WETTING IN GRANULAR FLOWS: DEBRIS FLOWS & ICE AVALANCHES

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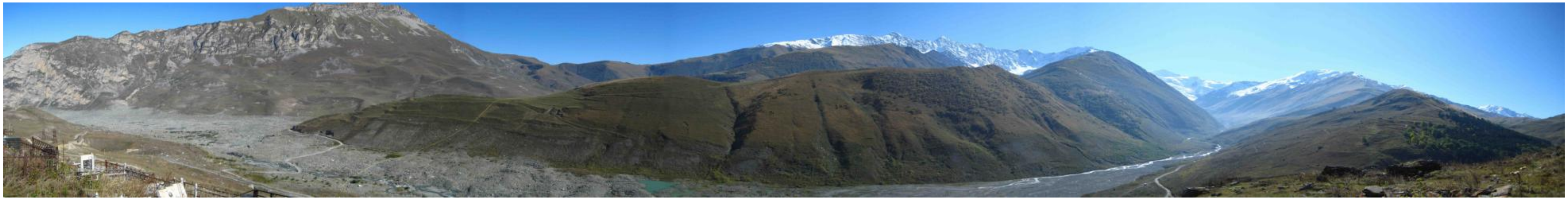
Debris flows

- Fast moving, subaerial gravitational flows of water, sediments and coarse material (rocks, trees boulders)
- A general term encompassing lahars, landslides, jökulhlaups.

e.g. Vargas, Venezuela 1999



- With our debris flow experiments we want to
  - Understand the effect of various flow variables, e.g. surface roughness, particle size
  - Measure velocity profiles, pore pressure and basal shear and normal stress
  - Test the influence of the larger particles in the flow
  - Link the extreme values of dynamic properties to bulk values

Design Criterion - Similarity

- Always difficult in particle laden

Parameter	Name	Force Balance	Notts Chute	USGS Chute	1982 Oddstad
$N_{Bag} = \frac{\phi_s \rho_s d^2 \dot{\gamma}}{(1-\phi_s)\mu}$	Bagnold number	Inertial grain stress to viscous shear stress	2	400	4
$N_{Sav} = \frac{\rho_s d^2 \dot{\gamma}^2}{(\rho_s - \rho_f) g h \tan\theta}$	Savage number	Inertial grain stress to friction	0.2	0.2	2×10^{-4}
$N_{fric} = \frac{N_{Bag}}{N_{Sav}}$		Friction to viscous shear stress	9	2×10^3	2×10^4
$N_{mass} = \frac{\phi_s}{(1-\phi_s)} \frac{\rho_s}{\rho_f}$	Mass number	Solid to fluid inertia	1	4	4
	c.f. Stokes number				
$N_{Rey} = \frac{N_{Bag}}{N_{mass}}$	c.f. Reynolds number	Fluid inertial stress to viscous shear stress	2.5	100	1
$Fr = \frac{u}{\sqrt{gh}}$	Froude number	Inertial to gravitational	0.6	10	3

Data from
Iverson Richard M., 1997, Physics of debris flows, *Rev. Geophys 35, 3, 245-296*

