Student Awards Form

# WAIS Workshop 2023 Agenda (all times CDT)

**Cloquet Forestry Center**
**Cloquet, MN USA**

## Monday, September 25

| | | |
|---|---|---|
| 4:00 pm – 8:00 pm | Check in: Pick up badges, room keys (check in Wednesday and Thursday will be available during breaks in the agenda) | CFC Cabin 36 |
| 5:00 pm – 5:30 pm | WAIS Workshop Steering Group Meeting: All are welcome to join to discuss the future of WAIS Workshops | CFC Auditorium |
| 6:00 pm | Icebreaker and pizza dinner | CFC Cabin 36 |

## Tuesday, September 26 – All oral presentations in CFC Auditorium

*Presenters upload slides by 7 am here*

Breakfast: 7:00 am – 8:00 am

| Session 0 | Welcome | Presenter |
|---|---|---|
| 8:00 am | Welcome to WAIS Workshop 2023 | WAIS Committee |
| 8:15 am | Local Introduction | |

| Session 1 | New Technology & FAIR Science | Presenter |
|---|---|---|
| 8:30 am | Phase-sensitive radar measurements of englacial strain rates in diverse glacial settings | Jonathan Kingslake |
| 8:40 am | ALPACA: Automated Lightweight Portable Analyzer for C-Axes | Merlin Mah |
| 8:50 am | Open Polar Radar Software and Services to Standardize Radar Echograms: Progress and Examples | Knut Christianson (invited) |
| 9:00 am | Discussion | All |

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|---|---|---|
| 9:20 am | One minute poster teaser pitches (upload **one** slide here by 7:00 am) | |

Refreshment Break: 10:20 am – 10:40 am

| Session 2 | Atmosphere & Ocean Drivers I | Presenter |
|---|---|---|
| 10:40 am | Buoyancy Gradient-Driven Flow of Warm Subsurface Waters Into Geometrically Complex Ice Shelf Cavities | Garrett Finucane |
| 10:50 am | The Effects of Turbulent Mixing on Seawater Intrusion: Dynamics and Melting | Madeline Mamer |
| 11:00 am | Evaluating Atmospheric River Signatures in West Antarctic Ice Core Isotopic Records | Emma Robertson |
| 11:10 am | Ice on the Move: What observing the underside of Antarctica's ice shelves now can tell us about future sea level rise | Peter Washam |
| 11:20 am | Historic Shear Margin Migration at Conway Ice Rise: An Integrated Data-Model Approach | Paul Summers |
| 11:30 am | Coastal polynyas enable transitions between high and low West Antarctic ice shelf melt rates | Ruth Moorman |

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|---|---|---|
| 11:40 am | Helicopter-deployed ocean sensors reveal meltwater-driven buoyant upwelling in the Thwaites Glacier Tongue cavity, West Antarctica | Jamin Greenbaum |
| 11:50 am | Discussion | All |

Lunch: 12:15 pm – 1:15 pm

| Session 3 | Funders' Perspective | Presenter |
|---|---|---|
| 1:15 pm | View from NASA | NASA |
| 1:35 pm | View from NSF | NSF |

| Session 4 | Piecing the Puzzle Together I | Presenter |
|---|---|---|
| 1:55 pm | Insights into mélange-calving interactions and glacier stability using SAR-based velocity mapping of mélange within Greenland fjords | Michalea King (invited) |
| 2:05 pm | Synchronous, hydro-fracture-driven drainages of neighboring supraglacial lakes and their impact on ice flow | Stacy Larochelle |
| 2:15 pm | Scars of tectonism promote ice-sheet nucleation from Hercules Dome into West Antarctica | Andrew Hoffman |
| 2:25 pm | The impact of frozen sediments on basal friction for soft-bedded glaciers and ice streams | Luke Zoet |
| 2:35 pm | Accelerating understanding of Ice Sheet – Solid Earth feedbacks and future sea-level change | Terry Wilson |
| 2:45 pm | Discussion | All |

Refreshment break: 3:10 pm – 3:30 pm

| Session 5 | WAIS Community Planning | Presenter |
|---|---|---|
| 3:30 pm | WAIS Community Plan mini-workshop | WAIS Organizing Committee |

Poster Session I: 4:30 pm – 5:30 pm
Dinner: 5:30 pm – 6:45 pm
Early-career and mid-/senior-career breakouts: 7:00 pm – 8:00 pm (locations TBD)

**Wednesday, September 27**
*Presenters upload slides by 7 am here*

Breakfast: 7:30 am – 8:30 am

| Session 6 | Observational & Modeling Gaps I | Presenter |
|---|---|---|
| 8:30 am | Antarctic RINGS: A SCAR Action group to understand the Antarctic Coastal zone through international collaboration | Kirsty Tinto (invited) |
| 8:40 am | Outcrop perspectives on spatial and temporal effects of topography on the marine-terminating Puget Lobe of the Cordilleran Ice Sheet | Marion McKenzie |
| 8:50 am | How much, how deposited, how old – what can we learn from sediments in Pine Island Bay? | Rob Larter |

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|---|---|---|
| 9:00 am | RAICA: Korea-US collaboration establishing a Ross-Amundsen Ice Core Array to better understand West Antarctic coastal climate | Peter Neff |
| 9:10 am | Radiostratigraphic Connection between the South Pole and Hercules Dome | Shivangini Singh |
| 9:20 am | Accessing ice rheology using physics-informed deep learning | Yongji Wang |
| 9:30 am | Discussion | All |

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

| **Session 7** | **Uncertainty Quantification** | **Presenter** |
|---|---|---|
| 10:20 am | Global mean sea level exceeded preindustrial levels in the Holocene | Roger Creel (invited) |
| 10:30 am | Investigating Stress States and Rift Propagation on Pine Island Glacier with Time-Dependent Strain-Rate Fields | Sarah Wells-Moran |
| 10:40 am | 123 years of Antarctic surface mass balance and atmospheric circulation history: Implications for Antarctica's contribution to sea level rise | David Scheinder |
| 10:50 am | Controls on the modeling of ice deformation | Meghana Ranganathan |
| 11:00 am | Discussion | All |

| **Session 8** | **WAIS in the Community** | **Presenter** |
|---|---|---|
| 11:25 am | Virtual Ice Community Engagement (VICE) Squads: Building Inclusivity and Collaboration in Cryospheric Sciences | Jeremy Bassis |
| 11:35 am | ICECReW: Connecting and Training Icy Early Career Researchers with an annual workshop | T.J. Fudge |
| 11:45 am | Organizing WAIS Workshop: Tweaks and turns from the past five years | WAIS Organizing Committee |
| 11:55 am | Discussion | All |

Lunch: 12:20 pm – 1:20 pm

| **Session 9** | **Atmosphere & Ocean Drivers II** | **Presenter** |
|---|---|---|
| 1:20 pm | Accelerated Antarctic ice loss through ocean forced changes in subglacial hydrology | Sophia Pinter |
| 1:30 pm | Ice-Penetrating Radar Evidence for Widespread Seawater Infiltration in West Antarctic Ice Shelves | Riley Culberg |
| 1:40 pm | Late 20th-century Increase in Antarctic Snow Accumulation Drives Modest Mitigation of Sea Level Rise | T.J. Fudge |
| 1:50 pm | The history of CDW upwelling and heat delivery to the Amundsen Sea Embayment during the 20th century: a paleoceanographic perspective | Svetlana Radionovskaya |
| 2:00 pm | Discussion | All |

Refreshment Break: 2:20 pm – 2:40 pm

| Session 10 | Piecing the Puzzle Together II | Presenter |
|---|---|---|
| 2:40 pm | A mid-Holocene unpinning of the Ross Ice Shelf from Ross Bank: one down, two to go! | Benjamin Lindsay |
| 2:50 pm | Unlocking the subglacial time machine: Constraints on the climate sensitivity of ice sheet behavior from subglacial precipitates | Slawek Tulaczyk |
| 3:00 pm | The formation of tidally-modulated landforms at rapidly retreating grounding lines | Kasia Warburton |
| 3:10 pm | Radar-Derived Crystal Orientation Fabric Suggests Divide Stability at Hercules Dome During the Last Ice-Sheet Deglaciation | Benjamin Hills |
| 3:20 pm | Glacial sequences and surficial features appear in Antarctic GeoMAP, a continent-wide detailed geological map dataset of Antarctica | Christine Siddoway |
| 3:30 pm | Discussion | All |

Poster Session 2: 4:00 pm – 5:30 pm
Dinner: 5:30 pm – 7:00 pm

**Thursday, September 28**
*Presenters upload slides by 7 am here*

Breakfast: 7:15 am – 8:15 am

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|---|---|---|
| 8:15 am | ECR Breakout Report Back | Breakout Leads |

| Session 11 | En- and Subglacial Advances | Presenter |
|---|---|---|
| 8:30 am | Subglacial discharge accelerates ocean driven retreat of Aurora Subglacial Basin outlet glaciers over the 21st century | Tyler Pelle |
| 8:40 am | Towards 3D englacial ice velocity fields using airborne radar interferometry | Thomas Teisberg |
| 8:50 am | Recent onset of drainage of Subglacial Lake Engelhardt upstream of a retreating grounding line, West Antarctica | Bryony Freer |
| 9:00 am | Subglacial Precipitates Constrain Timing and Forcing of Ice Lowering in a Ross Sea Outlet Glacier During Termination I | Jessica Gagliardi |
| 9:10 am | Discussion | All |

Refreshment Break: 9:30 am – 9:50 am

| Session 12 | Observational & Modeling Gaps II | Presenter |
|---|---|---|
| 9:50 am | The Uncertain Future of Antarctica: Impact of Extreme Weather Events | Xun Zou |
| 10:00 am | On the impact of seawater intrusions on basal melt rates in the grounding zone of Thwaites Glacier, Antarctica | Ratnakar Gadi |
| 10:10 am | Using surface topography to fill gaps between ice-penetrating radar surveys: A new Antarctic map of mesoscale bed topography | Helen Ockenden |
| 10:20 am | ICESat-2 Measurements of Supraglacial Lake Depths Across the Antarctic and Greenland Ice Sheets 2018-2023 | Philipp Arndt |

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|---|---|---|
| 10:30 am | Radioglaciological window to the bed of Thwaites Glacier | Robert Bingham |
| 10:40 am | Discussion | All |

| **Session 13** | **Actionable community discussions** | **Presenter** |
|---|---|---|
| 11:00 am | To be finalized | All |

Lunch: 12:00 pm to 1:00 pm

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

· CryoCloud Collaborative Jupyter Hub

· Data and DAACs

## Posters

| Title | Presenter |
|---|---|
| Quantifying the Influences of Ice Rheology Parameters on the Ice Flow Response to Climate Forcing | Jaela Allen |
| Characteristics of the Bed of Thwaites Glacier from a Seismic Profile of the Center Flow Line. | Sridhar Anandakrishnan |
| Assessing West Antarctic Ice Rise Climatology and Ice Core Site Suitability Using Reanalysis and Back-Trajectory Analysis | Julia Andreasen |
| West Antarctic pedogenic carbonates record insolation driven snow melt | Terry Blackburn |
| Investigating Subglacial Geology Near West Antarctic Ice Sheet Divide | Louise Borthwick |
| Investigating the influence of debris-bed friction on basal slip using a numerical ice flow model | Jeremy Brooks |
| Bending, Crevassing and Rifting of Ice Shelves: Comparison of Analytic and Numerical Models with Observations | W Roger Buck |
| Study of the Grounding Zone of Getz Ice Shelf, Antarctica Using Differential Synthetic-Aperture Radar Interferometry | Hanning Chen |
| The 50-Year History of an Ice Doline on the Amery Ice Shelf, Antarctica | Chase Chivers |
| REMA Version 2: A New Standard in Antarctic Digital Elevation Data | Michael Cloutier |
| Filling the Holes: Submesoscale Instabilities in Ice Shelf Cavities | Kaylie Cohanim |
| Late Miocene to Pleistocene lithostratigraphic changes from IODP Site U1522 on the Ross Sea Continental Shelf | Kniya Duncan |
| An Examination of Surface Melt Inducing Atmospheric Rivers over the Antarctic Peninsula | Brendan Eckerman |
| Improving Bathymetry Estimates Beneath Amundsen Sea Ice Shelves Using a Geostatistical Markov Chain Monte Carlo Inversion of Airborne Gravity Data | Michael Field |
| Link Between Iceberg Melt and Diatom Productivity Demonstrated Through Analysis of Mid-Pliocene Amundsen Sea Interglacial Sediments | Heather Furlong |
| A Physics-Based Parameterization to Predict Mean Depth and Areal Coverage of Supraglacial Melt Ponds | Danielle Grau |
| Constraining subglacial till properties from acoustic techniques | Dougal Hansen |
| Water Column Properties and Ice-Ocean Interactions Beneath Erebus Glacier Tongue, Antarctica | Veronica Hegelein |
| Beardmore Ice Shelf melt channels and their connection to Ross Ice shelf basal bodies | Andrew Hoffman |
| Antarctic grounded icebergs from WorldView stereo-photogrammetry and ICESat-2 laser altimetry | Susan Howard |
| Impacts of tidewater glacier advance on iceberg habitat | Lynn Kaluzienski |
| US-SCAR, Representing the US in the Scientific Committee for Antarctic Research | Lynn Kaluzienski |
| Glacial isostatic adjustment contributes to retreat of stable grounding line zones over the last deglaciation in the Ross Sea | Sam Kodama |

| Title | Presenter |
|---|---|
| Onshore-Offshore Geologic Investigation of the Amundsen Sea Embayment | Caitlin Locke |
| Antarctic Atmospheric Rivers in the Present and Future Climates | Michelle Maclennan |
| Using clustering algorithms to characterize basal morphology | Samuel Marcus |
| Using Diatom Assemblages from Deglacial to REcent to Study Ice-Ocean Interactions Offshore the Totten Glacier, East Antarctica | Rachel Meyne |
| Deepening the glacial history of the McMurdo Dry Valleys, Antarctica by fingerprinting glacial tills with provenance tools | Dan Morgan |
| Influence of Cyclic Effective Pressure Oscillations on Glacial Slip | Natasha Morgan-Witts |
| Glacial sequences and surficial features within Antarctic GeoMAP, the new open-access geological map dataset of Antarctica | Paul Morin |
| Englacial stratigraphy of the Ellsworth Subglacial Highlands, West Antarctica | Felipe Napoleoni |
| Insights into Subglacial Hydrology from Sedimentological Analysis of an Esker and Experimental Simulations | Francisca Nunez Ferreira |
| Antarctic Subglacial Trace Metal Cycling Tracks Climate Across Glacial Termination III | Gavin Piccione |
| A Simulation Approach to Characterizing Sub-Glacial Hydrology | Christopher Pierce |
| Insights on bottom current variability as determined from sedimentary analyses of shallow bathymetric highs | Lindsay Prothro |
| Spatial and Temporal Patterns in Ice Shelf Rift Mélange Across Antarctica From Combined Satellite Observations | Chancelor Roberts |
| Fragilariopsis kerguelensis Morphometry as a Sea Surface Temperature Proxy for the Late Pleistocene Southern Ocean | Joseph Ruggiero |
| East Antarctic Age-Depths Constrained from Englacial Architecture | Becky Sanderson |
| The role of footloose-type calving at the front of the Ross Ice Shelf | Nicolas Sartore |
| Multi-decadal Record of Sensible-Heat Polynya Variability from Satellite Optical and Thermal Imagery at Pine Island Glacier, West Antarctica | Elena Savidge |
| Drivers and Mechanisms of Rift Propagation: Initial Observations on the Thwaites Eastern Ice Shelf, West Antarctica | Meghan A Sharp |
| Observing persistent polynyas at the Antarctic coastline with year-round ICESat-2 surface elevations and Landsat temperature fields | Tasha Snow |
| Modernizing curation at OSU-MGR: New technologies and FAIR-enabled science for Antarctic and Southern Ocean sediment core samples | Val Stanley |
| IODP 1537: The Correlation Between Scotia Sea Diatom Abundances and Climate Over the Last 130,000 Years | Garrett Strittmatter |
| A unique sample and data resource for ice-sheet & environmental change: the Polar Rock Repository | Jamey Stutz |
| High-Resolution Diatom Analysis Reveals Oceanographic, Glacial, and Climatic Changes in the Western Amundsen Sea, Antarctica | Magkena Szemak |

| Title | Presenter |
|---|---|
| The United States Antarctic Data Center (USAP-DC): A FAIR resource for data archive and re-use | Kirsty Tinto |
| Integrating Basal Melt Rates of Ross Ice Shelf from ROSETTA-Ice Airborne Sounding Radar Survey and NASA/UCI Ice Sheet System Model | Kiera Tran |
| Mass changes in Antarctica using GRACE and GRACE-FO MWI and LRI data | Isabella Velicogna |
| Ocean-Driven Melting near and within Ice Shelf Basal Channels and Crevasses | Sarah Villhauer |
| Sediment Flux in the Eastern Amundsen Sea: How did it get there and when? | Julia Wellner |
| Constraining Ice Core Paleofire Proxies During Dansgaard-Oeschger 8 | Caroline Wexler |
| Targeting sites of subglacial volcanism in the central West Antarctic rift system | Duncan Young |
| An Improved Parameterization of the Ice-Ocean Boundary Layer | Ken Zhao |
| The effects of non-Newtonian, transient and Newtonian viscosities on GIA-induced crustal motions and their implications for GPS observations in Antarctica | Shijie Zhong |

# Quantifying the Influences of Ice Rheology Parameters on the Ice Flow Response to Climate Forcing

**Ms Jaela Allen**[1], Dr Meghana Ranganathan[2], Dr Alexander Robel[2]
*[1]Miami University, [2]Georgia Institute of Technology*

The rate of ice flow partly controls mass loss from the Antarctic Ice Sheet. When assessing uncertainty in future ice sheet behavior, it is important to quantify the contribution from ice flow. In Glen's Flow Law, stress is related to strain rate by two parameters: the flow rate parameter, A, and the stress exponent, n. Uncertainty in A and n produce uncertainties in projections of future ice flow, but the magnitude of this effect is not fully constrained. Here, we use a flowline model to simulate an idealized ice sheet and demonstrate the effects of physically-reasonable variations in n and A on ice sheets at various timescales. These simulations are designed to illustrate how uncertainty differences in n and A result in different projections of ice retreat, velocity, mass loss, and thickness, even when starting from a single initial ice sheet state. These simulations show that an increase in the flow exponent (n) produces less ice sheet retreat over 10,000 years. Varying magnitudes of A can affect whether the glacier retreats and advances, where smaller values of A produce ice sheet advance and mass gain. Lastly, the effects of ice rheology are more pronounced after approximately 1000 years. These results suggest that, on long timescales, n and A significantly affect ice sheet behavior and thus uncertainties in these parameters produce significant uncertainties in future behavior.

# Characteristics of the Bed of Thwaites Glacier from a Seismic Profile of the Center Flow Line.

**Dr Sridhar Anandakrishnan**[1], Dr Coen Hofstede[2], Dr Ole Ziesing[2], Dr Olaf Eisen[2], Dr Andrew Smith[3], GHOST Project Team[1,2,3]
*[1]Penn State University, [2]Alfred Wegener Institute, [3]British Antarctic Survey*

We present the results of a  reflection seismic profile of the center flow line of Thwaites Glacier, West Antarctica. The survey was conducted from the region of "GHOST Ridge" (the farthest downglacier we could travel, approximately 70 km from the current grounding line) and was 208 km in length. Along the line the ice thickness varied from 1400 m to 2800 m. The profile was collected in 14 days in January 2023 using a vibratory (vibroseis) source at a 75m source spacing and a 1.5 km long 60-channel towed snow streamer with a 25m group interval.

The bed consists of regions of higher topography that are 10 to 20 km long areas, with considerable variability (blocky bedforms, 100-200 m high and several km long) interspersed with 30 to 60 km long smooth gently dipping areas. The vibroseis signal penetrated ~200 m into the bed revealing the internal structure and stratigraphy of the bed.. Interpretation has to be treated with caution as the subglacial bedforms have off-nadir reflections. The blocky structures have a steep unstratified stoss side followed by a kilometers long flat stratified lee side ending steeply and are identified as Crag-and-Tail features. The smoother slightly dipping areas consist of basins (2-3km long, 20-30 m deep). The center of the profile has a large, 20 km long and 110 m deep, basin. Throughout the profile, 100-150 m above the bed, we see englacial reflections, stronger above the higher areas with Crag-and-Tail features and weaker at the smoother areas. The sequences of englacial reflections vary from single at the weaker areas to 250 m at the strongest areas.

# Assessing West Antarctic Ice Rise Climatology and Ice Core Site Suitability Using Reanalysis and Back-Trajectory Analysis

**<u>Ms Julia Andreasen</u>**[1], Dr Peter Neff[1], Dr Brooke Medley[2]
*[1]University of Minnesota, [2]NASA Goddard Space Flight Center*

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 (SMB) 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 climatology and airsheds of ice rises along the WAIS coast–features which are ideal locations for ice core recovery and paleoclimate reconstructions. The WAIS coast ice rises in this study include Farwell Island, Noville Peninsula, Sherman Island, King Peninsula, Canisteo Peninsula, Bear Peninsula, Martin Peninsula, Wright Island, Carney Island, Siple Island, Dean Island, and Guest Peninsula.

Precipitation at these sites has a range of drivers, including atmospheric pressure anomalies (high and low), westerly wind strength, and atmospheric rivers, all of which can promote northerly moisture transport and thus snowfall to coastal ice rises depending on their longitude. We investigate the climatology of these ice rises with ERA5 and MERRA-2 reanalyses and assess each location for seasonal to annual temperature and precipitation trends. 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 will reveal how airsheds differ across the coast, with increased snow accumulation across eastern WAIS and decreased accumulation over western WAIS, and will be compared to radar-derived snow accumulation time series (Operation IceBridge). This comparison is integral to improving understanding of regional ocean-atmosphere influences on snowfall as well as surface mass balance calculations in the vicinity of ice shelves for future ice core sites. These future ice cores, collected under the new Ross-Amundsen Ice Core Array (RAICA) effort, will expand spatial and temporal climate perspective beyond what can be gained from climatology analyses and snow accumulation alone–adding insight into past fluctuations in temperature, sea ice conditions, winds, atmospheric river frequency and intensity, and more.

