In defense of ice mélange

Jason Amundson

UAS UNIVERSITY OF ALASKA SOUTHEAST

What is ice mélange?

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Extreme Ice Survey

Why ice mélange matters (in Greenland)

1. Glacier buttressing/inhibiting calving ← I'll focus on this

Why ice mélange matters (in Greenland)

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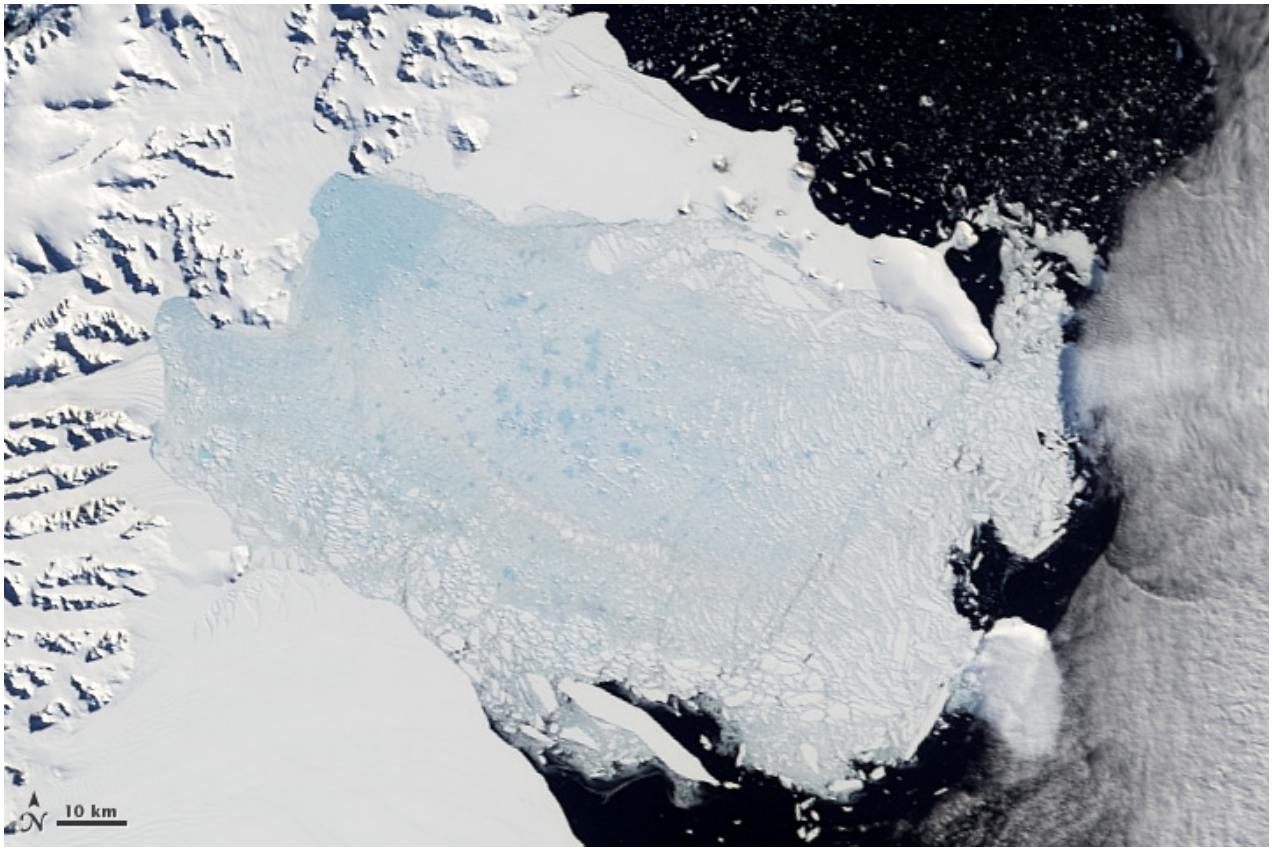
2. Ocean waves
   - Waves may promote calving (MacAyeal et al., 2009)
   - Waves can be used to monitor calving activity (Nettles et al., 2008; MacAyeal et al., 2010; Amundson et al., 2012)
   - Ice mélange can affect wave frequency (MacAyeal et al., 2012)
3. Iceberg capsize
   - Iceberg-terminus contact force
     - Generation of seismic waves (Tsai et al., 2008; Walter et al., 2012)
     - Promotion of ice fracture and subsequent calving
   - Generation of ocean waves and turbulence (Burton et al., 2012)
4. Submarine melt
   - Inject freshwater at depth
   - Ice-rafted debris? (Jennings and Weiner, 1996)
   - Need to take into account iceberg melt when analyzing oceanographic data
5. Atmosphere-ocean interactions

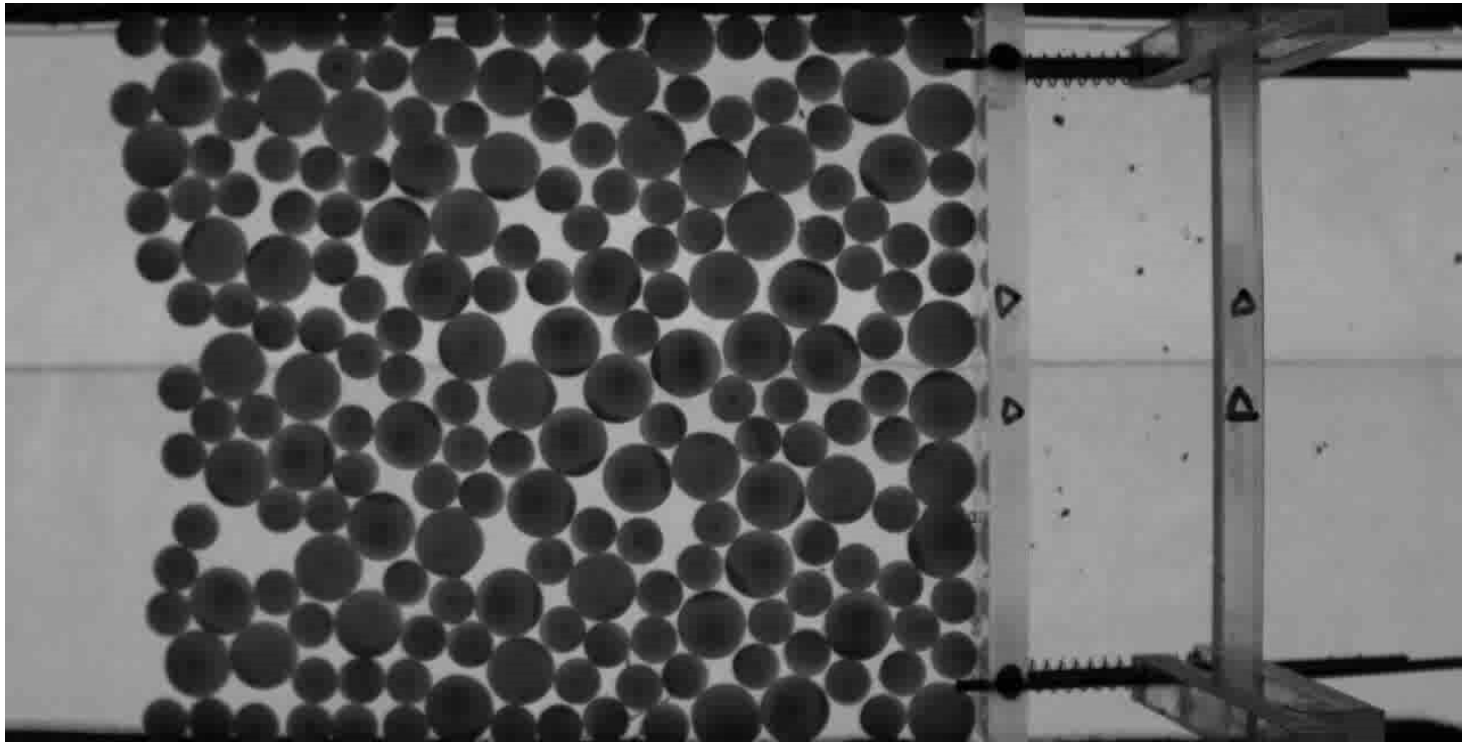
Other reasons that ice mélange matters

- Processes must share some similarities with ice shelf collapse observed in Antarctica. Can observations from “small and accessible” fjords teach us something about iceberg interactions during ice shelf collapse events?



