Student Awards Form

WAIS Workshop 2024 Agenda (all times EST)

University of Florida
Gainesville, FL USA

Monday, November 11

2:00 pm – 5:00 pm	Check in: Pick up badges, swag (check in Wednesday and Thursday will be available during breaks in the agenda)	Century Ballrooms
5:00 pm – 5:30 pm	WAIS Workshop Steering Group Meeting: All are welcome to join to discuss the status and future of WAIS Workshops	TBD (Lobby or Century A)
6:00 pm – 8:00 pm	Icebreaker and pizza dinner 3650 SW 42nd Ave, Gainesville, FL	Swamphead Brewery

Tuesday, November 12 – All oral presentations in Century Ballroom B & C

Upload your Tuesday presentation slides by 7 am here.

Breakfast: 7:00 am – 8:00 am

Session 0	**Opening Business**	**Presenter**
8:00 am	Welcome to WAIS Workshop 2024 & Goals	WAIS Committee
8:15 am	Local Introduction	Mickey MacKie

Session 1	**Piecing the Puzzle Together**	**Presenter**
8:30 am	Synchronization of the Antarctic ice-ocean-atmosphere system and global climate began 1.5 million years ago	Mike Weber
8:40 am	Using subglacial lake genomes to uncover the origin and evolution of microbes beneath West Antarctic Ice Sheet	Brent Christner
8:50 am	Widespread Antarctic change during the 8.2 ka event	Roger Creel
9:00 am	Discussion	All

9:30 am	One minute poster teaser pitches (upload your 1 slide here by 7:00 am	Poster Presenters

Refreshment Break: 10:15 am – 10:40 am

Session 2	**Observations and Modeling Gaps**	**Presenter**
10:40 am	SCAR RINGS Action group work towards facilitating airborne geophysical surveys and co-ordinated research on the Antarctic Ice Sheet margin	Kirsty Tinto
10:50 am	The Influence of Bed Topography on Water Column Mixing and Ice-Ocean Interactions at Erebus Glacier Tongue, Antarctica	Veronica Hegelein
11:00 am	Novel Record of Grounding and Ungrounding of the Venable Ice Shelf since 1906	Caitlin Locke
11:10 am	Thwaites Glacier thins and retreats fastest where ice-shelf channels intersect its grounding zone	Allison Chartrand
11:20 am	Basal melt and sliding in Antarctic grounding zones: New theory, models and observations	Alex Robel
11:30 am	Discussion	All

Lunch: 12:00 pm – 1:00 pm

Session 3	Perspective from the Funding Agencies	Presenter
1:00 pm	View from NSF	NSF
1:20 pm	View from NASA	NASA
1:40 pm	Discussion	All

Session 4	New Software, Processing, and Data Compilations	Presenter
2:00 pm	Building software-defined radar systems with the Open Radar Code Architecture (ORCA)	Thomas Teisberg
2:10 pm	Refocusing on Radiostratigraphy: Novel Processing of Radar Sounding Data for New Insight into Ice Dynamics and Ice-Sheet	Ben Hills
2:20 pm	Effect of Weather Events on Antarctic Ice Shelf GNSS Reflected Signal Coherence	Sophie Anderson
2:30 pm	Using Cryosat-2 to fill the gaps within the time series of surface elevations measured in the Siple Coast by the ICESat and ICESat-2 altimetry missions	Eric Bruno Kabe Moukete
2:40 pm	Discussion	All

Refreshment break: 3:10 pm – 3:30 pm

Session 5	Piecing the Puzzle Together	Presenter
3:30 pm	Noble gas water samples reveal active subglacial volcanism beneath Kamb Ice Stream	Peter Washam
3:40 pm	Retreat history from the western Ross Sea during the last deglaciation	Jacob Anderson
3:50 pm	Evidence of repeated West Antarctic Ice Sheet loss during late Pleistocene interglacials from Amundsen Sea IODP Expedition 379 drillcore	Reed Scherer
4:00 pm	How long was the LGM in Antarctica? Well it depends...	Ryan Venturelli
4:10 pm	Discussion	All

Poster Session: 4:30 pm – 5:30ish pm
Dinner: 5:30 pm – 6:45 pm
Post-dinner breakouts: 7:00 pm – 8:00 pm (locations TBD)

Wednesday, November 13

Upload your Wednesday presentation slides by 7 am here.

Breakfast: 7:30 am – 8:30 am

Session 6	En- and Subglacial Advances	Presenter
8:30 am	Observed Meltwater-Induced Flexure and Fracture at a Doline on George VI Ice Shelf, Antarctica	Alison Banwell
8:40 am	Can Partial Loss of Lateral Shear Cause an Ice Shelf to Collapse? A Case Study on Pine Island Glacier	Sarah Wells-Moran
8:50 am	Deep learning the flow law of Antarctic ice shelves	Yongji Wang
9:00 am	Impacts of Temperature- and Stress-Dependent Rheology on Ice-Shelf-Front Bending	Emily Glazer
9:10 am	Recent Fracture-Flow Variability on Thwaites Ice Shelf, West Antarctica	Shujie Wang

9:20 am	Von Mises Stress a Good Predictor of Fracture Initiation in Ice Slabs	Riley Culberg
9:30 am	Discussion	All

Refreshment Break: 10:00 am – 10:20 am

Session 7	Climate Change Communication	Presenter
10:20 am	Communicating about Climate Change and the West Antarctic Ice Sheet	Megan Ennes (invited)
10:50 am	Community Discussion	All

Session 8	WAIS in the Community	Presenter
11:30 am	Gear sharing for cryosphere scientists; an early career initiative supported by CryoCommunity	Marion McKenzie
11:40 am	Animating Antarctica, Motivating the World—harnessing today's most powerful creative medium in Antarctic outreach and science communication	Marlo Garnsworthy
11:50 am	Discussion	All

Lunch: 12:20 pm – 1:20 pm

Session 9	New Tech and FAIR Science	Presenter
1:20 pm	Quantarctica4: Looking beyond our own disciplines with an updated version of the interdisciplinary mapping tool for Antarctic research	Ben Hills
1:30 pm	Automatically Detecting Persistent Polynyas in the Thwaites Region using Geophysically Contextualized Deep Learning	Ellie Abrahams
1:40 pm	The Polar Rock Repository: a Unique Resource for Antarctic Cryosphere Research	Anne Grunow
1:50 pm	Changing our perspective of the polar coastal margins with the new NASA Surface Water and Ocean Topography (SWOT) mission	Tasha Snow
2:00 pm	Discussion	All

Refreshment Break and optional Florida Museum excursion: 2:30 pm – 4:00 pm
Poster Session : 4:00 pm – 5:30 pm (please break down your poster and easel after this session!)
Dinner: 6:00 pm – 8:00 pm at The Wooly (20 N. Main St. Gainesville, FL)

Thursday, November 14

Upload your Thursday presentation slides by 7 am here.

Breakfast: 7:30 am – 8:30 am

	Visions from the Future	Presenter
8:30 am	Early career report back	Marion McKenzie Julia Andreasen

Session 10	Observational & Modeling Gaps	Presenter
8:40 am	Passive Seismic Imaging of Subglacial Conditions on Thwaites Glacier	Paul Winberry

8:50 am	Stochastically Simulating Mass-Conserving Subglacial Topography: Estimating Topography Uncertainties from Sparse Radar Measurements	Niya Shao
9:00 am	Late Holocene emergence of the Rockefeller Mountains, Marie Byrd Land using in situ cosmogenic C-14	Jamey Stutz
9:10 am	Reanalysis Evaluation of Climatic Controls at Coastal WAIS Ice Rises	Julia Andreasen
9:20 am	Discussion	All

Refreshment Break: 10:00 am – 10:30 am

Session 11	**Where the ice and ocean meet**	**Presenter**
10:30 am	Probabilistic Gravity Inversion of Sub-ice-shelf Bathymetry in West Antarctica using Markov Chain Monte Carlo for Improved Uncertainty Quantification	Michael Field
10:40 am	Two new 150m ice cores and ground geophysics at Canisteo Peninsula, Amundsen Sea, West Antarctica: successful first fieldwork for the Ross-Amundsen Ice Core Array (RAICA) initiative	Peter Neff
10:50 am	West Antarctic glacier retreat triggered by polynya response to meridional winds	Gemma O'Connor
11:00 am	Surface Momentum Transfer in Sea-Ice Covered Regions: Floe-Scale Dynamics	Rohaiz Haris
11:10 am	Whillans Ice Plain Stick-Slip Motion and Slowdown Varies at Long-Period Tidal Frequencies	Zachary Katz
11:20 am	Discussion	All

11:50 am	Wrap up	WAIS Workshop Committee

Lunch: 12:00 pm to 1:00 pm

Afternoon Workshops: 1:00 pm – 4:00ish pm

- *Data and DAACs: What to expect when you need to post or access data*
- *WAIS Workshop Proceedings: Computational notebooks as a platform to publish interactive, open-access articles from the WAIS Workshop*

Posters

Title	Presenter
Antarctic Ice Sheet development during the Miocene: paleoceanographic insights from east of New Zealand	Imogen Browne
"The Effect of Inclusion Geometry on the Polarimetric, Reflectivity, and Attenuation Signatures of Englacial Water in Ice Penetrating Radar Data	Annie Cheng
Exploring interactions between ice sheets and sea level change using a newly coupled ice sheet (PISM) - GIA model	Sam Chester
Updating Antarctic Snow Accumulation Estimates: A Comparative Analysis of GPS-IR Data from L1 and L2 Frequencies	Maile Corso
Ice properties and dynamics inferred with polarized radar sounding in an airborne survey near the South Pole	Lucas Holt
A comparison of the effects of rheology on crack propagation along ice shelves using phase-field techniques.	Kris Houdyshell
Blank space: Revisiting uncertainties for Ramped PyrOx radiocarbon ages of Antarctic marine sediments	Theresa King
Inferring ice-rise rheology using physics-informed neural networks	George Lu
New Antarctic sub-ice-shelf bathymetry estimates derived from Markov chain Monte Carlo gravity inversions	Emma MacKie
Joint Interpretation of Radar and Seismic Imaging for Constraining Subglacial Conditions Across the Eastern Shear Margin of Thwaites Glacier	Daniel May
Mixed Diatom Assemblages and the History of Ice: Ross Bank, Antarctica	Rachel Meyne
"Quantifying subglacial groundwater exfiltration in West Antarctica since the Last Deglaciation	Ellie Miller
Quantifying erroneous age of bulk AIOM radiocarbon dates in Southern Ocean surface sediment samples	Joseph Ruggiero
A hierarchy of ICESat-2 land ice data products for accelerating science with satellite laser altimetry	Matthew Siegfried
CryoCloud: Harnessing open science and cloud computing to accelerate cryosphere research	Tasha Snow
Not Your Average Berg: Development of a Coupled Mélange/Ocean Model	Paul Summers
Using Diatom Analysis to Pinpoint Antarctic Ice Sheet Extent and Dynamics in the Pennell Basin During Pleistocene-Holocene	Magkena Szemak
Subglacial conditions in an ice-stream/pinning-point system estimated from unsupervised clustering analysis of bed-echo waveform structure	Hannah Verboncoeur
Geomorphology and seismic-stratigraphic framework of Ross Bank Ice Rise Rim Moraines	William Weber

Automatically Detecting Persistent Polynyas in the Thwaites Region using Geophysically Contextualized Deep Learning

Dr Ellianna Abrahams[1], Dr Tasha Snow[2], Eojin Lee[3], Michael Field[4], Dr Karen Alley[5], Dr Stéfan van der Walt[6], Dr Fernando Pérez[6], Dr Matthew Siegfried[7]
[1]Stanford University, [2]NASA Goddard Space Flight Center, [3]Columbia University, [4]University of Florida, [5]University of Manitoba, [6]University of California, Berkeley, [7]Colorado School of Mines

Persistent sensible heat polynyas, coastal open water areas surrounded by sea ice that form from warm meltwater plumes annually in the same location, occur at many of the ice shelf fronts around the eastern Amundsen Sea, West Antarctica, and are detectable in visible and thermal satellite imagery. Observing these features at the surface can provide crucial information about the subsurface ice-ocean interactions that lead to their formation. However, persistent polynyas are challenging to detect automatically since existing labeled data for training is sparse and other areas of open water have similar spectral signatures in satellite imagery. Furthermore, these polynyas represent a small fraction (in Landsat, 103 pixels) of the overall scene (107 pixels), limiting the ability of traditional machine learning approaches in the case of high (<1% of all pixels) class imbalance. We present a novel approach for injecting geophysical context, derived from persistent polynya formation, into the detection pipeline to improve automated detection. We trained our new algorithm on Landsat 8 imagery and then searched 403 Landsat 8 and 9 scenes from 2013 to 2023 for coastal polynyas in the Amundsen Sea region of Antarctica. We filtered candidates for polynyas that reoccur within the same 3 km radius at least three times in the 11-year record, and validated the outcomes by hand. We demonstrate that this approach improves the accuracy of polynya detection, recovering all previously characterized polynyas in the region as well as uncovering new candidate persistent polynyas. We used thresholding techniques to generate time series of recurrence and extent. We found a median occurrence of 9 polynyas open each year, with the fewest open polynyas in 2020 (N = 5) and 2022 (N = 4) and the most open polynyas in 2014 (N = 13) and 2023 (N = 13). We show relationships between variability of the polynyas (e.g., occurrence, area) with potential regional drivers (e.g., ocean temperature, climate indices, freshwater outflow), highlighting the potential for using machine learning built for remote sensing to address critical gaps in our understanding of ice-ocean processes.

