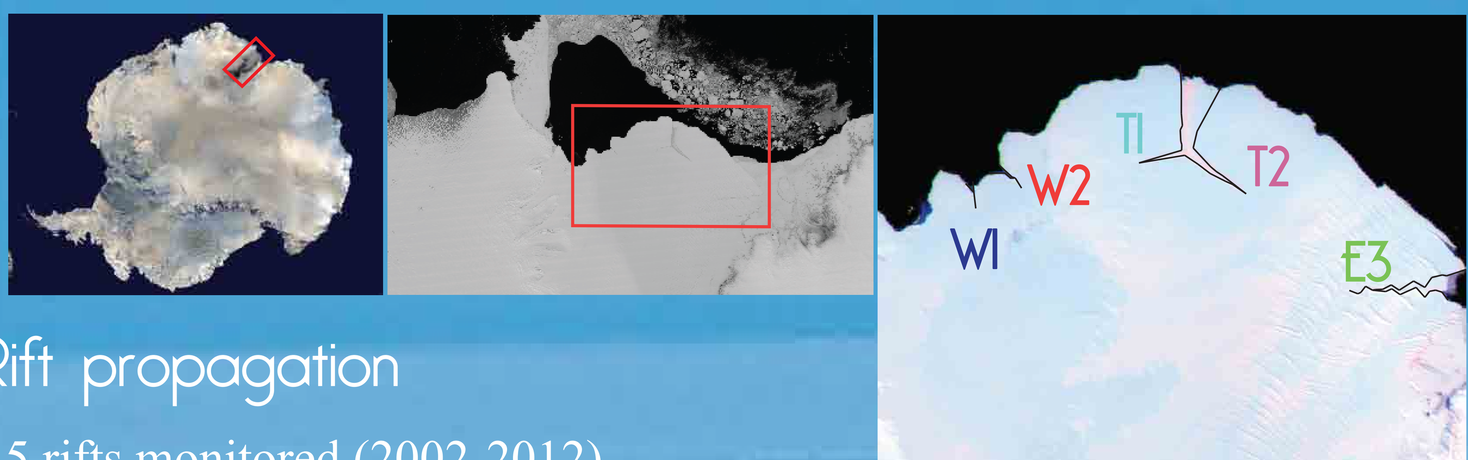
Structurally-compromised Ice: Observations of Rift Behavior at the Highly Fractured Amery Ice Shelf, East Antarctica and Implications for the Icy Shells of Enceladus and Europa

Abstract: 2139
Location: 665

C. C. Walker[1] (catcolwa@umich.edu), J. N. Bassis[1]
[1]Atmospheric Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109

The Amery Ice Shelf, East Antarctica



Rift propagation

- 5 rifts monitored (2002-2012)
- Multi-angle Imaging SpectroRadiometer (MISR) and Moderate resolution Imaging SpectroRadiometer (MODIS) imagery.

What is changing at the Amery?

- To address the question of what drives rifting, we begin by asking, what else changes at the Amery? Changing environmental factors like ocean swell and atmospheric temperatures have been suggested in the past as contributors to rift propagation.
- If the environment affects rifting:
  - Higher temperatures would lead to increased propagation
  - High sea ice concentration suppresses ocean swell and we would expect propagation to slow
- Do we see this pattern? NO!
- Fluctuating temperatures and ocean swell signals do not correlate consistently with propagation patterns.

