Center for Oldest Ice Exploration

ANNUAL REPORT

July 12, 2023

I. GENERAL INFORMATION

Date submitted:	June 30, 2023
Reporting period:	October 1, 2022 - September 30, 2023
Name of the Center:	**Center for Oldest Ice Exploration**
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CONTEXT STATEMENT

The Center for Oldest Ice Exploration (COLDEX) is an NSF Science and Technology Center (STC) funded in 2021. COLDEX is a multi-institution collaboration to find and analyze the oldest ice preserved in the Antarctic ice sheet. The overarching goal is to understand how Earth's climate system functions under warmer than present conditions – conditions humanity very likely faces in the near future. COLDEX is headquartered in the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University.

COLDEX research goals are underpinned by several decades of research on cores drilled through the polar ice sheets. This work has revealed how the composition of Earth's atmosphere and climate are linked on many time scales, from ice-age cycles to abrupt climate changes, and provides the groundwork for our understanding of human impacts on climate and the environment. However, the existing ice core data do not extend far enough back in time to reveal how the Earth system behaves under warmer than present conditions. Reaching these time periods is critical for understanding our future, and is also a significant challenge, requiring a coordinated approach and sustained collaboration of numerous research groups. COLDEX also addresses challenges in making polar science more equitable for people from diverse backgrounds and perspectives, and in making scientific knowledge from our work relevant, useful, and accessible to educators, policymakers, students, and a broad range of communities.

The COLDEX **vision** is that we will advance our understanding of the controls on Earth's climate by obtaining and synthesizing new knowledge of climate and atmospheric composition beyond the ice age cycles of the Pleistocene, into the Pliocene, and possibly beyond. COLDEX will help create a more diverse and inclusive polar and earth science community.

COLDEX's **mission** is to use geophysical imaging, modeling, and novel exploration tools to identify a site for a deep ice core in the Antarctic interior that extends to at least 1.5 million years. Ice coring near the ice sheet margin will provide records of Antarctic climate and atmospheric composition extending even further back in time.

COLDEX will create a national sample archive, recruit, and mentor the next generation of polar researchers, and increase participation of underrepresented groups in polar science. It will provide education, professional development, and field experiences for early career scientists, undergraduates, graduate students, and K-20 educators. COLDEX will also facilitate knowledge transfer within the scientific community and to external stakeholders.

COLDEX **values** the open, honest exchange of ideas, data, and technology. All participants are expected to engage in improving equity, diversity, and inclusion. The COLDEX leadership team commits to transparent, inclusive leadership, organization, and management.

The initial participating institutions involved in COLDEX and their primary roles are outlined in the table below.

Institution	Role	Lead Representative
Oregon State University (OSU)	Lead Institution	Ed Brook
American Meteorological Society (AMS)	Teacher Professional Development	Elizabeth Mills
Amherst College	Exploration	Nick Holschuh
Brown University	Early Career Researcher Leadership	Meredith Hastings
Dartmouth College, Ice Drilling Program	MSI Faculty Professional Development	Mary Albert
Princeton University	Ice Coring; Ice Analysis	John Higgins
University of California, Berkeley (UCB)	Exploration	Ryan Bay
University of California, Irvine (UCI)	Ice Analysis	Eric Saltzman
University of California, San Diego, Scripps Institution of Oceanography (UCSD)	Exploration; Ice Analysis; Ice Coring	Jeff Severinghaus
University of Kansas, Center for Remote Sensing of Ice Sheets (KU)	Exploration	John Paden
University of Maine, Climate Change Research Institute (UMaine)	Ice Coring; Ice Analysis	Andrei Kurbatov
University of Minnesota, Duluth (UMD)	Exploration	John Goodge
University of Minnesota, Twin Cities (UMN)	Knowledge Transfer; Field Research and Data	Heidi Roop
University of Texas, Institute of Geophysics (UTIG)	Exploration	Duncan Young
University of Washington (UW)	Modeling and Ice Dynamics; Ice Analysis; Exploration	Michelle Koutnik

To assess our progress towards the Center's goals, we have developed a Strategic and Implementation Plan that defines a set of optimal outcomes and associated objectives for the areas of research; diversity, equity, and inclusion; education and leadership; knowledge transfer; and management and integration. In this section, we will briefly outline our goals in

these areas, the milestones we have set for ourselves, and our progress towards them, all of which will be described in greater detail in later sections of this report.

Background

Climate is a fundamental property of our planet's environment. There is profound interest in understanding Earth's climate history and how natural influences and human activities cause climate to change. In a geologic context the long cooling of the last 50 million years (Ma) is now being reversed by the warming driven by anthropogenic greenhouse gas emissions. This transition and its consequences concern all of humanity.

Our knowledge of climate history is grounded in study of the geologic record, acquired in large part by measuring chemical, biological and physical properties of geologic deposits that reflect elements of climate at the time they were formed. Such climate "proxies" include the width of tree rings, pollen preserved in sediments, the chemistry of fossil shells of marine organisms, and many others. Ice cores retrieved from polar ice sheets play a central role in this research. The ice record provides detailed information about past temperatures, snow accumulation, atmospheric circulation, dust deposition, aerosol chemistry, and many other properties directly linked to climate. Moreover, the ice traps small samples of the atmosphere, providing a highly accurate record of past atmospheric composition, particularly the concentrations of greenhouse gases. This atmospheric record is a unique and powerful attribute of ice cores and provides clear evidence for a strong link between atmospheric carbon dioxide (CO_2) and Earth's climate (Figure I.1). Climate knowledge gained by studying ice cores speaks vividly to diverse audiences across scientific disciplines, to all educational levels, and with strong societal impact.

While existing ice core data add immeasurably to our understanding of climate, the current continuous ice record extends back only 800,000 years before present (800 ka B.P.) (Figure I.1). This time frame is insufficient to provide critical information from periods when Earth's climate was significantly warmer and/or greenhouse gas levels were higher than today.

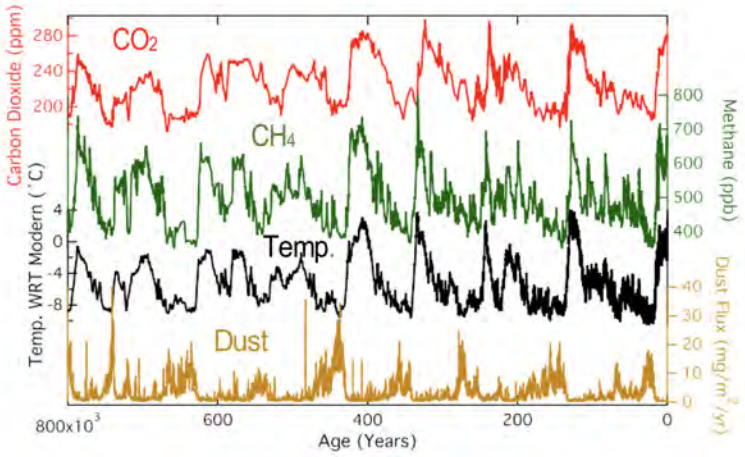


Figure I-1. Existing continuous history of atmospheric carbon dioxide, methane, Antarctic temperature, and dust, from EPICA Dome C and other ice cores.

The ice cores with the longest continuous climate record are from the interior of the East Antarctic ice sheet, the largest and most stable of the polar ice sheets. Finding ice older than 800,000 years in this region has been challenging, not only because of the difficulties in working in the most remote place on the Earth surface, but also because unique conditions are required to preserve the oldest ice from melting or distortion by ice flow near the base of the ice sheet. Discontinuous old ice is also present in locations around the margin of the ice sheet, where ice flow has stranded it near topographic barriers. This archive is largely unexplored, but recent work, including data described in this report, provides a tantalizing view of a few older time periods back to ~3 Ma B.P., and one sample near the base of the ice margin at Allan Hills that dates to 4 Ma.

Information from ice older than 800,000 years is vital for understanding how climate will evolve as greenhouse gas levels continue to rise, and for developing a deeper understanding of long-term trends in Earth history. COLDEX aims to extend the ice core record to at least 1.5 Ma B.P. by drilling and analyzing a continuous ice core in East Antarctica, and to much older times using discontinuous ice sections at the base and margin of the ice sheet. COLDEX will address fundamental questions critical for understanding past and future climate change, including sensitivity to higher levels of greenhouse gases, the role of greenhouse gases in the evolution of ice age cycles, and the behavior of the Antarctic ice sheet in warmer climates.

Finding locations where old ice is still present is a major, complex challenge. Models of the ice sheet suggest promising but geographically restricted targets. Unfortunately, these models are limited by large uncertainties in parameters like the geothermal flux at the base of the ice sheet, long-term history of ice accumulation and flow, and ice thickness and subglacial topography. Finding sites for retrieving very old ice therefore requires a concerted effort to better characterize: 1) the ice sheet interior, through radar echo sounding, geophysical measurements of the underlying crust, and investigation with "rapid-access" tools; 2) ice-sheet behavior over million-year time scales, including flow that thins and deforms the ice; 3) the ice-water-rock interactions that melt, overturn, and otherwise modify the deepest ice; and 4) the nature and age of "stranded" old ice sections on the ice sheet margin. To accomplish these tasks, COLDEX has formed a strong collaboration among ice core geochemists, solid-earth geoscientists, ice sheet modelers, and engineers from 13 U.S. universities, integrating knowledge of past climate, ice dynamics, subglacial geology, and technologies for direct and remote measurement of subsurface properties. The discovery of ice as old as 800 ka B.P. in existing continuous deep cores was largely serendipitous. It is clear that a dedicated effort, with an entirely new multidisciplinary approach, is needed to find, analyze, and unlock the secrets of older ice.

COLDEX will create an archive of well-documented ancient ice samples that will foster future discoveries. The search for old ice will provide a framework for disseminating information about climate change and polar science to students, teachers, the media, policy makers and the public. It will provide a focal point for efforts to increase diversity in the ranks of polar researchers, and provide a variety of experiences for students and early career scientists. COLDEX will form a long-lasting network of established scientists, undergraduates, graduate

students, and postdoctoral scholars working together to advance science and shape a more inclusive community.

Plans and Performance Indicators

COLDEX has defined *Optimal Outcomes* for each area of the Center, high-level statements about what COLDEX aspires to accomplish. Associated with those outcomes are a set of *Objectives*, Center strategies for achieving those outcomes. Here we will briefly review the optimal outcomes and objectives for each Center area.

Research: Exploration and Ice Sheet Modeling

Optimal Outcomes:

1. Identify sites for a continuous 1.5 million year ice core in the East Antarctic interior capable of at least resolving orbital cycles in climate variables including water isotopes, dust, and trapped gases.
2. Provide exploration data sets, models, instrumentation, and relevant metadata from COLDEX useful for, and used by, the wider scientific community.

Objective:

1. Find site or sites for a 1.5 million year ice core through acquisition and interpretation of new airborne and ground based geophysical data and in situ information from Ice Diver, integrated with ice sheet modeling.

Research: Ice Coring and Ice Analysis

Optimal Outcomes:

1. Recover ice cores from the Antarctic ice sheet margin with discontinuous ice sections dating to 3 million years or older.
2. Develop a robust and flexible workflow for identifying and characterizing ice age and stratigraphic orientation in disturbed ice.
3. Obtain atmospheric gas and ice chemistry data to understand the role of greenhouse gases in warmer climates and the nature of the transition to the late Pleistocene ice age cycles.
4. Create a well-documented ice sample archive for the broader scientific community.

Objectives:

1. Collect shallow ice cores at ice margin sites.
2. Establish a workflow for building paleoclimate records in disturbed basal and ice margin samples.
3. Develop paleoenvironmental records and document the sample archive for the wider scientific community.

Diversity, Equity, and Inclusion

Optimal Outcomes:

1. Welcoming Community. A COLDEX community that is open and welcoming to people from historically marginalized identities and that is viewed by the polar science community as an example.
2. Inclusive Leadership and Mentoring. Individuals within COLDEX at all career stages will gain leadership skills for safe, equitable, and inclusive team science (in the lab, field, and meetings).
3. Diversity of Polar Science Community. The polar science community will be more diverse, as COLDEX will support career pathways and minimize attrition for students and early career scientists from historically marginalized identities.
4. Communication. COLDEX external communication, especially in education and knowledge transfer, will be sensitive to and challenge the exclusive nature of historical narratives in polar science.

Objectives:

1. Creating a welcoming culture within COLDEX.
2. Provide, and encourage practice of, inclusive leadership skills.
3. Increasing diversity in polar sciences.
4. Broaden the reach of polar science content/messaging to the public and other audiences, especially to previously excluded identities and communities.

Education and Leadership Opportunities

Optimal Outcomes:

1. Increased awareness and appreciation of ice core and polar sciences through the engagement of K-12 through graduate students, postdocs, teachers, and professors in COLDEX research goals. Engagement with these groups will increase diversity of participants in ice core and polar sciences.
2. A well-trained group of students and postdoctoral researchers contributing to the COLDEX mission who obtain skills and experience relevant to their future work and through development of professional skills.
3. A well-trained group of students and postdoctoral researchers who successfully incorporate education, outreach, and science communication to science and non-science audiences throughout their careers.
4. Successful implementation of inclusive education opportunities that are developed through incorporation of diverse perspectives, particularly those that have not historically taken part in and may challenge the “status quo” of ice core and polar science activities.

Objectives:

1. Bring ice core and climate science to K-12 and university curricula.
2. Develop the next generation of ice core and climate scientists.
3. Evaluate all COLDEX educational programs.

Knowledge Transfer

Optimal Outcomes:

1. New partnerships, collaborations, and mentoring relationships are established across the COLDEX team, including across and within participating institutions, participant career stages, and disciplinary expertise.
2. New partnerships, collaborations, and knowledge exchange opportunities are established between the COLDEX team, other researchers, and industry partners.
3. COLDEX successfully leverages our disciplinary expertise and perspectives, knowledge transfer, education, and evaluation approaches to deepen public engagement in Earth and climate sciences.

Objectives:

1. Expand and facilitate connections across the current network of those who engage with COLDEX research, education, and knowledge transfer activities.
2. Support effective, consistent communication of polar and climate-related knowledge to diverse audiences.
3. Expand impact of COLDEX participants on applied climate science, science communication best practices and actionable science.

Management and Integration

Optimal Outcomes:

1. COLDEX management will operate effectively in a transparent manner, enabling COLDEX members to achieve their research, education, DEI, and knowledge transfer goals.
2. COLDEX members will perceive themselves as belonging to a cohesive, welcoming community with shared goals and values.
3. Research, education, knowledge transfer, and diversity, equity, and inclusion activities and values will be integrated across all aspects of the Center.

Objectives:

1. Establish Center leadership and management.
2. Establish effective communication with participants to establish and maintain integration of Center activities and goals.
3. Facilitate external communications with the media, policymakers, and the general public about COLDEX activities.
4. Integration of Center science, education, knowledge transfer, and diversity, equity, and inclusion efforts into an enduring Center culture.
5. Provide support to COLDEX participants investigating new funding streams and collaborations for COLDEX-related activities.
6. Ensure oversight and evaluation of COLDEX by seeking feedback from the External Advisory Committee on an annual basis, as well as from the annual NSF site visits, and regularly assess progress towards management and integration goals.

7. Manage and facilitate field and ice core logistics planning with participants, NSF and USAP logistics providers.
8. Make COLDEX data and technology openly and widely available within and outside of COLDEX.
9. Implement a program of ethics training.
10. Create and maintain COLDEX Intellectual Property Plan

Progress towards Center Goals

In this section, we will provide a summary of our progress towards our goals in each of the Center areas and highlight significant accomplishments made during the current reporting period. In subsequent sections, we will detail the related *milestones*, specific achievements required to meet objectives, and the progress we have made toward reaching those milestones.

Research: Exploration and Ice Sheet Modeling

- Significant expansion of ice penetrating radar data sets in interior East Antarctica between the South Pole and Dome A, revealing detailed subglacial topography and internal ice sheet structure, allowing further evaluation of potential new ice core sites for a continuous ice core back to 1.5 million years.
- Construction of the Ice Diver-Dust Logger vehicle, a thermal probe designed to melt its way through ice sheets and measure dust content as a way to count climate cycles and determine the age of deep ice core sites before drilling.
- Final core site recommendation for intermediate depth (~1200 m) ice core at Allan Hills that could reach >1Ma.

Research: Ice Coring and Ice Analysis

- Development of the oldest ice core data constraining atmospheric composition and mean ocean temperature, with results back to ~3 Ma from ice cores along the Antarctic ice sheet margin.
- Expansion of analytical methods for analyzing very old ice from regions where original layering has been distorted by glacier flow.
- Collection of new ice cores in the Allan Hills Blue Ice Area and reconnaissance coring in Elephant Moraine region

Diversity, Equity, and Inclusion

- We launched a demographic survey for our participants and have analyzed the first year of results. The survey is now part of the onboarding process for all new members, and members are regularly reminded to take the survey if they have not yet done so. We are tracking demographic data of COLDEX participants over time and comparing to data available for geosciences and other polar projects.
- We distributed and analyzed the first Sense of Belonging survey for COLDEX participants. Initial results suggest that most members have a high sense of belonging.

- We offered several workshops focused on inclusive leadership skills, including Cultural Competency, Inclusive Mentoring, Inclusive Leadership, Implicit Bias training, and Bystander training. We also hosted invited seminars by Dr. Andrea Balbas (California State University Long Beach) and Dr. Meredith Nash (Australian National University) that focused on these topics.
- Discussion about team leadership and group dynamics were held with each field team before leaving for the field. In particular, these discussions focused on the best ways to support each other and keep team members safe in light of the findings of the 2022 NSF SAHPR report. Pettit and Neff also created and distributed field team best practices documents, based on documents from the International Thwaites Glacier Collaboration.
- We launched the COLDEX Feedback Portal on our member website, with the goal of providing all COLDEX community members with a mechanism to provide both positive and negative feedback to COLDEX.
- Working toward our goal of building and strengthening relationships with Minority Serving Institutions (MSIs), we have submitted an NSF GEOPaths proposal led by Kristen Rahilly, Director for Education, in collaboration with Linda Hayden from Elizabeth City State University, an HBCU, entitled “Strengthening the pathway from STEM to polar science through the search for oldest ice and the COLDEX-ECSU Fellowship program.” The proposal is under review.

Education and Leadership Opportunities

- The first COLDEX School of Ice was held at Oregon State University in August 2022 with 13 participants, and featured presentations from multiple COLDEX faculty and graduate students. Participants made and interpreted methane measurements from ice cores and toured the new COLDEX Continuous Flow Analysis lab at OSU.
- The first formal COLDEX Research Experiences for Undergraduates (REU) season is underway. We requested and received an REU supplement from NSF, allowing us to place 12 REU students instead of the 7 initially budgeted. We had a diverse pool of 180 applicants. 50% of selected participants are from historically marginalized identities in polar science and 75% identify as female or female/non-binary. Research projects for the summer 2023 cohort involve work in ice exploration, ice modeling, and ice analysis across 6 COLDEX institutions: University of Washington, Oregon State University, University of California, Irvine, University of California, San Diego/Scripps Institution of Oceanography, the University of Texas at Austin, and the University of Maine.
- The COLDEX Oldest Ice Short Course was held in May 2023 on Whidbey Island, WA. A total of 23 early career researcher participants joined the course: 15 were COLDEX graduate students or postdocs, 1 participant was a COLDEX researcher new to ice core science, and 7 participants were new to center activities. The major learning objectives centered on the COLDEX science mission with a specific focus on exploration and modeling topics, as well as two interactive sessions on science communication.
- The pilot of the new Project Ice program for K-12 teachers ran from June 7 - June 30, 2023, including an online component of the graduate course through PennWest University and an in-person workshop at Oregon State University. Content will include

four modules: “Understanding the Polar Regions”, “Ice Core Science and Engineering”, “Land Ice, Sea Ice, Grounded Ice, and Impacts on Sea Level Rise” and “Ice Core Science and Paleoclimatology.” During the in-person week, participants used hands-on, inquiry based activities to learn more about ice and ice core properties.

Knowledge Transfer

- We developed and adopted, after engagement across COLDEX, a center-wide Strategic Communication Plan. This ‘living plan’ will guide communication and engagement efforts and will be updated annually.
- Our external engagement and knowledge transfer efforts and research have provided critical insights into needs and tools for more effectively communicating about Antarctica and climate change in the U.S. national news discourse and enabled us to connect with and develop relationships with a range of diverse journalists from tribal news outlets to large national news desks.
- COLDEX is estimated to have reached over 1 million listeners through radio outlets in Year 2
- TV outlets across the United States covered COLDEX, with Oregon and California having the most mentions. The estimated audience reach for national television is 63,000 viewers.
- Dozens of print and online media outlets covered COLDEX research and researchers, including The Weather Channel, Physics Today, Scientific American, BBC, Insider, National Public Radio, The New York Times, CBS News, and The Hill.
- COLDEX received 204 media mentions ranging from institutions (Dartmouth), to major media outlets (Chicago Tribune, Yahoo News).
- SpaceX’s Starlink satellite dish that gave scientists unprecedented connectivity generated viral social media activity after Elon Musk himself Tweeted about the project.
- By the end of the field season, COLDEX’s Twitter following exceeded 7,500 followers, up from around 200 prior to the start of the field season.
- PhD student Austin Carter (Scripps) grew a considerable following on TikTok, posting videos of COLDEX fieldwork live from Allan Hills, Antarctica using Starlink. Individual videos have up to 21 million views. Austin’s personal account gained ~60,000 followers through the field season.
- Given the geographic and disciplinary breadth of the Center, internal knowledge transfer and exchange are also essential to our overall success. Our surveys and focus groups are providing actionable insights to improve our activities including our early career researcher training and education efforts and activities intended to share knowledge across the Center**.** This internal, research-centered approach to internal knowledge transfer not only improves our Center’s interactions but also informs the field of team science. Work from these early efforts will be in peer-review by the end of Year 2.
- The Knowledge Transfer team supported a range of early career training and other professional development, including science communication training related to intercultural communication, working with journalists, and developing one’s identity as a

science communicator as well as ways to set goals and metrics for science communication activities.
- 2022 Pulitzer Center Climate Science Reporting Fellow Christian Elliott reported on COLDEX's first year of searching for the Earth's oldest ice in multiple venues: Deustche Welle's *Living Planet* podcast, *Scientific American* magazine, and *Undark* digital magazine. His work has received a great deal of engagement and has been republished/syndicated in *Slate*, *Mother Jones*, *Popular Science*, and *Ars Technica*. Rather than documenting scientific fieldwork in the traditional sense, he focused on the back-end lab work done by younger scientists and the lack of diversity in the field. Elliott, who is currently an audio storytelling intern for NASA, is a finalist for CCNow's Student Journalist of the Year.

Management and Integration

- Integrity and Professional Ethics Policies, Data Management and Sample Allocation Policies, and Strategic Communication Plan were all finalized and implemented.
- We have maintained a public-facing website with news, events, and information about COLDEX programs, and kept up-to-date a Member Information website with a COLDEX handbook and links to many resources for members.
- We held our first Annual Meeting in September 2022 at Oregon State University, with 74 registrants across all career stages and member institutions.
- Attendance at monthly seminars, all-hands meetings, and subgroup meetings is consistent and many members engage with each other regularly at these meetings as well as on our very active Slack workspace.
- We worked with an expert from the OSU College of Business to conduct a review of our Strategic Plan and initiated evaluation of our educational programs.
- The Director for Field Research and Data had extensive engagement with NSF/USAP/ASC science planners, project managers, and implementers through the 2022-23 field season, including pre- and post-season briefings, and extensively coordinated across COLDEX field teams.
- The long-term public archive of COLDEX data has been established, and internal data sharing is now available.

II. RESEARCH

1. Center's overall research goals.

The Center has defined six Optimal Outcomes in the Research section of the Strategic and Implementation Plan - two in the theme of Exploration and Ice Sheet Modeling, and four in the theme of Ice Coring and Ice Analysis.

Exploration and Ice Sheet Modeling Optimal Outcomes

1. Identify sites for a continuous 1.5 million year ice core in the East Antarctic interior capable of at least resolving orbital cycles in climate variables including water isotopes, dust, and trapped gases.
2. Provide exploration data sets, models, instrumentation, and relevant metadata from COLDEX useful for, and used by, the wider scientific community.

Ice Coring and Ice Analysis Optimal Outcomes

1. Recover ice cores from the Antarctic ice sheet margin with discontinuous ice sections dating to 3 million years or older.
2. Develop a robust and flexible workflow for identifying and characterizing ice age and stratigraphic orientation in disturbed ice.
3. Obtain atmospheric gas and ice chemistry data to understand the role of greenhouse gases in warmer climates and the nature of the transition to the late Pleistocene ice age cycles.
4. Create a well-documented ice sample archive for the broader scientific community.

2. Strategic plan objectives and progress towards milestones.

<u>Exploration and Ice Sheet Modeling Objectives and Milestones</u>

Objective 1: Find site or sites for a 1.5 million year ice core through acquisition and interpretation of new airborne and ground based geophysical data and *in situ* information from Ice Diver, integrated with ice sheet modeling.

- *Milestone 1A: Develop a comprehensive and traceable workflow that plans for interdependencies between instrument development, data collection, and modeling in order to clarify how multiple instruments and activities contribute to achieving the objectives.*
    - This document has been completed, led by Michelle Koutnik (UW) and Duncan Young (UTIG). The workflow includes relevant science-defined instrument requirements, a timeline for deliverables, and responsibilities for each component of work. We have been putting this into practice as new airborne data streams are released and integrated in models, as well as for planning the 2023-24 airborne field campaign.

- *Milestone 1B: Acquire, process, and interpret airborne geophysical data in COLDEX survey region of East Antarctica and identify regions for more detailed ground-based surveys to follow.*
    - Required aircraft certification flights in Canada were conducted in summer 2022.
    - University of Kansas (KU) experienced significant delays in delivery of electronics parts, shipping of the UHF antenna fairing, and then lost opportunities for joint testing with University of Texas (UTIG) in McMurdo due to weather delaying a flight crew swap. Joint flight operations were delayed until the second South Pole survey flight (CXA1/F07), at which point we discovered a significant VHF EMI impingement due to the UHF power regulators that obscured the bed return in the VHF system (the UHF power regulation system had been updated after the Calgary test flight due to power mismatch issues discovered there). Given the relative maturity of the systems, we prioritized the VHF system for survey flights, reserving time near the South Pole for testing and debugging of the UHF system. We were able to complete three joint flights after the EMI noise issue had been mitigated by cable rerouting and shielding.
    - Additional certification flights needed for fully certifying KU wing antennae will be conducted in summer 2023. Certification flights have been targeted to begin July 17 (with equipment installation starting July 10) 2023. This schedule, driven by aircraft availability, may impact the Kansas readiness for the field season with new wing antennas required for detecting vertical ice motion between the two seasons.
    - We acquired the first phase of COLDEX airborne radar data in a broad area between South Pole and Dome A (Figure II-1). USAP experienced significant turmoil during the 2022-23 field season with rapidly changing approaches to COVID mitigation, which delayed our schedule and impacted our productivity. Given COLDEX's priority, we were able to mitigate these iterating approaches by slipping our schedule by one month (at the expense of other field programs). Weather at the South Pole was not as accommodating as we would have wished with a full flight/day ratio of 47% (including weekends and holidays). We were still able to complete 14 full survey flights, although one was affected by EMI issues and another could not survey the primary survey area due to weather, and instead did Hercules Dome as a backup target (the final season of Hercules Dome reconnaissance work was one of the projects affected by COLDEX's delay; the survey flight came out of Hercules Dome's original flight allocation). All-in-all we were able to obtain adequate regional coverage of the COLDEX survey region, and we can consider this activity as complete.
    - KU and UTIG are now coordinating on avoiding the EMI issues that impacted the first season.
    - Gravity and magnetic data were also acquired on most COLDEX flight lines and will be analyzed as part of the PhD thesis of Megan Kerr at University of Texas.
    - Planning for field work for 2023-24 field season of airborne work is underway. Support information packages are complete and field team staffing is mature. We are exploring the possibility with NSF and ASC of adding measurements at Dome C in addition to Dome A.

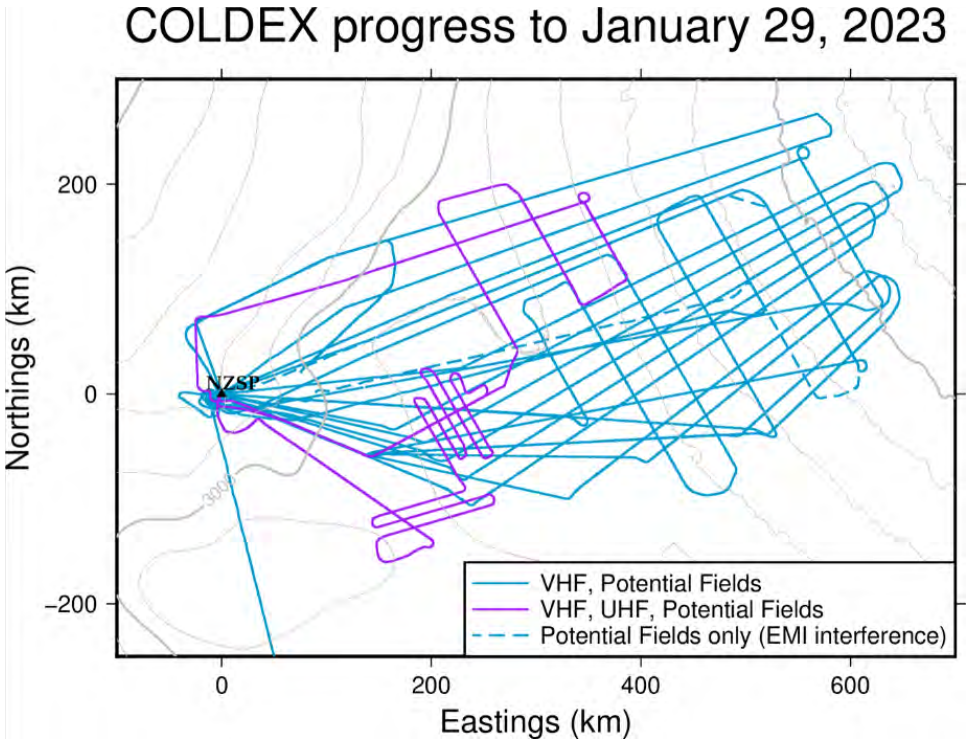


Figure II-1. Final COLDEX radar and potential fields flight map from 2022-2023 field season.