Retreat history from the western Ross Sea during the last deglaciation

Dr Jacob Anderson[1]
[1]Lamont-Doherty Earth Observatory, Columbia University

Comprehensive deglaciation chronologies of the marine-based ice sheet in the Ross Embayment are required to improve the accuracy of ice sheet models. Currently geological constraints are fragmented, limiting our ability to effectively assess ice sheet behaviour during the last deglaciation. New 10Be exposure ages from Mount Discovery in the western Ross Sea, will provide a complete record of timing and rate of retreat from the onset of deglaciation to the transition to a floating ice shelf. These data will provide a benchmark for ice sheet model-data comparisons, improving our understanding of marine-based ice sheet processes and provide context for contemporary retreat rates.

Effect of Weather Events on Antarctic Ice Shelf GNSS Reflected Signal Coherence

Sophie Anderson[1], Dr Jade Morton[1], Dr Kenneth Jezek[2], Dr Joel Johnson[2]
[1]University of Colorado Boulder, [2]The Ohio State University

This study investigates the potential utility of reflected Global Navigation Satellite System (GNSS) signals for remote sensing of storms and melt events on Antarctic ice shelves. The spaceborne GNSS-Reflectometry (GNSS-R) method uses a constellation of satellites in low-Earth orbit (LEO) to capture GNSS signals after they reflect off Earth's surface; the power and phase of these reflected signals can be processed to obtain geophysical information about the reflection location. Our previous work has demonstrated that the GNSS signal carrier phase coherence of Spire Global Inc. grazing angle GNSS-R data is related to the surface topography, deformation, and roughness of the Antarctic Ice Sheet and ice shelves, as smoother, less deformed areas scatter the signal more coherently. For the Ross Ice Shelf specifically, coherence has been shown to be quantitatively correlated with centimeter-to-meter-level surface roughness, defined as the standard deviation of surface height. Weather conditions, such as snow or rainfall, near surface wind patterns, and ice surface melting, are expected to impact the surface roughness and density of the top layer of the ice shelf and are likely to be visible in the GNSS-R coherence data as a result.

Surface roughness is itself a key parameter for evaluating the stability and mass balance of ice shelves, but given the outsized impact that extreme weather events have on Antarctic ice shelves, GNSS-R could be an even more impactful tool if it is demonstrated to be useful for sensing weather-related changes to the ice shelf surface. A large-scale analysis of precipitation events between 1979 and 2016 revealed that, for many Antarctic ice shelves, the storms with the largest 10% of daily total precipitation make up more than half of the annual precipitation (J. Turner et al., "The Dominant Role of Extreme Precipitation Events in Antarctic Snowfall Variability," Geophysical Research Letters, 2019.). In addition, atmospheric river events associated with extreme temperature swings, surface melt, sea-ice disintegration, large swells, and rainfall preceded more than 60% of the major calving events on the Larsen ice shelves between 2000 and 2020 (J. D. Wille et al., "Intense atmospheric rivers can weaken ice shelf stability at the Antarctic Peninsula," Communications Earth & Environment, 2022.). We examine the GNSS-R carrier phase coherence of several ice shelves before and after individual storm and melt events to understand if the impact of weather on the surface is measurable with GNSS-R data. GNSS-R is a new method for ice shelf research, and its high spatial and temporal resolution can complement existing and planned sensors such as NISAR and CryoRad. This work is the first step to determine if GNSS-R data can be applied to detect the short-term impact of weather conditions on ice shelf evolution.

Reanalysis Evaluation of Climatic Controls at Coastal WAIS Ice Rises

Julia Andreasen[1], Dr Peter Neff[1]
[1]Department of Soil, Water, Climate, University of Minnesota

The coastal margin of the West Antarctic Ice Sheet (WAIS) is a dynamic and critical region where ice, ocean, and atmosphere converge. Persistent regional ice loss is of global concern for sea level rise. Despite its importance, direct climate observations along coastal WAIS are extremely limited. Ice core records are largely unavailable along the coast from the Ross Sea to the Amundsen Sea, restricting observational surface mass balance constraints to the continent's inland regions. To address this gap, we utilize reanalysis datasets as well as air mass back trajectories to assess the climate controls on snowfall at ice rises along the WAIS coast– features which are ideal locations for ice core recovery and paleoclimate reconstructions.

Precipitation at these sites is driven by a range of interrelated factors, including atmospheric pressure anomalies, westerly wind strength, atmospheric rivers, and additional Pacific and Southern Hemisphere climate indices. We investigate the climatology of these ice rises using the following ERA5 and MERRA-2 reanalysis variables: temperature, precipitation, wind direction and speed, geopotential height, sea surface temperature, and sea ice concentration, as well as RACMO temperature and precipitation data. Broad area averages of these variables are correlated with localized precipitation at each ice rise to determine which locations best reconstruct westerly winds, El Niño Southern-Oscillation, Southern Annular Mode, Amundsen Sea Low, and other relevant parameters. Additionally, we use HYSPLIT to calculate meteorological cluster means of 10-day back trajectories from 2001-2021, determining the moisture source region of annual and seasonal snowfall arriving at each site. These data reveal stronger westerly wind correlations and ENSO correlations at more western WAIS ice rises (coastal Marie Byrd Land), stronger Bellingshausen Sea high pressure correlations at eastern WAIS ice rises (coastal Ellsworth Land), and the best reconstruction of Thwaites climate at mid-coast ice rises. Understanding likely climate controls on snowfall at WAIS ice rises can guide future siting of ice cores collected under the international Ross-Amundsen Ice Core Array (RAICA) effort, selecting locations that capture the range of climate forcings relevant to ongoing ice-ocean-atmosphere change along this coastline.

Observed Meltwater-Induced Flexure and Fracture at a Doline on George VI Ice Shelf, Antarctica

Dr Alison Banwell[1], Dr Laura Stevens[2], Dr Ian Willis[3], Dr Rebecca Dell[3], Dr Douglas MacAyeal[4]
[1]CIRES, University of Colorado Boulder, [2]University of Oxford, [3]University of Cambridge, [4]University of Chicago

Global Navigation Satellite System (GNSS) observations and ground-based timelapse photography obtained over the record-high 2019/2020 melt season are combined to characterize the flexure and fracture behavior of a previously formed doline on George VI Ice Shelf, Antarctic Peninsula. The GNSS timeseries shows a downward vertical displacement of the doline center with respect to the doline rim of ~60 cm in response to loading from a central meltwater lake. The GNSS data also show a tens-of-days episode of rapid-onset, exponentially decaying horizontal displacement, where the horizontal distance between the doline rim and its center increases by ~70 cm. We interpret this event as the initiation and/or widening of a fracture, aided by stress perturbations associated with meltwater loading in the doline basin. These observations, together with our timelapse photos of circular fractures around the doline, suggests the first such documentation of meltwater-loading-induced ‘ring fracture’ formation on an ice shelf, equivalent to the fracture type proposed as part of the chain-reaction lake drainage process involved in the 2002 breakup of the Larsen B Ice Shelf.

Antarctic Ice Sheet development during the Miocene: paleoceanographic insights from east of New Zealand

Dr Imogen Browne[1], Dr Molly Patterson[1], Ms Thea Barbelet[1], Ms Gretl King[1], Dr Adriane Lam[1], Dr Melissa Berke[2], Mr Jared Nirenberg[3], Dr Georgia Grant[4], Dr Greg Browne[4], Dr Rob McKay[5], Dr Bella Duncan[5], Dr Denise Kulhanek[1,6]
[1]Binghamton University, [2]University of Notre Dame, [3]Brown University, [4]Institute of Geological and Nuclear Sciences, [5]Victoria University of Wellington, [6]Christian-Albrechts University of Kiel

The Early to Middle Miocene (23-11.6 Ma) is of interest to climate scientists as it encompasses both the Miocene Climatic Optimum (MCO; ~17-14.7 Ma), the warmest interval of the Neogene, and the Middle Miocene Climatic Transition (MMCT; ~14.7-14 Ma), a major interval of global cooling and growth of Antarctica's ice sheets. Global ocean circulation also underwent major changes during the Early to Middle Miocene, including a permanent cooling of surface to deep ocean temperatures, and intensification of deep water formation around Antarctica. A well-dated drift deposit at Ocean Drilling Program (ODP) Site 1123 located at 3290 m depth on the Chatham Rise, east of New Zealand lies in the pathway of a deep Western Boundary Current (WBC) which flows along the continental rise. A grain size record from Site 1123 has been used to reconstruct orbitally paced (41 kyr) changes in the intensity of the deep WBC from 15.5-14.7 Ma and 14.4-12.5 Ma (Hall et al., 2003). Inferred changes in current strength including maximum intensity and erosion from 14.7-14.4 Ma reflect regional oceanographic changes related to growth of Antarctica's ice sheets and intensification of deep water formation. Here we constrain the long-term evolution of sedimentary and oceanographic processes at Site 1123 from ~20.5-14.6 Ma and ~14.4-13.7 Ma by combining existing physical property, grain size, and carbonate data with new x-ray fluorescence (XRF) scanning data and cyclostratigraphic analyses. We demonstrate changes in depositional processes on million-year timescales that reflect changes in regional tectonics, volcanic activity, and intensity of the deep WBC east of Chatham Rise. Variability in physical properties and XRF elemental data on glacial/interglacial timescales may reflect regional oceanographic changes related to orbitally paced variability of Antarctica's ice sheets and deep ocean circulation. This study provides insight into tectonic and geologic processes occurring in New Zealand during the Early to Middle Miocene and provides perspective on how Southern Ocean circulation, which ventilates the global ocean and influences global climate, may have changed in the past.

Thwaites Glacier thins and retreats fastest where ice-shelf channels intersect its grounding zone

Dr Allison Chartrand[1,2], Dr Ian Howat[3], Dr Ian Joughin[4], Dr Benjamin Smith[4]
[1]University of Maryland, [2]NASA Goddard Space Flight Center, [3]Ohio State University, [4]University of Washington

Antarctic ice shelves buttress the flow of the ice sheet but are vulnerable to increased basal melting from contact with a warming ocean and increased mass loss from calving due to changing flow patterns. Channels and similar features at the bases of ice shelves have been linked to enhanced basal melting and observed to intersect the grounding zone, where the greatest melt rates are often observed. The ice shelf of Thwaites Glacier is especially vulnerable to basal melt and grounding-zone retreat because the glacier has a retrograde bed leading to a deep trough below the grounded ice sheet. We use digital surface models from 2010–2022 to investigate the evolution of its ice-shelf channels, grounding zone position, and the interactions between them. We find that the highest sustained rates of grounding-zone retreat (up to 0.7 km yr^{-1}) are associated with high basal melt rates (up to ~250 m yr^{-1}) and are found where ice-shelf channels intersect the grounding zone, especially atop steep local retrograde slopes where subglacial channel discharge is expected. We find no areas with sustained grounding zone advance, although some secular retreat was distal from ice-shelf channels. Pinpointing other locations with similar risk factors could focus assessments of vulnerability to grounding zone retreat.