# ICESat-2 Measurements of Supraglacial Lake Depths Across the Antarctic and Greenland Ice Sheets 2018-2023

**Mr Philipp Arndt**[1], Dr Helen Amanda Fricker[1]
[1]*University of California San Diego*

Accurate projections of Antarctica's contribution to future sea level rise require better understanding of relevant mass balance processes for inclusion in ice sheet models. Seasonal surface melting is widespread across the Antarctic ice sheet's coastal margins, forming complex supraglacial hydrological networks that evolve quickly in response to regional atmospheric drivers. Pooling and storage of meltwater in supraglacial lakes can weaken and fracture the floating ice shelves, and has been linked to their collapse by hydrofracture. This ultimately leads to accelerated discharge of upstream grounded ice into the ocean, which causes sea level rise. In a warming climate, surface hydrology on Antarctica's grounded ice is likely to become increasingly similar to Greenland's current ablation zone, where supraglacial lake drainages can lead to bedrock lubrication and speed-up of grounded ice flow. Both this "Greenlandification" of the Antarctic margin, and the loss of ice shelves are highly uncertain factors in future projections of Antarctica's contribution to sea level rise. To understand the underlying mechanisms and assess their impacts, we need accurate estimates of ponded water volumes on both ice sheets. Due to these lakes' inaccessible locations and ephemeral nature, few direct meltwater depth measurements exist. Current estimates are inferred from passive optical satellite imagery, based on poorly-constrained models of light attenuation in water. Recent studies have shown that NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) photon-counting laser altimeter is capable of obtaining accurate supraglacial lake depths. Where the instrument's green light is able to penetrate the water column and reflect back from the lake bed, the photon-level data product (ATL03) contains a vertical point-cloud transect, showing both the lake's surface and its bed. In principle, ATL03 can be used to determine water depth by fitting lines to both the lake's flat surface and to its bed below, taking their elevation difference, and correcting for the refractive index for the speed of light in water. However, the ATL03 data catalog holds 500 terabytes of unstructured point cloud data, and less than 0.01% of data over the ice sheets contains melt lakes, which has made it challenging to use for this application. We developed a fully automated and scalable algorithm for lake detection and depth determination at 5 m along-track resolution, making it possible to extract melt lake depths from ICESat-2's entire data catalog in an efficient and reproducible manner. We present the resulting complete data set of supraglacial lake depths across both ice sheets between October 2018 and April 2023. Where available, this data includes contemporaneous cloud-free Sentinel-2 surface reflectance values that can be used to tune and validate existing imagery-based algorithms, or to train new models. This enables accurate quantification of melt lake volumes on the ice sheets and will improve our understanding of the impacts that meltwater pooling has on the future stability of the Antarctic ice sheet, and its contribution to sea level rise.

# A mid-Holocene unpinning of the Ross Ice Shelf from Ross Bank: one down, two to go!

**Mr Benjamin Lindsay**[1], Dr Philip Bart[1]
[1]*Louisiana State University*

The Ross Ice Shelf (RIS) calving front is currently controlled by two pinning points. On its northwestern side, the RIS is pinned to Ross Island, a subaerial volcanic island. On its northeastern side, it's pinned to Roosevelt Island, a shallow submarine bank. A third pinning point formerly existed in central Ross Sea at Ross Bank, a broad, shallow submarine bank that is located about 100 km north of the current calving front. Here, we present our analyses of core from expeditions NBP9407 and NBP9601 to constrain the timing of this unpinning event. Legacy core from the crest of Ross Bank recovered an unconsolidated and fossiliferous sand-rich surface unit that overlies finer-grained subglacial and sub-ice-shelf sediments. The fossil content and sand is attributed to active winnowing of the post-glacial sediments by strong ocean currents. The oldest radiocarbon date from a barnacle plate in this winnowed sediment indicates that RIS had unpinned and its calving front moved south of the bank crest by 5698 ± 162 cal. years BP. It is not yet clear why the RIS would have unpinned from Ross Bank in the mid-Holocene but the event has left only two pinning points stabilizing RIS, the world's largest mass of floating ice.

# Virtual Ice Community Engagement (VICE) Squads: Building Inclusivity and Collaboration in Cryospheric Sciences

**Jeremy Bassis**[1], Dr. Jessica Meija[2], Dr. Leigh Stearns[3], Dr. Lauren Miller[4]
*[1]University Of Michigan, [2]University of Buffalo, [3]University of Kansas, [4]University of Virginia*

Despite significant growth over the past decade, the cryosphere community has failed to diversify. Furthermore, the pandemic and recent report highlighting sexual harassment, assault, and stalking at United States bases in Antarctica have further emphasized the lack of equity and inclusivity within the broader cryosphere community. Here we present a newly founded project that aims to tackle the lack of diversity in the cryosphere community. This project, Virtual Ice Community Engagement (VICE) Squads, aims to address the under-representation of diverse voices in cryospheric sciences by fostering a more inclusive community with shared values, norms, and a sense of belonging that can serve as both support and refugium for marginalized scholars and allies within the cryosphere community. VICE Squads will be virtual networks of cryosphere scholars, cutting across geographical, career, and disciplinary boundaries, formed around either shared interests and geographic regions. These squads will encourage inclusivity, storytelling, sharing of perspectives, and professional development, providing a forum for inter/multidisciplinary discussions at the forefront of cryospheric science. In addition to VICE Squads, we aim to host professional development workshops and conference "watch parties" to foster networking and interaction between scholars unable to attend conferences in person.

## Radioglaciological window to the bed of Thwaites Glacier

**Professor Robert Bingham**[1], Ms Helen Ockenden[1], Dr Julien Bodart[1], Dr Andrew Smith[2], T ITGC-GHOS[3]
*[1]University of Edinburgh, [2]British Antarctic Survey, [3]ITGC-GHOST*

Thwaites Glacier, identified as West Antarctica's weakest underbelly, holds an estimated 65 cm of potential global sea-level rise, and is already experiencing dramatic thinning and retreat in its lower reaches. These phenomena have motivated an international consortium of researchers – the International Thwaites Glacier Collaboration – to focus a programme of field-data acquisition on the glacier ultimately to inform modelling projections of the catchment's future. Two of the key inputs required to improve modelling projections are the shape and rheology of the ice-sheet bed, which formed the focus of the GHOST (Geophysical Habitat of Subglacial Thwaites) project's first programme of geophysical measurements on Thwaites Glacier in the austral season 2022/23.

We present here a first view of the bed underlying a 10 km x 20 km patch of Thwaites Glacier sounded by high-frequency ground-penetrating radar (the British Antarctic Survey's DEep-LOoking Radio Echo Sounder; DELORES). The surveyed site is located 70 km upstream of the grounding zone but, crucially, immediately upstream of a feature, GHOST Ridge, which marks a potential point of stability under projected grounding-zone retreat and is also the upstream limit of the highly crevassed terrain that forms the glacier's lowest reach.

The results show a highly variable and mixed subglacial terrain and we highlight the following. 1) The subglacial landscape is characterised in part by a network of channels which appear fluvial in form and largely match predicted hydrological pathways draining subglacial lakes from upstream; 2) the mesoscale shape of the landscape matches well with its predicted form inverted from the satellite-derived surface elevation and velocity fields; and 3) the basal reflectivity is highly variable, reflecting both the likelihood of a mixed sediment/rock bed and the persistent challenges of incorporating basal slipperiness accurately into modelling parameterisations.

# West Antarctic pedogenic carbonates record insolation driven snow melt

Mr Noah Brigham[1], **Prof. Terry Blackburn**[1], Jessica Gagliardi[1], Prof. Slawek Tulaczyk[1], Prof. Christine Siddoway[2]
[1]*University of California, Santa Cruz,* [2]*Colorado College*

Changes in paleoclimatic records for global ice volume often coincide with orbitally driven changes in high latitude insolation. It remains unclear, however, how these relatively small changes in insolation influence ice mass, and whether absolute intensity, controlled by precession, or summer duration, controlled by obliquity, exerts a greater control. This is particularly true for Antarctica where temperatures remain below freezing even during peak warming. Here we present a temporal and geochemical record of West Antarctic surface melting, recorded by pedogenic carbonate formation on rocky outcrops. This new paleoclimate archive for past surface melting currently consists of 10 individual samples from 7 different field sites that range from 350 to 2500 m in elevation and span from the Amundsen Sea sector to the Ross Sea sector. Geochemical proxies permit reconstruction of the formation environment and mechanisms, while U-Th geochronologic data constrain the timing of surface melting. Isotopic data support water sourcing from local snow melt, that weathers local rock and saturates calcite through evaporation. More specifically, heavy oxygen and carbon isotopic data confirm calcite formation through the surface (i.e. subaerial) evaporation of local snow melt, while calcite strontium isotopic compositions match that of individual host cobbles, indicating that surface melt extracts salts from each cobble individually. U-Th isochron dates for all dated samples, over the entire continent-scale sample suite, record formation between 1-5 ka. These ages do not scale with cosmogenic exposure dates and each sector contains high elevation sites where calcite formation post-dates the time of ice lowering by tens of thousands of years -- observations inconsistent with melting and calcite formation in response to Holocene ice lowering. Rather these late Holocene U-Th dates coincide both with an increase in melt layer frequency at Siple Dome (Das and Alley, 2008) as well as peaks in summer temperatures extracted from the West Antarctic Ice Sheet Divide ice core (Jones et al., 2023), the latter of which has been interpreted to result from rising precession and Southern Hemisphere summer insolation through the Holocene. A comparison between the time of calcite formation and Southern Hemisphere summer insolation permits estimation of a tipping point in annual maximum summer insolation, of ~555 mW/m$^2$, above which snow is lost from rocky surfaces. The coincidence in calcite formation with time periods marked by rising summer insolation, rather than summer duration, the latter of which declines through the Holocene, supports the role of precession, rather than obliquity in controlling West Antarctic ice mass.

# Investigating Subglacial Geology Near West Antarctic Ice Sheet Divide

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Subglacial topography and geology exert a strong influence on glacier and ice-sheet dynamics. The subglacial geology under Thwaites Glacier and the West Antarctic Ice Sheet (WAIS) has been broadly defined using potential field methods and geologic reconstructions. In this study, we investigate the subglacial geology along a ~30 km long profile near WAIS Divide in the near sub-ice region (100s of meters) to upper crustal structure (few kilometer scale) using long-offset seismic and ground-based gravity-anomaly methods. The seismic results show no clear critically refracted waves that arrive before the direct waves, indicating that the layer immediately below the ice has a seismic velocity less than or similar to that of the ice such that the refracted wave either doesn't exist or is obscured. Gravity anomalies show small variation of about 6 mGal along the profile, with a low in anomaly values at the downstream end of the line. These results suggest that the ice in this area lies on top of relatively homogenous unconsolidated sediments or sedimentary rocks. The subglacial geology in this area has not been defined previously. Therefore, our results add new information on the geology and conditions beneath the Thwaites Glacier basin and the WAIS.

# Investigating the influence of debris-bed friction on basal slip using a numerical ice flow model

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Slip laws relate the slip velocity of a glacier to its basal shear stress and are necessary relations for modeling the motion of glaciers and ice sheets. Existing slip laws describe vastly different physical behavior, from unbounded “rate-strengthening” power law behavior to bounded Coulomb-like behavior to “rate-weakening” behavior in which shear stress decreases at higher slip velocities. When implemented in ice sheet models, the choice of basal slip law sensitively affects glacier dynamics and predictions of grounding line migration and sea level rise. Therefore, a key objective of glaciological research is to improve physical parameterizations of basal slip for use in ice sheet models. Previously derived slip laws assume that basal ice is “clean” without entrained rock fragments and sediment, and that the ice is separated from the underlying bed by a thin, frictionless water film. However, observations at the base of real glaciers confirm that basal ice is typically dirty and debris-rich. The friction between basal ice debris and the bed is therefore an understudied source of basal drag that is rarely considered in slip laws, but may be of primary importance in mixed bed (hard and soft) locations such as Thwaites Glacier, Antarctica.

Here, we determine the effect of debris-bed friction on basal slip laws using the finite element ice flow model Elmer/Ice. We conduct simulations for periodic two-dimensional sinusoidal and stepped bed topography for a range of velocities using “clean ice” conditions. Once the simulation geometry reaches steady state for a given prescribed horizontal velocity, we use outputs for effective pressure, cavity geometry, and bed-normal ice velocity to calculate basal drag due to debris-bed friction for a variety of debris-bed contact force theories. Our results demonstrate in general that debris-bed friction is a source of drag in basal slip laws, but the magnitude of drag is heavily dependent on the chosen debris-bed contact force theory and the size distribution and areal concentration of basal debris. Future work will investigate debris-bed friction for three-dimensional geometries and include model simulations informed by experimental results of slip over a stepped bed.

# Bending, Crevassing and Rifting of Ice Shelves: Comparison of Analytic and Numerical Models with Observations

**Dr. W Roger Buck**[1], Emily Glazer[1], Ching-Yao Lai[2]
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The breakup of ice shelves can lead to acceleration of adjacent grounded glaciers, as was well documented for the disintegration of the Larsen B ice shelf. Rifts involved in shelf breakup likely begin as crevasses that initially cut only part of the way through an ice shelf. Rifts may form when a crevasse cuts entirely through an ice shelf. In recently published work we used a novel treatment of the opening of seawater-filled basal crevasses that, unlike previous studies, allows elastic bending of the floating ice shelf. The work suggests that basal crevasses could propagate high enough to link with surface crevasses to form rifts only if the buttressing force was zero or negative.  However, ice shelves appear to rift and disintegrate even for moderate positive buttressing.  A simple force balance calculation and numerical models show that, if freshwater fills crevasses, a through-going crevasse could open for buttressing comparable to that inferred for rifts (i.e. for a buttressing number of ~ 0.2).

The bending of ice shelf edges has been a focus of much attention for two reasons. First, some shelf edges, including many in West Antarctica, show upward bending while simple theory suggests that they should tend to bend down due to hydrostatic stress at the shelf front. Second, surface water may pool in the characteristic “moat” inward of the “rampart” at the upwardly bent shelf edge and this water may help drive calving.  The widely discussed explanation for up-bending is that it is a result of the upward load of a “bench” of ice below the sea surface attached to the shelf edge. We consider an alternative idea that does not depend on a bench. Our numerical results show that, for a range of rheologic properties, warm ice surfaces result in downward shelf bending, while for colder, surfaces we predict upward bending of the edge. We describe an analytic treatment of the dependence of bending in a freely floating (and extending) ice shelf with power-law rheologic parameters for ice.  The results of the analysis are confirmed with a fully two-dimensional numerical model of viscoelastic deformation of a floating ice shelf.

# Study of the Grounding Zone of Getz Ice Shelf, Antarctica Using Differential Synthetic-Aperture Radar Interferometry

**Mr Hanning Chen**[1], Dr Eric Rignot[1,4], Dr Bernd Scheuchl[1], Dr Pietro Milillo[2], Dr Mathieu Morlighem[3], Dr Enrico Ciracì[1,4], Mr Jae Hun Kim[1]
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The grounding line marks the boundary where ice transitions from grounded to floating. It plays a crucial role in controlling glacier flow and in turn the contribution of ice sheets to sea level rise. As oceanic tides and atmospheric pressure fluctuate, the grounding line migrates over a region which we name 'grounding zone', which extends beyond the flexure zone where the glacier adapts to flotation. Using a time series of differential radar interferometry from Sentinel-1 and COSMO-SkyMed missions, we measure the grounding zone of Berry Glacier of the Getz Ice Shelf, in West Antarctica from year 2019 to year 2021. The grounding zone extends over more than 10 kilometers, which is several orders of magnitude larger than expected for ice in hydrostatic equilibrium over a non-deformable bed, and is the widest zone ever reported in Antarctica. We find that the migration is not in phase with the oceanic tide, but rather oscillates between three states of grounding line position. The migration reveals intrusions of seawater beneath grounded ice in the range of cm to several 10 cm. The largest migration is 18 km along a deep subglacial trough at the glacier center. The bed trough is several 100 m deeper than represented in BedMachine Antarctica. In 2019-2021, we observe a long-term migration to the west and glacier speed up, which indicates a progressive widening of the glacier. Such seawater intrusions will generate rapid melt of grounded ice at tidal frequencies due to the high entrainment speed of seawater. We expect the results to be of considerable importance for ice sheet modeling because ice sheet models currently do not include such intrusion, yet predict that including them would make the models more sensitive to warmer waters. This work is funded by a grant from the NASA Cryosphere Program.

# The 50-Year History of an Ice Doline on the Amery Ice Shelf, Antarctica

**Chase Chivers**[1], Dr Catherine Walker[1]
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In the Antarctic austral summer, glacial surface melt accumulates into supraglacial lakes and streams and have been observed to increase the occurrence of hydrofracture. Surface melt on Antarctica's floating ice shelves represents one of the largest uncertainties in future projections of mass loss in Antarctica, with projections indicating a potential doubling of melt by 2050. As ice shelves provide a buttressing force to the continental ice, surface melt may play an outsized role in the future stability of the Antarctic Ice Sheet.

"Ice dolines," a feature caused by the rapid drainage of a (typically buried) englacial lake, may be important for the future stability of some ice shelves but have been left relatively understudied. The rapid drainage causes the surface to collapse and leaves behind a semi-circular depression ~>10 m in depth. This has largely been ascribed to hydrofracturing which would allow the meltwater to drain to the underlying sea, possibly aided by tidal flexure of the ice shelf. Even long after the collapse event ice dolines may promote future instability by being a potential weakness in the ice and the depression may aid the collection of meltwater.

Here, we focus on the 50-year observational history of an ice doline on the Amery Ice Shelf in East Antarctica that abruptly collapsed within several days in 2015. We present one of the first documentations of the long-term history of an ice doline prior to collapse, the circumstances surrounding the collapse, and the evolution post-collapse. To investigate this long-term history and collapse, we leverage multiple remote sensing observations (e.g., LandSat imagery, ICESat-2 altimetry), derived products (MEaSUREs ITS_LIVE surface ice velocities), and regional climate (RACMO2.3p2) and tidal (CATS2008) models. We will discuss the evolution of the ice doline prior to collapse, the environmental conditions surrounding the collapse and correlate the factors that lead to its abrupt drainage, as well its evolution over the past eight years.

# Open Polar Radar Software and Services to Standardize Radar Echograms: Progress and Examples

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For the past fifty years, ice-penetrating radar has been a primary tool to map the thickness, the underlying bedrock geometry, and the internal structure of ice sheets and glaciers. Due to the experimental nature of radar technology and supporting logistics, polar radar groups around the world have produced custom radars, custom processing software, and custom data products, all with different standards, formats, and data sharing policies. Though unintended, this fragmented approach has resulted in siloed scientific research when using polar radar data, which leads to lower efficiency research and less accessible data and results. The Open Polar Radar (OPR) organization seeks to establish a curated software ecosystem to consolidate polar radar software and services and make the associated datasets standardized, searchable, and follow Findable Accessible Interoperable and Reusable (FAIR) principles – all in a community driven process. OPR is global in scope and seeks to involve radioglaciology domain scientists, AI data scientists, and the software and data engineers behind the various satellite, airborne, and ground-based ice penetrating radar data collected over ice sheets, mountain glaciers, sea ice, and planetary icy bodies. The initial effort is focused by an NSF EarthCube project titled Collaborative Research: EarthCube Capabilities: Open Polar Radar Software and Service. This project focuses on the datasets collected by the Alfred Wegener Institute (AWI), British Antarctic Survey (BAS), Center for Remote Sensing of Ice Sheets (CReSIS), Lamont-Doherty Earth Observatory (LDEO), University of Texas Institute for Geophysics (UTIG), and the University of Washington (UW). In this presentation, we will present several examples of diverse radar datasets that can now be accessed and processed using the open-access and publicly available OPR software toolbox. We will also present results from several algorithms developed for the OPR toolbox that will be leveraged by this effort and enable new analyses, including reprocessing of legacy data using standardized processing flows, vertical velocity estimation from repeat (multi)pass data, and tomographic (3D) digital elevation model extraction. Finally, we seek input from the community on both data and algorithmic priorities that would enable benefits to the broader scientific community beyond radioglaciologists.

# REMA Version 2: A New Standard in Antarctic Digital Elevation Data

**Michael Cloutier**[1], Cole  Kelleher
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In October of 2022 the Polar Geospatial Center released the second version of the Reference Elevation Model of Antarctica (REMA), a continental 2m resolution Digital Elevation Model produced from commercial electro-optical satellite imagery. This talk will highlight the significant improvements in data quality, production methodology, and temporal availability over the initial release made available in 2018. These enhancements include filling of void areas, water/coastline flattening, mosaicking methodology, inclusion of subantarctic islands, and the introduction of an additional 5 years of satellite observations. We will also discuss the outlook for future REMA improvements and releases.

# Filling the Holes: Submesoscale Instabilities in Ice Shelf Cavities

**Ms Kaylie Cohanim**[1], Andrew Stewart[1]
[1]*University of California-Los Angeles*

The largest source of uncertainty in future sea level rise and climate change is the potential loss of ice from the Antarctic Ice Sheet. Ice loss and the stability of the Antarctic Ice Sheet are highly sensitive to the ocean-driven melting beneath ice shelves. Thus, ice-ocean interactions play an important role in accurately predicting melt rates. Melt rates are often calculated using plume models based on simplified, conceptual theories. However, the more complex physical processes, such as instabilities and mixing— which can potentially alter plume properties and thereby melting— are neglected in these theories. Additionally, these processes go unaccounted for in numerical models; studies tend to either examine the small-scale Kolmogrov resolving range near the ice shelf-ocean interface, or the coarse mesoscale (O(10−100)km) resolving range in regional models, implying that the processes occurring at the scales in between, i.e. the submesoscale (O(1 − 10) km), have been neglected.

We hypothesize that ice shelf environments are conducive to submesoscale instabilities that can alter the plume properties, and thereby melt rates. Studies of overflows and gravity currents along sloping bottom boundaries have shown that symmetric and baroclinic instabilities develop. Such instabilities can generate mixing and modify the boundary layer. Ice-melt plumes beneath ice shelves can be thought of as an ”upside-down” version of an overflow or gravity current along a sloping bottom. In this study, a high-resolution, idealized numerical configuration is used to examine submesoscale activity in the sub-ice shelf cavity. Preliminary results agree with our hypothesis and suggest that symmetric instability develops in our 2-D simulations, potentially influencing the development and properties of the ice melt plume.

# Global mean sea level exceeded preindustrial levels in the Holocene

**Roger Creel[1]**, Jacqueline Austermann[1], Robert Kopp[2], Nicole Khan[3], Torsten Albrecht[4], Jonathan Kingslake[1]
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Global mean sea-level (GMSL) change during the Holocene (11.7 – 0 ka), an interval when global mean temperatures may have surpassed early industrial (1850 CE) values, provides a powerful lens to examine how the cryosphere and oceans react to climate warming. Nearfield evidence from Antarctica indicates that sectors of the West and East Antarctic Ice Sheets retreated inland of their present-day extents during the Holocene. Yet previous reconstructions indicate that early industrial GMSL exceeded all Holocene levels. We estimate Holocene GMSL and ice volume by merging relative sea-level observations with glacial isostatic adjustment predictions from an ensemble of ice-sheet models as well as novel estimates of the postglacial evolution of thermosteric sea-level and mountain glacier volume. We demonstrate that GMSL likely (probability P = 0.79) surpassed early industrial levels in the last 7500 years, reaching 0.27 m (-3.1 to 1.0 m, 90% credible interval) above present 3000 years ago; that Holocene GMSL may have peaked to 1.5 m above present levels; and that the Antarctic Ice Sheet likely (P = 0.66) had volume smaller than present within the last 6000 years. We find a 250 year lag between Antarctic air temperature and volume change, underscoring the vulnerability of the future Antarctic ice sheet to 20th and 21st century warming. Comparing our results to future projections, we find that rates of GMSL rise up to 2150 CE will very likely (P > 0.9) exceed any rates in the last 5000 years, and that by 2080 GMSL will more likely than not be the highest in at least 115,000 years.