- Processing airborne data is now in progress. VHF ice thickness data extracted with a conditioned convolutional neural network was distributed to the Exploration and Modeling Group at the end of the reporting period. Quicklook radioglaciological data have been distributed within the COLDEX team. The UW modeling group is starting to use these data in ice-flow models, and this analysis will progress into the Fall when traced internal layers are available. Gravity and magnetic data were also acquired on all flight lines and are currently being analyzed.
- Data formatting and validation in advance of public availability is underway. Synthetic Aperture Radar (SAR) focused processing is largely complete, and will be interpreted by graduate students and a team of interns this summer. COLDEX radar data will be made freely available on the Open Polar server (including ApRES data). We anticipate data availability will be completed by the end of the year 2 award period if not sooner.
- Initial results include 1) finding and extending the time transgressive scour zones in Dome A first identified by Das et al., 2013, Nature Geoscience, 6), which lie in the northern part of the survey; 2) improved resolution on a smooth flat-topped mountain feature in the southern part of the survey area, which we are terming the “Elbow”; and 3) assessing the true topographic saddle of the ice sheet, an area also in the southern part of the survey.
- Initial interpretation of the new airborne data collected by the COLDEX team focused on the region close to the South Pole, initially and informally called the “Saddle Site.” The team managed to collect three airborne radar profiles of ~100 km length each over the “Saddle Site” (also known as the True Topographic Saddle). The A-A’ line in

Figure II-2 denotes one of the three radar profiles collected. The profile itself is shown in the next figure (Figure II-3).

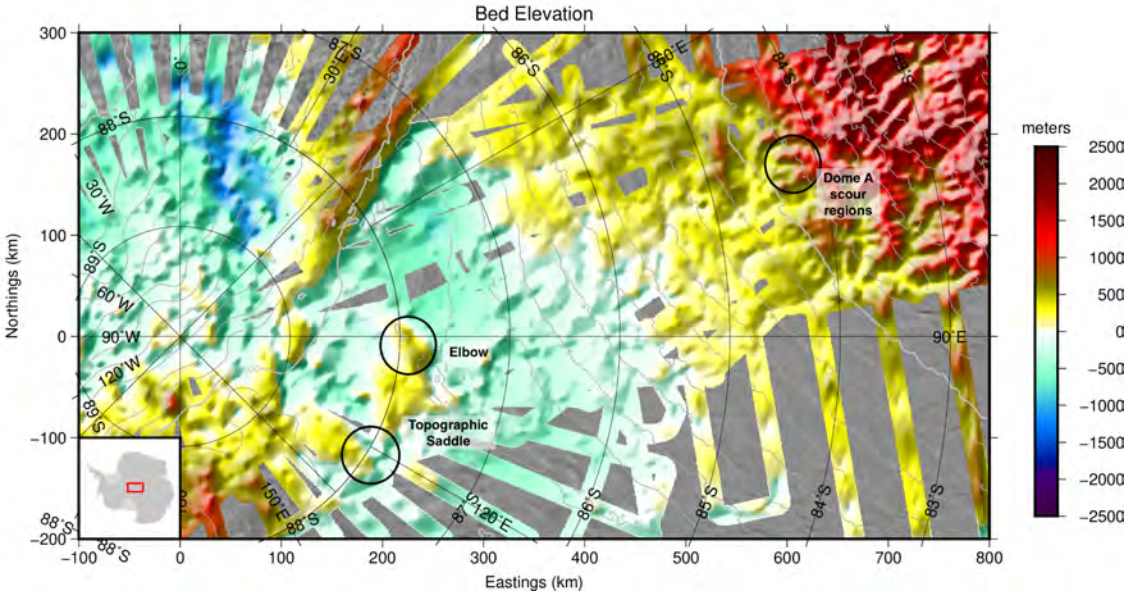


Figure II-2: Updated bed elevation map of the COLDEX region, showing sites of interest. More work on subglacial water detection and englacial stratigraphic mapping are required.

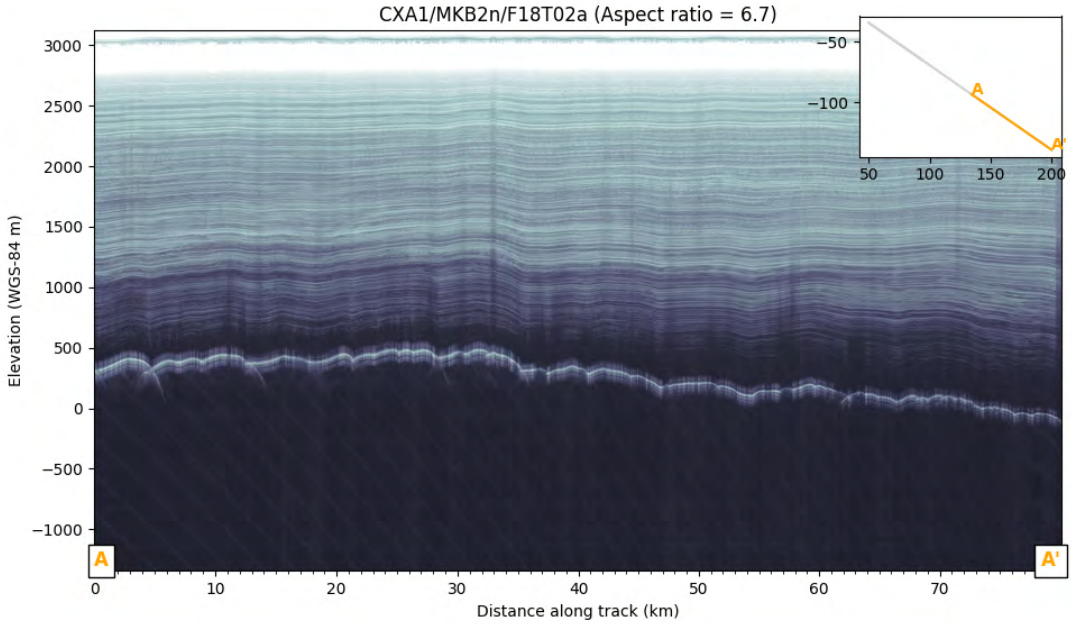


Figure II-3: At the Topographic Saddle site (A'), ice thins from an unfavorable ~3000 m to more favorable ice thickness of ~2600 m to the south (A).

- The first impression of this radar profile at the Topographic Saddle itself suggests that the ice may be too thick (~3000 m) to host frozen bed conditions (geothermal heat causes basal melting at ice depths greater than about 2600 m – 2800 m in typical East Antarctic crystalline bedrock). Deeper interpretation in coming months

will no doubt refine this initial conclusion, however. Thinner ice, ~2600 m, is present on a nearby parallel line.

- The relatively nearby region, which we are calling the “Elbow” site (Figure II-2), is promising because the ice is only 2500 m thick, and the mountain top is quite flat over about 12 km (Figure II-4). The Elbow site is located at about 87.9 S, 90 E. The very smooth bedrock on top of the mountain suggests that it has been abraded over very long timescales (probably during warmer climates such as >13 million years ago) into a highly reflective, smooth surface that would be ideal for preservation of old ice.

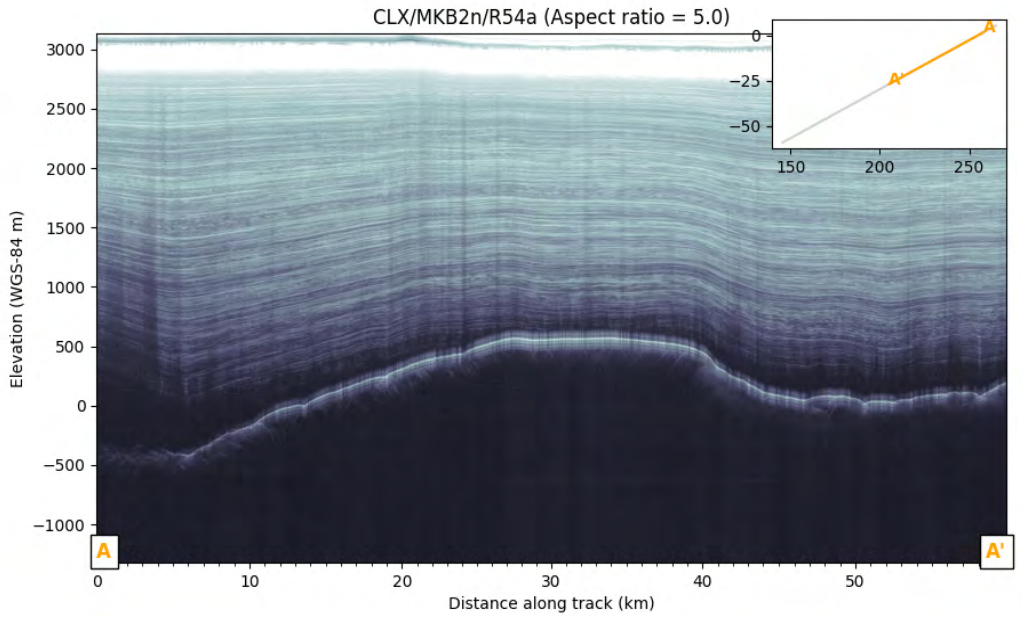


Figure II-4: Radar line at the “Elbow”, located at 87.8˚S/90˚E, with favorable ice thickness of ~2600 m, and visible englacial layers near the ice-rock interface. More work is needed to assess the underlying geology and upstream stratigraphy.

- *Milestone 1C: Acquire, process, and interpret ground-based radar and geophysical data in regions of interest.*
  - Most of this activity for site selection for interior 1.5 Ma ice core occurs in later years of COLDEX. We have a pending request to NSF to support a limited ApRES (Automated Phase Sensitive Radio Echo Sounding) survey near the South Pole (at the Elbow or Saddle side locations). This activity was designed and would be led by Nick Holschuh, Amherst College. Advance planning for these field activities has been ongoing with USAP logistics planners.

- *Milestone 1D: Construct, test and deploy Ice Diver vehicle for age vs. depth information in ground-based survey regions.*

- We completed design, testing and final construction of new front and rear melt heads with thoroughly modeled thermal characteristics and heated using COTS cartridge heaters modified and thoroughly tested for high-voltage, long-duration operation (Figure II-5). All Ice Diver work is led by Dale Winebrenner at UW.

Figure II-5. Example Ice diver dust logger melt head with COTS heater cartridges.

- Design, testing and construction of revised electronics to support dust-logging equipment as well as new communications equipment is now complete. Failure of inductive modems to perform according to manufacturers' specification even on the bench necessitated new design and implementation of fiber-optic communications subsystem, which has now been successfully completed.
- Design, testing and construction of new Ice Diver sections for dust-logger components, including a laser and sapphire port in the Ice Diver sidewall, as well as new pressure vessel to house the dust-logger photomultiplier tube now complete (Figure II-6).

Figure II-6. New Ice Diver section to include a sapphire optical port for the dust-logger laser.

- Ryan Bay (UC Berkeley) assembled and tested a complete dust logger system including controller, motherboard, photon counter, cables and connectors. Bay sent the system to Tim Elam with the Winebrenner group in order to begin testing together with the Ice Diver microcontroller. Bay will send a second complete system once fine details are determined.
- Bay made further modifications to the Labview data acquisition system (DAQ) for the dust logger, and also developed a C program to serve as a backup DAQ. Jesse Dosher of Winebrenner's group worked on the DAQ for the Ice Diver. Dosher is incorporating the DAQ for the Dust Logger into that of the Diver. Bay also completed several dust logger electronics tasks including:
    - Reprogrammed dust logger microcontroller firmware to work with the controller board of the Ice Diver.
    - Completed construction and testing of three (3) dust-logger motherboards. All boards were fully functional on initial testing and no failures have occurred in subsequent tests.
    - Programming nine (9) microcontrollers with firmware customized for Ice Diver.
    - Tested seven (7) legacy photon counters (Hamamatsu HC135 and H9319) individually with a 405-nm Stingray laser in an optical enclosure. Counters were tested for dark noise rate, linearity, sensitivity and overflow condition. All counters passed examination and can be used for builds. The Stingray laser

output was characterized as a function of control voltage. Unlike lasers used in most previous dust loggers, the slimline Stingray is not temperature controlled.

- Bay conducted data analysis comparing the Dome C dust log (taken in 2010) with the dust signal (magnetic susceptibility) from the marine core U1537. Core 1537 has been identified by Jessica Ng (graduate student in the Jeff Severinghaus group, UCSD) as a promising marine record for comparing with COLDEX dust logs in order to identify Myr ice, because of its proximity to both Antarctica and Patagonia. The analysis is simplified from that described in Bay et al. (2010, JGR, v.115). Dynamic time warping is used to match ordered elements of two time series in order to compare records (Figure II-7). After warping the U1537 dust record to the EDC dust log using the optimal matching path, the correlation between the two records is >0.95. This high value is partly artificial because warping also tends to optimize correlation, however, such a high value is only possible if the time series are similar, i.e., the records are a match. The warping path (in green) serves as a preliminary age map. This confirms that U1537 is a suitable template marine sediment record for comparison with COLDEX Ice Diver/Dust Logger data back to Myr timescales. Bay assisted Jessica Ng (UCSD graduate student) in preparation of a paper describing this work for submission to Climate of the Past and for inclusion as a chapter in her dissertation (Ng, 2023, UCSD PhD Thesis and recently submitted to Climate of the Past).

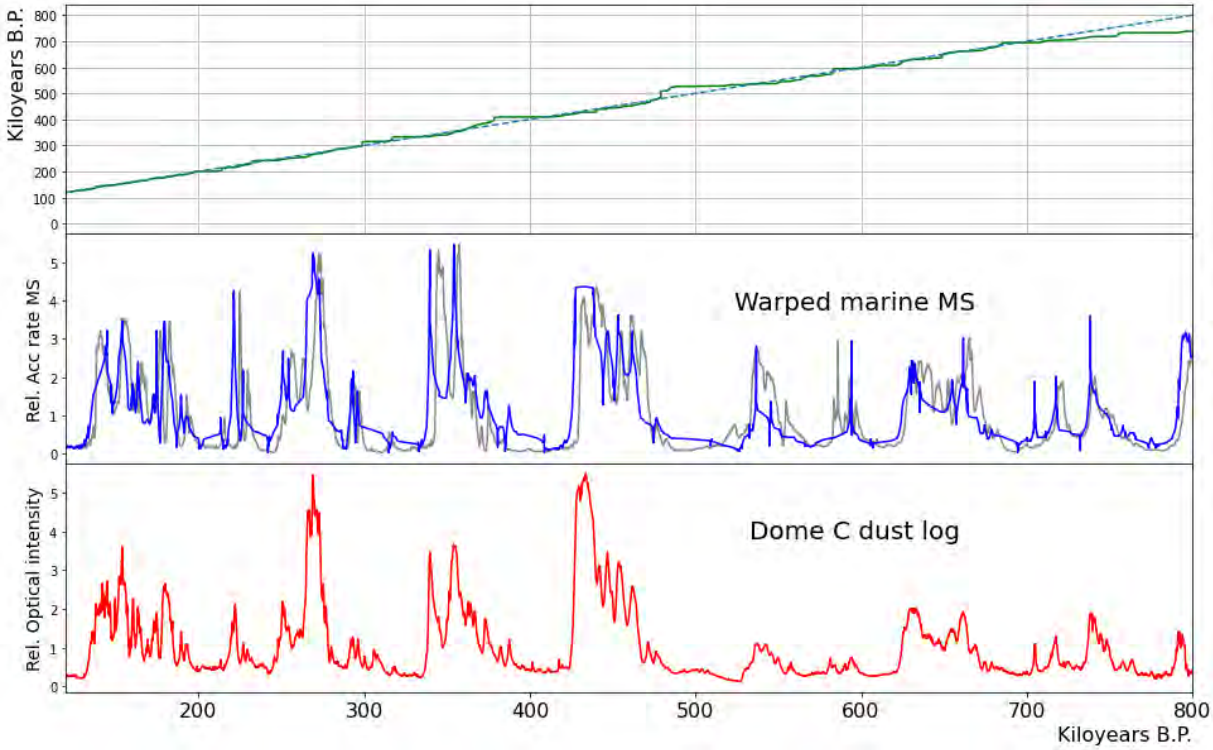


Figure II-7. Time warping of EDC Ice Core Dust log with marine dust record from core U1537 (Weber, et al, 2022, Nat Commun, v.13)

- Ryan Bay also assembled, tested and delivered a second dust logger to Winebrenner's group, in order to field two complete Ice Divers in the Greenland test. Bay and Winebrenner's group continued weekly zoom meetings.
- Winebrenner's group completed revisions to system firmware to accommodate dust-logger and new communications subsystem.
- Winebrenner's group also completed revisions to surface-side high-voltage power supply and implementation of battery backup for high reliability in case of generator failures.
- Final system assembly and system-level testing for Ice Diver is completed.
- Planning and scheduling summer 2023 Greenland field test in collaboration with Polar Field Services personnel, including site selection, electrical power provision, flight scheduling, and cargo handling completed.
- The group completed preparation of field crew including physical qualification and emergency cold weather gear procurement.
- Note that as of July 11 the Greenland field test has been postponed because of the discovery of a fault in the spooled high voltage cables that power ice diver that would have prevented the vehicles from functioning properly. We are currently evaluating the problem and seeking alternative testing solutions.

- *Milestone 1E: Conduct glaciological modeling that integrates geophysical and Ice Diver information to assess possible ice core sites.*
  - Although it is too early to integrate with ice diver information, the general process of integrating models and geophysical data has begun. At UW, we have been adapting flowband model code to East Antarctica and also assimilating UTIG radar-layer picks and geometry data for a site near Lake Snow Eagle (not for COLDEX, but as a separate problem and test). Shuai Yan (UTIG) has provided the data sets and is working with Michelle Koutnik on the modeling for this site, which helps us prepare for East Antarctic applications. The initial ice thickness data are being incorporated into a flowband ice-flow model to assess the impact of accumulation scour zones that occur on the upper reaches of the flight survey towards Dome A.
  - Kinematic model runs have been established to interpret the unconformities imaged in the airborne radar data. Simple model set ups reproduce the main features and provide estimates of depths affected in the survey area.

- *Milestone 1F: Maintain connection with Rapid Access Ice Drill (RAID) project to identify possible use of RAID in COLDEX site selection.*
  - John Goodge (University of MN and RAID PI) participates regularly in COLDEX activities and meetings, with particular effort to support Exploration planning, provide insight into integration and deployment of various tools, support DEI efforts, and mentor younger researchers.
  - Goodge also is providing petrographic analysis of rock fragments recovered from an Allan Hills blue ice core, for possible use in age analysis.

- Goodge is leading efforts on refinements and upgrades to the RAID drilling facility and planning for a RAID Science Planning Workshop in 2024 that will synergistically align with COLDEX goals.
- On a separately funded track, the RAID program continues to make excellent progress on its planned refinements and upgrades to the Fluid Circulation System and other components of the drilling facility. Details of RAID's continuing efforts are reported separately to the NSF but available on request.
- Limitations of the USAP program to deploy the RAID drilling platform in the field pose a great risk to RAID's planned contribution to the COLDEX program. Goodge, J. Severinghaus, and others continue to advocate and conduct forward planning for deployment of the RAID system as a complementary tool in the Exploration phase of the program, including ground-based radar, airborne geophysics and IceDiver melt probe.

- *Milestone 1G: Integrate all available information to choose a site or sites for a deep ice core.*
  - See initial discussions of modeling and initial radar data above.

<u>Ice Coring and Ice Analysis Objectives and Milestones</u>

Objective 1: Collect shallow ice cores at ice margin sites.

- *Milestone 1A: Develop a set of site selection criteria for the Allan Hills and Elephant Moraine shallow drill sites, drill, and return ice cores.*
  - New polarimetric radar (ApRES) data collected near shallow boreholes at the Allan Hills during the 2022-23 field season are promising. Preliminary results indicate both the range and ice fabric can be resolved. This work is led by UW graduate student Margot Shaya. Margot will deploy with I-187 to the Allan Hills this coming season (2023-24), to make repeat ApRES measurements to evaluate rates of ice-sheet thinning, and also to make new radar measurements at other existing shallow boreholes in the ablation zone.
  - Two new shallow ice cores were collected at Allan Hills in regions of suspected >1 Ma ice (Figure II-8). Core locations were based on the age structure of previously drilled cores, including new data from ALHIC 1901. ALHIC 2201 is a 92 m, 24 cm diameter core near the site of ALIC 1901, which contains 4 Ma ice near the bed. The goal was to encounter that layer above the region of basal contact. ALHIC 1902 is an extension of a core started in 2019, now deepened to 206 m. Several short cores (<15 m) were also drilled in areas of interest, including one at Elephant Moraine, a region COLDEX may deploy to in future field seasons. The drilling season was delayed due to the slowdown of work at the beginning of the field season caused by the McMurdo COVID outbreak. Initial plans included collecting a third deep core.
  - Additional work at Allan Hills included temperature profiles in existing boreholes using both thermistors (UCSD) and a fiber optic distributed temperature system

(DTS) (UW). Preliminary analysis suggests interesting variability related to ice flow and verifies low (<25˚C) basal temperatures in the shallow boreholes.

- Extensive planning was conducted in spring 2023 for core processing activities which began at the NSF ICF on June 12, 2023. This included planning staffing, living arrangements, sampling protocols and cut plans, internal sample requests and evaluation of requests by the sample allocation committee, and liaison with the ICF staff.
- Extensive logistics planning for the 2023-24 drilling season at Allan Hills was also conducted in spring 2023, including selection of team members, SIP preparation, and related work. This planning continues.
- The Allan Hills 2022-23 field team was one of the first Antarctic projects to experiment with the use of a STARLINK internet terminal in the field. It worked well with the exception of power consumption, which limited the time it could be used if powered only with solar powered systems. The terminal contributed to team safety, communications with home institutions and COLDEX management, and facilitated several social-media based communications, which were widely viewed.

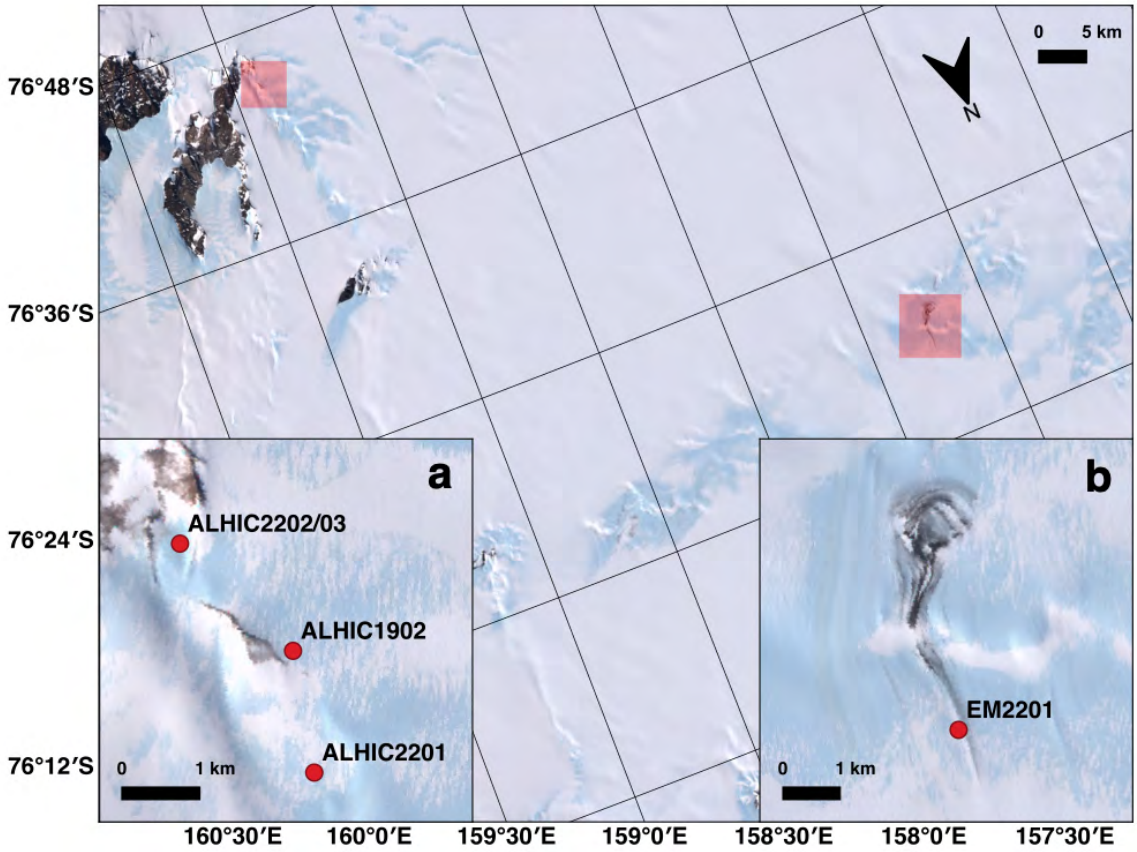


Figure II-8. Location of ice cores at Allan Hills and Elephant Moraine.

- *Milestone 1B: Intermediate depth core at Allan Hills (scope contingency in logistics planning; this activity would have started in the 2023-24 field season but we have learned that the planned equipment staging will not happen this season).*

- New ground-based radar and geophysical data acquired in 2022-23 from the Allan Hills region, together with previous ground-based radar (Kehrl et al. 2018), and findings of discrete samples of ice with ages back to 4Ma (Shackleton et al. 2022), gives confidence that we can extract a continuous ~1200m core that dates back 1+Ma. The new data identify a site where ice older than 205 ka is somewhat higher above the bed than previous data suggested, providing more confidence in old ages at the bottom of a core at this site.
- Final drill site has been proposed by Howard Conway based on the field work conducted on 22/23.
- ASC, NSF and ANG arranged for a SLACO (Ski Landing Area Control Officer) to visit the COLDEX team camp at Allan Hills on Jan 8, 2023. The SLACO did fly-overs of the region (in a Twin Otter) and we also surveyed surface conditions at our potential sites using skidoos. In conversation SLACO said that a groom team using skidoos to smooth the bumps would be needed prior to landing a LC-130. We have not yet seen the report but understand that landing is likely possible. Ice thickness at the site we have identified is less than 1200m and the site is within the boundaries of the ANG surveys of the region for a suitable landing site for an LC-130. It could be groomed to be suitable for Basler support. As mentioned above, the intermediate core was identified as “scope contingent” in the COLDEX logistics planning. We have learned that staging drilling equipment will not be supported during the 2023-24 field season. Drilling fluid for the project, a major cargo component, has been shipped to McMurdo, as has the FORO 1650 drill.

Objective 2: Establish a workflow for building paleoclimate records in disturbed basal and ice margin samples.

- *Milestone 2A: Create centralized COLDEX laboratory for analyzing chemical parameters in COLDEX cores.*
  - Status of all COLDEX Experimental and Analytical Facilities is summarized in Table II-1, at the end of Section 2.
  - New walk-in freezer for the continuous melter system has been built, and all other updates to the space have been made. Freezer is operating normally.
  - The Aerodyne laser spectrometer for high resolution methane concentrations is on order but delayed (supply chain issue). The instrument has been constructed and is operating with the required precision and response time. The Aerodyne group is now working with us to fine tune some aspects of its performance. We expect delivery later in summer 2023. Existing instrumentation can stand-in adequately. We are working with French colleagues in Grenoble to refurbish a third methane laser spectrometer.
  - Abakus particle detector is now operating, and testing has been successful. The Abakus will be integrated in the CFA setup over the coming weeks (June-July 2023).
  - Ice core melter is functioning in reach-in freezer prior to move to the walk-in. Gas handling system for air-water separation and standardization tested and functioning

well. A second complete gas handling system was constructed for another project and will be available for use or adaptation if needed, after summer 2023.

- OSU graduate student (Abby Hudak) and postdoc (Asmita Banerjee) were both recruited and are working on all aspects of the CFA system. Hudak is focusing on Abakus particle measurements and Banerjee on gas measurements.
- New continuous-flow sample-and-standard handling apparatus for water-isotope analysis was constructed and extensively tested and validated by the UW group (led by Eric Steig, with UW undergrad Noah Brown and research technician Maciej Sliwinski). The system was delivered to OSU (Figure II-9), and integration with the OSU CFA system began the first week of June 2023.
- The UCI group continued lab work on ion detection using electrospray mass spectrometry for CFA analysis and trained a new graduate student in electrospray/MS/MS and ICP-MS. They also began experimental development of segmented flow sample storage for use with CFA, and are providing a fraction collector for collecting discrete samples for ion measurements. Because the electrospray methodology is experimental, the ICP-MS capabilities at existing laboratories at both UCI and OSU provide important backup analytical capabilities.