The Effect of Inclusion Geometry on the Polarimetric, Reflectivity, and Attenuation Signatures of Englacial Water in Ice Penetrating Radar Data

Annie Cheng[1], Dr Dustin Schroeder[1], Dr Natalie Wolfenbarger[1], Ms Riley Shaper[1]
[1]Stanford University

Ice penetrating radar has been widely used in the past five decades to study the thickness, internal structure, and beds of ice sheets. However, the presence of liquid melt within ice, for example, in regions of englacial water and temperate ice across Antarctica and Greenland, can drastically change radar reflectivity and attenuation measurements. Here, we explore how the shape and orientation of melt inclusions in ice can confound the interpretation of polarimetric radar sounding data. Using effective medium theory to find the bulk electrical permittivity of ice with melt, we calculate anisotropic permittivity tensors that result in polarization-dependent reflectivity and attenuation. Furthermore, we show how ice-water interfaces containing the same volume fraction of melt are found to produce drastically different signals depending on their shape and orientation. We further discuss how radar polarimetry can serve as an avenue to reduce ambiguities introduced by the shape and orientation of melt inclusions in ice.

Exploring interactions between ice sheets and sea level change using a newly coupled ice sheet (PISM) - GIA model

Mr. Sam Chester[1], Dr. Jacqueline Austermann[1], Dr. Torsten Albrecht[2]
[1]Columbia University, [2]Potsdam Institute for Climate Impact Research

Ice sheets are highly sensitive to changes in local topography and relative sea level. Over glacial cycles, sea level variations are primarily controlled by ice volume changes and glacial isostatic adjustment (GIA), which is the response of the Earth's solid surface, gravity field, and rotational axis due to changes in ice and ocean load. As ice sheets grow and shrink they change the local topography and gravity field both of which modulate relative sea level. Such effects can result in critical feedbacks between GIA and ice sheet dynamics, notably the possible stabilization of the grounding line during ice mass loss (Gomez, 2010). Typically, thermomechanical ice sheet models approximate the effects of GIA by modeling only certain processes, e.g. local bed deformation, and/or accounting for only local GIA rather than global effects. Recent work has focused on coupling ice sheet models to more comprehensive models of GIA to better understand ice sheet stability over past glacial cycles and under future anthropogenic climate change. However, the coupling of these two systems presents practical and computational challenges and requires modelers to make critical assumptions that may influence their results. Here, we develop a new coupled model and explore a range of coupling schemes to further understand how these modeling decisions influence the predicted dynamics and ultimately our understanding of ice sheet-sea level interaction. We couple a widely used GIA model with the open-source, thermomechanical Parallel Ice Sheet Model (PISM). The GIA model solves the 'sea level equation', assumes a 1D maxwell viscoelastic Earth structure and accounts for rotational feedbacks (Kendall et al., 2005). We experiment with a range of coupling approaches inspired by previously published methods and directly compare the results to illustrate the influence of the coupling assumptions. We also explore the influence of the coupling time step and particularly the relationship between the coupling timestep and the maxwell time of the mantle in the GIA model. Our results shed light on the different assumptions used in previous studies and help future modelers make informed decisions when coupling these complex systems.

Using subglacial lake genomes to uncover the origin and evolution of microbes beneath West Antarctic Ice Sheet

Dr Brent Christner[1], Christina Davis[1], Kyuin Hwang[2], Ok-Sun Kim[2], Amanda Achberger[3], John Priscu[4]
[1]University of Florida, [2]Korea Polar Research Institute, [3]Texas A & M, [4]Montana State University

Siple Coast ice streams are underlain by water-saturated sediments and lakes fed by a hydrological network beneath West Antarctic Ice Sheet (WAIS). Two lakes in this region [Whillans Subglacial Lake (SLW) and Mercer Subglacial Lake (SLM)] have recently been drilled into and sampled using environmentally clean hot water drilling techniques. The physical, biogeochemical, and microbiological measurements from SLW and SLM support a proposition for chemosynthetic ecosystems in which the major pathways of new carbon assimilation may be supported by chemoautotrophy and the oxidation of methane sourced from their sediments. Most of the abundant taxa in SLW and SLM are phylogenetically related and distinct from those observed in marine waters beneath Ross Ice Shelf, implying the existence of a hydrologically linked subglacial biome beneath WAIS. Analyzing the genomic features of microbes from SLM's water column and sediments allowed us to identify key metabolic pathways used in the subglacial ecosystem, as well as examine the evolutionary relatedness of their genomes to known species. We found that lineages from SLM evolutionary grouped to the exclusion of microbial genomes from other sources and possessed genes with low similarity to known proteins. Though accurately dating the evolutionary timescale between the genomes of subglacial taxa and their nearest neighbors is challenging, the high levels of divergence observed would not be expected if complete WAIS collapse occurred during the last interglacial period (i.e., Lau et al. 2023, Science, 382:1384-89). Our results provide new insight on the metabolic capabilities and evolution of microbial populations that are isolated within the cold, low energy conditions of the deep Antarctic cryosphere.

Updating Antarctic Snow Accumulation Estimates: A Comparative Analysis of GPS-IR Data from L1 and L2 Frequencies

Maile Corso[1], Matthew Siegfried, Zachary Katz, Hannah Verboncoeur, Marianna Marquardt
[1]Colorado School of Mines

Quantifying surface mass balance in Antarctica is challenging due to the large spatial scales and difficult logistics of continuous monitoring with ground instruments. Global navigation satellite system interferometric reflectometry (GNSS-IR) offers a method for monitoring snow accumulation with high temporal sampling, while also providing spatial scales suitable for validating satellite remote sensing data and climate reanalysis products. This technique uses signal to noise ratio recorded by the receiver to estimate the height of the GNSS antenna above the snow surface (the reflector height), which generates a time series of snow accumulation as reflector height decreases. Previous studies in Antarctica have largely only used Global Positioning System (GPS) L1 frequency (1575.42 MHz) for estimating reflector height from multipath signals and demonstrated that GNSS-IR L1-estimates have sub-decimeter precision at daily resolution. However, additional frequencies and constellations exist that may improve both accuracy and precision of GNSS-IR retrievals. Here, we reprocess 40 GNSS stations from West Antarctica with combined L1 and L2 (1227.60 MHz). The results are compared to in situ measurements of reflector height to assess uncertainty improvements from multi-frequency GNSS-IR retrievals to better quantify time series of snow accumulation and surface mass balance.

Widespread Antarctic change during the 8.2 ka event

Dr. Roger Creel[1], Dr. Ryan Venturelli[2]
[1]Woods Hole Oceanographic Institution, [2]Colorado School of Mines

Past Antarctic Ice Sheet (AIS) thinning rates and contribution to global mean sea level (GMSL) yield critical information about future AIS vulnerability to abrupt forcing. The response of AIS to an abrupt climate event ~8200 years ago, when Laurentide Ice Sheet (LIS) collapse and a proglacial lake outburst together slowed overturning circulation, remains unknown. Combining three decades of exposure age and marine sedimentary data with a novel AIS volume estimate, we show that rapid AIS thinning and Antarctica's largest Holocene GMSL contribution occurred at 8.5-8 ka, coincident with circumpolar deep water penetrating the Antarctic shelf. Our results underscore how fast the AIS can respond to Northern Hemispheric forcing and suggest that ongoing and future Greenland melt will likely accelerate Antarctic thinning.

Von Mises Stress a Good Predictor of Fracture Initiation in Ice Slabs

Dr. Riley Culberg[1], Dr. Ching-Yao Lai[2], Dr. Emma Mackie[3]
[1]Cornell University, [2]Stanford University, [3]University of Florida

Surface crevasses promote calving, alter bulk ice rheology, transport surface meltwater, and modulate the surface energy balance. Therefore, constraining the spatial distribution of fractures and the conditions under which they form is important for understanding current and future ice sheet mass balance. However, fracture mapping is challenging due to the wide range of spatial scales involved (from cm-wide fractures to crevasse fields tens of kms in extent) and a single, generally applicable value for the bulk tensile strength of ice at the field scale remains elusive. Here, we use Greenland's ice slabs to study fracture initiation, with the goal of predicting large-scale spatial patterns of crevassing. Ice slabs are a good natural laboratory because these low stress regions are likely near the limit where fractures first form and even narrow crevasses are observable during the summer once the winter snow melts off.
We first manually delineate surface crevasses in ice slabs using ~11,000 km^2 of 0.5 m resolution WorldView imagery collected during the summer of 2012. We then derive the surface von Mises stress from satellite ice velocity maps and train a logistic regression model to predict the observed fracture zones. In the process, we quantify which methods for calculating stresses lead to the highest agreement between observed and predicted fracture zones. Our model predicts an effective tensile strength for ice slabs between 94.1-117.3 kPa and effectively discriminates between fractured and unfractured zones with a regionally cross-validated F1 score of 0.825±0.001, demonstrating that the von Mises stress is spatially robust predictor of fracture initiation in Greenland. We then apply the trained model to the full Greenland Ice Sheet ice slab area and quantify uncertainty by producing an ensemble of predicted fracture zone maps that consider uncertainty in surface temperatures, ice viscosity, and ice velocity. Our model predicts that ice slab fracture initiation zones are widespread in marine-terminating sectors but much rarer in land-terminating sectors, implying large regional differences in the propensity for high-elevation surface-to-bed meltwater drainage across Greenland. In the future, these methods could be applied to other regions, including Antarctica ice shelves, to better assess present and future fracture vulnerability.

Animating Antarctica, Motivating the World—harnessing today's most powerful creative medium in Antarctic outreach and science communication

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With a constant barrage of media at our fingertips and many pressing global and local issues ever competing for attention, capturing policymakers/stakeholders, the general public, educators, and young people with easily understood, scientifically accurate, and engaging information is particularly challenging. Retaining the attention of an overwhelmed, media-saturated populace and spurring them into action is even more difficult. But in looking at the success of video-friendly social media platforms, viral videos, and memorable public service announcements, it's hard to disagree that, in 2024, no medium has as much power and as broad a reach as short-form video. This medium can be experienced easily, immediately, and repeatedly. An engaging video is rapidly disseminated around the world, can be used in multiple situations (such as educational settings), and endures in minds and hearts.

We—an author/illustrator and a software engineer, both of us science communicators—examine how we combine scientific data, art, poetry/writing, animation, and music to create compelling videos and other materials that can be shared on social media, used in educational and outreach settings, and simply enjoyed. We share our creative and technical process for three animations we produced for the documentary film The Lake at the Bottom of the World, other creative polar science communication projects, and our work-in-progress for the SWAIS2C project and beyond. This presentation provides concrete examples of our visual storytelling, data visualization, animation, and videography that we have used successfully to inform and engage broad audiences with Antarctic issues.

Impacts of Temperature- and Stress-Dependent Rheology on Ice-Shelf-Front Bending

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Classical treatments of ice-shelf bending suggest that shelf fronts should bend downwards, due to the distribution of hydrostatic water pressure at the front. However, there are several observed instances in lidar data of upward-bending ice-shelf fronts. While this phenomenon has often been attributed to a buoyant force created by a submerged ice bench, recent work suggests that vertical variations in viscosity within the ice shelf, caused by a temperature gradient, can induce an internal bending moment that causes the shelf front to bend upwards, even in the absence of a bench.

To investigate this novel bending mechanism, we present the first two-dimensional, viscoelastic models of ice-shelf-front bending with depth-varying rheology. Our results confirm the thin-plate analytic prediction that an ice-shelf front can bend upwards with a sufficiently cold surface temperature and a sufficiently high ratio of activation energy to flow-law exponent. The results also demonstrate that the evolution of the flexural wavelength over time is consistent with analytic approximations of viscous bending. The relationship between the edge deflection amplitude and the flexural wavelength closely matches that of the thin-plate prediction, until higher deflection amplitudes are reached, at which point uplift starts to outpace what is predicted by the analytics. These deviations are attributed to two-dimensional effects related to faster lateral flow of warm ice near the base of the shelf.

Model results also demonstrate that the internal moment mechanism produces uplift with a shorter flexural wavelength than the submerged bench mechanism, and a stronger dependence of uplift amplitude on ice thickness. These differences can be leveraged to discern between causal mechanisms of the upward bending seen in lidar data, which we illustrate with an example from the Ross Ice Shelf front. This upward-bending ice front has a wavelength more closely resembling what is expected from the internal moment mechanism. This fact, coupled with the cold surface temperatures at Ross and the lack of a visible submerged ice bench, imply that an internal bending moment is likely responsible for uplift in that region. We also illustrate how comparing model results with data offers a way to constrain the parameters describing ice rheology.

