Seismic Waves Used to Measure How Ice Shelf Rifting Velocity Is Limited by Ocean Coupling

Other Journal Item

Author(s):
Hudson, Thomas

Publication date:
2024-04

Permanent link:
https://doi.org/10.3929/ethz-b-000664023

Originally published in:
AGU Advances 5(2), https://doi.org/10.1029/2024AV001189

ADVANCING EARTH AND SPACE SCIENCES

AGU Advances

VIEWPOINT
10.1029/2024AV001189

Seismic Waves Used to Measure How Ice Shelf Rifting Velocity Is Limited by Ocean Coupling

T. Hudson[1]

[1]Institute of Geophysics, ETH Zürich, Zürich, Switzerland

Correspondence to:
T. Hudson,
thomas.hudson@erdw.ethz.ch

Citation:
Hudson, T. (2024). Seismic waves used to measure how ice shelf rifting velocity is limited by ocean coupling. *AGU Advances*, *5*, e2024AV001189. https://doi.org/10.1029/2024AV001189

Received 1 FEB 2024
Accepted 12 FEB 2024

Author Contribution:
Writing – original draft: T. Hudson

Ice shelves play an important role in controlling how fast ice moves off the Antarctic continent into the oceans, promoting sea-level rise. These floating bodies of ice effectively buttress the grounded ice behind them, hindering the flow of ice off land while also somewhat reducing the exposure of the grounding line to ocean melting (Gudmundsson, 2013). Their importance can perhaps be exemplified by comparing Antarctic ice streams terminating at ice shelves to Greenland's directly exposed calving fronts (Benn et al., 2017), where ice is currently being lost at a far greater rate (Oppenheimer et al., 2019). However, Antarctic ice shelves are vulnerable to rifting (Larour et al., 2021) and catastrophic breakup (Glasser & Scambos, 2008). Olinger et al. (2024) use seismology to shed new light on how such rifting can be limited by ocean coupling.

Olinger et al. (2024) use observations combined with numerical modeling to highlight how vulnerable ice shelves can be to rifting, and in particular how the ocean can play a role in setting rifting velocity (see Figure 1). This work is particularly exciting for two reasons. First, they combine satellite and seismic observations with a numerical model, to not only understand but also quantify the rifting process. Second, they find that coupling of the ice shelf rift with the ocean actually limits the rate of rift propagation. This is contrary to the majority of ice shelf-ocean interactions, which generally act to exacerbate ice shelf instability (e.g., Holland et al. (2008)).

Satellite observations are one of the most effective means of observing ice shelf rifting. Olinger et al. (2024) use Synthetic Aperture Radar (SAR) imagery to map changes in the rift extent at Pine Island Glacier (PIG) ice shelf, before and after a major rifting event. However, one of the greatest challenges posed by such remote sensing data is the poor temporal sampling (Baumhoer et al., 2018). This is evident in the data used by Olinger et al. (2024), where they analyze images six days apart, only capturing the rift extent prior to and post the major rifting episode. During this time, they find that the rift lengthens by 10.5 km. Capturing higher resolution temporal behavior of the rift is critical for understanding rifting in more detail. Olinger et al. (2024) use seismic observations from instruments deployed on the ice shelf to provide continuous temporal sampling of the rift. They searched through the continuous data to identify the dominant rifting event, which they assume accommodated the majority of rifting observed in the satellite data. From this rifting event, they observe an increase in seismic energy from surface waves of 300 s duration, which allows them to quantify a rifting velocity of 35 m s^{-1}. Although this velocity may appear fast from a glaciology perspective, theory suggests that fractures of pure ice exhibiting brittle fracturing should propagate near the Rayleigh wave speed (Freund, 1990), ~1,500 m s^{-1} (Roethlisberger, 1972).

To address the considerable difference in observed versus theoretical rift propagation velocity, Olinger et al. (2024) turn to numerical modeling. Combining observations with models is inherently challenging, yet can provide important new insights into physical processes. The authors exemplify this in their work. They present a simplified ocean-coupled fracture model based on coupling the conservation of fluid momentum with linear elastic fracture mechanics. The key take-home message from the authors' work is that water entrained into the rift acts to oppose rift opening, which limits the rift opening rate. Their result demonstrates the insight that a simple model can provide: in this case an explanation for the seismically-observed rift opening rate, at least to first order.

While the results of Olinger et al. (2024) are exciting in themselves, the work also raises some questions about future research directions. One limitation of their work is that they assume that most of the rifting is confined to one seismic episode. However, in many cases, especially where there might be many suture zones, rifts may propagate via many short episodes rather than one long episode. Satellite data are currently blind to this. The authors show the value of seismic observations in quantifying the rift process, and it would be feasible going forward to search for many smaller rifting episodes in a similar data set. It is also possible that some rifting is accommodated aseismically and that the seismic efficiency of rifting may be significantly less than 1. In that case, seismic data alone might not provide a sufficient picture of the process. One further thought is that ice shelves can