Figure II-9. Picarro laser spectrometer and custom-built vaporizer and standardization system built by UW being installed in OSU COLDEX laboratory (June 7 2023). View from inside the CFA freezer.

- *Milestone 2B: Develop initial ice core chronologies using argon and krypton isotope dating.*

- An extensive chronology for the ALHIC 1901 ice core (collected in 2019; location in Figure II-8 above) has been generated using ^{40}Aratm dating, by Sarah Shackleton at Princeton. We are now very well positioned to analyze new ice cores from the 2022-2023 field season. The new analyses involved the training of Dr. Valens Hishamunda, who will take over ^{40}Ar analyses when Dr. Sarah Shackleton departs for a faculty position at Woods Hole Oceanographic Institution in spring 2024. The latest age vs. depth plot for this core is shown below (Figure II-10). The oldest age for this core is 4 Ma and several dates are older than 2 Ma. Additional measurement will be conducted on this core. The CO_2 data depicted in Figure II-10 are discussed in sections below.

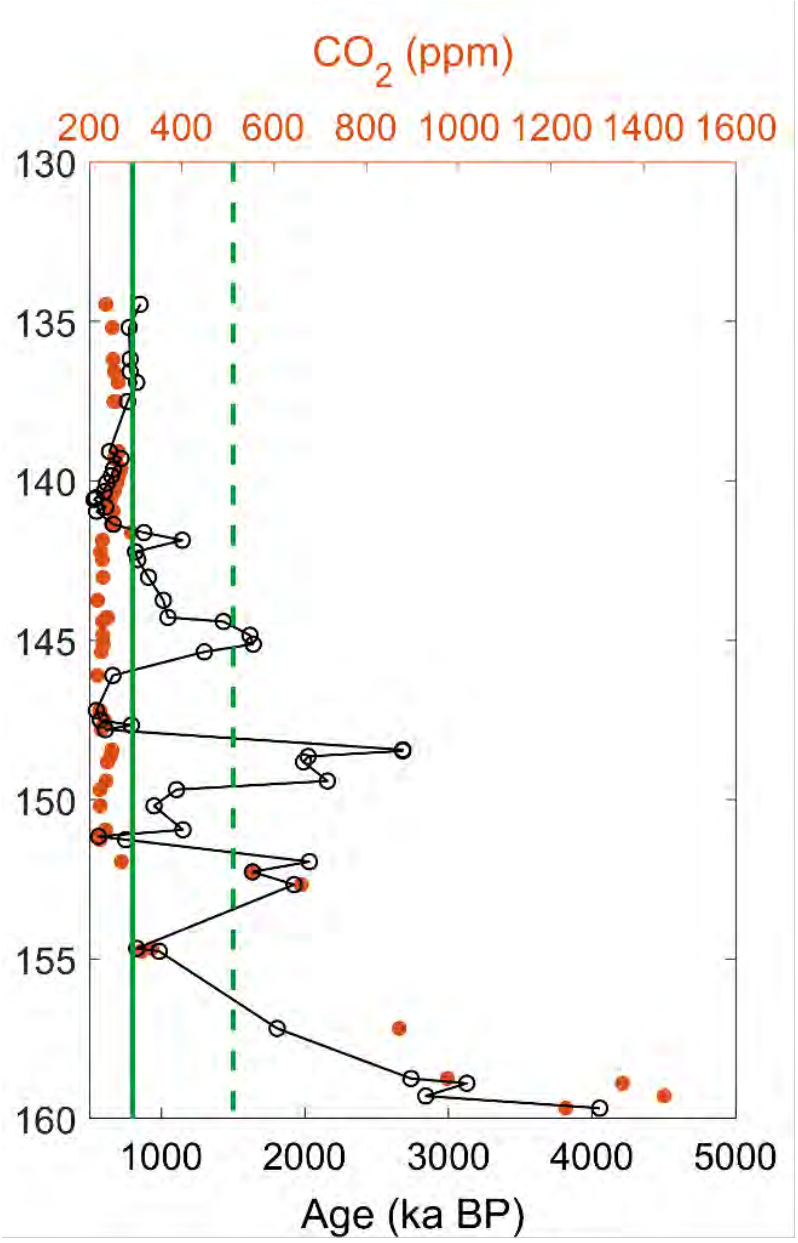


Figure II-10. ^{40}Aratm age and CO_2 concentration vs depth for ALHIC 1901. Unpublished data from Sarah Shackleton, Princeton (ages) and Julia Marks Peterson, OSU (CO_2).

- Our capability for ^{81}Kr dating of ice and workflow was developed and tested with extraction and analysis of three 1kg, 130ka samples and one 4kg, 129 ka sample from Taylor Glacier (extracted at Princeton and analyzed by the ATTA lab in Hefei, China, a group collaborating with the Princeton COLDEX investigators). The 4kg sample had a ^{81}Kr age of 143 ka (±24/21ka, analytical error) and the three 1kg samples had a ^{81}Kr age of 137 ka (±16ka, standard deviation of 3 samples). These results confirm the capabilities of the extraction system at Princeton. The 1kg ice samples were some of the first ever tested on the new, low volume ATTA system in Hefei and confirm the lab's capability for running 1kg ice core samples.
- The current analytical precision of Ar measurement at Princeton is 0.004 per mil (improved from 0.006 per mil from Yan et al, 2019). This translates to an improvement in precision from ±90 to ±60 kyr. The sample size was also reduced from 800g of ice to 500-600g of ice.

- *Milestone 2C: Develop hyperspectral imaging capabilities at NSF ICF with new camera equipment acquired by COLDEX*.
  - This milestone has been met. Hyperspectral equipment has been installed and tested at the NSF-ICF (led by Andrei Kurbatov, U. Maine and T.J. Fudge, U.W.)

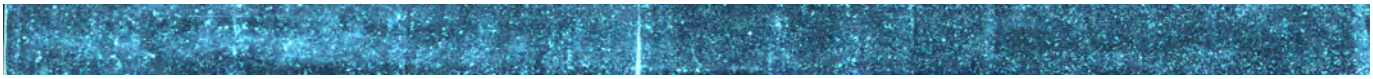


Figure II-11. Hyperspectral image of South Pole Ice Core from a depth of 1317 m depth. The bright white tapered line in the middle of the core is a punched tephra (ash) layer. Core length is 1m.

  - HSI was first employed in May 2023. In addition, an upgraded ECM method (T.J. Fudge, UW) was tested on WAIS Divide and SPICEcore ice (Figure II-11). The new DC electrode geometry, with the rolling electrodes with significantly smaller ice contact area (Figure II-12), was shown to achieve the same precision as previous measurements. This proof of concept opens opportunities to increase the spatial resolution of ECM measurements for COLDEX cores.

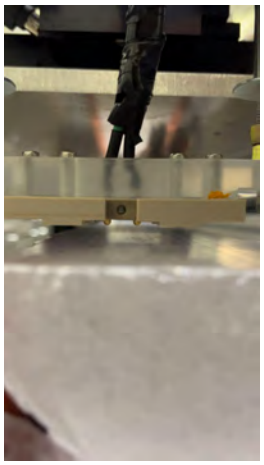


Figure II-12. DC electrodes on ICF ECM system are gold-plated spring-loaded balls that improve ice contact by rolling as the measurements are made along the core.

- The ECM and HSI have also been used jointly on Denali ice core ice in preparation for the COLDEX core processing in June. First imaging of COLDEX ALHIC2201 core is planned for this year (June 2023).
- We developed preliminary python based data processing scripts and applied them to hyperspectral images collected during a January 2-6, 2023 imaging campaign at the NSF-ICF.

- *Milestone 2D: Refine ice core chronology and assess the stratigraphic orientation of ice samples using a suite of analytical techniques.*
  - Technology described above will ultimately be used for these activities and tests are described below.
  - The electrical layering of deep ice of the Denali ice core was imaged with new ECM methods and HSI in preparation for measurements on COLDEX ice in June 2023 (Figure II-13). Strong layering was observed with ECM. Despite the narrow diameter core (3") and many core breaks, tilted layers were resolved. HSI images had to be made on half-cores instead of slabs, which complicates the interpretation and is ongoing.

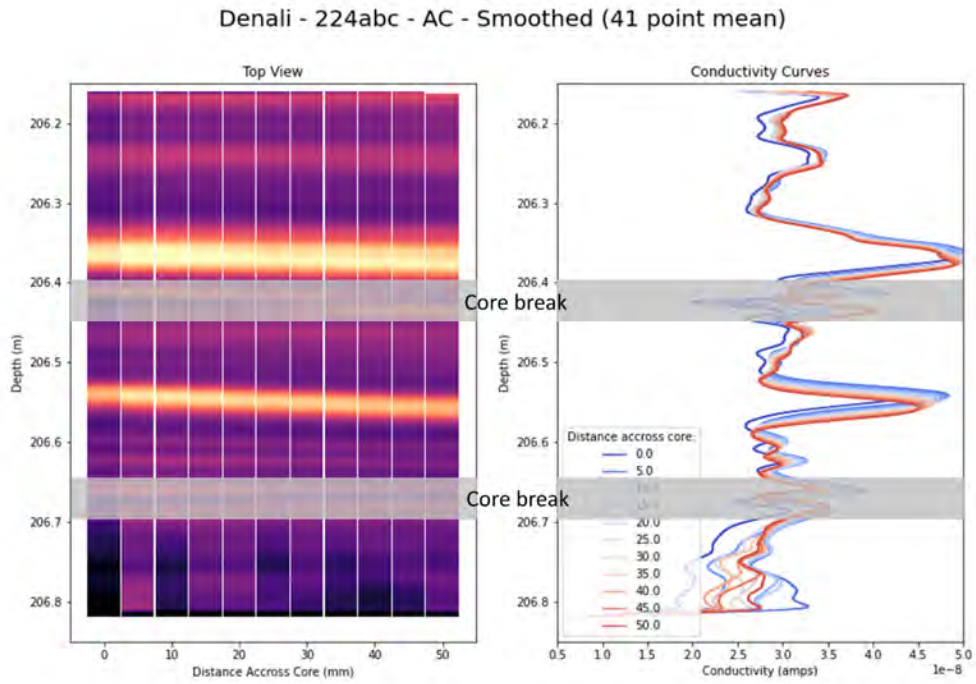


Figure II-13. Left panel shows electrical conductivity (light is high conductivity, dark is low conductivity) of the surface of the split Denali ice core. Right panel shows the conductivity of each track, colored from blue on the left to red on the right of the core. The layer at 206.55m has a tilt of 20 degrees.

- High resolution discrete (1cm) samples of water isotopes have been measured on opposite sides of the ALH1901 core at 141m depth (Figure II-14) (UW grad student Lindsey Davidge with undergrad Haley Lowes-Bicay and lead research technician Andrew Schauer). The horizontal (across core) distance between samples is 22 cm. The measurements show reproducible values, but with a depth offset of

approximately 5 cm, indicating that the layers are dipping about 13 degrees across the core. The ice has an age of about 450 ka. ECM and HSI measurements are planned on the remaining core samples to compare with the water isotopes. This finding clearly demonstrates that three-dimensional measurement spacing of isotopic samples can discern stratigraphic dip.

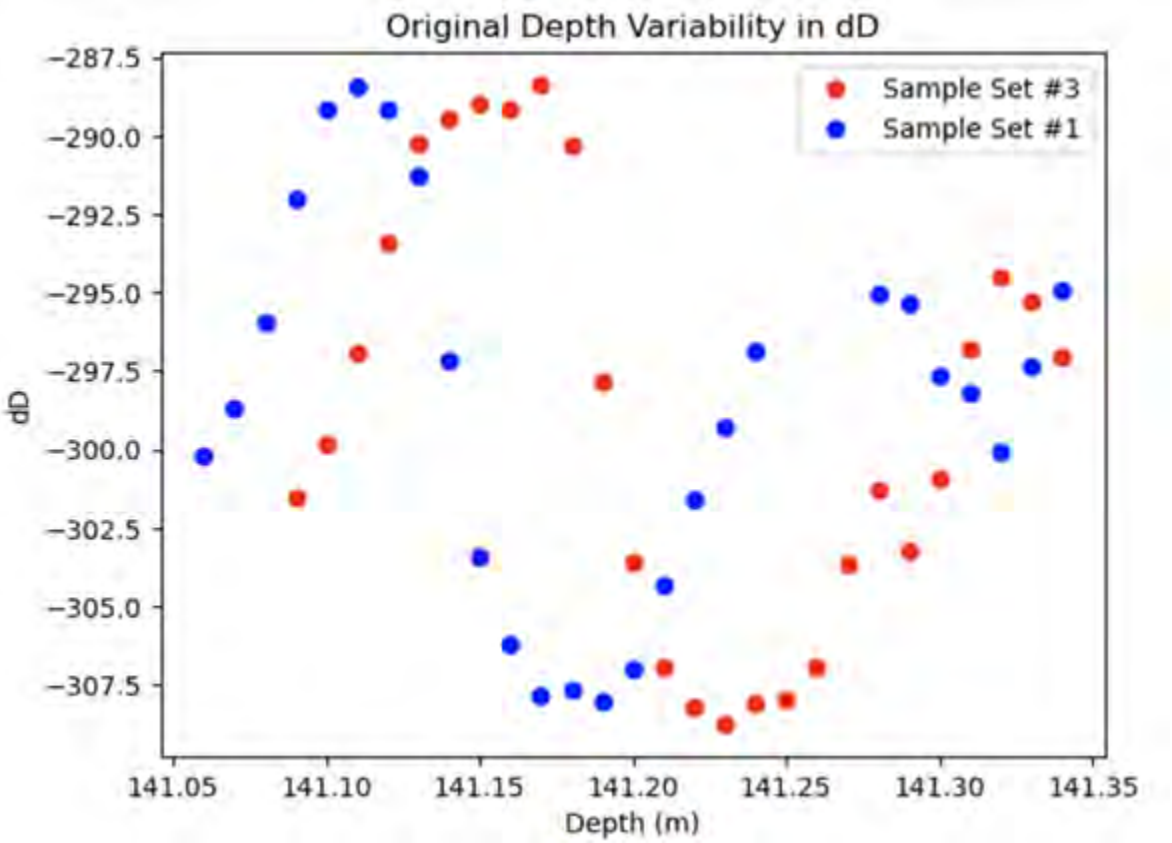


Figure II-14. 1 cm resolution water isotope data (δD) on ALH1901. Sample sets are separated by 22 cm horizontally. The ~ 5 cm offset vertically translates to a 13 degree dip.

- *Milestone 2E: Increase throughput of dry extraction ice core CO_2 measurements.*
  - At OSU we have designed and fabricated all of the components for the new crusher system, including refrigeration system and sample chamber holder, vacuum gauges and pumps, linear motion feedthrough and needle head for ice crushing. There were some delays in sourcing an appropriate linear motion vacuum feedthrough. We chose initially to produce just one crushing chamber, but if tests are successful the system will easily accommodate the planned three chambers for faster sample throughput. In the meantime our existing CO_2 analysis system is functioning excellently and available for use.
  - The new vacuum line will be assembled and coupled to an existing gas chromatography system for CO_2 analysis in July-September 2023.
  - A new method for introducing gas standards for the CO_2 system has been tested and works well, and will aid in automating this aspect of the analysis.

Objective 3: Develop paleoenvironmental records and document sample archive for the wider scientific community.

- *Milestone 3A: Develop publicly available metadata and data about core sites, analyses, and archived ice core samples.*
    - We have worked to archive field reports and ground penetrating radar data from previous Allan Hills field work at the USAP Data center, under the original award numbers. These documents provide valuable context but are often not saved for public use.
    - 2022-23 field reports from COLDEX field work are being archived at USAP data center (in progress June 2023). Allan Hills shallow drilling in 2022-23 was supported by NSF 1744993 and the field report will be archived under that award.
    - COLDEX is actively working with NSF ICF to make ice core samples from Allan Hills cores available to the scientific community. We have an agreement that ICF will maintain publicly available databases of all cores, and the COLDEX sample allocation committee will receive and evaluate sample requests, both from within and outside COLDEX. A sample request form and procedure have been developed and are available on the COLDEX web site. We are already advertising the availability of core samples at scientific meetings and through the web site and will continue to do so.
    - COLDEX is also working with NSF ICF to develop best practices for capturing age and other information relevant to sampling in a form best suited for stratigraphically discontinuous ice cores.

- *Milestone 3B: Develop schedule of ice analysis, including technical and sample requirements for different labs, measurement plan, preliminary data availability, archive plan.*
    - Technical and sample requirements for all labs surveyed as part of planning 2022/23 core processing.
    - Internal data archive is active in the form of a separate shared Google Drive, with access requiring acknowledgment of data policies. We will transition to a Globus server this summer (see management section).
    - Internal sample distribution is managed by the sample allocation committee using the form and a process developed for all (internal or external) sample requests.

- *Milestone 3C: Acquire basic chemical and imagery data for all COLDEX cores (stable isotopes, dust, soluble chemistry).*
    - The first cores to be analyzed will be sampled in June 2023 and we anticipate starting analysis in early fall.
    - Cores from the 2019-2020 field season continued to be analyzed for water isotopes, dust and imagery as described elsewhere in this report.

- *Milestone 3D: Acquire records of greenhouse gases, other atmospheric constituents, dust, and radiogenic isotopes for COLDEX cores.*

- We are working on records of atmospheric composition now from two ice cores, ALHIC 1901, which contains ice as old as 4 Ma (see Figure II-10) and ALHIC 1903, which spans the last interglacial period and part of the previous glacial period. ALHIC 1903 is important to COLDEX because measurements in that core help us understand signal preservation in the Allan Hills records, by comparison to other ice cores. This work is also supported by an award made prior to COLDEX, which is coming to a close (OSU, Maine, Princeton, UCSD collaboration).
- Graduate student Julia Marks Peterson at OSU has developed CO_2 and CH_4 concentration records from ALHIC 1901. Data back to 2.7 Ma are shown in Figure II-15. Some of these results were reported in the year 1 progress report but we have added additional CO_2 and CH_4 concentration data, conducted stable isotope analysis for CO_2 on a number of samples, and investigated the preservation of the atmospheric signal in the ice between 500 and 800 ka in more detail. A paper led by Marks Peterson describing the data back to 2.7 Ma is in the initial stages of preparation.
- Using the ^{40}Ar ages in the section of the core that overlaps with the dated EDC ice core (500-800 ka) as a starting point, it is possible to further constrain sample age by matching the CO_2, CH_4 and $\delta^{18}Oatm$ (not shown) data to the EDC record. Preliminary results suggest that each Allan Hills data point in this time interval can be dated fairly precisely to EDC intervals and that the Allan Hills record is primarily sampling intermediate or interglacial periods, perhaps because of non-deposition during full glacials. Further analysis is ongoing.
- The data back to 2.7 Ma, while still somewhat limited, do not reveal CO_2 concentrations higher than ~270 ppm. This is an intriguing result since climate reconstructions generally suggest warmer than present temperatures before the MPT. We are too early in the interpretation stage to speculate on the implications.

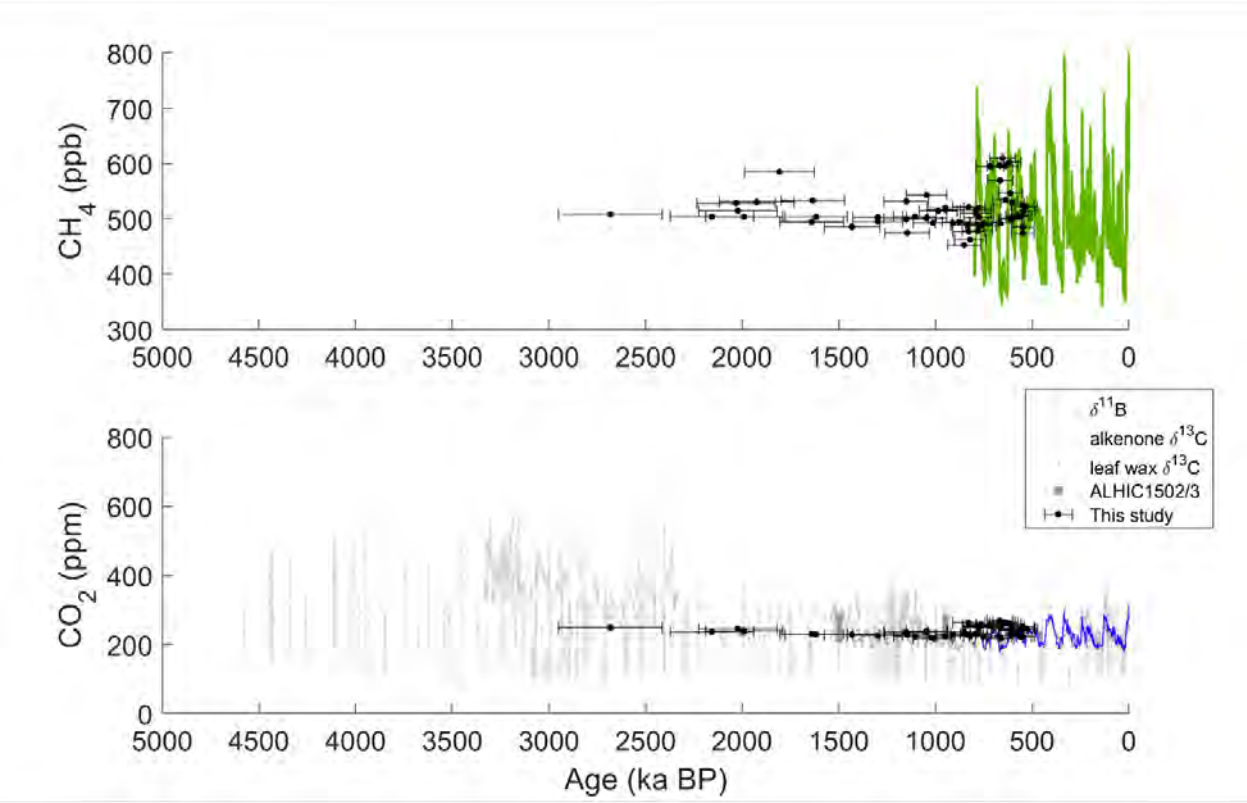


Figure II-15. CO_2 and CH_4 concentrations to 2.7 Ma from ALHIC 1901. The EPICA Dome C CO_2 and CH_4 records, and marine proxies, are also shown.

- The oldest samples (see depth vs. age in Figure II-10 above) appear to be impacted by CO_2 derived from organic matter near the base of the ice sheet, based on depleted carbon isotopic compositions (see below) and very high CO_2 concentrations. Similar observations were made in limited samples from previous work. A preliminary analysis using stable isotope data and a two-component isotopic mixing model is consistent with CO_2 concentrations in samples between 2.7 and 4 Ma of less than 350 ppm (Figure II-16).

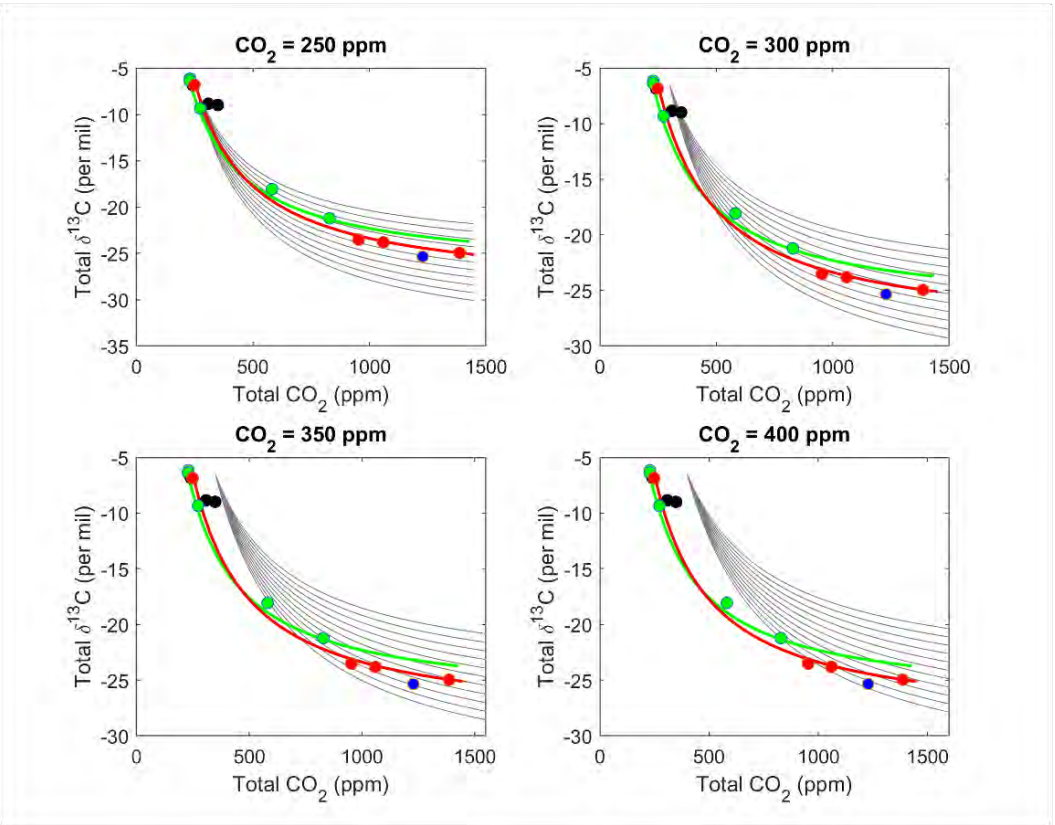


Figure II-16. CO2 and $\delta^{13}C$-CO_2 data for ALHIC 1901 ice core. Mixing lines for two component mixing model with range of end member organic matter $\delta^{13}C$ suggest atmospheric concentrations below 350 ppm for the oldest samples.

- We also have measured methane (using discrete samples) in most of the samples measured for CO_2 concentrations (Figure II-15). Methane concentrations also fall in the middle of the range found in < 800 ka time periods, with the exception of a few anomalously high values near the bed (not shown). We have plans to pursue isotopic measurements to investigate the origin of the high values.
- Jeff Severinghaus' group at UCSD has measured samples from the ALHIC 1901 core for ^{15}N of N_2, ^{18}O of O_2, ^{17}O of O_2, Ar/N_2 ratio, and conducted low-precision measurements of $^{40}Ar/^{36}Ar$ and $^{38}Ar/^{36}Ar$ in the Scripps Noble Gas Isotope Laboratory. Specifically, the deeper part of the core that contains ice up to 4 million years old was analyzed. One important finding is that the Ar/N_2 ratio was not anomalously enriched relative to atmosphere, as we had suspected it might be based on Sarah Shackleton's measured Kr/Ar ratio of +103 per mil in the 4 million year old ice. So this latter finding remains a mystery, and the hypothesis of melt-refreeze adding excess Kr is clearly inconsistent with our Ar/N_2 measurement of -10 per mil (Kr is twice as soluble as Ar, and Ar is twice as soluble as N_2, so we should have seen a measured Ar/N_2 +50 per mil if the melt-refreeze hypothesis was correct). All data were passed to Julia Marks Peterson at OSU, who is doing her thesis on this topic. Severinghaus assisted Julia in making the gas loss corrections to ^{18}O of O_2 and ^{17}O of O_2, which are potentially useful for dating the ice. Unfortunately,

the precision of the ^{17}O measurement was too low to infer past atmospheric CO_2 mixing ratios (based on observed correlations of this parameter with CO_2 in younger ice cores). This is due to the very small amount of ^{17}O present in the whole air samples of ~1 mlSTP. The COLDEX group is planning to pursue a dedicated ^{17}O measurement campaign in the future to better constrain CO_2 concentrations in the oldest samples from ALHIC 1901.

- Mean ocean temperature constraints based on noble gases back to 3.1 Ma were reported previously and are the subject of a paper in preparation by Sarah Shackleton at Princeton.
- OSU has produced CO_2, CH_4 and total air content data from the ALHIC 1903 ice core covering the Marine Isotope Stage 6 to 5e time period. Greenhouse gas records for this time period are well known from other ice cores, but analyzing this core provides two opportunities for COLDEX. One is to understand the reliability of Allan Hills greenhouse gas records. Our data from this core (Figure II-17) show excellent agreement between existing records of methane and carbon dioxide concentration and expected values of total air content. A second opportunity is to analyze gases in “bubbly” ice covering this time period. Most, if not all, deep ice cores covering this time period are deep enough that air is in clathrate form. Clathrate poses some obstacles to extracting and analyzing trace gases, particularly carbon dioxide and its isotopic composition, and sample sizes are limited from deep cores. ALHIC 1903 is a 24 cm diameter core providing large amounts of ice for a variety of analysis. In our case we are using ALHIC 1903 for isotopic measurements in carbon dioxide, which will both better establish the record of this property and its reliability in Allan Hills cores. Figure II-17 shows progress to date. At this point we see general agreement with previous data and continued analyses as time allows should fill in data in sufficient detail to improve the existing isotopic record.