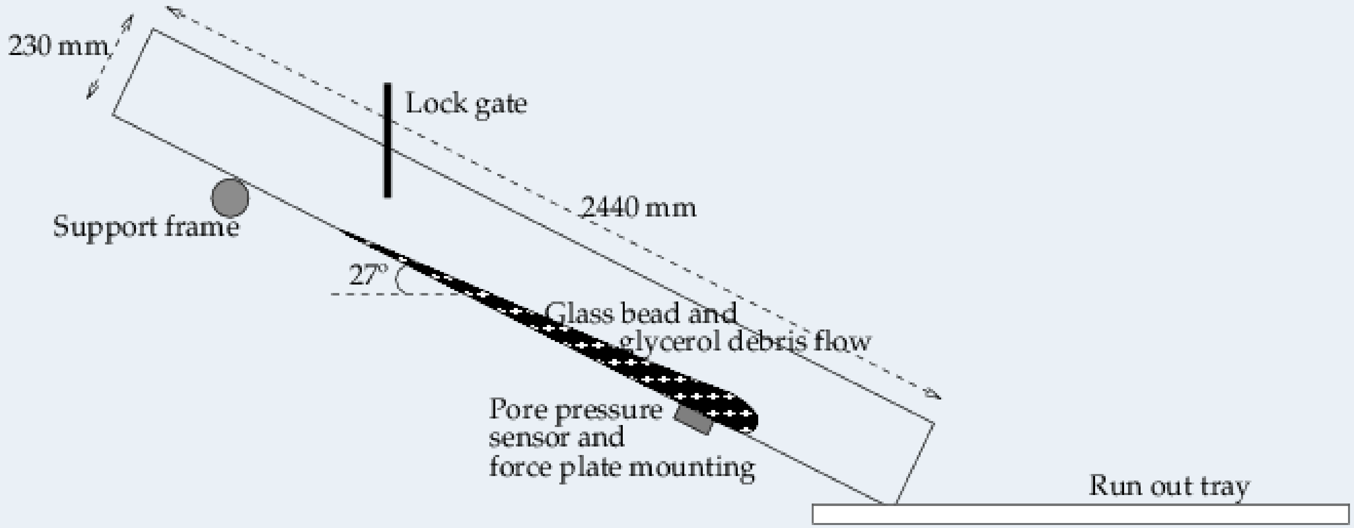
Experiment Design

2D CHUTE

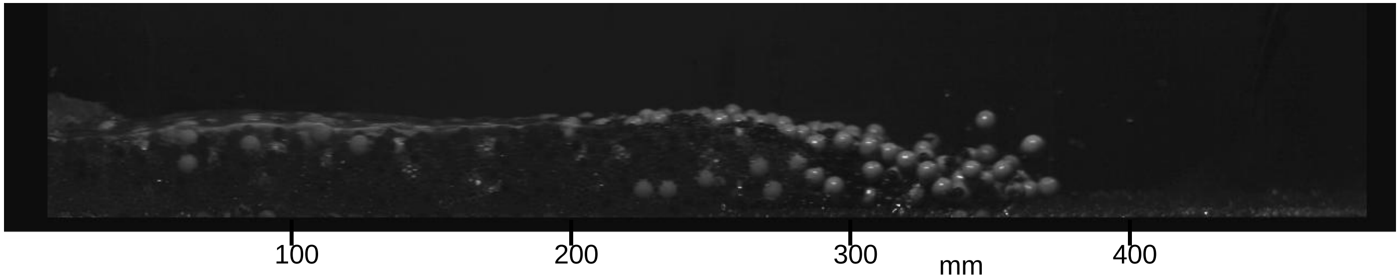
Lock release

Variable	Notation	Values	(units)
Solids volume fraction	ϕ_s	0.6	
Volume of solids	$\phi_s V$	1	litre
Roughness length	$[d_{r1}, d_{r2}, d_{r3}]$	[2, 4, 8]	$\times 10^{-3}$ m
Angle of inclination	θ	27°	
Solids: glass beads			
Density	ρ_s	2600	kg m^{-3}
Diameter	$[d_1, d_2, d_3]$	[2, 4, 8]	$\times 10^{-3}$ m
Fluids: water, glycerol			
Density	$[\rho_{f1}, \rho_{f2}]$	[1000, 1260]	kg m^{-3}
Viscosity	$[\mu_1, \mu_2]$	[1.41, 0.8]	Pa s

Experiment


230 mm
Lock gate
2440 mm
Support frame
27°
Glass bead and
glycerol debris flow
Pore pressure
sensor and
force plate mounting
Run out tray

What happens?



- Snout formation
- Longitudinal and vertical particle size and volume fraction variation
- Distinct granular and quasi-viscous regions