Other reasons that ice mélange matters

- Ice mélange is possibly the largest granular material on Earth, and is quasi 2-dimensional. Can studies of ice mélange teach us about the general nature of granular materials?



Kuo and Dennin, in press

A brief history of ice mélange

- Break-up of sea ice preceded large-scale calving events in North Greenland
- Proposed mechanisms by which sea ice can affect glaciers:
  - Provide resistance to prevent crevasse formation – but no sign of buckling in sea ice
  - Damp long ocean waves, reducing bending stresses – how much bending stress can you really produce in a thick glacier?
  - Suppress wind generated waves and mixing of the upper ocean – however, warm water is located at depth…
  - "Glue" together a partially or fully disintegrated terminus

Higgins, 1991; Reeh et al., 2001

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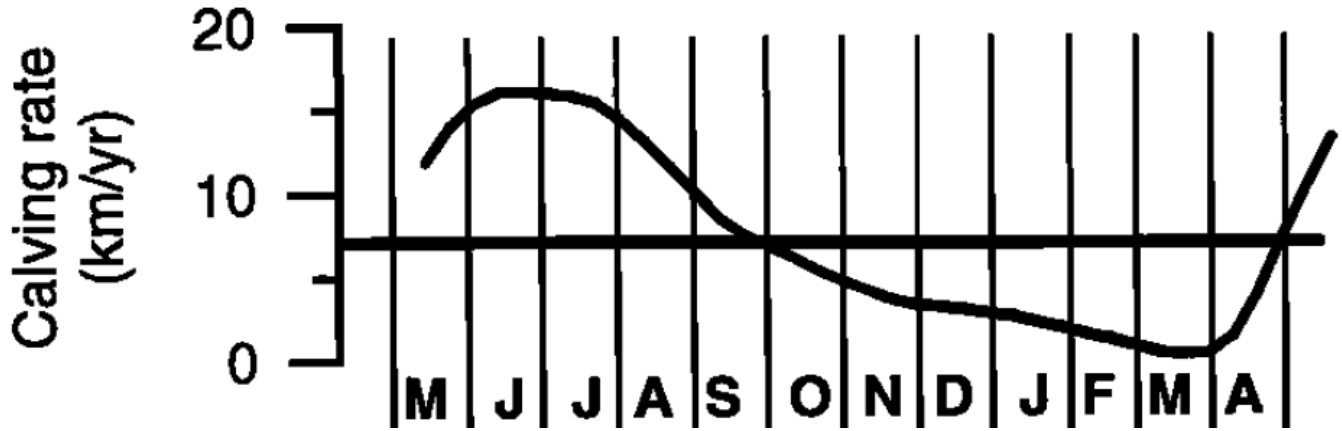
A brief history of ice mélange

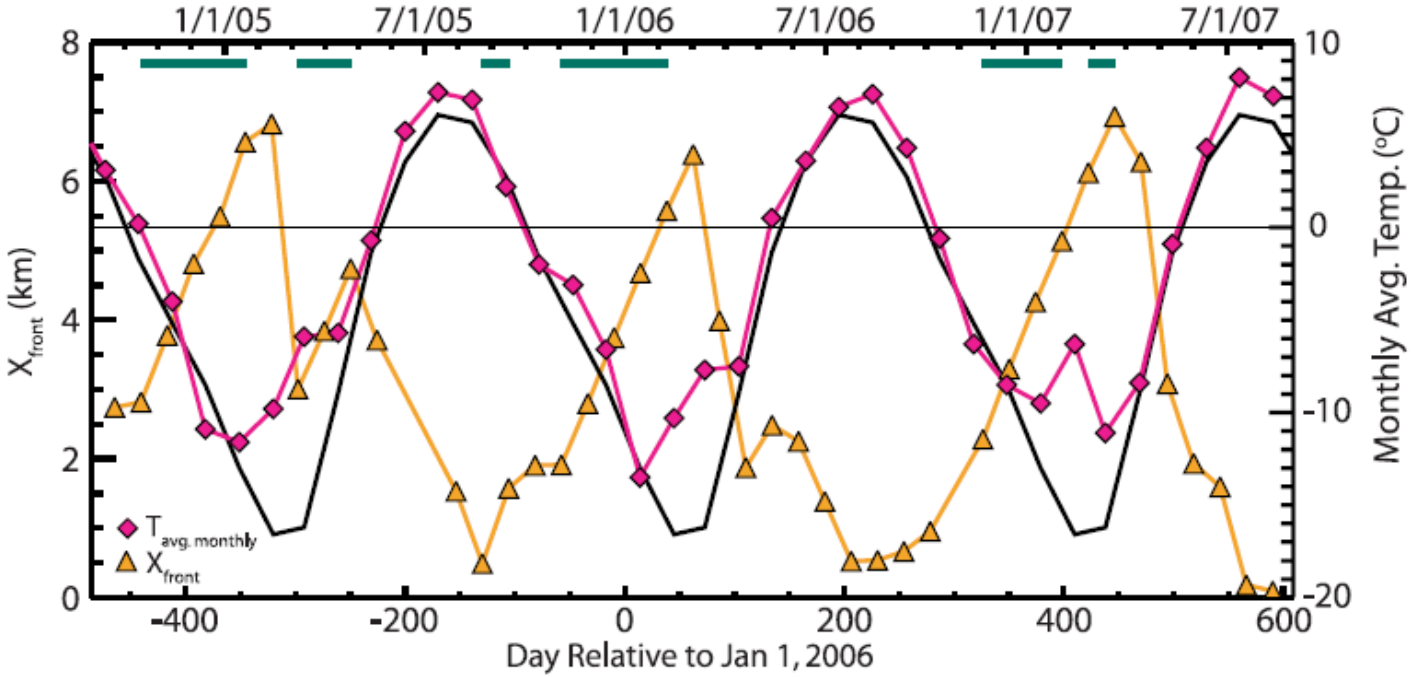
- At Jakobshavn Isbræ:
  - The calving rate in summer is 6 times larger than the calving rate in winter
  - The abrupt onset of calving in the spring, gradual decrease in calving rate in autumn, and small seasonal variations in ice flow suggest that ice mélange affects calving rates



Sohn et al., 1998; Harrison and Echelmeyer, 1991

A brief history of ice mélange

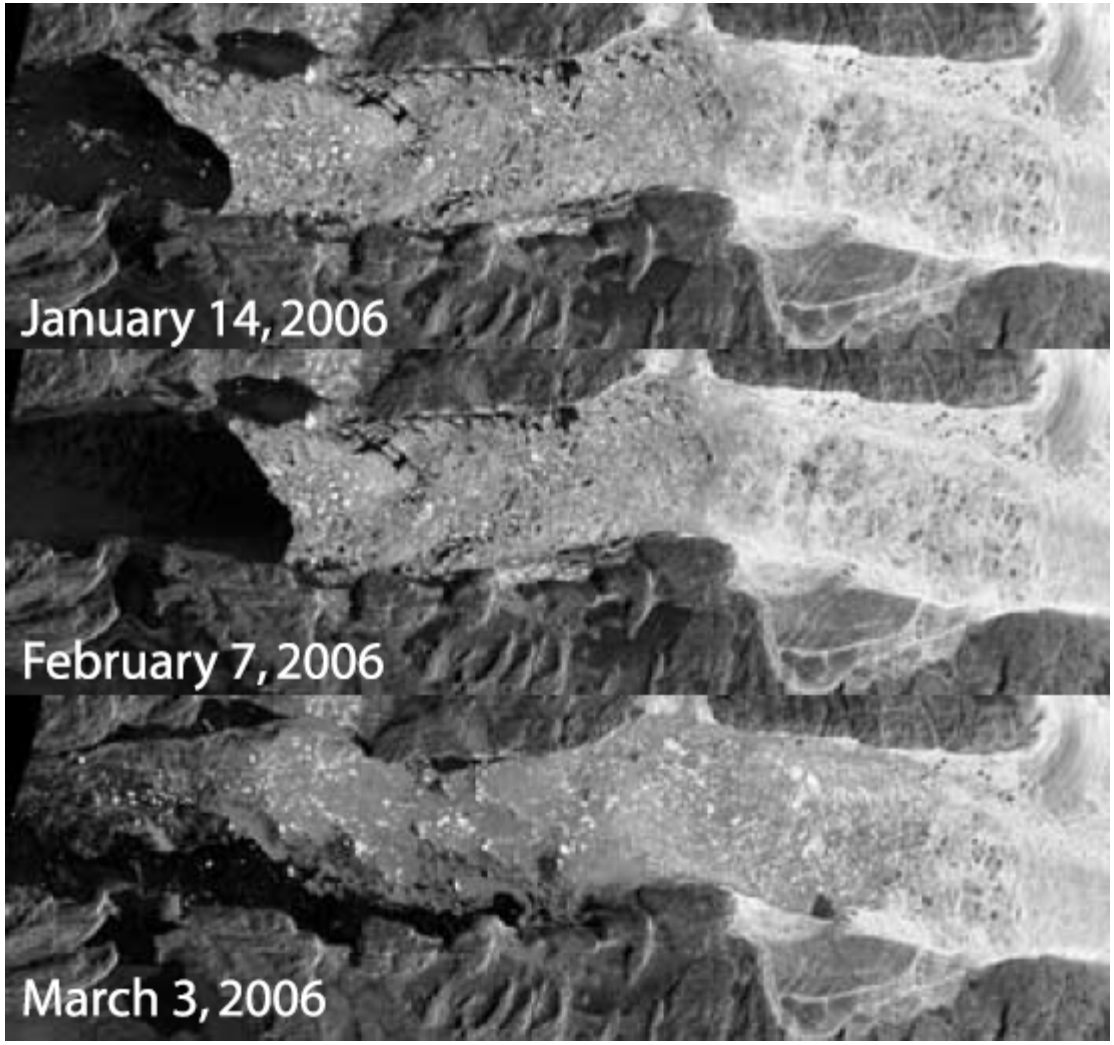
- Seasonal retreat starts before air temperatures rise above freezing
- Seasonal re-advance starts when air temperatures are quite high