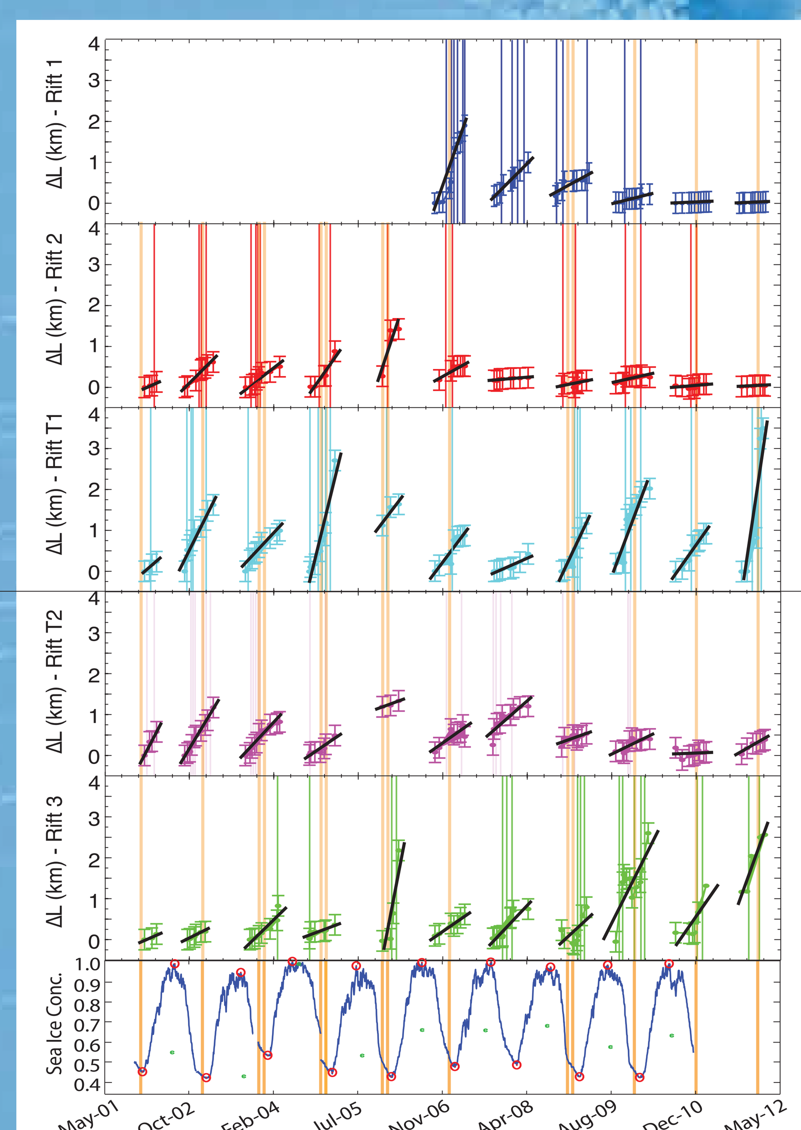
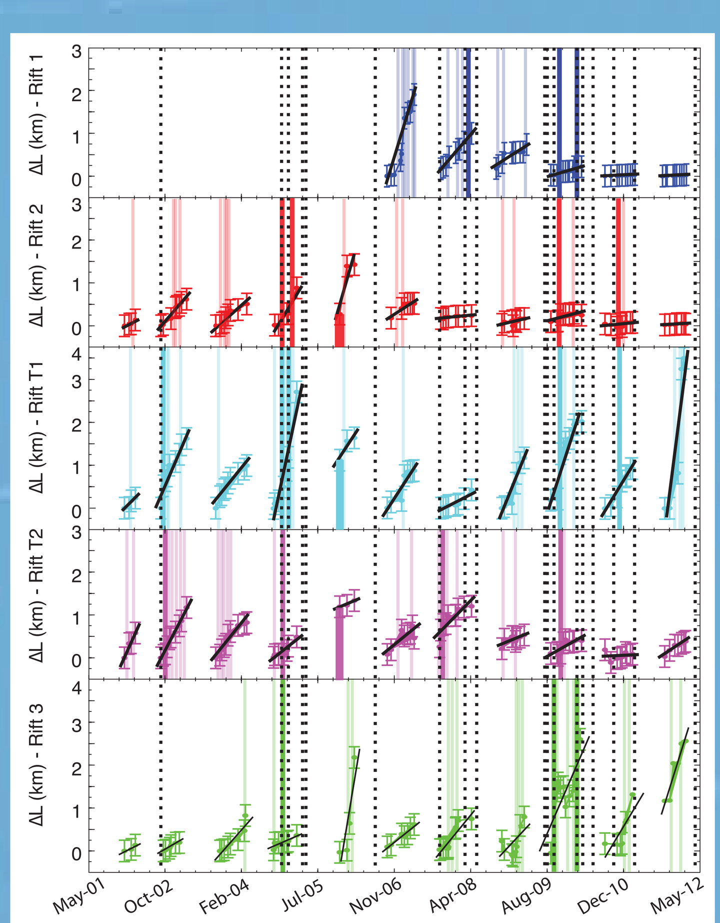


