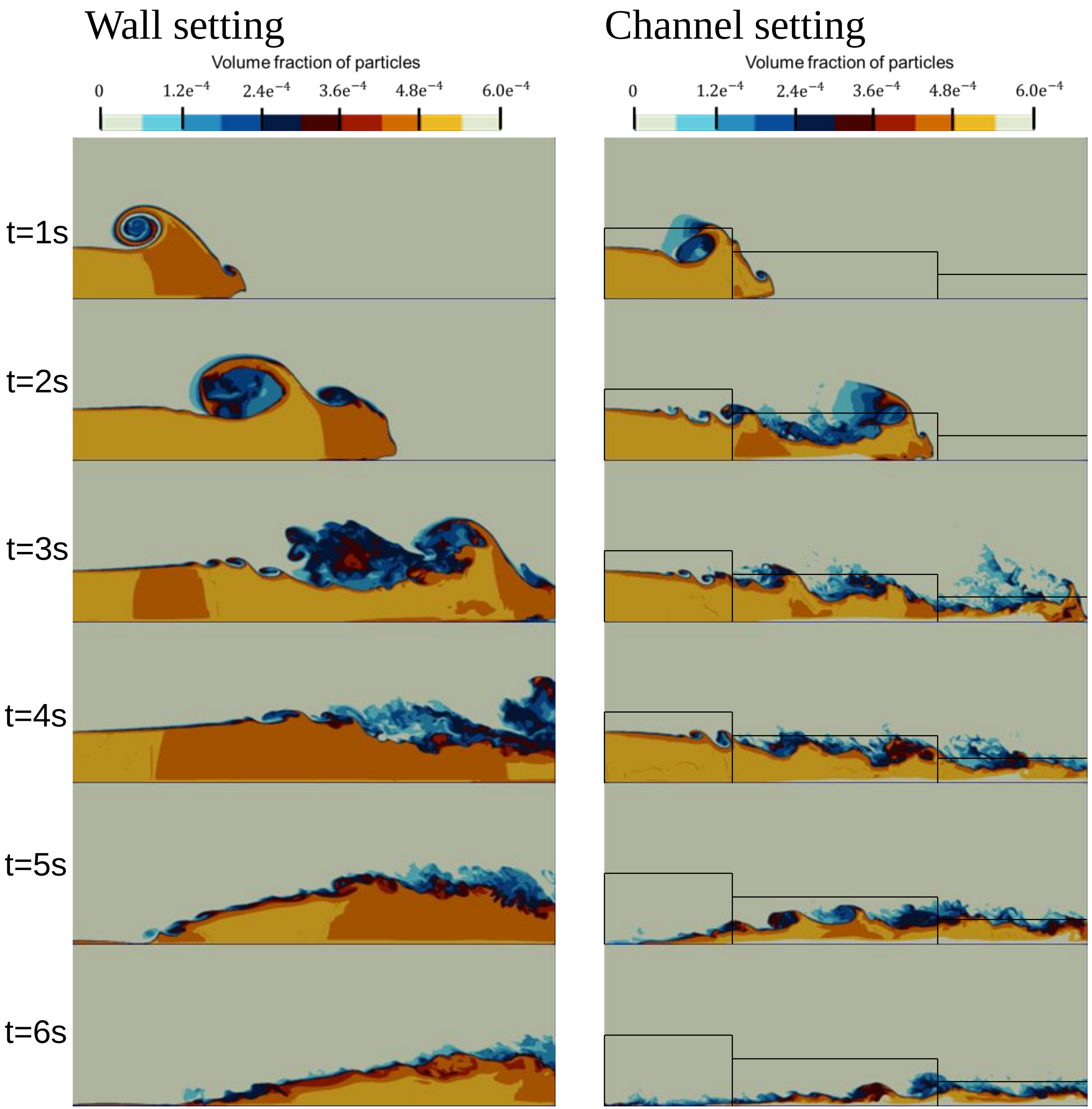
Calculation conditions

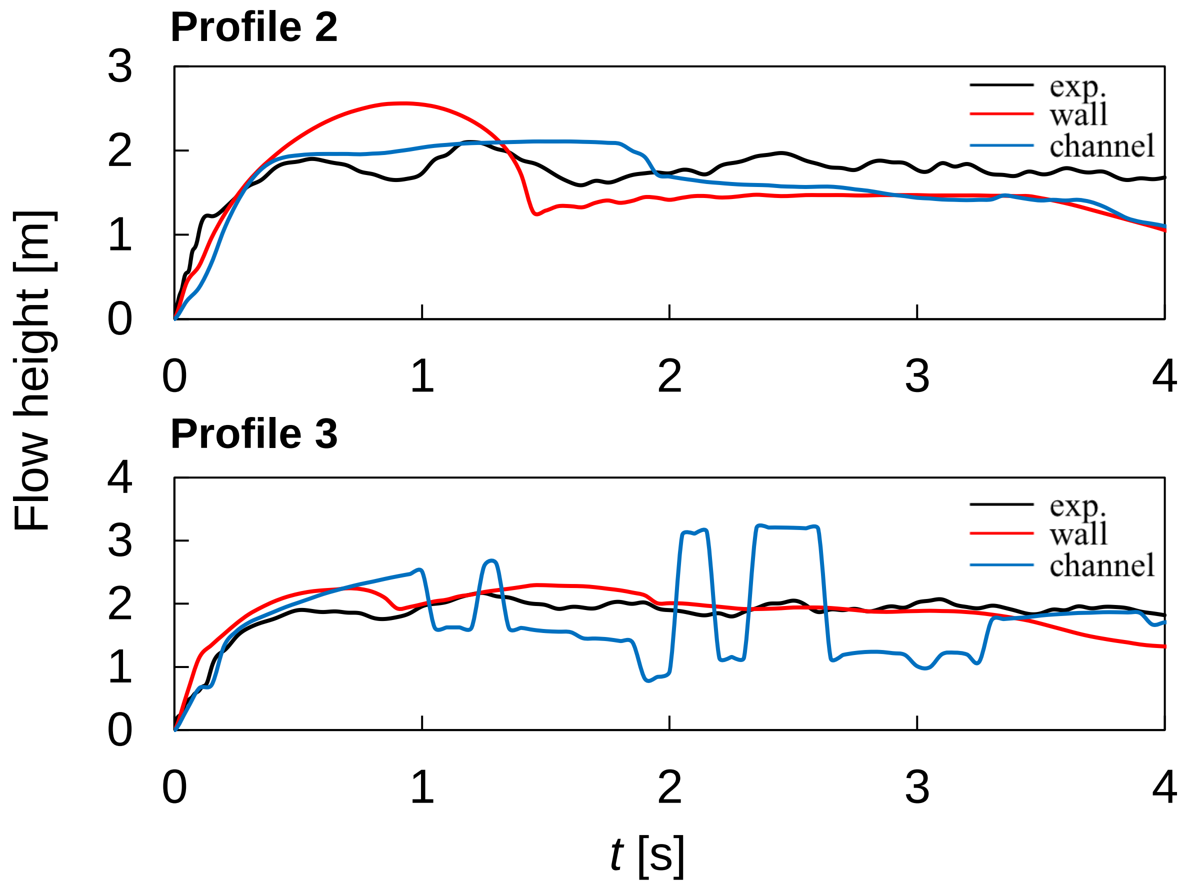


- Two calculation domains, wall (b) and channel (c) setting, were prepared to investigate the effects of topography.

- For validation of our model, we used the dataset provided by PELE (Cerminara et al., 2021) and compared about flow height, velocity.

