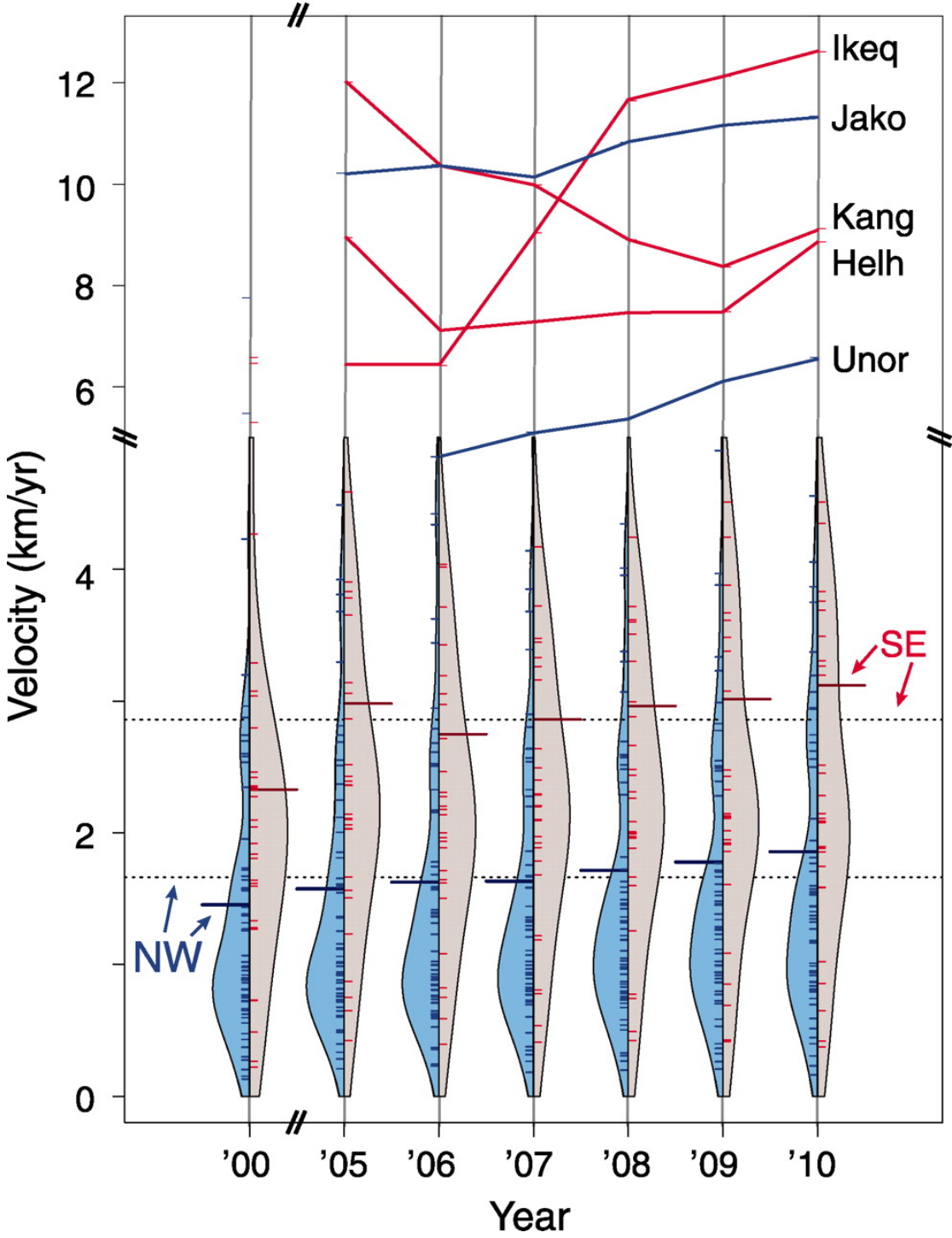
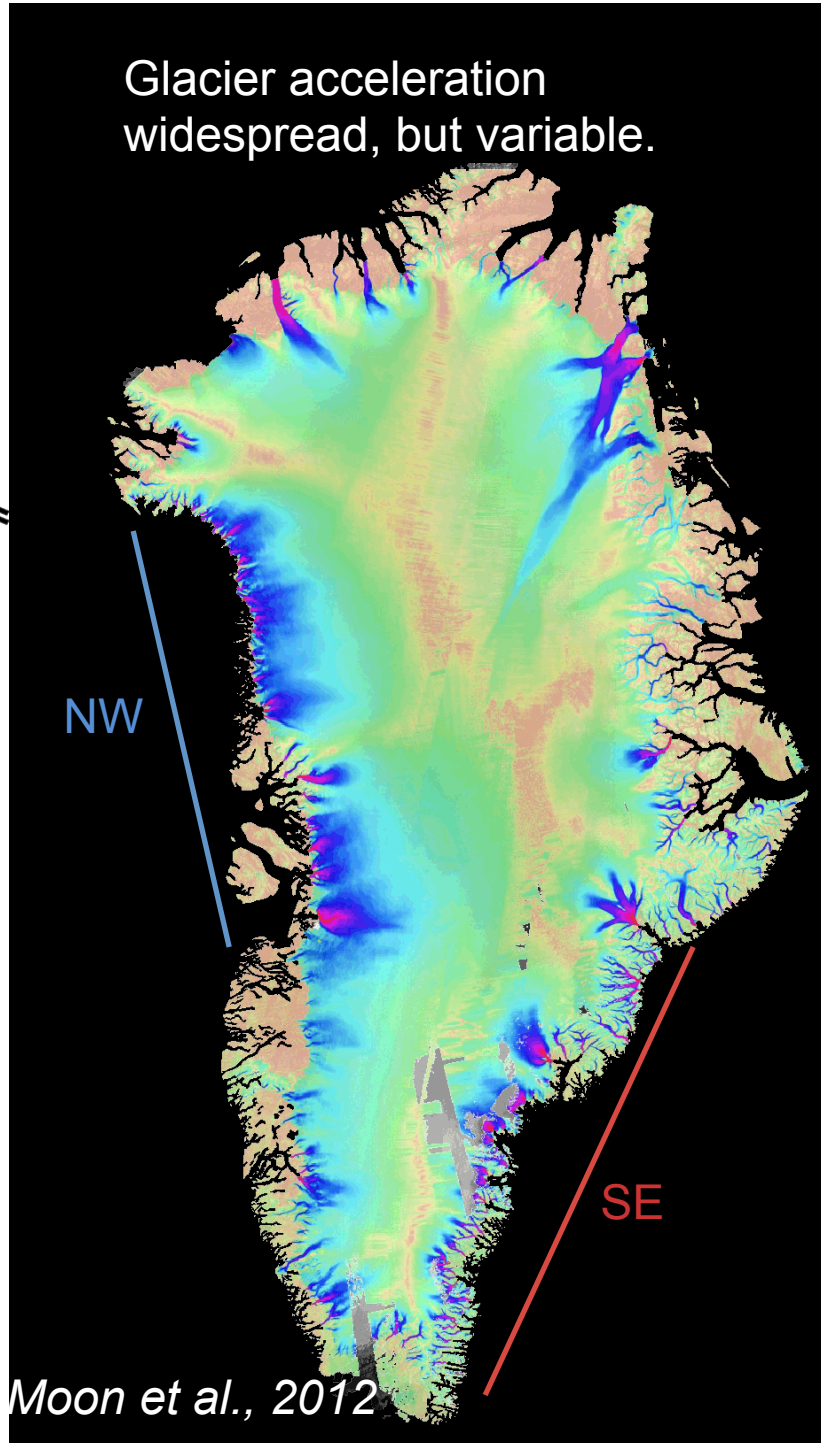
Ice sheet response to ocean forcing

Ian Joughin, Polar Science Center, Applied Physics Lab, UW

With contributions from Ben Smith, David Holland, Richard Alley, Mark Fahnestock, Ian Howat, Dana Floricioiu, Twila Moon, and Martin Truffer


Velocity (km/yr)
0
2
4
6
8
10
12
Ikeq
Jako
Kang
Helh
Unor
NW
SE
'00
'05
'06
'07
'08
'09
'10
Year