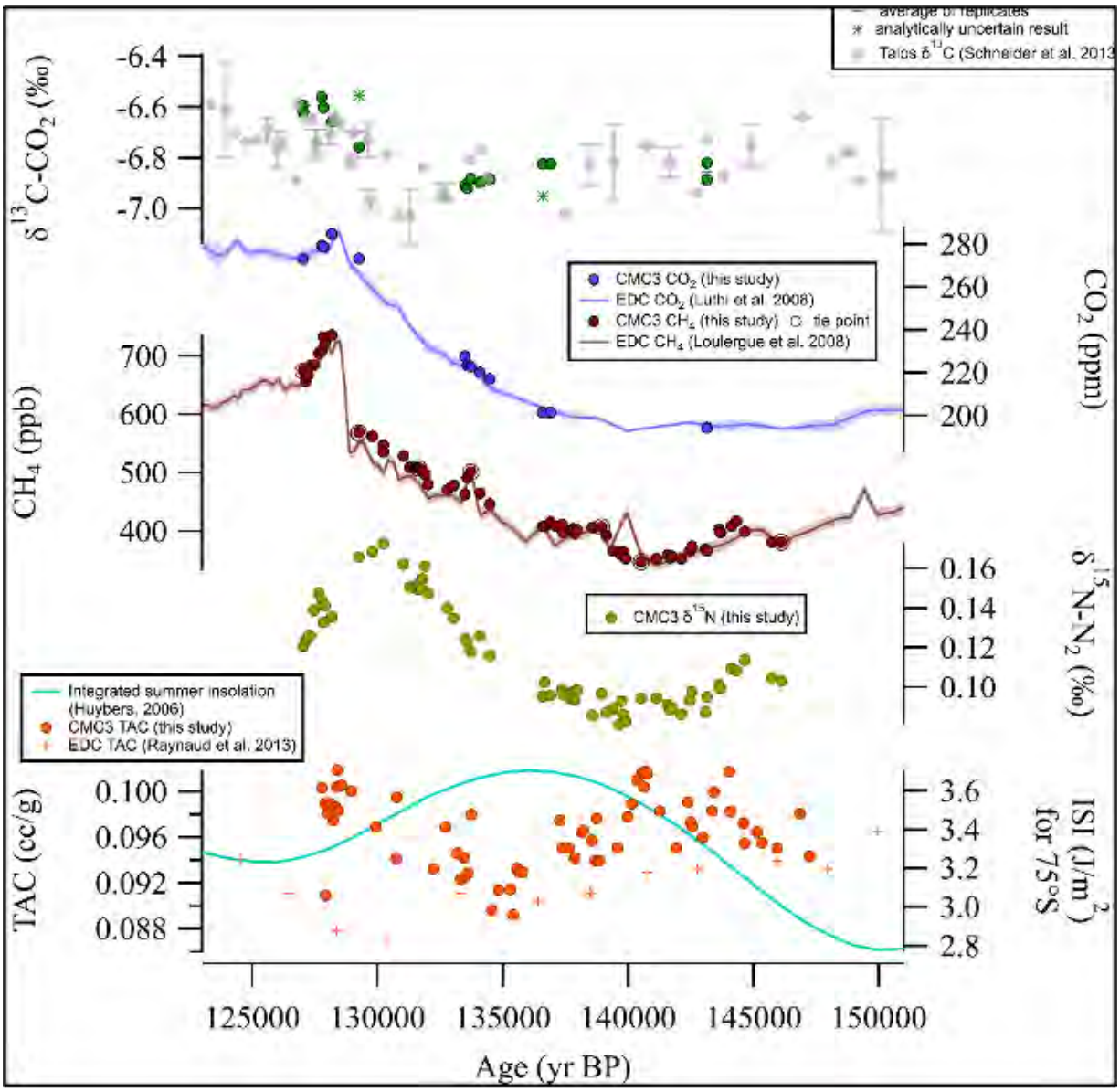


Figure II-17. Comparison of paleoclimate records across Termination II. From top to bottom: a record of $\delta^{13}C$-CO_2 from Talos Dome in gray (Schneider et al., 2013, Climate of the Past, v. 9) and ALHIC1903 in green (this work), CO_2 record from EPICA Dome C (Lüthi et al., 2008, Nature, v. 453, blue line) and ALHIC1903 (blue circles, this study), CH_4 from EPICA Dome C (Loulergue et al., 2008, Nature, v, 455) maroon line) and ALHCI1903 (maroon circles, this study), $\delta^{15}N$-N_2 from ALHIC1903 (this work), and total air content (TAC) from EPICA Dome C (Raynaud et al., 2007, EPSL, v. 261, orange crosses) and ALHIC1903 (orange circles, this study) as well as the integrated summer insolation for 75°S (Huybers, 2006, Science, v. 313).

- At UCSD, Ph.D. candidate Austin Carter and Dr. Sarah Aarons conducted a comprehensive analysis of ice core samples spanning from Marine Isotope Stage (MIS) 6 to 5e from the ALHIC 1903 ice core. The work on the last interglacial is supported by a separate award to Aarons (NSF OPP Award #2035580) as well as GSA funds for U chemistry work conducted by Carter, but is reported here for completeness and due to relevance to the older ice cores. Further field work for her

work and further work on dust chemistry in the older COLDEX cores is supported by COLDEX. The samples underwent decontamination, melting, filtering, and digestion procedures. Carter and Aarons also initiated studies of older ice in the ALHIC 1901 core.

- Methods for analyzing dust concentration and size distribution using a Coulter Counter were established and utilized. Additionally, rare earth element concentrations in the ice core dust were measured using an Inductively Coupled Plasma Sector Field Mass Spectrometer (ICP-SFMS) at the Ohio State University. Scanning electron microscope (SEM) imaging was employed to examine dust on discrete samples. Austin also developed a preliminary ice age scale for the Allan Hills Ice, specifically for the MIS 6 to 5e transition, based on an existing chronology.
- To separate elements like strontium (Sr) and neodymium (Nd), heat-shrink teflon columns were fabricated by Austin and Dr. Aarons. Each column was individually calibrated to maximize the yield of these elements during the chemical purification process. Austin completed the chemistry work in summer 2022, and measurements for Sr and Nd isotopes were conducted in fall 2022. The data are currently being interpreted, and a manuscript is being prepared for publication. Please find the unpublished figures below, with more detailed explanations of the data in the figure captions (Figures II-18, II-19, and II-20).
- Ph.D. candidate Carter has been trained in Antarctic field work, ice core sample collection and processing, clean lab chemistry, data analysis and dissemination. Carter and Aarons trained two undergraduate students (Anusha Goswami and Justin Han) in making heat shrink teflon columns and column chemistry for separating isotopes for measurement. Preliminary results for the geochemical portion of this work have been disseminated at the AGU 2021 Fall meeting, the Ice Core Open Science meeting in 2022 at Scripps Institution of Oceanography, the International Partnership in Ice Core Sciences in Crans-Montana, Switzerland, and the Ice Core Open Science Meeting in 2023 at the University of Washington.
- In summer 2023, Austin and COLDEX REU student Alissa Choi will collaborate on generating a dust concentration record for the ALHIC1901 ice sample using a Coulter Counter.
- Currently, Austin is working on Chapter 2 of his dissertation, which involves uranium dating on the ALHIC1901 ice sample. This particular ice has already been dated using argon dating techniques to determine its age to be between 500-800 ka. In January 2022, Austin initiated the process of modifying the UC San Diego radioactive license to include uranium isotopes, specifically U-233. After receiving approval from the State of California in November 2022, Austin was able to obtain a U-233/U-236 reference standard in March 2023. The processing of the ALHIC1901 ice sample for uranium dating will take place during the summer of 2023.

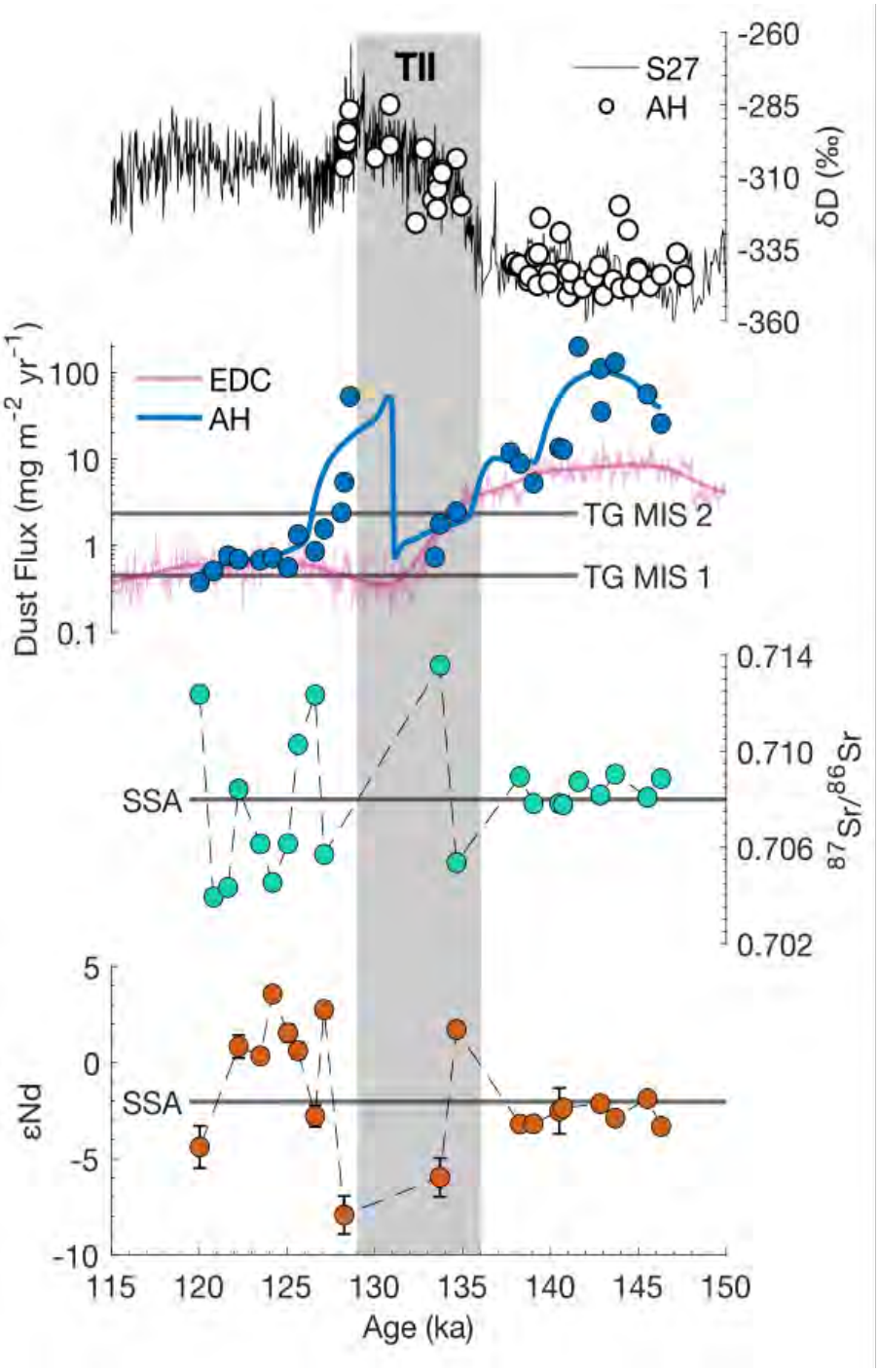


Figure II-18. Properties of Allan Hills ice across the MIS 6 to 5e deglacial transition. a, Continuous δD_{ice} from nearby S27 (black line)[44] with discrete δD_{ice} from ALHIC1903 (white circles). b, Discrete dust flux at ALHIC1903 (blue circles) with smoothed flux (blue line) compared to EDC[21] with discrete flux (light pink) and smoothed flux (dark pink). All data are smoothed using nonparametric regression using 50-year step sizes with 2,500-year window sizes. c and d, Sr and Nd isotopic compositions of dust from ALHIC1903. Horizontal line represents the mean isotope composition for southern South America (SSA, >50 ºS). Note: 2σ error bars are smaller than symbol size for all Sr and some Nd values.

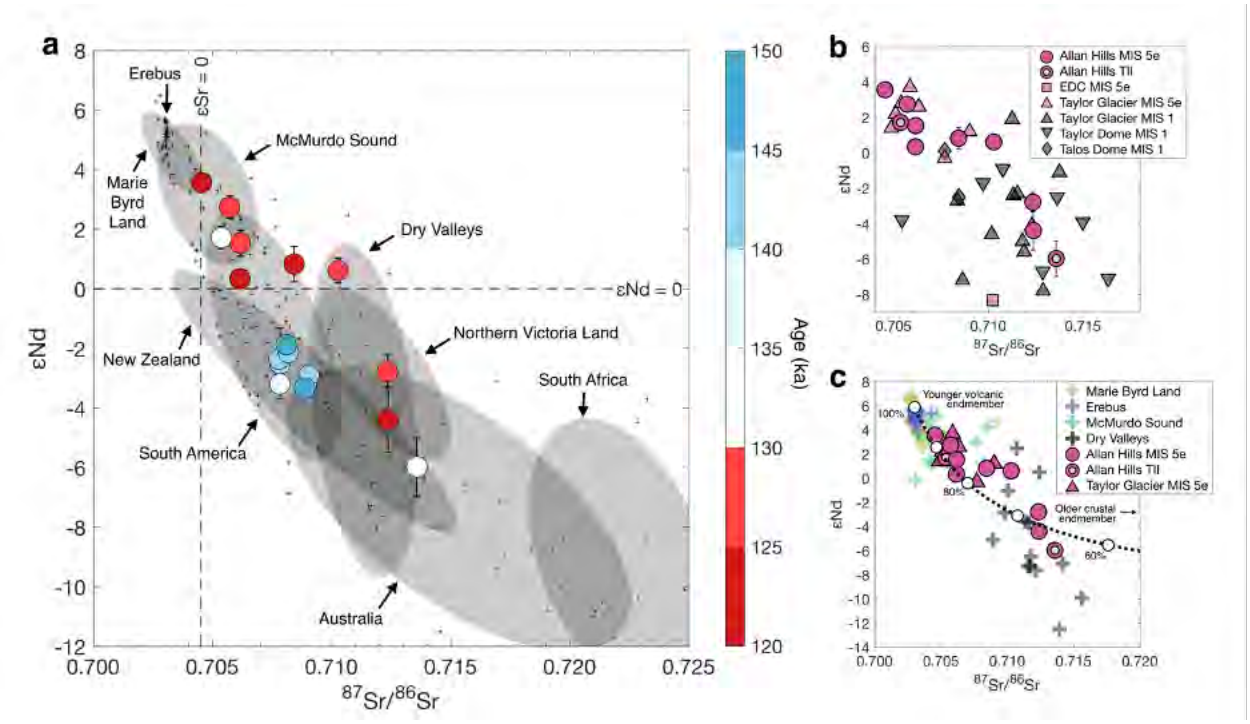


Figure II-19. Sr-Nd isotopic composition of dust. a, Allan Hills dust (circles) compared with data from potential source areas (PSAs)[7,24–29,32]. Individual data points from PSAs are represented as gray crosses, and isotopic fields for the PSAs are represented by 75% confidence ellipses, calculated from data within 1.5 standard deviations of the mean. Dashed lines represent the isotopic ratios of the chondritic uniform reservoir for Nd (e_{Nd} = 0)[45] and the unfractionated mantle for Sr (εSr = 0)[24]. Error bars represent two sigma error. b, Dust from MIS 5e (pink markers) compared with dust from MIS 1 (black markers). c, Mixing model of younger volcanic and older crustal endmembers with dust from MIS 5e at the Allan Hills and Taylor Glacier[6]. Note: axes ranges are different for a, b, and c to include the breadth of PSA data and explore the differences between interglacial periods.

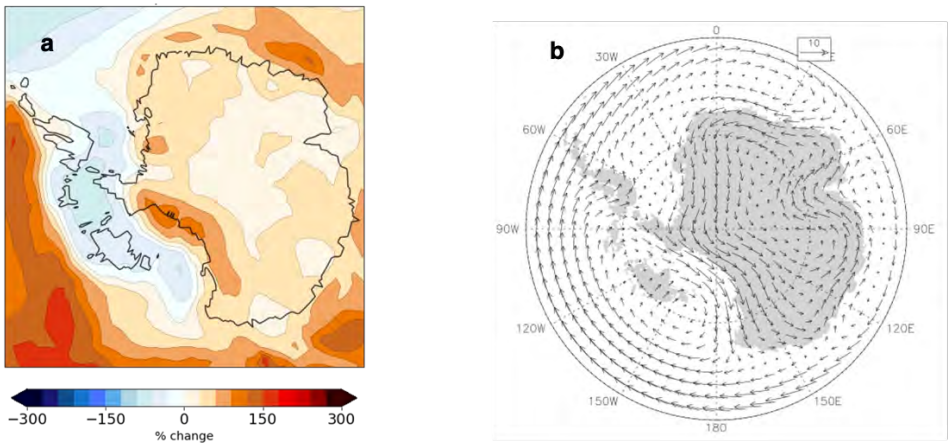


Fig. II-20. iCESM1 Earth System model simulations. a, Changes in dust deposition (%) to Antarctica during MIS 5e compared to the preindustrial in response to a prescribed WAIS collapse topography. b, Simulated regional winds showing vector speed and direction during MIS 5e compared to the preindustrial in response to a prescribed WAIS collapse topography.

- At UC Irvine, graduate student Jenn Campos-Ayala and researcher Murat Aydin have analyzed Eemian COLDEX samples for acetylene/ethane and other trace gases. They also analyzed Allan Hills ice core samples (MIS5e and 6) for ultra-trace gases. Results were obtained for acetylene, ethane, methyl chloride, methyl bromide, and carbonyl sulfide. The most notable result is the observation of acetylene levels well below Holocene levels, suggesting that tropical fire emissions during the Eemian were lower than during the Holocene. There is evidence of *in situ* chemical production of ethane and methyl chloride presumably associated with dust/volcanic particulate matter.
- Development of sample archive for wider scientific community is described elsewhere in this report.

Table II-1: Status of COLDEX Experimental/Analytical Facilities

New Facilities/Instruments

Facility	Status	Comments	PI/Institution	Results Produced
Ice Diver/Dust Logger Thermal Probe	● Initial two Ice Diver vehicles constructed. ● Vehicles prepared for Greenland Summit test ● Planning for Summit test complete	Scheduled on site at Summit, Greenland July 21, 2023	Dale Winebrenner, US Applied Physics Lab	Still in test phase.
Centralized Analytical Laboratory at OSU	● Walk-in freezer for CFA melter installed. ● Aerodyne CH_4 and CO laser spectrometer ordered. Supply chain problems delayed receipt. ● Abukus dust analyzer received, tested, operational. ● Picarro water isotope analyzer and sample handling system integrated and tested at OSU. ● Gas handling/air extraction system tested and operational with OSU CH_4 and CO Picarro. ● Cation and anion measurements by electrospray mass spectrometry proved difficult. Backup up plans for ICPMS and ion chromatography developed.	Integration of gas analyzer, water isotope analyzer, and fraction collection for ice chemistry begins in July 2023.	Christo Buizert (OSU), Eric Steig (UW), Eric Saltzman (UCI)	Still in test phase.
Hyperspectral Imaging System	● Purchased and installed at NSF ICF. Testing in progress.	Extensive testing and data collection at CPL in June 2023	Andrei Kurbatov (UMaine)	Initial imagery of Allan Hills ALHIC 1901 core in June 2023

Upgraded ECM System	● Refurbished at UW and re-installed at NSF ICF ● New DC electrode geometries are in testing	Initial measurements on COLDEX ice completed in June 2023	T.J. Fudge (UW)	3D Electrical stratigraphy of select sections using measurements on two perpendicular faces
OSU Multi-port CO_2 crusher system	● All components ordered and on site. ● Assembly beginning.	Existing CO_2 analysis system operational.	Ed Brook (OSU)	NA
KU COLDEX 750 MHz radar	● Central fuselage array designed and constructed; wing arrays in development. ● 2D echograms ● 3D echograms in development ● Interferograms on repeat lines in development	Deployed in 2022-23	John Paden (KU)	Limited field data due to interference problems.

Existing Facilities/Instruments

Facility	Status	Comments	PI/Institution	Results Produced
Dry extraction system for CO_2 isotope analysis	Operational	Available for COLDEX, limited other commitments	Ed Brook (OSU)	CO_2 concentrations and isotope ratios from ALHIC 1901 and 1903
Dry extraction system for CO_2 concentration analysis	Operational	Available for COLDEX, limited other commitments	Ed Brook (OSU)	CO_2 concentrations from ALHIC 1901
Wet extraction system for CH_4 concentration analysis	Operational	Available for COLDEX, limited other commitments	Ed Brook (OSU)	CH_4 concentrations from ALHIC 1901 and 1903
Wet extraction system for CH_4 isotopic measurements	Operational for δ^{13}C-CH4	Available for COLDEX, limited other commitments	Ed Brook (OSU)	Preliminary $\delta^{13}C$-CH_4 measurements on ALHIC 1901

Water isotope cavity ringdown laser spectrometers	Operational for δ D and $\delta^{18}O$	Instruments at UW, University of Maine, OSU COLDEX laboratory	Eric Steig (UW) Andrei Kurbatov (Maine) Christo Buizert (OSU)	Detailed isotopic measurements examining stratigraphic integrity of Allan Hills cores (UW). Measurements for all samples from ALHIC 1901 and 1903 measured for gases (Maine). Technique development for ^{17}O measurements.
Stable isotope mass spectrometers and extraction lines for isotopic measurements of O2/N2/Ar and $^{40}Ar/^{38}Ar$.	Operational	Available for COLDEX	Jeff Severinghaus (UCSD)	Measurements of isotopic composition and ratios of O2/N2/Ar in ALHIC 1901 and 1903. Dating with $^{40}Ar/^{38}Ar$.
Stable isotope mass spectrometers and extraction lines for isotopic measurements of heavy noble gases and $^{40}Ar_{atm}$ dating	Operational	Available for COLDEX	John Higgins and Michael Bender (Princeton)	Measurements of heavy noble gases for mean ocean temperature constraints, measurements of argon isotopes for dating old ice in ALHIC 1901
Coulter counter, clean room, ICMPS	Operational	Available for COLDEX	Sarah Aarons (UCSD)	Dust concentration and size distribution in ALHIC 1903. Heavy isotope dust provenance tracers in ALHIC 1903

GCMS and gas extraction lines for acetylene, ethane, methyl chloride, methyl bromide, and carbonyl sulfide in ice core air.	Operational	Available for COLDEX	Eric Saltzman and Murat Aydin (UC Irvine)	Measurements of listed gases in ALHIC 1903
UTIG Airborne Radar	Operational	Available for COLDEX	Duncan Young and Don Blankenship (UTIG)	2022-2023 airborne data
Gravimeter	Operational	Available for COLDEX	Duncan Young and Don Blankenship (UTIG)	2022-2023 airborne data
Magnetometer	Operational	Available for COLDEX	Duncan Young and Don Blankenship (UTIG)	2022-2023 airborne data
Ground-based Autonomous Phase sensitive radar (ApRES - 300MHz center frequency).	Operational	Available for COLDEX	Howard Conway (UW)	2022-23 data at Allan Hills: Measured depth-profiles of ice fabric at 26 sites. Repeat measurements next season will be used to calculate vertical-strain rates.
Ground-based GSSI radar with 200 MHz hyper-stacking antenna to map near-surface stratigraphy.	Operational	Available for COLDEX	Howard Conway (UW)	2022-23 data at Allan Hills: Profiles totaling 126 km used to map the firn/ice transition in the accumulation zone
UW ground-based 7 MHz impulse radar to map bed	Operational	Available for COLDEX	Howard Conway (UW)	2022-23 data at Allan Hills:

topography, ice thickness and internal stratigraphy.				Profiles totaling 55 km used to identify the site for extracting a continuous core extending back 1+Ma
LA ICPMS system	Operational	Available for COLDEX	Andrei Kurbatov and Paul Mayewski (UMaine)	Sampling Allan Hills ALHIC 1901 core in Fall of 2023
Distributed temperature sensing (DTS) using a fiber optic cable deployed down the CMC1 borehole in the ablation zone	Operational	Available for COLDEX	Howard Conway (UW)	2022-23 data at Allan Hills: Temperature near the bed (~150m) was -28.7C; geothermal heat flux ~46mW/m2
Radiogenic isotope mass spectrometer for measuring strontium and neodymium isotopes in ice core dust	Operational	Available for recharge	Janne Koorneef (Vrije Universiteit)	ALHIC 1903 data

3. Research highlights and findings.

- Development of the oldest ice core data constraining atmospheric composition and mean ocean temperature, with results back to ~3 Ma from ice cores along the Antarctic ice sheet margin.
- Expansion of analytical methods for analyzing very old ice from regions where original layering has been distorted by glacier flow.
- Significant expansion of ice penetrating radar data sets in interior East Antarctica between the South Pole and Dome A, revealing detailed subglacial topography and internal ice sheet structure, allowing further evaluation of potential new ice core sites for a continuous ice core back to 1.5 million years.
- Construction of the Ice Diver-Dust Logger vehicle, a thermal probe designed to melt its way through ice sheets and measure dust content as a way to count climate cycles and determine the age of deep ice core sites before drilling.
- Collection of new ice cores in the Allan Hills Blue Ice Area and reconnaissance coring in Elephant Moraine region
- Final core site recommendation for intermediate depth (~1200 m) ice core at Allan Hills that could reach >1Ma.

4. Problems encountered and anticipated.

- The COVID outbreak in McMurdo Station in the 2022-23 field season significantly slowed the three COLDEX field programs (airborne geophysics at South Pole, ground based geophysics at Allan Hills, ice coring at Allan Hills). All three groups were able to deploy but did not accomplish all of their original goals. Given the extreme circumstances we are comfortable with what we were able to accomplish and in continuing our year two field plans. We had good contingency plans and very good communication with the field teams in dealing with these issues. Excellent support was provided from USAP and NSF to help make the field work possible.
- Two field activities are categorized as “scope contingent” in the draft operational notice for COLDEX field work. One is an intermediate depth core at Allan Hills, described elsewhere in this report. Staging for this activity was to start in the 2023/24 field season but will not be happening this year. We are uncertain at this time about whether this activity will move forward. A second was a limited ground based radar campaign in the region of the “Saddle Site,” also described elsewhere in this report. This activity is also not planned to be supported as originally requested. NSF is considering a more limited (3-4 days) phase sensitive radar deployment for COLDEX (in the “Elbow” site region) in this coming season.
- Supply chain delays have caused some issues for COLDEX though we are able to handle these so far. One is a delay in the delivery of the Aerodyne laser spectrometer, but as described above we have a back-up instrument that functions well. A second was the installation of a walk-in freezer for our CFA system. The refrigeration system was delayed for many months. However, it has been installed and will be turned on the week of July 12.

We have an excellent relationship with the freezer technician so do not anticipate any problems.

- Testing and shipping of new KU radar systems was a problem for COLDEX, as also described elsewhere in the report. Flight testing in summer 2022 was not sufficient to reveal EM interference between UTIG and KU radars because the KU radar system was not sufficiently operational, due to very tight timelines for construction (a consequence ultimately of the late start date of the STC funding). Additional flight testing is needed in summer 2023 and has been scheduled, but there are some concerns about meeting the tight timeline for that test. We are monitoring the situation and developing contingency plans for which radar systems will be deployed. The UTIG radar, which is very mature, is ready for deployment.
- A last minute problem, described further above, caused a postponement of the ice diver field test.

5. Plans for next reporting period.

- We will pursue our Year 3 research goals as outlined in the Strategic and Implementation Plan, and complete any Year 1 or 2 goals that were delayed. We do not anticipate any major changes in research direction in year 3 with the exception of the possibility that the scope contingent field plans will ultimately not be realized. We anticipate several foundational journal articles to be published in year 3, including
- An initial COLDEX paper on greenhouse gas data described in this report.
- An initial COLDEX paper on mean ocean temperature records described in this report.
- At least one initial paper on COLDEX airborne radar findings.
- We also anticipate a number of other papers related to materials presented in this report. More detailed publication planning will be conducted over the summer of 2023 and plans for year 3 publication finalized during our annual meeting in September.

III. EDUCATION

1. Center's overall education goals.

The Center has defined four Optimal Outcomes in the Education and Leadership section of the Strategic Plan. They have not changed since the previous reporting period.

1. Increased awareness and appreciation of ice core and polar sciences through the engagement of K-12 through graduate students, postdocs, teachers, and professors in COLDEX research goals. Engagement with these groups will increase diversity of participants in ice core and polar sciences.
2. A well-trained group of students and postdoctoral researchers contributing to the COLDEX mission who obtain skills and experience relevant to their future work and through development of professional skills.
3. A well-trained group of students and postdoctoral researchers who successfully incorporate education, outreach, and science communication to science and non-science audiences throughout their careers.
4. Successful implementation of inclusive education opportunities that are developed through incorporation of diverse perspectives, particularly those that have not historically taken part in and may challenge the "status quo" of ice core and polar science activities.

2. Strategic plan objectives and progress towards milestones.

Objective 1: Bring ice core and climate science to K-12 and university curricula.

- *Milestone 1A: Incorporate COLDEX research and participants into Ice Drilling Program "School of Ice" (SOI) for faculty at Minority Serving Institutions.* Per our original plans, SOI is not being offered through COLDEX in Year 2 (but ran successfully in Year 1 and is scheduled to repeat in Years 3-5).
    - School of Ice ran successfully at Oregon State University from August 7 – 12, 2022 with 13 participants
        - Multiple COLDEX faculty and graduate students presented during the workshop: T.J. Fudge, Christo Buizert, Ed Brook, Danielle Whittaker, Kristen Rahilly, Jon Edwards (graduate student), Katie Wendt (postdoc), Julia Marks Peterson (graduate student), Kaden Martin (graduate student), Demetria Eves (undergraduate student).
        - School of Ice participants analyzed and interpreted methane measurements from ice cores as well as took a tour of the new COLDEX Continuous Flow Analysis lab at OSU.