# Ice-Penetrating Radar Evidence for Widespread Seawater Infiltration in West Antarctic Ice Shelves

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Seawater infiltration in the firn of Antarctic ice shelves and subsequent brine layer formation was first identified in the early 1960s. Later studies have suggested that brine drainage into shallow surface crevasses might initiate full-thickness hydrofacture. More recent work has hypothesized that brine layers may precondition ice shelves for the formation of meltwater firn aquifers, a type of water reservoir that has been implicated in the disintegration of parts of the Wilkins and Wordie ice shelves. Persistent brine layers might also alter the rheology of the ice shelf through latent heating and salt entrainment in the ice matrix. However, outside of extensive surveys on the McMurdo Ice Shelf, brine layer observations remain extremely sparse in both space and time, making it difficult to assess their role or relative importance in ice shelf stability.

Here we use airborne ice-penetrating radar data from NASA's Operation IceBridge to map brine layers in ice shelves on the Antarctica Peninsula and West Antarctica, including Abbott, Nickerson, and Larsen D. We find that most brine layers coincide with regions where firn modeling has shown the 750 kgm-3 density horizon to be below sea level. We further identify and discuss three common modes of seawater infiltration: through porous firn at the calving front, through damage in the lee of ice rises or at the grounding line, and through the tips of deep basal crevasses. Our results demonstrate that seawater infiltration into ice shelves is common and often occurs in high accumulation regions with some ice damage. However, in some areas our observations record a long history of repeated infiltration events, suggesting that brine is not inherently destabilizing, and motivating further work on the interplay between meltwater aquifer formation, hydrofracture, and brine layers.

# Late Miocene to Pleistocene lithostratigraphic changes from IODP Site U1522 on the Ross Sea Continental Shelf

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In 2018 the International Ocean Discovery Program (IODP) Expedition 374 recovered a Upper Miocene to recent geological record from the Glomar Challenger Basin on the Ross Sea continental shelf Antarctica at Site U1522. One of the main objectives of drilling was to determine whether ice sheet overriding events observed at the Antarctic Geological Drilling Project (ANDRILL) Site AND-1B advanced to the shelf edge, thus helping to constrain the contributions of Antarctica's ice sheets to Pliocene sea level lowstands. Furthermore, this site provides an opportunity to assess paleoceanographic conditions at the outermost Ross Sea, where downhole logging may provide insights into the orbital controls on marine-based ice sheet extent. We present a new record of core mineralogy (~200 samples), for comparisons with high-resolution XRF core scanning data, shipboard physical property data, clast count data, ICP-MS geochemical measurements, and downhole logging data in order to contribute to studies focused on paleo ice-stream behavior. Initial statistical analyses reveal geochemical facies that support shipboard visual observations of clast changes throughout the record. Muddy diamictite intervals primarily have higher values of muscovite and natural gamma radiation (NGR), while interbeds of sandy and muddy diamictite show alterations in high values of quartz, L*, and K-spar/albite. Above Ross Sea Unconformity 2 (RSU2), diamictite variability within Pleistocene age strata appears to be compositionally different from below. The change in bulk mineralogy is consistent with an overall change in the variability in downhole NGR and magnetic susceptibility (MS) data. Down-core variations in geochemical facies presented, combined with sediment facies analyses and provenance scenarios, when compared to integrated studies from AND-1B, will contribute towards a better understanding of Antarctic ice stream variability during the late Miocene to Pleistocene.

# An Examination of Surface Melt Inducing Atmospheric Rivers over the Antarctic Peninsula

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Atmospheric rivers (ARs) are regions of extra-tropical cyclones that can bring significant amounts of heat and moisture to the coastal environments where they make landfall. They are characterized by a narrow, river-like stream of clouds with significant amounts of water vapor transported within. They occur worldwide, and have been observed to be increasing in intensity as a result of anthropogenic climate change. On the Antarctic Peninsula (AP), ARs have been shown to induce substantial surface melt events, even in the austral winter, indicating that there is a theoretical link between ARs and ice shelf stability. However, not all ARs that impact the AP induce surface melt events, indicating the importance of improving our understanding of the atmospheric conditions present during surface melt-inducing AR events. In this study, we use  the 2015 Guan and Waliser algorithm to detect AR events on the Larsen C ice shelf.  Once identified, we used both passive (NOAA's Special Sensor Microwave/Imager (SSM/I)) and active (NOAA's,Advanced Scatterometer (ASCAT)) satellite surface melt observations to determine if the AR induced a surface melt event. Within the 2015-2019 sample period, we identified 9 non-austral summer (March - November) ARs that induced a surface melt event, then selected 9 other non-melt-inducing AR events of similar duration and seasonality. Using ERA5 reanalysis datasets, we compared 2-meter temperature, 10-meter wind data, and 500mb geopotential height during melt-inducing ARs with their non-melt-inducing counterparts. We observed that melt-inducing ARs are associated with a stronger high/low pressure couplet, with a 500mb ridge axis located west of the AP at AR landfall. We also found that melt-inducing ARs have stronger northwesterly flow throughout their duration and increased post-AR Larsen C surface temperatures, when compared with non-melt-inducing ARs. These results illustrate the general atmospheric conditions present within non-austral summer melt-inducing ARs, allowing us to identify, analyze, and potentially forecast future AR events that may induce melt and theoretically threaten the stability of the AP's ice shelves.

# Improving Bathymetry Estimates Beneath Amundsen Sea Ice Shelves Using a Geostatistical Markov Chain Monte Carlo Inversion of Airborne Gravity Data

**Michael Field**[1], Emma MacKie[1], Atsuhiro Muto[2]
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Sub-ice-shelf bathymetry controls the delivery of warm CDW to the ice shelf bottom and grounding line, making the bathymetry beneath ice shelves of the Amundsen Sea critical inputs to ice-sheet and ocean models. Previous works have used inversion of airborne gravity data to model the bathymetry beneath these ice shelves, but they have included one-time corrections to shift the bathymetric surface according to interpolated errors or used deterministic inversion frameworks which lack robust uncertainty quantification. To provide more robust and reproducible bathymetry models, we propose a random walk Metropolis-Hastings Markov Chain Monte Carlo (MCMC) inversion approach, which iteratively generates model perturbations using random Gaussian fields and forward models the gravity disturbance of proposed bathymetry models. After convergence, our approach samples the posterior distribution allowing for estimation of the mean and variance of the bathymetry as well as realizations of different bathymetric surfaces. In addition to providing more robust bathymetry models, this work provides a step forward in the reproducibility of geophysical inversions by leveraging the growing open-access geoscientific computing ecosystem of Python.

# Buoyancy Gradient-Driven Flow of Warm Subsurface Waters Into Geometrically Complex Ice Shelf Cavities

**Garrett Finucane**[1], Professor Andrew L. Stewart[1]
[1]*UCLA*

Antarctic ice shelves are losing mass at drastically different rates, primarily due to melting by relatively warm Circumpolar Deep Water (CDW). Previous studies have identified seafloor bathymetry as a key obstacle to CDW intrusions across the continental shelf and beneath ice shelves, but a generalized theory for geometrically-influenced ice melt is lacking. This study proposes such a theory based on geostrophically-constrained CDW inflow, combined with a threshold bathymetric elevation that obstructs CDW access ice shelf grounding lines, referred to as the Highest Unconnected isoBath (HUB). This theory captures >90% of the variance in melt rates across a suite of process-oriented ocean/ice shelf simulations with various quasi-randomized geometries. Applied to observed ice shelf geometries and offshore hydrography, the theory captures >80% of the variance in measured ice shelf melt rates. These findings provide a generalized theoretical grounding for melt resulting from buoyancy-driven CDW access to geometrically complex Antarctic ice shelf cavities.

# Recent onset of drainage of Subglacial Lake Engelhardt upstream of a retreating grounding line, West Antarctica

**Bryony Freer**[1,2], Oliver Marsh[1], Anna Hogg[2], Helen Amanda Fricker[3], Dana Floricioiu[4]
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Subglacial hydrology, including the active filling and draining of subglacial lakes, remains one of the principle uncertainties in our projections of future Antarctic ice sheet dynamics. Satellite altimetry has provided observations of subglacial lake drain and fill over the past few decades by measuring patterns of surface elevation change above lake locations, but coverage is incomplete in space and time.

Subglacial Lake Engelhardt (SLE) is a >400 km² subglacial lake located beneath the Whillans Ice Stream in West Antarctica. We present findings using ICESat-2, which show that SLE started to drain in July 2021 - 20 years after the last recorded drainage event. The ice surface has lowered by ~4 m over the first 16 months of drainage and we expect it to fall by another 8-10 m over the next couple of years, as approx. 2 cubic kilometres of subglacial meltwater stored in SLE drains across the grounding line.

SLE is located just 5 km upstream of the grounding line (GL) west of Engelhardt Ridge, which we show using TerraSAR-X interferometry has retreated by 2-3 km over the past decade. Preliminary results indicate that the GL retreat here accelerated during phases of SLE drainage, and slowed during refilling. We also observe that part of the downstream GL further to the west has retreated by as much as 12 km since 2012. This region of ungrounding coincides with a much larger area of the Whillans Ice Stream extending to the west of the Crary Ice Rise that has been experiencing long-term thinning. It is not yet clear whether there is a link between the recent onset of SLE drainage and the observed patterns of GL retreat in this region, however if GL retreat continues at the current rate SLE is projected to link to the ocean in as few as 20 years. This will trigger the GL to rapidly retreat upstream by 35km, with potential for substantial consequences to ice dynamics in this complex part of the West Antarctic Ice Sheet.

Here we will present preliminary results from our study, combining over 20 years of observations from ICESat, ICESat-2, CryoSat-2, TerraSAR-X, RADARSAT-2 and REMA, and welcome discussion across the community to understand the wider implications of these findings.

# Late 20th-century Increase in Antarctic Snow Accumulation Drives Modest Mitigation of Sea Level Rise

Mr. Advik Eswaran[2], **Tyler Fudge**[1], Dr. Olivia Truax[1]
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Increasing Antarctic snow accumulation can mitigate sea level rise, but there is considerable uncertainty around both past snowfall trends and future projections. Here, we present an ice core-based reconstruction of Antarctic accumulation using the Last Millennium Reanalysis, an established paleoclimate data assimilation framework. Utilizing ice core water isotope and accumulation records and an ensemble of multiple CMIP5 climate model simulations, we produce annually resolved reconstructions from 1801-2000 CE. The reconstructions demonstrate significant skill through strong satellite-era (1981-2000) correlation with instrumental reanalyses and alternate proxy-based reconstructions; significant skill improvements are especially found in uncertain, low-accumulation regions far from existing proxy sites (e.g. the East Antarctic Plateau). Reconstructed trends indicate a positive trend in Antarctic accumulation over the 20th century (0.4 Gt yr-2 from 1901-2000), with a further acceleration in the late century (1.1 Gt yr-2 from 1957-2000). The increase in accumulation translates to a total sea level mitigation of ~1 mm from 1901-2000, driven by a significant continent-wide rise in mitigation beginning around 1970 (0.7 mm dec-1 from 1970-2000). Our estimates of consistently increasing West Antarctic sea level mitigation broadly agree with previous studies. However, we find a much smaller magnitude of continent-wide sea level mitigation: a discrepancy attributable to divergent estimates of accumulation trends in East Antarctica.

# ICECReW: Connecting and Training Icy Early Career Researchers with an annual workshop

ICECReW 2023 Organizing Team, Bess Koffman[1], Ursula Jongebloed[2], Julia Andreasen[3], Emma Robertson[4], **Tyler Fudge**[1],
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ICECReW, the Ice Core Early Career Researcher Workshop, is an annual workshop designed to foster connectivity and collaboration among early career researchers (primarily within three years of PhD) and to produce review papers, proposal ideas, and other specific outcomes. Participants in ICECReW 2022 included 45 early career researchers from a range of ice-related fields. Fifty percent of participants identified as women, and 55% self-identified as a member of an underrepresented group. ICECReW 2022 focused on identifying future research directions by synthesizing previous contributions. The outcome was 10 short articles published in Past Global Changes Magazine (https://pastglobalchanges.org/publications/pages-magazines/pages-magazine/129548). These articles sought to introduce ice core science to undergraduate-level students as well as adjacent researchers. ICECReW 2023 was a 1.5-day workshop ahead of the Ice Core Community Meeting. Participants worked in teams of 2-4 people to write a one-page proposal that was sent to NSF program managers. After the workshop, teams met with Paul Cutler, the Antarctic Glaciology Program Manager, to receive feedback on their ideas. The third ICECReW meeting for 2024 has been recommended for funding with the plan for future workshops to occur on a schedule of one stand-alone meeting every 5 years (one graduate student generation) and pre-workshops the other four years. The 2024 meeting will be held in early May 2024 preceding the Ice Core Community Meeting in Portland, ME.

# Link Between Iceberg Melt and Diatom Productivity Demonstrated Through Analysis of Mid-Pliocene Amundsen Sea Interglacial Sediments

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Continentally sourced nutrients from meltwater and icebergs carry bioavailable iron and other key limiting nutrients. Iceberg and meltwater influence on diatom productivity has been long suggested, but direct seeding of higher productivity in the WAIS sector of the Southern Ocean during times of ice sheet collapse has never been demonstrated. Here we document direct correspondence of pulses of ice rafted debris (IRD), thus iceberg melt, and enhanced diatom production and accumulation in the outer Amundsen Sea of the WAIS during the mid-Pliocene. IODP Exp. 379 obtained records from the Amundsen Sea continental rise, to document WAIS history in an area experiencing the largest ice loss in Antarctica today. The recovered sections contain no apparent unconformities and include intervals characterized by diatomite and diatomaceous ooze, coincident with deposition of pulses of ice rafted debris. SEM imagery from IODP 379, Site U1532B, was used to document microstratigraphic records of mid-Pliocene (~3.9 Ma) interglacial sediments characterized by distinct intervals of IRD-rich diatomite. These horizons are overlain and underlain by sediments containing infrequent IRD and lower diatom abundance. We document sand and granule-sized ice rafted grains encased in diatomite laminae, including soft-sediment micro-deformation indicating local iceberg melt as the diatomite accumulated. Intervals with little or no evidence of IRD are bioturbated and have lower diatom abundance. Layers containing high abundance of IRD along with nearly monospecific assemblages of the pelagic diatom Thalassiothrix antarctica and preserved zooplankton fecal pellets with concentrated clusters of barite grains are indicative of high primary productivity. The data provides evidence to support the hypothesis that continentally sourced nutrients during ice sheet retreat, seed diatom productivity in the Southern Ocean. Pulses of IRD likely coincide with marine ice sheet retreat and collapse, with melting icebergs primarily from the Thwaites and Pine Island Glaciers. These results may contribute to interpreting past WAIS history by providing another proxy for ice sheet models of potential collapse events, and suggest that ongoing Antarctic ice sheet retreat may be enhancing Southern Ocean diatom production.

# On the impact of seawater intrusions on basal melt rates in the grounding zone of Thwaites Glacier, Antarctica.

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Thwaites Glacier currently contributes 4% of all global sea-level rise. In the last two decades, the glacier has lost more than 1,000 billion tons of ice. Recent observational studies have documented the rapid retreat of its grounding line. Modeling studies have considered the impact of bed topography, ocean thermal forcing, and sub-glacial discharge on ice shelf melt rates and glacier evolution. Most prior studies considered a fixed grounding line with little to no melt at the grounding line. Recent observations, however, reveal kilometer-scale variations in the position of the grounding line at tidal frequencies, which translates into seawater intrusions over considerable distances beneath grounded ice. Here, we investigate the impact of seawater intrusions on the basal ice shelf melt rates.

We use a general circulation model (MITgcm) with an ice-shelf package and model seawater intrusion in narrow (1 m), long (many km) cavities at tidal frequencies. We model the melt rates as a function of the length of the seawater intrusions and the magnitude of ocean thermal forcing. We find melt rates up to 100 m/yr at the cavity entrance, decaying to zero inside the cavity, along with a secondary peak 6-7 km from the cavity entrance. These high melt rates are compatible with recent observations and suggest that seawater intrusions play a major role in glacier evolution.

## Subglacial Precipitates Constrain Timing and Forcing of Ice Lowering in a Ross Sea Outlet Glacier During Termination I

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Existing $^{10}Be$ exposure dates and $^{14}C$ dates from the area of Hatherton glacier, situated in the Transantarctic Mountains and flowing into the eastern Ross Ice Shelf, have been interpreted as showing a local glacial maximum occurring at ~10 ka that is followed by pronounced ice surface lowering to near the modern level beginning at ~6 ka. An alternative and valid interpretation places an initial ice lowering stage between 20 and 18 ka, followed by thickening between 18 and 10 ka that leads to the second thinning phase between 10 and 6 ka. This initial ice lowering event is coincident with pronounced Southern Ocean warming during Heinrich Stadial 1 (HS1) while the subsequent thickening is broadly aligned with the Antarctic Cold Reversal (ACR), a period of millennial-scale cooling during Termination I observed in ice core temperature reconstructions that is the result of a period of enhanced circulation of the Atlantic Meridional Overturning Circulation (AMOC). Here we present U-series dates and geochemical data from numerous samples collected from three distinct morphologies of subglacial chemical precipitates in Magnis Valley, a dry valley tributary of Hatherton glacier. Each distinct texture, morphology and chemical composition indicates a different subglacial environment beneath Hatherton, but all 13 subsamples share the same age of 16 ka, coinciding with HS 1 and the first interval of apparent ice lowering in the cosmogenic record. Many of these samples are capped by a thin opal layer, which likely formed during the ACR in response to ice sheet thickening. The morphological and chemical differences between the three different calcite samples suggest that they came from different waters and/or individual flushing events, which suggests a significant hydrologic response. This new interpretation of ice lowering and thickening at Hatherton glacier will have major implications for our understanding Antarctica's response to the most recent glacial termination. There is growing acceptance that subglacial precipitate formation is driven by cycles of ocean forcing and subsequent ice acceleration and enhanced subglacial hydrologic connectivity. Thus the presence of calcites dated to 16 ka from Magnis Valley also implicates ocean forcing, rather than the later sea level rise, as the mechanism driving ice retreat in the Ross Sea during the early stages of Termination I.

# A Physics-Based Parameterization to Predict Mean Depth and Areal Coverage of Supraglacial Melt Ponds

**MS Danielle Grau**[1], Dr Alexander Robel[1]
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The occurrence of supraglacial melt ponds in Antarctica has increased over the past two decades and has been linked to large-scale ice shelf destabilization and collapse. In this work, we utilize the fractal (self-affine) self-similarity of ice surface topography in Antarctica to derive a set of physics-based parameterizations that can predict the mean depth and areal coverage of melt ponds on ice shelves. The first component of this project uses ICESat-2 data to confirm the self-affinity over varying length scales consistent with observations of supraglacial melt lakes across Antarctica. Next, we use an algorithm that realistically fills surface depressions with meltwater on randomly generated self-affine surfaces. We then estimate simple diagnostic parameterizations for the mean pond depth and area which compare well to hundreds of randomly generated surfaces. Finally, we validate these new parameterizations by comparison to Landsat-derived melt ponds observations on Amery and Larsen C ice shelves. In future work, we plan to apply this parameterization to improve albedo and hydrofracture calculations within large-scale climate and ice sheet models.

# Helicopter-deployed ocean sensors reveal meltwater-driven buoyant upwelling in the Thwaites Glacier Tongue cavity, West Antarctica

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The most rapidly retreating glaciers in Antarctica are in the Amundsen Sea Sector of the West Antarctic Ice Sheet, of which Thwaites Glacier is the largest. Warm ocean water is known to drive melting beneath the floating extensions of glaciers in the region which is associated with glacier retreat through loss of buttressing. However, numerical ocean circulation models are presently unable to reproduce peak melt rates estimated from satellite altimetry missions and progress in addressing this discrepancy has been slow due to the difficulty of observing ice shelf cavities. Here we use new full depth ocean temperature and salinity profiles to show that meltwater-driven buoyant upwelling draws otherwise stratified deep warm water into contact with floating ice in the Thwaites Glacier Tongue. The profiles were obtained using a new helicopter-based approach where expendable sensors are lowered into full thickness rifts in the ice tongue. We also use new model results as evidence that subglacial freshwater enters Thwaites' cavity in the area where melt rates are presently highest. We propose that the resulting buoyant upwelling contributed to the collapse of the Thwaites Glacier Tongue and now allows warm water to drive additional melt inside full thickness rifts, suggesting a potential positive feedback mechanism inherent to ice shelves overlying warm ocean cavities. Although only direct water sampling can definitively discriminate subglacial freshwater from iceberg melt, the new ocean profiles show that subglacial freshwater forcing cannot be ruled out, highlighting a critical uncertainty in our process understanding of Thwaites' melt and likely other marine-terminating glacier systems.

# Constraining subglacial till properties from acoustic techniques

**<u>Dougal Hansen</u>**[1], Dr Luke Zoet[1], Dr. Atsu Muto[2], Neal Lord[1], Peter Sobol[1]
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Active source seismic analyses have been used widely in glaciology to infer deformational properties of basal till beneath ice streams. Subglacial effective pressure, N, is one of the key parameters required for estimating till deformation and thus glacial motion but is notoriously hard to measure. Common techniques for estimating N have been the labor-intensive practice of measuring it directly from boreholes and connected moulins or in some cases inferring it from surface-velocity inversions. Acoustic wave theory indicates that the N of water-saturated granular sediments, like subglacial till, is related to the seismic-wave propagation velocity and thus the acoustic impedance and seismic reflection amplitude. This theory is mildly sensitive to the grain-size distribution of the sediment but quite sensitive to N and porosity of the sediment. The canonical view in glaciology is that the reflection amplitude of the seismic wave primarily conveys changes in the porosity of the substratum, and therefore has been used to infer deeply deforming till layers. However, the fundamental acoustic principals of wave travel through a saturated porous medium indicate that N can also have primary control on the wave speed and, by extension, reflection amplitude. In environments where porosity may not vary greatly, like critically strained tills, it is possible that effective pressure exerts the dominant control on seismic reflection amplitude. To constrain the relative contributions of effective pressure and porosity to the seismic reflection amplitude, we measure acoustic reflection from the ice–bed interface within a cryosphere ring shear device where temperate ice is slid atop a water saturated deformable till layer under a prescribed effective pressure. In this setup, effective pressure of the system can be precisely varied, and porosity can be precisely recorded, while a series of acoustic piezo-electric transducers continually transmit and receive acoustic waves that have been reflected from the ice–bed interface in order to record the reflection properties of the interface. Here we show initial results of the study and how they may affect interpretations of deformation within subglacial tills.