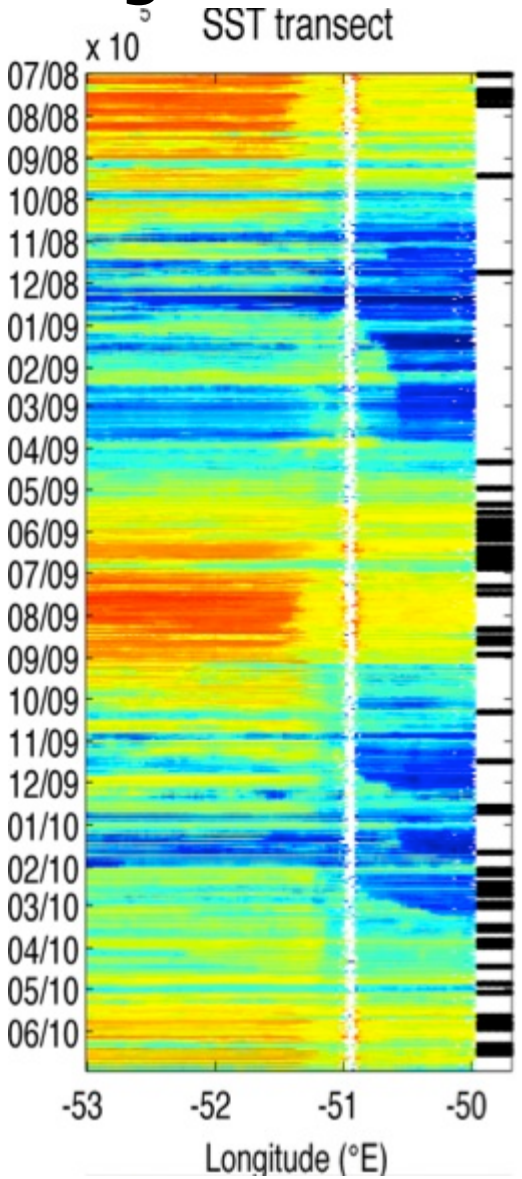


- Suggests complex processes (e.g., jamming of icebergs after a summer of calving, growth of sea ice in fjord related to subglacial discharge, …)
- Similar patterns observed for fjords with seasonal ice mélange

Joughin et al., 2008; see also Howat et al., 2010

A brief history of ice mélange

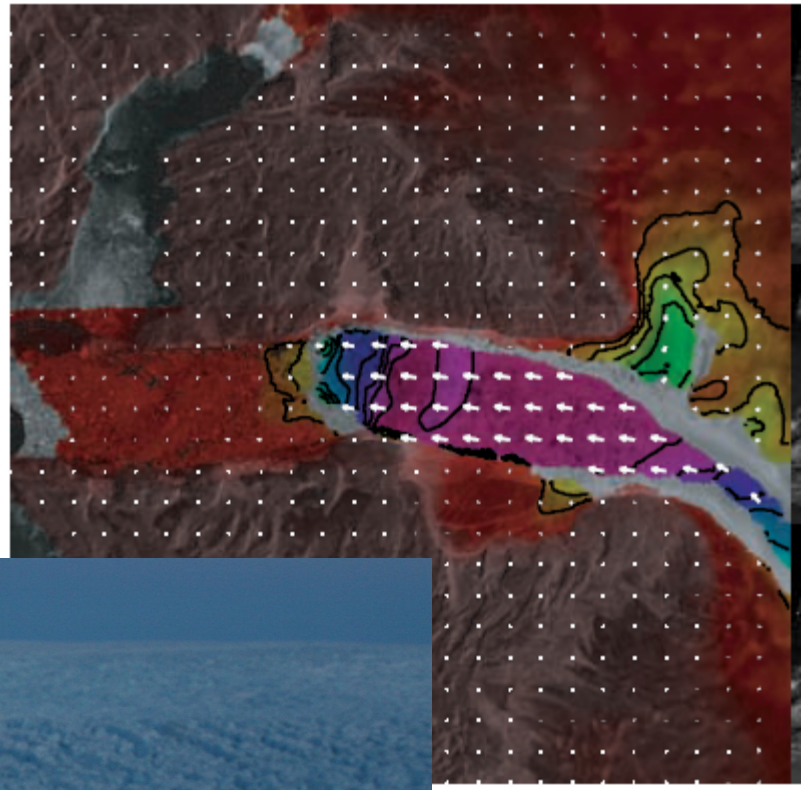


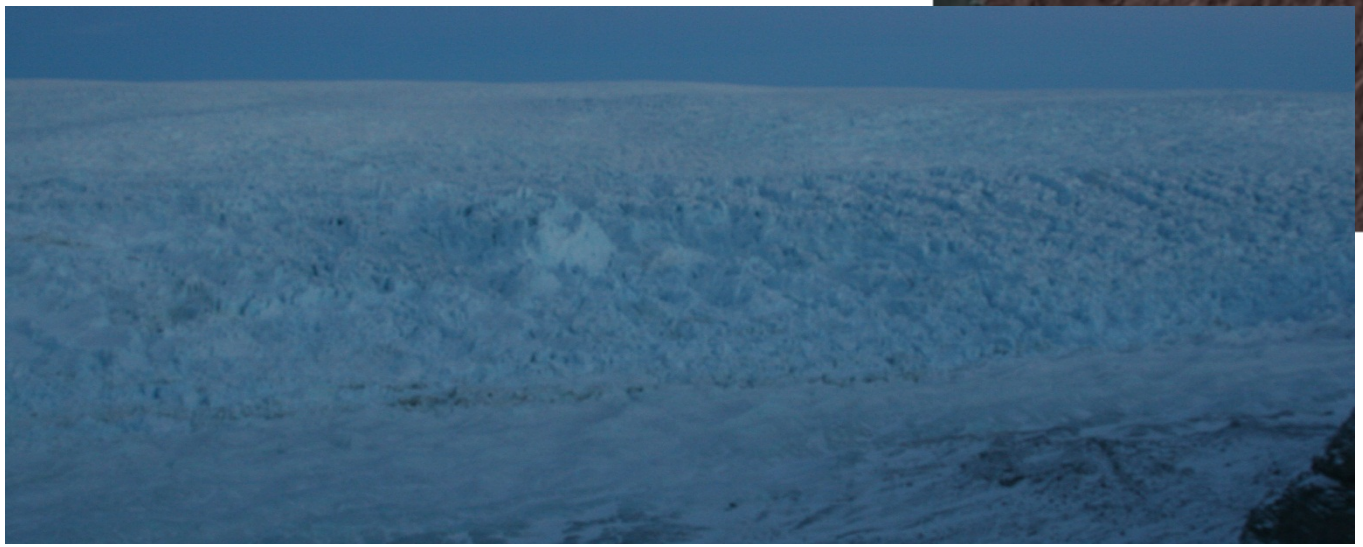


Joughin et al., 2008; Cassotto et al., in prep

A brief history of ice mélange

- During winter, the ice mélange is pushed down fjord by the advancing glacier. Where does the glacier end?

