Euler-Euler simulation of drifting snow
HPC Enabling of OpenFOAM for CFD Applications
Cineca

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OUTLINE

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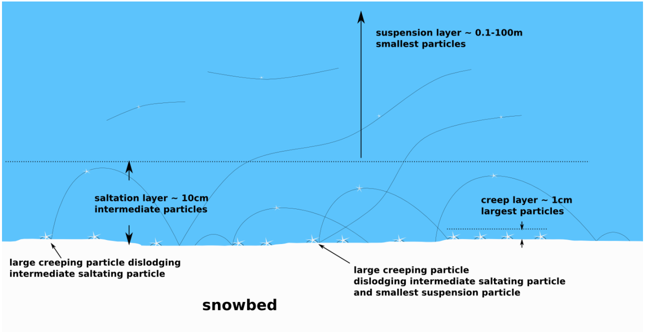
MOTIVATION 1/2



Aeolian transport modes during drifting snow.

MOTIVATION 2/2

- Substantial northern construction market
- Modern building codes (NBC 2010, ASCE 2010) use 50-year ground snow load corrected for,
    - Building type
    - Roof shape and slope
    - Wind exposure
- Above based on limited type of buildings and empirical cases
- Can seldom be applied to ever-changing modern building shapes and meteorological conditions
- Structural, financial and human consequences often disastrous

Previous Research

- Mostly Eulerian-Eulerian 1-way coupling:
  - Airflow not affected by snow (snow volume fraction < 0.01);
  - Mixture-based, transport of Snow Density (SD) approach (Naaim et al. 1998, Sato et al. 1993, Tominaga et al. 1999, Tominaga et al. 2011, Uematsu et al. 1991);
  - Volume Of Fluid (VOF) approach (Bang et al. 1994, Beyers et al. 2004, Beyers et al. 2008, Moore 95, Sundsbo 1998, Thiis 2000).
- Hybrid approach (Gauer 1999):
  - Eulerian one-way coupling in the suspension layer;
  - Eulerian two-way coupling in the saltation layer **based on equilibrium formulations!!!**

Research Objectives

- To develop a reliable and accurate CFD tool for prediction of snow loads and snowdrift profiles, on and around building structures.
  - Should be able to account for two-way coupling in the saltation layer.
  - Should work in transient mode to account for non-equilibrium effects.

Research Methods

- Numerical CFD approach based on the OpenFOAM toolkit.
- Existing solver twoPhaseEulerFoam most adapted to present needs:
  - Two-phase flow
  - Eulerian-Eulerian formulation (much less expensive than Eulerian-Lagrangian)
  - Transient
- Requires the following modifications:
  - Particle phase viscosity model appropriate for drifting snow
  - Numerical stability issues to be addressed

2-WAY COUPLING FORMULATION 1/3

- Ensemble-averaged incompressible continuity equation,

$$\frac{\partial \alpha_i}{\partial t} + \nabla \cdot \left(\alpha_i \vec{u}_i\right) = 0 \tag{1}$$

- Ensemble-averaged incompressible momentum equation:

$$\frac{\partial}{\partial t}\left(\alpha_i \vec{u}_i\right) + \nabla \cdot \left(\alpha_i \vec{u}_i \vec{u}_i\right) + \nabla \cdot \left(\alpha_i \bar{\bar{R}}_i\right) = -\frac{\alpha_i}{\rho_i} \nabla p + \alpha_i \vec{g} + \frac{\vec{M}_i}{\rho_i} \tag{2}$$

α_i: volume phase fraction of phase i
$\vec{u}_i$: velocity of phase i
$\bar{\bar{R}}_i$: combined Reynolds and viscous stress
p, $\vec{g}$, ρ_i: static pressure, gravitational acceleration and phase density respectively

2-WAY COUPLING FORMULATION 2/3

- $\vec{M}_i$: averaged inter-phase momentum transfer

$$M_i = \frac{1}{\alpha_i}\left(F_d + F_l + F_{vm}\right) \tag{3}$$

  F_d, F_l, F_{vm} are the drag, lift and virtual mass forces respectively

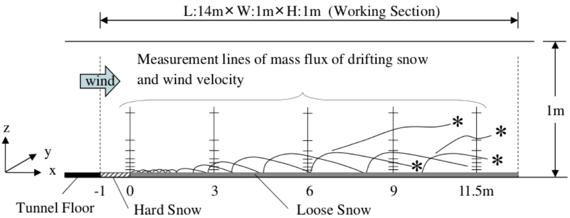
- Originally classical $\kappa - \epsilon$ model for the continuous phase
  - Replaced by the Realizable $\kappa - \epsilon$ model

2-WAY COUPLING FORMULATION 3/3

- $\bar{\bar{R}}_i$: combined Reynolds and viscous stress
  relies on Boussinesq approximation
- new drifting snow viscosity model for high rates of strain,
  - force balance over a sliding and rolling particle
  - accounts for aerodynamic friction and collision forces
  - depends on α_i and particle-scale rate of strain
- Maxwell viscosity model for low rates of strain
- intermediate treatment is a work in progress...
  source of instability!