Figure (right): Occurrences of >0˚C monthly temperatures (orange) and sea ice concentration (blue, bottom).

What else is changing at the Amery?

Like straws on a camel's back? Increased Sensitivity to Tsunamis

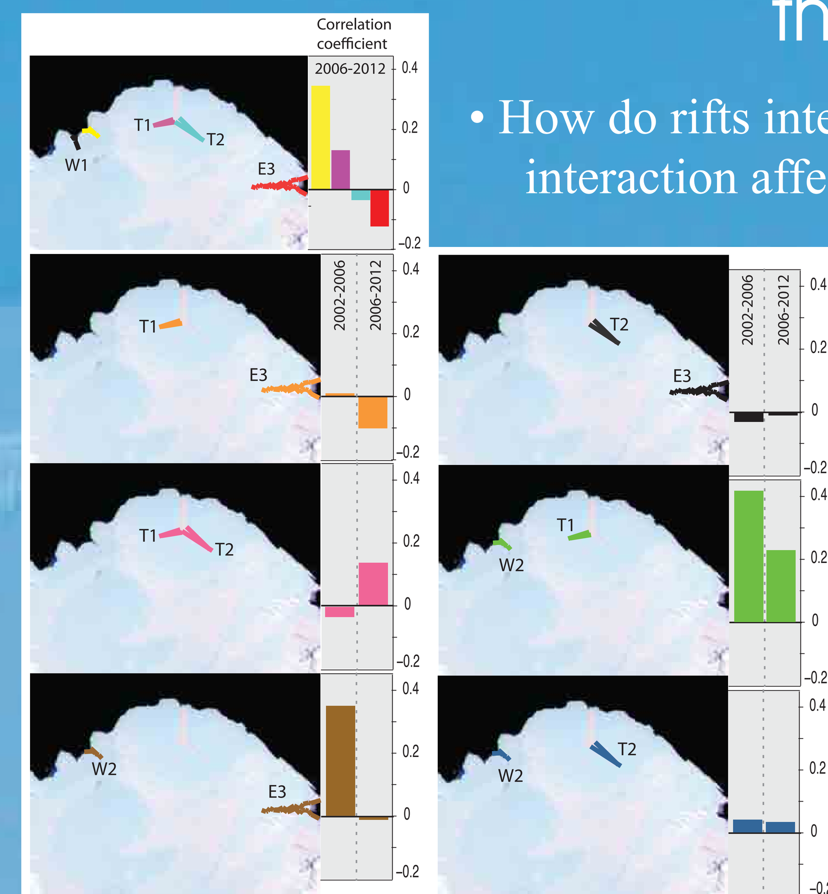


- Tsunamis with runup potential in the Amery region are marked (black)
- Example: All 5 rifts show large jumps in length after the 2004 December Sumatra tsunami
- Water pressure propagation into rifts by wave impact increases stress at the rift crack tip

Is this observed elsewhere?