Flow regimes

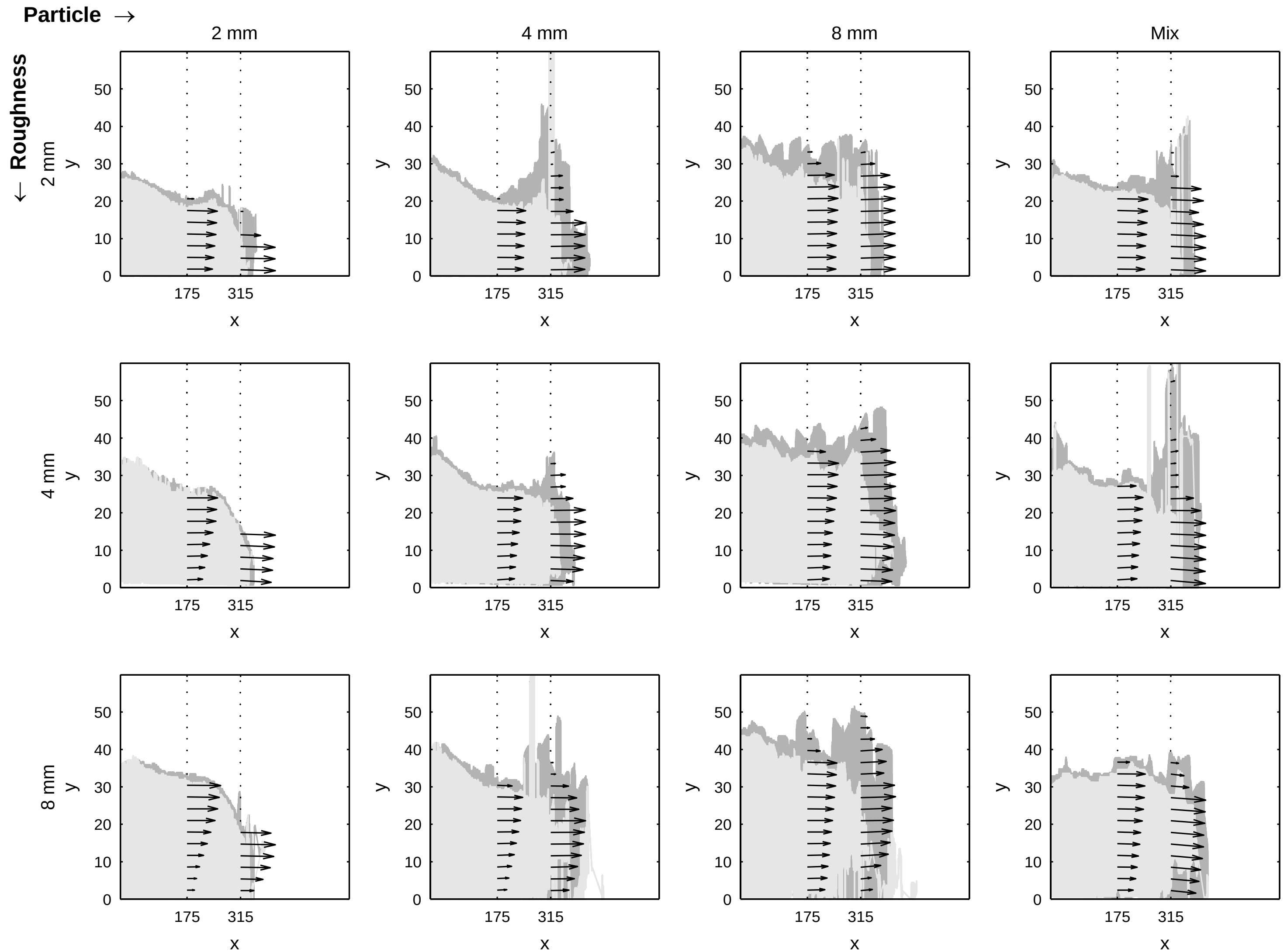
Quivers scaled by 0.1

SD>150 mm s^{-1} Granular region, dark grey

Low SD, quasi-viscous, pale grey

14 frame (0.2 s) averages

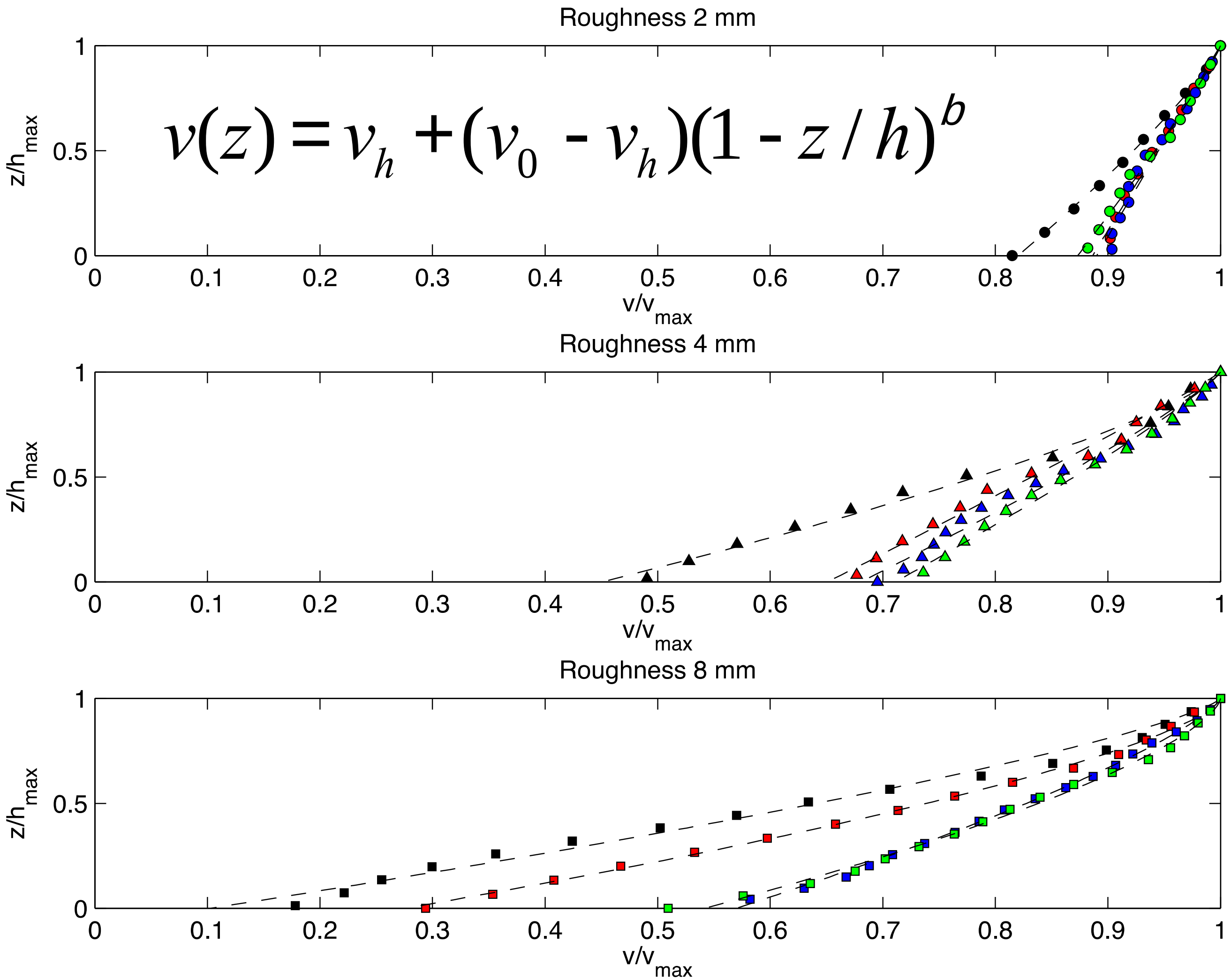
Velocities 600--1000 mm s^{-1}



Velocity profiles

By roughness length

Particle size increases with black, red, blue. Green is a mixture



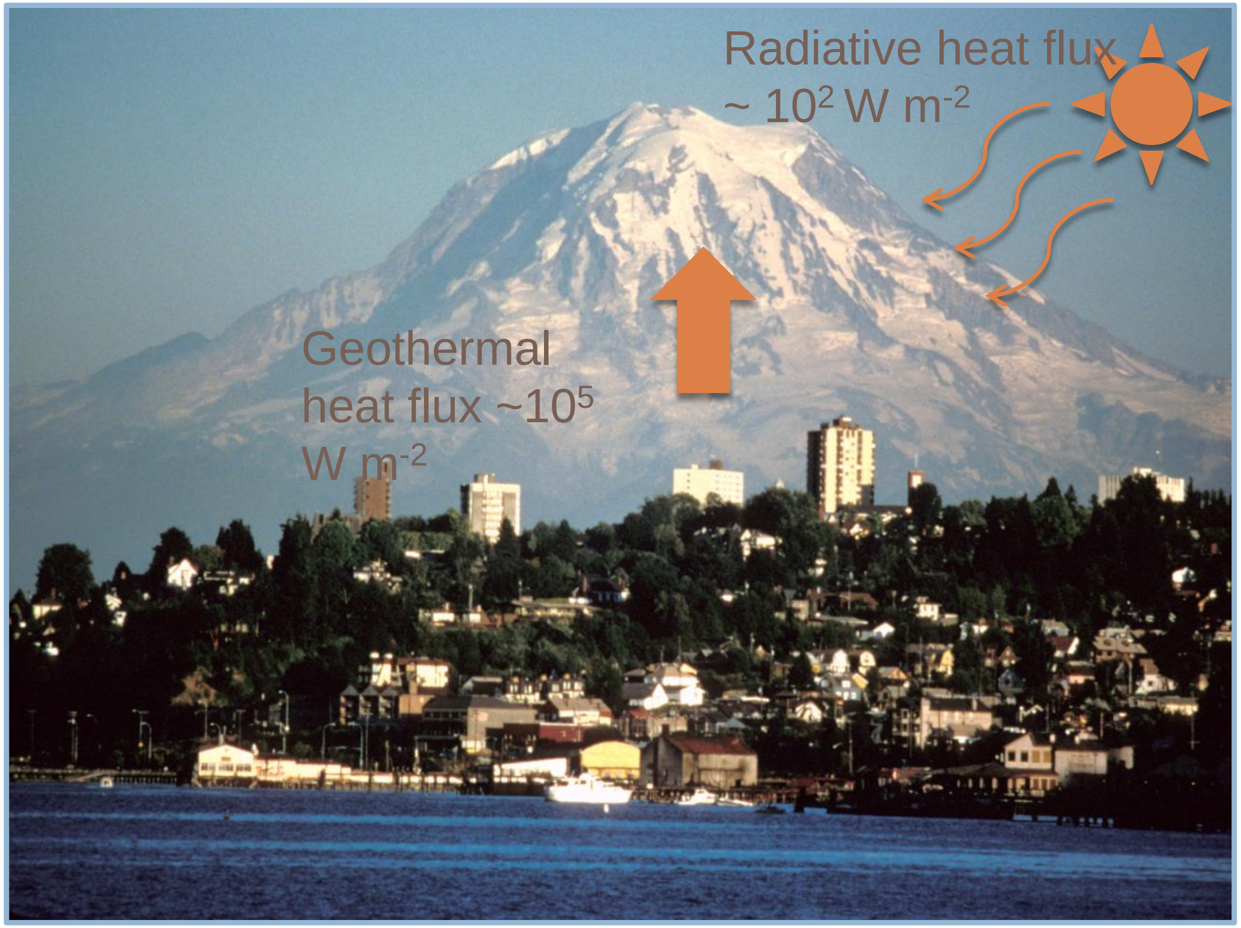
Conclusions: Debris

- We have a method for systematically determining the extent of quasi-viscous/granular behaviour within a debris flow
- Roughness is only important in the quasi-viscous regions when the roughness length is greater than or equal to the mean particle size
