Exploratory Ice Loss Intervention Workshop: Final Report

Spring, 2024

Summary

On December 9-10, 2023, a workshop on the technical feasibility of ice preservation was held at Stanford University. This workshop hosted ~40 geoscientists who discussed potential initiatives that could slow ice loss from Antarctic glaciers such as Thwaites and Pine Island. The workshop explored various ice-sheet bed and ice-adjacent ocean interventions.

The majority of participants were North American glaciologists and polar oceanographers, with the remaining participants covering a few other scientific disciplines (history of Antarctica, polar microbiology, polar atmospheric dynamics, governance), potential funders, some press, and members of the organizing committee (from computer, political, and decision science). Many polar scientists were invited specifically because they were skeptical of the concept of ice preservation, and not all attendees listed on this report support further research in this area. There was a broad consensus that there are significant unknowns regarding the feasibility of the two concepts described below, and should there be progress in this field, rigorous scientific research is needed to determine if these ideas are viable and worth pursuing.

There were specific recommendations for future research, along with numerous general questions about the risks and viability of the specific glacier preservation approaches. Beyond discussing research into the technical feasibility of glacier interventions there were also questions of ethics, governance, legal framework, politics, and public opinion, as with any intervention in any Earth system.

Some participants suggested next steps, including follow-on workshops, modeling studies, and initial field trials. While motivated by a desire to preserve ice and mitigate sea-level rise, such field trials would be guided by the parallel needs of exploring basic scientific questions into ice dynamics and subglacial hydrology. Thus, they would answer questions relevant both to ice preservation for reducing rates of sea-level rise and to understanding ice-sheet behavior under a warming climate.

Background

We do not know when or how fast parts of the two existing polar ice-sheets will destabilize, but it is likely the consequences would be catastrophic. Rapid and significant sea-level rise will inundate coastal communities and cause mass migration, salinate groundwater and destroy cropland, and erase small-island states, among many other negative effects. The glaciology community has been investigating the current state and potential future evolution of polar ice sheets over the last several decades. This workshop was focused on how glaciological research can be used to answer the question: “Can ice sheet destabilization be prevented?”

Some members of the glaciology community are assessing options for slowing the contribution of ice-sheet deterioration due to climate change, with the goal of reducing rates of sea-level rise. Currently, much of the projected high-risk and high uncertainty of sea-level rise from marine ice-sheet instability is expected to come from two primary glaciers in the Antarctic: Thwaites and Pine Island. Any mechanism that slows the flow or reduces melting of those glaciers could reduce the rate of sea-level rise and the risk of ice-sheet collapse, thereby enhancing global stability and providing extra time to work toward effective mitigation. While the workshop primarily focused on scientific issues regarding the technical feasibility of ice intervention, it also laid the foundation for a concurrent examination of ecological impacts and socially acceptable governance of the research and any subsequent intervention. These issues will be further examined during a workshop planned for 2024.

Outcomes

The workshop had three breakout sessions focused on basal intervention, ocean intervention,

and other ideas.

Basal Intervention

The basal intervention approach aims at increasing the friction between the ice-sheet and the underlying bed, thereby slowing its flow toward the sea. The workshop identified two primary mechanisms, both requiring improved scientific understanding of glacier dynamics. One basal intervention method would actively pump basal water out through boreholes to decrease the basal water volume and pressure and increase frictional contact between the ice-sheet base and the subglacial bed. The second method would remove heat from the glacier bed via passive thermosyphons in order to freeze the ice-sheet to the bed, which should have a mechanical effect similar to that of subglacial water pumping.

The discussed studies to improve the understanding of these processes include theoretical work, modeling studies, and field trials. All would address glacier preservation with scientific methods familiar to glaciological research. The majority of the discussed experiments are, at least in the short- and mid-term time frame (several years to a decade), closely aligned with the scientific questions posed by traditional glaciological research, with ‘traditional glaciology research’ defined as ‘observing glacier behavior, quantifying changes, and attempting to understand and model the reasons for historically observed changes and predict likely future changes’. However, pursuing these questions with the aim to possibly modify the system would likely change priorities in glaciology research, an additional concern to those noted above about potential interventions in Earth systems.