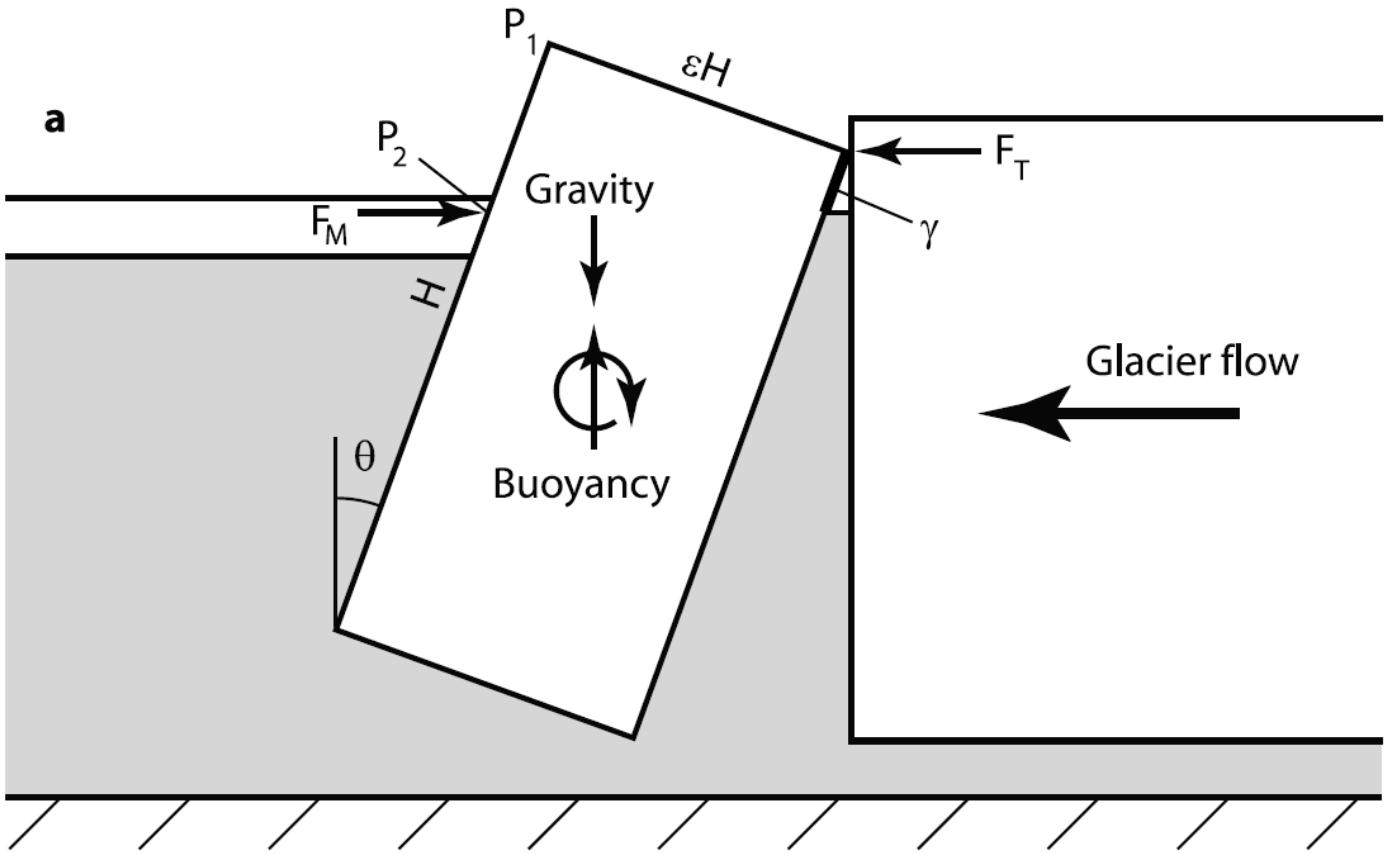




Joughin et al., 2008; Amundson et al., 2010

A brief history of ice mélange

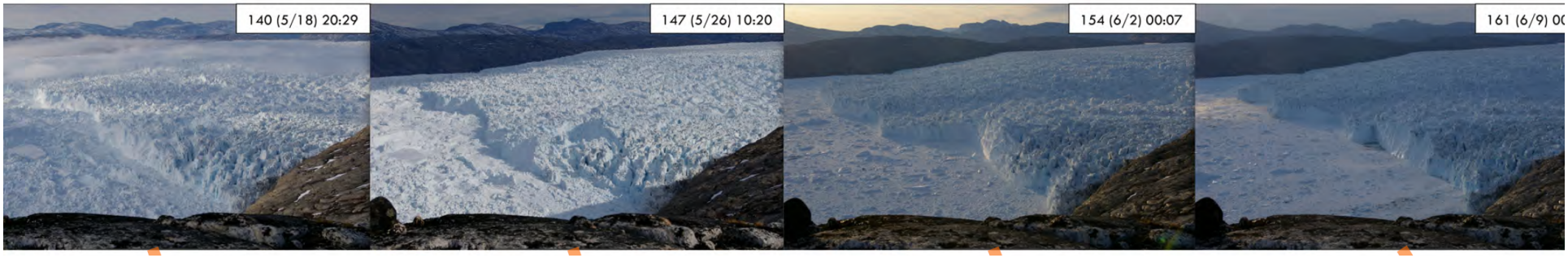
- Force required (from the mélange) to keep an iceberg from capsizing is comparable to the change in back-force from tides (10^7 N/m for a Jakobshavn-sized iceberg)

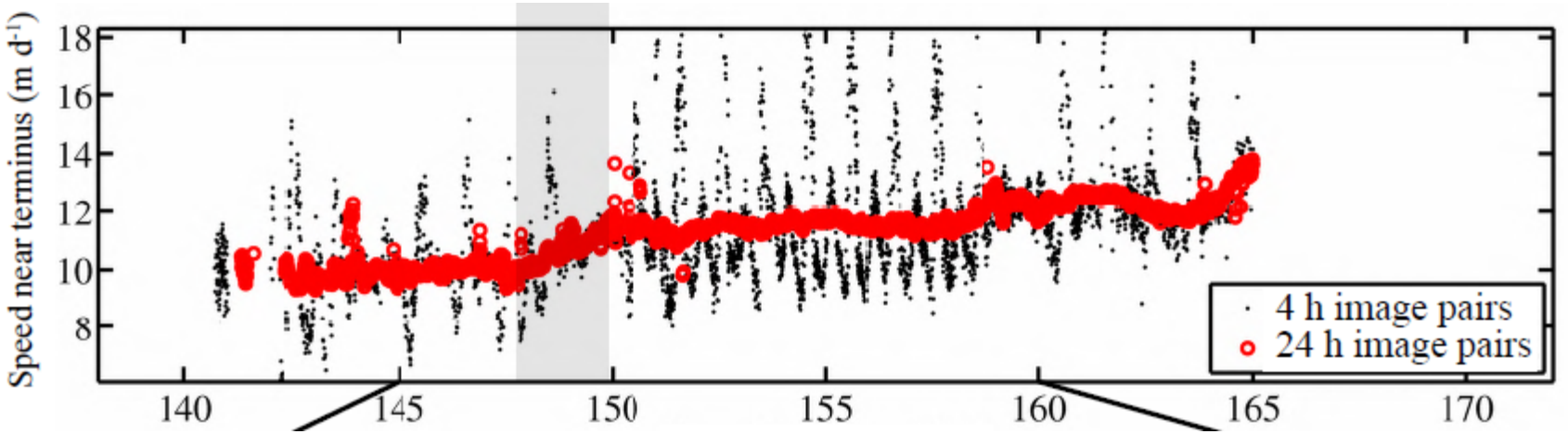


Amundson et al., 2010

A brief history of ice mélange

- Small speed-up observed at Store Gletscher during clearing of seasonal ice mélange
- Speed-up could be explained by a loss of resistive force from the mélange; resistive force estimated to be an order of magnitude smaller than the driving force