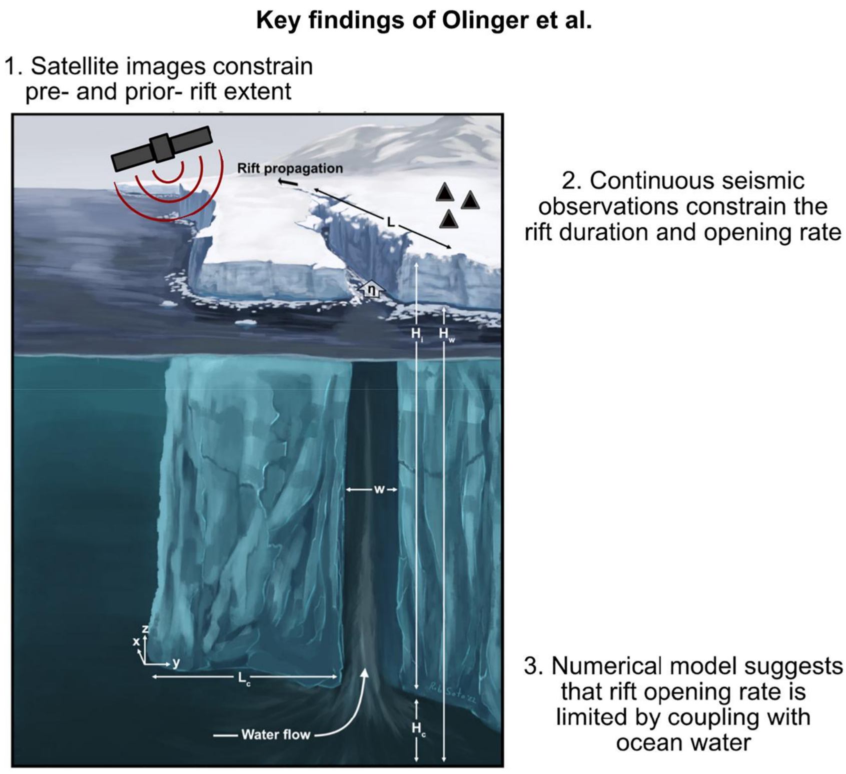

Figure 1. Schematic diagram, adapted from Figure 2 of Olinger et al. (2024), summarizing the findings of that work.

vary considerably, especially regarding basal topography and cavity depth. Going forward, it would be interesting to understand how consistent the behavior observed by Olinger et al. (2024) is for other ice shelves.

In summary, Olinger et al. (2024) show how high temporal sampling of rift dynamics combined with simple numerical modeling can shed light on a fundamental process. Their intriguing result demonstrates that hydrodynamical coupling of the ocean with the ice rift actually acts to limit rift propagation rates. Whereas most ocean-ice interactions tend to promote ice shelf damage, this is an example of how fluid interactions can enhance ice shelf stability, or at least slow the processes that promote collapse. The authors' work shows promise for using remote sensing and seismic data in combination with models to better understand rifting, a critical process that influences the stability of ice shelves.

References

Baumhoer, C., Dietz, A., Dech, S., & Kuenzer, C. (2018). Remote sensing of Antarctic glacier and ice-shelf front dynamics—A review. *Remote Sensing*, *10*(9), 1445. https://doi.org/10.3390/rs10091445

Benn, D. I., Cowton, T., Todd, J., & Luckman, A. (2017). Glacier calving in Greenland. *Current Climate Change Reports*, *3*(4), 282–290. https://doi.org/10.1007/s40641-017-0070-1

Freund, L. B. (1990). *Dynamic fracture mechanics*. Cambridge University Press. https://doi.org/10.1017/CBO9780511546761

Glasser, N. F., & Scambos, T. A. (2008). A structural glaciological analysis of the 2002 Larsen B ice-shelf collapse. *Journal of Glaciology*, *54*(184), 3–16. https://doi.org/10.3189/002214308784409017

Gudmundsson, G. H. (2013). Ice-shelf buttressing and the stability of marine ice sheets. *The Cryosphere*, *7*(2), 647–655. https://doi.org/10.5194/tc-7-647-2013

Holland, P. R., Jenkins, A., & Holland, D. M. (2008). The response of Ice shelf basal melting to variations in ocean temperature. *Journal of Climate*, *21*(11), 2558–2572. https://doi.org/10.1175/2007JCLI1909.1

Larour, E., Rignot, E., Poinelli, M., & Scheuchl, B. (2021). Physical processes controlling the rifting of Larsen C Ice Shelf, Antarctica, prior to the calving of iceberg A68. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(40). https://doi.org/10.1073/pnas.2105080118

Olinger, S. D., Lipovsky, B. P., & Denolle, M. A. (2024). Ocean coupling limits rupture velocity of fastest observed ice shelf rift propagation event. *AGU Advances*, *5*(1), e2023AV001023. https://doi.org/10.1029/2023AV001023

Oppenheimer, M., Glavovic, B. C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., et al. (2019). Sea level rise and implications for low-lying islands, coasts and communities. In *IPCC special report on the ocean and cryosphere in a changing climate* (pp. 321–445).

Roethlisberger, H. (1972). *Seismic exploration in cold regions*. Corps of Engineers, U.S. Army, Cold Regions Research and Engineering Laboratory.