The Polar Rock Repository: a Unique Resource for Antarctic Cryosphere Research

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While Antarctica offers many opportunities to study cryosphere processes, its location provides challenges in terms of logistical accessibility and environmental impacts. Use of existing samples from remote outcrops offers scientists the ability to expand the scientific and geographic scope of their research. The Polar Rock Repository (PRR) was created by the NSF Office of Polar Programs to preserve and freely provide access to rock, terrestrial core, unconsolidated till/soil, and marine dredge samples from Antarctica and the Southern Ocean for scientific research. The PRR contains sample collections and media that are relevant to understanding changes in the Antarctic Ice Sheet. More than 63,000 samples are available online in the PRR database for research use. PRR samples can be requested from the website for analyses involving destructive techniques (the website has tutorials and easy online ordering features).

The PRR has also created a media archive of over 6,000 images (with some images dating back over 60 years) that can provide glaciological, geological, and logistical information as well as provide a record of temporal change associated with surface features (snow cover, ponds, icebergs, streams, etc.). The PRR has added geochemical data associated with PRR samples to the PetDB catalogue to make polar information more accessible through community online databases, facilitate global correlations, and potentially reduce redundant analytical costs.

By making geological materials and metadata available to the cryosphere community, the PRR represents an important resource for helping to answer key questions involving ice sheet-ocean interactions. Multi-field searchable criteria that may be important to the cryosphere community include: (1) Subglacial precipitates; (2) Pedogenic calcite – weathering salts; (3) Coral/marine invertebrates and plants on dredge clasts; (4) Lichen, cyanobacteria and soil residues; (5) Fe-Mn nodules and crusts; (6) Fe-oxide surface coatings; (7) Glacial surface features; (8) Glacial erratics ; (9) Media of outcrops and landscapes.

Multiple publications from high-impact journals have used samples and data from the PRR in recent years for studies addressing climate related questions:

- Millennial scale climate cycles in the East Antarctic ice sheet since the Pleistocene have been documented using U-series methods on subglacial precipitates.
- Provenance studies using PRR samples, in conjunction with IODP cores, suggest a large West Antarctic Ice Sheet can explain early Neogene sea-level oscillations.
- Magmatic dynamics and eruption forecasting from PRR volcanic samples at Deception Island, one of the most active volcanoes in Antarctica.
- Carbon isotopic composition for evaluation of δ13Corg excursions in paleo-atmospheric reconstruction.

Surface Momentum Transfer in Sea-Ice Covered Regions: Floe-Scale Dynamics

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In polar regions, sea ice plays an important role in constraining the ocean's surface momentum budget by mediating kinetic energy transfer between the atmosphere and the ocean. Climate models typically represent sea ice as a continuum, which does not resolve the interactions between individual pieces of ice (floes) and may bias momentum transfer to the ocean. These ice-ocean interactions are particularly relevant for polar boundary currents, such as the Antarctic Slope Current, the East Greenland Current and the Antarctic Coastal Current which mitigate the transport of heat towards marine terminating glaciers and ice shelf cavities.

Here, we use a discrete element model of sea ice, SubZero, to investigate how floes influence the bulk rheological properties of a granular sea ice cover. We conduct simulations with SubZero in a channel configuration, forced by prescribed meridional ocean shear, to determine how sea ice concentration and floe-size distributions affect the shear stress sustained by the pack. A more rigid ice pack, resulting from larger floes or a higher pack concentration, prevents sea ice deformation and helps with the lateral transfer of momentum across the sea ice cover. We interpret the shear strength of the pack as a bulk shear viscosity coefficient, which linearly relates the shear stress and strain rate. The shear viscosity increases with floe size and sea ice concentration up to a limit corresponding to a fully packed field. On the other hand, smaller floes are more prone to breakage, which further diminishes their ability to sustain a shear stress. We also analyze perturbation kinetic energy as an indicator of how individual floes deviate from the mean sea ice pack motion. This energy increases with sea ice concentration up to 90%, but decreases sharply beyond this point due to the more rigid pack dampening both linear and rotational perturbations of individual floes.

We also show preliminary results in simulations that couple the sea ice floe model to a non-hydrostatic ocean model. This approach allows us to capture complex feedback mechanisms between the atmosphere, sea ice and ocean occuring at the kilometer scale. Comparisons with a traditional visco-plastic sea ice model (Gonzalez de Diego et al. 2024) suggest that floe-size dependency in momentum transfer is not appropriately captured by this continuum model, motivating the need to develop better representations of the granular sea ice regime within global climate models.

The Influence of Bed Topography on Water Column Mixing and Ice-Ocean Interactions at Erebus Glacier Tongue, Antarctica

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Marine-terminating glaciers connect grounded ice sheets to the ocean, where the ice then interacts with water of varying hydrographic properties based on circulation processes occurring over a range of spatial and temporal scales. Here, we discuss data gathered with the remotely operated vehicle Icefin from beneath Erebus Glacier Tongue (EGT) in McMurdo Sound, Antarctica that show how regional ocean circulation interacts with local seafloor topography to drive spatially variable melting along the glacier underside. Our measurements reveal that a large-scale subglacial ridge ~30-50 m tall runs nearly flow-parallel down the central axis of the tongue and inhibits under-ice circulation, thus creating distinct water properties on either side of the ridge. Both sides of the subglacial cavity demonstrate mixing between High Salinity Shelf Water (HSSW) and Glacial Meltwater (GMW), but the HSSW on the northern side of the ridge is colder and saltier, with lower dissolved oxygen (DO) concentrations. The southern side has better exposure to McMurdo Sound and is ventilated more easily, which allows DO that is taken up through biological activity to be replenished and explains this lateral trend. Melt rates throughout the southern side of the cavity are between 1.31-1.62 m/yr, with a maximum GMW concentration of 0.236 mL/L. Although no melt rate calculations are available on the northern side, the maximum GMW concentration is 0.195 mL/L. If GMW builds up over time and newly-formed HSSW is less easily advected beneath glacier, this could eventually slow the melt rate. Near the grounding line, where the ice and seafloor are in proximity, lower DO concentrations are again observed due to poor ventilation. Here, the bed leaves its mark directly on the ice, where a small angular ridge a few meters wide extending from the grounding line creates a tunnel in the ice above it, preserving the previously grounded shape while melting. In this area, the melt features overlay imprints from the seabed, changing the texture of the ice compared to other areas of the glacier. These findings demonstrate that oceanic melt can take advantage of pre-existing imprints on the ice by the seafloor and impact the resulting morphology of melt features.

Refocusing on Radiostratigraphy: Novel Processing of Radar Sounding Data for New Insight into Ice Dynamics and Ice-Sheet History

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Englacial layers are a product of historic accumulation and are reshaped by ice deformation. Hence, radio-echo sounding (RES), which can resolve englacial layering, has gained broad adoption as an observational tool to infer ice age and/or ice dynamics from ice stratigraphy. However, the resolved stratigraphy in radar images is not always continuous, which then prevents the conventional interpretation of ice-sheet processes and history. For example, stratigraphy can be disrupted by fractures, unconformities, or power losses associated with either birefringence or steeply dipping layers. Rather than perceiving the stratigraphic disruptions as a data obstruction, we aim to investigate the underlying processes that drive disruptions and then interpret them as a signal, leveraging them to interpret ice properties and physical processes. Here, we focus on two types of layer disruptions, birefringent and layer-dipping losses. Birefringent losses are driven by anisotropy in the ice column, with a polarized wave rotating in and out of view of the receive antenna in a predictable way. Layer-dipping losses are generally a synthetic-aperture processing artifact, with destructive interference between traces. Since both anisotropy and layer dip are associated with the ice dynamic history, extracting them as a signal and comparing with the present-day surface velocity allows us to infer how ice flow has changed. We use these techniques along two flowline transects at Cook Glacier, which drains much of the Wilkes Subglacial Basin, East Antarctica—a basin as large as the West Antarctic Ice Sheet potentially susceptible to similar marine ice-sheet instabilities.

Quantarctica4: Looking beyond our own disciplines with an updated version of the interdisciplinary mapping tool for Antarctic research

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Quantarctica is a comprehensive data package developed by the Norwegian Polar Institute for use with QGIS, an open source GIS software, and will soon be available as a new updated version, Quantarctica4. It provides a wide range of Antarctic geospatial data suitable for research and teaching purposes. The package includes high-resolution satellite images, topographic maps and various scientific datasets covering geophysical, geological, glaciological and climatological aspects of Antarctica. It also includes administrative boundaries, including protected areas, and logistical information such as research station locations. Quantarctica datasets are freely available for download and are provided in standard GIS formats such as shapefiles and GeoTIFFs, making them accessible and easy to use. The package is highly customizable, allowing users to add their own data to suit specific research needs. Supported by a community acting as theme editors and developers, the Norwegian Polar Institute offers workshops, most recently at the SCAR Open Science Conference (Chile), and documentation to help users to effectively utilize the package. We will present the latest update with new datasets and improvements. Overall, Quantarctica4 is a valuable resource for anyone involved in Antarctic research or education, providing a comprehensive and easy-to-use collection of geospatial data.

Ice properties and dynamics inferred with polarized radar sounding in an airborne survey near the South Pole

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Radar polarimetry is a useful sounding technique in glaciological research because of its sensitivity to glacier anisotropy. Individual ice crystals are electrically anisotropic, and when the crystals are brought into alignment by ice flow, they create a bulk anisotropy in the glacier. By comparing the speeds of radar waves with different polarizations, we can therefore extract information about ice properties and a history of ice flow. By characterizing differences in ice crystal alignment, we may uncover historical and contemporary ice flow patterns, providing insights into the dynamic behavior of the Antarctic ice sheet. Radar polarimetry not only deepens our quantification of glaciological processes, but also contributes to evolving models of ice sheet dynamics in a warming world. Much of the Antarctic ice sheet has been surveyed with airborne radar sounding; however, those valuable datasets have historically been kept private, with access only by the research group who originally gathered them. Recently, a shift toward open access has driven groups to do data releases; for instance, the British Antarctic Survey recently released all data from its Polarimetric Airborne Scientific Instrument (PASIN). Here, we use one of the PASIN-2 surveys, PolarGap, which was flown in 2015-2016, covering the South Pole, Foundation and Recovery Glaciers, and parts of East Antarctica. Much of the PolarGap survey was flown in 'polarimetric' mode, meaning there are multiple transmit and receive antenna elements with some oriented parallel and some perpendicular. We processed the PASIN-2 survey data using the CryoCloud environment and an S3 bucket, observing differences in two-way travel time between the two polarizations for the same radar trace.

A comparison of the effects of rheology on crack propagation along ice shelves using phase-field techniques.

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Antarctic glaciers have accelerated significantly in the last thirty years, and this change is largely determined by the amount of ice calving into the Southern Ocean. The rate of calving is directly related to the propagation of throughgoing fractures, called rifts. Rifts can form from the propagation of small cracks in the ice, and the rate of crack growth depends on the mechanisms controlling this process. On both short and long time scales, ice behaves as a viscoelastic material. Traditionally large-scale models of ice-shelf flexure and crevasse propagation ignore the potential for creep and exclusively use linear elastic behavior. Conversely, models of ice-sheet flow exclude the elasticity of ice and only represent its flow by a power-law relation between stress and strain rate. The aim of this work is to (1) unify the discrepancy between representing ice shelves as either a viscous or elastic material and (2) incorporate these physics into models of crevasse evolution using phase-field techniques. Both of these aims are addressed by comparing models of the evolution of a small-scale surface crack in a purely elastic or viscoelastic material. To do so, we are using a phase-field in COMSOL Multiphysics software to represent the phase distribution of the cracked or uncracked ice for a single crevasse. The primary model outputs of interest are an evolution of the crevasse and description of the stress distribution around its tip with time and displacement. As a control case, we assume pure elasticity governs fracture propagation and use this framework to describe unstable brittle fracture of a crevasse. Then, to test the importance of viscous effects, we include viscoelastic models that represent the transient and steady state response of ice to flexure. The results of crevasse evolution as governed by differing rheological models indicate that viscoelastic effects can play a role in the propagation of a crevasse until throughgoing fracture. The results of these experiments can inform models of rift propagation and elucidate the importance of unifying ice's viscous and elastic behavior in ice-sheet models. Little is known about the mechanism responsible for the motion of a crevasse upon repeated loading and unloading and is a topic of future work.