- To do: lots!

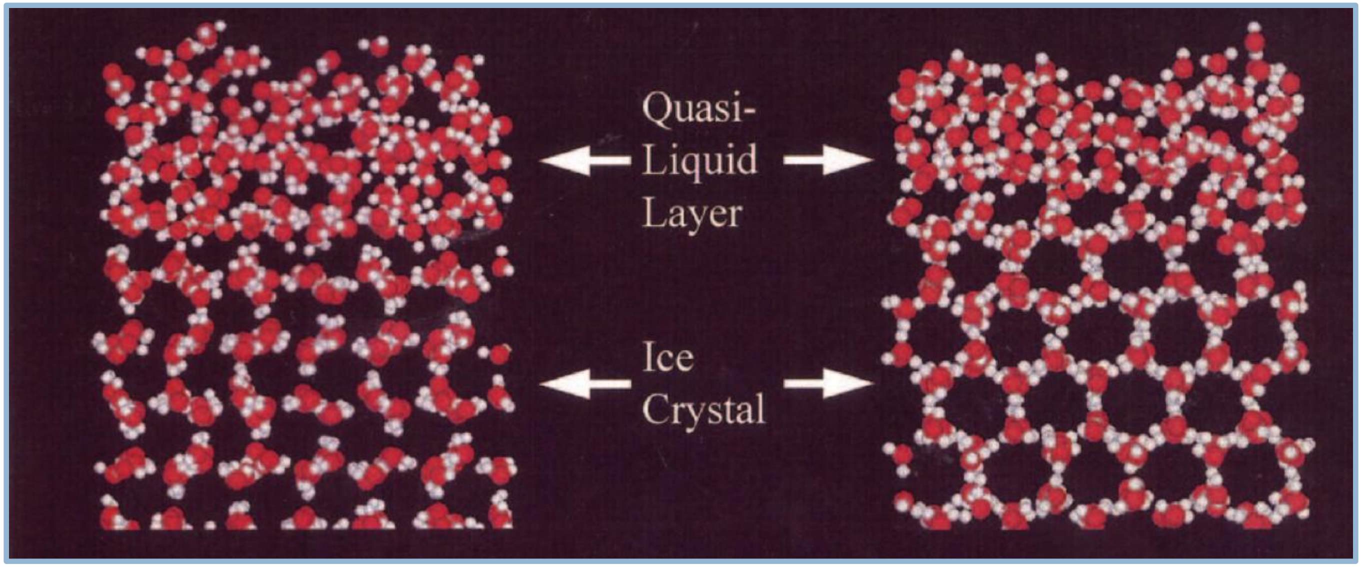
Ice avalanches

An increasingly prevalent phenomenon (Huggel et al 2008)

Can exhibit surprising mobility



Pre-melting



- Crystalline substances exhibit a disordered, ‘liquid-like’ layer even well below melting point

Wetted granular materials

We're asking

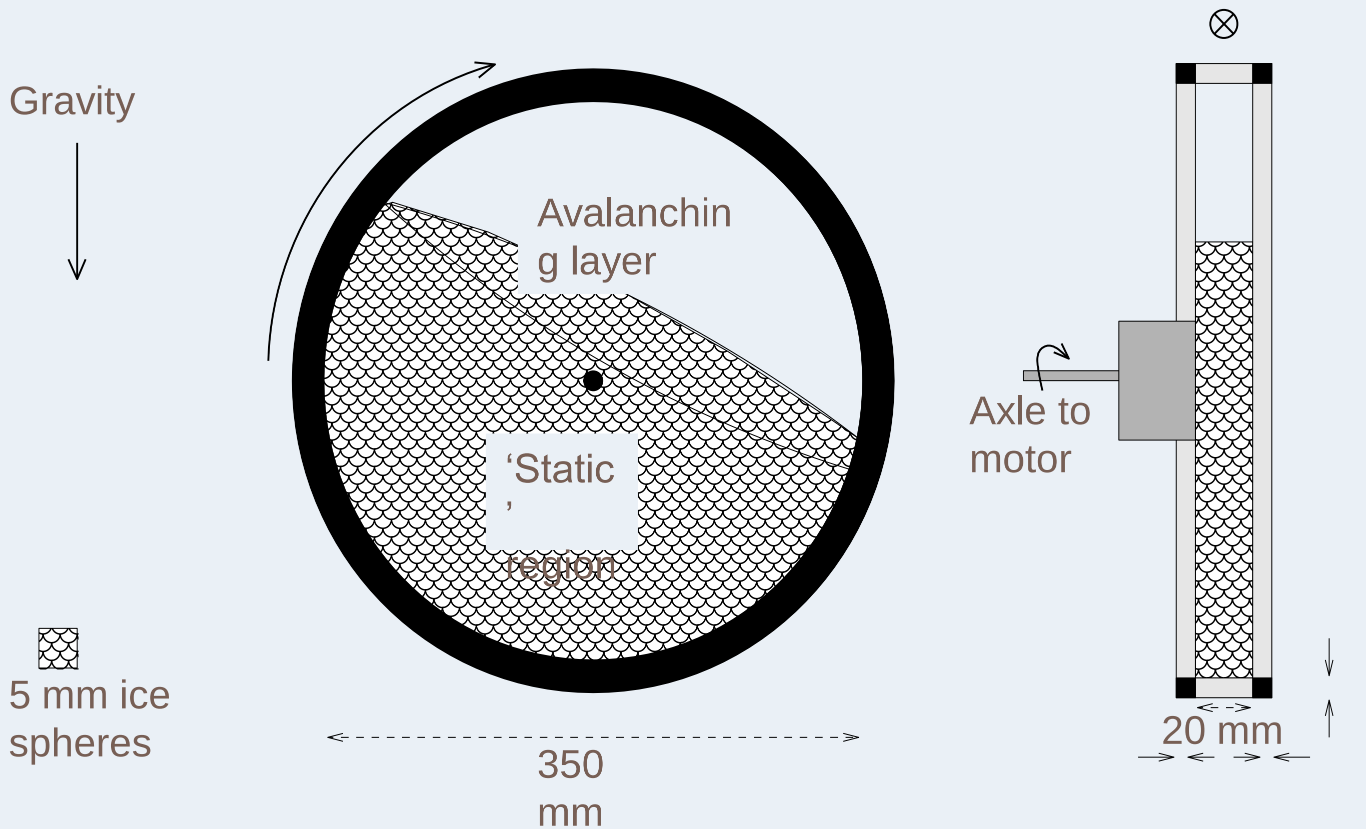
- How does pre-melting affect a granular flow of ice?
- Do granular collisions enhance pre-melting?
- Can controlled pre-melting provide an improved method of testing moisture effects in granular flows?