Workshop members also identified questions regarding the technical feasibility of the proposed interventions. For pumping, the number of boreholes required is unknown, and may prove prohibitive. The large energy requirement to keep boreholes from refreezing would require developing clean power systems for the harsh Antarctic environment. Dispersal of basal water at the surface requires developing appropriate snow-making and dispersal systems. Thermosyphons are unproven at this scale. The temperature gradient may limit their effectiveness; internal ice deformation may shear them apart. These questions would have to be studied concurrently with the scientific research, so that any successful intervention could be operationalized, should it prove both scientifically feasible and socially desirable. Ultimately, the questions related to potential feasibility, or lack thereof, of glacier preservation approaches cannot be answered without further scientific research specifically focused on these issues.

More broadly from the above technical and operational concerns, it was suggested that if ice supply to the marine boundary is reduced due to slower flow from the above methods, but melt rate at that boundary remains high due to warm ocean waters, grounding line retreat and

an increase in the rate sea-level rise could occur.

The breakout session on basal interventions led to a working group that is currently developing one possible research agenda, considering both modeling studies and small field trials.

Ocean Intervention

The ocean intervention session addressed ways to use curtains or other physical structures to block or disrupt warm water from flowing down submarine canyons from the edge of the continental shelf to the edge of the ice-sheet. This concept has been more thoroughly studied than basal intervention, with several existing peer reviewed publications on the topic, and is being pursued in a variety of modeling studies and laboratory trials. A range of concerns on logistic feasibility, cost, and impacts on local ecosystems were raised.

There are two basic ways to lower ocean thermal forcing on the ice shelves: (1) lowering the temperature of the water and (2) reducing the water flow rate. The breakout session covered a range of possibilities, including a few newer and relatively unexplored ideas. One was mixing deep and shallow waters to lower the temperature of the deep water while slowing it, perhaps with large (100 m diameter) horizontal impellers in the upper cold waters. A second idea involved hydro-kites to reduce momentum from horizontal water flow - a technique that has been deployed elsewhere.

Scientific opinions differed regarding the likelihood, timing, and scale of a collapse of the Amundsen Sea outlet glaciers, and range from estimating the system as stable for multiple centuries to already collapsing. There were differing opinions about research priorities for reducing that uncertainty. While most research has focused on the Amundsen Sea, the Totten Glacier may also be a large potential contributor to sea-level rise – hence worthy of more research. There was general agreement about the urgent need for better data on ocean currents and basic system knowledge such as DNA markers for biodiversity. These are challenging studies, given working conditions in the Amundsen Sea and Antarctica in general. Given the few ships equipped for these tasks, the multinational alliances common in Antarctic science will be needed – increasing the importance of appropriate governance mechanisms.

Workshop members also discussed current controversies regarding the social acceptability of proposed sea bed curtain intervention, extending to whether it was appropriate to conduct studies motivated by that intervention, unless they had independent scientific value. There was less controversy over the value of data collection cruises to Greenland and Antarctica, research involving small scale tank tests, small scale marine tests, and studies in Arctic environments collaborating with community knowledge-holders who know local systems. There was general

agreement on the need to gain social license for any research and ensure that any tests were conducted without any significant harm to natural systems. Securing that license would require discussions that were informed by the knowledge of ocean and ice modelers, scientists from other disciplines (e.g. marine biology, social scientists), and individuals from other stakeholder groups.

Governance

The third breakout group focused on a proposal for a large-scale governance structure to address polar geoengineering interventions more generally (including, but not limited to, the two interventions discussed above). This proposal included plans for a governance structure that would include existing scientific and government regulatory bodies, and impacted populations (e.g. island states). However, the form of the representative body was not well defined for this latter group. The inclusion of impacted populations here is not only to decide when/if to intervene based on the current set of proposals, but also to help craft both the science and potential new solutions.