#WAISworkshop WAIS West Antarctic Ice Sheet Workshop

Using Cryosat-2 to fill the gaps within the time series of surface elevations measured in the Siple Coast by the ICESat and ICESat-2 altimetry missions.

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The ICESat, ICESat-2, and Cryosat-2 satellite altimetry missions provided a two-decade-long record of ice sheets' surface elevations and revealed complex changes over the West Antarctic Ice Sheet. This talk will focus on changes in the southernmost Siple Coast ice streams, draining into the Ross Ice Shelf, the Mercer and Whillans ice streams. The elevation change time series, reconstructed from the ICESat and ICESat-2 laser altimetry missions and partitioned into changes due to surface processes and ice dynamics, show markedly different dynamic behavior in 2003-2009 and after 2018 in this region. From 2003 to 2009, rapid dynamic thickening was limited to the trunk of the Whillans Ice Stream, and dynamic thickness change was minor along the Mercer and Whillans ice streams, except in regions with active subglacial hydrology. However, during the ICESat-2 period, rapid dynamic thickening was observed along both ice streams, while, in their onset region, the previously observed dynamic thinning ended with a large region reaching equilibrium.
Between 2009 and 2018 there is a gap and as a consequence, it is hard to know what happened exactly between those two epochs of different trends. A solution could be to bring in the surface elevations measured by the mission Cryosat-2. Cryosat-2 fills the gaps between ICESat and ICESat-2, and the overlap between Cryosat-2 and ICESat-2 offers the possibility to sample the ice sheet topography with a finer resolution in space and time. However, radar signals penetrate the firn, bringing a bias within the measured surface elevations. Therefore, the surface elevations coming from Cryosat-2 should be corrected. Laser altimeters over the ice sheets are less sensitive to ice penetration, and consequently make good conditioning data to estimate the bias in Cryosat-2 due to ice penetration. We use the realignment of Cryosat-2 to coincide with ICESat-2, to estimate the offset between the surface elevations measured by both missions. Within a 1 square km area, using the data from ICESat/ICESat-2, we model a spatiotemporal covariance of the surface elevations. The covariance model is used with the locations from Cryosat-2 to estimate surface elevations, which we subtract from the original measurement from Cryosat-2. The elevation offset between Cryosat-2 and ICESat/ICESat-2 is thus computed using spatiotemporal kriging. The database formed is used to interpolate the bias over the points from Cryosat-2 that do not coincide with ICESat and ICESat-2. The results show a negative bias within the data from Cryosat-2, which is consistent with the idea that radar signals are more subject to surface and volume scattering. After final corrections, the time series are re-computed using sequential Gaussian simulations, and compared with other solutions, for example, the time series from ITS_LIVE (https://its-live.jpl.nasa.gov/).

Whillans Ice Plain Stick-Slip Motion and Slowdown Varies at Long-Period Tidal Frequencies

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Whillans Ice Plain, a 15,000 km² region of the West Antarctic Ice Sheet flowing into the southern Ross Sea, lurches forward 0.2 to 0.6 m over the course of about 30 minutes once or twice per diurnal ocean tidal cycle. These slip events, responsible for up to 90% of total ice plain motion in some locations, are correlated with the complicated mixed regional ocean tides. The ice plain has been decelerating for at least the past 50 years, recently accommodated by a decrease in slip event frequency. Integrating 11 years (2008 to 2019) of 15-second resolution Global Navigation Satellite System (GNSS) data from past field campaigns provides novel insight into Whillans Ice Plain dynamics, connecting individual events to decadal trends. We reprocessed GNSS data from 53 stations and used a linear least squares thresholding algorithm to automatically detect >4500 slip events during the 11-year observational period. We sum the number of slip events occurring within windows ranging from 3 to 40 days to observe long-term trends in event frequency beyond the previously detected correlation of slips with ocean tides on diurnal time scales. In addition to an overall slowdown signal, event frequency varies cyclically at semiannual and monthly periods, with more events occurring during periods of lower tidal range. Slip-event frequency also becomes increasingly variable over the record, namely an increase in the difference between mean number of events during maxima versus minima of long-period variations in tidal range. Combining analysis of long-term trends and individual slip events will help predict future dynamics of Whillans Ice Plain and provides key observations for comparison during modeling of stick-slip and stagnation processes.

Blank space: Revisiting uncertainties for Ramped PyrOx radiocarbon ages of Antarctic marine sediments

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Radiocarbon (^{14}C) dating marine sediments on the Antarctic continental margin is complicated by a lack of biogenic carbonate and reliance on acid insoluble organic carbon (AIOC) which contains reworked material. In regions wherein local primary productivity does not dominate the depositional environment (i.e., glaciomarine sediments), AIOC dates produce radiocarbon ages significantly older than true depositional ages. Ramped PyrOx (RPO) is a sample preparation method used to effectively un-mix sedimentary organic carbon (OC) by exploiting differences in its thermochemical stability. Isolating young, syndepositional OC at lower temperature intervals from pre-aged, allochthonous OC at higher temperature intervals allows for resulting ^{14}C ages to approach true depositional timing. Since the initial use of RPO for ^{14}C dating Antarctic sediments in 2008, a deeper understanding of the method has resulted in advanced applications around the Antarctic continental shelf, including ice-proximal sediment records from the Antarctic Peninsula. The RPO method exposes the AIOC fraction to a ramped temperature gradient and the oxidized pyrolysis products are cryogenically purified on a vacuum line to isolate and quantify CO_2 for ^{14}C dating. The procedural blank (background correction) is monitored by processing ^{14}C-dead and modern materials, and a mass-balance correction is applied to unknown environmental samples. As more blanks are analyzed, the blank correction is routinely updated and interrogated to reflect the most accurate values. Here we revisit previous blank corrections and assess the effect of updated values on previously established ^{14}C ages. We aim to create a space for researchers incorporating ^{14}C-based sediment chronologies to learn about inherent uncertainties in the RPO method and improve communication within the field to increase the accuracy of sedimentary age models.

Novel Record of Grounding and Ungrounding of the Venable Ice Shelf since 1906

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Buttressing provided by sub-ice-shelf pinning points contributes to Antarctic Ice Sheet stability by reducing ice discharge across the grounding line and regulating sea level rise. On Antarctic ice shelves, satellite-derived ice rises or rumples have been identified as sub-ice-shelf pinning points where the ice-shelf base is attached to the seafloor. These surface expressions have been used to measure ice-shelf thickness change back to 1973 (Miles & Bingham, 2024). Here we combine time series analysis of Landsat imagery with aerogravity-derived bathymetry to identify the history on a point beneath the Venable Ice Shelf that last unpinned in ~1988. Landsat imagery shows no present-day ice-shelf surface expression above this ~520 m deep bathymetric feature, but reveals relic crevasses downstream. Reconstruction of the grounding history from available satellite data shows intermittent grounding on the pinning point since ~1906, demonstrating that thinning and loss of ice-shelf buttressing has been occurring on the Venable Ice Shelf for ~70 years.

Inferring ice-rise rheology using physics-informed neural networks

George Lu[1], Dr Yongji Wang[2,3], Dr Ching-Yao Lai[2], Dr Jonathan Kingslake[1]
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Ice rises are regions adjacent to ice shelves where grounded ice flows outwards from a local topographic high. They play an important role in the stability of the Antarctic Ice Sheet, and are key locations for drilling ice cores. They also carry many physical uncertainties — models that use commonly assumed ice rheology parameters are unable to reproduce profiles of englacial vertical velocity measured using ice-penetrating radar. Consequently, more efforts are needed in constraining ice-rise rheology. We present a framework to invert for englacial effective viscosity using vertical velocities collected by phase-sensitive radio-echo sounders (pRES) on ice rises in the Weddell Sea Sector of Antarctica, and novel inversion methods based on physics-informed neural networks (PINNs). We comprehensively consider a full-Stokes momentum balance along with mass conservation in our inversion, while avoiding prior assumptions about the functional form of ice rheology. We will discuss the development of these PINNs, apply them to synthetic problems, and present our preliminary results. This work will demonstrate the utility of PINNs in solving inverse problems, and the inferred rheology from the ice-penetrating radar data will help inform ice-sheet model parameterizations and ice-core dating techniques.

New Antarctic sub-ice-shelf bathymetry estimates derived from Markov chain Monte Carlo gravity inversions

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We present new bathymetric estimates for numerous ice shelves along the margin of Antarctica. These bathymetries were derived through a novel Markov chain Monte Carlo gravity inversion technique where topographies are iteratively perturbed within a stochastic framework until convergence is achieved. This workflow yields an ensemble of bathymetric surfaces where each realization satisfies airborne gravity constraints. This bathymetric ensemble accounts for uncertainties in density and the non-uniqueness of gravity. While conventional gravity inversion approaches yield a single bathymetric estimate, our approach produces an ensemble that can be used to propagate uncertainty in ice sheet models. These maps are an update on previous gravity inversion results and will provide an important reference for ice sheet and ocean models. This work was conducted by undergraduate students in the context of a Course-based Undergraduate Research Experience.

Joint Interpretation of Radar and Seismic Imaging for Constraining Subglacial Conditions Across the Eastern Shear Margin of Thwaites Glacier

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The Thwaites Interdisciplinary Margin Evolution (TIME) project, within the International Thwaites Glacier Collaboration (ITGC), focuses on understanding the evolution and stability of Thwaites Glacier's eastern shear margin, a dynamic region which is expected to have significant influence on the future of the West Antarctic Ice Sheet. During the 2023-24 field season, the TIME field team carried out a comprehensive active source seismic survey, including a dense array of 1000 three-component seismic nodes located along a 27-km centerline and within a 3 by 5.5-km grid crossing the eastern shear margin at the "T2" field site. Active source seismic reflection and refraction data were collected from 671 explosive source locations, using 4kg "Poulter" charges. We present 2D seismic reflection imaging results from the survey's centerline, as well as initial results of seismic refraction and amplitude-vs-offset (AVO) analyses focused on providing constraints on subglacial conditions across the shear margin. In addition to the seismic reflection and refraction studies, we incorporate co-located airborne radar collected in the 2019-20 field season using the British Antarctic Survey's polarimetric PASIN2 system, as well as ground-based bistatic radar data collected in the 2023-24 field season into our interpretations. By combining observed seismic and radar reflectivity, we aim to infer spatial variations in the basal thermal state, material properties of the bed, as well as bed roughness in order to provide insight into the evolution of the eastern shear margin. This interdisciplinary approach offers new observation constraints on cross-margin subglacial geology and bed conditions, enhancing our understanding of the shear margin's role in the broader context of the evolution and stability of Thwaites Glacier.

Gear sharing for cryosphere scientists; an early career initiative supported by CryoCommunity

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A need for connection to resources regarding gear sharing, packing lists, and a list of local used gear shops was expressed at the 2023 West Antarctic Ice Sheet meeting by early career members of the cryosphere community. To address this need, a webpage has been developed through CryoCommunity with support from the Polar Science Early Career Community Office (PSECCO) to directly connect individuals seeking to borrow gear to those willing to lend gear. In addition to providing a platform for these connections, this shared community space will include packing lists for region-specific field work, locations of affordable used or repaired gear in cities across the United States, and lists of ProDeal and other discounts afforded to field-going polar scientists. We aim for this initiative to become self-sustaining by creating connections across geographically isolated and siloed glaciology departments in lieu of developing and maintaining a localized “gear repository”. A survey was shared with the wider glaciology community to determine direction of efforts (n=25). Among other results, the majority of respondents indicated the gear they would lend is new, slightly, or well used (94.7%). In order to address respondent concerns regarding quality assurance, timeliness of gear receiving/return, transparency of use, sanitation, and responsibility of cost, we will develop a gear lending agreement template that users can adapt for their own purposes. While we will establish general community guidelines for the gear sharing page, we understand the requirements for particular gear usage may vary widely. With this in mind, those using the page are encouraged to edit the lending agreement to establish expectations for borrowing timelines, responsibility of cost, and other logistical details. Overall, the development of this shared resource is meant to address a gap in field accessibility within the polar sciences and increase opportunity and access to the field for all polar scientists. We seek feedback from the community on this initiative and hope to increase engagement through open discussion.