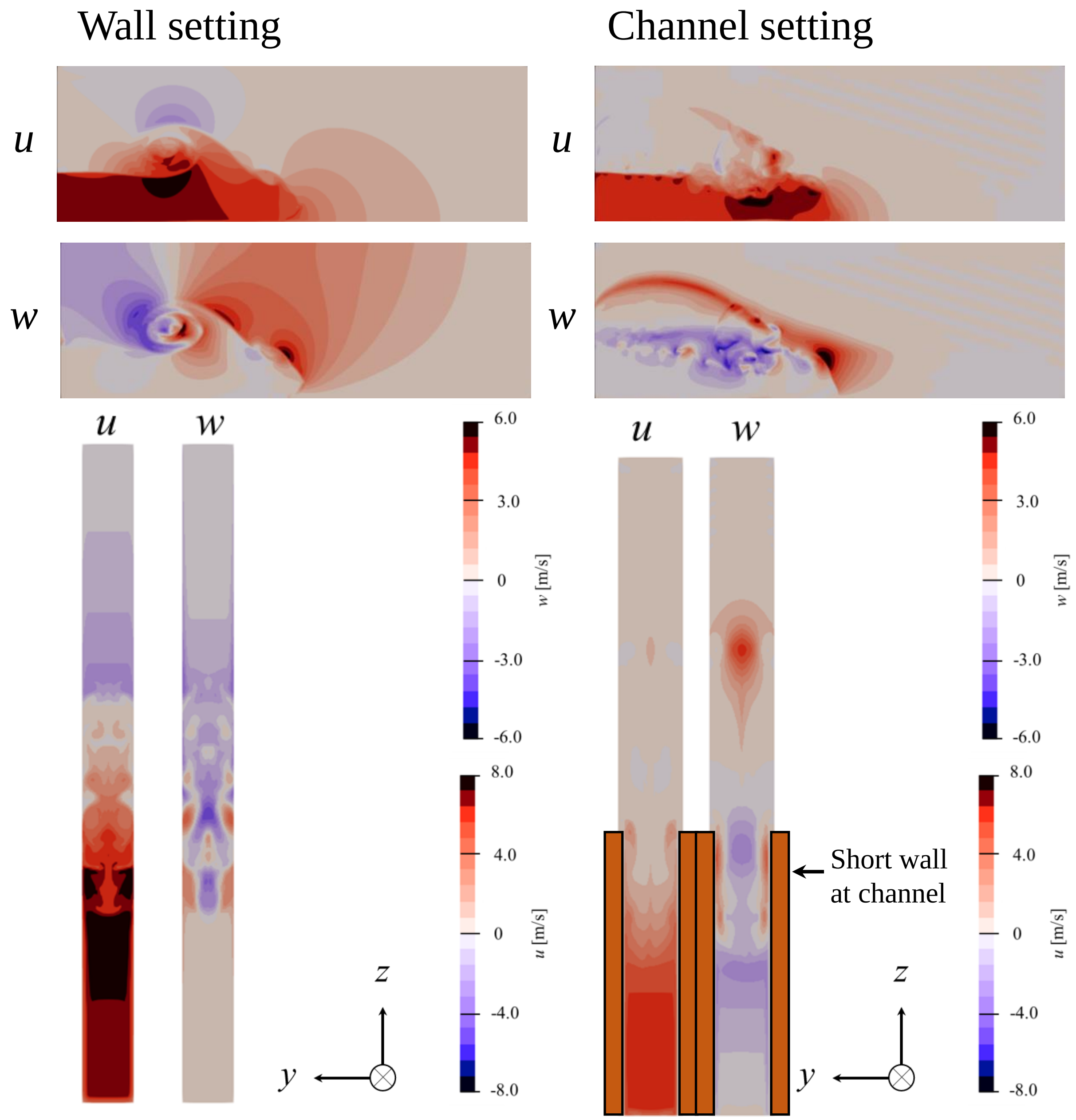
Results – Flow height

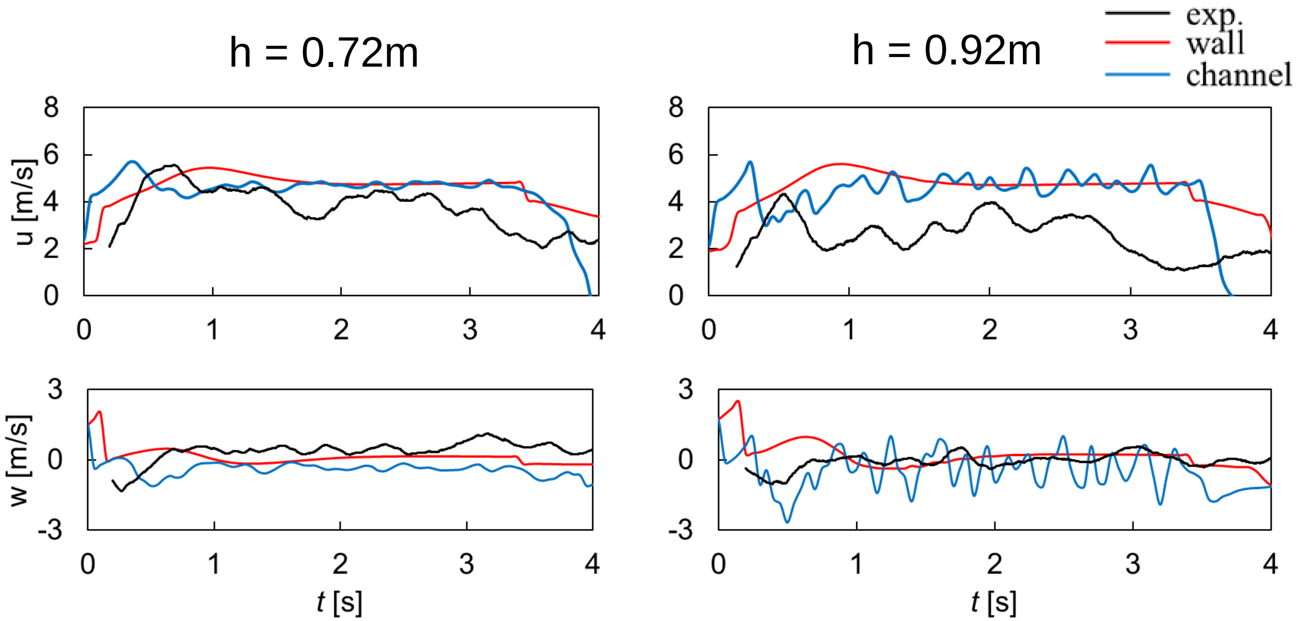




- In wall setting, large wake is generated behind the nose, and it is the dominant in the dilution process.
- In channel setting, although the amount of overflow to the outside of the channel was small, smaller vortices are generated and at the body and tail.
- Both calculation results showed good agreement with experimental result, and channel one is closer.