Experiment

A rotating drum, for the generation of continuous avalanches of ice particles.

Replicates:

1) Avalanching shear flow.
2) Interaction with basal material.



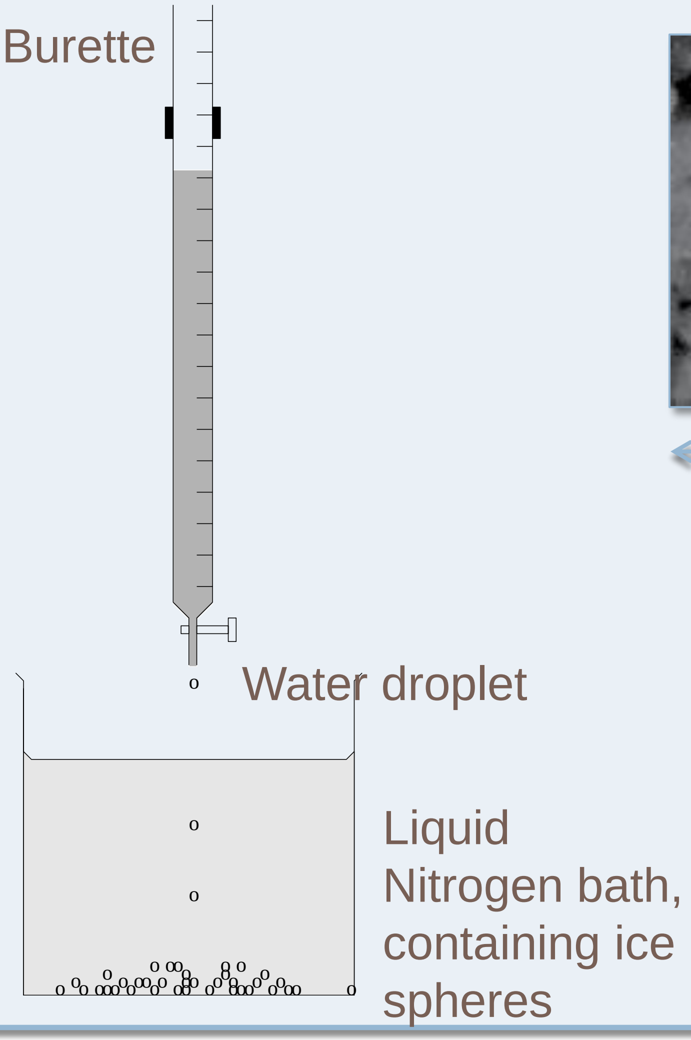
Ice manufacture

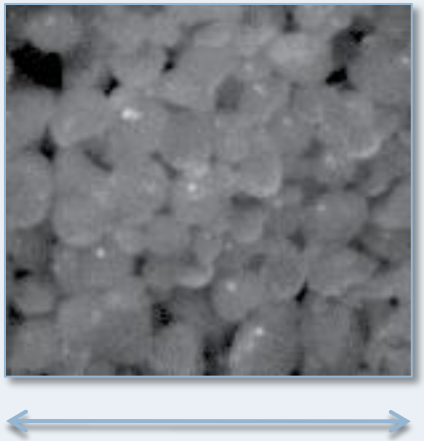
Drip water from a burette into a liquid Nitrogen bath.

Allow the N_2 to evaporate.

4mm-5mm ice spheres.

Use straight away.





~30 mm

Programme

Preliminary tests

- Cold room temperature:
  - -4, -2, -1, 0ºC
- Rotation rate:
  - 16 rpm
- Fill fraction:
  - 0.47
- High Speed Camera:
  - IDT M5 MotionScope, 50 mm f2.0 lens.

Results

Half second bursts of high speed (500 Hz) video recordings, every 2 minutes.