Mixed Diatom Assemblages and the History of Ice: Ross Bank, Antarctica

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During the post-LGM, the WAIS first contracted from deep-water troughs and then from shallower-water banks. Deglacial succession from the troughs shows a classic succession from subglacial sediments, deposited below fast-flowing ice streams, that transitions upcore to sub-ice-shelf and open-marine sediments accumulated following grounding line and calving front retreat, respectively. Diatom assemblages in these sediment provide powerful evidence for making these environmental interpretations. For example, open-marine facies contain abundant *Fragilariopsis curta*, a sea-ice diatom (Leventer, 1998). In comparison, deglacial successions for bank crests are poorly studied. Understanding bank stratigraphy is important because retreating ice shelves may have formed ice rises. Ice rises, like Roosevelt Island, buttress what would otherwise be faster ablation of grounded ice. Data acquired during NBP2301/02 demonstrate that Ross Ice Shelf (RIS) was formerly pinned to Ross Bank, a broad shallow area in central Ross Sea. Here, we evaluate the diatom assemblage data from sediment cores across Ross Bank. The deglacial succession is represented by a sand-rich residual glacial marine deposit. In the upper few centimeters, the diatom assemblage indicates a moderately winnowed but relatively intact open marine succession. In the underlying sediments, the diatoms show oscillations between moderate and intense reworking. These downcore variations indicate that the intensity of winnowing on the bank was variable across time and space. Identifying moderately winnowed intervals in core is important because they may contain other evidence that can be used to reconstruct the timing of RIS unpinning and other clues as to how the deglacial conditions evolved.

Quantifying subglacial groundwater exfiltration in West Antarctica since the Last Deglaciation

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Over the past 50 years, investigations into subglacial hydrologic systems beneath the Antarctic Ice Sheet (AIS) have primarily focused on the presence of lakes and rivers. However, recent geophysical surveys and modeling efforts indicate the presence and potentially critical role of deeper groundwater systems in shaping the Antarctic continent. Our understanding of groundwater in Antarctica remains limited, largely due to the challenges associated with accessing ice-bed interface, located beneath several kilometers of ice. Recent studies have illuminated the connection between ice sheet dynamics and subglacial hydrology, suggesting that glacial thinning reduces the mechanical load on sub-ice aquifers, causing groundwater to exfiltrate out of the sediment at the ice-bed interface at measurable rates. These rates, however, have only been explored for contemporary timescales (~15 years), potentially overlooking the long-term behavior of glacial and groundwater systems over geologic timescales.
To assess the role of glacial thinning on groundwater exfiltration across extended timescales, we utilize data from the Informal Cosmogenic-Nuclide Exposure-Age Database (ICE-D) to derive deglacial thinning rates across Antarctica from the Last Glacial Maximum (~20 kyr) to the present. We estimate groundwater exfiltration rates of 2.5 to 74.5 mm/yr during the recent, geologic past at 28 sites in West Antarctica, by incorporating these rates into a hydromechanical model described by Robel et al. (2023). These paleo-exfiltration rates are comparable to, or exceed, contemporary estimates by an order of magnitude in certain regions (assuming a sediment permeability of $k = 10^{-13} m^2$), suggesting the mobilization of significant groundwater volumes over extended timescales. Our findings underscore the dynamic and complex nature of Antarctic subglacial hydrology over the past 20 kyr, emphasizing the importance of accounting for groundwater in studies of deglaciation processes and further exploring their broader implications for ice flow, basal melting, and adjacent marine ecosystems.

Two new 150m ice cores and ground geophysics at Canisteo Peninsula, Amundsen Sea, West Antarctica: successful first fieldwork for the Ross-Amundsen Ice Core Array (RAICA) initiative

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The Pacific coastline of West Antarctica is changing rapidly—experiencing thinning, mass loss, and retreat of ice shelves critical for stability of the West Antarctic Ice Sheet (WAIS). Despite this observed change due to complex ice-ocean-atmosphere interactions perturbed by combined internal and forced climate processes, there remains a paucity of terrestrial climate records and surface mass balance observations along the ~1900 km-long coastline from Ross Ice Shelf to Pine Island Glacier. Ice rises, regions of grounded ice within ice shelves, are ideal ice core sites and many are located along the WAIS coastline—providing opportunity to reconstruct coastal climate and environmental parameters back decades to millennia at annual resolution.

An international team successfully collected two 150 meter long ice cores on either side of the ice divide of Canisteo Peninsula ice rise, 130 km north of Pine Island Glacier. Supported by the South Korean icebreaker RV ARAON and two AS-350 helicopters, the camp of 8 people spent 13 days at the site in mid-January 2024. 280 km of radar lines were traversed by two snow mobiles, observing ice thickness, internal structure, and shallow surface mass balance variability. ApRES was conducted at one ice core site. One core was collected 500 meters northeast of the Canisteo Peninsula ice divide, using the US IDP Foro 400 drill; a matching core was collected 500 meters southwest of the divide, using a Japanese-manufactured KOPRI ice coring drill.

Once analyzed, these approximately 150-200 year-long cores will provide baseline proxy observations of fundamental climate variables (temperature, wind, snowfall) which play a poorly-quantified role in forcing Amundsen Sea regional glacier change. They will also expand on the existing inland WAIS ice core array, build on the completed International Thwaites Glacier Collaboration, and—with the recovery of additional cores—eventually connect to Korean and other international ice coring efforts in the Ross Sea and Victoria Land regions.

West Antarctic glacier retreat triggered by polynya response to meridional winds

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West Antarctic outlet glaciers are in a stage of rapid retreat, modulated by wind-driven exposure to warm Circumpolar Deep Water (CDW). Retreat likely began in the mid-20th century and is often attributed to increased poleward CDW transport forced by increased eastward winds at the continental shelf break. This eastward wind trend is a feature of some historical climate simulations but is not supported by proxy observations. We present an ensemble of regional ocean simulations and proxy-constrained climate reconstructions and show that shelf-break zonal winds are a poor indicator of CDW transport. Instead, cumulative southward wind anomalies over the continental shelf cause coastal polynyas to close, driving anomalous warming near the ice shelves, increasing ice-shelf melting. The increased supply of meltwater enhances a cross-shelf density gradient that strengthens the shelf-break undercurrent, further enhancing CDW transport toward the glaciers. Our results highlight the importance of cumulative local meridional winds and associated sea ice changes on ice-shelf melting in West Antarctica. Proxy reconstructions show a historical southward wind trend over the continental shelf -- an extension of Amundsen Sea Low deepening -- providing the atmospheric forcing that can explain the initiation of West Antarctic glacier retreat during the mid-20th century.

Basal melt and sliding in Antarctic grounding zones: New theory, models and observations

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Evidence from Earth's history indicates that the West Antarctic Ice Sheet was likely much smaller during periods not much warmer than today. Considerable effort in the last decade has been devoted to explaining the glaciological processes responsible for this sensitivity using ice sheet models with novel parameterizations. One candidate explanation focuses on the intrusion of seawater upstream of Antarctic grounding lines, causing enhancement of basal melting and sliding, and a potential doubling of ocean-induced Antarctic ice loss compared to models that do not include such processes. In this talk, I will highlight new theoretical and modeling work on the fluid dynamical processes that set the distance of seawater intrusion and the resulting basal melt rate, and why existing basal melt parameterizations may be inadequate to describe this process. I will also discuss the flood of new observational studies finding evidence for seawater intrusion in Antarctica and Greenland, while previewing new evidence from altimetry for enhanced sliding across many Antarctic grounding zones. I will conclude by proposing strategies for developing better representations of these processes in models using novel laboratory experiments and observational campaigns.

Quantifying erroneous age of bulk AIOM radiocarbon dates in Southern Ocean surface sediment samples

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Accurate chronologies of past glacial change are critical for contextualizing the changes in ice mass we observe today. Radiocarbon (^{14}C) dating of carbonate fossils and acid insoluble organic matter (AIOM) in marine sediments is the most commonly used method for constraining these changes in the Holocene and late Pleistocene. Due to acidic Southern Ocean bottom water and a shallow Carbonate Compensation Depth, many places around the Southern Ocean are lacking in carbonate fossils, leaving us to rely largely on AIOM ^{14}C. However, many AIOM dates from surface sediments in the Southern Ocean appear erroneously old due to post depositional carbon mobilization by a variety of glacial and oceanographic processes (Andrews et al., 1999). To better understand the sources of this erroneous age in Southern Ocean sediments, we analyzed 171 previously published surface sediment samples, comparing the degree of erroneous dating to several glacial, geologic, bathymetric, and ocean variables to see if these errors correlate with specific processes. These processes include geomorphic context (bathymetry and bedforms), sedimentology, inland geology and glaciology, and various oceanographic variables such as sea surface temperature, annual sea ice cover, and concentrations of oxygen, nitrogen, and phosphate, from the Quantarctica3 database (Matsuoka et al., 2021).

We find that surface sediments from the Antarctic Peninsula and the Ross Sea are areas with the highest degree of erroneous age, with derived ^{14}C age in core tops via AIOM being up to ~25,000 years old, whereas core tops in the Amundsen Sea, East Antarctic Margin, and adjacent to the Amery Ice Shelf display the youngest ages. Our current line of questioning involves asking why these areas display different ranges of erroneous age, and what specific environmental factors make areas like the Antarctic Peninsula and Ross Sea have older apparent surface ages than other parts of the Southern Ocean. We hope that this study will provide insight into the reliability and precision of marine radiocarbon chronologies in the Southern Ocean and beyond, helping researchers select the most appropriate radiocarbon dating methods, be it bulk AIOM, Ramped PyrOx, or carbonate fossils.

Evidence of repeated West Antarctic Ice Sheet loss during late Pleistocene interglacials from Amundsen Sea IODP Expedition 379 drillcore

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Far-field sea-level data and numerical models suggest that the inherently unstable West Antarctic Ice Sheet (WAIS) underwent major mass loss during the Pleistocene, raising global sea level by several meters. However, direct evidence from continuous geological records proximal to the WAIS is rare and has been inconclusive. Here we report paleotemperatures based on a diatom morphometric proxy and changes in clay mineral assemblages in drill core sediments deposited on the Amundsen Sea continental margin through the last 800,000 years. Our results show that summer sea surface temperatures exceeded a commonly reported threshold for WAIS retreat, and the supply of glacigenic detritus sourced from the main outlet glaciers in the Amundsen Sea sector of the WAIS almost entirely ceased during previous post-Mid-Pleistocene transition warm periods. The clay results document the loss of glacial drainage basins and the enhancement of intensified deep-water advection towards the Antarctic margin during warm interglacial periods, indicating that ocean forcing drove the deglaciations.

Stochastically Simulating Mass-Conserving Subglacial Topography: Estimating Topography Uncertainties from Sparse Radar Measurements

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Despite its critical role in ice sheet models, subglacial topography generally remains sparsely sampled by airborne ice-penetrating radar. In Antarctica, gaps in-between radar lines typically range from 10s to 100s of kilometers. In fast flowing regions, the physical law of mass conservation can be used to relate well-observed surface velocity to bed elevation, enabling interpolations of bed elevation in the data gaps. However, solving a unique bed topography from the mass conservation equation is an ill-posed problem, requiring a smoothness constraint on the topography solution. The deterministic solution violates topographic roughness observed in the radar data. Furthermore, this single solution of topography might not reveal the inherent uncertainties from sparse measurements.

In this study, we propose a novel approach to generate an ensemble of realistically rough and mass-conserving subglacial topography through Markov chain Monte Carlo sampling. In each iteration of each chain, we perturb the topography with geostatistics methods that reconstruct spatial covariance statistics observed in radar data. Then, the perturbed topography is accepted with a probability derived from its deviation from mass conservation law. After the Markov chains converge to steady-state, an ensemble of topography could be sampled from the chains. We tested the method on both Denman Glacier and Totten Glacier and successfully generated multiple different topography constrained by both radar measurements and the mass conservation equation. Moreover, the geostatistics update reproduces the covariance structure in radar data such that every generated topography has a more realistic roughness compared to the numerical solution.

This method provides a possibility to incorporate realistically rough topography into ice sheet models while avoiding artifacts caused by the violation of mass conservation. Furthermore, multiple subglacial topography realizations can reveal the inherent uncertainties caused by sparse radar measurements. Incorporating a stochastically simulated topography ensemble provides new opportunities to propagate uncertainty in interpolating topography measurement to the result of downstream models.