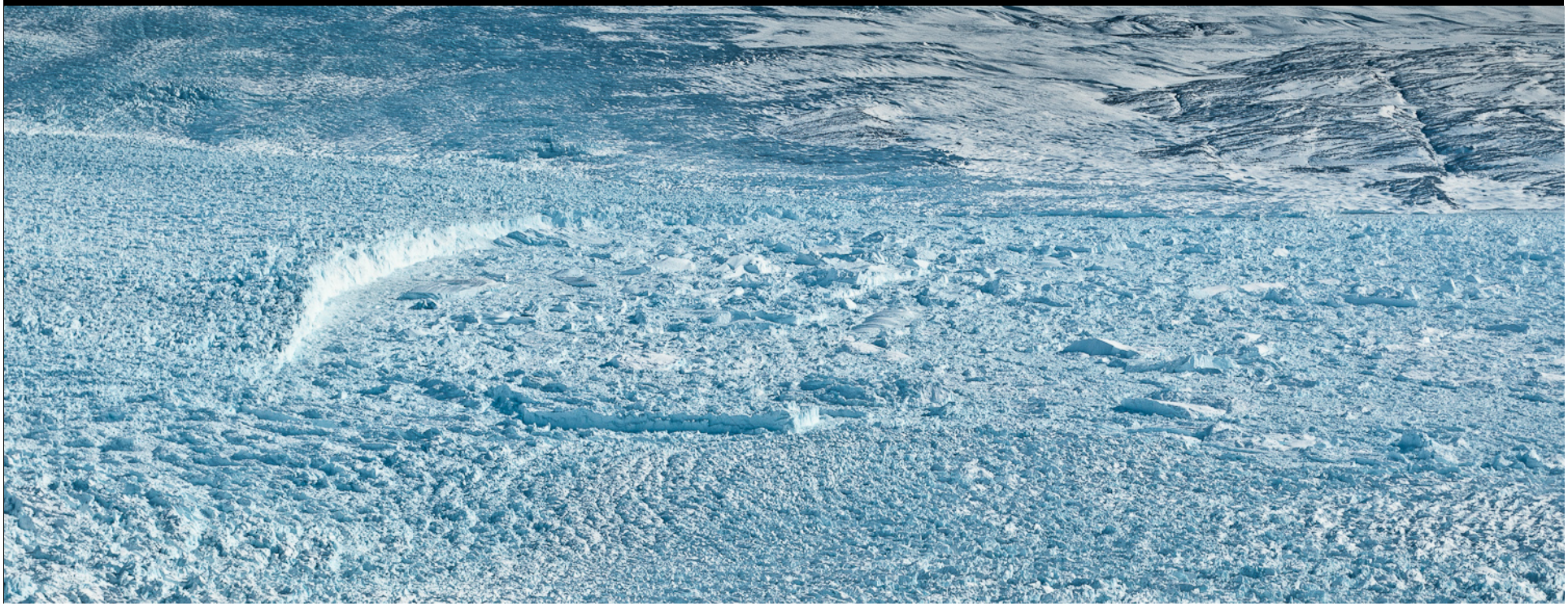

Glacier acceleration
widespread, but variable.
NW
SE
Moon et al., 2012

IPCC Caveats

The ice sheets of Antarctica and Greenland could raise sea level greatly. Central parts of these ice sheets have been observed to change only slowly, but near the coast rapid changes over quite large areas have been observed. ***In these areas, uncertainties about glacier basal conditions, ice deformation and interactions with the surrounding ocean seriously limit the ability to make accurate projections.***

Ice Ocean Primer

Outlet Glacier Termini

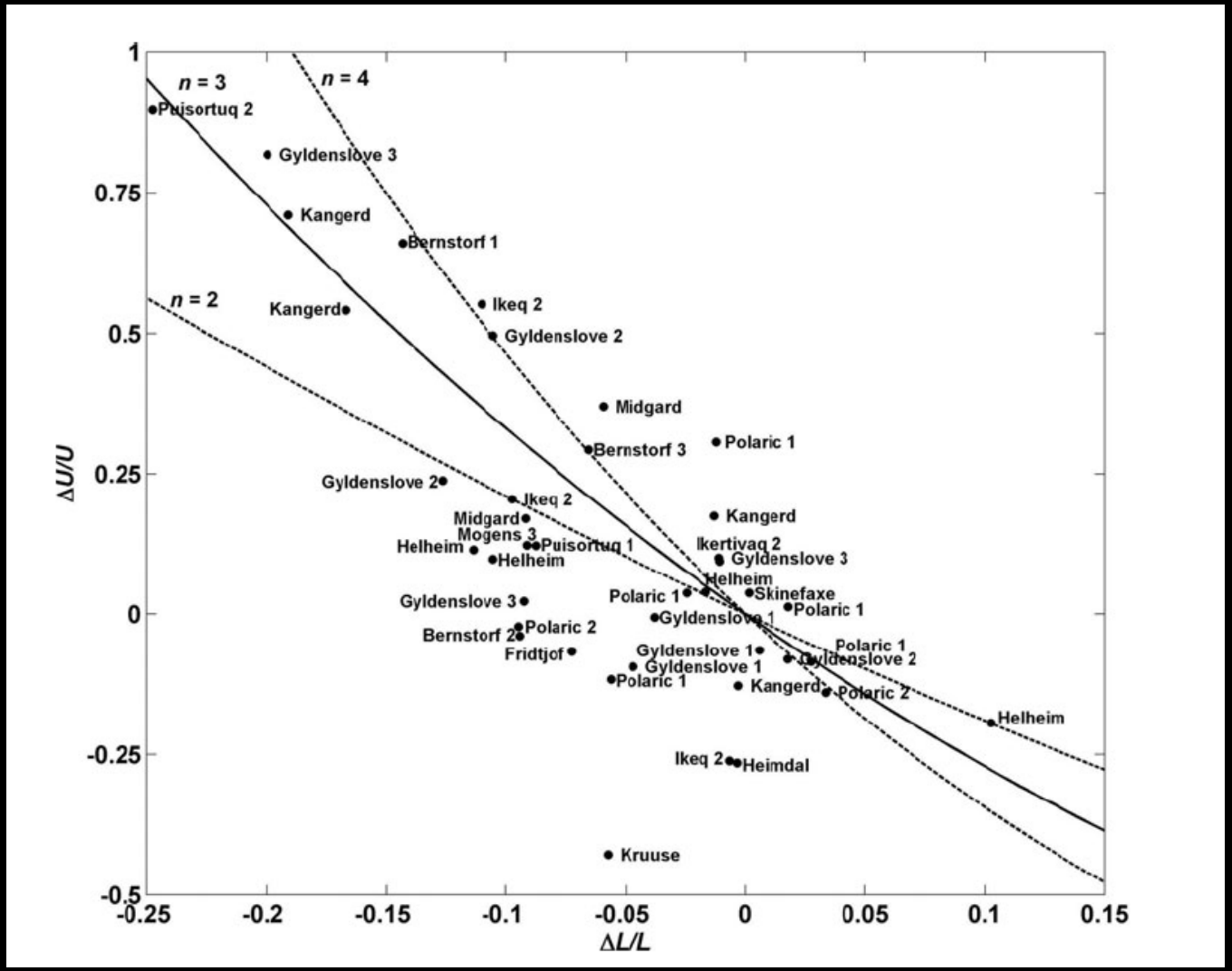


Terminus, South Branch, Jakobshavn Isbrae, May 25, 2013

Synchronous retreat and acceleration of southeast Greenland outlet glaciers 2000–06: ice dynamics and coupling to climate

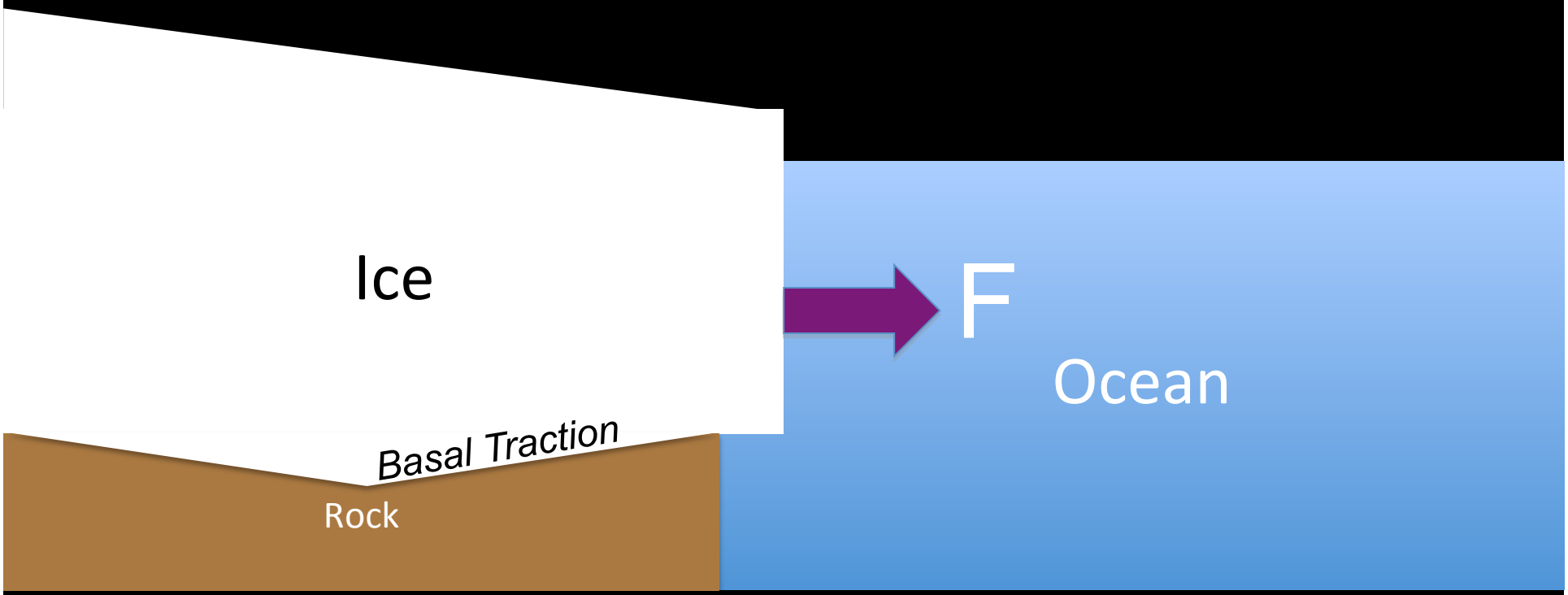
Ian M. HOWAT,[1,2,3] Ian JOUGHIN,[1] Mark FAHNESTOCK,[4]
Benjamin E. SMITH,[1] Ted A. SCAMBOS[3]