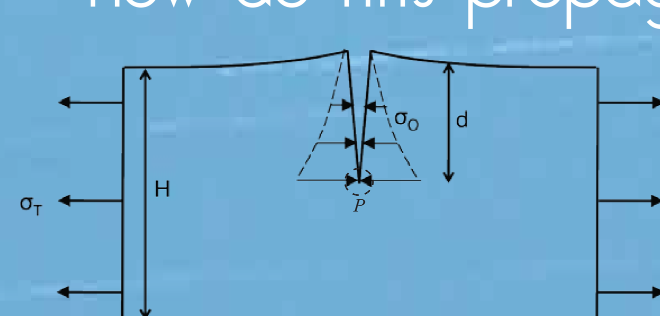
- Larsen C (2004)
- Abbott (2010/11)
- Shackleton (2004)
- Ross (2011)
- Fimbul (2004)
- Filchner (2004)
- Brunt et al. (2011): Sulzberger (2011)

In-harmonious or in-tandem? the Multiple Rift Effect



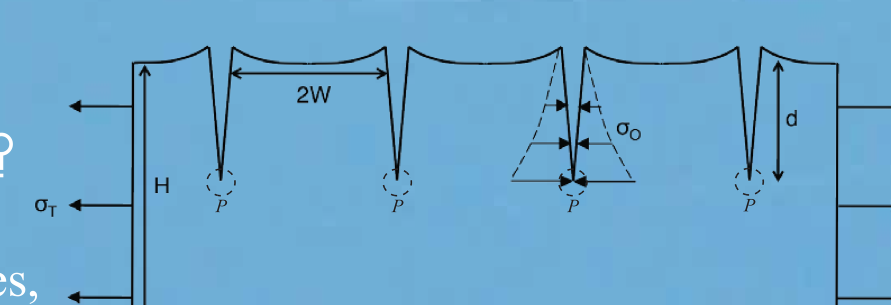
- How do rifts interact with one another? How is this interaction affected by the addition of a new rift?
- Left: Correlation coefficients of observed propagation signals for each pair of rifts.
- Rift W1 initiated in 2006, so analysis was split into two phases: 2002-2006 and 2006-2012.
- Observable (left): Correlation between rift pairs for each half of the decade.
- This highlights rift interaction
- Correlation: response to same mechanism
- Anti-correlation: stress trade-off
- Existence of multiple rifts at front of shelf and their interplay could speed up or increase likelihood of a future collapse event
- Planetary perspective: Icy moons (e.g., Enceladus, Europa) are heavily fractured
- Models of fractures as singular, isolated features may produce inaccurate estimates of stress required

How do rifts propagate?: The vertical dimension



- Linear elastic fracture mechanics (LEFM) can be employed to model propagation
- Stress intensity factor (*K*): describes the concentration of stress at the crack tip (*P*).
- Once stress intensity surpasses a critical value, K_{IC}, crack will propagate to relieve stress until $K < K_{IC}$.
- Net K, and therefore penetration depth, is dependent upon applied tensile stress and glaciostatic overburden stress

What happens in highly fractured surfaces?



- The LEFM method still applies, but is modified to account for the fact that no tensile stress can exist in the sections of ice between crevasses.
  - Dependent on ratio of crevasse spacing W to depth d
- Overall effect: stress intensity decreased ⟶ higher tensile stress needed to reach same depth as individual crevasse (or to penetrate ice layer)

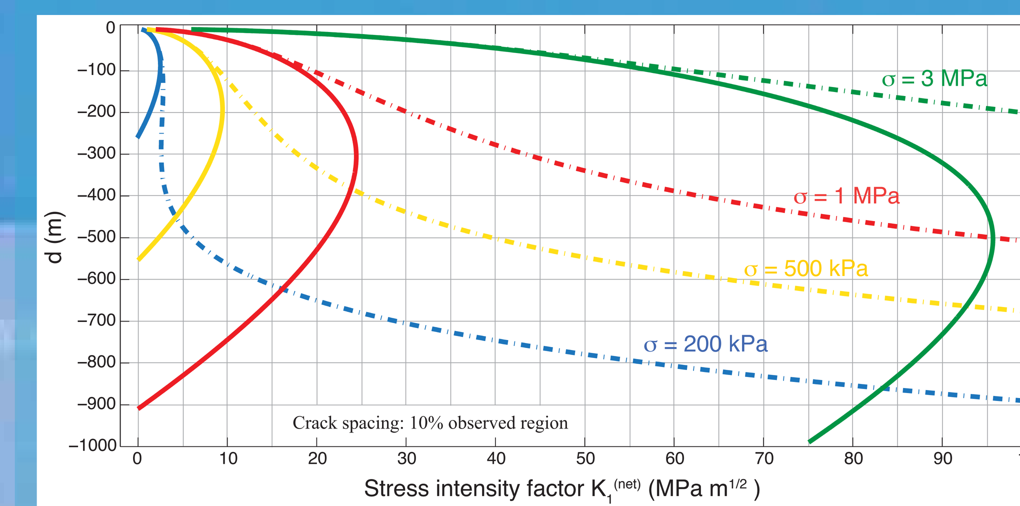
Acknowledgements:

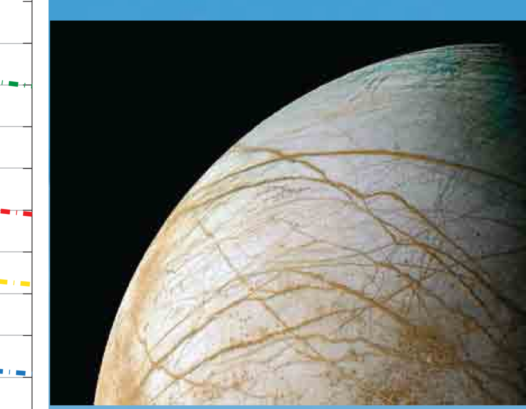
This work is funded by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and partially supported by the Michigan Space Grant Consortium (MSGC).

Background image: Amery Ice Shelf, courtesy J. Behrens.

Considering a structurally-compromised shell

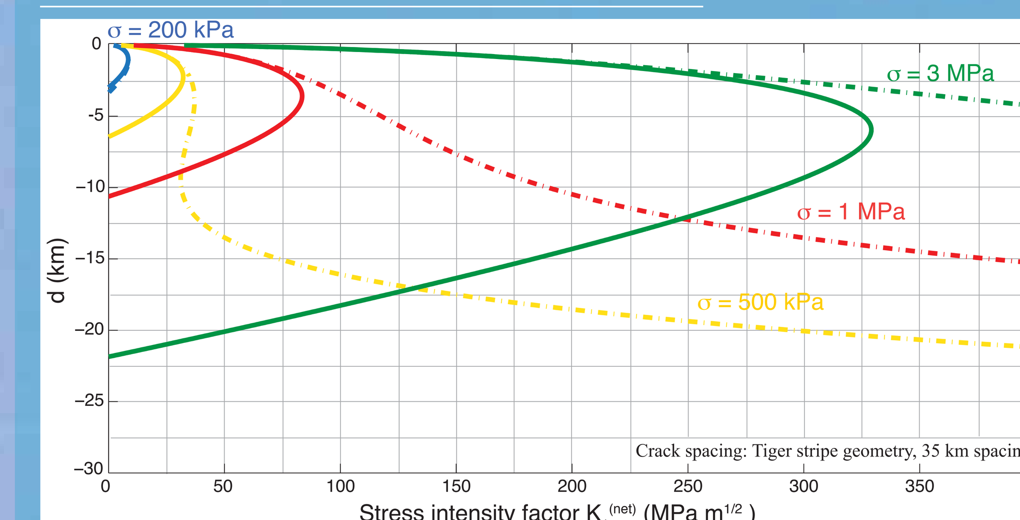
Ex.:1-km Europa ice shell

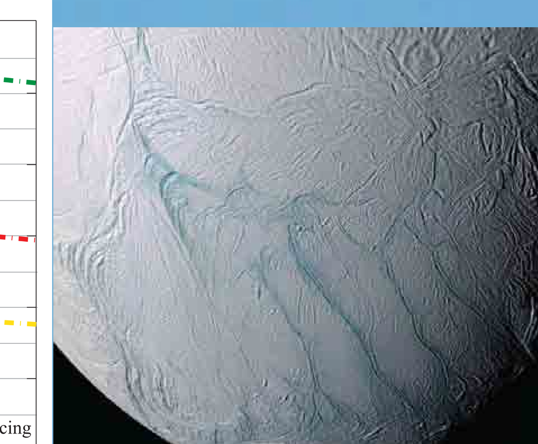




- Single crack (solid): > 0.2 MPa stresses can drive full-layer rupture
- Multiple cracks (dashed): 3 MPa needed to fully rupture brittle ice layer

