SCALING LAWS FOR MELTING ICE AVALANCHES

B. Turnbull, Phys. Rev. Lett. 107, 258011 (2011)

Team 6

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http://kiddiescornerdeals.com/wp-content/uploads/2011/12/ice-age-a-very-mammoth-christmas.jpg

OUTLINE OF THE TALK

- Motivation
- Experiment and Method
- Results
- Critical Analysis and Impact
- Summary

COLLAPSE OF KOLKA GLACIER

Satellite map of the Caucasus mountain range Kolka glacier is just west of Mt. Kazbek.

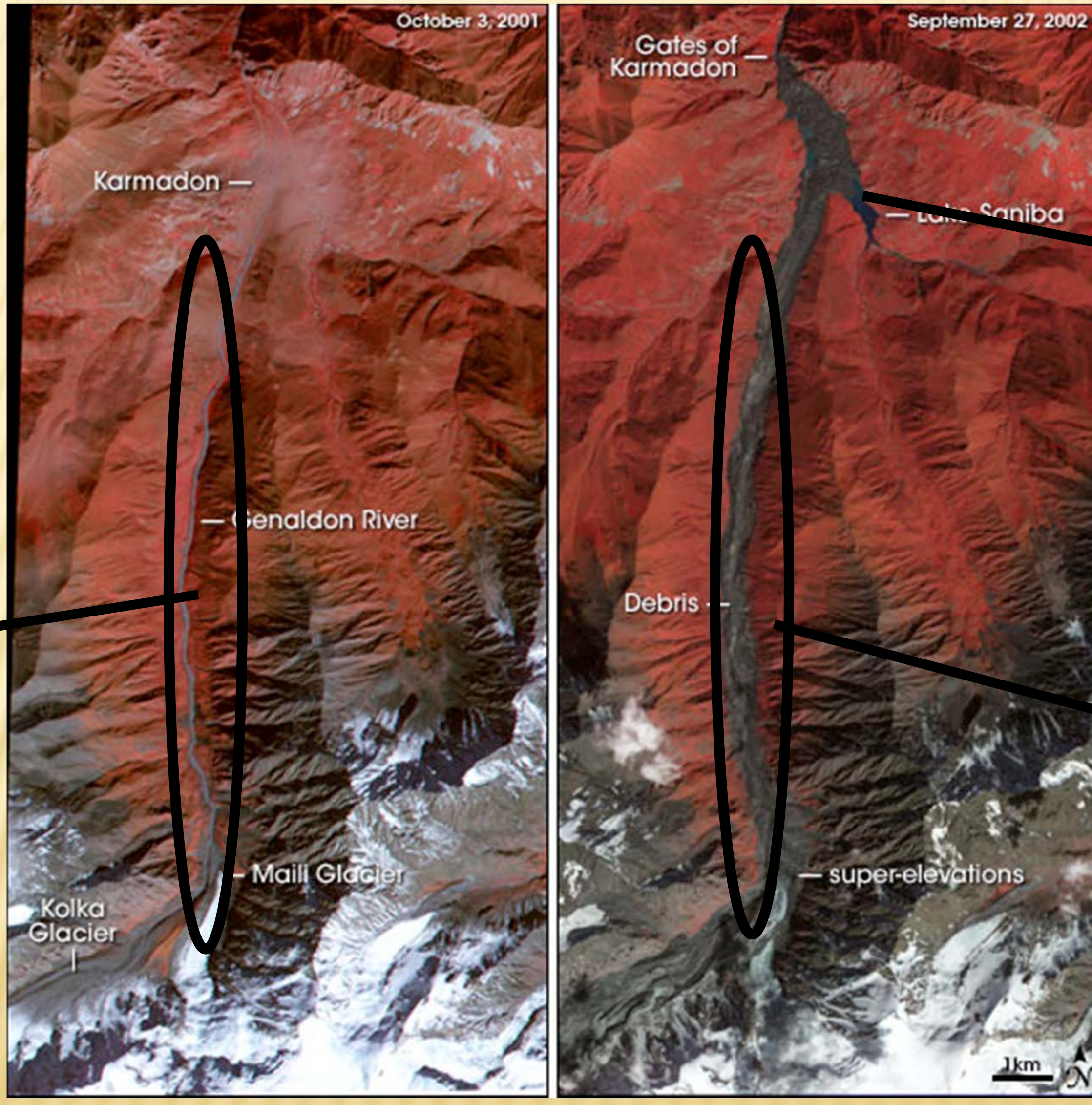
-Largest historically documented ice avalanche
-Caused the death of 140 people
-Destroyed important infrastructures
-Dammed several marginal lakes

http://earthobservatory.nasa.gov/Features/Kolka/
C. Huggel et al, Nat. Hazard Earth Sys. 5, 173 (2005).