Journal of Glaciology, Vol. 54, No. 187, 2008



Speedup vs. Terminus Retreat

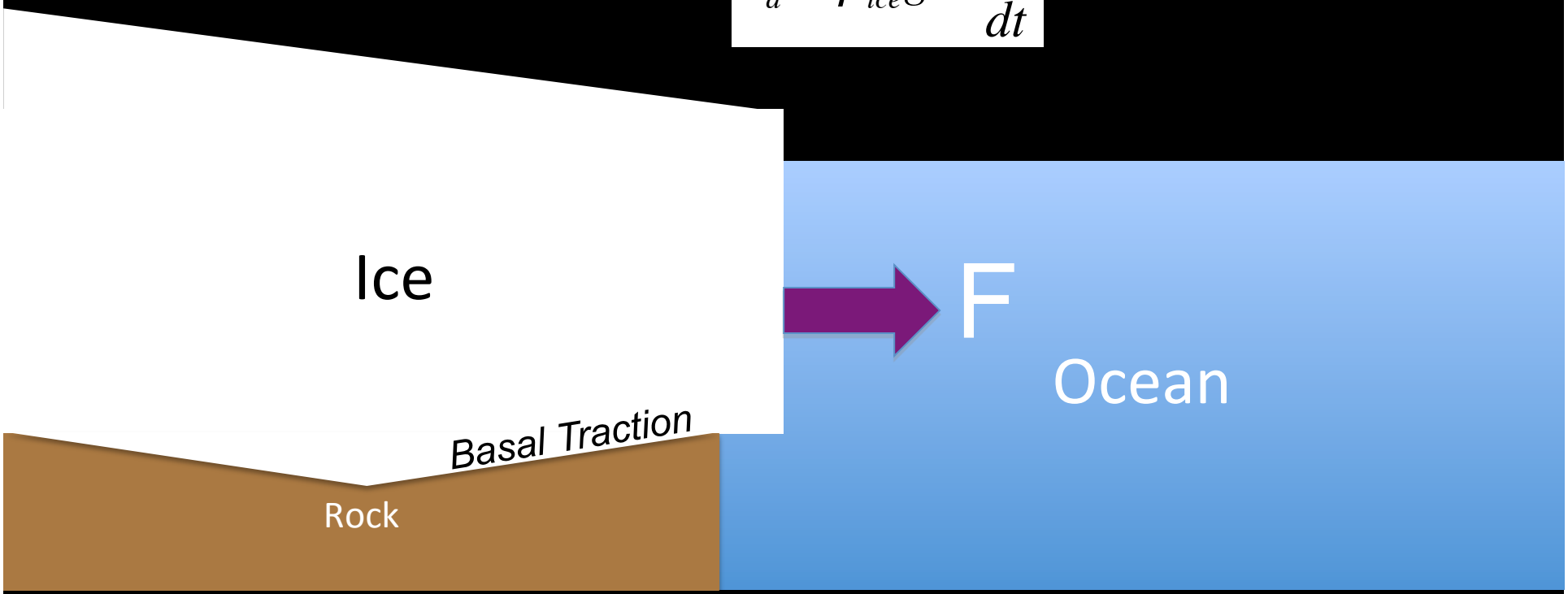
Ice-Ocean Boundary



Column integrated pressure difference across face yields a net force (pull), F on the glacier, which is distributed longitudinally upstream.

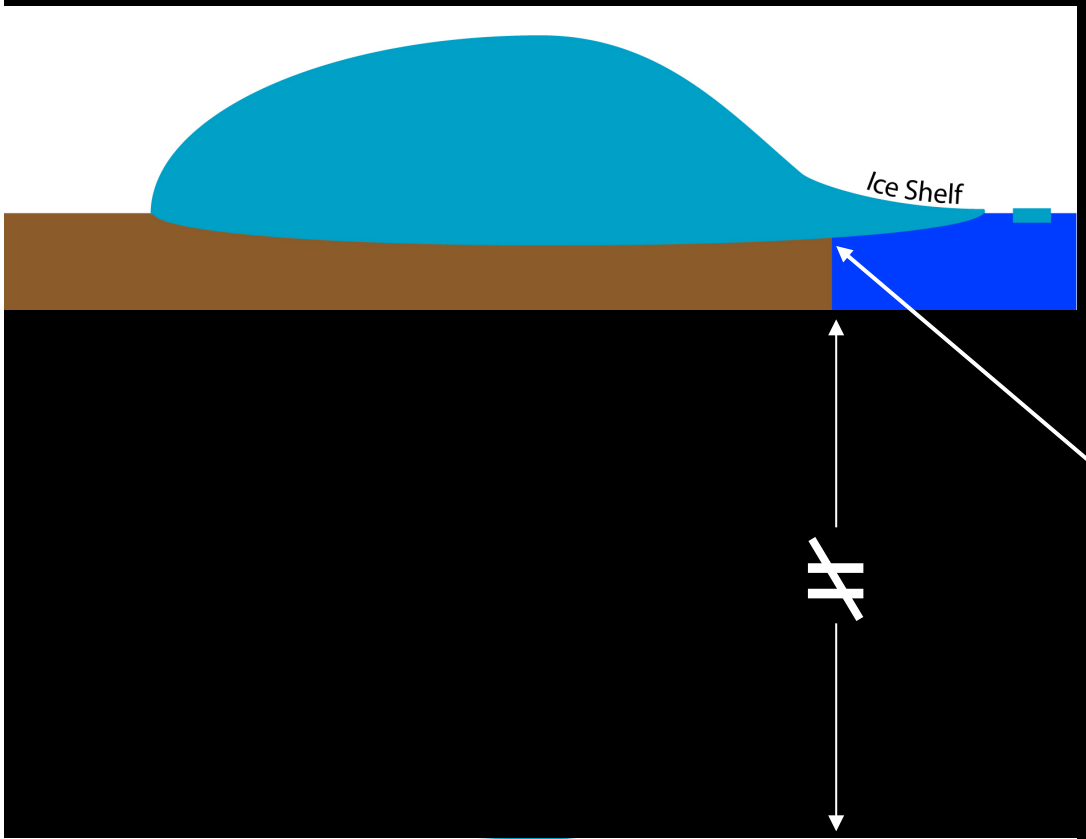
Driving Stress

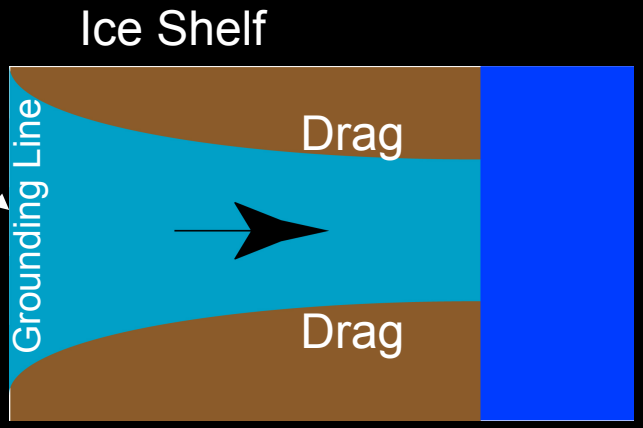
$$\tau_d = \rho_{ice} g H \frac{dz}{dt}$$

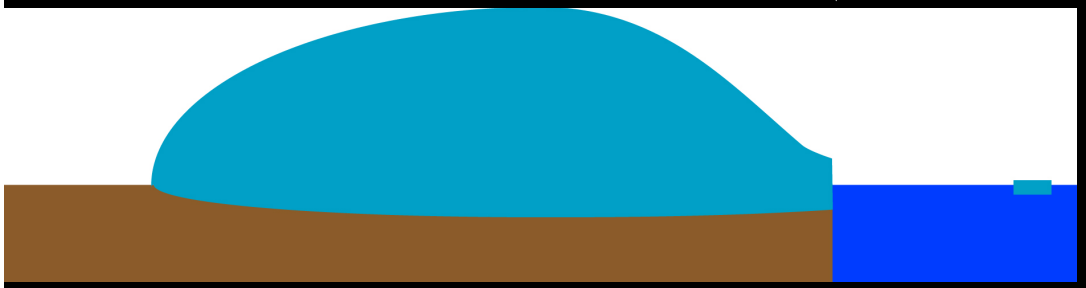


Basal traction at bed near terminus must accommodate both terminus and driving stress.