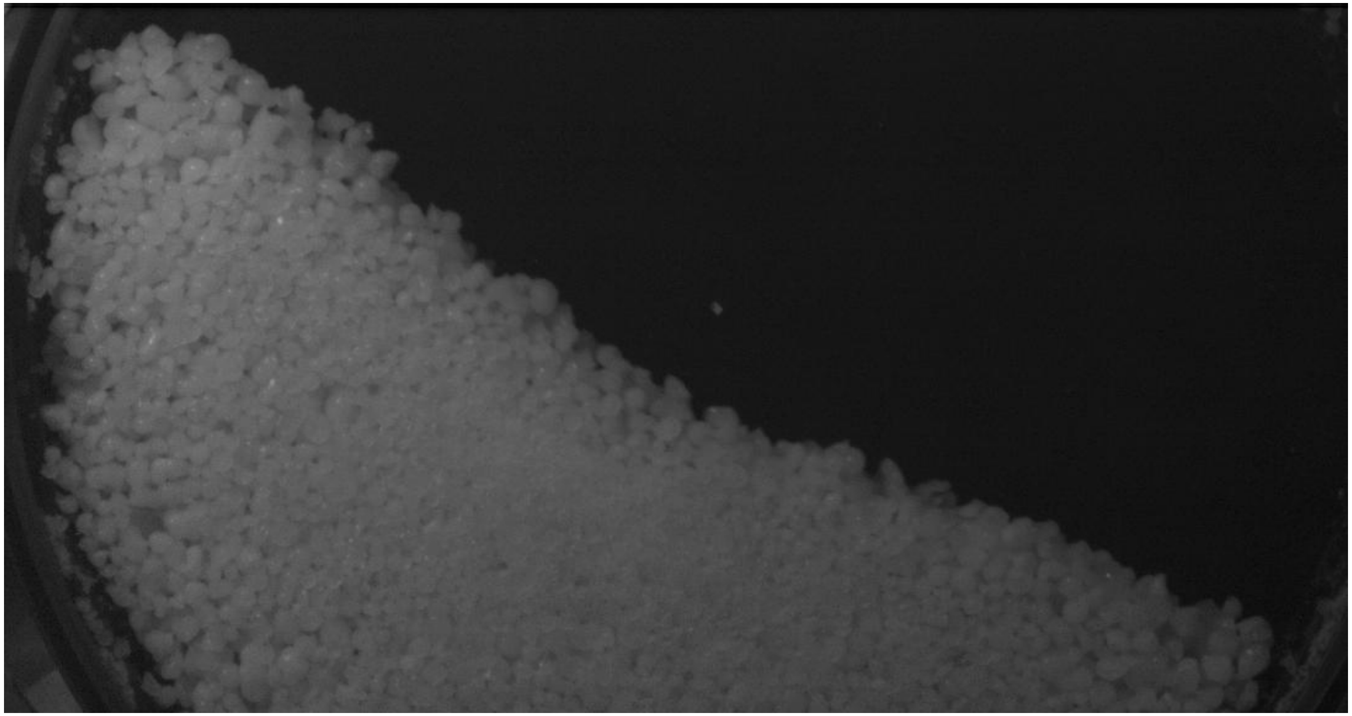


Image analysis

PROCESSES: Time averaging

Masking

TO IDENTIFY:

Flow surface

Average inclination

Characteristic profile line

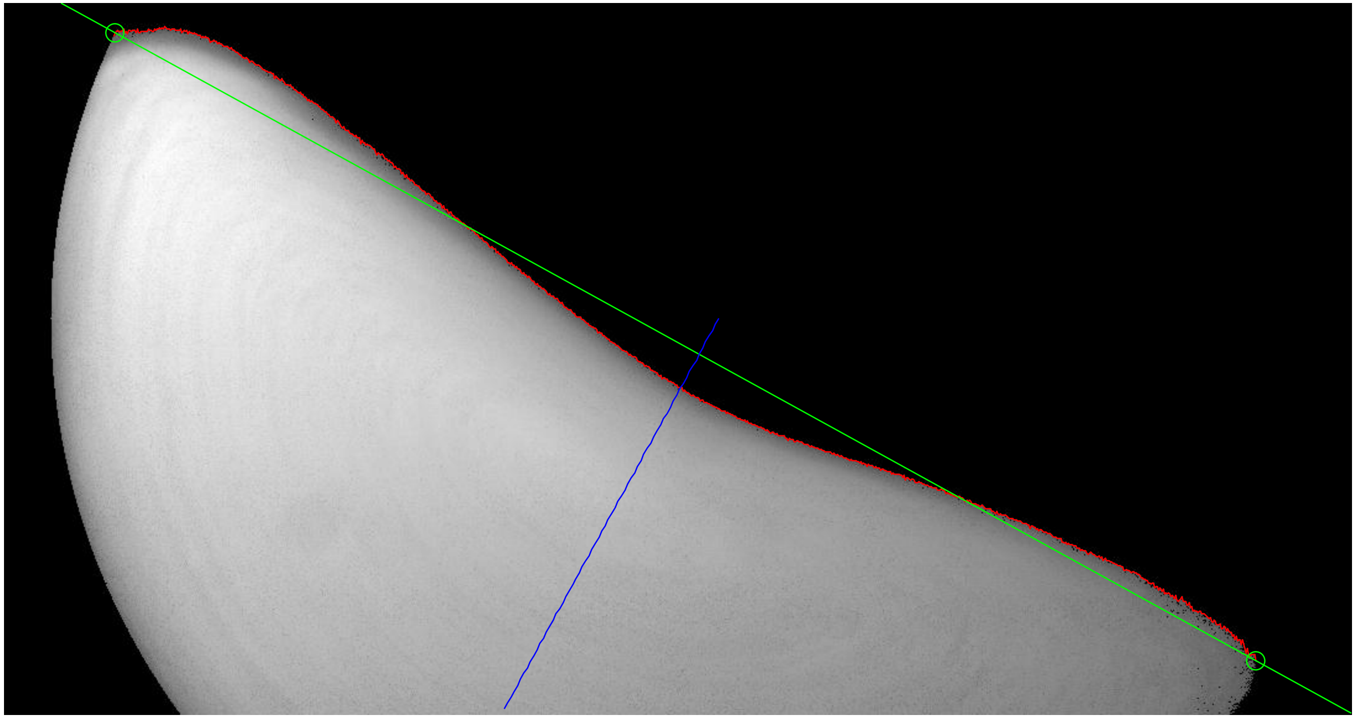
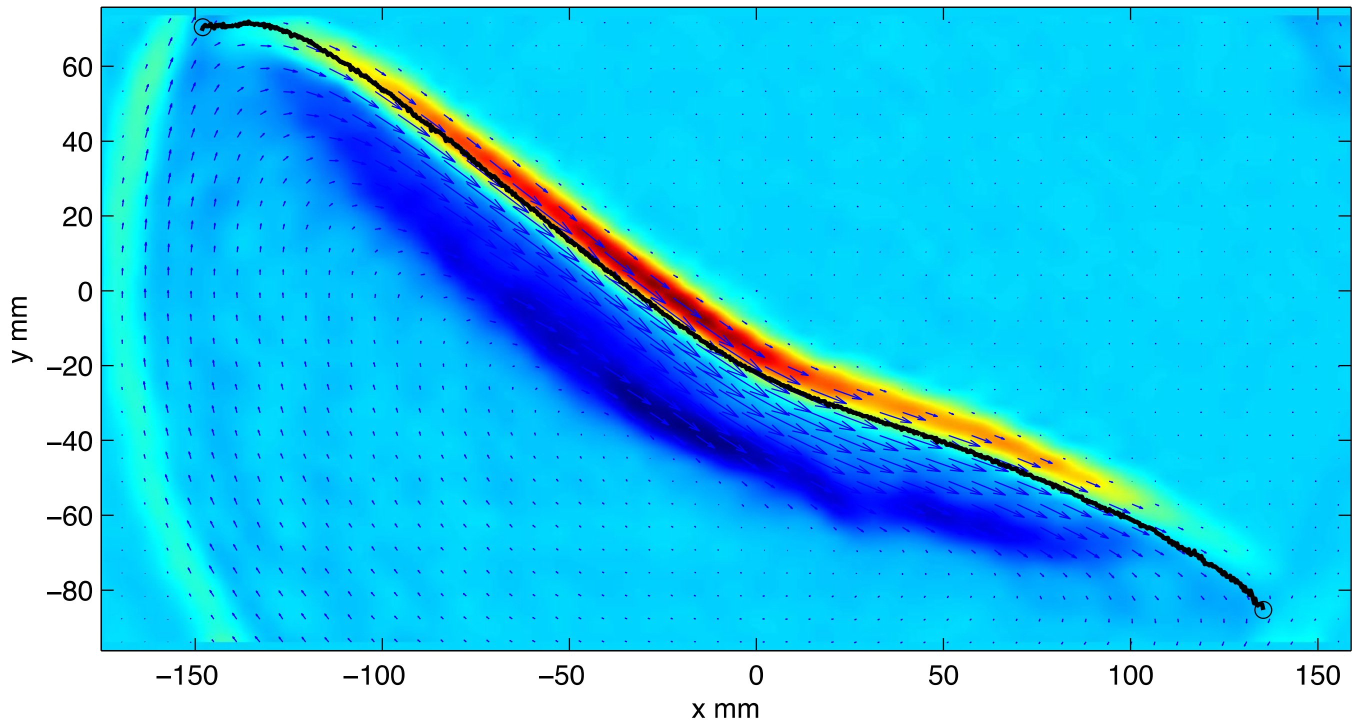