SATELLITE IMAGES TAKEN BEFORE AND AFTER THE COLLAPSE

Before

After



River

New lake was formed

Debris from the collapse

http://earthobservatory.nasa.gov/Features/Kolka/

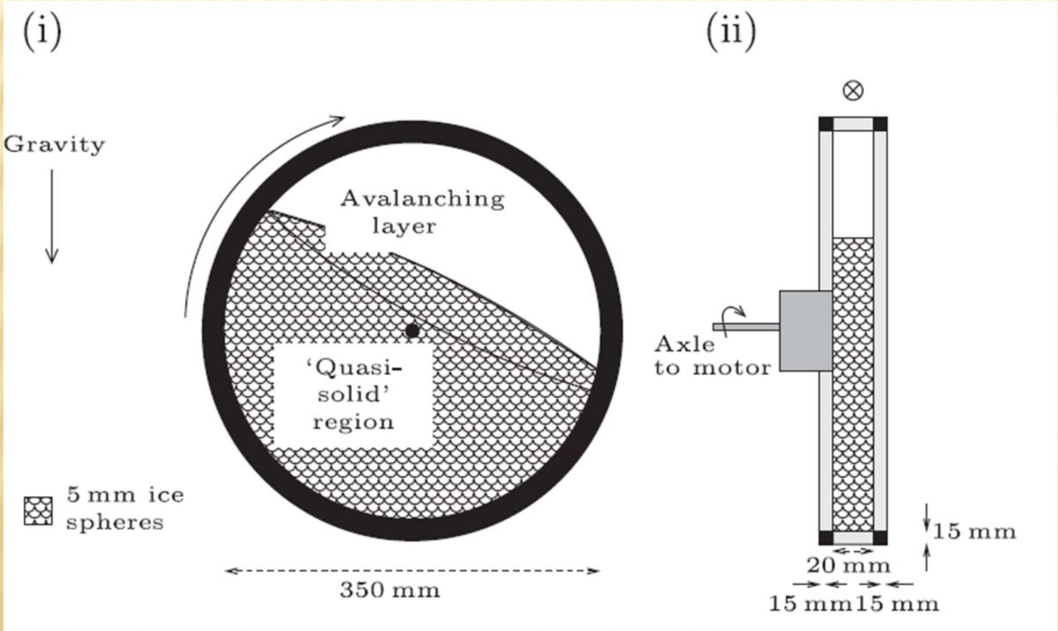
MODELING THE AVALANCHE

- Current models (dry granular flows and multiphase debris flows) can capture aspects of this avalanche but not the physics behind extraordinary flow rate
- Need a simple physical model to understand the process
- This paper tried to answer the question:

  What are the effects of interfacial melting to the flows?

AVALANCHES IN A DRUM

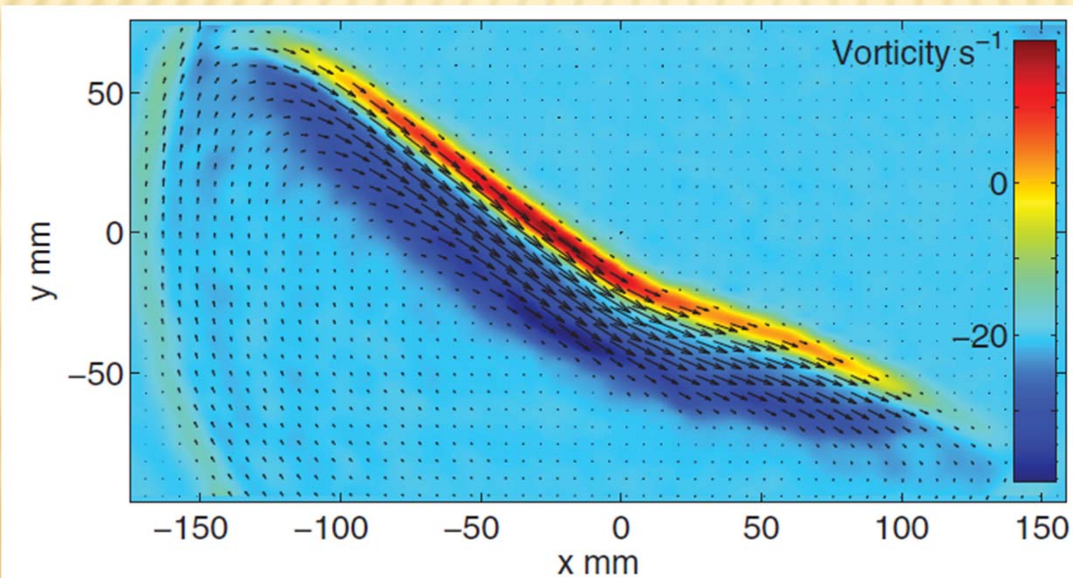
- Set-up: Narrow drum, 47% filled with ice particles
- Dripped water into liquid nitrogen to produce ice particles with ~5mm in diameter