A hierarchy of ICESat-2 land ice data products for accelerating science with satellite laser altimetry

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The Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) mission developed and serves a hierarchy of data products that cover Earth's land-ice masses and provide a range of processing levels, from a point cloud of geolocated photons (ATL03) to gridded surface elevation change (ATL15). These products enable cryospheric scientists to access, process, and interpret satellite laser altimetry data regardless of remote sensing expertise. The five current land-ice data products (ATL03, ATL06, ATL11, ATL14, and ATL15) and their underlying algorithms were established and designed pre-launch by the ICESat-2 Science Definition Team's Land Ice Group and have undergone periodic updates and re-releases post-launch as the ICESat-2 Science Team evaluated the characteristics of on-orbit data. The higher-level products (ATL11 and higher) have been developed in an open-source framework, and the open-source SlideRule online service provides on-demand access to photon data (ATL03) and custom segmented (ATL06-like) products. A new land-ice mass-change product is currently under development that will provide a freely available, up-to-date geodetic mass balance product for the duration of the ICESat-2 mission (2018 to present) at 1 km resolution for the research community.

CryoCloud: Harnessing open science and cloud computing to accelerate cryosphere research

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Ice front-ocean systems at the Antarctic margins are some of the most poorly observed systems around Antarctica. High spatial and temporal resolution remote sensing data (e.g., visible, thermal infrared, and altimetry), sometimes in combination with field observations and machine learning techniques or other state-of-the-art statistical methods, can be used to detect ice-ocean features and automate full-continent analyses to speed up data processing and create a broader understanding of the physical processes driving change. However, with these ever expanding volumes of data and the need for more advanced computing infrastructure, new collaboration, open science, and workflow approaches are required. Here, we use a multi-platform study of sensible heat polynyas in the Amundsen Sea as an example to demonstrate the power of open science and cloud-computing workflows for addressing new kinds of ice-ocean questions while democratizing science within our WAIS communities. We use CryoCloud, a cloud computing ecosystem and network of cryosphere scientific communities, to expand inclusivity, accessibility, transparency, and reproducibility in our scientific workflows. This community model enables learning and curation of the technical knowledge required to facilitate an open-source, interconnected, and science-accelerated vision of the future for our community.

Changing our perspective of the polar coastal margins with the new NASA Surface Ocean and Water Topography (SWOT) mission

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The NASA Surface Ocean and Water Topography (SWOT) radar altimeter launched in late 2022 with the promise of making the first global survey of Earth's surface water, observing the ocean's surface topography in fine detail, and measuring how bodies of water change over time. The primary payload included the Ka-band Radar Interferometer (KaRIn) system with two swaths (V- and H-polarized) that span 50 km across each with a 20 m nadir gap between and a nominal cross-track resolution of ~10 m. SWOT captures radar measurements and downlinks them to ground stations in High-Resolution mode (10 m nominal resolution, generally acquired over terrestrial water), which is the satellites native capturing resolution, or in Low-Resolution mode (250 m resolution, acquired over open ocean). Until SWOT, ocean surface topography resolved the ocean surface at a spatial resolution of 100 km at ~weekly intervals, a technological development that had remained fairly stagnant since the 1990's. SWOT's performance was expected to vastly outperform historical missions, but even those expectations were substantial underestimates. SWOT now delivers 0.83 cm vertical height error, making the instrument often more accurate than the calibration methods used by the mission.

While holding tremendous potential, SWOT was not designed or to-date used for cryosphere applications. The new science team convened in June was the first time a Cryosphere Working Group was formed. Mission data include gaps along the Antarctic coastline where satellite resets are programmed to repeatedly occur, no High-Resolution acquisitions, no acquisitions poleward of 78 degree, and product artifacts that make measurements of surfaces substantially higher than the ocean surface challenging. However, because of its orbit, SWOT gathers measurements along the WAIS coastline ~daily regardless of cloud cover. Here, we show ice-ocean features, like the Pine Island Bay gyre, at near-daily resolution that have never been previously captured by satellite, fully mapped in one snapshot, or observed continuously through time. The instrument can capture iceberg-generated and tidal waves, mountain glacier surfaces alongside their downstream hydrology, and iceberg shape. The next four years will be used to understand SWOT applications to Antarctic sea ice, ocean, hydrology, and glacier processes and determine measurement uncertainties for mixed ice and ocean surfaces. In just a few orbit cycles, SWOT upended our understanding of many ocean processes across the globe; we have similar expectations for the Antarctic coastline.

Late Holocene emergence of the Rockefeller Mountains, Marie Byrd Land using in situ cosmogenic C-14

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The fate of the West Antarctic Ice Sheet is intricately linked to the Ross Ice Shelf, which acts as a primary drainage system and buttress for grounded ice upstream. The timing and pattern of grounding line retreat, since the Last Glacial Maximum (~20,000 years ago), have sparked intense debate. Three contrasting scenarios suggest significantly different timelines and retreat patterns. These differences complicate our ability to disentangle the mechanisms for and make accurate future predictions of ice sheet change. Current models primarily rely on observations from the western Ross Sea, sub-Ross Ice Shelf sediments, and many outlet glaciers draining through the Transantarctic Mountains.

While geological constraints for grounding line retreat exist for the outer eastern Ross Sea, they mainly indicate changes in extent, inferring variations in ice thickness and volume. Onshore, the scarcity of glacial deposits at the Rockefeller Mountains, which are typically used to reconstruct past glacial thickness, presents a challenge. To address this, we analyze legacy bedrock samples, held at New Zealand's National Petrology Reference Collection (NPRC) and PETLAB database, from previous expeditions to document glacial changes along the Rockefeller Mountains, a low-relief archipelago of nunataks situated at the eastern margin of the Ross Ice Shelf.

By carefully examining samples for a preserved, weathered upper surface and purifying quartz from two distinct sample sets, we present new in situ cosmogenic Beryllium-10 and Carbon-14 data that suggest a late Holocene emergence of the Rockefeller Mountains. This finding aligns with nearby evidence indicating regional ice sheet thinning and retreat during this period. Our study not only contextualizes existing and ongoing ice sheet modeling efforts aimed at understanding the mechanisms of regional ice sheet re-advance but also highlights the value of legacy samples in addressing data gaps in hard to access field locations.

Not Your Average Berg: Development of a Coupled Mélange/Ocean Model

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Marine terminating glaciers can be strongly influenced by processes at the ocean margin, including ocean forcing from the intrusion of warm waters, mechanical buttressing of ice mélange, and release of fresh meltwater. These processes require resolution beyond the limit of conventional large scale ice sheet models, and thus are often parameterized for projections of global sea level rise. Parameterizations based on bathymetry and offshore ocean conditions in some narrow fjords of Greenland have been shown to explain much of the observed oceanic forcing or induced glacial melt, but in many cases such simple parameterizations do not prove useful. At the local scale, processes like meltwater release from icebergs within fjords and embayments have been shown to significantly alter oceanic conditions, potentially accelerating the delivery of warm waters to the glacial front and grounding lines. Additionally, mechanical stabilization can come from the presence of an ice mélange at the front of the glacier, but the impact of this mélange on oceanic conditions is poorly understood.

In this work, we focus on the connection between ice mélange and ocean conditions to better understand the coupled mélange/ocean system. We utilize the MIT general circulation model (MITgcm) for our ocean modeling, including the shelfice and iceberg packages to model the presence of a mélange front and the thermomechanical feedbacks between the mélange and the ocean cavity. We utilize a dynamic mélange model, glaciome1d, to solve for the evolution of the ice mélange, enabling a full coupling of the mélange/ocean system. We focus on an idealized, 2D cross section of a fjord, and in future work will apply similar methods to develop GLACIOME, a 3D coupled modeling system with realistic geometries relevant to Greenland and Antarctica.

Using Diatom Analysis to Pinpoint Antarctic Ice Sheet Extent and Dynamics in the Pennell Basin During Pleistocene-Holocene

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The Ross Sea is a critical region for understanding the long-term dynamics of the Antarctic Ice Sheet (AIS), particularly the interactions between the West Antarctic Ice Sheet and East Antarctic Ice Sheet in the central Ross Sea. Within this region, the Pennell Basin spans 100 km in width and 470 km in length and features a 450m deep saddle connecting the flanking Pennell and Ross Banks. This saddle likely provided stability to grounded ice in past glacial cycles. Ongoing and recent works use geomorphic datasets to evaluate the fluctuations in post-glacial grounding line position (Tenti et al., in prep) and grounding duration (Danielson and Bart, 2024) in the vicinity of the Pennell Basin saddle. These studies estimate that the maximum grounding line position of the most recent glacial cycle represents a late-stage advance that was likely held for less than 1000 years. Despite extensive research in the Ross Sea, gaps remain in our understanding of AIS behavior in the Pennell Basin during the Pleistocene-Holocene, largely due to challenges with radiocarbon dating and integration of multi-proxy core data with high-resolution geomorphic context. Here, we build on these geomorphology studies and present new data exploring the dynamics of the ice-proximal environment from a micropaleontological and sedimentological perspective. We integrate data from diatom assemblages, grain-size, and physical properties from three Kasten cores—KC01 and KC02 from expedition NBP2301, and KC52 from NBP2403—to demonstrate the changeable nature of grounding zones on the cusp of post-glacial retreat. Preliminary results from KC01 and KC02, which lie beyond the maximum extent of grounded ice during the last glacial period, contain two primary units that together make up a deglacial sequence. The first, at the base of the cores, is a heterogeneous basal unit of diatom-bearing mud with minor sand. In this unit, it appears that terrigenous and biogenic sedimentation vied for dominance in what was likely a dynamic and occasionally restricted ice-shelf environment with frequent open ocean exchange. The upper unit contains diatom-rich muds and sands, suggesting open marine conditions. KC52, located further south on the Pennell Basin saddle between two backstepping grounding-zone wedges, penetrated through a deglacial sequence into an underlying glaciomarine unit. The diatom data suggest this basal unit is possibly open marine. However, the assemblage is different enough from that of the core tops that we suspect it could represent the open marine sediment from before the AIS expanded overhead to its maximum extent. Future radiocarbon dating of the basal glaciomarine unit should confirm whether the AIS postglacial advance in this region was as short-lived as suggested by geophysical data. While further analysis is required to confirm the timing of observed events, it is clear that the ice-ocean interactions at the grounded ice margin were highly varied through the end of the glacial period into the deglacial.

Building software-defined radar systems with the Open Radar Code Architecture (ORCA)

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Field teams often rely on ice-penetrating radar as part of their geophysical instrumentation, but they usually have few choices for what instrument to bring. Only a few off-the-shelf ice-penetrating radar systems exist. Commercial GPRs are often pressed into service, but these systems are mostly not phase coherent. In all cases, the radar systems tend to be expensive, so teams are often left to use whatever they happen to have.

The Open Radar Code Architecture (ORCA) is an open-source codebase and set of blueprints for building low-cost ice-penetrating radar systems that can be tailored to specific observational needs. ORCA is built to leverage off-the-shelf software-defined radios as a flexible core that can be re-configured by a single YAML file to operate across a range of frequencies, bandwidths, chirp waveforms, and more. Filters, amplifiers, and other front-end components may be added to meet specific requirements.

Our group has developed and deployed several ice-penetrating radar systems built on top of ORCA, including a ground-based multi-static radar, a fixed-wing UAV-borne radar system, and a snowmobile-towed multi-frequency radar. Each of these designs are available as blueprints to be built and used as-is or modified.

Leveraging their common codebase, all ORCA-based radars save data and configuration information in a common format, which allows for most of the post-processing code to be reused across systems. This also helps to facilitate cross-comparison between radar data from different systems, as the most important system parameters are stored in a human and machine-readable configuration file.

In this presentation, I will go over the basics of how ORCA is structured, show example datasets collected in Svalbard, Greenland, and Antarctica across three different ORCA-based systems, and show useful starting points for building your own ice-penetrating radar instruments.