This breakout room also developed a strategy for parallel scientific efforts to address basic scientific questions (e.g. earth systems model enhancements), which are critical for both ice intervention and sea-level science more generally. These efforts are intended to:

- Facilitate an oppositional but supportive alliance between supporters and detractors of ice intervention
- Address the need for larger earth systems expertise (including physical science expertise outside of traditional glaciology).
- Keep expertise for governance, modeling and observations in regular conversation with one another.
- Support a deliberate focus on null results in addition to traditional positive results to best direct research towards the greatest impact
- Define and oversee work-stop clauses and off-ramps should operations ever occur.

Proponents of this structure recognized that the current public funding is inadequate for the necessary collective scientific leaps forward to actualize the intervention efforts suggested here.

Next Steps

The organizers conceptualized this workshop as initiating one of three interdependent tracks: on scientific and technical feasibility, social license and public engagement, and funding. This workshop explicitly focused on the first track, however, the next steps suggested at the

workshop cover a range of areas beyond the scientific and technical feasibility.

Issues related to specific geophysical processes

There are numerous specific issues, described above, within the domain of glaciology for the basal intervention or oceanography for the ocean intervention. The next steps for these research questions are to design experiments. Those experiments should engage stakeholders beyond the investigators and traditional peer reviewers, including individuals skeptical of these interventions, who can identify evidence that would allay or support their concerns depending on what the studies found. Specifically, some workshop participants recommended seeking funding for model studies and initial field trials in labs or at analog sites. Publications in this area should support null results, a topic not traditionally lauded by scientists or journals. Open science best-practices should be followed.

Issues within glaciology beyond geophysical processes

Other concerns addressed the broader field and culture of glaciology and science in general. Workshop participants raised concerns about potential risks from non-traditional funding sources and commercial interests in actual interventions, unexplored ecological impacts, the lack of connection between the workshop participants (mostly North American glaciologists) and the coastal and island communities most impacted by sea-level rise, and if the Antarctic Treaty does or could allow or support such work.

Some of these issues were recognized prior to the workshop and explicitly not covered as the focus was on technical feasibility. These and other similar issues should be addressed and regularly assessed and reviewed by the community at future workshops and at conferences with dedicated sessions. Many workshop participants stressed the vital importance of the other tracks - social license and public engagement, and funding. Some of the organizers from this event have begun planning these workshops, paying particular attention to the process and content of public engagement.

Issues beyond the domain of glaciology

Even though this event focused on scientific and technical feasibility, concerns were raised covering the general issues of climate change, global policy, individual and collective psychology and human behavior, and other areas far from glaciology. The most vocal concern in this category is that by doing research in this area, or even discussing these topics, the important step of emission reduction will be delayed or ignored in favor of this approach. The recommended next step for this last concern, that discussion of interventions may distract from mitigation efforts, was to stop any further discussions and research on this topic. This was a minority view.

Summary

There was general agreement that there are significant unknowns, and that the proposed interventions may prove infeasible. Research is required to determine if they or other methods can reduce the rate of sea-level rise and the risks of marine ice-sheet collapse.

At the moment, the workshop participants are spread on a spectrum, and the distribution of that spread is not clearly defined. One end suggests no further discussion because even discussing this distracts from mitigation efforts. The other is recommending research via models and initial field trials after robust peer-review, to learn more about glacier, ice-sheet, and ocean dynamics in order to test the viability of ice preservation methods.

The end goals of both ends of this spectrum are the same - to reduce ongoing and projected rates of sea-level rise, and reduce the probability of catastrophic sea-level rise. One end hopes to do this through emission reduction alone. The other through emission reduction coupled with interventions.

Other Information

Funding

The workshop was funded by Vinton G. Cerf and Stephen D. Crocker (Edgemoor Research Institute, a 501(c)(3) non-profit). Meeting space donated by Stanford University.