(B. Turnbull, Phys. Rev. Lett. **107**, 258011 (2011))

OBSERVING MOTION OF ICE PARTICLES

- Drum rotates slowly at 3.75s per revolution
- Record motion by high-speed video: 250-500 frames every 2 mins at 500Hz (experiment lasts for 45 mins)
- Temperature bath: -4^{o}C,-2^{o}C, -1^{o}C and 0^{o}C



Velocity (arrows) and Vorticity (color) Map at -4^{o}C

(B. Turnbull, Phys. Rev. Lett. 107, 258011 (2011))

ANALYSIS BASED ON SEVERAL ASSUMPTIONS

- Velocity of particles change slowly ~O(minute)

- Shape of particles not change systematically before and after the experiment
  - change in shear layer velocity due to melting alone

DETERMINE PHYSICS BY DIMENSIONAL ANALYSIS

- **Buckingham π Theorem:** n variables in m dimensions, physical equation can be expressed in (n-m) dimensionless variables

- 8 variables and 2 dimensions (length and time) in this system, 6 groups of parameters

TWO KEY DIMENSIONLESS PARAMETERS

- Dimensionless wetting:
  - Increases with time, decreases as energy increases

$$m = \frac{\tau\, {d_p}^2 \Omega^3}{E}$$

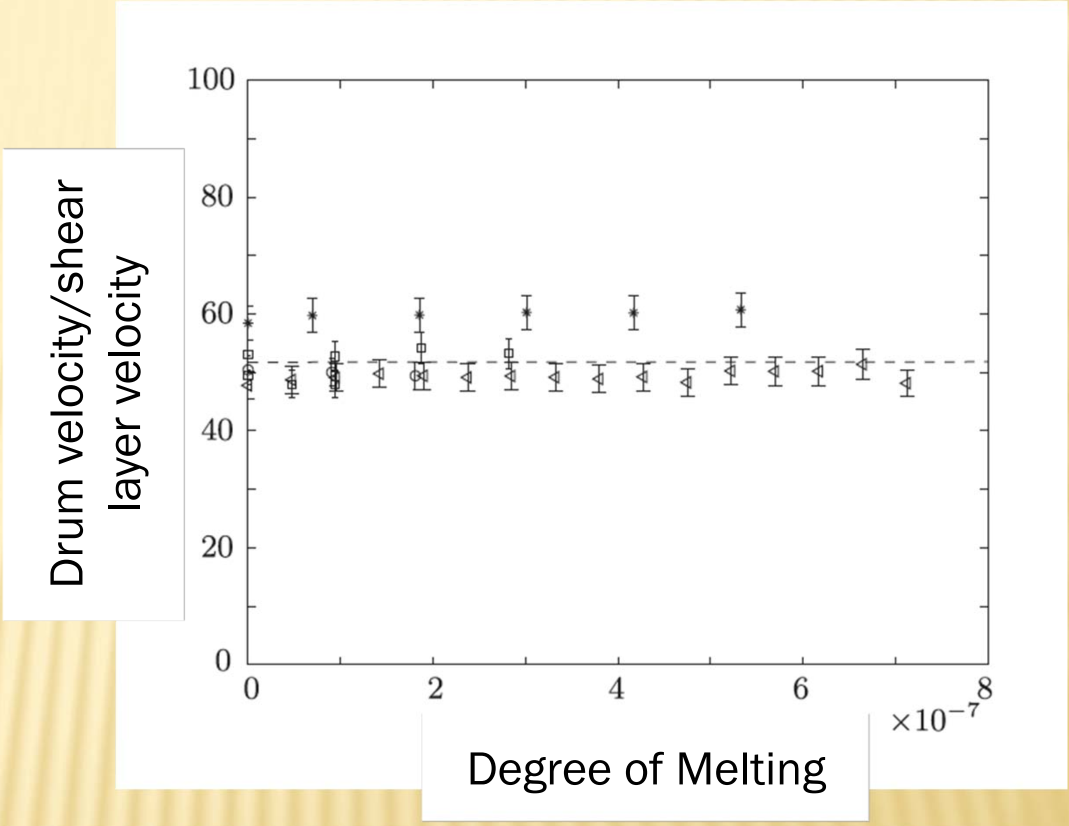
,where $\tau\Omega$ is the dimensionless time and $\frac{E}{{d_p}^2\Omega^2}$ is the dimensionless energy associated with melting