        - School of Ice was evaluated by Jana Bouwma-Gearhart and graduate student Caitlin Kepple.
    - COLDEX offered assistance for the SOI program at Dartmouth this year, by connecting Louise Huffman and Bill Grosser with Stephanie Jarvis as an education evaluator. Rahilly is also participating in Louise and Bill's "Virtual Field Lab" training workshop in July.
    - We are also exploring the potential and feasibility of involving interested SOI participants in COLDEX research projects, either individually or with their students. Activities in this reporting period include:
        - Formal engagement in 6 month-long mentorship by 4 COLDEX individuals (Kaden Martin, Liam Kirkpatrick, Skyler Jacob, Kristen Rahilly) with research program for high school students in Chicago run by 2021 SOI participant Allison Hennings. Total of 5 students mentored on individual research projects related to COLDEX or polar science.
        - Virtual presentations by Christo Buizert and Kristen Rahilly in June 2023 School of Ice workshop offered through the Ice Drilling Program at Dartmouth.
        - Outreach with students at Sacramento City College through online STEMinar hosted by SOI participant Nana Ngassam, outreach focused on COLDEX mission and REU program - Kristen Rahilly.
        - Outreach with SOI participant Shannon Othus-Gault's (Chemeketa Community College) students - online panel discussion with Cate Bruns, Ed Brook, Erin Pettit, and Kristen Rahilly on May 17.
        - Outreach in SOI participant Shannon Othus-Gault's classroom focused on COLDEX science mission and undergraduate opportunities - Kristen Rahilly.

- *Milestone 1B: Develop and implement "Project Ice" K-12 teacher education program with the American Meteorological Society, incorporating COLDEX research and scientists.* The pilot program is on track to be delivered in June 2023 at Oregon State University.
    - Applications for the pilot offering of Project Ice were received from K-12 teacher leaders in DataStreme Leadership roles and/or those that are Certified AMS Teachers. We received 20 applications and selected 12 participants with most of the remaining applicants being alternates. One person had to give up their space, so we used our first alternate position.
    - COLDEX research themes and advancements were incorporated into a hybrid graduate level course for K-12 teachers. Chad Kauffman (PennWest) worked with appropriate staff on the Project Ice summer course shell and finalized the dates for the full course (1st five-week summer session), which includes several weeks of online coursework, the one-week residency, and then the completion of the online portion of the course. Abigail Stimach (AMS) engaged with her graduate school liaison at PennWest to ensure a proper "handoff" of participant information and logistical procedures.

- AMS staff (Mills, Stimach, and Smoak) recruited participants, and implemented pre-workshop online modules. In-person workshops at Oregon State University, and post-workshop online modules are scheduled for June and July 2023.
- Louise Huffman created an Ice Drilling Program document of “Basic Understandings of Ice Core Science” and worked with Beth Mills to revise it for use in guiding the development of the curriculum for Project Ice.
- Rahilly and Mills designed four modules: “Understanding the Polar Regions”, “Ice Core Science and Engineering”, “Land Ice, Sea Ice, Grounded Ice, and Impacts on Sea Level Rise” and “Ice Core Science and Paleoclimatology.”
- Planned presentations and participation of multiple COLDEX faculty, postdocs, and students during June 2023 workshop component of Project Ice: T.J. Fudge, Ed Brook, Asmita Banerjee, Kaden Martin, Demie Huffman, Jenn Campos-Ayala, Megan Kerr, Ellen Mutter, Julia Marks-Peterson, Kristen Rahilly
- Rahilly is facilitating delivery of Project Ice at OSU through logistical support.
- The project team discussed evaluation with COLDEX post-doc Joon Park and started to draft project evaluation questions.

- *Milestone 1C: Provide opportunities to involve COLDEX students, postdocs, and faculty in formal and informal K-12 outreach.*
    - Rahilly regularly encourages involvement in national K-12 classroom outreach organizations. During the current reporting period, she has engaged early career researchers (ECRs) and COLDEX faculty in online and in-person outreach through Upward Bound (in February report), and with the online ANSEP outreach program.
    - Rahilly is also exploring the possibility of developing and/or sharing opportunities for synchronous and asynchronous pedagogical training for COLDEX participants interested in formal or informal educational outreach. She regularly shares all opportunities to be involved in outreach with ECRs specifically, as well as COLDEX faculty, through the COLDEX Slack workspace and personalized invitations. She is currently evaluating the possibility of holding inclusive pedagogy training in the fall.

Objective 2: Develop the next generation of ice core and climate scientists.

- *Milestone 2A: Develop and implement a new Research Experiences for Undergraduates (REU) program that engages a diverse group of undergraduate students in COLDEX sponsored research projects, advertising widely across listservs, at conferences, and through School of Ice alumni at Minority Serving Institutions with target applicant pool that has at least the same percentage of students from historically minoritized identities as national baseline.*
    - We recruited a diverse group of potential undergraduate student participants from COLDEX and non-COLDEX institutions. We received a total of 180 student applicants for the 2023 REU program: 60% female, 46% non-white racial identity, 5% community college students, 10% first generation.
    - Rahilly created an REU website with an FAQ section and ran open office hours every Tuesday during December and January to help make the application process

inclusive. She also recruited REU students through an REU workshop on December 7 and at the American Geophysical Union meeting in December, the Geological Society of America meeting in October, and the National Diversity in STEM meeting in October hosted by the Society for Advancement of Chicanos/Hispanics and Native Americans in Science

- We requested and received an REU supplement from NSF, allowing us to place 12 REU students instead of the 7 initially budgeted.
- Our goal was to support at least seven REU students per year at COLDEX institutions, with at least 50% of participant students from historically marginalized identities in polar science. Undergraduate research student Melyssa Fenton is analyzing data from our recruitment process. 6 of the 12 selected students (50%) have identities that have been historically marginalized in STEM, and 8 students (75%) identify as female or female/non-binary. 2 students (17%) are community college students, and 3 students (25%) were previously associated with COLDEX through the 2022 pilot REU program (only 1 of these three students received part-time funding).
- A virtual pre-REU orientation was held online June 7-8, 2023. We chose this format in order to be more inclusive, making it more accessible to REU students with caregiving responsibilities.
- To support a strong REU community, we have created a schedule of remote workshops, and Rahilly created a COLDEX REU handbook, which contains information about fun activities as well as local safety/well-being resources for each host institution.
- Weekly remote workshops are built around the National Association of College and Employers (NACE) Career Competencies map. Each week, students will meet to reflect on the career competencies they are building throughout the REU and to learn skills such as giving scientific talks, presenting posters, collaboration, communicating science, and formulating research questions.
- REU students will present their research at the COLDEX Annual Meeting in September, and they will give “mini-talks” for the August monthly COLDEX seminar.
- To grow our network of COLDEX REU alumni, we have an active Slack channel with new REU students added, continuously updated at least a few times a week with internal and external opportunities for both present and former undergrads/postbaccs.
- We are actively developing a cohort of science mentors involved in the REU program with continual mentor training and collaborative problem-solving objectives throughout the life of the REU. Nearly all mentors attended the GEO REU network-hosted “inclusive mentor” training at the end of April. The recording was shared with those that couldn’t attend. Rahilly is also communicating with mentors on a dedicated Slack channel to ensure they know what to expect in terms of products (for instance, the mentoring agreements that students will fill out with them).

- *Milestone 2B: Create graduate student and postdoc positions at individual COLDEX institutions, successfully recruit and mentor students and postdocs, particularly from underrepresented groups.*
    - We continue to recruit graduate students and postdocs to individual institutions within the Center. Rahilly and Christo Buizert held online office hours in winter 2022-23 for prospective graduate students.
    - We are providing opportunities for graduate students and postdocs to increase mentoring and teaching experience through mentoring of REU students, involvement in delivery of SOI and Project Ice curriculum, and connection to outreach opportunities with K-12 students. For example, all six COLDEX ECRs who attemded the site visit have also been invited to talk to the Project Ice participants in person on Tuesday afternoon.
    - The COLDEX ECR community was notably strengthened by the in-person May workshops (ICECReW, open science meeting, COLDEX short course).
    - We are highlighting academic and non-academic career paths in the polar science community in and outside of COLDEX. We will be holding a career panel in July for the REU program that will be co-advertised to the ECR community. Meredith Hastings will also have a career panel in her leadership workshop in September (see Milestone 2C). The PSECCO-COLDEX sponsored alternate career paths database should be launching soon. COLDEXers provided about half of the potential contacts for that database.
    - Our goal is to monitor successful mentoring of graduate students and postdocs through annual surveys centered on research mentorship experiences including cultural diversity awareness of research mentors, and through annual tracking of student and postdoc field deployments, paper authorship (through self-reporting on individual development plans), and graduation rates. Rahilly is working with evaluator Joon Park to create an evaluation for COLDEX ECRs to share their experiences with mentorship, etc.

- *Milestone 2C: Create and implement a leadership and career development workshop program for early career scientists, open to participants from COLDEX institutions and outside groups, advertised widely including within the Association of Early Career Polar Scientists, Ice Core Young Scientists, and other similar groups.*
    - We aim to develop and implement annual workshops to train participants in leadership, mentoring, and team building. A draft agenda has been completed for the upcoming annual workshop to take place at OSU in September 2023, in conjunction with the COLDEX Annual Meeting. Meredith Hastings at Brown is leading this effort.
    - In the next reporting period, the workshop plan will be advertised and an application will be released with a pre-developed rubric.
    - A total of 30 workshop participants will be sponsored to attend each year, with a goal of 15 participants from within COLDEX and 15 from the broader Earth science community.
    - Hastings is also engaging leadership of other polar science early career to optimize delivery and planning of workshops in context of other related activities nationally

and internationally. Hastings is in contact with the Polar Science Early Career Community Office (PSECCO) to learn about their recent Polar Postdoctoral Leadership Workshop, including feedback from participants on the content and overall scoping of the workshop.

- *Milestone 2D: Develop and maintain an inclusive student/postdoc culture that promotes participation in COLDEX activities.*
    - Rahilly works to maintain an active early career researcher group within COLDEX. The COLDEX ECR community is growing, with monthly meetings based on both logistics and research. Spring 2023 monthly meetings have been well-attended, with participation increasing after the May Ice Core Open Science Meeting and COLDEX Short Course.
    - An ECR Committee helps plan activities and ensures that the ECRs have a voice in COLDEX. Committee members serve a term of 1 year. The newest committee consists of Jenn Campos Ayala, Megan Kerr, Demie Huffman, Julia Marks Peterson
    - We have developed a formal reporting mechanism, via a web portal to provide a safe space for students and postdocs to voice concerns (see Diversity section of this report).
    - Rahilly has developed a Professional Development Plan (PDP) and is working with COLDEX postdocs and graduate students to fill them out with their mentors.
    - Two COLDEX graduate students will be participating as panelists in an upcoming US Association of Polar Early Career Scientists webinar on July 20. The webinar focuses on science communication with social and traditional media sources and will feature PhD student Cate Bruns (UMN) and PhD student Austin Carter (UCSD).
    - COLDEX short course held on Whidbey Island, WA May 10 - 12, 2023 included 16 COLDEX early career researchers and 7 early career scientists who were not previously involved in center activities. The 7 external ECRs have been added to COLDEX as affiliate members, and several have been engaging in regular COLDEX meetings.

- *Milestone 2E: Provide scholarship funds for graduate student and postdoc research related to COLDEX goals (at COLDEX and non-COLDEX institutions).* We distribute an annual call for proposals to graduate students and postdocs within and outside of COLDEX to propose innovative research projects or international collaborations that further COLDEX objectives.
    - COLDEX ECR scholarships have been widely advertised through the COLDEX network, Cryolist, Hercules Dome listserv, IDP listserv, and on the PSECCO and Polar Impact Slack workspaces.
    - To date we have received 9 applications (including from undergraduates) and have distributed $20,713 in funds so far. Four applicants were internal to COLDEX, and 5 were external.

Objective 3: Evaluate all COLDEX educational programs.

- *Milestone 3A: Create and implement an evaluation framework allowing for summative and formative feedback.*
    - Initial evaluation framework developed with Jana Bouwma-Gearhart based on an interactive, data-driven, program improvement design in summer 2022. Rahilly is meeting with postdoc Joon Park, who will be conducting COLDEX evaluations under the supervision of Bouwma-Gearhart, on a weekly basis to discuss evaluation goals and timelines. They are working on developing a detailed evaluation plan for ECR and REU student experiences in COLDEX.

3. Integrating research and education.

Below, we detail the ways in which we are facilitating the integration of research and education activities at COLDEX.

- Facilitate a COLDEX Research Experience for Undergraduates (REU) program that engages COLDEX faculty, staff, postdocs, and students as research mentors on COLDEX-related research projects
    - Research mentors proposed projects for students in November - December 2022. Research projects for the summer 2023 cohort involve work in ice exploration, ice modeling, and ice analysis across 6 COLDEX institutions: University of Washington, Oregon State University, University of California, Irvine, University of California, San Diego/Scripps Institution of Oceanography, the University of Texas at Austin, and the University of Maine.
    - Mentors are 12 faculty/staff and 9 early career researchers (graduate students and postdocs). COLDEX Early Career Researchers are designated as co-mentors with faculty.
    - REU students will attend an online orientation during the week of June 5 to learn about the overall COLDEX mission as well as the benefits and opportunities of being part of an STC. Ed Brook and Danielle Whittaker will join the orientation schedule to discuss these issues. Students will also be attending a seminar on research ethics and colonialism in geoscience hosted by the GEO REU network.
    - The summer professional development workshop series offers numerous opportunities for COLDEX faculty, postdocs, and graduate students to share their research and professional journeys with students. Specifically, there will be three sessions that will result in larger incorporation of the COLDEX network into the REU program: a session on informational interviews with COLDEX, a career panel including COLDEX and non-COLDEX researchers, and a graduate school Q&A session featuring COLDEX graduate students.
    - COLDEX REU students are expected to come to the monthly all-COLDEX seminars and are encouraged to attend at least one pillar monthly meeting. REU

students are also expected to present their research at the COLDEX annual meeting in September.

- Support and acknowledge early career researcher success in research
    - Recent first-author publications by Lindsey Davidge (PhD student at University of Washington), Julia Andreasen (PhD student at University of Minnesota), Kaden Martin (PhD student at Oregon State University), Olivia Williams (PhD student at Oregon State University), and Abby Hudak (PhD student at Oregon State University) were celebrated on the COLDEX Slack workspace.
    - 9 COLDEX graduate students and postdocs were first author presenters at the International Partnerships in Ice Core Science (IPICS) meeting in October 2022.
    - 12 COLDEX graduate students, postdocs, and undergraduates were first author presenters at the American Geophysical Union 2022 Fall Meeting.
    - 20 COLDEX graduate students, postdocs, and undergraduates were first author presenters at the Ice Core Open Science Meeting in May 2023.
- Incorporate COLDEX faculty, staff, and early career researchers in Project Ice workshop
    - Activities, field trips, lectures, and lab tours included COLDEX faculty members Edward Brook (OSU), Christo Buizert (OSU), T.J. Fudge (UW), Kristen Rahilly (OSU), COLDEX ECR participants Julia Marks Peterson (OSU), Megan Kerr (UT Austin), Demie Huffman (UMN), Jenn Campos-Ayala (UC Irvine), and Ellen Mutter (Amherst College).
    - Kristen Rahilly authored two modules for Project Ice, heavily incorporating COLDEX science and field objectives.
    - Project Ice participants are being provided with pre-reading that heavily incorporates COLDEX research, such as the *Physics Today* article featuring COLDEX and other oldest ice research teams “Scientists drill for oldest ice to reveal secrets about Earth’s climate”
    - Project Ice pre and post cognate test includes numerous questions about the COLDEX scientific mission and oldest ice site selection.

3. Highlighted internal education activities.

COLDEX Oldest Ice Short Course

- Led by: **Ed Brook, Michael Bender, John Goodge, Nick Holschuh, Michelle Koutnik, Peter Neff, Heidi Roop, Sarah Shackleton, Kristin Timm, and Duncan Young**
- Intended Audience: **Early Career Researchers (primarily graduate students and postdoctoral researchers)**
- Number of Attendees: **23**

The COLDEX Oldest Ice Short Course was held directly after the Ice Core Open Science Meeting from May 10 - 12, 2023 on Whidbey Island, WA. A total of 23 early career researcher participants joined the course: 15 were COLDEX graduate students or postdocs, 1 participant was a COLDEX researcher new to ice core science, and 7 participants were new to center activities. The major learning objectives centered on the COLDEX science mission with a

specific focus on exploration and modeling topics. The final activity was an interactive group activity that allowed students to examine measured and modeled Antarctic ice sheet characteristics in order to determine the location they would select as a potential oldest ice site. Additionally, two interactive sessions on science communication were led by Director for Knowledge Transfer Heidi Roop and guest instructor Dr. Kristin Timm (University of Alaska Fairbanks). The science communication sessions focused on the roles scientists play as communicators and effective intercultural communication.

Preliminary evaluation results (19/23 respondents) show that 18/19 respondents strongly agreed (1 somewhat agreed) that the short course was a safe environment for learning and 16/19 strongly agreed (3 somewhat agreed) that the short course was a welcoming environment for learning. All learning objectives resulted in overall growth in participant learning and 15/19 respondents strongly agreed that the course positively benefited them as researchers (4/19 somewhat agreed). Areas for improvement for the iteration in Year 3 include reaching more racially and ethnically diverse participants (13/19 participants identified as white) and the potential to move the course to the time right before the COLDEX annual meeting so that participants can continue to engage with the wider COLDEX community after the course.

Project Ice

- Led by: **American Meteorological Society staff**
- Intended Audience: **K-12 teachers**
- Number of Attendees: **12 (pilot program, Year 2)**

The pilot of the new Project Ice program ran from June 7 - June 30, 2023. The online component of the graduate course ran through a learning management system out of PennWest University (beginning June 7 - the week of June 19). The in-person workshop was run at Oregon State University from June 26 - June 30. Over the online and in-person components, participants covered the content from four modules: “Understanding the Polar Regions”, “Ice Core Science and Engineering”, “Land Ice, Sea Ice, Grounded Ice, and Impacts on Sea Level Rise” and “Ice Core Science and Paleoclimatology.” During the in-person week, participants used hands-on, inquiry based activities to learn more about ice and ice core properties. Participants analyzed ice in the OSU Ice Core Laboratory, toured the OSU Marine and Geology Repository, and met with numerous COLDEXers (see milestone 1B and section 3).

Research Experience for Undergraduates (REU) Program

- Led by: COLDEX, Kristen Rahilly
- Intended Audience: COLDEX undergraduates
- Number of attendees: 6.5 (year 1), 12 (year 2)

The COLDEX REU program ran in pilot form in Year 1 (Summer 2022), with students working in their home institutions. As part of this program, a weekly virtual professional development workshop was held, open to any interested undergraduates at COLDEX institutions. We had 6 students receive a stipend by COLDEX during the summer, 1 student receive a partial stipend, and approximately 3 - 5 students that joined the open weekly professional development

workshops. Out of these students, 3 students will be beginning PhD programs in ice core science in Fall 2023. One student has been awarded a COLDEX Scholarship to continue her work in the lab of Dr. Sarah Aarons for her senior thesis project in 2023-2024. One student attended our COLDEX Oldest Ice Science Short Course. Three students that participated in the weekly workshop series last summer are now joining the 2023 COLDEX REU cohort.

The COLDEX REU program has been fully launched during Year 2. Projects were proposed by research mentors in November 2022, students applied to the program from December 1 - February 1, 2023, and a selection committee of 5 COLDEX participants selected the top applicants using a rubric that centered on which students would receive the greatest positive impact from participation in the program. The weekly professional development workshop series will run from June 14 - August 16, 2023 with a virtual orientation from June 7 - 8. All REU students will present progress in short talks during the all-COLDEX seminar on August 7 and will present posters during the COLDEX Annual Meeting in September, 2023.

4. Highlighted professional development activities.

ECR Leadership and Career Development Workshop

- Led by: **Meredith Hastings**
- Intended Audience: **Early Career Researchers from within and beyond COLDEX**
- Number of Attendees: **30**

The Early Career Researcher Leadership and Career Development workshop will be run for the first time within COLDEX from September 8 - 9, 2023. The workshop will be directly after the COLDEX annual meeting, allowing for connections made at the meeting to further develop as well as to encourage workshop participants new to the center to attend the annual meeting as well. The audience for the workshop will be senior PhD students, postdocs, and early career faculty. Meredith Hastings, President of the Earth Science Women's Network and co-PI of the ADVANCEGeo program, will be facilitating the workshop alongside Chris Olex, an expert speaker and trainer in personal, leadership, and team development. The workshop will also include a career panel with a variety of academic and non-academic career paths represented.

5. Highlighted external education activities.

Activity name	**Target Audience**	**# of participants/ people reached**	**Learning goals and outcomes (if appropriate)**
ANSEP Insight Session	ANSEP 6 - 8th grade students online	40	Learn from COLDEX Scientist (Maciej Sliwinski) about career path, scientific journey, and scientific job

ANSEP Discovery Lesson	ANSEP 6 - 8th grade students online	40	Describe how an ice core is formed from winter and summer snow layers, with volcanic ash layers interspersed Calculate the age of the oldest layer of ice in an ice core Analyze different ways to get older ice layers closer to the surface
OSU SMILE Days Presentations	Middle and high school students from around Oregon	150	Describe how an ice core is formed from winter and summer snow layers, with volcanic ash layers interspersed Calculate the age of the oldest layer of ice in an ice core Describe science mission of COLDEX
Science careers Zoom chat with SOI faculty alum students at Chemeketa CC	STEM college students at Chemeketa Community College	20	Learn about interdisciplinary science Learn about different career paths Learn about COLDEX and other REU opportunities
Classroom visit with Chemeketa CC SOI alum Shannon Othus-Gault	Geoscience college students at Chemeketa Community College	23	Identify the importance of the mid-Pleistocene Transition Evaluate the COLDEX scientific mission using paleoclimate data Learn about COLDEX and other REU opportunities
Workshop: How to find and apply for undergraduate science research experiences (in collaboration with IMOD STC and U. Washington Molecular Engineering Materials Center and U. Washington Clean Energy Institute	Undergraduates	16	Intro to COLDEX, IMOD, MEMC, and CEI REU programs How to look for potential REU programs Why to do undergraduate research How to apply
Seminar given about COLDEX and REU program with Sacramento City College (hosted by SOI alum V. Nana Ngassam)	Undergraduates at Sacramento City College	100	Intro to COLDEX science and the COLDEX REU program, overview of REU programs in general and where to search for opportunities.
COLDEX REU open office hours (offered every Tuesday in Dec and Jan)	Undergraduates interested in COLDEX REU	5	Answer questions about COLDEX REU and application (Kristen Rahilly)

COLDEX REU graduate student open office hour	Prospective COLDEX graduate students	12	Answer questions about COLDEX graduate work and COLDEX science (with Christo Buizert and Kristen Rahilly)
Upward Bound/TRiO outreach	High school students visiting OSU from South Albany HS	35	Lead students on tour of ice core lab and freezer (Julia Marks Peterson) Hands on activity: creating an ice core model and counting ice layers (Rahilly) Host hybrid student panel with COLDEX grads focusing on working in Antarctica (Marks Peterson, Martin, Carter, Shaya, Kirkpatrick)
Mentorship of Chicago high school students working with School of Ice alum Allison Hennings (“RISE” program)	Students from Illinois Mathematics and Science Academy and Oak Park River Forest High School	5	Research mentorship from 4 COLDEXers: Kaden Martin, Liam Kirkpatrick, Skyler Jacob, Kristen Rahilly
REU Lightning Session presentation during Geological Society of America fall meeting	Undergraduates attending the Geological Society of America meeting	40	Give brief overview of COLDEX REU program Answer questions from interested undergrads Network with other REU program managers

6. Problems encountered and anticipated.

No major problems were encountered in this reporting period.

7. Educational plans for next reporting period.

During COLDEX Year 3, educational programming will continue as described in the strategic plan. Notably, all of our educational programming will be running in full during Year 3. This includes a full REU cohort, Project Ice, and School of Ice running in summer 2024. We will also hold a COLDEX short course and leadership and career development workshop during Year 3. If the NSF GEOPAths proposal is funded, initial recruiting of the cohort of fellows from Elizabeth City State University will begin in January 2024.

IV. Knowledge Transfer

1. Center's overall knowledge transfer goals.

The Center has defined three Optimal Outcomes in the Knowledge Transfer section of the Strategic Plan.

1. New partnerships, collaborations, and mentoring relationships are to be established across the COLDEX team, including across and within participating institutions, participant career stages, and disciplinary expertise.
2. New partnerships, collaborations, and knowledge exchange opportunities are to be established between the COLDEX team, other researchers, and industry partners.
3. COLDEX will successfully leverage our disciplinary expertise and perspectives, knowledge transfer, education, and evaluation approaches to deepen public engagement in Earth and climate sciences.

2. Strategic plan objectives and progress towards milestones.

Objective 1. Expand and facilitate connections across the current network of those who engage with COLDEX research, education, and knowledge transfer activities.

- *Milestone 1A: Conduct and maintain network mapping research and social network analysis of COLDEX participants over the duration of the Center.*
    - We have distributed a biannual survey (Fall 2022 and Spring 2023) to internal COLDEX members to collect key knowledge transfer activities. A PhD candidate is taking the lead on analyzing these data.
    - Using the data from this survey, we generated an initial COLDEX knowledge network map which we have shared with COLDEX members. With the updated data that we are analyzing from the Spring 2023 survey, we are tracking network growth, and will continue to track growth with future surveys.
    - Moving forward, we will use data from this network map to identify target areas for establishing new connections among members.

- *Milestone 1B: Establish mutual working relationships with contacts from government, industry, non-profit, and for-profit sectors. Build a collective culture of knowledge sharing and exchange across the COLDEX network.*
    - We identified 10 key voices in polar science journalism and distributed invitations to participate in a media training event at the Ice Core Community Science Meeting
    - We invited 11 journalist experts to participate in a Climate Journalism Workshop at the U.S. Ice Core Open Science Meeting in May 2023, where they received training in how to integrate Antarctica and sea level rise in climate reporting, established relationships with earth and climate scientists, and connected with community

members and decision-makers being directly affected by the impacts of sea level rise.
    - We established a new volunteer-based partnership with Media and Climate Change Observatory.
    - We continue to engage state, federal and media stakeholders to inform about COLDEX and collect input on application, opportunities for amplification and shared learning/knowledge exchange.
    - We conducted an Audience Engagement survey to help us understand current COLDEX stakeholders and knowledge needs and opportunities to fill those gaps.
    - Ed Brook and Christo Buizert have been working with Aerodyne Research on developing a COLDEX methane analyzer. Collaborations like this one provide opportunities for the application of new technology and analytical and research advancements developed by COLDEX.

- *Milestone 1C: Establish a protocol for addressing external COLDEX inquiries and related communication and knowledge needs.*
    - We developed a Communication Support Request Form to direct COLDEX participants' requests for support for communication or engagement-related inquiries. This form is available on the COLDEX member website and linked in the COLDEX member handbook.
    - We developed a Media and Press Request Workflow to guide COLDEX participants' communication with COLDEX leadership and KT team upon engaging with the media. This guide is available on the COLDEX member website and linked in the COLDEX member handbook.

- *Milestone 1D: Lead and contribute each year to sessions and presentations at professional society gatherings (e.g., workshops, meetings, town halls, webinars) to share COLDEX approaches and outcomes related to our research, education, knowledge transfer, diversity, equity and inclusion activities, and key findings.*
    - The Knowledge Transfer team contributed to a presentation at the EGU General Assembly and represented COLDEX in three AGU presentations across three divisions: Union Session, Science and Society, and Education.
    - We hosted a dedicated journalist climate communication training workshop at the Ice Core Community Meeting in partnership with the Hercules Dome Ice Core Project (see Milestone 1B). This included participation of several COLDEX and non-COLDEX scientists from across disciplines.
    - Ed Brook and other COLDEX researchers collaborated with the Hercules Dome group and others on proposing an AGU 2023 ice core session.
    - Ed Brook opened discussions with leaders of Beyond EPICA-Oldest Ice (BE-OI) group about collaborating on special sessions at major conferences. COLDEX has agreed to collaborate with BE-OI on major old-ice related session at 2024 EGU meeting in Vienna.
    - Brook agreed to participate in IDP Town Hall on Scientific Drilling in the Polar Regions at AGU 2023.

- *Milestone 1E: Develop monthly remote seminar series with internal and external speakers from diverse research fields and practice areas, made available to collaborators and colleagues outside of COLDEX.*
    - We maintain a monthly speaker schedule and regularly solicit suggestions from COLDEX members for new speakers. Speakers during this reporting period include:
        - Dr. Joe MacGreagor (NASA): AntArchitecture: A SCAR Action Group mapping the age structure of the Antarctic ice sheet to clarify its stability
        - Dr. Ed Gasson (University of Exeter): The Antarctic Ice Sheet past and future: using paleoclimate data to constrain future sea level rise
        - Dr. Masanobu Yamamoto (Hokkaido University): Reconstruction of atmospheric CO2 concentration over the past 1.5 million years based on leaf wax (long-chain n-fatty acid) carbon isotope record from the Bay of Bengal.
        - Dr. Meredith Nash (Australian National University): Building diversity, belonging, inclusion, and equity in remote polar field environments
        - Dr. Ralph Harvey (Case Western Reserve University): Meteorite Concentrations and Old Ice: "in a relationship" or "it's complicated"?
        - Dr. Alan Haywood (University of Leeds): The Pliocene Model Intercomparison Project: Scientific Results and the Way Ahead
        - COLDEX Researchers: Initial findings from the first COLDEX field season
        - Dr. Carlo Barbante (University Ca'Foscari Venice): Beyond EPICA – Oldest IceCore: The European Effort to Obtain A 1.5 Myr Greenhouse Gas – Climate Feedback Record from an Ice Core in East Antarctica.
        - Dr. Kenji Kawamura (National Institute of Polar Research), title TBA
        - Presentations by COLDEX Research Experiences for Undergraduates (REU) 2023 Participants

Objective 2. Support effective, consistent communication of polar and climate-related knowledge to diverse audiences.