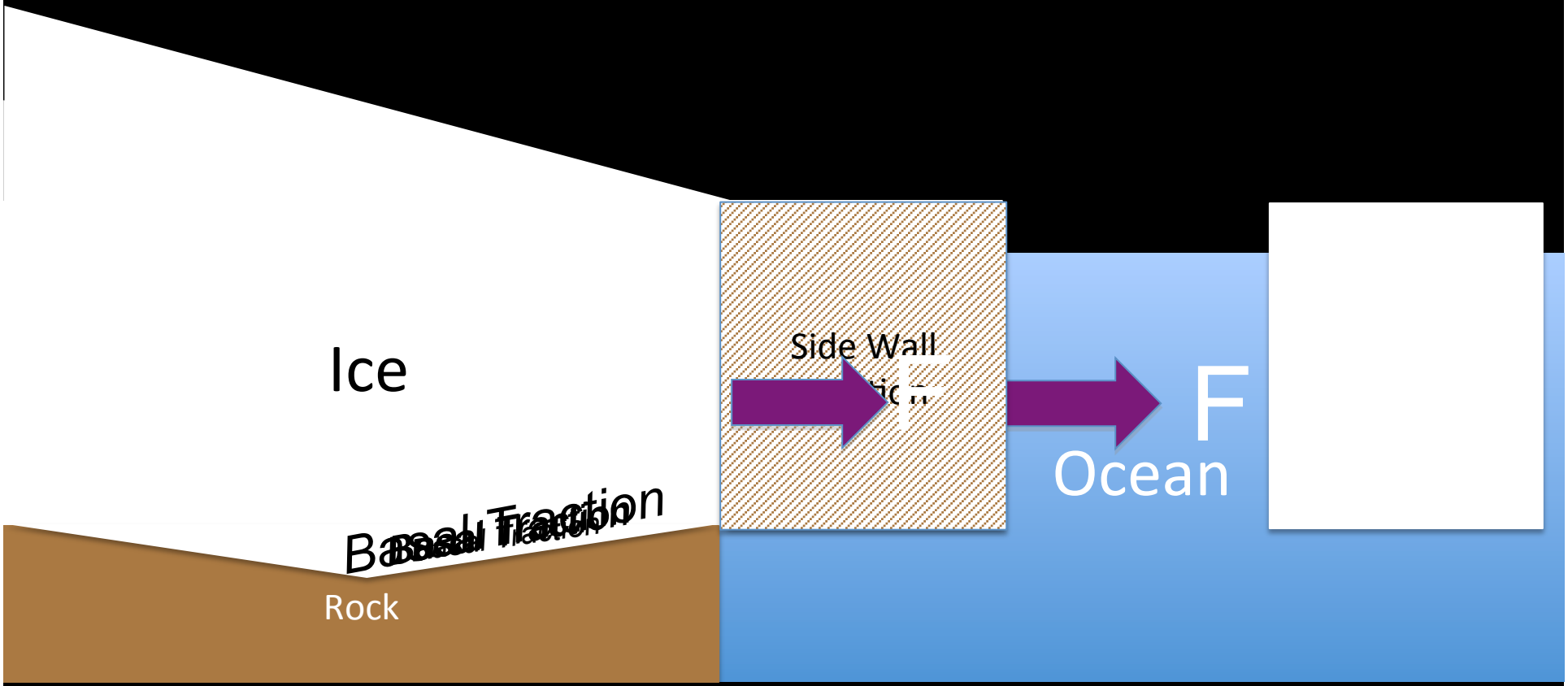
Ice Shelf Buttressing







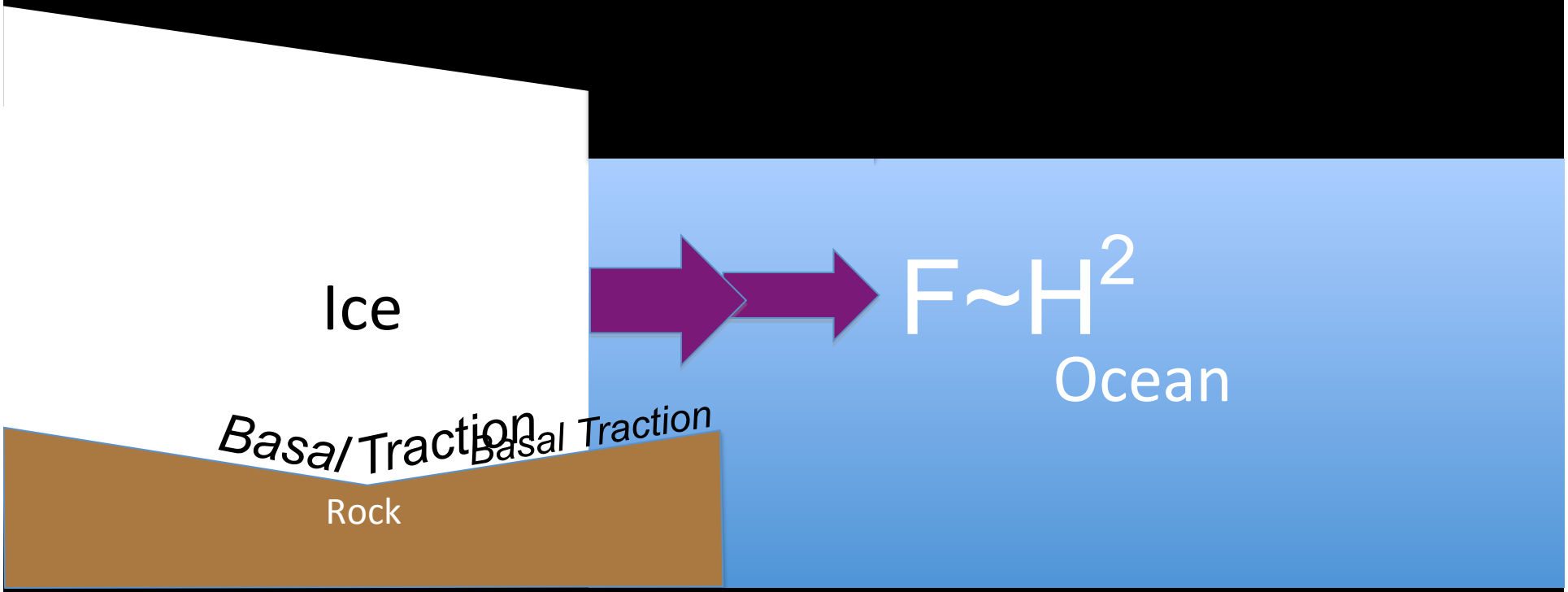
Ice-Ocean Boundary



Speed ~ (Basal Traction)^n

Small changes in traction lead to large changes in speed.

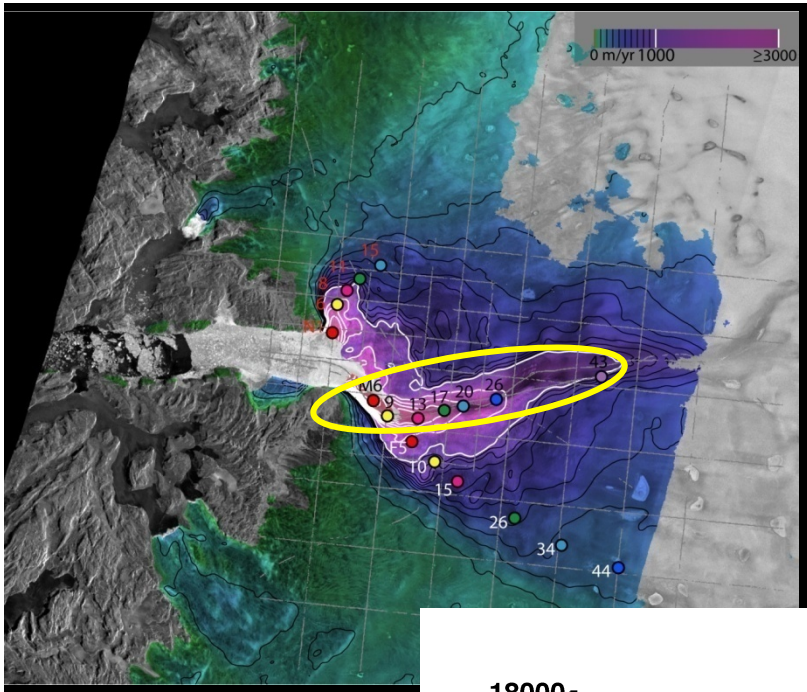
Terminus or Grounding Line Retreat



Speed ~ (Basal Traction)^n

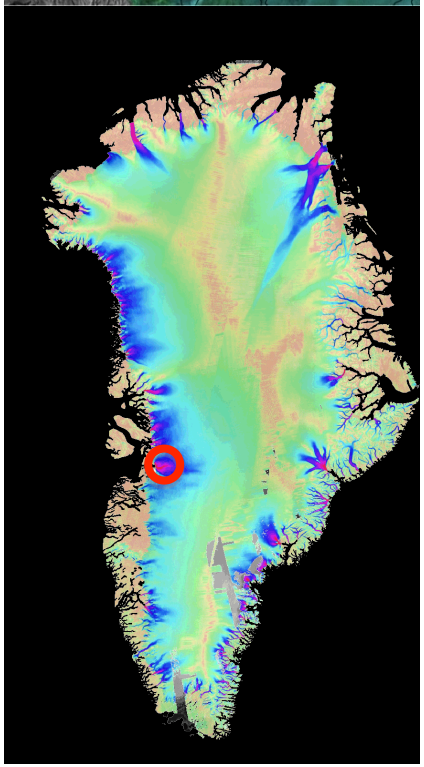
Ice must speed up to produce more basal traction