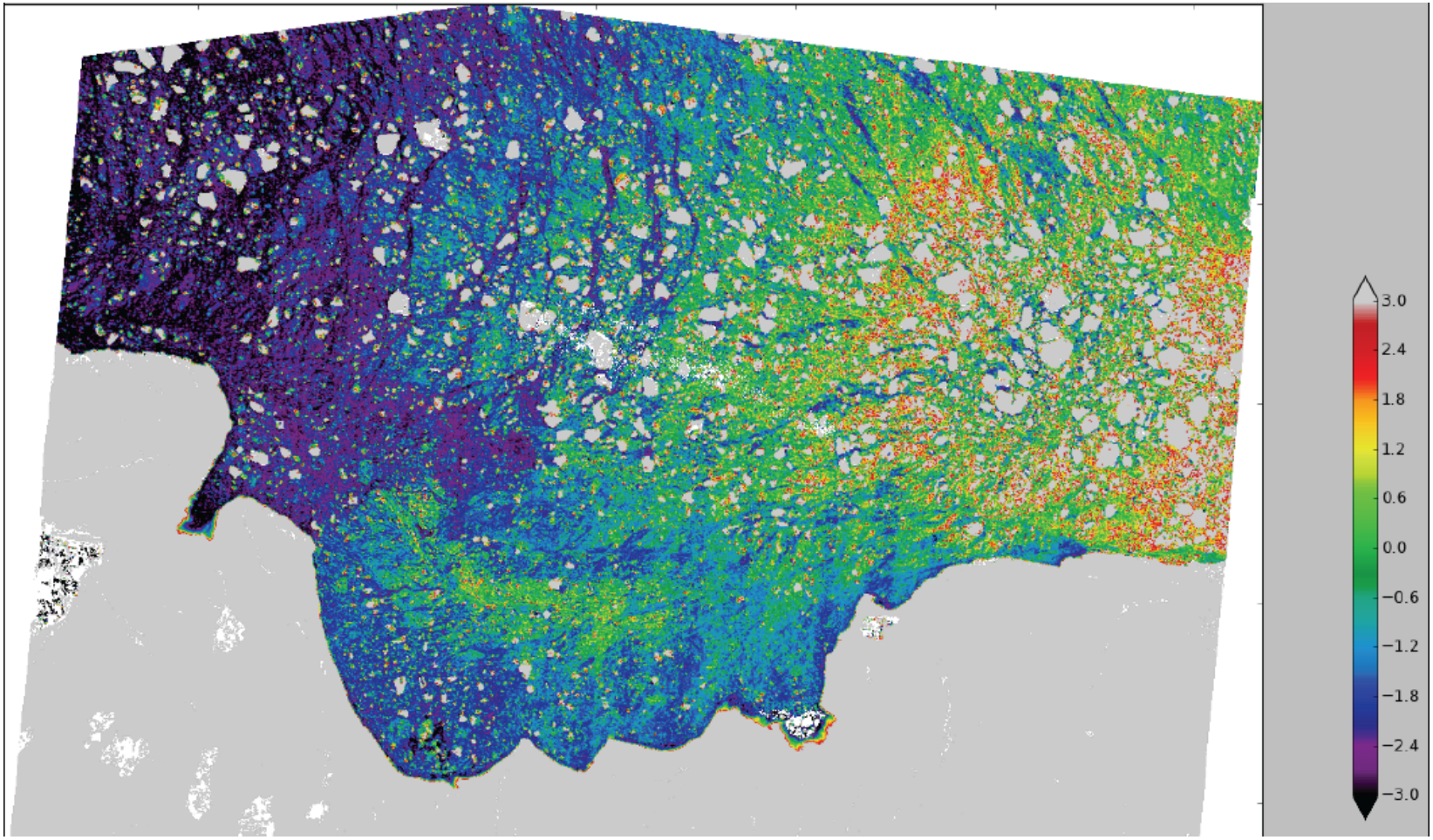




Walter et al., 2012

Future directions: Satellite imagery

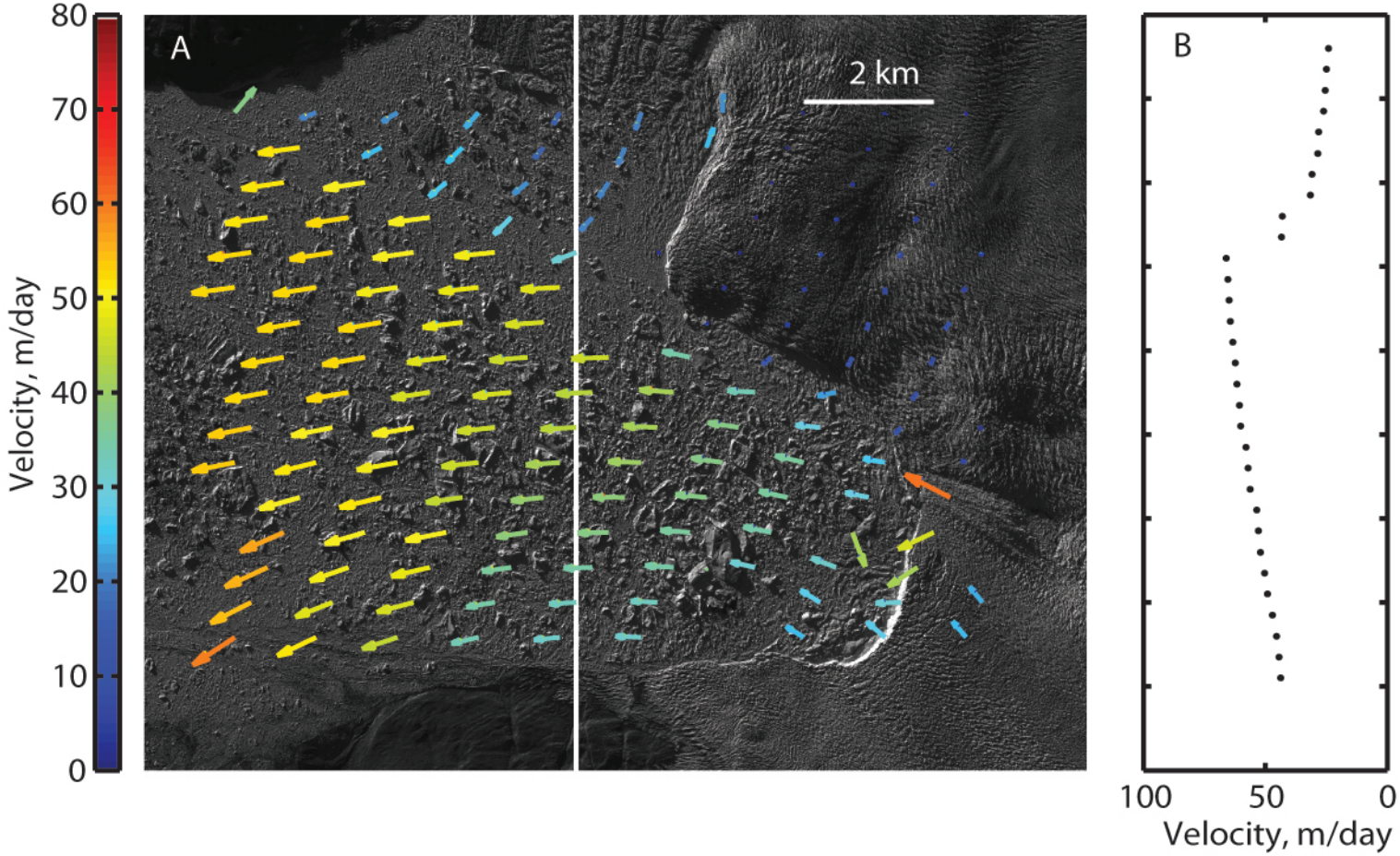
- World View DEM of Ilulissat Icefjord (Jakobshavn Isbræ)