Image analysis

Particle Image Velocimetry provides velocity and vorticity data.

Time-averaging over video burst smoothes the data.



Dimensional analysis

Shear layer velocity, u_s

Rotation rate, Ω

Particle size, d_p

Fill fraction, ϕ

Drum size, D

Energy for melting, E

Time, τ

Shear layer thickness, h_s

Gravitational acceleration, $g\sin\alpha$

$$u_s = f(\Omega, \quad d_p, \quad \phi D, \quad E, \quad \tau, \quad h_s, \quad g\sin\alpha)$$

The energy required for melting, comprises that needed to bring the ice to its melting temperature and the latent heat of fusion. For an experiment $\Delta\Theta$ below freezing

$$E = \Delta\Theta\, c_p + \ell\,.$$

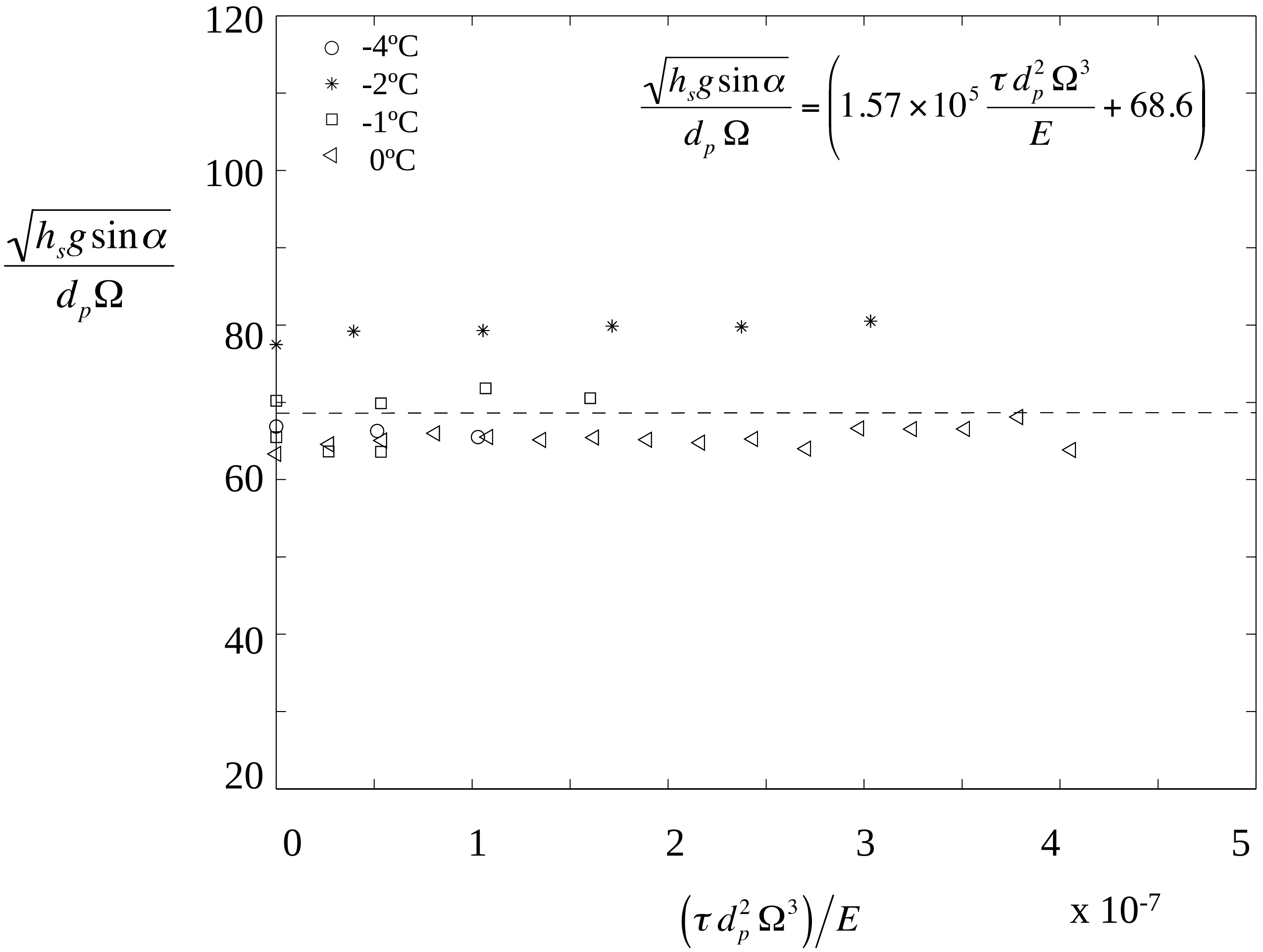
8 variables in 2 dimensions leads to 6 non-dimensional groups to fully describe the problem.