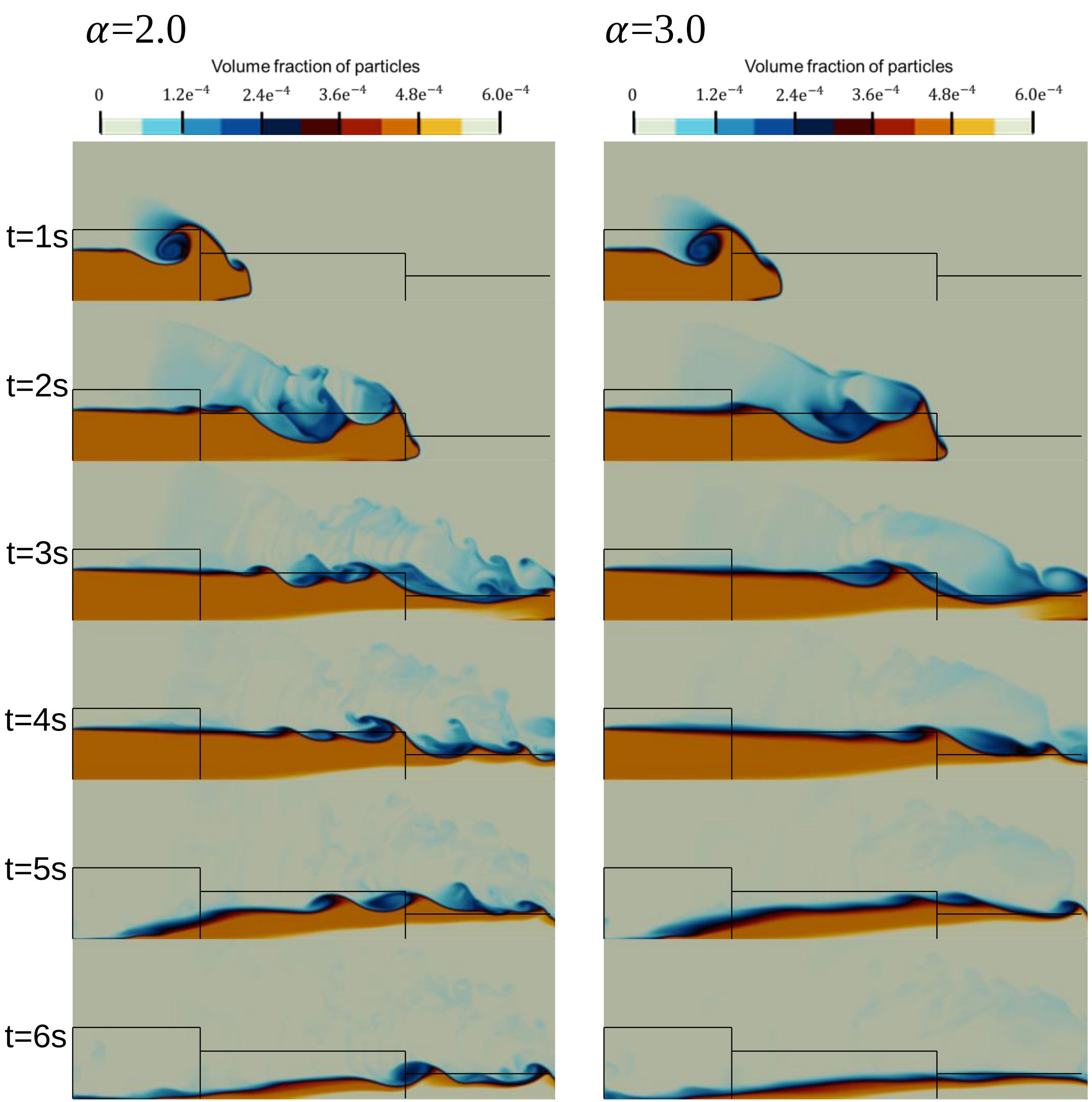
Results – Velocity

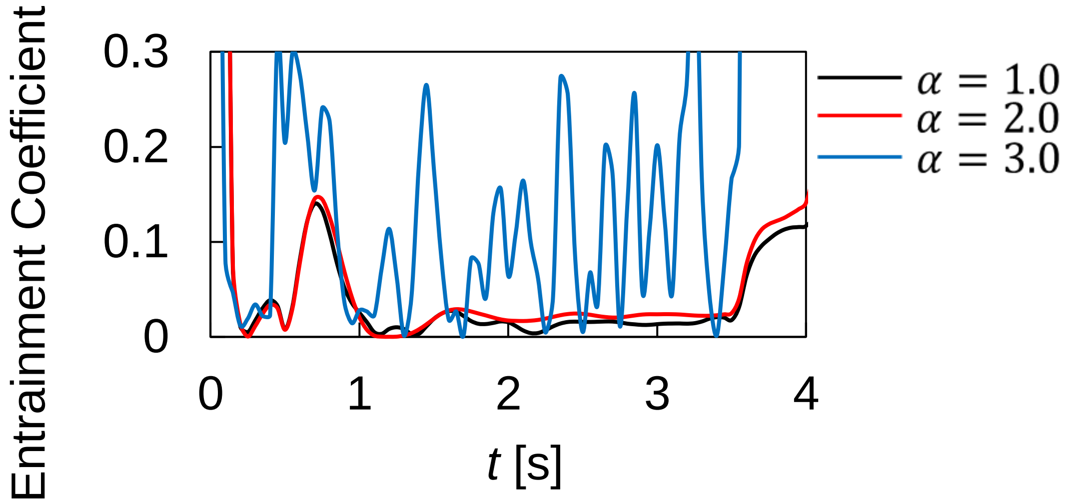




- Boundary conditions makes the difference of velocity fields, and it affects entrainment process.
- cross-sectional view suggests that the velocity components around wall is higher than at center in both cases.
- Velocity in simulation results raise up faster than experiment because calculated velocity field includes the air behavior which does not contain any particles.

Results – Entrainment





The entrainment coefficient, E, follows the Morton-Turner-Taylor entrainment hypothesis:

$$E = \left| \frac{U_{cross}}{U_{stream}} \right|$$

- Increasing the width of the filter was confirmed to increase the volume over most of the area.

- The filter width is suggested to be smaller than 3 considering the entrainment coefficient range of 0.05~0.14, which is observed in previous experimental study (Breard & Lube, 2017).

Conclusion

➢ Our 3D multiphase model showed good agreement with flow height & velocity field of experimental dilute pyroclastic flow.

➢ The difference in velocity distribution given by topographic considerations leads to a difference in velocity with the surroundings, which in turn affects eddy formation.

➢ In comparison with experimental values, it may be necessary to apply some operation to simulation results in the cross-sectional direction instead of the value at center.

➢ The investigation of entrainment by several filter width can suggest that the turbulent effects in the entrainment process in pyroclastic surge has a possibility to be larger than other density current.

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References

Photo recorded by Aso Volcano Museum, 21th, Oct., 2021

G. Lube, E. C. P. Breard, S. J. Cronin and J. Jones, 2015, Synthesizing large-scale pyroclastic flows: Experimental design, scaling, and first results from PELE, Journal of Geophysical Research: Solid Earth, **120**, 1487-1502, DOI: https://doi.org/10.1002/2014JB011666

M. Cerminara, E. Brosch & G. Lube, A theoretical framework and the experimental dataset for benchmarking numerical models of dilute pyroclastic density currents, arXiv:2106.14057

Y. Ishimine, 2005, Numerical study of pyroclastic surges, Journal of Volcanology and Geothermal Research, **139**, 33-57, DOI: https://doi.org/10.1016/j.jvolgeores.2004.06.017