- Froude number:
  - Characteristic velocity scale divided by shear layer wave velocity

$$F = \frac{u_s}{(h_s\, g \sin\alpha)^{1/2}}$$

STUDY FOUND SEVERAL QUANTITIES WERE INTERDEPENDENT

- Drum and shear layer velocities
- Particle diameter and shear layer thickness



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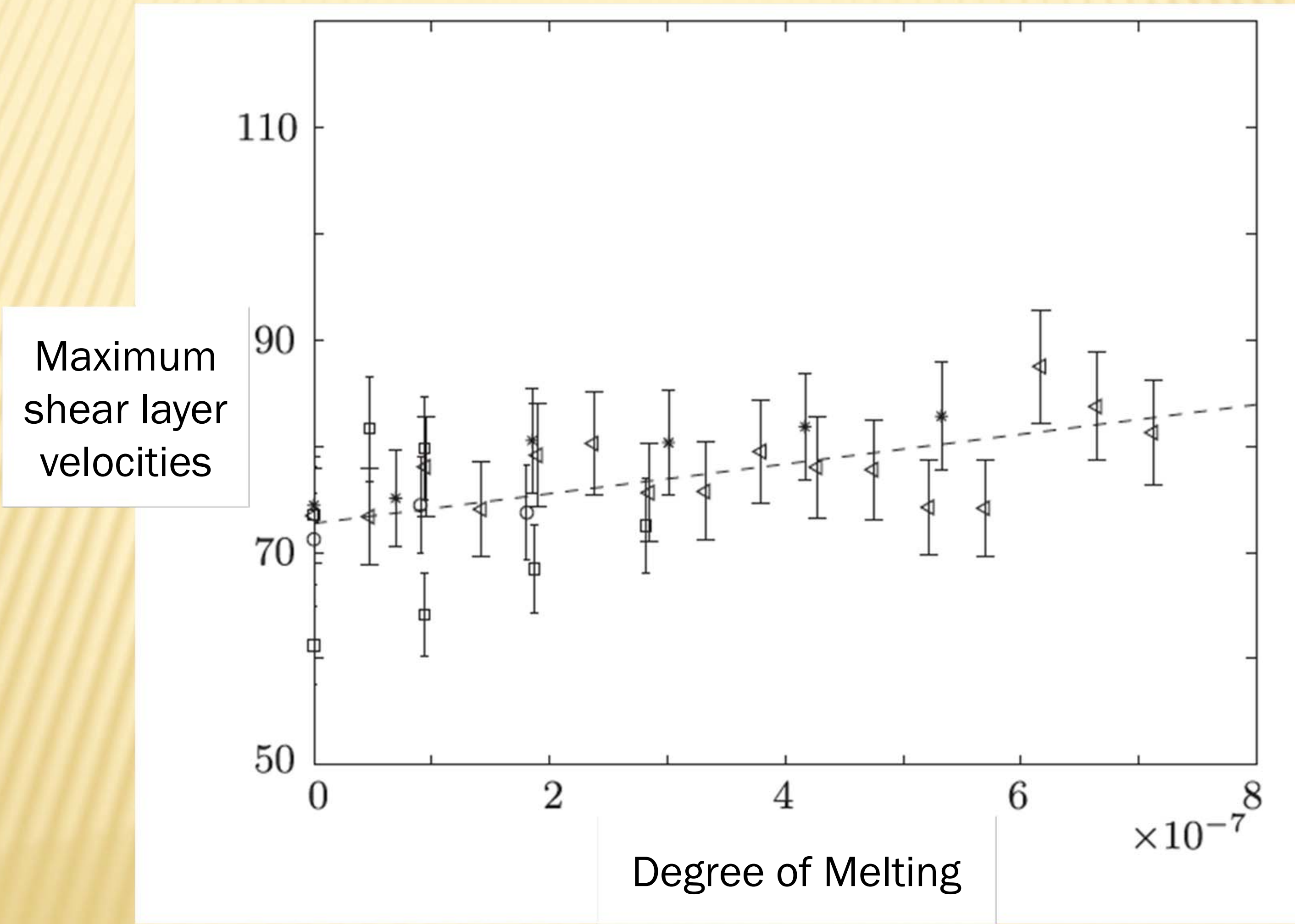
APPLICABILITY TO PHYSICAL SYSTEMS