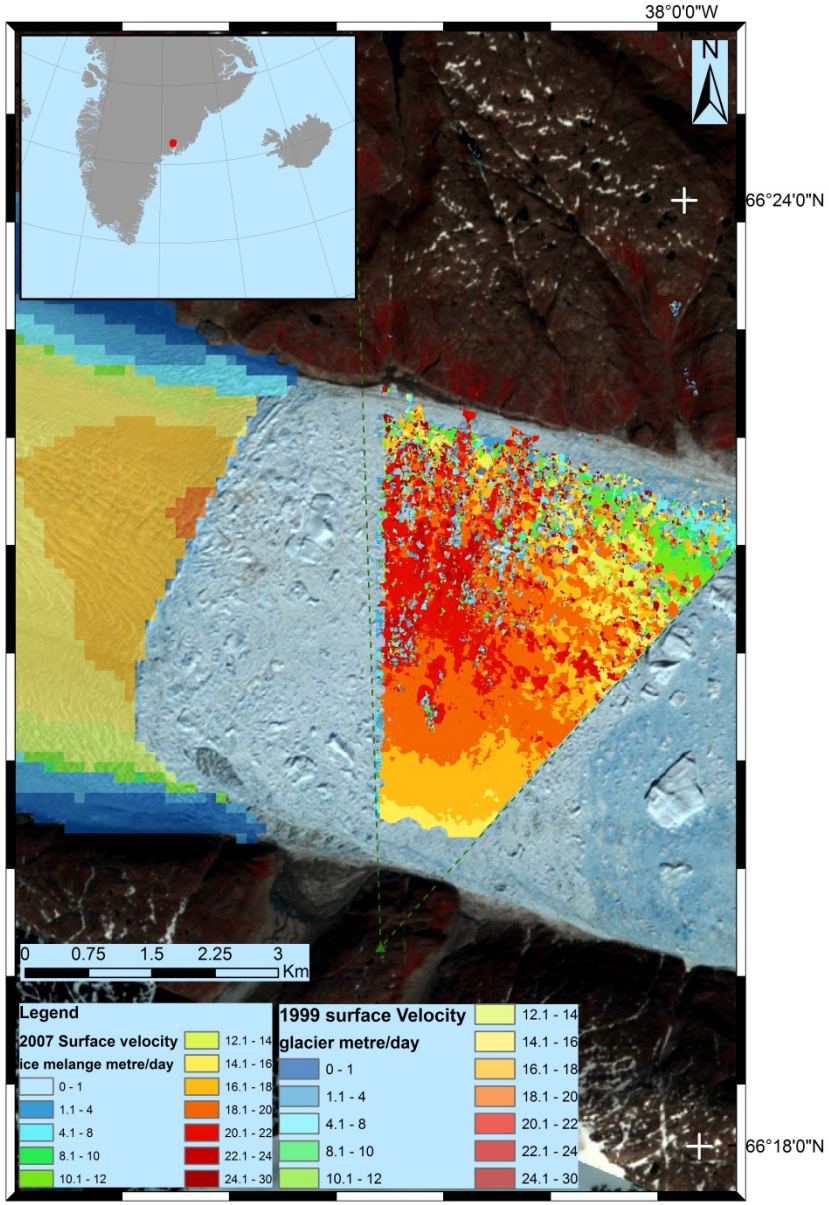
courtesy of D. Shean

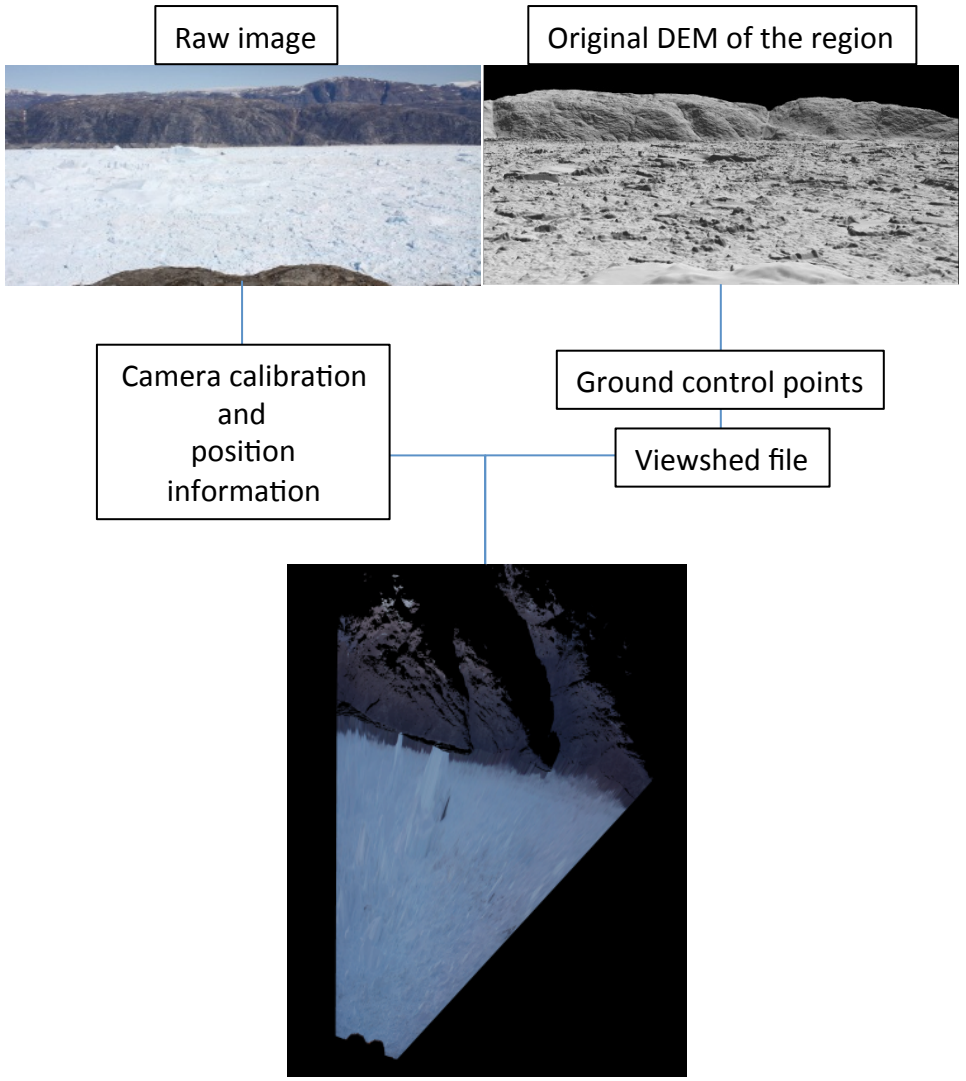
Future directions: Satellite imagery

- Ilulissat Icefjord/Jakobshavn Isbræ: 25 June – 6 July 2010



Future directions: Timelapse photography

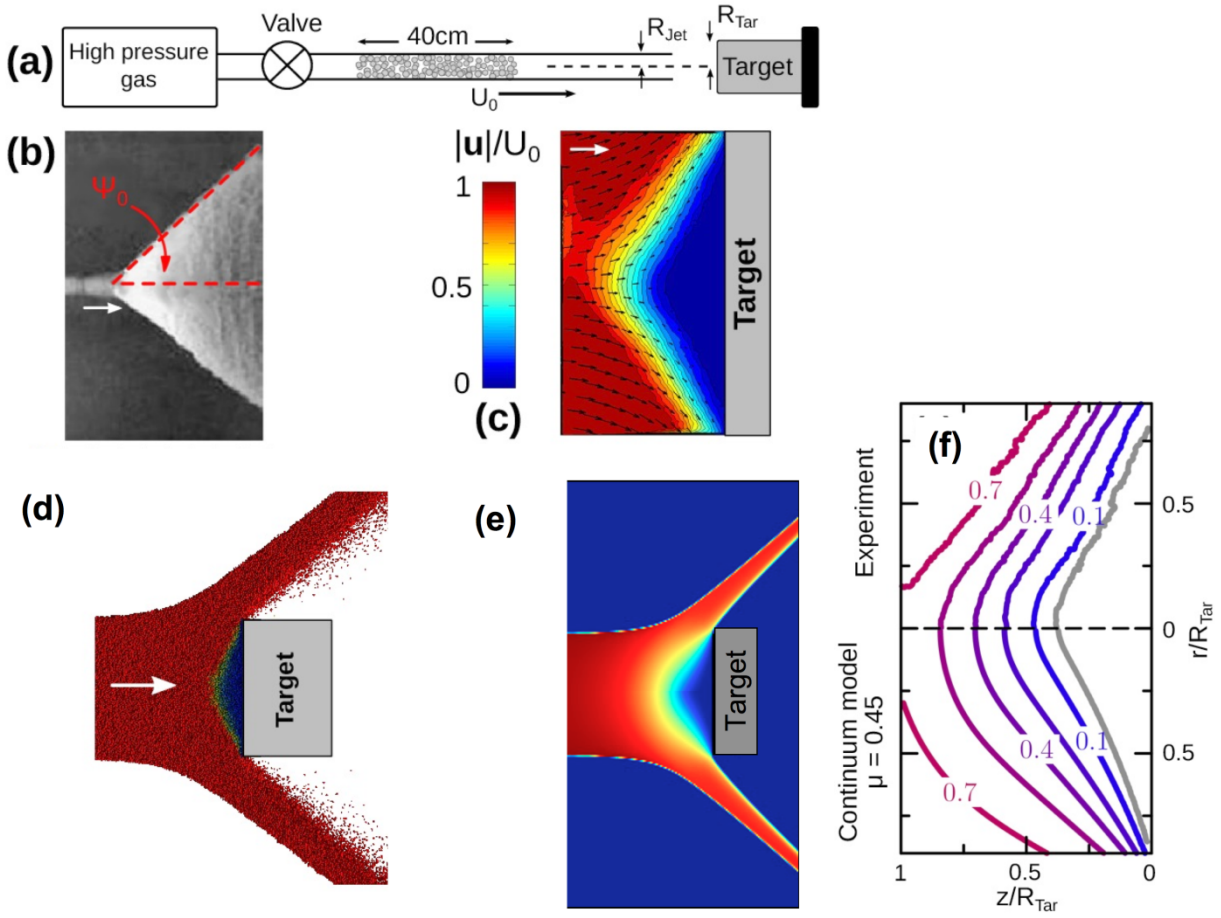




courtesy of Y. Drocourt, T. James, T. Murray, and R. Borgo

Future directions: Numerical modeling

- Borrow ideas and methods from granular mechanics

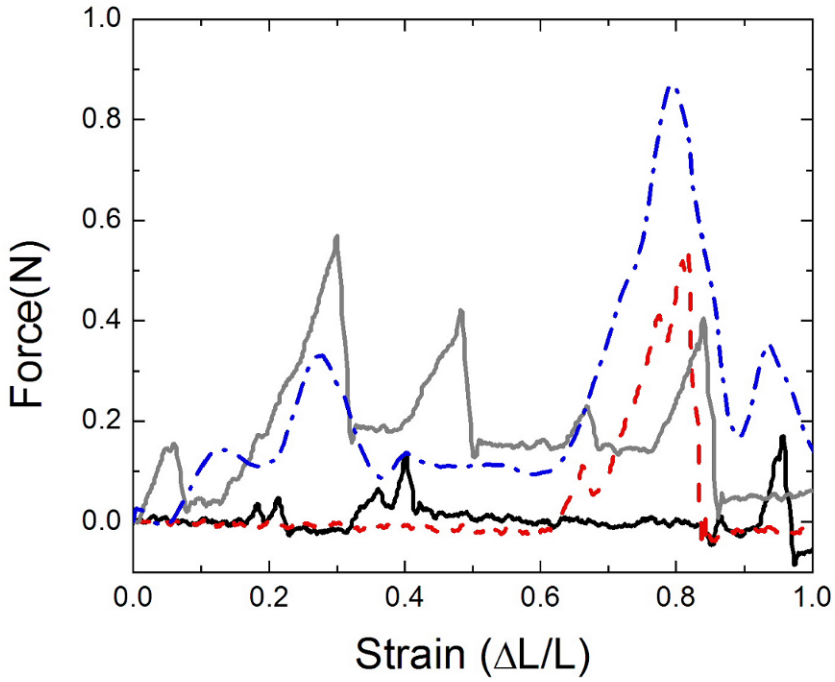


Ellowitz et al., 2013