SCAR RINGS Action group work towards facilitating airborne geophysical surveys and co-ordinated research on the Antarctic Ice Sheet margin

. Kirsty Tinto[1], Kenichi Matsuoka[2], Xiangbin Cui[3], Rene Forsberg[4], Fausto Ferraccioli[7], Tom Jordan[5], Felicity McCormack[6], Geir Moholdt[2]
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Accurate constraints of ice thickness and bed topography at the ice-sheet margin are critical for estimates of current Antarctic ice discharge and predictions of the future of the Antarctic Ice Sheet. RINGS is an action group within the Scientific Committee on Antarctic Research (SCAR) that exists 1) to assess the current state of knowledge of fundamental boundary conditions and the potential impact of new data, and 2) to provide a forum to co-ordinate international efforts to acquire and integrate new data for improved understanding of mass balance. Work towards these goals has included regionally-focused workshops on the East Antarctic margin and the Peninsula, as well as the development of a shared values agreement on which to base collaborative work. To further develop the scientific rationale for the high-priority science topics, RINGS has analyzed a range of published data, including the Bedmap3 FAIR database, IBCSO version 2, modelled surface mass balance reconciliation, and results from ISMIP6. Here, we present an overview of these new findings to clarify the scientific rationale for conducting further bed topography surveys in the ice sheet margin. We include new analyses on sub-ice shelf seafloor bathymetry and highlight future collaborative opportunities.

Subglacial conditions in an ice-stream/pinning-point system estimated from unsupervised clustering analysis of bed-echo waveform structure

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Ice-shelf pinning points, where floating ice locally regrounds on bathymetric highs, regulate ice-sheet mass loss by enhancing ice-shelf buttressing. However, the effect of pinning-point buttressing depends on the grounded ice-stream system upstream, which evolves with broader climatic, glaciologic, and/or geologic changes. Constraining basal conditions in ice-stream/pinning-point systems—particularly through methods that minimize dependence on uncertain englacial properties (e.g., temperature gradients, impurities)—offers new insights into how basal processes (e.g., changes in subglacial hydrology, basal friction, grounding-zone migration) influence the ongoing buttressing evolution. Here, we used radio-echo sounding (RES) observations collected by the Center for Remote Sensing and Integrated Systems (CReSIS) in the 2013–14 austral summer to characterize the basal conditions of Crary Ice Rise and the upstream Whillans Ice Stream. We compiled and clustered normalized bed-echo waveforms through an unsupervised K-Means algorithm to group waveforms with similar structures within the study region. We mapped the cluster outputs and synthesized their spatial distributions with other regional data products (e.g., englacial layer slopes, ice-surface velocity, surface elevation change) to identify spatial patterns indicative of subglacial hydrology, subglacial sediment properties, basal crevassing, and inferred basal friction within the RES survey. Our clustering method and data synthesis provide an attenuation-independent process for characterizing basal conditions in historically difficult regions like Whillans Ice Stream, where uncertainty in the conditions through which the radar wave propagates has previously made assessing the basal environment challenging. Expanding the application of our method over the decades-long RES archive in this region will enable our observations of the evolving subglacial and englacial processes that impact ice-stream/pinning-point buttressing feedbacks.

Deep learning the flow law of Antarctic ice shelves

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Antarctic Ice shelves play a vital role in controlling ice mass loss into the ocean, mitigating global sea-level rise. However, the fundamental mechanical properties of these ice shelves, especially their flow law and viscosity structure, can not be directly measured on a continental scale. Here, we leverage the vast availability of remote-sensing data and physics-informed deep learning to investigate the rheology of glacial ice on various Antarctic Ice Shelves. We find that ice-shelf rheology differs substantially between the compression and extension zones. In the compression zones near the grounding line, the rheology closely obeys power laws that follow composite rheology, enabling the determination of the stress exponent n. In the extension zone, which comprises most of the ice shelf area, ice exhibits anisotropic properties. We construct the first ice-shelf-wide viscosity maps considering anisotropy that precisely capture the suture zones of different ice shelves. Suture zones are known to inhibit rift propagation, yet are currently not well represented in numerical ice-sheet models. The stress exponent and viscosity structure, inferred from real observations, dictate the fate of ice shelves from their initial discharge from grounded ice sheet to eventual collapse into the ocean, thus are essential for predicting the mass loss of the Antarctic Ice Sheet.

Recent Fracture-Flow Variability on Thwaites Ice Shelf, West Antarctica

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The rapidly-changing Thwaites Ice Shelf is crucial for understanding ice-shelf instability and its implications for sea-level rise from Antarctica. Fractures play a significant role in this region but are poorly characterized, especially regarding their vertical depth. To address this gap, we developed a robust workflow that adapts to surface topography complexities to characterize time-varying fracture vertical properties over Thwaites using ICESat-2 altimetry measurements. We derived seasonal flow velocities from Sentinel-1 data and analyzed climate reanalysis data to examine flow-fracture interactions in the context of oceanic and atmospheric changes. The results revealed distinct fracturing and flow patterns between the eastern and western sectors of the ice shelf. Significant fracturing was observed along the shear margin and near the grounding line in the eastern sector, correlating with flow speed increases exceeding 90% at shear zones. In contrast, the western glacier tongue exhibited a less progressive fracturing pattern, with an active fracture zone downstream of the historical grounding line and overall flow deceleration. This is likely due to the stabilizing effects of grounding-zone geometry, a subglacial sill, and increased coupling to the slower-moving eastern sector. Atmospheric and oceanic reanalysis data suggest that atmosphere-sea-ice-ocean interactions could destabilize an ice shelf through shallow oceanic warming. Warm winters, reduced sea ice, and favorable winds and ocean currents can cause shoaling of warm Circumpolar Deep Water, facilitating access of warm waters to thin, structurally vulnerable areas such as shear margins and basal channels. This intensifies fracturing and triggers damage-flow-acceleration feedback that could lead to eventual ice-shelf destabilization.

Noble gas water samples reveal active subglacial volcanism beneath Kamb Ice Stream

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The ice streams along the Siple Coast of West Antarctica have a history of stagnation and reactivation, which directly impacts the rate of ice discharge and subsequent sea level rise. The production and migration of water beneath the ice and its lubrication of the bed has been hypothesized as an underlying cause for this start-stop behavior of the ice streams. Kamb Ice Stream is presently stagnant at its grounding line, the point where ice reaches the ocean and displaces sea level. This absence of ice flow offsets mass loss from other parts of West Antarctica; however, if the ice stream were to reactivate this could increase ice discharge and sea level rise. Here, we present noble gas and Helium isotope concentrations, in addition to physical oceanographic measurements from a subglacial channel at the Kamb Ice Stream grounding line. These data quantify the flux of subglacial freshwater flowing into the ocean and link this water to upstream volcanic activity through 3He enrichment. Estimates of geothermal heat flux passing through the channel are modest, but significant above background Antarctic levels. Ultimately, these exciting data provide constraints for highly uncertain variables such as subglacial freshwater flow and geothermal heating beneath West Antarctica and add to the puzzling story of ice stream behavior along the Siple Coast.

Synchronization of the Antarctic ice-ocean-atmosphere system and global climate began 1.5 million years ago

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As an integral part of Earth's climate system, the Antarctic Ice Sheet (AIS) impacts global sea level and interacts with Southern Ocean climate on a variety of timescales. A lack of long and continuous records of AIS variability on orbital timescales, however, has challenged our understanding of the complex interplay between the AIS, ocean, atmosphere, and biogeochemical cycles and its contribution to the evolution of Plio-Pleistocene climate. Here we use well-dated, high-resolution sediment records from Iceberg Alley in the Southern Ocean in combination with climate and ice-sheet model simulations to show that key components of the Antarctic ice-ocean-atmosphere system started to synchronize with orbitally-paced global climate change with the mid-Pleistocene transition (MPT) ~1.5 million years ago (Ma). Only toward the end of the MPT at ~0.9 Ma, AIS ice volume increased and its orbitally-driven changes began to synchronize with global climate. By ~0.4 Ma, all components of the Antarctic climate and ice-sheet system were locked into a strong orbital rhythm. The weak response of this system to orbital forcing prior to 1.5 Ma indicates sensitivity thresholds for the Southern Ocean and the AIS and the increased response to CO_2 forcing since then. Our findings provide new insights into understanding key changes that accompanied the MPT in the Southern Hemisphere as well as the means to benchmark the sensitivity of existing earth-system models to external forcings. This pertains to both the carbon-cycle and the ice-sheet components, both of which are crucial for future projections of climate-carbon-cycle feedbacks and sea-level rise.

Geomorphology and seismic-stratigraphic framework of Ross Bank Ice Rise Rim Moraines

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Ross Bank is a broad submarine bank in central Ross Sea approximately 100 km north of the RIS calving front. A large area of the bank crest rises above 300 meters water depth (~3000 km2). The crest of the bank rises to 170 m water depth. From the crest, the east flank dips steeply into Glomar Challenger Basin. The west flank dips gently into Pennell Basin. To the north, the bank crest gradually deepens and narrows. On the south end, Ross Bank ends abruptly in deep water. Its depth and location strongly suggest that the bank was a major pinning point of the Ross Ice Shelf during the post-LGM after grounded ice retreated from the adjacent basins, Pennell and Glomar Challenger basins. Here we characterize Ross Bank geomorphology and stratigraphy using a grid of multichannel seismic data acquired during expedition NBP2301/2. The available age control from previous studies suggests that a post-LGM ice rise first existed on Ross Bank following ice-stream retreat in Glomar Challenger and Pennell basins after 15.1 kyr BP and 11.5 kyr BP. Our analysis shows that ice rise rim moraines are recognized on high-resolution multibeam bathymetry are mostly too small to be easily resolved with seismic data. In the subsurface, the bank is composed of semi-horizontal sedimentary strata. Lower Miocene strata are exposed on the bank flanks. The strata include grounding-zone wedges and thin-bedded units. The available core data suggests that a thin (less than 2 meters) residual glacial marine deposit is widespread on the bank crest above 400 meters water depth.

Can Partial Loss of Lateral Shear Cause an Ice Shelf to Collapse? A Case Study on Pine Island Glacier

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Ice shelves provide a crucial buttressing stress that resists the seaward flow of ice through interactions with pinning points and slower-moving ice or rock in shear margins. When an iceberg calves off an ice shelf, it can remove the connection of the ice to buttressing points. The exact consequences of this decoupling are unclear, especially as it relates to ice shelf collapse. We use Pine Island Glacier (PIG) as a case study in ice dynamics after a potentially destabilizing calving event. Between 2017 and 2020, the Southern shear margin of PIG migrates 5 km outwards from the main trunk of the glacier, accompanied by a visible increase in damage in Sentinel-1 imagery. This migration is possibly triggered by a calving event in 2017, potentially decoupling the ice shelf from the previous shear margin. After the 2017 calving event, we observe a significant decrease of inferred compressive and shear stresses across the entire PIG ice shelf, resulting in almost the entire ice shelf transitioning to a tensile stress regime. We hypothesize that this transition to an almost purely tensile stress regime over the broader ice shelf in response to a relatively small change in the coupling between the fast-flowing ice shelf and slow-moving surrounding ice is a primary mechanism for ice-shelf collapse. As a first step to investigating this hypothesis, we aim to replicate these observations using the Icepack Glacier Model, creating an idealized ice shelf with similar boundary conditions to PIG. We investigate how ice velocity, thickness, and principal stresses change as portions of one shear margin decouple. Once we can replicate our observations in the model, we plan to run the model forward to see how a radical shift in stress regime affects future ice shelf stability.

Passive Seismic Imaging of Subglacial Conditions on Thwaites Glacier

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Subglacial bed-type (bedrock or sediment) is a significant control on fast glacier-motion. Geophysical techniques provide a relatively efficient means to explore variations in bed type. The GHOST project collected a range of geophysical datasets to explore variability in bed type beneath Thwaite glacier including active source seismic and radar measurements. Over the course of two seasons an array of ~ 200 Magseis Fairfield ZLand 3C nodal seismometers were deployed on Thwaites. The primary goal of this array was to record glacier generated seismicity to explore subglacial dynamics via subglacial stick-slip events and ice dynamics via crevasses generated seismicity. We explore the potential use of this seismic array to image bed type using passive source seismic methods. We will present initial results using two complimentary methods. First, we use the receiver function method, which leverages the recording of earthquakes to identify converted waves that are produced by significant material boundaries, such as those that occur at the ice-bed interface or between sediment-bedrock interfaces. Second, we explore the use of ambient-noise seismic-imaging to measure seismic surface waves traveling across the network. We then use these surface-wave measurements to measure phase velocities which can then be used to identify the presence of large sedimentary layers. We will present initial results of spatial variability in sedimentary structure across our study area and how these are related to variations in basal conditions and flow-speed of Thwaites Glacier. Finally, we will show how these data can be used to extract information about sediment properties that can be linked interpreted in terms of physical properties that influence ice sheet flow speed such as porosity.