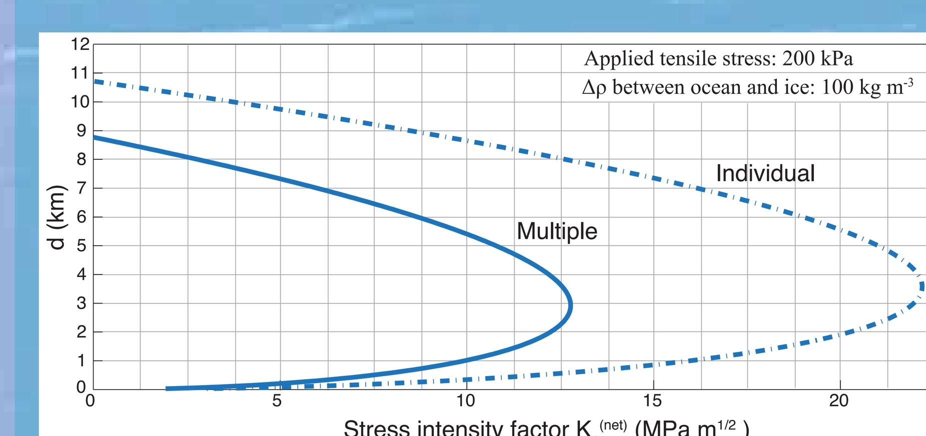
Ex.: 30-km Enceladus ice shell





- Single crack (solid): > 0.5 MPa stresses can drive full-layer rupture
- Multiple cracks (dashed): >>3 MPa needed to fully rupture brittle ice layer

Basal crevasses and water pressure



- Crevasses can also form at the base of the ice shell
- Basal crevasses can fill with water, which counteracts the overburden stress at depth
- Ex.: 30-km Enceladus shell
- Individual crevasse is predicted to penetrate deeper than a crevasse that lies among a number of crevasses at the same amount of applied tensile stress
- Another approach: Glaciologists employ Nye (1957) zero-stress model to investigate penetration depth of closely-spaced crevasses (surface & basal).
  - A plus: this approach makes no assumptions on fracture strength.
  - The Nye zero-stress estimate for this example 30-km shell: 9300 m.

Main Conclusions:

- Existence of multiple fractures in the ice shell necessitates the consideration that little tensile stress can exist within the slabs of ice separating adjacent crevasses.
  - Consequently, larger tensile stress is needed for a field of fractures to occur.
- Another contributor to stress intensity factor: membrane and bending stresses

References:

[1] Hurford, T.A., et al. (2007) Nature, 447, 292-294. [2] Lopes, R.M.C. and Carroll, M.W. (2008) JHU Press. [3] Manga, M. and Wang, C.-Y. (2007) GRL, 34, L07202. [4] Mitri, G. et al. (2008) Icarus 196, 216-224. [5] Miyamoto, H.G., et al. (2005) Icarus, 177, 413-424. [6] Nimmo, F. (2004) JGR-Planets, 109, E12001. [7] Olgin, J.G., et al. (2011) GRL, 380, L02201. [8] Parker, A.P. (1998) Army Armament Research Contractor Report, ARCCB-CR-98009. [9] Patterson, W.S.B. (1994) Pergammon/ Elsevier. [10] Rudolph, M.L. and Manga, M. (2009) Icarus, 199, 536-541. [11] Smith-Konter, B. and Pappalardo, R.T. (2008) Icarus, 198, 435-451. [12] Tada, H., et al. (1973) Del Res. Corp. [13] van der Veen, C.J. (1998) Cold Regions Science and Technology, 27, 31-47.