Future directions: Laboratory experiments

- Can observe and measure "everything"
- Gives insights into processes

A



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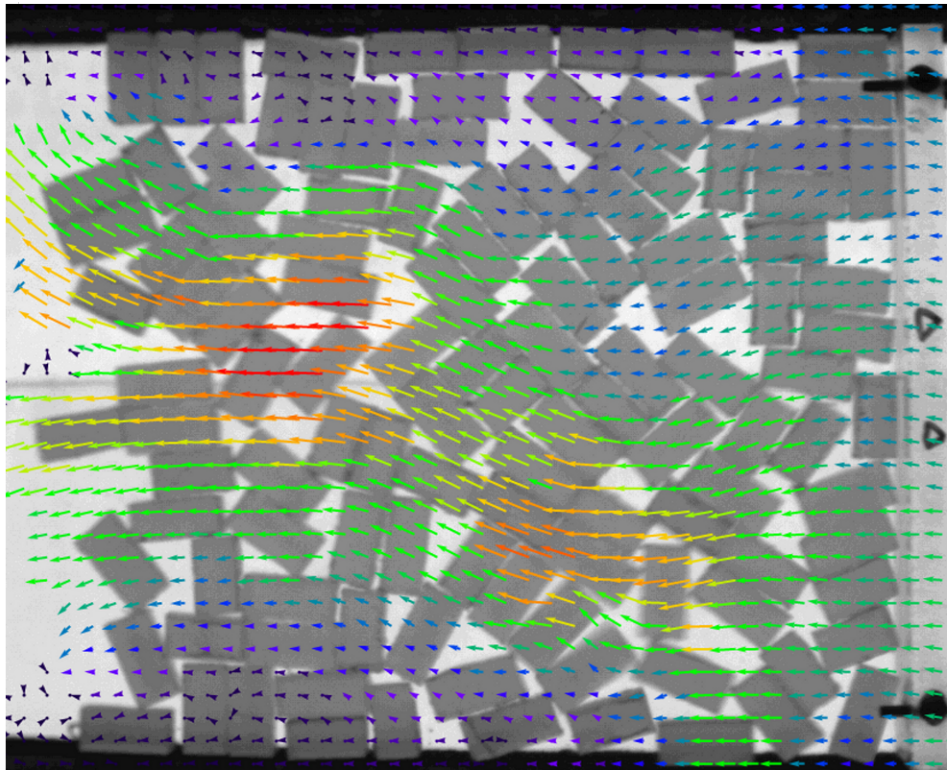
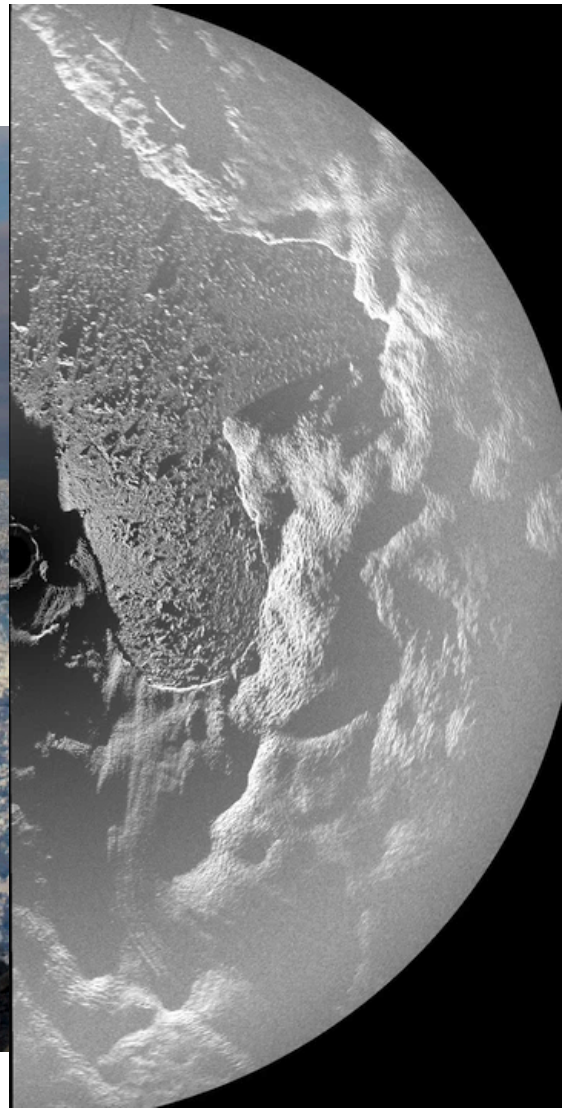


Kuo and Dennin, in press

Future directions: Terrestrial radar

- The perfect tool for studying ice mélange?



courtesy of R. Cassotto, M. Fahnestock, and M. Truffer

Summary

- Ice mélange appears to affect calving, at least seasonally
  - How important are seasonal variations?