- *Milestone 2A: Develop and execute a Center-wide strategic communications plan with priority external audiences reviewed and updated annually.*
    - Our Knowledge Transfer team developed a Strategic Communication Plan, which is available on the COLDEX website. The team presented this plan to COLDEX participants during the January 2023 All-Hands Meeting for feedback and to raise awareness of plan, priorities, and action steps.
    - Our Knowledge Transfer team submitted environmental communication research to a peer-reviewed journal and is preparing a publication for peer-review to share both our social network results and the results of our Antarctic media analysis.
    - The COLDEX social media presence is being co-managed with content being posted regularly about a range of COLDEX activities from student opportunities to research summaries/videos. Our Twitter following grew substantially during the first field season to nearly 8,000 followers. We also created and published coordinated Twitter content during AGU to amplify our reach to AGU membership and showcase early

career researchers. Peter Neff has continued to share about COLDEX work and media events through personal @icy_pete accounts with a wide following (~ 250k followers across platforms).
    - The Managing Director maintains an up-to-date website suitable for internal and external COLDEX audiences. During this reporting period, we added a blog where we posted weekly updates from Peter Neff about our field teams in Antarctica as well as posts by graduate students.
    - We created a biannual, public newsletter that we use to share information about COLDEX research and education efforts. We also used this platform to publish weekly updates from our field teams during the 2022-23 Antarctic field season.
    - The Knowledge Transfer team is working with the COLDEX Director of Education & Leadership to share ideas for how to engage incoming REU cohort in communication best practices and COLDEX storytelling. The REU students will be creating a number of communication products throughout the summer to showcase their learning. These will be placed on an Arc StoryMap that will be shared across the internal COLDEX network. Students will also join the GEO REU network in a workshop about social media communication.
    - The Knowledge Transfer team identified four primary audiences for our strategic communications efforts. These audiences were identified through dialogue and a formal audience engagement survey which assessed the current reach, assets and interests across the COLDEX member participants.
    - Director for Knowledge Transfer Heidi Roop has been leading the cultivation of a relationship with CBS News national Climate Desk to do dedicated long-format storytelling across at least 5 outlets nationally about COLDEX. Video recording at Princeton and the Ice Core Community meeting took place in April and May 2023 and we are actively working with NSF on the potential to bring a team of three from CBS to develop this long format story (now in process for ‘24-’25 field season).

Objective 3. Expand expertise of COLDEX participants on applied climate science, science communication best practices and actionable science.

- *Milestone 3A: Provide annual professional development opportunities for Center participants to engage with applied scientists, practitioners, and communication professionals.*
    - Roop designed and facilitated the Climate Journalism Workshop at U.S. Ice Core Open Science Meeting, where Center participants were invited to build connections and share their research with 11 journalist attendees (see Milestone 1B).
    - Roop designed and led Early Career Researcher communication training for the COLDEX Oldest Ice Short Course in May 2023 (see Education section of this report for more details), which included science communication best practices and a focus on intercultural science communication. Roop brought a facilitator, Kristin Timm (University of Alaska Fairbanks) to focus on culturally competent science communication, based on the top learning need articulated in the COLDEX audience engagement survey distributed in September 2022.

    - Peter Neff shared the realities of Antarctic science and fieldwork within the US Antarctic Program with COLDEX students at the Oldest Ice Short Course This is a foundation of understanding of Antarctic science logistics and realities that grad students do not typically receive, but may learn after many years of Antarctic work.
    - Graduate student Cate Bruns provided science communication training to early career students and REU cohort during the annual meeting and in a virtual engagement, including a panel discussion on science communication.

- *Milestone 3B: Create communication materials and assets to increase COLDEX Center participants' knowledge of COLDEX-related climate, education, knowledge transfer and other key research approaches and findings.*
    - A summer REU student worked to create a suite of communication assets to share with different audiences. These assets are now on the COLDEX shared drive including Twitter templates, postcards, slides, letterhead, policy brief, etc.
    - More outreach materials have been created specifically related to the COLDEX mission and these can be written up into lesson plans and shared as resources.
    - Dedicated Twitter materials and templates were created by Roop and UMN graduate student Demie Huffman to showcase COLDEX research and activities throughout the AGU Fall Meeting

- *Milestone 3C: Support development of a graduate student cohort with experience in multidisciplinary research and provide consistent engagement of social and communications-focused graduate students in all COLDEX activities, including field work.*
    - Roop designed and led Early Career Researcher communication training for the COLDEX May short course which included science communication best practices and a focus on intercultural science communication (see Milestone 3A).
    - Roop mentored and supported 2 PhD students at the University of Minnesota who are working directly on interdisciplinary COLDEX research. Both KT graduate students are heavily involved in the COLDEX ECR community and in COLDEX: one is just now "retiring" from the ECR Committee and the other is just beginning on the ECR Committee. Both students typically attend the KT, Education, and DEI monthly meetings. One COLDEX ECR Scholarship has been awarded to a KT graduate student.
    - Graduate student Cate Bruns provided science communication training to early career students and REU cohort during the annual meeting and in a virtual engagement, including a panel discussion on science communication.

3. Knowledge transfer highlights.

- **We developed and adopted, after engagement across COLDEX, a center-wide Strategic Communication Plan.** This 'living plan' will guide communication and engagement efforts and will be updated annually.
- **We continue to implement an innovative, data-driven approach for Knowledge Transfer efforts**. COLDEX sees Knowledge Transfer as having two critical dimensions that

are important to our overall success in achieving our goals as a Center including **external** and **internal** knowledge transfer:

- Our ***external engagement and knowledge transfer efforts and research*** have provided critical insights into needs and tools for more effectively communicating about Antarctica and climate change in the U.S. national news discourse and enabled us to connect with and develop relationships with a range of diverse journalists from tribal news outlets to large national news desks.
    - COLDEX participants have shared their work in a range of outlets from scientific conferences, through expert testimony to the State legislatures and through substantial media engagement. Between September 2023 and January 2023 COLDEX benefitted from coverage across a range of national and international news outlets, print, radio, TV, social media outlets. Coverage spiked at key milestones in the project, such as the launch of field season. Social media posts through COLDEX's channels and science team also amplified media reach.
    - Key media engagement takeaways:
        - COLDEX is estimated to have reached over 1 million listeners through radio outlets in Year 2
        - TV outlets across the United States covered COLDEX, with Oregon and California having the most mentions. The estimated audience reach for national television is 63,000 viewers.
        - Dozens of print and online media outlets covered COLDEX research and researchers, including The Weather Channel, Physics Today, Scientific American, BBC, Insider, National Public Radio, The New York Times, CBS News, and The Hill.
        - COLDEX received 204 media mentions ranging from institutions (Dartmouth), to major media outlets (Chicago Tribune, Yahoo News).
        - SpaceX's Starlink satellite dish that gave scientists unprecedented connectivity generated viral social media activity after Elon Musk himself Tweeted about the project.
        - By the end of the field season, COLDEX's Twitter following exceeded 7,500 followers, up from around 200 prior to the start of the field season.
        - PhD student Austin Carter (Scripps) grew a considerable following on TikTok, posting videos of COLDEX fieldwork live from Allan Hills, Antarctica using Starlink. Individual videos have up to 21 million views. Austin's personal account gained ~60,000 followers through the field season.
- Given the geographic and disciplinary breadth of the Center, ***internal knowledge transfer and exchange*** are also essential to our overall success. The opportunity and imperative of a Science and Technology Center is to bring together diverse experts to respond to, and innovate, across fields and disciplines and to develop new, critical scientific knowledge. COLDEX's mixed methods approach to social network analysis provides valuable insights into the state of Center-wide integration,

cross-Center interactions, mentorship and connectivity of early career researchers, and information about the efficacy and impact of different Center activities intended to connect, train and broaden participation and retention of researchers within the Center. **Our surveys and focus groups are providing actionable insights to improve our activities including our early career researcher training and education efforts and activities intended to share knowledge across the Center.** This internal, research-centered approach to internal knowledge transfer not only improves our Center's interactions but also informs the field of team science. Work from these early efforts will be in peer-review by the end of Year 2.

- **In Year 2, the Knowledge Transfer team supported a range of early career training and other professional development**, including science communication training related to intercultural communication, working with journalists, and developing one's identity as a science communicator as well as ways to set goals and metrics for science communication activities. We also hosted journalists for a dedicated climate change reporting training that was underpinned by our Antarctic media analysis research that was completed in partnership with the Hercules Dome Ice Core Project. This journalism workshop also included interaction with practitioners and community members experiencing and responding to the impacts of sea level rise and climate change. This type of activity helps build strong connections between science in Antarctica and the real-life impacts that stem from Antarctica.

4. Problems encountered and anticipated.

- The Knowledge Transfer pillar of the Center lacks needed capacity and resources to advance and support the broader research, reach and impact of COLDEX. Dedicated capacity for implementation is needed to achieve the goals of the Center-wide Strategic Plan, the Strategic Communications Plan and to respond to requests from across the Center, as well as be responsive to the recommendations from the COLDEX Advisory Committee. Current dedicated capacity for Knowledge Transfer coordination and implementation is limited to 12.5% FTE for faculty per year (spread across two faculty members) and 1.5 FTE of graduate student support to advance the evaluation and Knowledge Transfer research agenda. Year 3 faculty effort will be substantially less at a combined 6.25% FTE. As recognized by the Advisory Committee and past NSF reviews, a plan for identifying additional resources and/or staff capacity is needed to more effectively support COLDEX Knowledge Transfer efforts and implementation priorities.
- There have been challenges for early career researchers and their sense of belonging within the Center, especially for those working in different research disciplines that are not earth science or geophysics-related research.

5. Plans for next reporting period.

Year 3 efforts will support continued progress on the internal and external Knowledge Transfer research, training and engagement efforts in alignment with the Strategic Communications Plan. This will include continued dedicated media and practitioner engagement, working with elected and industry leaders, research communities, and participation in the Center's various activities,

gatherings, and regularly recurring Executive Committee and community meetings. We will continue our media analysis and workshop evaluation efforts for more effectively engaging the media in effective Antarctic news coverage and will continue to distribute and analyze our network development and engagement needs through our regular social network and audience engagement surveys, as well as our newly established media and communications tracking workflows. As effort allows, some work will likely focus on trying to identify and secure additional resources for Knowledge Transfer implementation efforts through potential grants and donor engagement.

V. EXTERNAL PARTNERSHIPS

1. Center's overall goals for developing external partnerships.

COLDEX aims to form external partnerships with other organizations that will broaden our impact and contribute to our research, education, and diversity goals.

2. Strategic plan objectives and progress towards milestones.

Although External Partnerships is not a specific section of our Strategic Plan, we do point to plans to form such partnerships, most notably in the Diversity section where we discuss plans to partner with Minority Serving Institutions, as well as collaborating with the Hercules Dome ice coring project. As the Center progresses, we are tracking the activities resulting from external partnerships, including student recruitment, publications, presentations, grant proposals, and educational activities, as part of our overall outcomes. In the section below, we highlight progress in forming and maintaining such partnerships.

3. Partnership activities.

Activity: Broadening participation in polar sciences
Organization(s) involved: Earth Science Women's Network, Inspiring Girls Expeditions, Polar Science Early Career Community Office (PSECCO), US Association of Polar Early Career Scientists (USAPECS), Interagency Arctic Research Policy Committee (IARPC)

COLDEX's connection to Earth Science Women's Network is through COLDEX participant Meredith Hastings at Brown University. Hastings is organizing professional development workshops for early career scientists for COLDEX, which will also be made available to people outside of COLDEX. The first of these workshops will be held in September 2023, in conjunction with the COLDEX Annual Meeting in Corvallis, OR.

Partnership with Inspiring Girls is primarily through COLDEX Director for Diversity, Equity and Inclusion, Erin Pettit, the founder of Inspiring Girls. We anticipate recruiting summer undergraduate students through the inspiring girls alumni network, starting in Fall 2023/Winter 2024.

Formal collaborations with PSECCO, USAPECS, and IARPC began in Year 2 of COLDEX. COLDEX will be joining the IARPC-led mentoring program along with PSECCO and USAPECS. This program is geared towards early career researchers (ECR) and COLDEX will be helping to

recruit faculty mentors as well as sharing the opportunity among the COLDEX ECR group. COLDEX will also host a virtual workshop on grant writing offered through this mentoring program in Spring 2024. COLDEX also collaborated with PSECCO on creating a “non-academic and alternative academic careers profile” for polar science researchers. This will become a soon-to-be published database of polar researchers who followed non-academic career pathways. Director for Education Kristen Rahilly became a USAPECS board member this year. COLDEX PhD students Catherine Bruns and Austin Carter will be involved as panelists in an upcoming USAPECS-hosted webinar on science communication.

Activity: Forming a new partnership with a Minority Supporting Institution
Organization involved: Elizabeth City State University

Working toward our goal of building and strengthening relationships with Minority Serving Institutions (MSIs), we have submitted an NSF GEOPaths proposal led by Kristen Rahilly, Director for Education, in collaboration with Linda Hayden from Elizabeth City State University, an HBCU, entitled “Strengthening the pathway from STEM to polar science through the search for oldest ice and the COLDEX-ECSU Fellowship program.” The proposed two year fellowship will integrate a cohort of 4 graduate student fellows into the broad, multi-institutional network of the Center for Oldest Ice Exploration (COLDEX) as full center participants while working on their degree at Elizabeth City State University (ECSU) as part of the Master of Science in Mathematics program.

Activity: Joint activities and interaction with the broader ice core and climate science community.
Organization(s) involved: U.S. Ice Drilling Program, Hercules Dome Project, Ice Core Working Group, International Partnerships in Ice Core Sciences

- COLDEX Monthly Zoom Seminars open to international groups involved in old ice research (Beyond EPICA-Oldest Ice, Australian Million Year Ice Project).
- Collaboration with Hercules Dome leadership and Juneau Ice Field Project in organizing the second annual US Ice Core Open Science Meeting (May 8-10, 2023, Seattle, WA).
- Collaboration with Hercules Dome project and other US ice core researchers to organize a special session on ice core research at the 2022 American Geophysical Union Meeting (December 2022).
- Collaboration with Hercules Dome project, other US ice core researchers, and Canadian ice core researchers (Alison Criscietello at University of Alberta, Anais Orsi at University of British Columbia and Dorthe Dahl Jensen at University of Manitoba) to bid for sponsorship of the 2026 International Partners in Ice Core Science Conference, to be held in Banff, Canada. The bid is likely to be accepted but formal announcement is pending.

Activity: Working with an industry partner to develop new laboratory equipment
Organization involved: Aerodyne Research

Christo Buizert and Ed Brook (OSU) are working with Aerodyne Research, a private company in Massachusetts, to design a custom laser spectrometer optimized for measuring methane in continuous flow analysis for ice cores. Existing commercial instruments are not optimal for the low flow rates required for ice core analysis, and as a result have slow response times. Aerodyne conducted experiments at their facility that demonstrated a very fast response time and excellent sensitivity, and we are going ahead with the custom instrument they proposed. We expect it will be of great utility to all ice core projects or other applications requiring very low flow rate operations. Delivery has been delayed due to supply chain issues but Aerodyne communicated recently that final assembly and testing is underway. Existing instrumentation (Picarro laser spectrometer) is functioning well and will be available for initial analyses if needed.

We are also working with colleagues at the University of Grenoble who specialize in developing laser spectroscopic instrumentation to rehabilitate another existing semi-custom instrument (SARA optical feedback cavity enhanced adsorption spectrometer) that is capable of fast response times for methane measurement, but is more complex to operate.

4. Problems encountered and anticipated.

In the COLDEX proposal, we described a plan to form a partnership with the Alaska Native Science and Engineering Program (ANSEP) involving recruiting ANSEP students to the COLDEX REU program, which will formally begin in summer 2023. Although we began exploring the possibility of matching an ANSEP student with a COLDEX REU research project for summer 2023, we were not successful in recruiting an ANSEP student for the COLDEX REU this year. We will reach out again during recruitment of the 2024 REU cohort. We did, however, involve COLDEX staff and researchers in two virtual outreach experiences with ANSEP middle school students.

5. Plans for next reporting period.

We will continue to develop recruiting relationships for undergraduate and graduate students through connections formed as part of the proposal process and later developments including School of Ice, Project Ice and the REU program. One potential relationship is with the Chemistry and Chemical Technology Department at Bronx Community College in collaboration with School of Ice alumni Neal Phillip and Paramita Sen, and a second is through the Geology Department at California State University Long Beach in collaboration with Andrea Balbas. We will also explore the development of partnerships with existing programs at our COLDEX Minority Serving Institutions, particularly through the Louis Stokes Alliance for Minority Participation (LSAMP) program at each institution. In Year 2, we have begun relationships through outreach at two School of Ice alumni institutions: Sacramento City College and Chemeketa Community College. We would like to explore further development of these and other relationships with School of Ice alumni institutions.

We also have a number of collaborations with other institutions and organizations that will grow in Year 3 through collaborative sessions at national meetings. We will be co-running a session titled “Broadening Participation in Materials Research and STEM" at the 2024 Materials Research Society Spring Meeting. This session will be run in collaboration with two other Class of 2021 STCs: Center for Integration of Modern Optoelectronic Materials on Demand (IMOD) and Science and Technology for Phosphorous Sustainability Center (STEPS) as well as two large research centers from the University of Washington: the UW Clean Energy Institute and the Molecular Engineering Materials Center (MEMC). We submitted a session proposal for the Fall 2023 Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) National Diversity in STEM conference. The session would be titled “Preparing your Pitch: Tips and Tricks when Talking to Diverse Audiences” and is a collaborative proposal between COLDEX, IMOD, the Byrd Polar and Climate Research Center, the Princeton Plasma Physics Laboratory, and the University of Colorado Boulder. We have also created an outline for a virtual polar-themed research experience for undergraduates program collaboratively run by COLDEX and the Byrd Polar and Climate Research Center, with plans to submit the proposal for funding in Year 3.

VI. DIVERSITY

1. Center's overall diversity goals.

The Center has defined four Optimal Outcomes in the Diversity, Equity, and Inclusion section of the Strategic Plan.

1. Welcoming Community. A COLDEX community that is open and welcoming to people from historically marginalized identities and that is viewed by the polar science community as an example.
2. Inclusive Leadership and Mentoring. Individuals within COLDEX at all career stages will gain leadership skills for safe, equitable, and inclusive team science (in the lab, field, and meetings).
3. Diversity of Polar Science Community. The polar science community will be more diverse, as COLDEX will support career pathways and minimize attrition for students and early career scientists from historically marginalized identities.
4. Communication. COLDEX external communication, especially in education and knowledge transfer, will be sensitive to and challenge the exclusive nature of historical narratives in polar science.

The DEI efforts built into all elements of the center are working directly to contribute to the development of US human resources. Rethinking and acting to change the culture of science internally and the messaging of science externally will work to slowly break down the barriers to entry and advancement in the polar sciences.

2. Strategic plan objectives and progress towards milestones

Below, we list our milestones developed to assess our progress towards each of our Diversity, Equity, and Inclusion objectives, and describe our progress towards these milestones.

Objective 1. Creating a welcoming culture within COLDEX.

- *Milestone 1A: Set expectation of open, welcoming community in all team interactions*. We continuously work towards maintaining an open, welcoming community, and have taken the following actions:
    - Created a consistent time and structure for community and relationship building during meetings. A regular feature of our monthly COLDEX seminars and all-hands meetings is a 5-minute breakout room session, where attendees are randomly assigned to small groups of 2-3 people to share responses to an icebreaker question.
    - Established multiple mechanisms to get feedback from COLDEX participants, including administering a written sense of belonging survey and providing a web-based feedback portal (see more information under Milestone 2B).

- Established community norms and values as part of the COLDEX Integrity and Professional Ethics Plan. We hold informal and formal discussions improving aspects of these (such as field team best practices, co-author guidelines, and data sharing).
- Created a COLDEX Team slide deck, available on the shared Google Drive and posted on the Member Information website, with templates for every member to post a photograph and short biography.
- Regularly provide workshops and discussions related to inclusivity (see more information under milestone 2A).
- Regularly review the onboarding process for new COLDEX members.
- Put significant thought into the structure and presentations at the COLDEX Annual Meeting to role-model inclusive leadership and structure activities to promote inclusive culture. A post-meeting survey was distributed in 2022 and the results will be used to improve the next meeting. A large majority of comments were positive, with the dominant suggestion being to provide a more comprehensive overview of the Center and its activities, a thread we have been following up on at other COLDEX activities, particularly in meetings with the ECR and undergraduate groups.

- *Milestone 1B: Create a COLDEX Equity and Inclusion Committee of 4-6 people across career stages and institutions to provide guidance to the Executive Committee on all equity and inclusion issues*. This milestone was met in summer 2022, with the following actions:
  - DEI Committee members consist of: the Managing Director, Director for Education, and Lead for ECR Professional Development, the DEI Assistant, and rotating members. Rotating committee members will serve a term of 2 years and include at least one ECR.
  - DEI committee nominations for rotating members were solicited from COLDEX membership and the committee was filled in Summer 2022.
  - The first meeting was held in August 2022, at which the committee defined terms of reference and meeting structure.
  - The committee is currently active and meets once a month with specific agenda items.

- *Milestone 1C: Create a COLDEX DEI Ambassador Team to encourage conversations and listening.* Actions are underway to meet this milestone:
  - Goals and actions for the DEI Ambassador Team have been defined. DEI Ambassadors will serve as the DEI advocates for the COLDEX Community. In doing so, the DEI Ambassadors will assist with the DEI elements of COLDEX's mission by elevating DEI goals in conversations, serve as peer mentors for COLDEX community members on DEI topics, and maintain a heightened awareness of what is happening across the COLDEX Community with respect to DEI efforts and DEI goals. These responsibilities occur during all regular COLDEX activities and the DEI Ambassador role is not expected to be a large additional time commitment.
  - Nominations for volunteers to join the COLDEX DEI Ambassador Team were solicited in May 2023.

Objective 2. Provide, and encourage practice of, inclusive leadership skills.

- *Milestone 2A: Develop and implement workshops and seminars to help all participants improve their leadership skills with emphasis on inclusive leadership.* We have conducted several activities to meet this milestone during the last reporting period, including:
    - Workshops offered:
        - Cultural competency workshop, led by Meredith Hastings and Erin Pettit, August 2022 All-Hands meeting and again at October 2022 All-Hands meeting.
        - Inclusive leadership workshop, led by Chris Olex, September 2022 COLDEX Annual Meeting
        - Inclusive mentoring workshop, led by Chris Olex, September 2022 COLDEX Annual Meeting
        - Bystander training, organized by Erin Pettit and Jamin Greenbaum, led by Jamin Greenbaum and Kristen Bennet (USGS) through the USGS' innovative StepUp! Employee Empowerment Strategies (SEES). This training was offered to participants deploying to Antarctica, October 2022.
        - Implicit bias training, led by Meredith Hastings, April 2023 All-Hands meeting
    - COLDEX invited seminars on leadership and DEI issues:
        - Dr. Andrea Balbas (California State University Long Beach): Building equity and inclusion by nurturing your generous impulses, September 2022 COLDEX Annual Meeting
        - Dr. Meredith Nash (Australian National University): Building diversity, belonging, inclusion, and equity in remote polar field environments, February 2023
    - Preparing field teams deploying to Antarctica:
        - Director for DEI Erin Pettit and Director for Field Research and Data Peter Neff facilitated discussion about team leadership and group dynamics for each field team before leaving for the field. In particular, these discussions focused on the best ways to support each other and keep team members safe in light of the findings of the 2022 NSF SAHPR report.
        - Neff further supported the 2022-23 Antarctic fieldwork teams while deployed in Antarctica, including ongoing resolution of issues with field safety staffing of I-188 (impacting sense of inclusion, safety, etc.). This involved discussing with the project team how staffing of a field safety mountaineer who was under investigation for an assault in McMurdo Station impacted camp safety and their ability to achieve science goals. This situation was reported to NSF via several means (direct to P. Cutler and M. Jackson, and also reported to NSF Safer Science by H. Conway), but no satisfactory response was received from ASC upon NSF request.
        - Pettit and Neff also created and distributed field team best practices documents, based on documents from the International Thwaites Glacier Collaboration.

    - Further discussions on various DEI topics, such as relevant research papers, are open to the community in the monthly open DEI meeting (ongoing).
    - Brook and Neff initiated collaboration with leaders of the Hercules Dome ice coring project to build leadership experience and skills in the US ice coring community (ongoing).

- *Milestone 2B: Define mechanisms for feedback, mediation, and accountability for issues among COLDEX participants (during meetings, field work, or time at home institution) that are codified in COLDEX Integrity and Professional Ethics Plan*.
    - We launched the COLDEX Feedback Portal on our member website in Spring 2023. The aim of this feedback form is to provide all COLDEX community members with a mechanism to provide both positive and negative feedback to COLDEX. We also encourage any community member to submit suggestions, ideas, concerns, and information related to Diversity, Equity, and Inclusion (DEI) in the Center and to any aspect of the Center structure and community. All input provides the Center information that helps us create meaningful change. COLDEX community members are always welcome to contact any member of the Feedback Review Committee directly if they prefer. The web form allows the submitter to choose their level of anonymity (full anonymity, limited anonymity, and full open communication) as well as to choose which member of the Feedback Review Committee initially receives their submission.
    - The Feedback Review Committee was formed to receive and respond to Feedback Portal submissions. When fully staffed, the Feedback Review Committee (FRC) comprises three COLDEX Executive Committee members (the Director, the Managing Director, and the Director for DEI), two members of the DEI Committee (rotating every other year and may also be on the Executive Committee), one ECR Committee member, and one COLDEX staff member (the DEI Assistant). Members will have training and a demonstrated interest in advancing diversity, equity, and inclusion in the Center. The FRC will address issues together with the exception of cases where specific committee members cannot participate for legal reasons, due to conflicts of interest, or at the request of the submitter. A protocol for handling and storing report documents and a workflow for responding to submissions has also been defined.
    - COLDEX Leadership, led by the Director for DEI, provides mediation and support when particular issues arise between individuals or teams (ongoing).
    - The DEI team administered a Sense of Belonging survey in Spring 2023. The purpose of this survey, which will be given at least once per year, is to assess the inclusiveness of the COLDEX community through time. Member feedback will help the Center acknowledge challenges and make changes to improve our cultural, leadership, and learning environments as we strive to be an inclusive community. The first part of the survey is based on tested and validated survey instruments presented in peer reviewed literature (Hagerty and Patusky, 1995). These instruments allow us to put our results in the context of other studies and other

communities. The second part includes more open ended questions that allow members to expand on their experience and provide feedback to improve COLDEX.
    - The DEI team also administered a post-fieldwork survey for COLDEXers who deployed to Antarctica in the 2022-23 field season.

- *Milestone 2C: Create an inclusive leadership award within COLDEX*.
    - The DEI committee has defined the structure for criteria and eligibility for the new COLDEX Inclusive Leadership Award, which will recognize exemplary leadership in advancing diversity, equity, and inclusion in the COLDEX community and beyond. Individual award recipients will be recognized at the COLDEX Annual Meeting and their travel to the meeting will be supported by COLDEX. Recipients will also be given a $1,000 award toward a COLDEX-related research, outreach, or DEI activity or event, such as a conference, workshop, or research. Highlights of recipients' accomplishments will be featured on the COLDEX website and in the COLDEX newsletter. Nominations for the first annual award will be solicited in summer 2023.

Objective 3. Increasing diversity in polar sciences.

- *Milestone 3A: Increase recruitment of students and collaborators from historically marginalized identities into COLDEX. Build relationships with faculty at MSIs to 1) provide connections to students for REU or graduate programs, 2) explore expanding COLDEX community by directly collaborating with MSI faculty, 3) help COLDEX refine strategic planning goals*.
    - Starting in summer 2022, we share best practices among COLDEX institutions for inclusive recruiting and retaining of early career scientists on an annual basis. Rahilly shared an opportunity to attend "Inclusive Mentor" training offered through the GEO REU network to all REU mentors. Rahilly and Pettit held mentor mini-training as part of the May COLDEX all-hands meeting.
    - We are tracking demographic data of COLDEX participants using surveys and comparing to data available for the geosciences, as data do not yet exist for the polar sciences (see section 3: Impact of these activities on increasing diversity at the Center). OSU undergraduate student Melyssa Fenton is analyzing demographic and other data for the REU student applicant pool, including selected applicants.
    - The Director for DEI and the Director for Education have developed a framework for a proposal for a PhD cohort model, intended to seek funding for a larger incoming cohort of graduate students. Discussions with key individuals and NSF are underway.
    - Working toward our goal of building and strengthening relationships with Minority Serving Institutions (MSIs), we have submitted an NSF GEOPaths proposal led by Kristen Rahilly, Director for Education, in collaboration with Linda Hayden from Elizabeth City State University, an HBCU, entitled "Strengthening the pathway from STEM to polar science through the search for oldest ice and the COLDEX-ECSU Fellowship program." The proposed two year fellowship will integrate a cohort of 4 graduate student fellows into the broad, multi-institutional network of the Center for

Oldest Ice Exploration (COLDEX) as full center participants while working on their degree at Elizabeth City State University (ECSU) as part of the Master of Science in Mathematics program.
    - We are also strengthening relationships with MSIs through faculty participation in the School of Ice program, and maintaining relationships with School of Ice alumni by involving them in subsequent activities. See the Education section of this report for more details.
    - We are working to strengthen connections with programs at COLDEX institutions that work with historically marginalized identities in STEM. Through our REU program, students have been placed at UT and UC Irvine. Rahilly is looking into further developing these connections, potentially through LSAMP programs at each institution.
    - In spring 2023, we held a Mentoring and Professional Development Plans workshop for COLDEX graduate students and their advisors, which focused on best practices for inclusive mentoring. The majority of REU mentors went to the GEO REU network "Inclusive Mentor" training at the end of April. Rahilly shared the video recording of the training for those who could not attend and shared all resources with the mentors.
    - We are providing REU mentors with training and support for inclusive mentoring, and ensuring that REU mentees have guidance on what to expect from a mentor or a research advisor. See the Education section of this report for more details.
    - Creating clear mentoring relationships is one of the first topics scheduled for the summer 2023 professional development workshop. Students (and mentors) will be provided instructions for creating a mentoring agreement.
    - To ensure a holistic review process for all applications, the Director for DEI and Director for Education have determined common holistic review protocols to be used in conjunction with institution specific reviews, and made them available to the wider COLDEX community. This review process is being evaluated for use going forward in the REU program.