- Experimental Froude Number Range: 1.4-1.6
- Physical Froude Number Range (Avalanches): 1-5
- Scaling laws valid for large physical flows
  - Perhaps not for all flows?

MAXIMUM SHEAR LAYER VELOCITY INCREASES WITH DEGREE OF MELTING



CONCLUSIONS

- Found a linear fit which is probably not accurate
  - Serves to demonstrate trend
- Melting increases shear velocity
- Greater velocities lead to greater melting
- Timescale of experiment short compared to physical timescales
  - i.e. timescale for bulk melting
- Only describes quasigranular regime

WAYS PAPER EXPANDS PREVIOUS WORK

- Generalizes drum model to real physical situation

- Uses ice particles rather than numerical simulations or beads and oil

INCONSISTENCIES FOUND WHEN COMPARING WITH PREVIOUS WORK

- Older work suggests drum geometry not applicable to “rough incline geometry”
  - i.e. not generalizable to physical systems
- Cited work old (2002-2003)
- Three regimes, but only investigates one
  - Granular
  - Correlated
  - Viscoplastic

CRITICAL ANALYSIS 1: INTEREST AND IMPACT

- Trying to hook in the wrong audience. Paper is mostly of interests to scientists studying small-scale granular flows.
- Main physical result (flow speed proportional to wetting) is fairly obvious.
- Impact on the problem of avalanche prediction/prevention?

CRITICAL ANALYSIS 2: EXPERIMENT AND SCALING ARGUMENTS

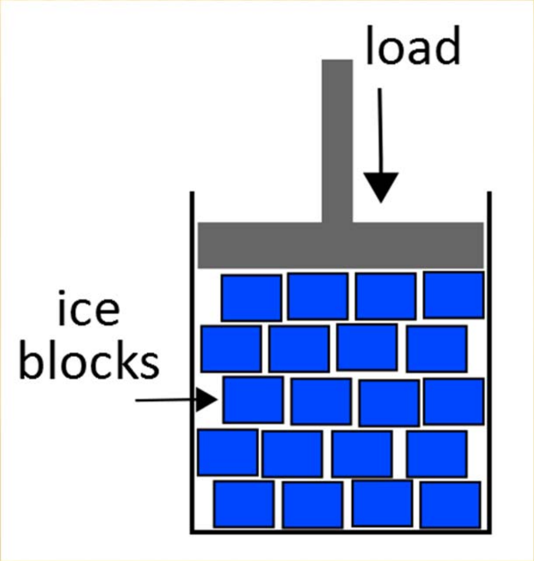
- Dependence of incline angle α on the drum rotation rate Ω, drum length scale D, and filling fraction φ?
- Should test the dependence of the maximum shear flow velocity on each variable appearing in the dimensionless wetting (they only vary temperature).

WORK SINCE…

- As of 2012/11/13, has been cited 3 times.
- Mentioned in a review article on wet granular materials (Herminghaus 2012).
- Stack of ice blocks subjected to a load and contained in a vertical cylinder (Laroche 2012).

• Rotating drum experiments with solid particles in various liquids (Leuptow 2012).

• Future work doesn't relate to shear flow of melting particles.



SUMMARY

- Investigated flow properties of the melting surface layer of avalanching ice particles.
- Postulated and confirmed the dependence of the maximum shear flow velocity on a set of dimensionless parameters.
- Maximum shear flow velocity increases linearly with wetting of the ice particles in the shear layer.