# Water Column Properties and Ice-Ocean Interactions Beneath Erebus Glacier Tongue, Antarctica

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In November 2018, the remotely operated underwater vehicle Icefin was used to access the subglacial cavity of Erebus Glacier Tongue in McMurdo Sound, Antarctica, reaching the grounding line and surveying local hydrographic conditions. Initial analysis from the oceanographic sensors revealed a density of $\sigma \approx 27.99$ kg/m³ at 0.10-0.25 °C above the in-situ freezing point throughout the subglacial cavity between depths of 180-310 m. The observed water properties are generally both colder and fresher than those of the local ambient water mass at McMurdo Sound, high salinity shelf water (HSSW), which suggests mixing with another water source in the subglacial cavity. Near the grounding line, the cameras and sonar on Icefin captured ripple-like features, which along with the lower temperatures and salinities than HSSW suggests that the above-freezing water is melting the ice and mixing with the generated glacial meltwater (GMW). Using the three-equation parameterization and the Gade Line, we explored mixing between HSSW and GMW, which gives a rough melt rate of 1.3 m/yr, and a maximum GMW fraction of 0.48 mL/L. Unique oxygen signatures were also observed between the three dives, and there is a subtle but notable decrease in dissolved oxygen with distance from the open ocean, from around 6.23 mL/L to around 6.20 mL/L at the grounding line. This suggests poor ventilation of the subglacial cavity and possible uptake from biological activity, which is further validated by the presence of macroscopic organisms visible in the HD cameras even near the grounding line. Additionally, dissolved oxygen appeared to be lower on the northern edge of the glacier tongue, indicating potential topographical influences on mixing and circulation in the region. The ice base in the region is strongly influenced by the topography of the bed and interactions with the surrounding sea ice as EGT advances off Ross Island. We observe varying ice surface textures with location on the glacier tongue, consistent with different rates and modes of melting. These data together place the EGT ice-ocean interactions in a regime somewhat different than other grounding line environments explored thus far with Icefin. We discuss how ocean conditions in this region create a variety of ice-ocean interactions and multiple observations that contextualize these findings.

# Radar-Derived Crystal Orientation Fabric Suggests Divide Stability at Hercules Dome During the Last Ice-Sheet Deglaciation

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Hercules Dome has been identified as a prospective ice-core drilling site due to its location in the bottleneck between East and West Antarctica and its potential to preserve ice from the last interglacial period. An ice core at Hercules Dome could provide insight into the history of the West Antarctic Ice Sheet during that time in which the global climate was most recently similar to today. The likelihood of a continuous, well-resolved, easily interpretable climate record preserved in an ice core extracted from Hercules Dome depends in part on the persistence of the divide location. A paleo ice-sheet model ensemble experiment predicts that differential thinning in the neighboring drainage basins, the Ross and Ronne ice shelves, during the last 10 thousand years could have forced divide migration at Hercules Dome by ~$10^0$-$10^1$ kilometers depending on the model physics. However, the model domain is poorly resolved and poorly constrained in this part of the ice-sheet interior.
Here, we link present-day and historical ice dynamics at Hercules Dome using ice-penetrating radar. Repeated radar acquisitions show that the vertical velocity profiles at Hercules Dome are consistent with the Raymond Effect expected at an ice divide. Radar polarimetry constrains the ice crystal orientation fabric (COF) for ice-flow history. COF develops over time as a result of cumulative strain, so it depends on both the pattern and consistency of ice flow. To contextualize our measurements, we then use a physical model to simulate the timescales for COF evolution. We find that the summit of Hercules Dome has been stable in its current ice-flow configuration, at least during the recent ice-sheet deglaciation in the mid Holocene. Divide stability has likely been due to a prominent bedrock ridge that had not been surveyed until now and was therefore not represented in the bed geometry of paleo ice-sheet models.

# Beardmore Ice Shelf melt channels and their connection to Ross Ice shelf basal bodies

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Melt channels have been observed beneath ice shelves in both Greenland and Antarctica, and arise when concentrated melt incises a trough into the ice shelf base. This concentrated basal melt locally thins a region of the ice shelf that promotes horizontal gradients in the ice shelf thickness and horizontal shear within the ice into the channel. The nonlinear deformation of ice with depth caused by secondary flow into the ice-shelf channel complicates the inference of basal melt from surface observations that typically make linear assumptions for vertical ice deformation with depth and would close the channel in the absence of continuous basal melt.

Using radar data from the Beardmore Glacier grounding zone, we image an extremely narrow subglacial channel (<500 m) that reaches a height of 200 m above the ambient ice-shelf draft. Idealized ice-flow modeling suggests that the channel's geometry is consistent with melt rates of at least 2 m/yr higher than the ambient rates. 1D plume modeling indicates that these high melt rates are likely driven by subglacial-meltwater discharge, consistent with the channel extending inland of the grounding zone. Downstream of the channel, we observe basal bodies expressed in radar layers imaged with broadband ultra-high frequency and high-frequency radar systems (MCoRDS and ROSETTA). These basal bodies form a group of four basal units that appear strongly just 40 km away from the Beardmore Glacier grounding zone. An unconformity feature that has been termed the continental meteoric ice (CMI) layer dips in the across-flow direction where these features meet the basal reflector; the CMI layer is conformal to this structure but not conformal to the ice base which is flat in the survey of the basal bodies. The reflectivity of the ice base also increases to the sides of the features. This suggests that the conductivity contrast within the feature and at the ice-ocean interface beneath the feature is not as large as the conductivity contrast at the ice-sea water interface at the sides of the basal bodies. Using idealized models of ice flow and ocean circulation we test the hypothesis that the Beardmore basal bodies are associated with accretion. Our observations and model experiments suggest strong linkages between the morphology of the ice shelf base, the ice shelf draft and the thermal driving of the ocean cavity and demonstrate the rich complexity of "cold" ice-shelf systems like the Ross and Filchner-Ronne.

# Scars of tectonism promote ice-sheet nucleation from Hercules Dome into West Antarctica.

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Geology and bed topography influence how ice sheets respond to climate change. Despite the West Antarctic ice sheet's capacity to retreat and advance quickly over its overdeepened interior, little is known about the subglacial landscape of the East Antarctic elevated interior that likely seeded West Antarctic ice streams and glaciers. At Hercules Dome, we use three-dimensional swath radar technology to image the upstream origin of large subglacial basins that drain ice from the Antarctic interior into West Antarctic ice streams. Radar imaging reveals an ancient, alpine landscape with hanging tributary valleys and large U-shaped valleys. On the valley floors, we image subglacial landforms that are typically associated with temperate basal conditions and fast ice flow. Formation mechanisms for these subglacial landforms are fundamentally inconsistent with the currently slowly-flowing ice. Regional aerogravity shows that these valleys feed into larger subglacial basins that host thick sediment columns. Past tectonism likely created these basins and promoted ice flow from Hercules Dome into the Ross and Filchner-Ronne sectors. This suggests that the landscape at Hercules Dome was shaped by fast-flowing ice in the past when the area may have served as or been proximal to a nucleation center for the West Antarctic ice sheet.

# Antarctic grounded icebergs from WorldView stereo-photogrammetry and ICESat-2 laser altimetry

**Susan Howard**[1], Laurie Padman[2]
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Icebergs that run aground on the Antarctic continental shelf provide barriers to sea ice flow and anchors for development of landfast sea ice, modifying the ocean-atmosphere exchanges of heat and freshwater to influence the coastal water mass properties that then play a role in ocean heat flux under ice shelves. At the same time, measured freeboard of grounded tabular icebergs can be used to infer approximate seabed depths in regions that are unmeasured by conventional bathymetric surveys.  Here, we report on measurements of icebergs in East Antarctica that we identify as being grounded based on Sentinel-1 SAR image sequences. We determine the elevations of these icebergs using a combination of stereo-photogrammetric digital elevation models from Maxar WorldView satellites and roughly coincident ICESat-2 laser altimetry. In locations where nearby direct measurements of bathymetry are available, we determine the reliability of iceberg-based depth estimates.

# Impacts of tidewater glacier advance on iceberg habitat

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Icebergs in proglacial fjords serve as pupping, resting, and molting habitat for seasonal aggregations of seals. To understand the impacts of changing ice availability on harbor seals, we quantified seasonal and annual changes in ice habitat in Johns Hopkins Inlet, a tidewater glacier fjord in Glacier Bay National Park in southeastern Alaska. Satellite-derived velocity measurements and digital elevation models indicate the glacier has continued to advance and thicken and has slowed down in recent years. From 2007--2021 the glacier advanced ~160 m, thickened ~23 m, and exhibited a gradual slowdown, especially from 2013--2021, during which time the velocity decreased by 45%. Like other advancing tidewater glaciers, the advance of Johns Hopkins Glacier over the past century has been facilitated by the growth and continual redistribution of a submarine end moraine, which has limited mass losses from iceberg calving and submarine melting and enabled glacier thickening by providing flow resistance. A 15-year record of aerial surveys reveals (i) a decline in iceberg concentrations concurrent with moraine growth and (ii) that the iceberg size distributions can be approximated as power laws with no clear trends in the power law exponent despite large changes in ice fluxes over seasonal and interannual timescales. In addition, despite large changes in ice fluxes over the past two decades, we find little variability in iceberg size distributions at Johns Hopkins Inlet, thus implying that the number of habitable icebergs is proportional to overall ice coverage and establishing a direct link between glacier dynamics and seal habitat. Together, these observations suggest that sustained tidewater glacier advance should typically be associated with reductions in the number of large, habitable icebergs, which may have implications for harbor seals relying on iceberg habitat for critical life-history events.

# US-SCAR, Representing the US in the Scientific Committee for Antarctic Research

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The Scientific Committee for Antarctic Research (SCAR) is an international organization that was created during the 1957-1958 International Geophysical Year (IGY) with the intent to continue the international scientific cooperation that was a hallmark of the IGY. SCAR's work addresses all aspects of Antarctic and Southern Ocean science and how research results can be used to inform policy related to the environmental management of this unique region.

For 65 years SCAR has successfully addressed and accomplished its two-fold mission of:

1. facilitating international scientific research collaboration in the Antarctic and Southern Ocean, and on the role of the Antarctic region in the Earth system; and
2. providing objective and independent scientific advice to the Antarctic Treaty System and other international policy bodies.

The US is a founding member of SCAR and American scientists have played a major and significant role in all aspects of SCAR's work. The Polar Research Board (PRB) of the National Academies is the US National Committee to SCAR and responsible for appointing delegates and representatives to SCAR. The US-SCAR team represents the US Antarctic scientific community and is a focal point for US participation in SCAR. US-SCAR is funded by a grant from NSF which has a primary goal to encourage more US scientists to become involved with SCAR. In addition to the PRB appointees, over 250 US scientists are formally affiliated with SCAR groups, and many others participate in various SCAR activities.

Currently, US-SCAR is working to keep the US Antarctic community aware of continuing and new initiatives relating to research about and from Antarctica through a variety of efforts, including organizing bi-annual virtual US Antarctic Science Meetings, maintaining an email list, broadcasting on social media, providing financial travel support for US scientists (especially early career researchers) to attend international SCAR meetings, compiling a formal Directory of US Antarctic Scientists, and expanding an interview series about US Antarctic researchers.

# Insights into mélange-calving interactions and glacier stability using SAR-based velocity mapping of mélange within Greenland fjords

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In many glacier-fed fjords around Greenland, calved icebergs mix and refreeze with sea ice to form a mixture called mélange. Previous studies at individual glaciers have found that mélange can influence the timing and duration of terminus change by inhibiting calving at the front, especially when the mélange aggregate is more rigid. We can extract a wealth of mélange variability and rigidity characteristics by extending ice sheet velocity mapping methods, which use interferometric correlation of SAR imagery, to mélange-occupied areas down-fjord of glacier calving fronts. Here we demonstrate how mélange velocity mapping is used to derive mélange prevalence and variability, and, when analyzed in conjunction with time series of near-front glacier velocity and terminus change, begin to constrain the impact of changing mélange conditions on glacier calving rates. These methods are designed to readily incorporate 12-day SAR imagery from the NASA ISRO Synthetic Aperture Radar (NISAR) mission, which will dramatically improve polar coverage and enable improved velocity mapping accuracies to decimeter scale in early 2024. Finally, we discuss the applicability of these methods to regions of West Antarctica, where recent work has highlighted the important role of mélange as binding material within Antarctic rifts, as well as identifying mélange as a potentially critical element in determining the upper limit of cliff calving rates and ice shelf stability.

# Phase-sensitive radar measurements of englacial strain rates in diverse glacial settings

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Many interesting glacial phenomena with implications for ice-sheet mass change involve variations in englacial strain rates. For example, we expect ice-stream flow over undulating basal topography to induce complex patterns of vertical shear, and drainage of supraglacial lakes to induce temporal changes in englacial deformation. Understanding these spatial and temporal variations in englacial deformation is important for testing ice flow models and for estimating the stresses generated by supraglacial lake drainage. Measuring englacial strain rates remains difficult; however, over the last 15 years, ice-penetrating radar methods, primarily designed for measuring sub-ice-shelf melt, have significantly improved our capacity to make such measurements. Two common instruments used for this purpose are the phase-sensitive radio-echo sounder (pRES) and the autonomous pRES (ApRES). In this presentation, we will describe several past, ongoing, and planned pRES and ApRES surveys aimed at measuring englacial strain in interesting glacial settings. Settings include around a sub-shelf melt channel (a survey carried out in 2013-14 on the Ross Ice Shelf), around draining supraglacial lakes (an ongoing survey in Greenland's ablation zone), along a flow line of Thwaites Glacier (a survey that is planned to be completed this coming season), and two planned surveys: one on Flask Glacier on the Antarctic Peninsula and another on Crary Ice Rise in the Ross Sea. Our aim is to showcase the diverse settings in which ApRES is being deployed, to discuss some challenges associated with the locations of the deployments, present preliminary results from past and ongoing surveys, and describe the development of innovative ApRES data storage and processing techniques that utilize cloud computing.

# Glacial isostatic adjustment contributes to retreat of stable grounding line zones over the last deglaciation in the Ross Sea

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Since the Last Glacial Maximum (26-19 ka; LGM; Clark et al., 2009), Antarctic ice streams in the Ross Sea (West Antarctica) retreated hundreds of kilometers to their modern grounding line positions. Over this time, glacial isostatic adjustment shifted the underlying topography, which strongly modulates the grounding line stability of marine ice sheets. Solid Earth ice-sheet interactions have been shown to promote stability of modern marine ice sheets (e.g. Barletta et al., 2018), nevertheless, to date, the impact of glacial isostatic adjustment's long term, deglacial trend on Ross Sea grounding line evolution across the last deglaciation has not been explored.

We show that glacial isostatic adjustment contributes to grounding line retreat over the last deglaciation in the Ross Sea by shifting the location of stable grounding line zones. We performed a suite of simulations that predict potential stable grounding lines in the Ross Sea on topography corrected for glacial isostatic adjustment. We used three different ice sheet histories (Whitehouse et al., 2012; Golledge et al., 2014; Gomez et al., 2018) to sample the range of plausible glacial isostatic adjustment patterns and magnitudes. Our numerical model ensemble encompasses a parameter sweep of accumulation rates, degree of ice shelf buttressing, and basal friction coefficients, and we performed our analysis along modeled Last Glacial Maximum ice streams (126 flowlines; Golledge et al., 2012).

Glacial isostatic adjustment causes a net retreat of stable grounding line positions from 20 ka to modern, with some ice streams experiencing up to 1000 km of retreat (Kodama et al., submitted). This retreat is driven by subsidence of the Antarctic Ice Sheet's peripheral bulge towards the shelf break, in combination with uplift inland, which migrates stable grounding line zones towards the modern coastline over the deglaciation. Interestingly, the Antarctic Ice Sheet history with the smallest excess LGM ice sheet volume (Gomez et al., 2018) produces a spatial pattern of change in stable grounding line positions consistent with patterns of retreat observed in the geologic record (Halberstadt et al., 2016; Prothro et al., 2020). Our results highlight the role of topography, as modulated by solid Earth processes, in shaping the history of ice sheet retreat.

# Synchronous, hydro-fracture-driven drainages of neighboring supraglacial lakes and their impact on ice flow

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Subglacial water is thought to play a key role in ice sheet dynamics and mass balance. As ice sheet surface melt expands and intensifies, a key question is whether surface meltwater will reach the bed and accelerate ice flow. Supraglacial lakes that drain through the kilometer-thick Greenland Ice Sheet via hydro-fracture provide an opportunity to investigate this question. Here, we present new in-situ observations of synchronous, hydro-fracture drainages at two lake pairs located at 950 m and 1150 m above sea level in the mid- to upper-ablation zone. We use Global Navigation Satellite System (GNSS) measurements of ice-surface deformation around all four lakes and pressure sensor recordings of water levels in one of the lower-elevation lakes to constrain the conditions leading to hydro-fracture as well as the associated ice flow response. In particular, we assess the hypothesis that the drainage of one lake may trigger the drainage of other, neighboring lakes. Our findings in West Greenland informs our understanding of ice sheet dynamics in general and provide insight into the future of the West Antarctic Ice Sheet.

# How much, how deposited, how old – what can we learn from sediments in Pine Island Bay?

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A number of studies have defined a boundary in the Amundsen Sea embayment between an inner continental shelf, which contains areas where crystalline bedrock is at or near the seabed, and the shelf further offshore, which is underlain by sedimentary strata that increase in overall thickness oceanward. Other studies have shown that much of the inner shelf in Pine Island Bay is covered by a drape of clayey silt averaging about 1 m in thickness, interpreted as having been deposited from meltwater plumes during the mid-late Holocene. Much thicker sediments have been shown to be present in isolated deep basins based on acoustic sub-bottom profiles and sparse seismic reflection profiles, including an estimated maximum thickness of >400 m in one basin close to the front of Pine Island Glacier.  Thus, the widespread impression exists that, apart from the thin Holocene drape, sedimentary cover in Pine Island Bay is restricted to isolated basins.

Here we examine the distribution and thickness of sediments in Pine Island Bay using a network of high-resolution seismic reflection profiles collected in 2020 on RV Nathaniel B Palmer cruise NBP20-02. We show that more extensive thick sediments are present near the front of Pine Island Glacier than have been reported previously. In some places sediment units exhibit characteristics that suggest their deposition was influenced by bottom currents. We also show that sedimentary deposits are present over the tops and on the flanks of some bathymetric highs that must have been former ice shelf pinning points. Finally, we consider what the extent, thickness and character of the sedimentary units identified tell us about glacial/glacimarine processes and ice sheet history in the area, and what could be learned by further study and sampling.

# Onshore-Offshore Geologic Investigation of the Amundsen Sea Embayment

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Understanding ocean-ice and Earth-ice interactions, including the geologic environment underlying ice sheets and ice shelves, is important for improving future projections of Antarctic Ice Sheet stability and sea level rise. Beneath ice sheets and ice shelves, the geologic environment exerts a fundamental control on ice flow via subglacial hydrology, ice rheology, and bed topography shape. In the Amundsen Sea Embayment, the interactions between subglacial geology and the overlying ice sheet need to be better understood in order to determine how these systems will influence the ice sheet's response to future climate change. A key component of the subglacial geology is the depth of the sediment between the bed/seafloor and the basement and the distinction between unconsolidated sediments and sedimentary rock. Offshore seismic profiles from the continental shelf offer constraints on the depth to the acoustic basement, but have considerable uncertainty in their interpretation. We have compiled available data from the offshore region together with gravity and magnetic data to help characterize the geophysical signature of basement rock in the area and to improve offshore estimates of sediment thickness. These interpretations will be combined with companion studies of the onshore environment to provide a new regional onshore-offshore geologic and tectonic model of the region that can be used to inform and refine regional interpretations of potential fields data across the Amundsen Sea Embayment that will improve our understanding of the interacting ocean, ice, and rock systems.

# Antarctic Atmospheric Rivers in the Present and Future Climates

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Atmospheric rivers (ARs) are long, narrow bands of moisture that propagate poleward from the midlatitudes and occasionally reach the Antarctic Ice Sheet. Despite occurring only ~3% of the time, Antarctic ARs contribute 10% of the annual precipitation and are major drivers for heatwaves, foehn events, and surface melting on ice shelves. While snowfall is currently the dominant impact of ARs over the grounded Antarctic Ice Sheet, the relative contribution of ARs to snowfall, rainfall, and surface melt may change in a warming climate, along with the frequency and intensity of AR events themselves. Here, we use the Community Earth System Model version 2 (CESM2) Large Ensemble to detect ARs during the current period (1980–2014) and future climate (2015–2100) under the SSP370 radiative forcing scenario. We use an AR detection threshold for the current period based on the 98th percentile of the meridional component of integrated vapor transport (vIVT). To account for projected future increases in atmospheric moisture content (Clausius-Clapeyron effect) and its impacts on vIVT, we scale our AR detection threshold for the future period by the relative change in integrated water vapor compared to the present-day climatology. We then describe how the frequency, intensity, and year-to-year variability in Antarctic ARs changes by the end of the 21st century by region, with links to changes in the large-scale atmospheric circulation accompanying ARs. Finally, we quantify AR-attributed precipitation, precipitation variability, and trends in the future climate, ultimately providing an early assessment of future AR-driven changes to Antarctic surface mass balance.

# ALPACA: Automated Lightweight Portable Analyzer for C-Axes

**Dr Merlin Mah**[1], Dr Joey Talghader[1]
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Ice fabric and microstructure—the crystal axis orientation and size, shape, and density of grains, bubbles, and other features—are vital to studies of ice core physical properties. Clues to ice sheet flow and temperatures, glacier stresses and responses, discontinuities and more can be deduced from the distribution and evolution of c-axes and grain boundaries. The traditional method to collect this data is by observing a glass-mounted sub-millimeter thin section through crossed optical polarizers while manipulating it on a four-axis motion stage. While this venerable technique, formalized by Rigsby, achieves unparalleled crystal-level accuracy and detail, it is also highly time- and labor-intensive: manually recording the c-axes within a single thin section can take a full day of researcher effort. Automated systems have followed in the decades since, but are generally large, expensive, lab-bound, and rare.

We introduce a next-generation refinement of these stationary automated c-axis analyzers. Re-analysis of the fixed-angle measurement sequence described by Wilen allows full c-axis discrimination from three motion axes, rather than the previous four. Combined with extensive use of computer-aided design, rapid prototyping technologies, and modern sensing and processing, this yields a fully-motorized low-cost system capable of analyzing 4" thin sections, robustly packaged in and operable from a single 15" x 12" x 7" transport case. The hardware design is demonstrated, and software features currently under development are discussed.

# The Effects of Turbulent Mixing on Seawater Intrusion: Dynamics and Melting

**Madeline Mamer**[1], Alex Robel[1], Chung Kei (Chris) Lai[1], Earle Wilson[2]
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Small scale variation in ocean-forced melt of ice sheets remains to be completely integrated within current ice-ocean coupled models. Computational expenses limit resolving cm to m scale ice-ocean dynamics and there exists few observational constraints on key parameters. Ultimately, these hindrances have resulted in defining the ocean and subglacial hydrologic systems as distinct and separate hydrological entities. However, within grounding zones where dense ocean water interacts with buoyant subglacial runoff, estuarine-like fluid dynamics can occur. Previous studies have demonstrated that salty, warm ocean water can penetrate beyond a glacier's grounding line within subglacial hydraulic systems, and recent observations appear to support this possibility. Such seawater intrusion can extend ocean-forced ice loss to grounded ice, a mechanism of ice loss not typically considered in coupled ice sheet-ocean models. In this work, we investigate the role of turbulent mixing in seawater intrusion and melt under grounded ice. Using a high-fidelity computational fluid dynamics solver, we simulate meltwater discharging from a subglacial space into an ocean basin to test the controls and influences on intrusion length. We find that the speed of fresh subglacial runoff and the geometry of the subglacial water system act as strong controls on the ability for seawater to intrude into the subglacial space, in agreement with previous work. We demonstrate the intrusion can be reduced under certain circumstances by turbulent mixing however, it does not eliminate seawater intrusion. Further, we determined that melt of grounded basal ice is an important secondary source of buoyant freshwater and hinders intrusion development. This secondary source of meltwater changes the dynamics of the subglacial space, reducing shear and suppressing near-ice thermohaline gradients. There exists considerable disagreement between established sub-shelf melt parameterizations and the modeled melt due to inaccurate assumptions about the structure of the boundary layer at the ice-ocean interface. Incorporating this mode of ice loss within current ice-ocean coupled models will require modification of the traditional parameterization schemes.