- *Milestone 3B: Support career development of participants from historically marginalized identities including appropriate mentoring and career planning.* In reviewing our Strategic Plan, we have determined that this milestone should be reworded to include all participants, and will add this revision to the next update of the plan. In support of this milestone, we have undertaken the following actions:
    - We held an inclusive mentoring workshop for all participants (mentors and mentees) at the September 2022 Annual Meeting, and we regularly review concepts to strengthen inclusive mentoring skills at COLDEX-wide monthly meetings. Additional training strategies are in the planning phase.
    - We hold ongoing discussions about appropriate ways to integrate and support ECRs at all levels in COLDEX, with the intent to provide them a voice and place at the table, without overburdening them.
    - We are requiring each COLDEX-funded graduate student and post doc to complete and regularly update a "Professional Development Plan" (PDP) modeled after the

Oregon State University postdoc Individual Development Plan (IDP). [The name was changed for use within COLDEX to avoid confusing the acronym with the Ice Drilling Program.] The Director for Education is actively encouraging regular individual, team, and self-assessment of this mentoring structure.
    - We have created feedback mechanisms that enable mentees and mentors to communicate concerns and seek support for their relationship as needed (see Milestone 2B).
    - COLDEX received official approval to join the IARPC-PSECCO-USAPECS mentoring program, allowing our ECRs to broaden their faculty and peer mentoring network in polar research.

Objective 4. Broaden the reach of polar science content/messaging to the public and other audiences, especially to previously excluded identities and communities.

- *Milestone 4A: Assess communication to avoid presenting exclusive narratives in our external (and internal) communication*.
    - In our Strategic Plan, we listed the following action items to assist in meeting this goal.
        - Assess existing ice core/polar science media narratives and create a living document with examples of exclusive narratives.
        - Create guidelines and structure for DEI Ambassadors and content creators to be able to review and modify messaging in a timely manner.
        - Provide mechanism for COLDEX participants to submit examples they see in the media or in our own messaging of either exclusive or inclusive messages.
    - Unfortunately, thus far we have not had the capacity to carry out these actions. At our monthly DEI community meetings and at COLDEX All-Hands Meetings, we have discussed the issue of exclusive narratives in media related to work in Antarctica with the COLDEX community. It is our intention that the DEI Ambassadors take on some of these actions in an informal manner in the future. In the next reporting period, we will work to find the best way to approach this goal, which may include revising this section of the strategic plan.
    - The Knowledge Transfer team has put together a set of resources for members engaging with the media to request training and/or assistance, and promoting inclusive narratives are one of the issues that can be addressed with this mechanism. See the Knowledge Transfer section of this report for more information.
    - Moving forward, we continue to re-evaluate this milestone in our Strategic Plan as well as our capacity to address this issue.

- *Milestone 4B: Create structure for assessing educational and other workshop material to encourage inclusive content and pedagogy.*
    - We have offered frequent DEI-related workshops to all COLDEXers, thereby ensuring that our education content creators have participated in such training.
    - Moving forward, the Director for DEI will work with the Director for Education to create a system for reviewing education and workshop content.

3. Impact of these activities on increasing diversity at the Center.

To better understand the diversity of the Center and be able to assess change, a demographic survey was sent to the COLDEX community in November 2022 and new members are asked to fill it out when they join. As of 5/17/2023, 76 of the 109 COLDEX participants (69.7%) active in the last year have filled out the demographic survey. This includes 44 Faculty/Staff (72.1% of those in COLDEX), 4 postdoctoral researchers (80.0% of those in COLDEX), 20 graduate student researchers (66.7% of those in COLDEX), 1 postbaccalaureate researcher (50% of those in COLDEX), and 7 undergraduate student researchers (63.6% of those in COLDEX). Targeted emails to non-responders have been sent, and reminders will continue to be sent a few times a year. Some key findings of the demographic survey at this point are:

- Race/Ethnicity: Most COLDEX participants identify as White, Euro-American, or European, with 88.6% of Faculty/Staff and 71.9% of ECRs selecting that option). Fourteen survey respondents (12.8%) identify as an Underrepresented Race/Ethnicity (URE), a grouping that includes race/ethnicity identities other than white. This is slightly less than the 15.8% (12 of 76 total participants) reported for the International Thwaites Glacier Collaboration (ITGC), a similar Antarctic science project (Karplus et al., in press) (Figure VI-1).

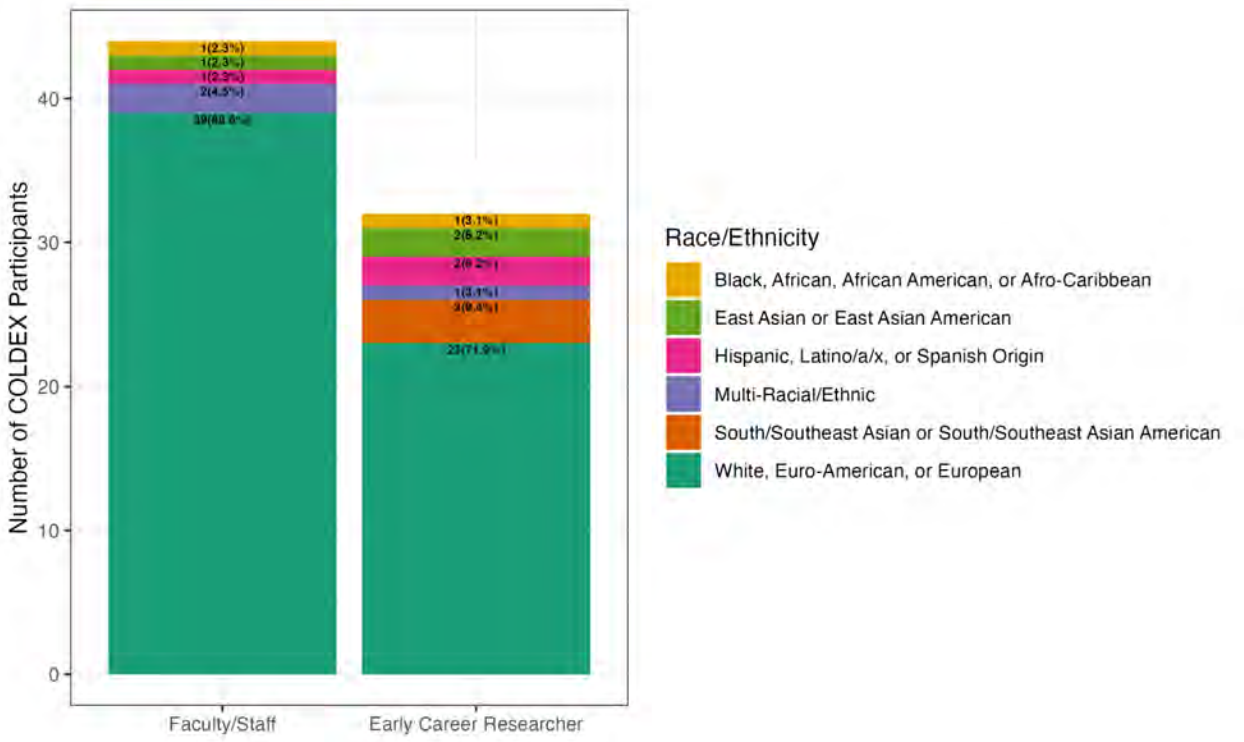
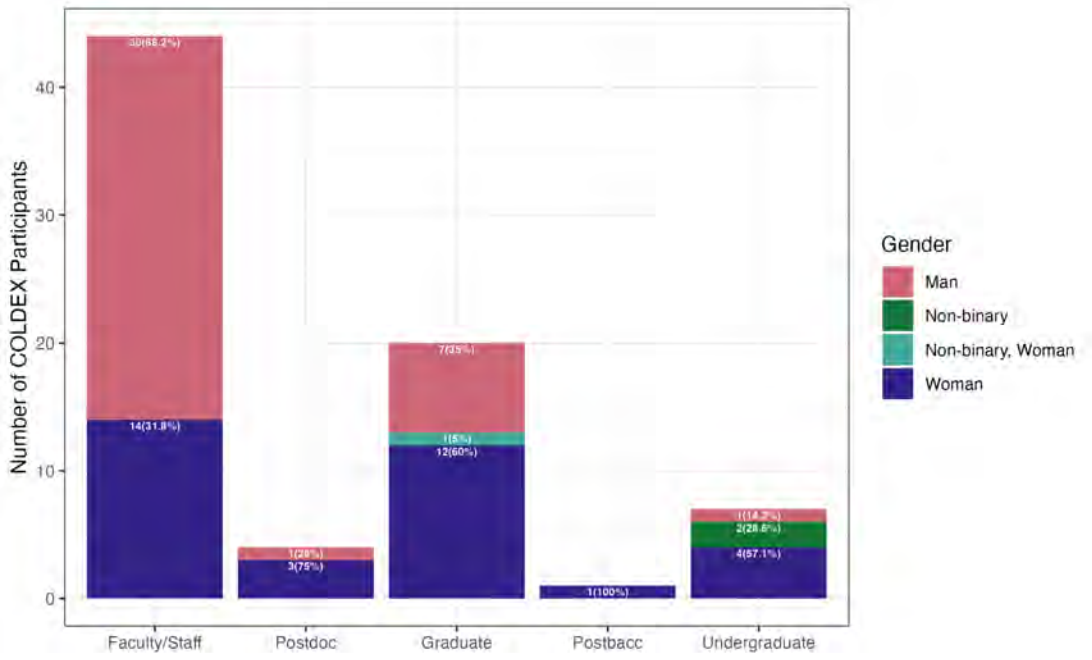


Figure VI-1. Race/Ethnicity of COLDEX participants by position.

- Gender: Of the 76 respondents, 39 (51.3%) identify as men, slightly less than the 56.6% of ITGC membership (Karplus et al., in press), 34 (44.7%) identify as women, 2 (2.6%) are non-binary, and 1 (1.3%) identifies as non-binary and a woman. The highest percentage of participants identify as women for every position group except

Faculty/Staff, which are predominantly men (Figure VI-2a). Two participants, both undergraduates, identify as transgender. The proportion of women at each ECR level is higher than in the broader physical and earth sciences where, in 2020, women earned 43% of Bachelor's degrees, 38% of Master's degrees, and 34% of Doctoral degrees and, in 2021, women comprised 46.0% of Master's and 37.8% of Doctoral enrollees (NCSES, 2023). In comparison, 60% of COLDEX graduate students and 62.5% of all COLDEX ECRs identify as women. URE respondents are more gender diverse than those that are white and include one of the two transgender respondents (Figure VI-2b).

(a)



(b)

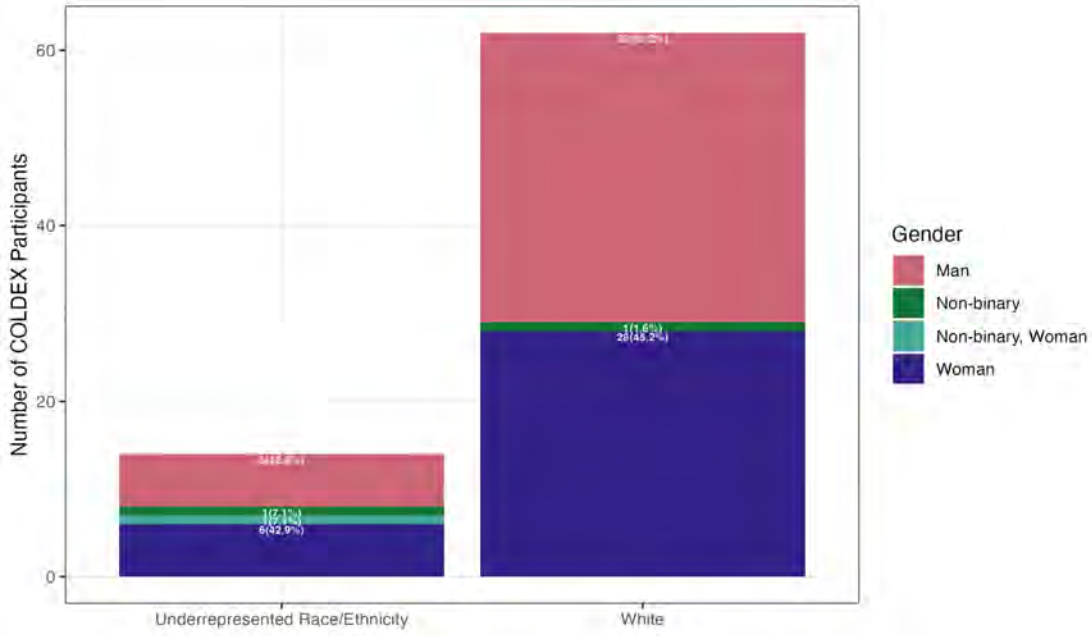
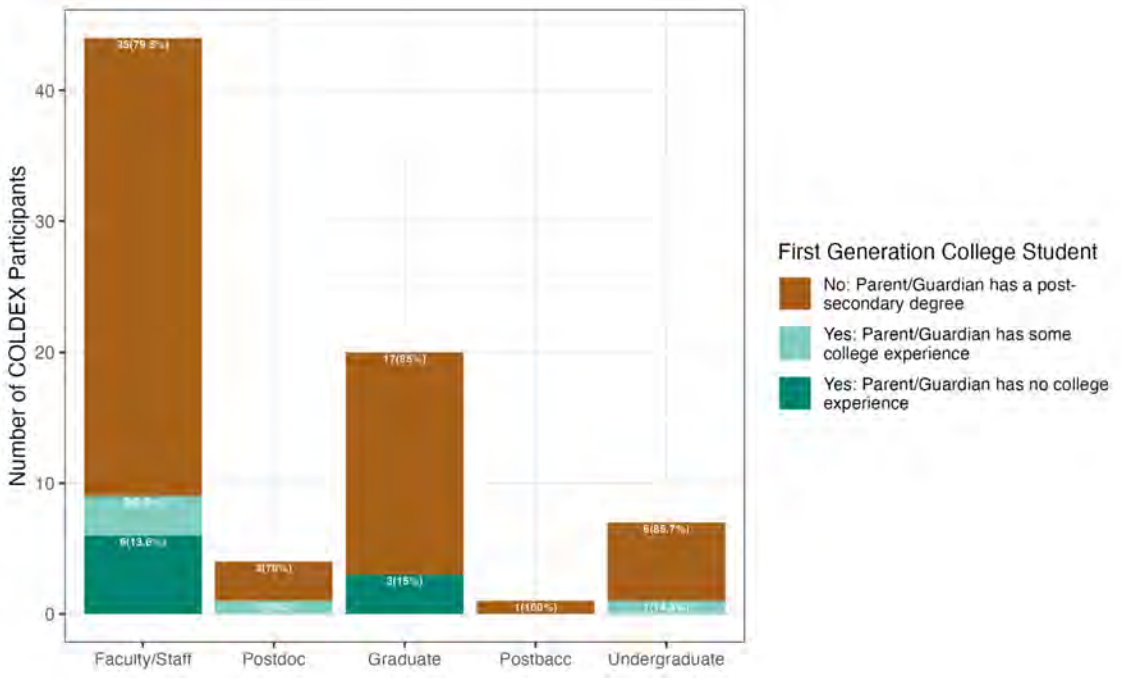


Figure VI-2. Gender identity of COLDEX participants by position (a) and race/ethnicity (b). Two undergraduates, one URE and one white, identify as transgender.

- Sexual Orientation: Individuals identifying as asexual, bisexual, gay or lesbian, queer, or other self-described sexual orientation comprise a larger portion of ECRs (43.8%) than Faculty/Staff (4.5%) as well as a larger portion of URE participants (35.7%) than white (17.7%).
- First Generation College Student Status: At every position level, a large majority of COLDEX participants were not (or are not, in the case of current undergraduate students) first generation college students and over half of COLDEX participants were not (or are not) first generation graduate students (Figure VI-3a, Figure VI-4a). A large majority of white participants have at least one parent/guardian with a post-secondary degree (87.1%) while slightly over half (57.1%) of URE participants do and 28.6% of URE participants have no parent/guardian with any post-secondary experience (Figure VI-3b). Half (50%) of URE participants have no parent/guardian with graduate school experience compared to 32.3% of white participants and slightly over a third (35.7%) have a parent/guardian with a graduate degree while over half (61.3%) of white participants do (Figure VI-4b).

(a)



(b)

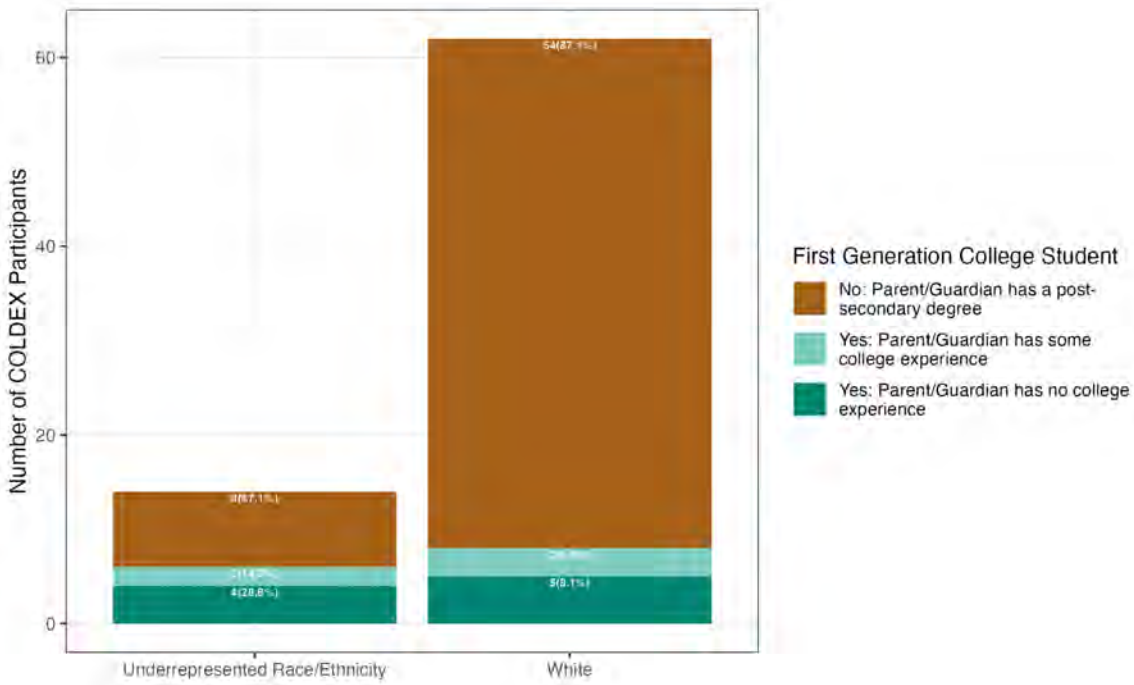
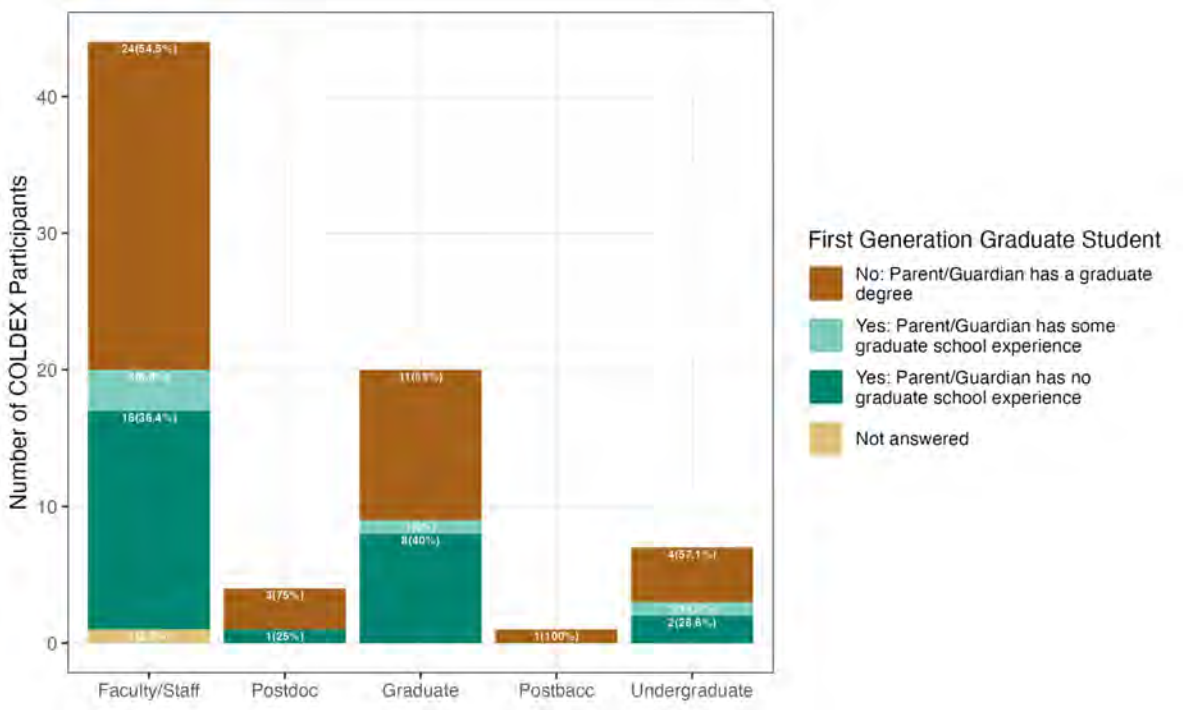


Figure VI-3. Parent/Guardian college experience by position (a) and race/ethnicity (b). Categories are based on answers to the question "At the time you entered college, had one or more of your parent(s)/guardian(s) attended college?"

(a)



(b)

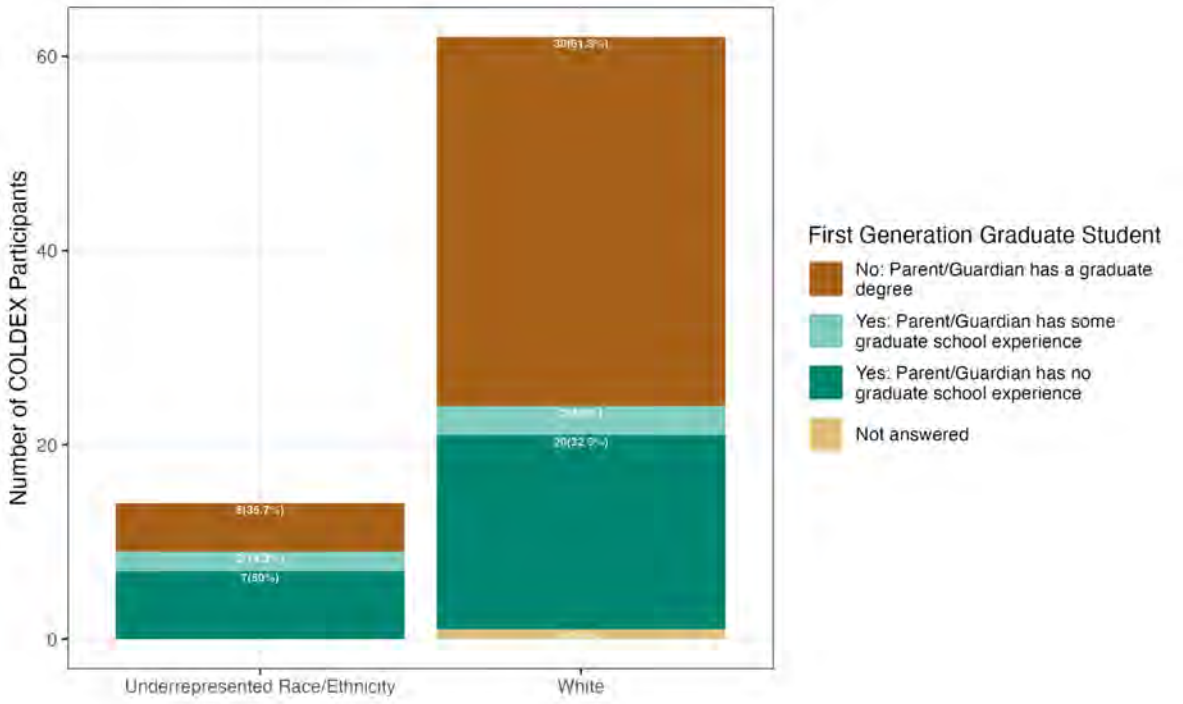


Figure VI-4. Parent/Guardian graduate school experience by position (a) and race/ethnicity (b). Categories are based on answers to the question "At the time you entered graduate school (or currently if you are an undergrad or postbacc), had one or more of your parent(s)/guardian(s) attend graduate school?". The single "not answered" response was a fill-in response from a Faculty/Staff participant who had not attended graduate school.

- Disability Status: Five participants, 3 (6.8%) Faculty/Staff and 2 (6.2%) ECRs, indicated they had one or more of the disability types recognized by NSF and 2 participants, both

ECRs, indicated they preferred not to answer. Of the 5 participants with these disabilities, 2 hold other (multiple) non-majority identities. Twelve participants, 7 (15.9%) Faculty/Staff and 5 (15.6%) ECRs, indicated they had one or more of the disabilities or conditions listed on a more comprehensive list than NSF uses and 7 participants, 1 (2.3%) Faculty/Staff and 6 (18.8%) ECRs, indicated they preferred not to answer that question. Of these twelve, 7 are women or non-binary, 2 are URE, 5 are asexual, bisexual, gay or lesbian, queer, other sexual orientation, or preferred not to answer about their sexual orientation, and 2 are transgender.

- U.S. Citizenship: Five participants, 4 ECRs and 1 Faculty/Staff, indicated they are not a US Citizen or Permanent Resident; four of those five are URE.
- Participation in COLDEX: Most COLDEX participants are involved in the Research pillar of COLDEX, which is also the only pillar in COLDEX with more men than women (Figure VI-5). The only pillars with any URE participants are DEI and Research: 4 (2 Faculty/Staff and 2 ECRs) are involved in DEI and all 14 are involved in Research.

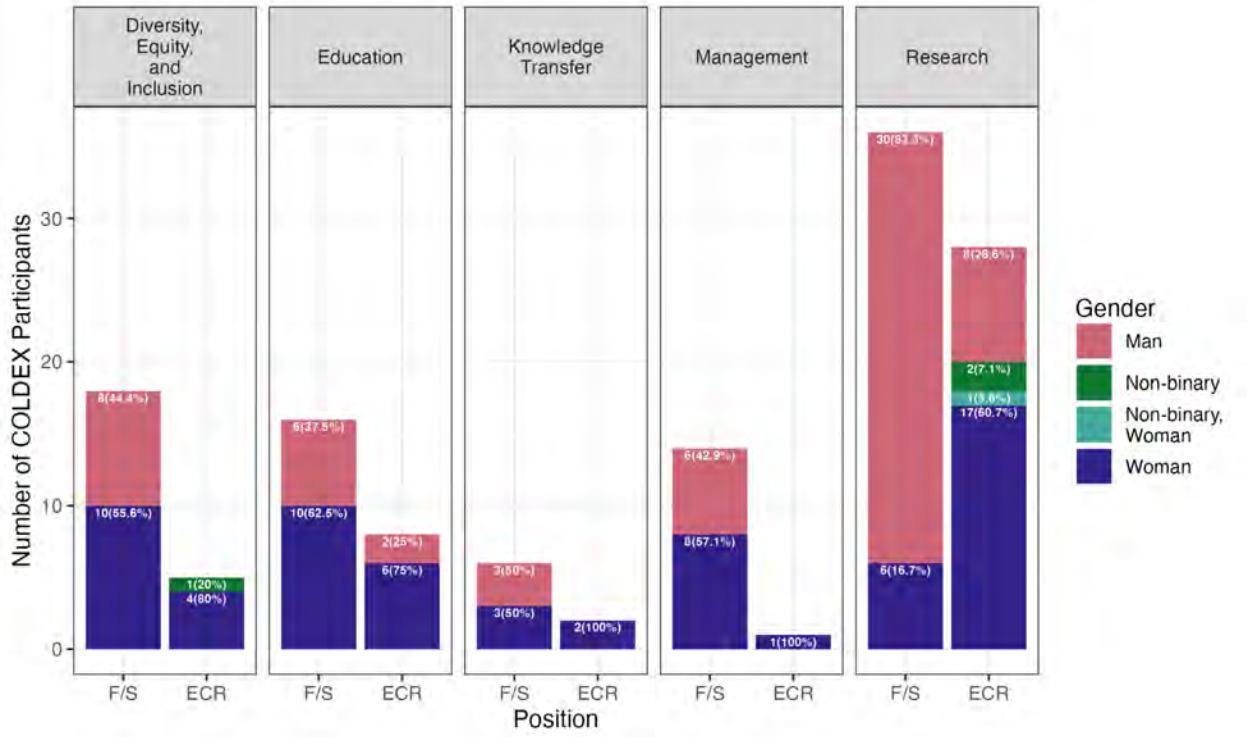


Figure VI-5. Number of COLDEX participants that indicated they are involved in each pillar of COLDEX by position and gender.