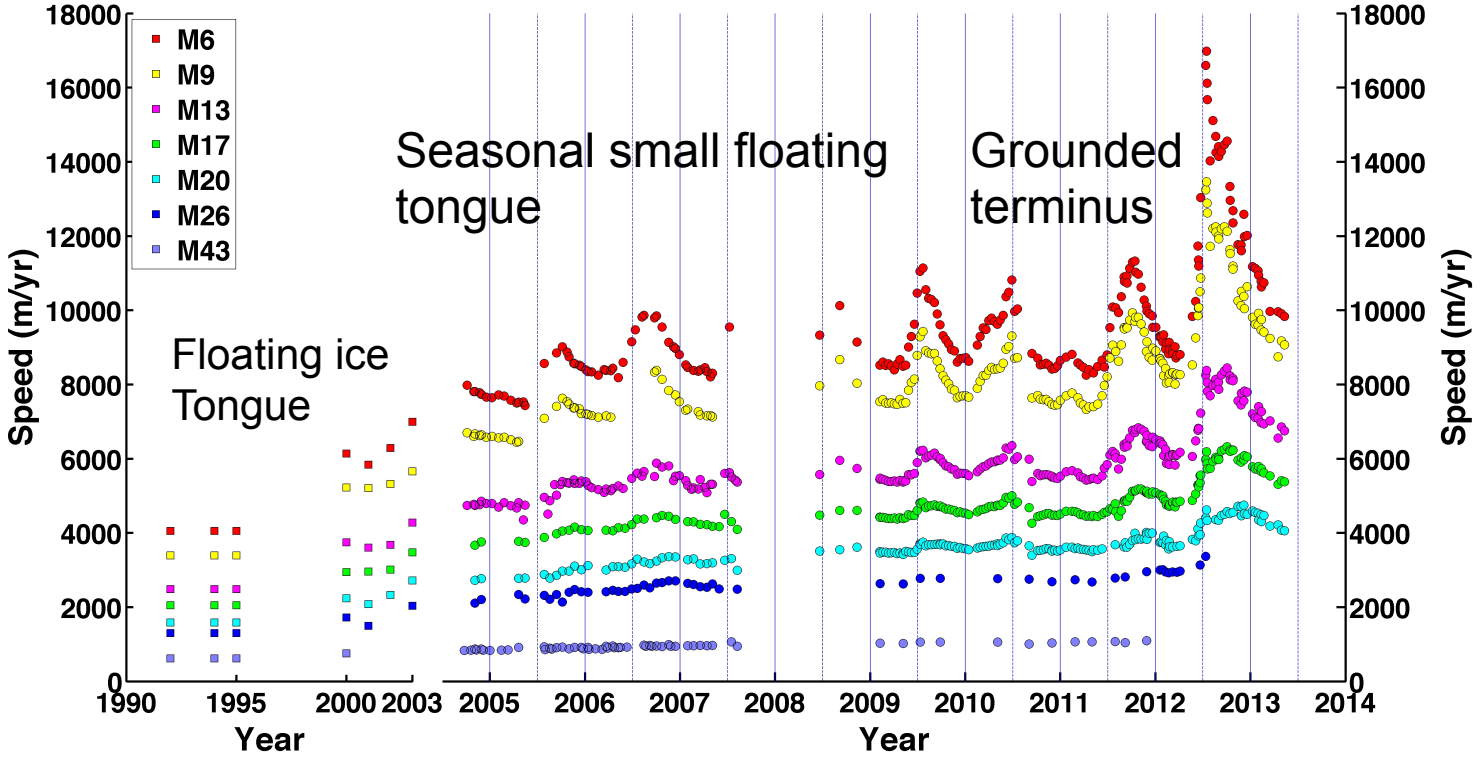
Outlet Glaciers



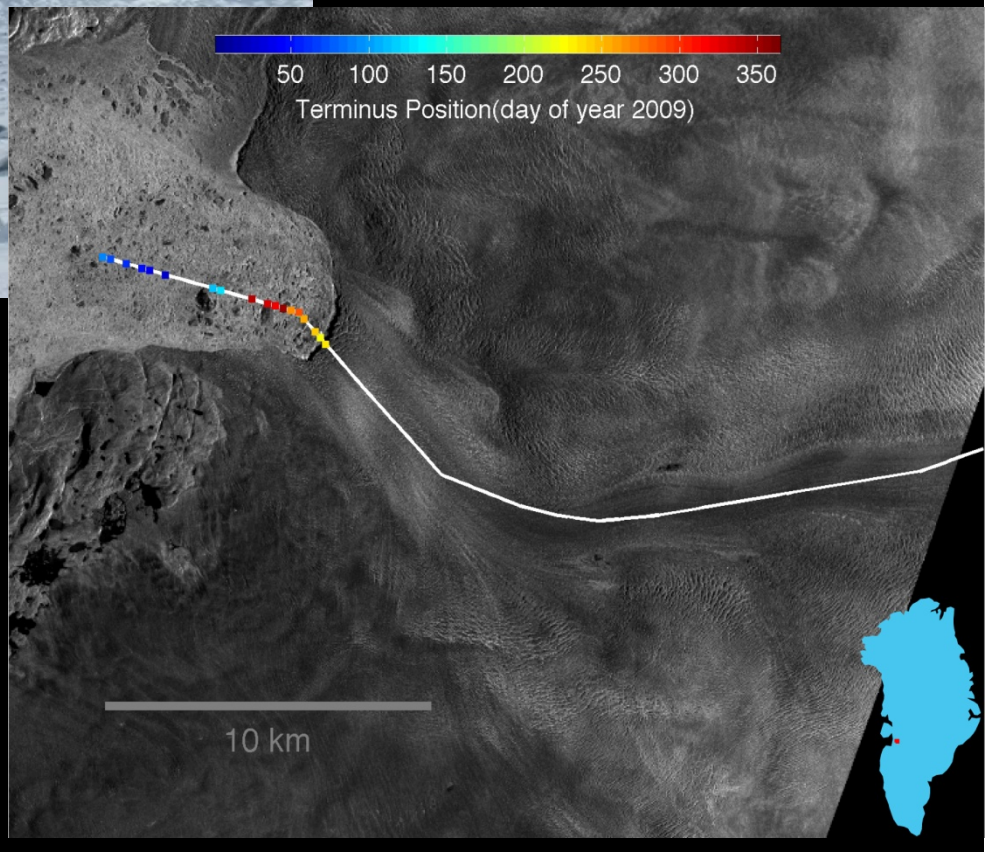
Jakobshavn Isbrae

Flow speed through time from ERS, LandSAT, RADARSAT, and TerraSAR-X.





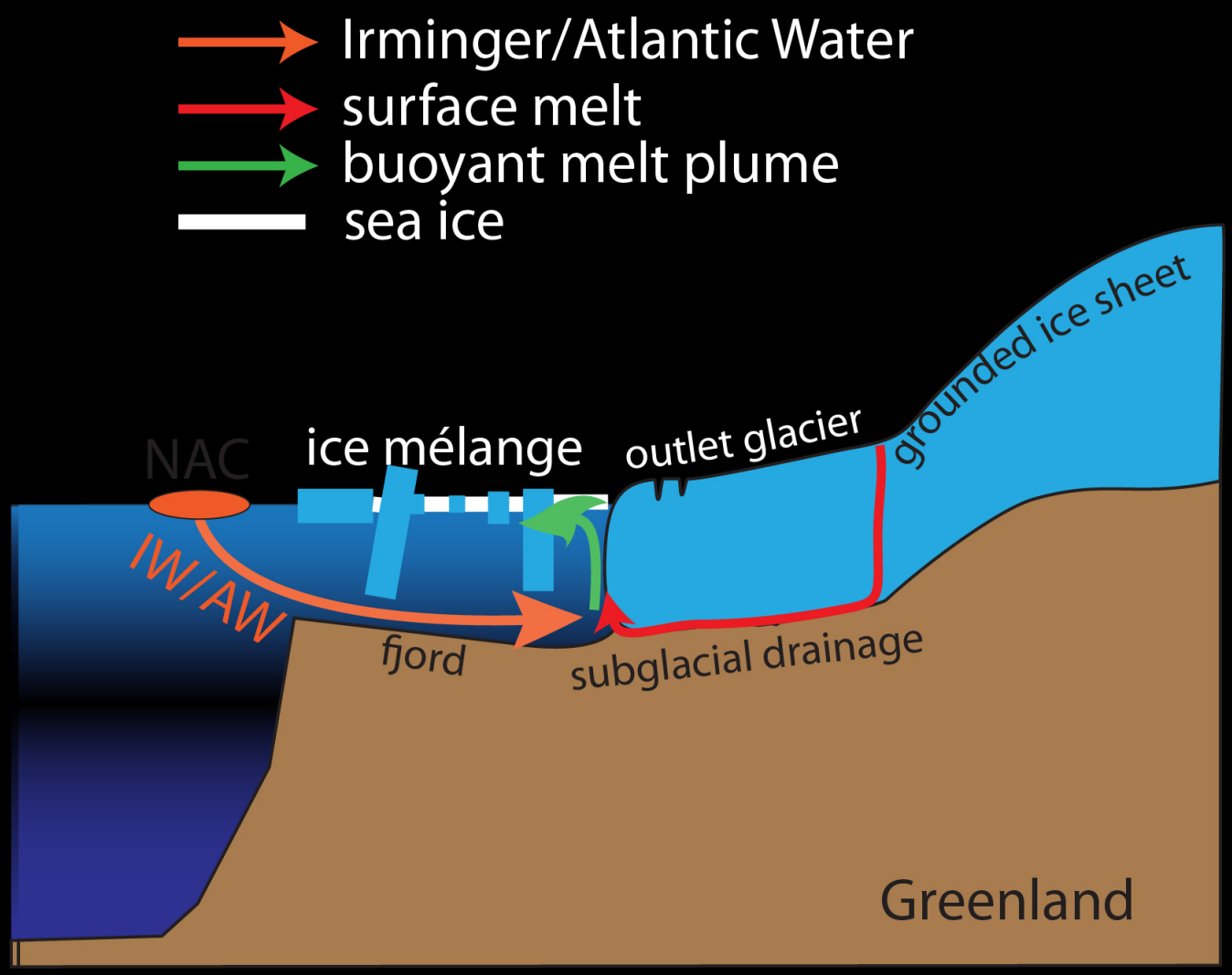
Time lapse video courtesy of M. Truffer & M. Fahnestock