# Using clustering algorithms to characterize basal morphology

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The morphology of a glaciers bed exerts a strong control on the slip rate of the overriding ice, and this is especially true in regions where glacier beds consist of a combination of rigid and deformable substrates, such as Thwaites Glacier. In hard bedded regions the basal morphology is set by the balance between subglacial quarrying and abrasion where quarrying tends to roughen the bed whereas abrasion tends to smooth the bed. However, even within the roughened terrains produced via quarrying there exists a significant range of morphologies with variations resulting from factors such as basal slip characteristics (e.g., slip speed, effective stress) and variations in rock properties (e.g., microfracture distributions, rock mass strength and toughness). Unlike morphology from abrasion, the variation in quarrying morphologies have not been described in detail. Parametrizing the ranges of these quarried morphologies between similar and dissimilar lithologies provides insight on the variance in fracture mode and rate of crack growth during quarrying, thereby helping to constrain crack growth in models of quarrying. Further, segmentation of glacial forefields based upon mode of erosion (abrasion/quarrying) will allow for more realistic estimates of hard bed shape under glaciers both with and without observable forefields. Using high resolution point clouds (~25 pts/cm$^2$) of ~154 m$^2$ areas in hard bedded glacial forefields at Jostedalsbreen, Norway, roughness, curvature, density, and 9 eigenvalue based parameters (in addition to RGB values) are calculated for each point at multiple scales, and unsupervised machine learning (clustering) is used to investigate spatial variance within the point clouds. A preliminary K means classifier with 6 clusters is successful in delineating quarried from unquarried surfaces, and identifies distinct classes within quarried surfaces.

# Outcrop perspectives on spatial and temporal effects of topography on the marine-terminating Puget Lobe of the Cordilleran Ice Sheet

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The stability of marine-terminating ice sheets is influenced by solid-Earth conditions, such as topography, at the grounded-ice margin. Understanding the role solid-Earth plays in ice margin retreat style is difficult to empirically observe within modern marine-terminating glaciers. Therefore, we turn to the deglacial record to observe the interactions between extinct glacial ice margin retreat and underlying topographic and solid Earth conditions. Sedimentary outcrops in the deglaciated Puget Lowland of Washington state were uplifted above sea level due to glacial isostatic adjustment (GIA). These outcrops record late Pleistocene Cordilleran Ice Sheet (CIS) behavior and provide a unique opportunity to assess spatial variability in marine ice-sheet activity. Based on paired stratigraphic and geochronological work with a newly developed radiocarbon marine-reservoir correction for this region, we identify step-wise retreat of the late-stage CIS into a marine environment about 12,000 years B.P., placing glacial ice in the region for about 3,000 years longer than previously thought. Additional rapid rates of vertical landscape evolution support a millennial-long stand still of marine-terminating ice, followed by continued retreat of ice in a subaerial environment. These results suggest rapid rates of solid Earth uplift and topographic support in the form of grounding-zone wedges stabilized the ice-margin in time for further landscape uplift, allowing for local ice retreat into a subaerial environment. Ultimately, this work leads to a better understanding of shallow marine and coastal ice-sheet retreat that is relevant to sectors of the contemporary ice sheets and marine-terminating outlet glaciers.

# USING DIATOM ASSEMBLAGES FROM DEGLACIAL TO RECENT TO STUDY ICE-OCEAN INTERACTIONS OFFSHORE THE TOTTEN GLACIER, EAST ANTARCTICA

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The marine based Totten Glacier system, which holds roughly 3.9 m sea-level equivalent ice, is rapidly losing ice mass at rates comparable to systems in West Antarctica. Presently, relatively warm modified Circumpolar Deep Water (mCDW) is upwelling onto the continental shelf suggesting that this glacial system is sensitive to ocean thermal forcing. To study deglacial to recent ice-ocean interaction of the Totten Glacier system, and how these interactions influenced this glacial system over longer timescales, we integrate sedimentological and diatom data from a 9-meter jumbo piston core (NBP1402 JPC43) taken from a bathymetric channel on the Sabrina Coast continental shelf. These analyses are used in conjunction with multibeam swath bathymetry and CTD data to contextualize modern observations with the sediment record. The core contains three distinct lithologic units spanning from the last Glacial Period to the recent: the basal unit is comprised of bedded muddy sands to sandy muds with low magnetic susceptibility (MS), overlain by a unit of high MS diatom-bearing muds and sands, followed by laminated diatom mud and oozes. Preliminary radiocarbon dating via ramped pyrolysis, a technique that thermochemically separates mixed pools of carbon from a bulk sediment sample, suggests that the basal unit was deposited during the last glacial period. We hypothesize that this unit records an initial period of high-velocity flow through the bathymetric channel, potentially deposited by a subglacial meltwater outburst from the Aurora Subglacial Basin. In the overlying unit, continued but lower velocity flow delivered finer-grained terrigenous debris. This unit has a high relative abundance of F. kerguelensis, a diatom species associated with the Antarctic Circumpolar Current, which points to the presence of mCDW on the continental shelf at this time, potentially a heat source for basal melting at the initiation of the last deglaciation of the Totten Glacier System. The upper 490 cm is highly biosiliceous laminated mud and ooze and records changes in oceanographic conditions through the Holocene. Ongoing work aims to provide further time constraints on sedimentologic and biological facies transitions as well as to produce a provenance record of the basal sandy section of the core to examine the origin of the sands.

# Coastal polynyas enable transitions between high and low West Antarctic ice shelf melt rates

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Recorded mass loss from the West Antarctic Ice Sheet (WAIS) has been dominated by discharge through rapidly thinning ice shelves in the Amundsen Sea embayment. The observed thinning is associated with high rates of basal melt by warm modified Circumpolar Deep Waters (mCDW) found at depth along the coast and within ice shelf cavities in the Amundsen Sea. Basal melt rates of these ice shelves track large (~400 m) decadal variations in the thickness of the warm water layer at their outlets that overwhelm multidecadal ocean warming trends in available observations. This variability is generally attributed to wind-driven variations in warm water transport from the open ocean towards ice shelves, though questions remain. Future projections of WAIS mass loss require accurate representation of the processes underpinning these large variations in the exposure of Amundsen Sea ice shelf cavities to ocean heat.

Inspired by conceptual representations of the global overturning circulation, we introduce a simple model for the evolution of the thermocline, which caps the warm water layer at the ice-shelf front and sets its thickness. Crucially, the model distinguishes between thermocline depth variability driven by changing warm water supply and changing warm water destruction or “transformation” into cooler surface waters by vertical mixing in coastal polynyas. This model demonstrates that interannual variations in rates of sea-ice formation in coastal polynyas can generate large decadal-scale thermocline depth variations, even when the supply of warm water from the open ocean is fixed. The modeled variability involves transitions between bistable shallow and deep thermocline states, associated with bistable high and low ice shelf melt regimes, enabled by feedbacks between basal melt rates and convective mixing at the ice front. Variations in either warm water supply or coastal polynya sea-ice formation can prompt transitions between these bistable states. Our simple model captures observed variations in thermocline depth and stratification strength at the Dotson Ice Shelf front, which we use as a case study, and poses an alternative mechanism for warm water volume changes to wind-driven theories.

# Deepening the glacial history of the McMurdo Dry Valleys, Antarctica by fingerprinting glacial tills with provenance tools

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In this project we use provenance tools to test for changes in the source area of glacial tills in the McMurdo Dry Valleys, Antarctica (MDV), which would indicate changes in the flow patterns of the glaciers that deposited them. The MDV contain an unparalleled terrestrial archive of glacial deposits, which extends back to at least 15 Ma, and that record multiple sources of ice that deposited them, including the northeast flowing ice that overrode the Transantarctic Mountains (TAM), the eastward expansion of the East Antarctic Ice Sheet (EAIS), the westward extension of the Ross Ice Shelf (RIS), and the growth of local alpine glaciers. Because many glacial tills and drifts in the Antarctic occur as isolated patches in disjointed outcrop patterns, it can be difficult to identify a till and determine its source. By characterizing tills in the MDV with provenance tools, we will be able to ask questions such as: has the provenance changed over time? If so, have glacial flow patterns or glacial erosion potentially changed the provenance over time? How much did the AIS override the MDV during the mid-Miocene? How far into the MDV did the EAIS and RIS extend in the late Cenozoic? Is there provenance information to support the presence or absence of fjords in the MDV during the Pliocene? How well correlated are tills of the same age in different valleys? To address these questions, we will determine the provenance of these tills utilizing a variety of methods, including bulk geochemistry from an XRF, grain size, organic carbon content, soil salt concentrations, and the uranium-lead (U-Pb) ages of detrital zircon sands contained in these tills.

In fall 2022, the field team from Vanderbilt, including 3 undergraduate students and 1 post-baccalaureate research assistant, went to Arena Valley, Vernier Valley, Lower Wright Valley, and the Royal Society Range to collect samples. Preliminary results indicate that grain size does not change with age of the till or source area. Organic carbon generally increases in older tills, but Arena Valley does not show this trend. The Chemical Index of Alteration (CIA) generally increases with till age, but overall values are low showing little weathering by hydrolysis in this area. Common geochemical markers used to distinguish provenance like Ba-Zr and Nb-Y, do not show much distinction between source areas, but Sr-Rb appears useful for characterizing provenance. We are separating detrital zircon from each unit in order to determine the zircon U-Pb age distribution of each till, which we hope will yield more robust provenance information.

#WAISworkshop

# Influence of Cyclic Effective Pressure Oscillations on Glacial Slip

**Natasha Morgan-Witts**[1], Dr Dougal Hansen, Dr Lucas Zoet
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Subglacial processes and mechanics are key factors in the evolution of a glacial system, as the ice-bed interface directly controls fast glacial slip. The variables within this system such as basal temperature, effective pressure (total minus water pressure) and mechanical properties of the substrate can vary depending on the environment and local inputs. Time variant cyclic effective pressure changes can occur at the ice-bed interface through meltwater fluxes and tidal oscillations acting upon the glacier terminus. These oscillations deviate the slip from steady state, however the exact repercussions are difficult to isolate given the small scale of the responses and limited access to the ice-bed interface. A large diameter cryogenic ring shear device was used to alleviate some of the limitations of direct field observations by experimentally slipping temperate ice over a till bed under cyclically loaded conditions. Temperate ice was sheared over saturated homogenous (glass beads) and non homogenous(till) sediment at 100 m/year with sequences of sinusoidal pressure oscillations varying in both amplitude and period. Results show hysteresis is present between basal drag and effective pressure, and that the hysteresis changes depending on the sediment type and the parameters (amplitude/period) of the oscillations. The differences between homogenous and non-homogenous till types indicate the composition of subglacial material is of first order importance to the system evolution, response to changing conditions, and overall slip rate.

# Glacial sequences and surficial features within Antarctic GeoMAP, the new open-access geological map dataset of Antarctica

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Antarctic GeoMAP, an open-access geological dataset in release as GeoMAP v.2022-08, is a geospatial resource for cross-discipline interrogation of rock exposures and geologic characteristics that influence cryosphere, polar ecology, environmental/biological niches, heat flow, meltwater pathways, and the interplay of dynamic systems that localize at the base and margins of the Antarctic ice sheet. It incorporates 'legacy' geological data from print maps, folios, and journal publications to reliably represent geology of the entire continent at 1:250,000 scale; or higher resolution, in some sectors. It offers new/improved representation of glacial sequences, geomorphology, and supraglacial water, as a basis for detection of future change. For the West Antarctic ice sheet community, map regions to be highlighted are the upper reaches of the Thwaites/Pine Island Glacier catchment and the margins of Ross Embayment. Glacial deposits from waxing and waning ice sheets reflect fluctuations in ice sheet extent and glacial dynamics. The composition and colour of exposed rocky outcrops influence the loci of ice melt. Some rock types emit heat which may localize ice melting; these may be illuminated by continent-scale evaluations of substrate chemistry and seasonal meltwater distribution.

GeoMAP is a product of international collaboration among contributors from 14 nations, under sponsorship of the Scientific Committee on Antarctic Research (SCAR). The collective effort yielded >99,000 distinct polygons that cover 52,000 km2. The attribute-rich (42 populated fields) and queriable GIS uses international GeoSciML data protocols and implements methodology of New Zealand QMAP / GNS Science to ensure spatial reliability and harmonized classification (not achieved at scale in any prior map compilation). Bibliographic links to 589 source maps and scientific literature lead users to primary sources and legacy data within the original scientific context. Equally important, the rich new dataset can be implemented in investigations using high-resolution satellite time series and artificial intelligence. GeoMAP v.2022-08 is freely available to download (https://doi.org/10.1594/PANGAEA.951482) and access in Nature Scientific Data (Cox et al. 2023, https://doi.org/10.1038/s41597-023-02152-9).

# Englacial stratigraphy of the Ellsworth Subglacial Highlands, West Antarctica

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The acceleration of ice mass loss across the West Antarctic Ice Sheet (WAIS) constitutes a significant concern in the context of projecting sea level rise. However, the limitations in available observations for constraining numerical models restrict our ability to effectively reduce uncertainties associated with estimations of sea level rise. In this study, we present recent investigations of internal stratigraphy of the Ellsworth Subglacial Highlands (ESH), a key region in the early glaciation of West Antarctica. This area has maintained stability since the Last Glacial Maximum (LGM), and it holds potential for enhancing our understanding by contrasting historical ice sheet dynamics with existing observations, thereby refining ice sheet model predictions. We have identified six distinct internal reflecting horizons (IRHs), which are traceable across this expanse. Additionally, we have identified two basal units situated at the ice-bed interface, exclusively atop higher elevated topography. By aligning our IRHs with previous studies utilizing BBAS and IMAFI surveys, we have successfully synchronized two of the internal IRHs with the WD2014 ice core. Furthermore, employing a 1-D model, we have determined the age of the remaining four IRHs. Our initial findings indicate the presence of a pre-LGM feature (approximately 16 ka) throughout the ESH, reinforcing the hypothesis of a stable ice dynamics regime in this region.

# RAICA: Korea-US collaboration establishing a Ross-Amundsen Ice Core Array to better understand West Antarctic coastal climate

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The Pacific coastline of West Antarctica is changing rapidly along much of its length—experiencing thinning, mass loss, and retreat of buttressing 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 (e.g. tropical Pacific Ocean variability, ozone depletion, greenhouse gas warming), 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—long identified by the international ice coring community as a gap in our global array of ice cores. 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. Several such records would fill the large data gap, improve satellite observations and firn densification models, and facilitate ground-truthing of regional climate model output used in ice sheet mass loss and sea level rise projections. A newly developed international collaboration between the United States, South Korea, and other partners seeks to collect two 150 meter long ice cores and complete a ground-based radar survey at an ice rise along the Amundsen Sea coast as part of the next RV ARAON cruise to the region (January-February 2024). This core will expand on US efforts establishing an inland WAIS ice core array in the early 2000s, build on ongoing contributions to the International Thwaites Glacier Project, and—with the recovery of one to several additional cores—eventually connect to South Korea and other nations' ice coring efforts in the Ross Sea and Victoria Land regions.

# Insights into Subglacial Hydrology from Sedimentological Analysis of an Esker and Experimental Simulations

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Subglacial water flow regulates basal water pressure, thereby affecting how glaciers slip over their beds. Water flow at the bases of glaciers is thought to be accommodated by a multitude of hydrological architecture types (e.g., cavities, films, Darcian flow, canals, channels etc…), but in many instances water flow is largely accommodated through channels. Direct examination of water flow in these channels in modern day glaciers is extremely difficult but the landforms left behind by channelized water flow can be found over large swaths of the Laurentide Ice sheet's footprint. Examination of the flowing subglacial water's ability to transport and deposit sediment within these subglacial channels provides valuable insights about subglacial glacier hydrology. Eskers are among the few landforms that preserve the records of these subglacial hydrological processes and are well preserved on the landscape. In this study, we investigate the relationship between sediment transport and subglacial hydrology through sedimentological analysis of a large esker, formed under the Chippewa Lobe, located in Bayfield County, and through the construction of an experimental setup that simulates sediment transport conditions within subglacial channels under either atmospheric or hydraulic pressures. These experiments allow us to observe sediment transport behavior under varying hydraulic pressure conditions within a subglacial channel and gain insights into its influence on deposition and erosion patterns that are observed within the esker.

We systematically examined the fabric, texture, and contacts of 18 sections within a 20 m vertical profile through the esker. Critical shear stress values were estimated using Andrew's equation (1983) based on the median grain size and the largest clast size in the section. Abrupt changes in the fabric and texture, sharp contacts, and a non-monotonic change in the critical shear stress were observed and indicate sudden changes in subglacial hydrologic conditions over the esker's formation history, suggesting variations in water velocity, channel size or pressure conditions. The experimental setup flows water and sediment through a unconfine and confine pipe under a constant pressure head gradient and provides valuable insights into the differences in sedimentological morphologies from subglacial channels which are at atmospheric and hydraulic pressure conditions. Under the former, we observe a transition from flat to U-shaped layers, while under the latter, we observe a shift from flat to a distinctive ridge (anticline) near the upstream section of the flow pipe. This study provides a deeper understanding of the complex relationship between sediment transport and subglacial hydrology in the process of esker formation.

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# Using surface topography to fill gaps between ice-penetrating radar surveys: A new Antarctic map of mesoscale bed topography

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Detailed knowledge of Antarctic bed topography is crucial for underpinning modelling projections of the extent and rate of future sea level rise from melting Antarctic ice. Ice penetrating radar and seismic surveys give us a broad scale picture of topographic relief, but the survey lines which form the basis of the Bedmap and BedMachine products are often spaced out by 15 km or more, leaving large gaps where bed topography is unknown. As a complement to the approaches taken by Bedmap and BedMachine, we have developed a technique which we call Ice Flow Perturbation Analysis which uses satellite datasets of the variations in elevation and velocity of the ice surface to infer mesoscale (2-30 km) features in the glacier bed, allowing us to fill these gaps across the whole continent without relying on interpolative techniques. Building on recent demonstrations of this method tested on Thwaites Glacier (https://doi.org/10.5194/tc-16-3867-2022) and Pine Island Glacier (https://doi.org/10.1017/jog.2023.50), we present here a new map of mesoscale features in the bed across the whole Antarctic Ice Sheet, produced using Ice Flow Perturbation Analysis. We compare the bed inferred from Ice Flow Perturbation Analysis with BedMachine Antarctica and selected radar surveys, and then explore a selection of interesting topographic features. When used alongside radar and seismic surveys which give broader scale (> 30km) topography, this new map has the potential to offer new insights into the geomorphological character of much of Antarctica.

# Subglacial discharge accelerates ocean driven retreat of Aurora Subglacial Basin outlet glaciers over the 21st century

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Recent studies have revealed the presence of a complex freshwater system underlying the Aurora Subglacial Basin (ASB), a region of East Antarctica that contains ~5.78 m of global sea level potential and is drained by glaciers that have been retreating and thinning since satellite altimetry remote sensing began. Yet, the role of subglacial discharge in driving contemporary and future retreat of ASB outlet glaciers has yet to be tested in a coupled ice sheet-subglacial hydrology numerical modeling framework. Here, we project the evolution of the primary outlet glaciers draining the ASB (Moscow University, Totten, Vanderford, and Adams Glaciers) in response to evolving subglacial and ocean forcing through 2100, following low and high CMIP6 emission scenarios. By 2100, ice-hydrology feedbacks enhance the ASB's 2100 sea level contribution by >30% (7.50 mm to 9.80 mm) in high emission scenarios and accelerate retreat of Totten Glacier's main ice stream by 25 years. Ice-hydrology feedbacks are particularly influential in the retreat of the Vanderford and Adams Glaciers, driving an additional 10 km of retreat in fully-coupled simulations. Hydrology-driven ice shelf melt enhancements are the primary driver of domain-wide mass loss in low emission scenarios, but are secondary to ice sheet frictional feedbacks under high emission scenarios. The results presented here demonstrate that ice sheet-subglacial hydrology interactions can significantly accelerate retreat of dynamic Antarctic glaciers and that future Antarctic sea level assessments that do not take these interactions into account might be severely underestimating Antarctic Ice Sheet mass loss.

# Antarctic Subglacial Trace Metal Cycling Tracks Climate Across Glacial Termination III

**Mr. Gavin Piccione**[1], Dr. Terrence Blackburn[1], Dr. Slawek Tulaczyk[1]
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Antarctic subglacial meltwaters are an important source of trace metals that fertilizes present day Southern Ocean ecosystems. However, the influence of basal meltwater discharge on ocean productivity over glacial-interglacial timescales is unknown, in part because of the difficulty in constraining the evolution of trace metal mobilization at the Antarctic ice-bed interface. Here we present a 25 kyr record of hydrogeochemical conditions and trace metal cycling beneath the East Antarctic Ice Sheet (EAIS) measured in a subglacial precipitate that formed across glacial termination III. Variations in precipitate texture and deposition rate record a subglacial hydrologic response across the termination, where increased meltwater flushing before the termination gives way to diminished subglacial hydrologic activity in the cold climate period following the termination. The isotopic composition (O, C, Sr, and U) of calcite tracks this apparent hydrologic change, with a higher fraction of meltwaters flushed from the ice sheet interior before and during the termination, and a shift towards the development of an isolated brine along the ice sheet margin after the termination. Elemental and spectroscopic data indicate that this post-termination hydrologic isolation led to the development of manganous/ferruginous conditions in precipitate parent waters that dissolved redox sensitive elements (Fe, Mn, Mo, Cu) from the substrate. These data support a connection between hydrologic activity and trace metal flux beneath the Antarctic ice sheet, where oxygen supplied through meltwater flushing prevent the dissolution of redox sensitive elements, while hydrologic isolation results in suboxic conditions drive biogeochemical weathering of metal-rich phases. The observed correlation between climate change across termination III and a shift towards more Antarctic subglacial trace metal cycling implies that subglacial hydrologic activity may link trace metal discharge with climate cycles on geologic timescales.

# A Simulation Approach to Characterizing Sub-Glacial Hydrology

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The structure and distribution of sub-glacial water directly influences Antarctic ice mass loss by reducing basal shear stress and enhancing grounding line retreat. A common technique for detecting sub-glacial water involves analyzing the spatial variation in reflectivity from an airborne ice penetrating radar (IPR) survey. Basic IPR analysis exploits the high dielectric contrast between water and most other substrate materials, where a reflectivity increase ≥ 15dB is frequently correlated with the presence of sub-glacial water. There are surprisingly few additional tools to further characterize the size, shape, or extent of hydrological systems beneath large ice masses.