Workshop conveners and organizers

Kenneth D. Mankoff, Alex Luebke, Christine Dow, Slawek Tulaczyk, Steve Crocker, Baruch Fischhoff, Vinton Cerf, Robert Axelrod

Workshop report prepared by (alphabetical last name)

Robert Axelrod, University of Michigan
William Colgan, Geological Survey of Denmark and Greenland (GEUS)
Steve Crocker, Edgemoor Research Institute
Rajashree Datta, University of Colorado, Boulder
Christine Dow, University of Waterloo
Baruch Fischhoff, Carnegie Mellon University
Kenneth D. Mankoff, National Aeronautics and Space Administration (NASA)
John Moore, University of Lapland

Mathieu Morlighem, Dartmouth University
Martin Truffer, University of Alaska Fairbanks
Slawek Tulaczyk, University of California, Santa Cruz

Appendix A: Workshop Agenda, Outline, and Schedule

The following pages were shared with workshop participants prior to the event, and the workshop attempted to generally follow the agenda, outline, and schedule below.

Workshop Agenda, Outline, and Schedule

Exploratory Antarctic Ice Loss Intervention Workshop
December 9 & 10, Stanford University

Summary:
The Exploratory Antarctic Ice Loss Intervention Workshop, December 9-10 at Stanford University, will gather 40+ world renowned glaciologists to evaluate potential ways to slow down the loss of Antarctic glaciers, focused on the Thwaites and Pine Island glaciers. The meeting will explore real-world tests to evaluate the technical feasibility of proposed interventions (e.g., subglacial water pumping, sea curtain temperature management, surface albedo modification). Participants will pool their knowledge about these interventions and identify research required to reduce critical uncertainties. The organizers view technical feasibility as necessary, but not sufficient for the social acceptability of any such interventions. Organizers are planning future meetings convening a broad set of stakeholders whose voices will inform the scientific discovery process related to Antarctic climate interventions.

Workshop Objective
Detailed plans and next steps to answer the questions:

Is there a technically feasible Antarctic Ice Loss Intervention that is worth pursuing?

- How big of an impact could it have?
- What are chances it could be accomplished in time?
- What do we need to learn to answer these questions?

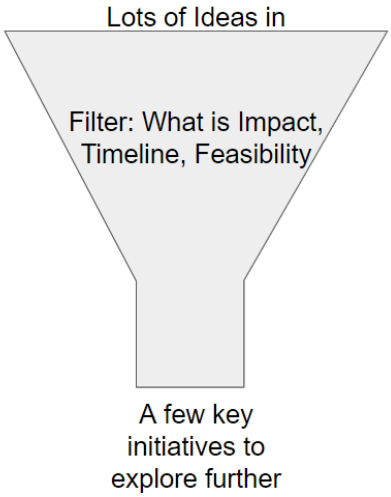
Rough Schedule outline:
Saturday Workshop: Location Stanford Design School
9:00 - 09:30 Coffee, Pastries & Fruit
9:30 - 10:30 Workshop Intro, objective & process, Guidelines, Summary of Chicago Workshop
10:30 - 11:30 Short presentations

- Mike Wolovick - Seabed curtains
- Brent Minchew - Subglacial
- Other ideas - 30 second pitches

11:30 - 12:00 - Post it note exercise, brainstorming
12:00 - 13:00 - Lunch conversations
13:00 - 14:30 - **Wide open discussion** on solutions, Blue readouts
14:30 - 15:15 - **Prioritization/convergence**
15:15 - 15:30 - coffee break
15:30 - 16:15 - Blue readout, Red readout
16:15 - 17:45 - **Detailed planning**, Blue readout
17:45 - 18:00 - Feedback on process, planning for Sunday
18:00 Dinner on Campus