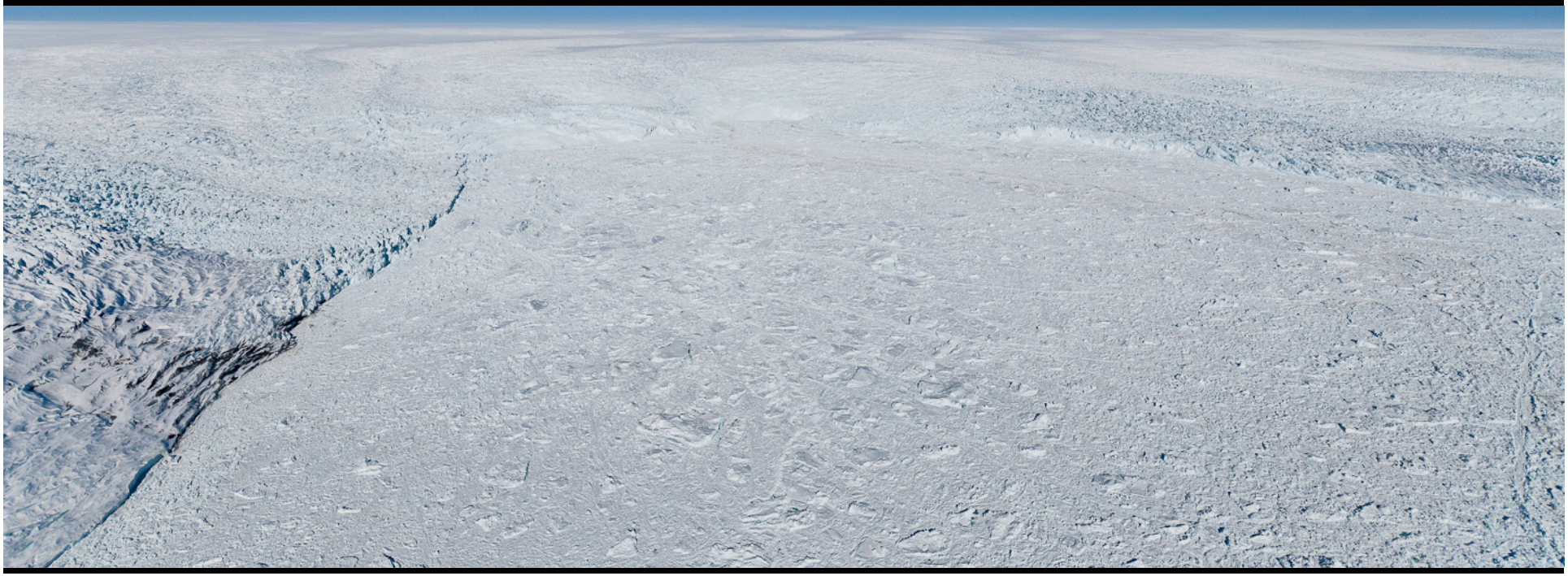
Terminus controls speed,

but what controls the terminus extent?

Ice-Ocean Interaction Near Outlet Glacier Termini

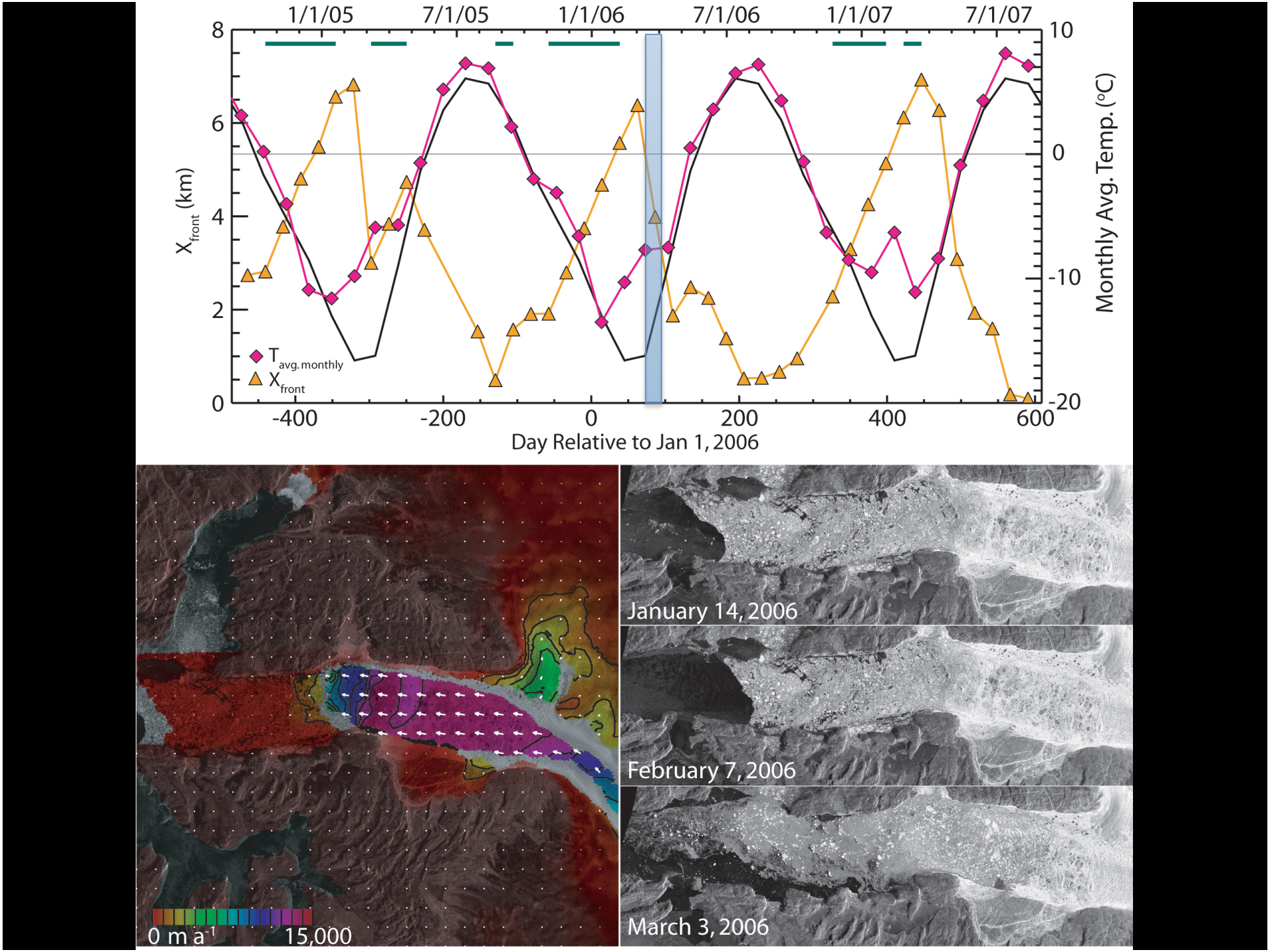


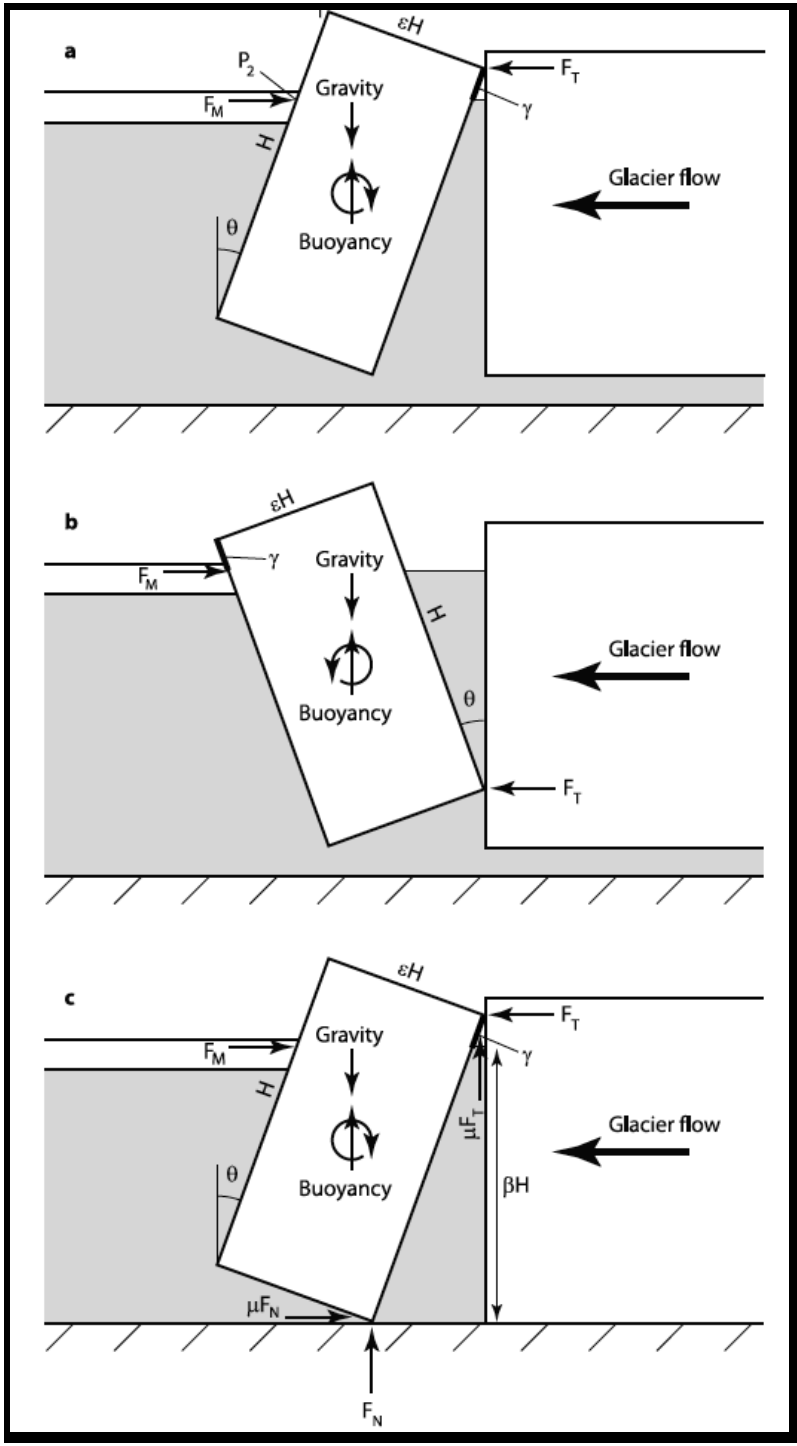
Ice Mélange



Jakobshavn Isbrae, Greenland

Mélange occupies area of former ice tongue


1/1/05
7/1/05
1/1/06
7/1/06
1/1/07
7/1/07
8
6
4
2
0
10
0
-10
-20
-400
-200
0
200
400
600
X_front (km)
Monthly Avg. Temp. (°C)
Day Relative to Jan 1, 2006
T avg. monthly
X front
0 m a-1
15,000
January 14, 2006
February 7, 2006
March 3, 2006



Analysis of the force balance for a calving iceberg suggests relatively small force from melange can suppress calving.