We adapted an existing radar backscattering simulator to model IPR reflections from sub-glacial water structures using the University of Texas Institute for Geophysics (UTIG) Multifrequency Airborne Radar Sounder with Full-phase Assessment (MARFA) instrument. Our series of hypothetical simulations modeled water structures from 5m to 50m wide, surrounded by bed materials of varying roughness. We compared the relative reflectivity from rounded Röthlisberger channels and specular flat canals, showing both types of channels exhibit a positive correlation between size and reflectivity. Large (> 20m), flat canals can increase reflectivity by more than 20dB, while equivalent Röthlisberger channels show only modest reflectivity gains of 8−13dB. Changes in substrate roughness may also alter observed reflectivity by 3−6dB. All of these results indicate that a sophisticated approach to IPR interpretation can be useful in constraining the size and shape of sub-glacial water, however a highly nuanced treatment of the geometric context is necessary.

Finally, we compared simulated outputs to actual reflectivity from a single IPR flight line collected over Thwaites Glacier in 2022. The flight line crosses a previously proposed Röthlisberger channel route, with an obvious bright bed reflection in the radargram. Through multiple simulations, we demonstrated the important role that topography and water geometry can play in observed IPR reflectivity. We ultimately conclude the bright reflector from our IPR flight line is more likely a broad area of wide distributed water, such as a series of flat canals or sub-glacial lake, instead of a Röthlisberger channel. The approach outlined here has broad applicability for studying the basal environment of large glaciers, and can aid in constraining the geometry and extent of sub-glacial hydrologic structures.

# Accelerated Antarctic ice loss through ocean forced changes in subglacial hydrology

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Recent changes in Southern Ocean temperature have been linked with catchment-wide Antarctic ice acceleration and loss. The ice sheet models producing future sea level projections, however, rely on controversial mechanisms to match this rapid response, possibly due to the omission of feedbacks between subglacial water pressure and ice velocity. While modern remote sensing data tie increased subglacial water pressure to ice acceleration, it is unclear whether this feedback regularly affects ice mass balance over centennial to millennial climate oscillations. Here we present a ten-thousand-year record of subglacial water dynamics and chemistry from ~110 ka East Antarctic calcite and sediment-bearing subglacial precipitates. Time series of sediment frequency and grain size indicate that subglacial meltwater flushing cycles correlate with Southern Ocean temperature. Similarly, shifts in calcite geochemical composition record climate-driven changes in subglacial water provenance. The synchronized changes in Antarctic basal hydrology with climate support subglacial water drainage systems as having a key role in transferring the climate forcing acting on ice sheet margins, deep into the ice sheet interior. The demonstrated coupling between subglacial water and climate clarifies the current rapid ice response to climate change in Antarctica and underscores a need and means to heighten the sensitivity of ice sheet models.

# Insights on bottom current variability as determined from sedimentary analyses of shallow bathymetric highs

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Even prior to multibeam swath bathymetry becoming a routine practice aboard polar research vessels, the analysis of side-scan sonar and bottom photographs, grab samples, and a few piston and box cores have led to the recognition that shallow banktops are sandy and tend to display a myriad of iceberg plowmarks. However, hopeful researchers continue to attempt to core banks to learn when the ice unpinned from these features. Numerous marine sediment core deployments during NBP1502A in the western Ross Sea failed to penetrate shallow banktops, with the exception of a single core (117 m long) collected at 350 m water depth on Pennell Bank. The core contains till with abnormally high shear strength and low water content for till in this region, and a transition to biogenic-rich sediments above with an age of ~6.5 cal ka BP, supporting the interpretation that Pennell Bank acted as a pinning point during deglaciation prior to complete retreat during the Late Holocene. In the central Ross Sea at Ross Bank, ongoing analysis indicates some NBP2302/2303 sediment cores resemble the Pennell Bank core at similar water depths. However, above ~300 m water depth on Ross Bank, the seafloor is sandy, and recovery was low or nonexistent, much like the failed attempts on shallow portions of Pennell Bank, suggesting this is a threshold depth below which winnowing of fine sediment is less pervasive. Winnowing from fast bottom currents in glacimarine settings has previously been shown to require a disturbance of some kind such as bioturbation or iceberg turbation to first partially suspend the sediment. Thus, great care must be taken to distinguish disturbed core sections from in-situ sections. Multibeam swath bathymetry data show the presence of some iceberg plowmarks above 300 m, but not as many as expected. Bottom photographs and a box core reveal an extremely sandy seafloor with ripple marks, indicating bedload transport processes are pervasive and could likely mask older iceberg plowmarks. Here, new grain size data, coupled with ADCP data and measurements of surface bedform morphology are used to calculate bottom current velocities and directions. With future microfossil and geochemical analyses and a careful lookout for turbated sediment, these data will provide insight on the complex oceanographic processes, including warm CDW impingement, affecting marine pinning points at present and throughout deglaciation.

# The history of CDW upwelling and heat delivery to the Amundsen Sea Embayment during the 20th century: a paleoceanographic perspective

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Observational records show that WAIS, and in particular Amundsen Sea Embayment (ASE) glaciers (especially Thwaites and Pine Island Glaciers) exhibit continuous and substantial thinning and grounding-line retreat from ~1940s, particularly accelerating from 1990s onwards (e.g. Mouginot et al., 2014; Rignot et al., 2019). At present, ASE glaciers serve as main outlets for the WAIS and their mass loss may contribute as much as ~1 m to global sea level rise by the end of the 21st century (e.g. DeConto et al., 2016). Modeling studies suggest that ASE glaciers are susceptible to runaway retreat (e.g. Joughin et al., 2014); and thus present a major source of uncertainty for future sea level rise (e.g. Rignot et al., 2014; DeConto et al., 2016; IPCC, 2019).

Ocean-driven melting of the underside of ASE glaciers is thought to be responsible for the majority of the ice loss, primarily driven by the upwelling of warm Circumpolar Deep Water (CDW) at the continental shelf edge and into the sub-ice-shelf cavities (e.g. Jenkins et al., 2010). CDW upwelling onto the ASE shelf varies due to natural decadal variability (e.g. Jenkins et al., 2018), longer centennial variability (Hillenbrand et al., 2017), as well as due to recent anthropogenic forcings (Holland et al., 2022). However, regional observational records are limited to the last few decades; thus, to this end, the exact history of CDW incursions and variability on the shelf during the 20th century remain unresolved.

Here, we present high-resolution preliminary foraminiferal geochemical data from marine sediment core(s) retrieved in Pine Island Bay on the southeastern ASE shelf in order to reconstruct the history of CDW incursions (and therefore heat supply) to the WAIS margin during the 20th century. Benthic foraminifera Mg/Ca record(s), a proxy for bottom-water temperatures, is accompanied by benthic foraminiferal δ13C record(s), used as a water mass tracer. Our preliminary results indicate that warm CDW may have upwelled onto the ASE shelf during the ~1940-1970 period, as indicated by an increase in Mg/Ca ratios and therefore temperature, and a decrease in benthic δ13C, supporting the recent findings that ASE glaciers started retreating during the 1940s (e.g. Smith et al., 2017). However, a subsequent increase in the presence of CDW on the shelf from ~1980 to present, as implied by a decrease of benthic δ13C, is not replicated by the benthic Mg/Ca temperature record, which decreases and remains low from ~1970; contrasting observational studies which show increasing ASE glacier mass loss since the 1940s. Furthermore, we present the target sediment cores for future foraminiferal trace metal and stable isotope analyses. This future work will aim to further constrain changes in CDW advection to the inner ASE shelf, particularly western Pine Island Bay and the western edge of the Dotson Ice Shelf, for the 20th century and beyond.

## Controls on the modeling of ice deformation

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Ice deformation is commonly represented by a power-law constitutive relation, Glen's Flow Law, where deformation (strain) rate equals stress raised to the power n and multiplied by a flow-rate parameter A. Glen's Law represents bulk ice rheology as a single power-law even though multiple mechanisms, each with their own power-law relation and parametric values, act together during viscous deformation (creep) of ice. Therefore, the relative importance of different creep mechanisms in naturally-deforming ice sheets controls the key parameters, n and A, in Glen's Flow Law. Here, we couple a composite flow law that explicitly represents individual deformation mechanisms with models for ice temperature and grain size to estimate the dominant deformation mechanism in the Antarctic Ice Sheet. We quantify the parametric and model uncertainties within the composite flow law to identify the primary sources of uncertainty underlying the modeling of ice deformation. Further, we demonstrate the importance of kinetic processes, such as the activation energies for creep, in controlling the dominance of deformation mechanisms. These results, coupled with recent observations of flow parameters, suggest a potential recalibration of parameters for ice flow and suggest the importance of further experimental and observational studies to better constrain the kinetics and thermomechanics of ice flow in order to reduce uncertainties in ice flow modeling.

# Spatial and Temporal Patterns in Ice Shelf Rift Mélange Across Antarctica From Combined Satellite Observations

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About half of the mass loss from Antarctica is by iceberg calving from its ice shelves. Iceberg calving events are preceded by the growth of through-cutting rifts, the complexities of which have been revealed by limited observations. Some rifts continue to grow, although with high spatial and temporal variability in rates of extension and/or widening, others fall dormant. Growth of active rifts accelerates during the austral summer, and following tsunami swells, boreal winter storm swells, and periods of high winds. Infilling mélange is also believed to play a mechanical role in rift growth, but whether it behaves as a wedge or an adhesive is unclear, mostly because observations have been insufficiently resolved in both space and time to test various hypotheses. NASA's ICESat-2 photon-counting laser altimeter, launched in late 2018, now provides sufficient vertical accuracy (~13 cm over the ice sheets), along-track resolution (~13 m footprint) and temporal sampling (weather-dependent 91-day repeat) to investigate the changing structure of mélange in individual rifts. We generated a custom land ice elevation product using SlideRule (ATL06-SR) with 10 m along-track point spacing (standard for ATL06 is 20 m) to resolve mélange surface expressions within rifts. We combined this with Landsat-derived rift geometries and WorldView multispectral imagery to characterize seasonality of mélange properties and its relationship to larger scale deformation linked to rifting. We applied this novel spatiotemporal analysis of mélange surface expressions to known rifts with varying levels of activity across Ross and Amery ice shelves. These data are the first to provide process-scale spatiotemporal information about mélange, and move us closer to understanding its importance for ice shelf rift evolution around Antarctica, including the rapidly-changing WAIS ice shelves.

# Evaluating Atmospheric River Signatures in West Antarctic Ice Core Isotopic Records

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The Antarctic Ice Sheet plays a critical role in sea-level rise and understanding its surface mass balance is essential. Extreme precipitation events, including those resulting from atmospheric rivers (ARs), contribute significantly to snowfall in Antarctica. However, the role of ARs in long-term accumulation trends remains uncertain. This study examines the potential of three West Antarctic ice core records to capture the signatures of ARs owing to the influence of ARs on the isotopic composition of snowfall. Using the ice cores and global climate reanalysis datasets, we examine relationships between AR meridional moisture transport (vIVT) and isotopic composition ($\delta^{18}O$). We find a significant association between AR-vIVT and isotopic enrichment, likely owing to the lower-latitude origin of AR moisture. Of the sites investigated, we find the westernmost, Thwaites Glacier site to be the most susceptible to enrichment from ARs, likely due to its lower accumulation rate and location relative to the climatological Amundsen Sea low (ASL). Disentangling the effects of ARs versus synoptic scale variability (e.g., the position and strength of the ASL) on the isotopic records remains challenging, highlighting the need for further investigations to more fully understand the impact of ARs on the isotopic composition of ice cores.

# Fragilariopsis kerguelensis Morphometry as a Sea Surface Temperature Proxy for the Late Pleistocene Southern Ocean

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Accurately quantifying SST during Earth's history is critical for understanding key processes that govern Earth's climate. The Southern Ocean (SO) diatom Fragilariopsis kerguelensis was proposed as an SST proxy by Kloster et al (2018) and Glemser and Kloster (2019). This proxy operates on F. kerguelensis populations displaying a "bimodal morphometry" in the SO, with specific ratios of a high/low rectangularity valves present at specific overlying SST. Low rectangularity valves are in higher concentration in warmer waters and at lower SO latitudes, whereas high rectangularity valves become more common in waters below 1°C and at higher latitude.

Here, we assess the use and limitations of this proxy using two sites in the outer Amundsen Sea: IODP 379-U1533 and JCR 179-PC496. (1) SSTs calculated by proxy from surface sediment assemblages to overlying modern SST, showing "modern" assemblages reflect SST within 0.5°C of modern surface water. (2) SST fluctuated throughout MIS-5, coinciding with benthic δ18O (LR04) peaks defined as MIS-5 substages a-e. (3) This proxy is currently only tuned to the Amundsen Sea due to biogeographic differences in F. kerguelensis populations. The bimodal morphometry seen in Amundsen Sea assemblages is not evident in assemblages recovered from the Sabrina Coast. (4) The minimum number of specimens needed to preserve the intrinsic variability of an F. kerguelensis population and accurately record SST in the Amundsen Sea is n<200. SSTs calculated in this study reflect the analysis of 200 F. kerguelensis specimens per sediment interval. Here, when an assemblage is randomly sampled 100 times, "n=200" specimens preserved the intrinsic variability of the sample; however, a smaller number of specimens will likely also preserve this variability. (5) An earlier study utilizing this proxy (Mastro, 2020) suggested MIS-5 was not significantly warmer than present, though earlier interglacials (MIS-11, 13, 15) warmed by at least 4°C. This more detailed analysis of MIS-5 corroborates the suggestion that MIS-5 was warmer only by ~1.5°C. (6) We outline steps for further development of this proxy in the Amundsen Sea and across the Southern Ocean. Although there is much more to learn about the drivers of F. kerguelensis morphology, we find this methodology provides a promising Southern Ocean paleoclimate proxy.

# East Antarctic Age-Depths Constrained from Englacial Architecture.

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Information on ice flow, basal properties, surface mass balance, and old ice distribution in Antarctica can be extracted from the internal architecture of ice using airborne radar surveys. In this study, underpinning a wider community objective to trace englacial stratigraphy across both West and East Antarctica, we identify and trace three key internal reflection horizons (IRH) across multiple surveys, connecting the South Pole to Dome Argus. Based on their intersection with the South Pole Ice Core and previous studies, we assigned ages of 39, 90 and 161 ka to the three IRHs; through tracing these to Dome Argus, which has already been stratigraphically connected further across the East Antarctic Ice Sheet, we establish here the first stratigraphic link between the South Pole and EPICA Dome C ice cores. While the 39 ka IRHs are most widely traced, all three IRHs provide insights into ice dynamics across the region's complex topography. The study reveals a drawdown in the layers around the South Pole, indicating the impact of geothermal heat flux and/or previous enhanced flow. The deepest IRH's fractional depth serves as a proxy for locating old ice, indicating that within the study area, the oldest ice likely exists in the deep valleys of the Gamburtsev Subglacial Mountains. These traced IRHs contribute significantly to a continental-scale database, which would provide validation for ice sheet models.

# The role of footloose-type calving at the front of the Ross Ice Shelf.

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Ice shelf calving has received significant attention in recent years, with substantial advances in theoretical, modeling, and observational approaches. Modes of calving range from frequent small-scale crumbling of the ice cliff to infrequent detachment of giant tabular icebergs. Here, we focus on intermediate-scale processes that have received less attention: calving due to bending stresses in the ice, also called the footloose mechanism.

When the cliff of an ice shelf is exposed to open water, wave-induced melting forms a notch near the water line of the calving front, which over time leads to the collapse of the overhanging ice slab. The submerged front of the ice shelf then protrudes beyond the subaerial cliff and is no longer in hydrostatic equilibrium. The excess buoyancy of this submerged protrusion (or foot) will cause the front of the ice shelf to bend upward, which results in a characteristic surface deformation that is referred to as a rampart-moat profile. When the bending generated stress exceeds the strength of the ice it triggers a calving event that can be orders of magnitude larger than the volume loss due to frontal melt itself.

Recent observational studies have revealed flexural deformations using surface elevation profiles of the Ross Ice Shelf (RIS) front from NASA ICESat-2 laser altimetry data, indicating the potential presence of a submerged foot and a deviation from hydrostatic equilibrium. We conduct a comprehensive analysis of observations and reanalysis data to assess wave erosion along the RIS calving front, and relate it to the foot growth. By leveraging satellite observations and a one dimensional elastic beam theory, we established a connection between our findings and the observed vertical deflection of the ice front.

# Multi-decadal Record of Sensible-Heat Polynya Variability from Satellite Optical and Thermal Imagery at Pine Island Glacier, West Antarctica

Elena Savidge[1], Dr. Tasha Snow[1], **Dr. Matthew Siegfried**[1]
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Persistent sensible-heat polynyas (thermodynamically maintained areas of open ocean surrounded by sea ice that occur near ice-shelf fronts) directly impact ice-shelf basal melt through heat exchange processes and may also relate to ice-shelf stability through fracture initiation and propagation. However, the lack of detailed multi-year records of polynya variability pose a barrier to assessing the potential interconnectivity between polynya and frontal dynamics. Here, we present the first multi-decadal record (2000–2022) of polynya area at Pine Island Glacier (PIG) from thermal and optical satellite imagery. We found that although polynya area was highly variable, there were consistencies in the timing of polynya maximal extent, and opening and closing. Furthermore, we found that the largest polynya (171 km2) in our record occurred at the western margin of PIG just 68 days before iceberg B-27 calved, suggesting that polynya size and position may influence rifting dynamics. We suspect that large sensible-heat polynyas have the potential to reduce both ice-shelf buttressing (via reduced landfast ice) and shear margin friction (via reduced contact with slower marginal ice), which may lead to instability and eventually contribute to calving. Our new dataset provides a pathway to assess coevolving polynya and frontal dynamics, demonstrating the importance of building long-term records of polynya variability across the continent.

# 123 years of Antarctic surface mass balance and atmospheric circulation history: Implications for Antarctica's contribution to sea level rise

**Dr David Schneider**[1,5], Dr Gemma O'Connor[4], Mr Ziqi Yin[2], Ms Zaria Cast[3], Dr Rajashree (Tri) Datta[2], Dr Eric Steig[4]
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Historical trends in Antarctic snowfall and surface mass balance (SMB) have been difficult to constrain and explain, giving little confidence in our ability to predict future SMB trends and ultimately, the contribution of the ice sheet to sea level rise. In recent years, the availability of dozens of well-dated, high resolution ice core records, advances in data assimilation, advances in climate models, and the urgency of addressing this problem have given us most of the data and tools that we need to solve it. In this presentation, we will first show the relative level of agreement and disagreement between model-based and observed (from a combination of ice cores and reanalysis) estimates of SMB trends over the past 123 years (1900-2022). We will then discuss the extent to which the disagreement between observed and model-based estimates can be explained by the atmospheric circulation history, as given in a recently published paleoclimate data assimilation product. We will also look briefly at observed and modeled SSTs as a possible explanation for observed vs modeled SMB differences. Taking the long view, the atmospheric circulation history shows clear signatures of anthropogenic influence. Human-driven changes in atmospheric circulation may be giving a one-two punch to the ice sheet - limiting the "expected" SMB increase in some regions while trending towards a wind pattern that increases the intrusion of circumpolar deepwater onto the West Antarctic continental shelf, increasing melting and ice discharge rates.

# Drivers and Mechanisms of Rift Propagation: Initial Observations on the Thwaites Eastern Ice Shelf, West Antarctica

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Mass loss from the West Antarctic Ice Sheet is expected to be one of the largest contributors to global sea-level rise in the coming decades. In particular, the vast Thwaites Glacier catchment relies solely on its last remaining ice shelf, the Thwaites Eastern Ice Shelf. Recent modeling experiments suggest that we are currently witnessing the later stages of ice-shelf buttressing loss, likely initiated in the early 1900s. At present, a set of five parallel rifts extend five-to-seven kilometers into the center of the Thwaites Eastern Ice Shelf and threaten its structural integrity. These rifts, which formed in 2016, have been propagating at speeds of approximately one kilometer per year and undergo intermittent accelerations by an order of magnitude that typically occur during austral spring. Although this implies an apparent seasonal pattern, the drivers of rift propagation remain unclear. Here, we present initial observations of the rifts, aiming to gain insight into drivers for both the background propagation rates and intermittent accelerations that control rift propagation. We aim to put the propagation of these rifts into context of recent weakening of the western shear zone and transverse rifts forming upstream as the ice shelf accelerates. We digitize Sentinel-1 imagery to monitor rift propagation through time, as well as to investigate the role of sea ice at the ice shelf front and lateral margins. To further investigate mechanisms of propagation, we present ground-based observations of ice-penetrating radar transects to examine rift geometry and a network GPS to calculate strain rates across the rift tips. These in-situ measurements are crucial for predicting mechanisms at play towards the anticipated collapse of the Eastern Ice Shelf in the coming years.

# Glacial sequences and surficial features appear in Antarctic GeoMAP, a continent-wide detailed geological map dataset of Antarctica

**Prof. Christine Siddoway**[1], Dr. Paul Morin[3], Mr Samuel Elkind[5], Dr. Simon C. Cox[2], Dr. Belinda Smith Lyttle[2], The GeoMAP team[4]
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Antarctic GeoMAP, an open-access geological dataset in release as GeoMAP v.2022-08, is a geospatial resource for cross-discipline interrogation of rock exposures and geologic characteristics that influence cryosphere, polar ecology, environmental/biological niches, heat flow, meltwater pathways, and the interplay of dynamic systems that localize at the base and margins of the Antarctic ice sheet. It incorporates 'legacy' geological data from print maps, folios, and journal publications to correctly geo-locate and reliably represent geology of the entire continent at 1:250,000 scale (higher resolution, for some sectors). It offers new/improved representation of glacial sequences, geomorphology, and supraglacial water, as a basis for detection of future change. For the West Antarctic ice sheet community, map regions to be highlighted are the upper reaches of the Thwaites/Pine Island Glacier catchment and the margins of Ross Embayment. Glacial deposits from waxing and waning ice sheets reflect fluctuations in ice sheet extent and glacial dynamics. The composition and color of exposed rocky outcrops influence the loci of ice melt. Some rock types emit heat which may localize ice melting; these may be illuminated by continent-scale evaluations of substrate chemistry and seasonal meltwater distribution.

GeoMAP is a product of international collaboration among contributors from 14 nations, under sponsorship of the Scientific Committee on Antarctic Research (SCAR). The collective effort yielded >99,000 distinct polygons that cover 52,000 km2. The attribute-rich (42 populated fields) and queriable GIS uses international GeoSciML data protocols and implements methodology of New Zealand QMAP / GNS Science to ensure spatial reliability and harmonized classification. GeoMAP v.2022-08 is freely available to download (https://doi.org/10.1594/PANGAEA.951482) and access via Nature Scientific Data (Cox et al. 2023, https://doi.org/10.1038/s41597-023-02152-9). Bibliographic links to 589 source maps and scientific literature lead users to primary sources and legacy data within its original scientific context.