- Probably a long ways from having a good rheological description of ice mélange
  - Need more data – new data sets show lots of promise
  - Need new physics – borrow ideas from granular mechanics and reach out to condensed matter physicists
  - A place in glaciology for lab experiments

- Ice mélange is an interesting and important component of tidewater glacier systems, regardless of how much it affects calving (directly)

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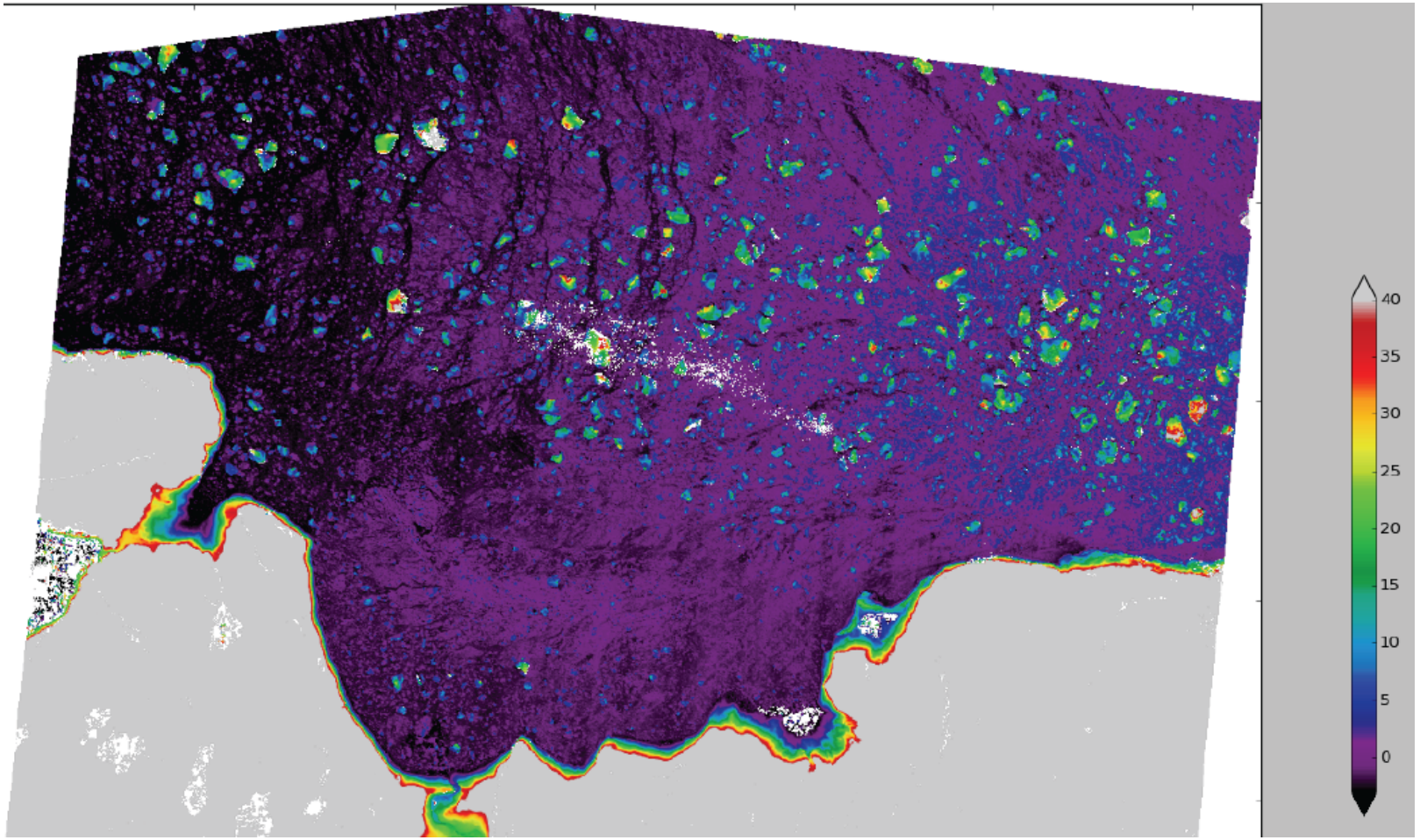
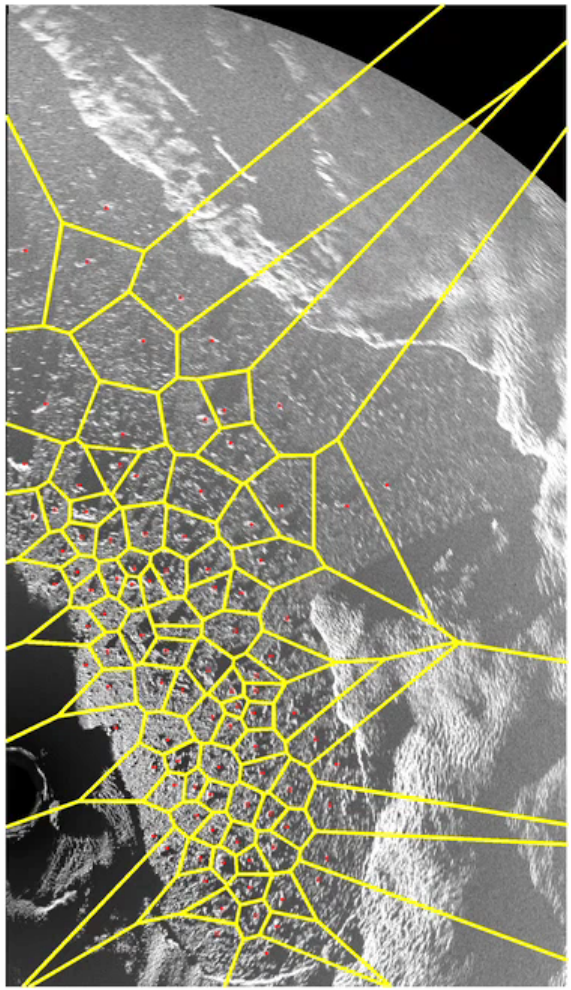
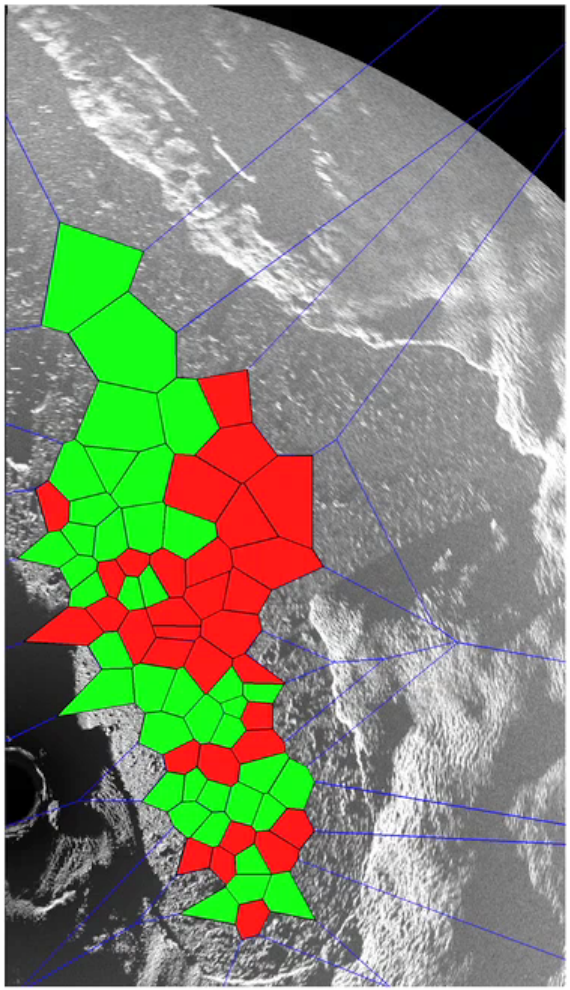


courtesy of D. Shean

Future directions: Terrestrial radar

- Track largest icebergs; divide area using Voronoi decomposition
- No obvious expansion or contraction during (one) calving event





processed by I. Peters