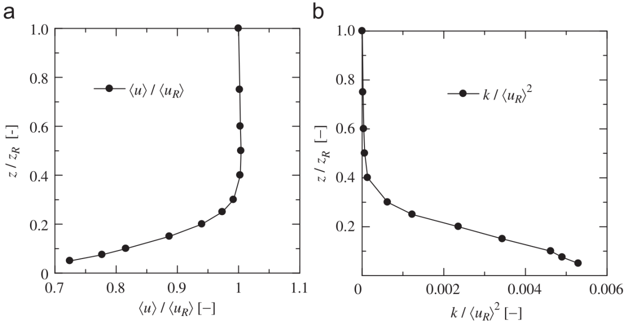
OKAZE WIND TUNNEL EXPERIMENT 1/3

- Wind tunnel experiment (Okaze et al., 2012);
    - Detailed measurements of velocity and snow flux profiles at several stations



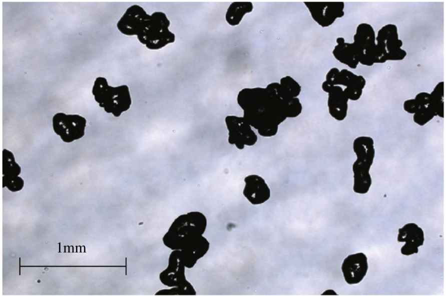
Okaze et al. wind tunnel experimental setup.

OKAZE WIND TUNNEL EXPERIMENT 2/3



Experimental inlet boundary conditions.

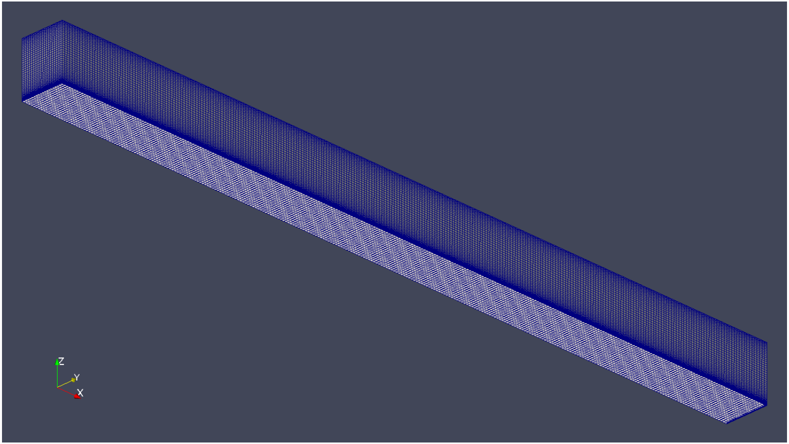
OKAZE WIND TUNNEL EXPERIMENT 3/3



Closeup of the snow particles used in the experiment.

PRELIMINARY NUMERICAL RESULTS 1/3

- Fully structured hexahedral mesh with 313880 cells

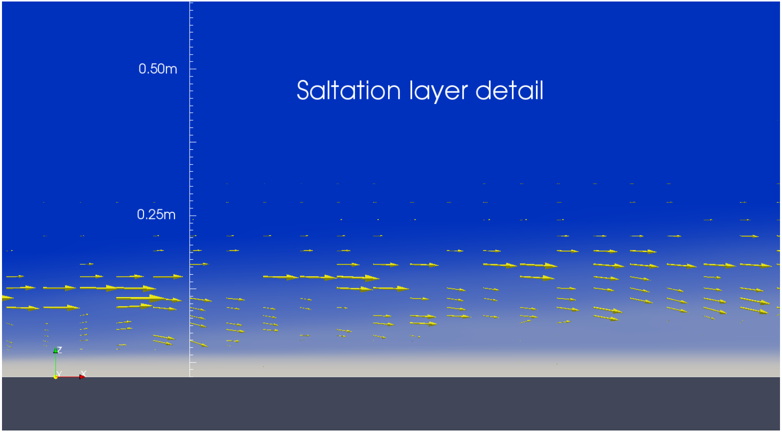


Overview of the computational mesh.

PRELIMINARY NUMERICAL RESULTS 2/3

Overview of drifting snow over the snowbed.

PRELIMINARY NUMERICAL RESULTS 3/3



Saltation layer detail.

CONCLUSIONS AND FUTURE WORK

- New viscosity model working as expected
  - saltation layer thickness
  - drifting snow restricted mostly to saltation layer
  - Lagrangian rebounding of particles reproduced in Eulerian frame
- Quantitative validation requires tuning of parameters
- Instability due to switching between low and high rate of strain viscosities

  Needs to be addressed!