# Radiostratigraphic connection between the South Pole and Hercules Dome

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The Last Interglacial (LIG) (129 to 116 ka) is a valuable timeframe for assessing how responsive the West Antarctic Ice Sheet (WAIS) is to warmer temperatures and if its collapse contributed to the higher global mean sea level in the past. Hercules Dome has been recognized as an ideal location for obtaining a deep ice core preserving a paleoclimate record unique to WAIS, attributed to its climatic positioning and undisturbed internal layering. We attempt to date the stratigraphy at Hercules Dome using airborne radar-sounding data acquired by UTIG's MARFA acquisition system through connection with an older dated airborne survey at the Pole-Pensacola basin and SPICEcore, in conjunction with the Center for Oldest Ice Exploration (COLDEX). The dated englacial stratigraphy can be used to better constrain accumulation rates and past ice flow to ascertain if the LIG record has indeed been preserved at Hercules Dome. This will also serve as an englacial stratigraphic connection between East and West Antarctica, a key goal of the AntArchitecture SCAR group.

# Observing persistent polynyas at the Antarctic coastline with year-round ICESat-2 surface elevations and Landsat temperature fields

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Enhanced localized basal melt rates can incise ice-shelf basal channels that structurally weaken ice shelves. These channels can provide conduits for buoyant meltwater, sourced from upstream locations or the grounding zone, which rise towards the ice-shelf edge and can form a surface plume at the ice front. This outflow often includes ocean water with enough residual heat to maintain locally sea ice-free ocean conditions, seasonally or year-round, for small areas near the ice front, termed 'persistent polynyas'. If the plumes reach the surface, they may impact local ice and sea surface characteristics enough for detection by remote sensing. Plume characteristics such as sea surface height (SSH) and temperature (SST) may provide information about the buoyancy, basal meltwater concentration, and ice shelf and sea ice melting potential of these plumes. Here, we combine Landsat 8 optical and thermal infrared imagery with surface elevation data from NASA's ICESat-2 mission to examine the relationships between sea ice/ocean surface heights and thermal gradients at the western Pine Island Glacier persistent polynya. We produce detailed maps of SST and sea ice temperature gradient from Landsat 8 that would not be possible with other existing, coarser temperature products. Ice and ocean temperatures indicate that the plumes have relatively cool SST compared to the surrounding ocean surface in summertime, and relatively warm SST in all other seasons. In summertime, we find anticorrelated SSH and SST within the polynyas: relatively cool water, presumably relating to summer plume temperatures, corresponds to higher SSH. In wintertime, we find lower sea ice heights and warmer ice temperatures at or immediately adjacent to known polynya locations, which we propose is caused by ice thinning from plume heat. Our work highlights the potential for examining ice-ocean processes by pairing high-resolution thermal imagery and altimetry measurements, and developing our understanding of basal meltwater discharge timing and occurrence.

# Modernizing curation at OSU-MGR: New technologies and FAIR-enabled science for Antarctic and Southern Ocean sediment core samples

**Ms Val Stanley**[1], Ms Maziet Cheseby[1], Ms Cara Fritz[1], Dr Emily Cahoon[1], Dr Anthony Koppers[1], Dr Joe Stoner[1], Dr Rupert Minnett[2]
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Oregon State University's Marine and Geology Repository (OSU-MGR) is responsible for the curation of twenty-four miles of marine sediment cores and >10,000 dredge rocks collected since the 1960's. OSU-MGR hosts four major research collections, including the Antarctic Core Collection, the world's largest collection of seafloor sediment samples from the Southern Ocean, as well as the Marine Geology and Geophysics Collection, which includes many cores from other worldwide locations adjacent to past and present marine terminating ice-sheets, including the Arctic Ocean. The global distribution and diversity of the combined collections in combination with a complete suite of modern analytical facilities offers a unique opportunity to collaborate in research, curation, and education.

In addition to long-term storage and archiving services, OSU-MGR includes:
- a main workspace large enough to run major sampling parties, research programs, and educational endeavors,
- a laboratory space for nondestructive analyses, including five track systems for physical properties, linescan and X-ray imaging, and XRF elemental analyses,
- a wet lab with a fume hood,
- a thirty-person classroom,
- and CT scanning at the College of Veterinary Medicine.

The OSU-MGR collections are an invaluable resource for the scientific community, as they are and will continue to be critical in our efforts to understand Earth's future. OSU-MGR staff are working to improve metadata records in order to build an effective modern inventory of the collection using modern digital collection management techniques, including QR-coded labels, barcode scanners, and a new tablet-based application. Current and future curation projects comply with FAIR data principles, with the goal of making all OSU-MGR collections and associated datasets more easily discoverable online. Over the next five years, we will update our sample request process, collect nondestructive data for legacy collections, and improve website functionality. We also aim to implement an automated system for assignment of persistent identifiers: IGSNs for cores, rocks, and subsamples collected for requests, and eventually DOIs for data produced in-house. By citing these identifiers in publications, OSU-MGR users will enhance discoverability of these samples, and therefore the impact of their research for years to come.

# IODP 1537: The Correlation Between Scotia Sea Diatom Abundances and Climate Over the Last 130,000 Years

**Mr. Garrett Strittmatter**[1], Dr. Jonathan Warnock[2], Dr. Reed Scherer[1]
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Located off the coast of the West Antarctic Ice Sheet, the Scotia Sea is a site of great significance in palaeoclimatological studies. This site of interest is along the Eastern side of the Antarctic Peninsula tip, in the direct flow of the Antarctic Circumpolar Current and with sediments rich in diatoms. Additionally, this site and section has a high sedimentation rate of ~148 m/MY. By collecting sediment cores rich in diatoms and other paleo proxies, we are able to gain insight into the variability of environmental conditions over time. Diatoms are primary producers made up of two siliceous frustules that readily preserve, making them a useful tool in climate studies. Sediment samples were taken from the core retrieved from IODP Site U1537, this study uses samples that cover the last ~130,000 years (MIS 5). This study looked at the Absolute Diatom Abundance (ADA), Relative Diatom Abundance for both species of diatoms and known ecological groups of diatoms and in the future the use of some f. Kerguelensis proxies such as Length/Width Normalized for Iron Availability, at a sample resolution of 1 cm / 20 cm. ADA is defined as the number of valves per gram, relative abundance is the percentage of the abundance that is made up of a particular group or species. Four ecological groups that are primarily identified at this site are the Well Mixed, Open Ocean, Sea Ice, and Subtropical groups. Results so far (~ 40 KYA) present an inverse correlation of the Absolute Diatom Abundance with the benthic oxygen isotope stack, in conjunction with an increase in productivity of the Sea Ice group of diatoms, implying increased productivity in cold water. This is the opposite of what would be expected of productivity, which is typically higher in warmer water, depending on species present at a site, in the Southern Ocean as the warmer temperature increases the preferred environment for the Open Ocean and Subtropical groups of diatoms. We are seeing the Open Ocean group of diatoms maintain a steady abundance (~70%) at this site with most changes in the conditions at this site. This trend suggests that at this site the primary driver of abundance is not the temperature, but more likely tied to the nutrient availability or another variable at this site. Understanding the driver of the temperature/productivity relationship, as well as species data from this site, can help us understand more about the variation of the climatic and ecological setting of the West Antarctic Ice Sheet and the Scotia Sea in specific and the variation in the location of the polar front over time. This study will increase the amount of data that we have both in location and depth at this site, increasing our knowledge of the West Antarctic Ice Sheet history and its impact on Southern Ocean primary productivity.

# A unique sample and data resource for ice-sheet & environmental change: the Polar Rock Repository

**Jamey Stutz**[1], Dr. Anne Grunow[1], Dr. Erica Maletic[1]
[1]*Polar Rock Repository*

The Polar Rock Repository (PRR) is a National Science Foundation funded facility that contains sample collections, metadata, and media that are relevant to understanding changes to Antarctic Ice Sheet through time. The PRR collection has supported a wide range of glacial reconstruction studies using cosmogenic nuclides, provenance compositional data, U-series age dating on subglacial precipitates, and trace metal paleotemperature proxies. PRR samples are also being used to make volcanic eruption forecasts and evaluate CO2 fluxing events that impact the Antarctic Ice Sheet. By making terrestrial and marine geological materials available to the earth science and cryosphere communities, the PRR represents an invaluable and unique resource that can help answer key questions involving the ice sheet-ocean interactions and the processes affecting glacial retreat.

The PRR provides online access to over 60,000 rock samples, glacial deposits, terrestrial drill cores, and marine dredge samples from Antarctica and surrounding regions. Samples can be ordered directly from our user-friendly website, prr.osu.edu, for research (including destructive techniques). The PRR has also created an extensive media archive of ground photos and videos, spanning over 60 years, that provide geological and glaciological information as well as a record of surface features (lakes, icebergs, streams, etc.) reflecting more recent change. Online multi-field searchable criteria useful to climate studies include subglacial precipitates, weathering salts coating rocks, coral/marine invertebrates on dredge samples, lichen and mosses, iron and manganese nodules, iron oxide coatings, glacial erratics and glacial striations, subglacial drill cores, and photos and videos of outcrops and landscapes.

# Historic Shear Margin Migration at Conway Ice Rise: An Integrated Data-Model Approach

**Mr Paul Summers**[1], Dr Andrew Hoffman[2], Dr Howard Conway[3], Dr Ginny Catania[4], Dr Al Rasmussen[3], Dr Knut Christianson[3], Dr Jenny Suckale[1]
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The dynamics of ice streams on centennial timescales are still poorly understood yet likely important for contextualizing the past and predicting the future of polar ice sheets. Spatially distributed observations of ice-sheet surface elevation and velocity are beginning to capture the ongoing response of the Greenland and Antarctic ice sheets to surface mass balance variability and ocean melt, but these satellite derived surface observations are limited to the last 50 years. To better understand the response of marine outlet glaciers and their confining shear margins to changes in past climate on multidecadal to centennial timescales, we examine the englacial stratigraphy of ice ridges across the Siple Coast, in particular Conway Ridge that sits in between the fast flowing Mercer and Van der Veen ice streams. Several lines of evidence suggest that Conway Ice Rise is less stable than other interstream ridges on the Siple Coast, including the lack of a Raymond arch in internal layers, vertical and horizontal discontinuities in internal layers, and a series of buried crevasses, which suggest a relic shear margin within the current seward promontory of the ice rise. These factors together suggest that Conway Ice Rise is a site for potential historic shear margin migration in response to changing driving factors over the past centuries.

The aim of this study is to present radar observations of relic shear margins at Conway Ice Rise and use modeling to determine whether changes in ice thickness and basal strength that related to large-scale retreat in the Ross Sector of West Antarctica during the last few centuries contributed to this shear margin migration at Conway Ice Rise. First, we use radar observations to constrain any historic shear margins positions preserved in radar stratigraphy of the Mercer Ice Stream and the neighboring Whillans and Van der Veen Ice Streams. Then, we develop a depth-averaged, thermomechanical free-boundary model that solves for both shear margin position and ice velocity to test different driving factors that promote changes in the ice-ridge velocity and evaluate whether these histories are consistent with the observed past shear margin migration.

We find that the inferred historic shear margin migration can only be reproduced in modeling when basal shear strength varies strongly with effective pressure. When basal strength is held constant, shear margins are very stable in response to changing regional conditions. From our model simulations constrained by signals of migration in our radar data, we argue that the subglacial hydrological system beneath Conway Ice Ridge has been well connected to the mechanics and position of the Mercer and Whillans grounding zones.

# High-Resolution Diatom Analysis Reveals Oceanographic, Glacial, and Climatic Changes in the Western Amundsen Sea, Antarctica

**MS Magkena Szemak**[1], Dr. Lindsay Prothro[1]
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The West Antarctic Ice Sheet (WAIS) is undergoing rapid glacial retreat, posing a significant threat to global climate, sea level, and elemental cycles. The sector of WAIS that has exhibited the highest rates of change are the outlet glaciers draining into the Amundsen Sea Embayment (ASE). These glaciers release high volumes of glacial meltwater, disrupting the formation of dense shelf water and enabling warm Circumpolar Deep Water (CDW) to freely access the underside of ice shelves and generate basal melt. The precise timing and frequency of these events are unknown, largely due to the remote location of the ASE, heavy ice coverage, and limited satellite observations over this region. However, with concerns that a large-scale collapse of this portion of the WAIS is possible on human timescales, it is crucial we understand the specific atmosphere-ocean-ice dynamics that drive elevated melt in this region.

To obtain the most complete spatiotemporal observations of this change while also avoiding the logistical challenges of working directly at the modern ice margin, we focus on the geologic record from the portions of the continental shelf that have already deglaciated. This study of ten archived sediment cores is the first-ever high-resolution diatom analysis to be conducted on the deglaciated continental shelf offshore of the eastern Getz ice shelves and the Dotson Ice Shelf, which currently see some of the most rapid volume changes of the WAIS. Diatoms are well diversified, and their composition and distribution are closely connected to ecological conditions, rendering them excellent proxies for environmental changes over time. Our analysis revealed four major paleoenvironmental units. One unit was dominated by sea-ice diatoms, one exhibited evidence of high primary production, one was characterized by a relatively high abundance of F. kerguelensis, which is commonly associated with warm CDW, and the final unit displayed elevated levels of reworked species. The distribution and relative timing of these units, as well as the overall unexpectedly low abundance of Chaetoceros and F. kerguelensis, were interpreted within the context of existing records of environmental conditions and deglacial retreat in the Amundsen Sea, shedding light on the intricate interplay between oceanic processes and glacial change over time. Most notably, diatom assemblages suggest strong similarities in water mass structure during both the present and the time of initial deglaciation following the Last Glacial Maximum; namely, these two intervals show that water column mixing, sea ice formation, and brine export are reduced due to the interference of fresh meltwater. This study also revealed discrepancies between different coring methods, highlighting the need for improved core handling in the field.

# Extraction of Ice Thickness Measurements from Digitized Historical SPRI-NSF-TUD Airborne Radar Echo Sounding at Ross Ice Shelf, Antarctica through Computer Vision Algorithms

**Mr Angelo Tarzona**[1], Dr. Winnie Chu[1], Ms. Hannah Verboncoeur[2], Dr. Matt Siegfried[2], Dr. Dustin Schroeder[3], Mr Abdullah Altaweel[1], Mr Brian Amaro[3], Ms Kiera Tran[1]
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During the 1960s – 1970s, the collaborative efforts of the Scott Polar Research Institute (SPRI), National Science Foundation (NSF), and the Technical University of Denmark (TUD) also known as the SPRI-NSF-TUD, collected valuable airborne radar echo sounding dataset containing ice shelf thickness observations at Ross Ice Shelf (RIS). This archival dataset presents an opportunity to expand our understanding of RIS evolution on a multi-decadal timescale. However, in contrast to modern airborne radar echo sounding data, the digitized Z-scope records did not have vertical scale information, which makes it difficult to extract ice thickness information. To tackle this hurdle, we introduce semi-automatic and automatic computer vision picking algorithms designed to extract surface and base features within the digitized Z-scope records. This enable us to show historical ice shelf thickness at RIS and compare these measurements with modern airborne radar echo sounding data at glaciologically important locations at RIS such as Roosevelt Island and Crary Ice Rise. In essence, our digitization and thorough examination of this historical dataset empower us to fully exploit the potential of this archival dataset to examine multi-decadal changes at Ross Ice Shelf.

# Towards 3D englacial ice velocity fields using airborne radar interferometry

**Mr Thomas Teisberg**[1], Dr Dustin Schroeder[1], Mr Paul Summers[1], Dr Mathieu Morlighem[2]
*[1]Stanford University, [2]Dartmouth College*

The rheology of ice is currently not well constrained. Numerical ice sheet models largely use Glen's law, despite growing evidence that it is not a sufficiently general description of ice rheology. Temperature, material composition, crystal orientation, and other factors play a strong role in the stress-strain relationship of ice. Because only extremely sparse measurements of these factors are available in the real world, laboratory experiments cannot be easily translated into rheology models for ice sheets. Using surface velocity and ice thickness data, recent data-driven techniques have shed light on ice rheology in specific locations, but these techniques are limited to areas where strong assumptions can be made such that surface velocity alone is sufficient to determine englacial strain rates.

Ice-penetrating radar systems, including both airborne and ground-based systems, have been shown to be capable of measuring the deformation of englacial layers through radar interferometry. The motion of these layers provides a constraint on englacial velocity throughout the region where layers are visible, however the strength and applications of this constraint have not been analyzed in detail.

Direct measurements of 3D englacial ice velocity fields could provide a way of directly estimating strain rates within ice sheets, enabling direct estimation of the spatially-variable ice effective viscosity.

We present preliminary work on a method of inverting for 3D englacial velocity fields from airborne ice-penetrating radar data. We also discuss implications for survey design and possible limitations of this approach.

# The United States Antarctic Data Center (USAP-DC): A FAIR resource for data archive and re-use

**Kirsty Tinto**[1], Frank Nitsche[1], Isabel Cordero[1], Alex Strong[1]
[1]*Columbia University*

The US Antarctic Program Data Center (USAP-DC) provides services to support the data needs and obligations of researchers across all disciplines of NSF-funded Antarctic research at all points of the data lifecycle. From discovery and reuse of existing datasets, to archive and catalogue of new results and preservation of historical datasets, we promote FAIR principles of data management to make data more Findable, Accessible, Interoperable and Reusable for all users. Here we provide an overview and introduction to the data center, including how to search for data at www.usap-dc.org or through the wide range of catalogue services with whom metadata is shared, including the Antarctic Metadata Directory (AMD), DataONE, and Polar Federated Search. We will demonstrate how to navigate between dataset and project pages to download individual datasets, including field measurements, lab studies and modeling results, and to discover the context of the projects through which they were originally acquired. For data providers we will introduce a newly-implemented dataset metric that is aimed to improve the FAIRness and encourage best practices for dataset submissions to the archive.

# Antarctic RINGS: A SCAR Action group to understand the Antarctic Coastal zone through international collaboration

**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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Regions where the Antarctic Ice Sheet reaches the coast are fundamental to our understanding of the linkages between Antarctica and the global climate system. Knowledge of bed topography at the ice-sheet margin is critical for accurate estimates of current Antarctic ice discharge, while bathymetry under ice shelves, bed topography along major outlet glaciers, and geology and subglacial hydrology near the coast are critical factors for predicting the future of the Antarctic Ice Sheet. None of these fundamental boundary conditions is adequately constrained by observations along the 62,000 km long margin of the Antarctic Ice Sheet.
The RINGS Action Group exists to (1) clarify the current knowledge gaps at the ice-sheet margin and assess the impacts of new data filling these knowledge gaps, and (2) develop a set of protocols to systematically collect, analyze, and share comprehensive airborne geophysical data. In this presentation we report on progress made towards these goals, future plans and opportunities for engagement.

# Integrating Basal Melt Rates of Ross Ice Shelf from ROSETTA-Ice Airborne Sounding Radar Survey and NASA/UCI Ice Sheet System Model

**Kiera Tran**[1], Dr Winnie Chu[1], Dr Laurie Padman[2], Dr Dustin Schroeder[3], Isabel Cordero[4], Angelo Tarzona[1]
*[1]Georgia Institute of Technology, [2]Earth and Space Research, [3]Stanford University, [4]Lamont-Doherty Earth Observatory*

Antarctica's ice-shelf mass loss is primarily influenced by basal melting and calving processes. When mass losses surpass inputs from grounded-ice flow across the grounding line and local surface mass balance (snowfall), the thinning and/or retreat of the ice shelf can lead to accelerated ice loss by diminishing ice-shelf buttressing, thereby enabling an increased flow of grounded ice into the Southern Ocean. Our project centers on examining basal melting of the Ross Ice Shelf (RIS). Through a comprehensive approach, we used data from the ROSETTA-Ice airborne sounding radar survey, a 1D heat transfer model, and the NASA/UCI Ice Sheet System Model (ISSM) to develop a connection between radar englacial attenuation and ice shelf basal melt rates, employing a physics model outlined in Holland and Jenkins 1999. By applying this methodology, we present a basal melt rate map for the Ross Ice Shelf along with other maps derived from two alternative attenuation rate calculations. All three maps reveal similar spatial patterns of basal melting. Overall, Western RIS shows higher melt rates compared to Eastern RIS. Furthermore, intensive high melting is observed along grounding lines and ice flow lines while low to no melting region is located inner of RIS. Intriguingly, the approach based on the ISSM indicates minimal melt rates in areas near Roosevelt Island, in contrast to the other two methods that identify higher melt rates. These discrepancies underscore the significance of comprehending how factors beyond oceanic processes, such as surface mass balance, might influence radar attenuation observations.

# Unlocking the subglacial time machine: Constraints on the climate sensitivity of ice sheet behavior from subglacial precipitates.

**Prof. Slawomir Tulaczyk**[1], Prof. Terrence Blackburn[1], Mr Gavin Piccione[1], Ms Jessica Gagliardi[1], Dr. Graham Edwards[2]
*[1]University of California, [2]Dartmouth College*

Constraining the sensitivity of the Antarctic ice sheet to climate variations remains one of the most important, but also one of the most intractable, scientific challenges in polar research. Antarctic ice cores yielded excellent constraints on past climate forcings. Still, there is a shortage of well-dated geologic records revealing how the ice sheet responded to these well-documented paleoclimate variations, particularly for periods preceding the Last Glacial Maximum. Over the last several years, the research group of Prof. Terry Blackburn (UCSC) has developed novel approaches that enable detailed U-series dating and comprehensive geochemical and isotopic analyses of subglacial precipitates, which formed between the 30 ka and 6 Ma, with some of them recording ca. 100 kyrs of continuous or nearly continuous subglacial precipitation. These subglacial archives already provided evidence supporting: (1) a significant ice retreat in the Wilkes Basin, East Antarctica, during MIS 11, a remarkably long interglacial (Blackburn et al., 2020), (2) high ice sheet sensitivity to millennial-scale climate warming events known as the Antarctic Isotopic Maxima from the Antarctic ice core records (Piccione et al., 2022), and (3) accelerations of outlet glaciers draining the Laurentide ice sheet into the Baffin Bay that were contemporaneous with the most recent Heinrich events (Edwards et al., 2022). Ongoing UCSC research on subglacial precipitates will yield further constraints on the climate sensitivity of ice sheets, as well as new, exciting insights into the long-term subglacial carbon cycle, the evolution of subglacial water geochemistry, and the long-term history of subglacial lake drainages. Over the longer time horizon, these unique and rich paleoarchives will revolutionize our understanding of ice sheet evolution on timescales ranging from hundreds of years to millions of years. With the collection and analyses of additional precipitate samples, it may be possible to reconstruct a (nearly) continuous history of Antarctic subglacial conditions covering the last several hundred thousand years or longer. Such a record can then be analyzed by comparison to ice core, cave, lake, and marine paleoclimate records to better understand the role of Antarctica in Earth's climate system.