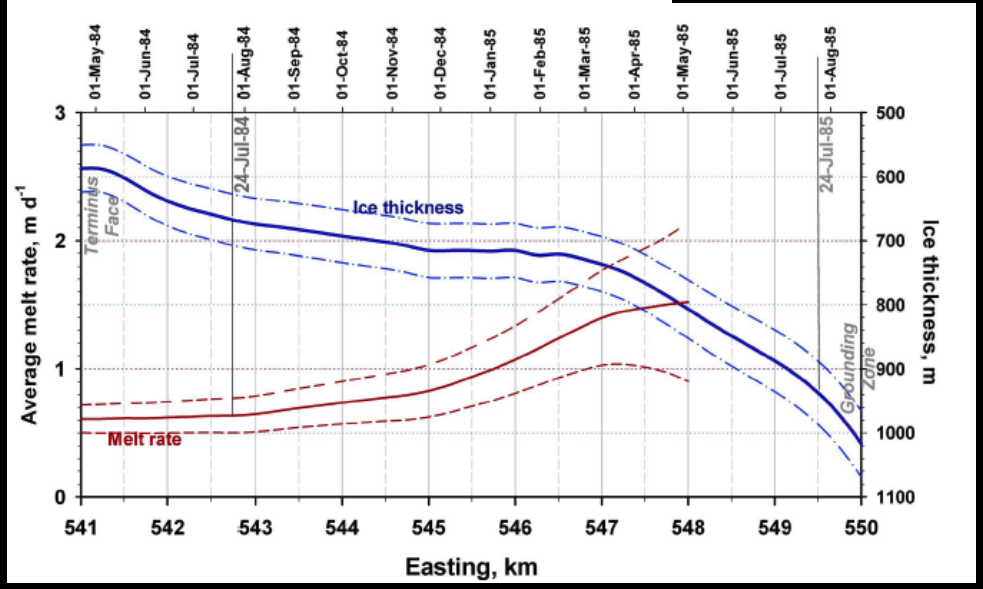
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, F01005, doi:10.1029/2009JF001405, 2010

J. M. Amundson,[1] M. Fahnestock,[2] M. Truffer,[1] J. Brown,[3] M. P. Lüthi,[3] and R. J. Motyka[1]

Ocean-Induced Melt

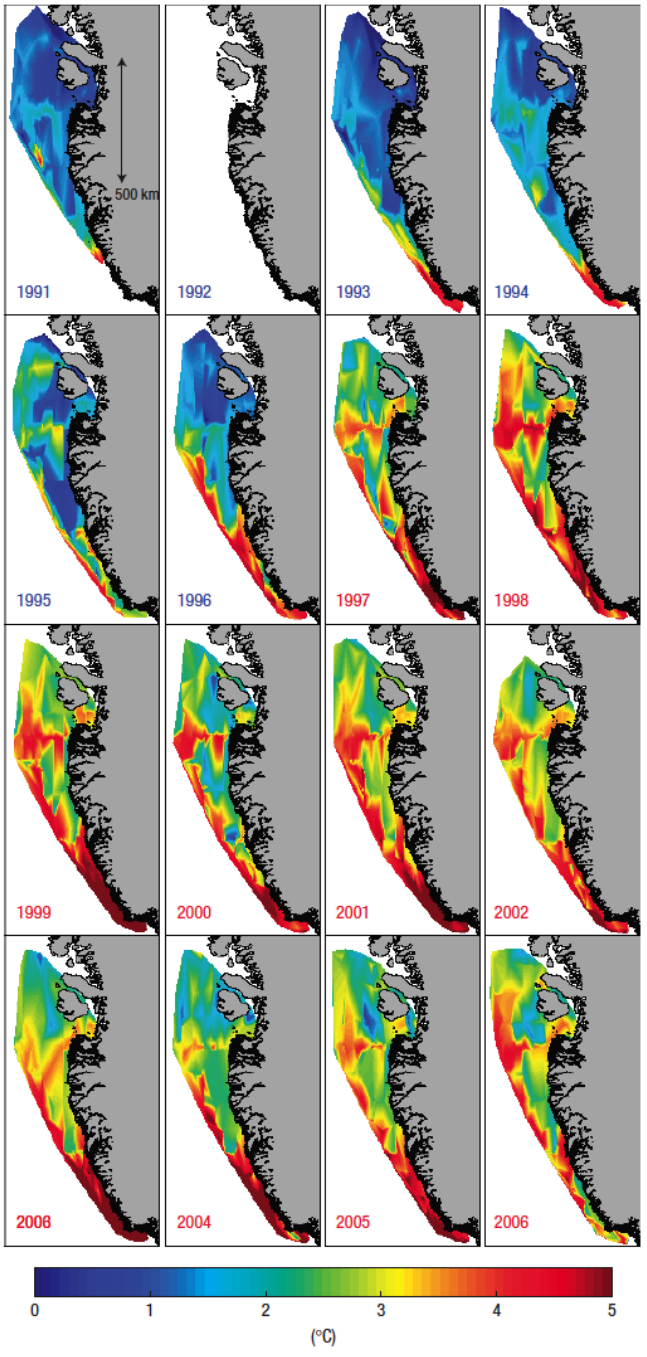
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, F01007, doi:10.1029/2009JF001632, 2011

Roman J. Motyka,[1] Martin Truffer,[1] Mark Fahnestock,[2] John Mortensen,[3] Søren Rysgaard,[3] and Ian Howat[4]



Melting may have played a major role when there was a floating tongue.

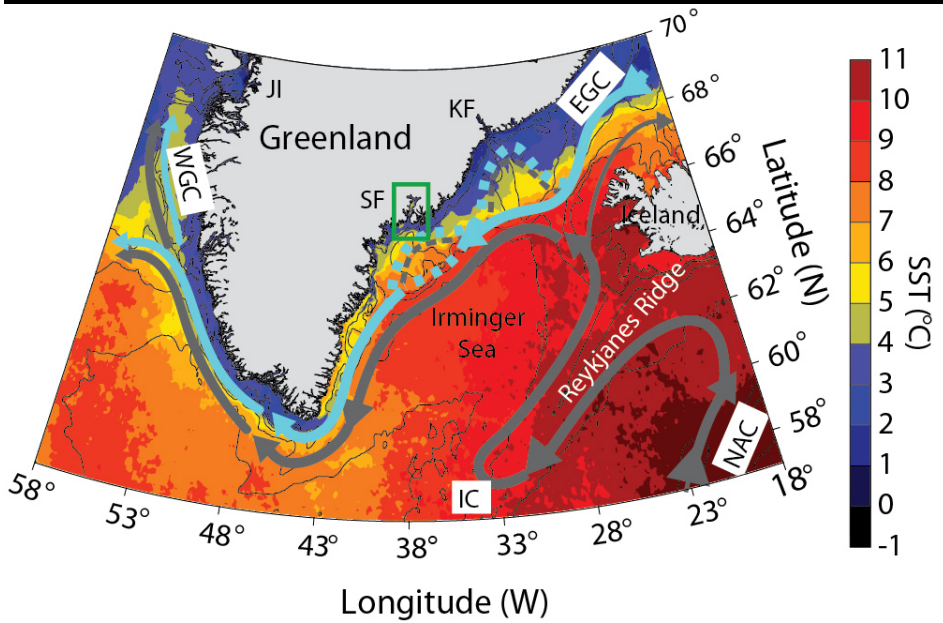
150-600m mean water temperature

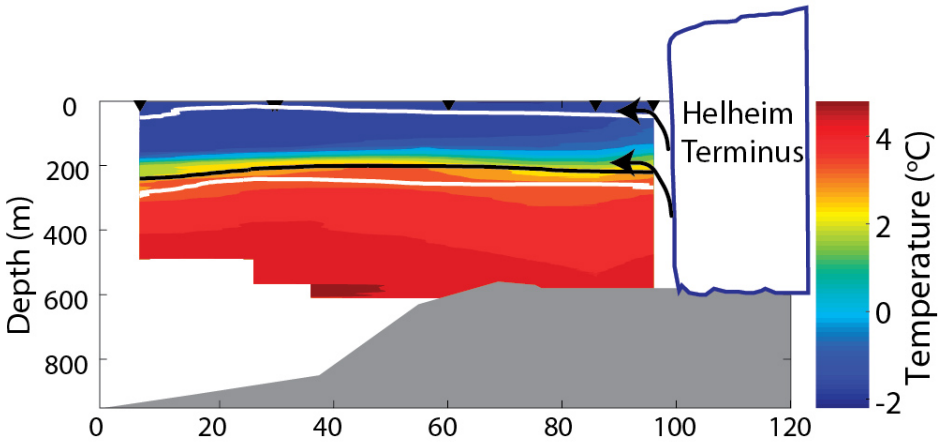


nature geoscience | VOL 1 | OCTOBER 2008 | www.nature.com/naturegeoscience

DAVID M. HOLLAND[1]*, ROBERT H. THOMAS[2], BRAD DE YOUNG[3], MADS H. RIBERGAARD[4] AND BJARNE LYBERTH[5]

Warm Water Making its way into Fjords, Promoting Large Melt Rates.





Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland

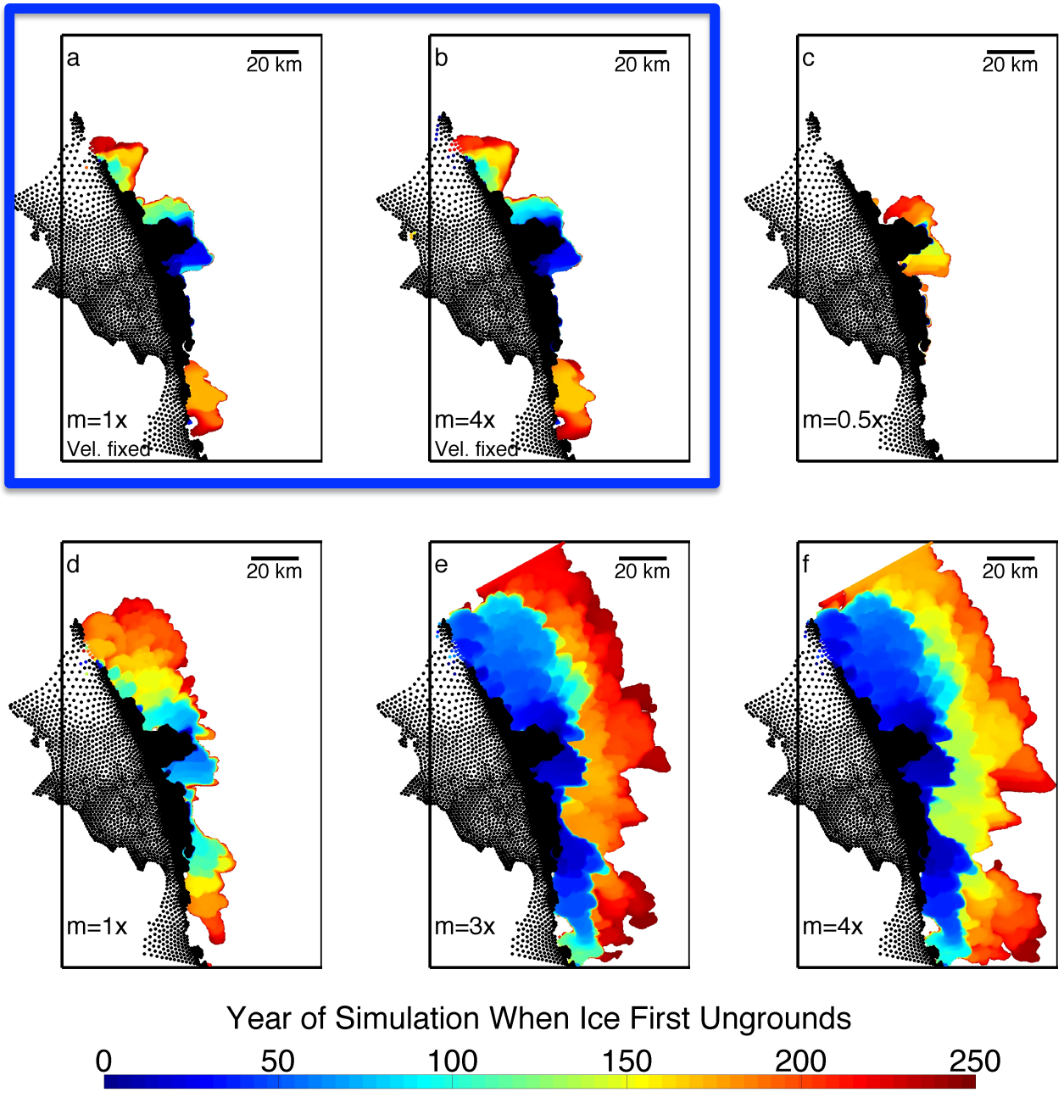
Fiammetta Straneo[1]*, Gordon S. Hamilton[2], David A. Sutherland[1†], Leigh A. Stearns[2†], Fraser Davidson[3], Mike O. Hammill[4], Garry B. Stenson[3] and Aqqalu Rosing-Asvid[5]

Impact of fjord dynamics and glacial runoff on the circulation near Helheim Glacier

Fiammetta Straneo[1]*, Ruth G. Curry[1], David A. Sutherland[2], Gordon S. Hamilton[3], Claudia Cenedese[1], Kjetil Våge[4] and Leigh A. Stearns[5]

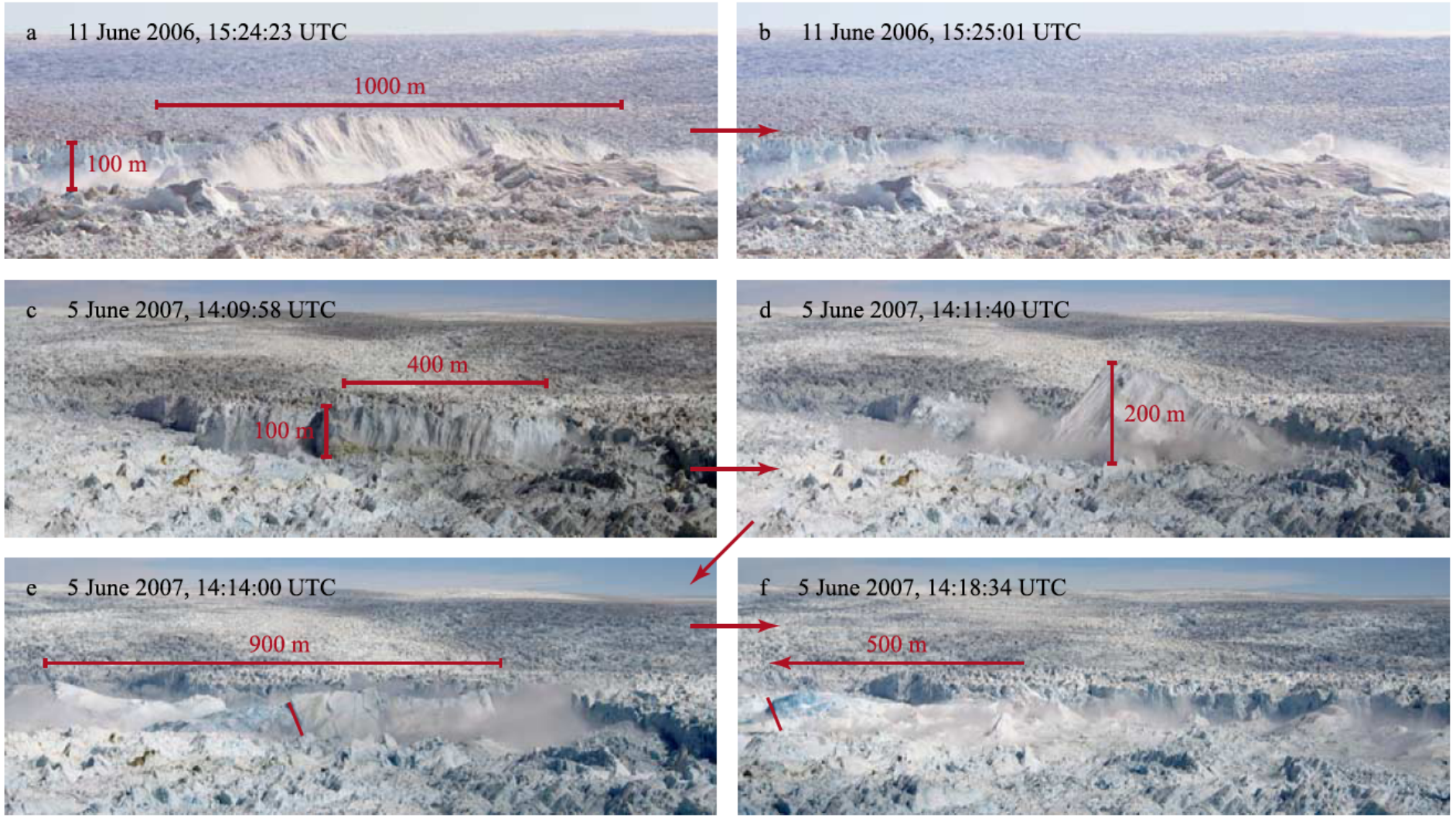
Challenges

- Multiple correlated forcings (melt, melange, water filled crevasses etc).
- Ice dynamics and other feedbacks.
- Logistically difficult access.
- Bed and fjord geometry.
- …



Simulations of Thwaites Grounding Line Retreat

AMUNDSON ET AL.: RESPONSE TO RECENT LARGE CALVING EVENTS



Instrumenting fjords to make much needed measurements both difficult and dangerous!

Summary

• Glaciers and ice sheets sensitive to ice-ocean interaction as nearby waters warm.

- Tidewater glaciers speedup as terminus recedes and such retreat appears to be linked to warmer water.
- Less clear which processes involving warmer water
  - Mélange role in supressing calving.
  - Role of melting on fast calving.
  - Other processes (e.g., warmer air temps and surface melt).