Sunday Workshop: Morning Location Stanford Design School, Afternoon Location Stanford Geocorner/Braun Corner
9:00 - 09:30 Coffee, Pastries & Fruit
9:30 - 10:00 Recap of Saturday for Sunday-only participants (if any)
10:00 - 11:30 Continue on detailed planning, use proposal outline
11:30 - 12:00 Final Technical group readout (eg, 3+ selected ideas)
12:00 - 13:00 lunch @ Geocorner/Braun Corner
13:00 - 13:30 Read out Political/regulatory/social/funding groups [Online]
13:30 - 14:00 Blue Report out summary [Online]
14:00 - 14:30 Red Report out summary [Online]
14:30 - 14:45 Vision for the future and next steps [Online]
14:45 Closing remarks, picture in Quad and campus tour option
15:00 and later for organizers to collect workshop data and plan next steps

General workshop flow:



1. Collect as many ideas and voices as possible
2. Rate and consolidate

3. Prioritize (Likelihood vs. Consequences)
4. Add more details

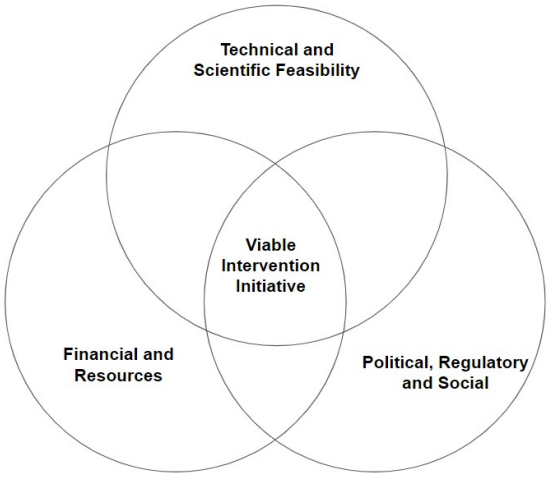
Guiding questions:

1. Might this concept have a large impact if it works?
2. What is the data needed to be collected to see if it works?
3. What kind of modeling is required to test whether this will work?
4. What's the worst that can happen?
5. If something bad happens, is it reversible?
6. What are the concerns that need to be mitigated?
7. Is this topic worth continuing to pursue? What would we have to know to decide if this is a good idea to continue to pursue?
8. More questions?

Summary report out and Next steps

- Facilitators/champions report out next steps and what could be accomplished/outcomes
- Red Team reports out key data that needs to be collected and key areas of concern
- Other report outs might include:
  - Financial
  - Political/egulatory/Public Policy
  - Social/Communication
- Final proposal(s) as output from workshop, ~2-3 months after event
  - Who, what, when, where, how much, next steps for gathering data and doing experiments and analysis
  - Schedule working follow up meetings

Viable solution space



Subgroups:

A. Modeling
B. Field data/sensors
    a. Aerogeophysics
    b. Surface geophysics
    c. Borehole-based glaciology
C. Lab work, prototypes, Engineering, Logistics
D. Strategic/vision, Political/Regulatory, Financial, Social

Scientific and Social Engagement process: Questions to ask at each phase, ICE Cycle

- **Impact:** Who is going to be Impacted?
- **Contribution:** Who can significantly contribute to the process?
- **Engagement:** How to engage key stakeholders throughout the process? Who can we bring to the table?
- Repeat the cycle as new
- information comes into focus

Appendix B: List of Participants

Adam Anderson
Bay Streaming LLC

Professor Robert Axelrod
Gerald R. Ford School of Public Policy
University of Michigan

Professor Timothy Bartholomaus
Department of Earth and Spatial Sciences
University of Idaho

Professor Ginny Catania
Jackson School of Geophysics
University of Texas at Austin

Dr. Vinton Cerf
Vice President and Chief Internet Evangelist
Google

Dr. Winnie Chu
School of Earth and Atmospheric Sciences
Georgia Institute of Technology

Mr. Niall Coffey
Department of Geophysics
Stanford University

Professor William Colgan
Geological Survey of Denmark and Greenland

Dr. Steve Crocker
Edgemoor Research Institute

Rajashree (Tri) Datta
Cooperative Institute for Research in Environmental Sciences
University of Colorado

Professor Christine Dow
Geography and Environmental Management
University of Waterloo