$$\frac{u_s}{d_p\,\Omega} = f\left(\frac{\phi D}{d_p}, \quad \tau\Omega, \quad \frac{E}{d_p^2\,\Omega^2}, \quad \frac{h_s}{d_p}, \quad \frac{\sqrt{h_s g\sin\alpha}}{d_p\,\Omega}\right).$$

Velocity scale ratio

RMS residual 8.7%

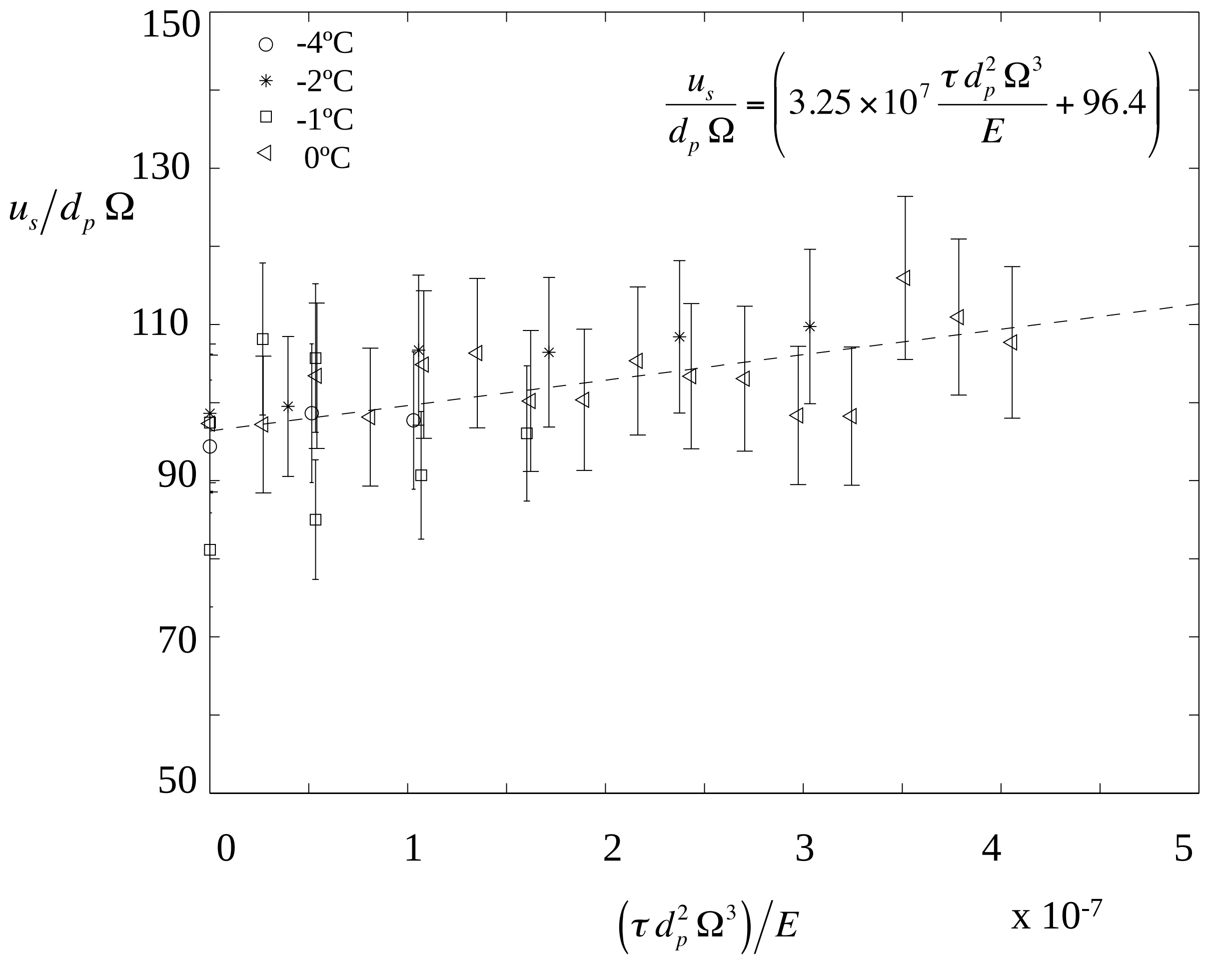
Temperature and time invariant



Shear layer velocities

Estimated errors ~ 9%

RMS residual 6.1%



Shear layer Froude number

$$\frac{u_s}{\sqrt{h_s g \sin\alpha}} = 0.015\frac{u_s}{d_p \Omega} \pm 0.001$$

- Experiments: Froude number in the range 1.4-1.6
- Field: Froude numbers between 1 and 5

Dreams…

- Statistical tests
- Much larger temperature ranges and time scales
- Different drum and particle geometries
- Melting/non-melting component mixtures

Conclusions: Granular Ice

- Melting through granular collisions and interfacial pre-melting occurs well below freezing point
  - How can melting through granular collisions be incorporated into the Clausius-Clapeyron phase transition equation?
- Wetting arising from melting reduces the apparent friction within the flow
  - But how important is this compared with other moisture sources?
- Dimensional analysis has provided a parameter space for further study

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