# Mass changes in Antarctica using GRACE and GRACE-FO MWI and LRI data

**Dr Isabella Velicogna**[1]
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The time series of mass changes in Antarctica from the GRACE mission 2002-2017 was extended in time with the GRACE-FO mission 2018-present, which uses both microwave interferometer (MWI) and laser ranging interferometer (LRI) instruments. We will show an update the GRACE/GRACE-FO measurements of mass balance in Antarctica from the continent size, West vs East, and large sectors of West and East. We compare the results with SMB models (RACMO, MAR, MERRA-2) since SMB dominates the seasonal to interannual variability as a cross-evaluation of GRACE and the models. We evaluate the impact of the accelerometer transplant of GRACE-FO on the results. Finally, we show initial results with LRI which offers the potential to improve the precision of the measurements vs the level-2 harmonics and also improve the spatial resolution (by a factor 2) and the temporal resolution (sub-monthly) of the mass balance estimates. We show examples of extraction of sub-monthly mass balance over Thwaites Glacier and over the ensemble Pine Island/Thwaites. We conclude on the potential impact of these results on modeling and sea level projections.

# Ocean-Driven Melting near and within Ice Shelf Basal Channels and Crevasses

**Ms Sarah Villhauer**[1], Dr Ken Zhao[2], Dr Erin Pettit[2], Dr Peter Washam[3]
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Ice shelves in West Antarctica and Northern Greenland have lost a significant amount of mass, thinned, and retreated over the past two decades. Ice shelves act as a stabilizing influence on grounded ice. However, we have a limited understanding of how various basal geometries—including channels, crevasses, and terraces—affect the basal melt rates of these ice shelves and impact ice shelf stability. A three-dimensional Large-Eddy Simulation of ocean circulation of ice shelf basal channels and crevasses is developed, with initial conditions and parameters motivated by observational data beneath Pine Island, Thwaites, and Petermann Ice Shelf. Our primary aim is to investigate how different conditions and forcings within ice shelf cavities impact the near-boundary dynamics and thermodynamics, which drive disparate magnitudes and spatial patterns of melt. In order to observe the behavior of ocean circulation within our designated basal geometries, we performed various perturbation experiments, including altering aspect ratio (channel height over channel width), magnitude of far field salinity, temperature, velocity, and tide velocity, and orientation of far field velocity.

# Organizing WAIS Workshop: Tweaks and turns from the past five years

WAIS Workshop Organizing Committee

Since its inception in 1992, the West Antarctic Ice Sheet (WAIS) Workshop has hosted a transdisciplinary scientific conference focused on marine ice-sheets and adjacent Earth systems, while supporting an active community of scientists at all career stages—from undergraduate students to emeriti. This long-running, discussion-oriented workshop has shaped and fostered research on the past and present state of WAIS and analog ice sheets, the processes that influence its ongoing change, and the present and future vulnerability of WAIS within a changing Earth system. The WAIS Workshop is where the latest studies of this rapidly evolving ice sheet are reported and interrogated through the transdisciplinary lens of WAIS scientists. The WAIS Workshop also serves as an innovation incubator, a forum where new conference designs can be tested and new community research priorities and directions are formulated and evaluated. Over the past five years, the WAIS Workshop, with the support of the National Science Foundation and NASA, has implemented a suite of changes to center community building, maintenance, and improvement, from implementing blind-review of abstract and travel-award submissions to hosting extended all-hands community health discussions and providing a free livestream available globally. In this presentation, we will discuss the successes and shortcomings of our recent efforts and share metrics that reflect the current state of the WAIS research community. By presenting our experiences, we hope to shed light on who the WAIS community is, where the research is going, and what the community needs, along with ways to engage all career stages both in person and virtually.

# Accessing ice rheology using physics-informed deep learning

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Ice flows in response to stresses according to the flow law, which is crucial for predicting mass loss in the Antarctic Ice Sheet. We leverage remote-sensing data and physics-informed deep learning to investigate the rheology (flow law) of glacial ice in Antarctic Ice Shelves. Our study reveals substantial differences in ice shelf rheology between compression and extension zones. In the compression zone near the grounding line, ice stress and strain rate obey a power law relation with the exponent n in the range of $1 < n < 3$. We identify areas where grain-boundary sliding dominates and infer local grain size of the ice shelf through composite rheology. In the extension zone, which comprises most of the ice shelf area, ice exhibits complex rheological behavior, differing from laboratory findings. By considering anisotropic viscosity our inferred viscosity structure well captures the suture zone of different ice shelves, which is important for the prediction of rift propagation.

# The formation of tidally-modulated landforms at rapidly retreating grounding lines

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Sea-floor landforms formed at past grounding lines provide a unique record of historic ice-sheet extent and retreat, vital for informing present-day ice-sheet modelling. Recently observed, delicate ribbed ridges preserve retreat speeds in their spatial patterns at the sea bed. Specifically, the ridge morphologies appear to provide evidence of extremely rapid, tidally-modulated retreat events from both the Larsen Inlet, eastern Antarctic Peninsula and from Thwaites Glacier, West Antarctica, at rates of several to over ten kilometres per year. Here, we present the first quantitative modelling to unambiguously connect these landforms to the daily tides over which they form.

We consider three different possible formation mechanisms for the ribbed ridges, based on analogies with grounding-zone wedges, moraines, and dune formation. We present simple mathematical models for the three mechanisms and discuss the resulting modelled landforms. We look at the similarities and differences between the modelled and observed ridges, and the implied consequences for formation timescales, ice-sheet retreat rates, and the deformation of subglacial till near grounding lines.

# Ice on the Move: What observing the underside of Antarctica's ice shelves now can tell us about future sea level rise

**Dr Peter Washam**[1], Dr Britney Schmidt[1], Dr Keith Nicholls[2], Dr Peter Davis[2], Dr Justin Lawrence[3], Dr Craig Stevens[4], Dr Christina Hulbe[5], Dr Huw Horgan[6,7,8], Veronica Hegelein[1], Dr Enrica Quartini[1], Dr Matt Meister[1]
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Earth's cryosphere represents one of the fastest changing ecosystems on the planet. Increasing oceanic and atmospheric temperatures are accelerating ice melt and discharge into the ocean, with mass loss from Greenland and Antarctica projected to raise sea level by up to 0.78 meters by 2100. While this projection is dramatic, individual marine-terminating glaciers will contribute to sea level rise differently, as a result of the degree of oceanic and atmospheric forcing they encounter. Focusing strictly on ocean forcing, Earth's marine-terminating glaciers experience a wide range of melting and freezing regimes that result from the ocean temperature, salinity, current speeds, and pressure. In this talk, we present four years of ice and ocean observations collected in Antarctica with the underwater vehicle Icefin. These cutting-edge observations provide information of how the ice and ocean interact in multiple settings from the warm-based, rapidly-melting and changing Thwaites Glacier to the cold-based, slowly melting and stagnant Kamb Ice Stream. The results illuminate a fascinating coupled system where variations in ocean properties interact with small-scale ice slopes to drive melting and freezing over a range of magnitudes. This provides necessary information that can be integrated into models to improve sea level rise projections. I encourage everyone who is curious about this topic to attend my talk. Don't worry there will be plenty of cool (and warm) videos!

# Sediment Flux in the Eastern Amundsen Sea: How did it get there and when?

**Julia Wellner**[1], Rachel Clark[1], Robert Comas[1], Julia Villafranca[1], Claus-Dieter Hillenbrand[2], Robert Larter[2], Alastair Graham[3], Kelly Hogan[2], Frank Nitsche[4], Rebecca Totten[5], James Smith[2], John Anderson[6], Lauren Miller[7], Becky Hopkins[8], Asmara Lehrmann[1], Allison Lepp[7], James Kirkham[9], James Marschalek[10], Laura Barnett[1], Victoria Fitzgerald[5], Georgina Garcia-Barrera[1], Santiago Munévar Garcia[7]
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In 2019 and 2020, two research cruises aboard the RV/IB Nathaniel B. Palmer targeted the areas in front of Thwaites and Pine Island glaciers to conduct geophysical surveys and collect marine sediment cores to investigate glacial and oceanographic history. Core chronology was determined from 210Pb dating of bulk sediment and also from some 14C ages from the limited calcareous microfossils found. These geochronological data are used to investigate sediment accumulation rates over the past century, in particular, and over the last several millennia in lesser detail. Additional sediment core proxies provide context to these rates and highlight relevant sediment transport processes; datasets include grain size and shape data, CT scans, magnetic susceptibility, and density. Core chronologies and facies are tied to 3.5 kHz CHIRP subbottom data, which is used to map the regional extent and thickness of sediment accumulations.

The high-resolution 210Pb chronologies, which span the last ~100+ years, indicate a regional accumulation rate of ~1 mm/yr for glacial marine mud, in part sourced from meltwater escaping from the subglacial environment. The longer term 14C records reveal variable accumulation rates of ~0.2 to 1 mm/yr; these longer term rates are by nature averages of periods of both high and low sedimentation. Both the 210Pb and 14C chronologies indicate higher accumulation rates, up to 4 mm/yr, of glacial marine mud at shallow and more ice-proximal locations. Local bathymetric features and proximity to the source of glacigenic materials control sediment accumulation patterns, resulting in highly variable patterns of sediment accumulation. The patchy nature of the sediment accumulation rates and facies patterns highlights the dangers of interpreting regional history from limited datasets.

The 14C ages provide minimum ages of grounding-zone retreat following the Last Glacial Maximum that indicate grounded ice was already close to its current position prior to 9.4 ka, while not excluding the possibility of further grounding-zone retreat and subsequent re-advance. Of particular note, 210Pb accumulation rates show a slowdown at several ice-proximal sites during recent decades, possibly in response to grounding-zone retreat in the last many decades.

# Investigating Stress States and Rift Propagation on Pine Island Glacier with Time-Dependent Strain-Rate Fields

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Despite its high contributions to sea level rise, the processes that control mass loss on the Pine Island Glacier (PIG) ice shelf are poorly constrained. In particular, processes involving fracture and calving on the PIG Ice Shelf, which provides back (buttressing) stresses on upstream ice, are not well understood due to sparse observations of the area. Here, we investigate the conditions under which full-thickness fractures (rifts) form and propagate on the PIG Ice Shelf using time-dependent strain-rate fields calculated from Sentinel-I synthetic aperture radar data collected between 2015 and 2020. We track three fractures as they propagate to full-thickness and result in a calving event. We estimate the stresses leading up to and along each fracture as the fracture evolves. We capture an increase in damage corresponding to a shift in the southern PIG shear margin, which results in increased stresses along the fractures and an overall loss of buttressing force of the ice shelf. Applying to our data the relation that the tensile strength of ice equals fracture toughness divided by the characteristic length of damage in the ice, as is common in linear-elastic fracture mechanics (LEFM), we investigate the applicability of LEFM to ice-shelf rifting. Our preliminary results show that LEFM predicts order of magnitude greater values of fracture toughness than the experimentally derived fracture toughness of glacier ice, suggesting that LEFM may not be applicable under the stress states and time scales present on PIG, though more data are needed to provide confidence in this supposition.

# Constraining Ice Core Paleofire Proxies During Dansgaard-Oeschger 8

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Fire emits large amounts of trace gases into the atmosphere that can impact climate and ice-albedo feedbacks. Understanding the relationship between modern fire and climate is difficult due to the rapid changes in both. Polar ice core records help us reconstruct a pre-industrial atmosphere to disentangle the complexities of fire and draw implications to understanding the modern global climate system.

Methane ($CH_4$), a potent greenhouse gas, has three preindustrial sources: wetlands, fire (biomass burning), and geologic emissions. These sources have distinct δ13C isotopic signatures and prior studies have utilized δ13C-$CH_4$ in polar ice cores to estimate past changes in magnitude over time. Ice core acetylene ($C_2H_2$) measurements have recently been suggested as a proxy for paleofire. Nicewonger et al. (2020) found a substantial difference in biomass burning inferred from acetylene and biomass burning inferred from δ13C-$CH_4$ during the past millennium. To further investigate the relationship between the two fire proxies, we compare $C_2H_2$ and δ13C-$CH_4$ during Dansgaard-Oeschger (DO) event 8, which began 38 kyr B.P. during the Last Glacial Period. DO8 was a period of abrupt warming followed by slow cooling.

A one-box global methane model is used to simulate $CH_4$ and δ13C-$CH_4$ during DO8. Biomass burning and wetland methane emissions were adjusted to optimize agreement with published EPICA EDML ice core δ13C-$CH_4$ measurements (Möeller et al. 2013). Acetylene biomass burning emissions were inferred from the South Pole and GISP2 measurements using sensitivities derived from chemical tracer model studies for boreal (60-90°N) and nonboreal (60-90°S) emissions (Nicewonger et al. 2020). Emission factors from Andreae (2019) were used to convert the inferred burning emissions of methane and acetylene to dry matter burned (amount of fire). The results show a significant difference between the methane-inferred and acetylene-inferred dry matter burned during DO8. The amount of methane-inferred fire is around a factor of five times larger than acetylene-inferred fire. A similar discrepancy was observed during the late preindustrial Holocene by Nicewonger et al. (2020). Possible explanations for this difference are discussed.

# Accelerating understanding of Ice Sheet – Solid Earth feedbacks and future sea-level change

**Dr Terry Wilson**[1]
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Climate, ice sheet and solid Earth dynamics are coupled. To accelerate progress in understanding coupling modes, and to establish the magnitudes and signs of coupling that influences future global sea level, better integration across disciplines is crucial. In Antarctica, tantalizing signatures of solid Earth – ice sheet feedbacks come from recent geodetic, geophysical, glacial geologic and glaciological studies, linked with ice sheet and GIA modeling. Many studies hypothesize causal relations, for example that isostatic rebound could drive grounding line readvance. More and stronger constraints on ice histories, subglacial topography, vertical land motion rates and patterns, Earth structure and rheology, and more, are needed to test such hypotheses about feedbacks and their consequences. In parallel, advances in modeling skills and computational efficiencies are essential to ingest diverse data and implement model runs at appropriate resolutions and time scales. For example, ice sheet models predicting intermittent grounding line retreat where topographic highs cause temporary stabilization, need to incorporate changing subglacial bedrock elevations where isostatic adjustment (upward or downward) is occurring at rapid rates, such as along the Amundsen Embayment margins. The accelerating pace of change calls for quickening our advances in process understanding through integrated science objectives, frequent cross-discipline and observationalist-modeller communications, and engaging and training students/early career scientists to carry complex interdisciplinary efforts forward.

# Targeting sites of subglacial volcanism in the central West Antarctic rift system

**Dr Duncan Young**[1], Dr. Shuia Yan[1], Ms Megan Kerr[1], Dr Donald Blankenship[1]
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The West Antarctic Rift System underlies the West Antarctic Ice Sheet, and while regional tectonic extension has ceased, local subareal volcanism over the Cenozoic is very apparent. Aerogeophysical data dating back to the 1990's have indicated a range of sites of compatible with both Cenozoic and active subglacial volcanism (Quartini et al.,. 2021, van Wyk de Vries, 2018). As such, their interactions with the ice sheet has the potential for a uniquely datable record of the evolution of the ice sheet (eg Spector 2018) and influence modes of heat flow transport to the base of the ice sheet. However these data are generally too sparse for detailed investigations of the origin, age and to develop strategies for sampling these features, or even to confirm if these features are volcanic at all. Here we review subglacial volcanic targets within easy reach of WAIS Divide or Byrd camp, with a aerogeophysical strategy that trades resolution for range and inductive for deductive scientific approaches.

Quartini, E., Blankenship, D. D., and Young, D. A., 2021, Active subglacial volcanism in West Antarctica, Geological Society Of London, Special Publication, 55, 785-803, https://dx.doi.org/10.1144/M55-2019-3

van Wyk de Vries, M., Bingham, R. G., and Hein, A. S., 2018, A new volcanic province: an inventory of subglacial volcanoes in West Antarctica, Geological Society, London, Special Publications, 461, 1, 231--248, 10.1144/SP461.7

Spector, P., Stone, J., Pollard, D., Hillebrand, T., Lewis, C., and Gombiner, J., 2018, West Antarctic sites for subglacial drilling to test for past ice-sheet collapse, The Cryosphere, 12, 8, 2741--2757, 10.5194/tc-12-2741-2018

# An Improved Parameterization of the Ice-Ocean Boundary Layer

**Dr Ken Zhao**[1], Dr Eric Skyllingstad, Dr Jonathan Nash
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Glacial melt rates at ice-ocean interfaces are commonly parameterized using a shear boundary layer assumption. However, this assumption has only been demonstrated to be appropriate for horizontal ice-ocean boundaries where the exchange of heat and freshwater across the mm-scale diffusive thermal and salinity boundary layers varies proportionally with the strength of external momentum, i.e. when buoyancy-driven turbulence is weak.

Guided by Direct Numerical Simulations of the ice-ocean boundary layer for varying geometric and ocean forcing parameters, I will present an updated understanding of the basic principles of
ice-ocean boundary layers (as a freshwater layer nested within a thermal layer nested momentum within a viscous velocity shear layer within a turbulent shear layer).

I will present simulation results that seek to merge the following turbulent ice-ocean boundary layer regimes:
(1) meltwater-driven buoyancy, (2) meltwater-driven shear, and (3) externally-driven shear (from both horizontal and vertical sources of momentum). In the absence of externally-driven flows, we find a dynamical transition from buoyancy-controlled to shear-controlled boundary layers for the thermal layer, but not the freshwater layer. By contrast, we find that externally-driven sources of shear can constrain both the thermal and diffusive freshwater layers. This improved understanding allows us to develop accurate predictions for the turbulence-constrained momentum, thermal, and freshwater boundary layer thicknesses, which is required to predict their fluxes and thus, ocean-driven ablation rate.

I propose and discuss the implications of a new parameterization for ablation rate at ice-ocean boundaries that modify commonly-used ocean heat, freshwater, and momentum budgets (plume theory and 3-equation thermodynamics) via new simulation-derived theories of near-boundary ocean-turbulence (turbulent transfer efficiency, plume entrainment, and friction velocity).

(Unlike this abstract, I aim to make this presentation as accessible as possible to an audience with diverse backgrounds and interests.)

# The effects of non-Newtonian, transient and Newtonian viscosities on GIA-induced crustal motions and their implications for GPS observations in Antarctica

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Recent ice melting in West Antarctica and Northern Antarctica Peninsula has caused rapid crustal motions with vertical and horizontal displacement rates that exceed 40 mm/year and 10 mm/year, respectively, at some locations, as recorded by GPS (e.g., Samrat et al., 2020; Barletta et al., 2018). Modeling the GIA process with ice-melting history indicated that to explain the GPS observations, the upper mantle viscosity is required to be ~10^18 Pas, which is two orders of magnitude smaller than that inferred for North America and Fennoscandia using observations of relative sea level change in the Holocene. Given that the land rebound rate significantly affects migration of the grounding lines and hence the stability of melting ice sheets and glaciers (e.g., the Thwaites glacier), it is therefore important to understand the mantle deformation mechanism (i.e., the rheology) with which the upper mantle of West Antarctica responds to the ice melting to give rise to the rapid crustal motions. We have formulated dynamic deformation models to determine crustal motions in response to ice melting at a constant rate (e.g., 1 meter of ice melting per year) for three different mantle rheological models: Newtonian, stress-dependent non-Newtonian, and transient rheology. Our calculations show that the surface rebound rate displays very different time dependence for different rheology. For the non-Newtonian rheology, the rebound rate increases with time and becomes the largest among the three rheological models after 120 years of continuous ice melting. For the transient rheology, the rebound rate increases rapidly with time initially and reaches its peak value after 60 years of continuous ice melting before gradually decreasing with time and eventually becoming smaller than that for non-Newtonian rheology at ~120 years. The Newtonian rheology gives the smallest rebound rate among the three rheological models. These calculations suggest a possibility to use the GPS observations to determine the dominant mantle deformation mechanism in West Antarctica, which helps provide a more robust model prediction for future crustal motions in West Antarctica.

# The impact of frozen sediments on basal friction for soft-bedded glaciers and ice streams

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Partially frozen sediments are frequently observed attached to the base of glaciers and ice streams. This “frozen fringe” exists as a conglomeration of ice, liquid water and sediment particles and potentially regulates ice mass flux by changing friction at the basal slip interface. However, fundamental questions remain unresolved—such as whether the frictional response arises from deformation in the fringe itself or in the saturated sediment below, as well as the manner in which large clasts lodged at the ice-bed interface influence this interaction. In this study, we conducted laboratory experiments to elucidate the impact of frozen sediments on basal friction during glacier slip over a saturated, granular material. Using a cryogenic ring shear device, we slid rings of temperate ice over saturated granular beds at temperatures, effective pressures, and ice velocities characteristic of the subglacial environment. We constrained the relationships between shear resistance, slip speed, and effective stress for cases with and without fringe. Results reveal that in the absence of fringe, the resistance to slip matches the Coulomb strength of the sediment past a threshold ice velocity, previously suggested to mark a transition from form drag at the ice-bed interface to skin friction at depth. We find qualitatively similar behavior with fringe–namely friction increases with speed up to a threshold, after which friction remains constant with variable ice speed and effective stress. However, the mechanical properties of the system with fringe preclude a direct application of existing conceptual models for glacier slip. To account for the observed response, we attribute the rate strengthening to a previously undescribed “mushy” zone located between the frozen-fringe and the water-saturated till.  In this mushy zone, ice saturation values fall below those found in the frozen fringe, but the interstitial ice is still sufficiently abundant to affect the rheology of the mixture. We explore how this “regularized Coulomb” behavior relates to both the rheology, composition, and thickness of the fringe and mushy zone. These findings demonstrate the contribution of fringe to basal friction and highlight its importance in understanding glacier motion and, by extension, landscape evolution in the cryosphere.

# The Uncertain Future of Antarctica: Impact of Extreme Weather Events

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Basal melting significantly contributes to the thinning and mass loss of Antarctic ice shelves. However, in specific regions like the Antarctic Peninsula, intensified surface melting is observed, rendering ice shelves susceptible to melt-induced hydrofracturing. Some study proposed a potential doubling of Antarctic surface melting by the 2100s, intensifying ice shelf vulnerability and emphasizing atmospheric forcing's growing significance. In addition to rising air temperatures, the notable influence of atmospheric rivers (ARs) draws attention, despite their infrequent occurrence in Antarctica. On the one hand, ARs transport extra moisture and heat from lower latitudes, promoting extensive surface melting. On the other hand, short-lived yet intense snowfall triggered by ARs significantly offset the mass loss.

In 2022, two intense ARs occurrences had a substantial impact on the Antarctic ice surface. The combined impact of ARs and foehn over the Antarctic Peninsula led to and record-breaking surface melting in February 2022. On March 18, 2022, East Antarctica encountered an extreme heat wave triggered by AR, which led to substantial snowfall across the East Antarctic Ice Sheet and intense coastal precipitation. In West Antarctica, Atmospheric Rivers (ARs) show a positive trend and are responsible for 40% of surface meltwater over the Ross Ice Shelf and nearly 100% over Marie Byrd Land during the austral summer from 1979 to 2017. This study utilizes high-resolution Polar WRF simulations, advanced model configurations, the Reference Elevation Model of Antarctica topography, and MODIS-observed surface albedo to investigate the influence of Antarctic AR activities on the ice surface during extreme events, with a specific emphasis on the surface energy balance. This presentation will commence by examining the occurrence of extreme weather events in Antarctica, delving into the escalating influence of atmospheric forcing on the ice surface.