Professor Robert Dunbar
School of Earth, Energy and Environmental Sciences
Stanford University

Dr. Shivani Ehrenfeucht
Geography and Environmental Management
University of Waterloo

Mr. Dai Ellis
Cascade Climate

Dr. Leslie Field
Bright Ice Initiative

Professor Baruch Fischhoff
Department of Engineering and Public Policy
Carnegie Mellon University

Mr. Douglas Fox
Freelance science and environmental writer
https://douglasfox.org/about/

Professor Helen Fricker
Scripps Institution of Oceanography
University of California at San Diego

Professor Natalya Gomez
Earth and Planetary Sciences
McGill University

Professor Robert Hawley
Earth Sciences
Dartmouth College

Dr. Rebecca Herman
Causal Inference and Climate Informatics Group
Deutsches Zentrum für Luft- und Raumfahrt

Dr. Benjamin Hills
Colorado School of Mines

Professor Christina Hulbe
School of Surveying
University of Otago

Dr. Bowie Keefer
Clean Energy Research Center
University of British Columbia

Professor David Keith
Department of Geophysical Sciences and Climate System Engineering Initiative
University of Chicago

Dr. Michalea King
Polar Science Center
University of Washington

Professor Ching Yao Lai
Department of Geophysics
Stanford University

Dr. Alex Luebke

Dr. Joseph MacGregor
Sciences and Exploration Directorate
National Aeronautics and Space Administration

Dr. Kenneth D. Mankoff
Goddard Institute for Space Studies
National Aeronautics and Space Administration

Ms. Yue (Olivia) Meng
Department of Geophysics
Stanford University

Professor Colin Meyer
Department of Engineering
Dartmouth College

Professor Jill Mikucki
Department of Microbiology
University of Tennessee at Knoxville

Alex Miller
Massachusetts Institute of Technology

Professor Brent Minchew
Program in Atmospheres, Oceans and Climate
Massachusetts Institute of Technology

Professor John C. Moore
Arctic Centre
University of Lapland

Professor Mathieu Morlighem
Department of Earth Sciences
Dartmouth College

Mr. Oliver Morton
Briefings Editor
The Economist

Profesor Sophie Nowicki
Department of Geology
University at Buffalo

Mr. Chang Hyeon (Joshua) Park
Department of Geophysical Sciences
University of Chicago

Mr. Sasha Post
Climate and Democracy
Additional Ventures

Professor Morgan Raven
Department of Earth Science
University of California at Santa Barbara

Professor Kate Ricke
Scripps Institution of Oceanography
University of California at San Diego

Mr. Joshua Rines
Department of Geophysics
Stanford University

Mr. Stan Robinson
Author
https://www.kimstanleyrobinson.info/node/428

Ms. Aurora Roth
Scripps Institution of Oceanography
University of California at San Diego

Mr. Oliver Sabot
Kissick Family Foundation

Dr. Ted Scambos
Earth Science and Observation Center, CIRES
University of Colorado at Boulder

Professor Christian Schoof
Earth, Ocean and Atmospheric Sciences
University of British Columbia

Professor Dustin Schroeder
Department of Geophysics
Stanford University

Professor Hélène Seroussi
Department of Engineering
Dartmouth College

Mr. Liam St Louis

Dr. Amanda Stoudt
Polar Research Board
National Academy of Sciences

Professor Leigh Stearns
Department of Geology
The University of Kansas

Professor Fiamma Straneo
Scripps Institution of Oceanography
University of California at San Diego

Professor Martin Truffer
Geophysical Institute
University of Alaska at Fairbanks

Professor Ryan Venturelli
Geology and Geological Engineering
Colorado School of Mines

Dr. Mark von Keitz
Grantham Foundation for the Protection of the Environment

Mr. James Wolff
Energy and Environmental Consultant

Dr. Michael Wolovick
Alfred Wegener Institute
Helmholtz-Zentrum für Polar- und Meeresforschung

Professor Gabrielle Wong-Parodi
Earth System Science
Stanford University