4. Impact of these activities on building center inclusive culture

- Initial Sense of Belonging survey results:
    - The first COLDEX Sense of Belonging Survey was distributed April 10, 2023 to June 8, 2023. Sixty COLDEX participants completed the Sense of Belonging Instrument (SOBI) portion of the survey (54.1% of the 111 participants as of June 5th, 2023). This includes 39 faculty/staff (63.9% of all COLDEX faculty/staff), 3

postdoctoral researchers (50.0%), 16 graduate student researchers (51.6%), 1 postbaccalaureate researcher (50%), and 1 undergraduate student researchers (9%). The low number of undergraduates completing the survey is likely due to the spring timing of the survey, well after the 2022 REU projects had wrapped up and before 2023 REU students had started. The SOBI, developed by Hagerty and Patusky (1995; Nurs Res. 44(1):9-13), consists of statements assessing feelings of fit and value on a 5 point agreement scale. Responses for negatively framed statements are reverse coded so that the highest score for each question is indicative of a strong sense of belonging, and all questions are rescaled to a numeric scale of 0-4. Mean scores of the whole instrument (SOBI) are assessed, as well as scores from the antecedent (SOBI-A) portion, which assesses the precursors to a sense of belonging such as one's motivation towards a sense of belonging, and the psychological (SOBI-P) portion, which measures sense of belonging in terms of valued involvement and fit in relationships.

- The mean and median SOBI score (the average of all SOBI questions) for all respondents is 2.9 with a range of 1.8 to 3.7. There is no substantial difference in SOBI scores among position levels, indicating that most participants feel a high sense of belonging in COLDEX. SOBI-P and SOBI-A scores are generally aligned, though for those with lower sense of belonging SOBI-P is lower than SOBI-A (Figure VI-6). SOBI-P statements include those related to the present situation, while SOBI-A statements are oriented towards an individual's prior experience with belonging. Thus, COLDEX members with a lower SOBI-P than SOBI-A do not feel a sense of belonging within COLDEX specifically but do in other contexts. Further analysis will focus on those with the lowest SOBI scores to understand who doesn't feel like they belong in COLDEX, the reasons for their low sense of belonging, and ways the Center can increase belonging for everybody. This analysis will include connecting demographic information from the demographic survey to the sense of belonging responses as well as qualitative analysis of the open-ended question responses in the survey.

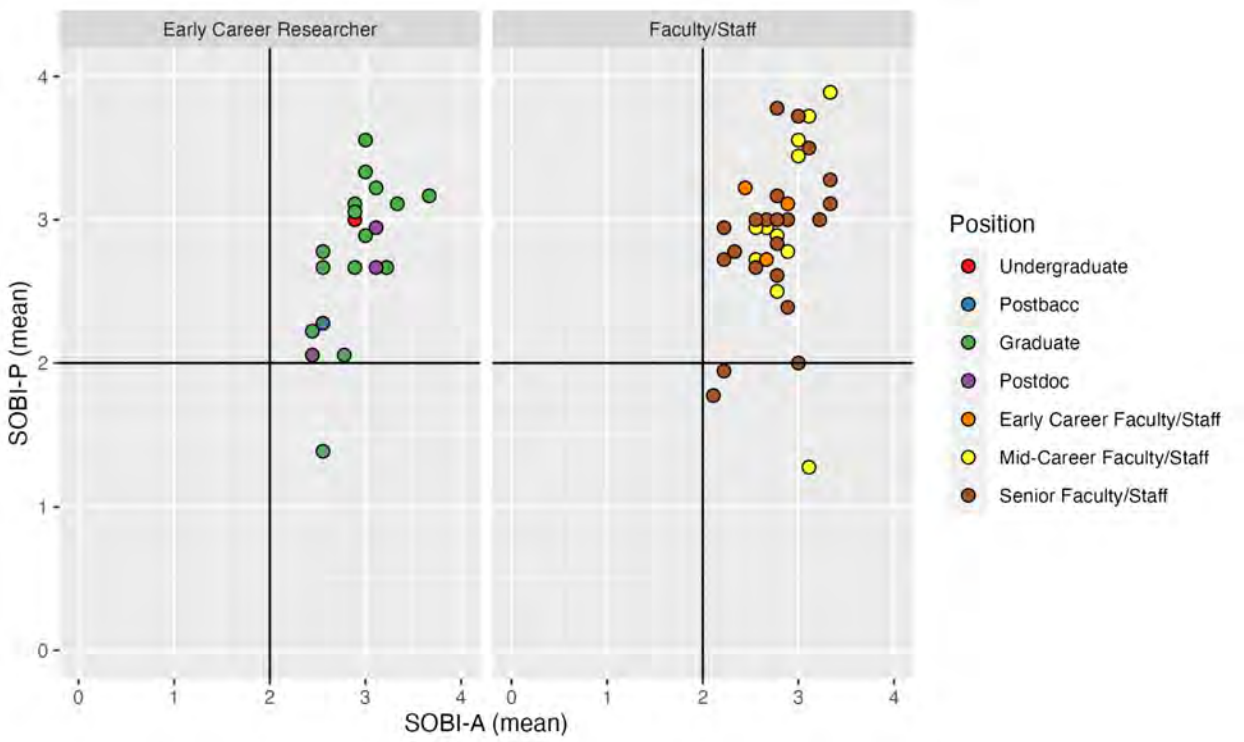


Figure VI-6. SOBI-P vs SOBI-A mean scores by position level.

- Initial Post-field survey results
    - Of the 24 respondents, 22 (91.3%) attended the pre-field team meetings hosted by Erin Pettit and Peter Neff. Of those 22, 21 (95.5%) agreed or strongly agreed that the meeting was a good use of time to prepare for the field season (1 neither agreed nor disagreed with the statement), 14 (63.6%) agreed or strongly agreed that the meeting's discussions on creating an inclusive environment helped them address interpersonal interactions during the field season (1 disagreed with the statement and the remaining 7 neither agreed nor disagreed), and 13 (59%) agreed or strongly agreed that attending the meeting gave them ideas and/or tools to address difficult behaviors if they occurred during the field season (the remaining 9 neither agreed nor disagreed).
    - Responses to the open ended questions about pre-field meetings are generally positive. Most found the pre-team meeting helpful for field logistics (such as the packing list), getting to know others on their team, and for building an inclusive team. Several respondents gave suggestions for improvement, such as more structure and facilitation as well as continuation of discussions past the single meeting.

5. Problems encountered and anticipated.

- Recruitment

- Our multi-faceted recruitment strategy for graduate students and postdocs includes broad and targeted social media, professional societies, and specific relationship building with partner institutions or organizations. In the first two years of COLDEX, and with a small number of graduate student positions available, the diversity of our graduate and postdoc population is not significantly different than that of peer science projects. Our REU recruitment strategy, which was similar, met our goal of recruiting more than 50% of the participants from underrepresented groups. We would like to increase the diversity of our graduate student cohort as well. In setting such a goal, we see three challenges, which offer opportunities for improving our efforts in a few places:
    1. The number of different institutions with separate application systems makes the graduate application and selection process complex for both interested students and for prospective advisors. Opportunity: We provided “office hours” for interested students to receive mentoring in their graduate applications and to understand COLDEX as a multi-institutional project. These office hours will be revised and continued. We are also striving to build relationships with students and faculty at conferences and through partner organizations.
    2. We have a limited number of funded graduate student and postdoc positions. Opportunity: We have submitted the GEOPaths proposal (mentioned in other sections of this report), we have encouraged COLDEX faculty and institutions to explore other funding mechanisms, and we have initiated additional proposal ideas to create more grad student opportunities, particularly using a cohort model to intentionally support students from underrepresented minority backgrounds.
    3. Polar science is still not as visible and may not appear as accessible and inclusive for students without faculty connections or other mentoring. Opportunity: Our REU program is creating a pathway for students from undergraduate institutions that do not already have strong polar science connections, School of Ice is broadening the number of faculty with polar science connections; therefore our base for potential applicants is growing, and other COLDEX education and communication efforts are aimed at not only sharing what we are learning, but changing the narrative of polar science to be more inclusive and accessible to students from across a spectrum of academic institutions and background.
- Sustaining COLDEX member engagement
    - The initial momentum of integrating DEI values across all of COLDEX has been successful. As we shift into different stages of the research, COLDEX member’s workloads shift and the needs shift for DEI efforts. On many large science teams, the DEI-related work is done mostly by early career researchers and by women and those from underrepresented minorities. We still have a broad spectrum of COLDEX members involved, but we anticipate that this may become an issue. Mitigation: The DEI Ambassadors program will intentionally include members

from all career stages and we will seek advice on additional ways to incentivize individual efforts, such as the DEI Award.

6. Plans for the next reporting period.

Our plans for the next reporting period include:

- Monitoring our progress towards Objectives 1, 2, and 3:
    - This year we completed the first round of our three surveys related to DEI progress: Demographic, Sense of Belonging, and Post-Field. Our intention is to complete these surveys at least once per year, as appropriate for the changes expected. In particular, the demographic survey only needs to be filled out by new members and anyone desiring to change their information and the sense of belonging would be beneficial to have each fall and spring. Starting next year, we will be able to report on trends within the Center. These reports will include more detailed analysis of the open-ended questions from the surveys than has been completed thus far.
- Objective 1: A welcoming culture
    - All of the activities developed through the first two years will continue with improvements based on feedback from the surveys and web portals. We will pay particular attention to people new to COLDEX, as integrating into an existing team can be challenging.
    - During the annual meeting we will present the first DEI Award and kick off the DEI Ambassadors program.
- Objective 2: Inclusive leadership
    - Workshops, discussions, and invited speakers will continue based on feedback.
    - COLDEX DEI and Education will continue to work together to provide inclusive mentoring and leadership skills across all career stages.
    - Collaboration with Herc Dome and the broader ice coring community will continue.
- Objective 3: Increase diversity
    - Work with COLDEX education to support the REU cohort and build longer term relationships with these students and encourage them to share with peers at their institution to broaden our reach for prospective graduate students.
    - Review and improve recruitment efforts and equitable hiring and admissions this fall for the graduate and post doc positions available. Review our “office hours” concept and consider whether we can expand this in an effective way, especially to support prospective students who may not have strong mentorship from their undergraduate institution.
    - Continue to seek ways of creating more graduate student opportunities, through partnerships or proposals.
    - Continue to develop partnerships with MSIs through School of Ice and expand relationships with MSIs through other connections such as research collaborations or brainstorming ways to create opportunities for their students to

learn about polar science. One mechanism we are exploring is a COLDEX “road trip” where a small team of COLDEX members visit a number of MSIs in one week.
    - Continue to provide, assess effectiveness (through feedback), and improve our mentoring and support structure for students and early career researchers from historically marginalized identities.
- Objective 4: Broaden reach through better messaging.
    - COLDEX will work to further create the structure to review content for exclusive messaging. We are still learning how best to approach this goal given individual expertise in communication within COLDEX and the needs across COLDEX. We may engage experts outside of COLDEX to review a subset of our educational and website content.

VII. MANAGEMENT

1. Center's organizational strategy, underlying rationale, and overall management goals.

COLDEX Management is guided by a core set of values, which inform the Center's organizational strategy. COLDEX values the open, honest exchange of ideas, data, and technology. All participants are expected to engage in improving equity, diversity, and inclusion. The COLDEX leadership team commits to transparent, inclusive leadership, organization, and management. No changes to our organizational strategy have been implemented since the last reporting period. The COLDEX Organizational Chart is provided in Appendix B.

The Center has defined three Optimal Outcomes in the Management and Integration section of the Strategic Plan.

1. COLDEX management will operate effectively in a transparent manner, enabling COLDEX members to achieve their research, education, DEI, and knowledge transfer goals.
2. COLDEX members will perceive themselves as belonging to a cohesive, welcoming community with shared goals and values.
3. Research, education, knowledge transfer, and diversity, equity, and inclusion activities and values will be integrated across all aspects of the Center.

2. External Advisory Committee

Our External Advisory Committee currently has the following members:

- Julie Brigham-Grette, University of Massachusetts Amherst, chair
- Judith Brown Clarke, Stony Brook University
- Kathie Dello, North Carolina State University
- Sidney Hemming, Lamont-Doherty Earth Observatory
- Bonnie Murray, NASA Langley Research Center
- Tas van Ommen, Australian Antarctic Program

3. Systems for supporting a fully integrated STC

Communication is the Center's key mechanism for maintaining transparency in decision-making and supporting inclusivity among the COLDEX community. The primary methods of intra-center communication are email listserv, Slack workspace, and standing monthly meetings via Zoom video conference. The COLDEX email listserv is used regularly to keep members informed about events and announcements, and to send out requests for information. All information sent out via email is also posted on the COLDEX Slack workspace, and members are encouraged to use dedicated channels for more informal conversations. The Center holds All-Hands meetings via Zoom video conferencing on a monthly basis, bringing current issues to the attention of COLDEX members and seeking their input. The leadership team for each COLDEX area (DEI,

Education & Leadership, Knowledge Transfer, Exploration & Modeling, and Ice Coring & Ice Analysis) holds a monthly group meeting. All COLDEX members, at all career stages, are welcome and encouraged to attend any meetings that interest them. Attendance at all meetings has been high, and stayed consistent over time.

All documents related to Center management and policies are stored in a shared Google Drive, to which all COLDEX members are granted access. The Managing Director also maintains the internal COLDEX informational website, which serves as a central location for members to find direct links to center policies, schedules and connection information for upcoming meetings and seminars, recordings of past seminars, minutes of past meetings, and other important resources. The internal website also serves as an onboarding tool for new members, providing an online COLDEX Handbook and a link to the demographic survey all new members are asked to fill out, as well slide decks explaining the COLDEX mission and plans for research, broadening participation, education, and knowledge transfer, plus a slide deck with member bios, to which new members are encouraged to add themselves.

4. Changes to the Center's strategic plan.

The initial Strategic Plan was submitted to NSF in April 2022, and we made small updates in response to feedback from NSF and the site visit review in June 2022. No changes have been made in this reporting period; however, structuring our quarterly progress reporting system to focus on strategic plan milestones has revealed areas that need better definition or clearer progress indicators. We will evaluate and update the plan annually, with the first update work planned for July-August 2023.

5. Strategic plan objectives and progress towards milestones.

Objective 1: Establish Center leadership and management.

- *Milestone 1A: Hire staff and implement effective Center management structures. This milestone was met in mid-2022 through the following actions:*
    - COLDEX hired a full-time Managing Director (Danielle Whittaker) and Director for Education (Kristen Rahilly) through widely advertised national searches with representation of COLDEX Director of Diversity, Equity, and Inclusion on both search committees. Directors for Diversity, Equity, and Inclusion; Knowledge Transfer; and Field Research and Data were established as roles for specific faculty participants in COLDEX.
    - Hired 0.5 FTE OSU-supported program assistant and created 0.5 FTE DEI assistant position (Stephanie Jarvis).
    - An executive committee that represents all components of COLDEX was appointed in year 1 and maintained through year 2. Weekly Executive Committee meetings have been established for input on decision making and sharing information and activities among COLDEX components.

- Quarterly internal progress reporting and review of sub award activity has been established.
- Weekly management meetings of OSU-based COLDEX staff have been established.
- Key OSU CEOAS staff and OSU Research Office staff with responsibilities for Center finances, reporting and administration are involved; this group meets quarterly.
- An internal financial reporting and tracking system has been developed in coordination with CEOAS business office staff.

- *Milestone 1B: Establish Executive Committee role in governance and oversight of COLDEX, including written committee charter. This milestone has been met, through the following actions:*
  - In the first year, we developed an Executive Committee charter with guidelines for executive committee decision making and governance, including mechanisms for adding or replacing members and ensuring the committee represents the broad spectrum of COLDEX activities and participants.
  - The Executive Committee aims to monitor the workload of early career executive committee members and other leaders in COLDEX to ensure that participation in Center leadership is not detrimental to career progress. In this reporting period, the Director and Managing Director met with all members of Center leadership (including Director-level participants and institution leads) to discuss challenges and opportunities, and this topic was one focus of those discussions.
  - COLDEX publication policies have been developed that 1) address how authorship of community publications of broad interest will be determined, 2) provide mechanisms to avoid conflicts over authorship on publications and meeting abstracts and provide appropriate credit for participants, 3) pay particular attention to ensuring that there are clear plans that provide for student and postdoc authored publications and avoid conflicts in publication plans within that group. These policies are included in the COLDEX Integrity and Professional Ethics Plan.

Objective 2: Establish effective communication with participants to establish and maintain integration of Center activities and goals. Maintain communication as a key mechanism for maintaining transparency in decision-making and supporting inclusivity among the COLDEX community.

- *Milestone 2A: Establish internal facing communications.* This milestone was met by mid-2022 with the following systems established:
  - COLDEX web site, shared Google drive, Slack workspace, email list serves, and regular Monday morning announcements and reminders.
  - Monthly communication between the Managing Director and all institution leads.
  - Monthly all-hands meetings that focus on in-depth discussion of progress and potential barriers to progress in the following areas: Diversity, Equity, and Inclusion; Ice Coring and Ice Core Analysis; Exploration and Modeling; Knowledge Transfer; Education.

- *Milestone 2B: Establish regular COLDEX monthly seminar series featuring both internal and external speakers.* This ongoing milestone is regularly met. Since the last reporting period, we have featured the following seminar speakers:
    - Dr. Peter Clark (Oregon State University): Global Temperature and sea-Level change over the last 4.5 Myr
    - Dr. Sarah Aarons and Austin Carter (Scripps Institution of Oceanography, COLDEX): Mineral dust insights into Earth surface conditions and atmospheric circulation
    - Dr. Georgia Grant (Institute of Geological and Nuclear Sciences Limited): Inter-hemispheric ice sheet contribution to global sea-level for 3.3-1.7 Ma
    - Dr. Joe MacGreagor (NASA): AntArchitecture: A SCAR Action Group mapping the age structure of the Antarctic ice sheet to clarify its stability
    - Dr. Ed Gasson (University of Exeter): The Antarctic Ice Sheet past and future: using paleoclimate data to constrain future sea level rise
    - Dr. Dale Winebrenner (University of Washington, COLDEX) and Dr. Ryan Bay (University of California Berkeley, COLDEX): Optical Age-Depth and Temperature Profiling for Fine-Scale Site Reconnaissance
    - Dr. Meredith Nash (Australian National University): Building diversity, belonging, inclusion, and equity in remote polar field environments
    - Dr. Ralph Harvey (Case Western Reserve University): Meteorite Concentrations and Old Ice: "in a relationship" or "it's complicated"?
    - Dr. Alan Haywood (University of Leeds): The Pliocene Model Intercomparison Project: Scientific Results and the Way Ahead
    - COLDEX Researchers: Initial findings from the first COLDEX field season
    - Dr. Carlo Barbante (University Ca'Foscari Venice): Beyond EPICA – Oldest IceCore: The European Effort to Obtain A 1.5 Myr Greenhouse Gas – Climate Feedback Record from an Ice Core in East Antarctica.

- *Milestone 2C: Create internal COLDEX data repository linked to website*.
    - Data policies are clear and current use of Google Drive continues as Oregon State research and academic computing experts develop a local data storage solution as they move away from expensive Google cloud storage. The form to request access to the internal data repository is linked on the internal COLDEX member website (see Milestone 8B for more details). COLDEX field reports and field reports from previous work related to COLDEX are included in the repository.

Objective 3: Facilitate external communications with the media, policymakers, and the general public about COLDEX activities.

- *Milestone 3A: Maintain ongoing communication, allocate responsibilities, and set standards and policies.* The Director and Managing Director regularly engage with the Knowledge Transfer team to ensure this milestone is met on an ongoing basis. As described in the Knowledge Transfer section of this report, the KT team has established the COLDEX Strategic Communication Plan and created a set of resources available to all COLDEXers.

Objective 4: Integration of Center science, education, knowledge transfer, and diversity, equity, and inclusion efforts into an enduring Center culture.

- *Milestone 4A: Potential new members can easily find information about how to get involved in COLDEX and access resources.* This milestone was initially met in early 2022, and we continue to review and update these resources. Activities include:
    - Creating an informational handbook for new and potential members, available on the COLDEX Member Information internal website.
    - Including all aspects of COLDEX in annual meetings, seminars, and other Center activities, including all-hands meetings focused on: mentoring and the COLDEX Professional Development Plan (Education), Strategic Communications Plan (Knowledge Transfer), Implicit Bias training (DEI), and research presentations from field teams (Research).

- *Milestone 4B: Opportunities to exchange information internally.* We ensured this milestone was initially met by early 2022 and continue to make sure such opportunities are offered.
    - We hold monthly COLDEX remote all-hands meetings and subgroup meetings open to all participants.
    - We held initial strategic planning meetings open to all participants in February-March 2022; we are planning annual updates of strategic plan with opportunities for all participants to contribute.
    - We hold COLDEX meetings/informal get togethers at professional conferences throughout the year, also open to interested people beyond COLDEX as feasible. Most recent examples include COLDEX get-togethers at the 2nd Annual Ice Core Open Science Meeting, and the 2022 AGU meeting.
    - COLDEX Slack workspace established in October 2021.

- *Milestone 4C: Create opportunities for participants to work across COLDEX themes.* Work towards this milestone is ongoing, with the following activities completed so far:
    - Collective development of COLDEX Integrity and Professional Ethics Plan, mentoring plans completed by fall 2022.
    - Data Management Plan (DMP) is in place and participants are regularly reminded of requirements including those extending to center ethics policies. DMP is to be annually reviewed by all COLDEX participants and highlighted at in-person annual meeting.
    - Recruitment and participation of COLDEX researchers in K-12, faculty, and Early Career professional development programs is ongoing, including:
    - Recruitment of ECRs for involvement in hybrid Upward Bound activity.
    - Recruitment of ECRs/Undergrads/Faculty in virtual ANSEP workshops
    - Involvement of faculty and ECRs in Project Ice.
    - Management of REU selection process and faculty mentors.
    - Facilitation of Professional Development Plan (PDP) sessions. COLDEX ECRs and their faculty advisors/supervisors are currently working on individual PDPs, which

have a strong focus on centering inclusive mentoring practices (for example: communication plan, focus on identifying competencies).

- *Milestone 4D: Annual Center meetings that integrate all COLDEX themes and provide opportunities for participant connections.* The first annual COLDEX meeting was held in September 2022 in Corvallis, OR and hosted 74 registrants (15 of which attended virtually) across all career stages and member institutions. The second meeting has been scheduled for September 2023.

- *Milestone 4E: Diversity, equity, and inclusion activities are valued by COLDEX members and enrich careers.* Progress toward this milestone is underway, including the following activities:
    - Provide training to early career researchers on how to present DEI activities in CVs, job applications, etc. Planned for September 2023.
    - COLDEX Inclusive Leadership Award criteria established, and will be open for nominations in summer 2023 (see DEI section).
    - COLDEX DEI meetings and activities highlighted in internal and external communications.

Objective 5: Provide support to COLDEX participants investigating new funding streams and collaborations for COLDEX-related activities.

- *Milestone 5A: Serve as a point of contact for COLDEX participants wishing to approach potential donors or funders*. Work toward this milestone is underway:
    - The Director has provided funding goals to OSU Foundation, and continues to maintain contact with foundation staff.
    - Future activity: the Director will work with COLDEX institutions to develop strategies to approach donors that do not conflict with institutional priorities or relationships.

- *Milestone 5B: Communicate funding opportunities to participants and encourage/facilitate proposals.*
    - The COLDEX leadership team regularly shares information about these opportunities on the COLDEX Slack workspace. COLDEX also facilitated the submission of an NSF proposal to a GEOPaths opportunity (see Education section for more details) and a Phase 1 Proposal to the Keck Foundation.

- *Milestone 5C: Seek new research partners who can take advantage of COLDEX samples, data, or programs.* Activities to meet this milestone are underway, including the following:
    - Advertising COLDEX activities and possible research directions through talks at conferences and other outlets: the Director regularly gives talks about COLDEX at national and international conferences (including AGU, IPICS, and the Ice Core Open Science Meeting) and encourages interested researchers to approach us about collaborations.

- Scholarship funds made available within and outside of COLDEX to seed new research by ECRs. The initial funding application was distributed in spring 2023, and several projects have already been approved (see the Education section for more details).
- Sample database of COLDEX ice cores at NSF-ICF is being made publicly available in coordination with NSF Ice Core Facility and per requirements of the COLDEX sample request process coordinated by the Director for FRD and the sample allocation committee.

Objective 6: Ensure oversight and evaluation of COLDEX by seeking feedback from the External Advisory Committee on an annual basis, as well as from the annual NSF site visits, and regularly assess progress towards management and integration goals.

- *Milestone 6A: Appoint External Advisory Committee (EAC) and develop EAC Charter including roles, responsibilities, and length of service.* This milestone was initially met in Spring 2022.
  - EAC member Tas van Ommen will be rotating off the committee. We have held initial discussions about new members and plan to invite one to two new members prior to the next annual meeting.
  - The Executive Committee met with the EAC in September 2022 and again in June 2023.

- *Milestone 6B: Initiate formal evaluation of educational programs.* This milestone has been met. The Director for Education has worked with our evaluator, Jana Bouwma-Gearhart from the OSU College of Education, to develop plans and a timeline for evaluation of educational programming. Much of the education programming started during Year 2. Rahilly is meeting with Joon Park (post doc assisting Bouwma-Gearhart) weekly to discuss evaluation needs, outcomes and goals, and ideal timelines. More details can be found in the Education section of this report.

- *Milestone 6C: Initiate internal and external evaluation of non-education components of COLDEX.* Work toward this milestone is underway, including:
  - The External Advisory Committee has been asked to provide an annual review of COLDEX progress. First meeting was held in September 2022, and the resulting report is provided in Appendix C.
  - On an annual basis, we respond to feedback from NSF Site Visit team and update the strategic plan accordingly.
  - Annual review of social network analysis is underway, with a publication planned for submission in June 2023.
  - We plan to evaluate different aspects of COLDEX each year, and have started with management and integration. In Spring 2023, Dr. Manuela Hoehn-Weiss from the OSU College of Business conducted a review of the COLDEX Strategic Plan and provided critical feedback, which we will incorporate into our next revision.

- Other evaluations in progress include the Sense of Belonging survey administered by the DEI team, and the Post-Fieldwork survey.

- *Milestone 6D: Quarterly review of participant activity.* The Managing Director established a process for collecting data from participants beginning in March 2022. Information from these progress reports is compiled and reviewed by the Executive Committee.

Objective 7: Manage and facilitate field and ice core logistics planning with participants, NSF and USAP logistics providers.

- *Milestone 7A: The Director for Field Research and Data will act as primary liaison between COLDEX and National Science Foundation (NSF) / United States Antarctic Program (USAP) for field logistics and the Ice Drilling Program for drilling, supporting the individual teams simultaneously carrying out COLDEX field research programs.*
    - The Director for Field Research and Data (Peter Neff) provides input to periodic updates of the COLDEX Operational Notice for field logistics; prepares and archives annual reports of field activities for open access at USAP Data Center; and assists individual COLDEX groups with field logistics planning.
    - In this reporting period, Neff has had extensive engagement with NSF/USAP/ASC science planners, project managers, and implementers through the 2022-23 field season, including pre- and post-season briefings. A great deal of learning was a part of this first cycle of fieldwork, which will be applied going forward to improve coordination between COLDEX and USAP. This will lead to increased likelihood of successful science outcomes at the same time as improving the experience of Antarctic deployment for team members and mitigating some challenges that occur in Antarctica stemming from poor planning/coordination.
    - Neff is also extensively coordinating across COLDEX field project teams I-187 (shallow coring) and I-185 (airborne geophysics) to plan for 2023-24 field season with support information packages developed and submitted by mid-late April 2023. Initial field team participants and alternates have been identified.
    - Neff met with ~20 COLDEX and USAP logistics experts May 2, 2023 to discuss past, current and future field needs in support of COLDEX science.
    - Neff is beginning to track and assist developing science and logistics plan for Ice Diver in the 2024-25 and 2025-26 seasons.
    - Neff continues to follow up with NSF on ASC staffing issues from 2022-23 field season that led to an inappropriate (actively being investigated for assault) field safety mountaineer being briefly sent to I-188 field camp at Allan Hills, Antarctica. To date we have limited information about why this occurred, and we are concerned about lack of transparency and communication from the US Marshal(s) who have jurisdiction over legal/criminal concerns at McMurdo Station and other USAP facilities. This limits confidence in avoidance of this issue in the future.

Objective 8: Make COLDEX data and technology openly and widely available within and outside of COLDEX.

- *Milestone 8A: Finalize and maintain COLDEX Data Management Policy (DMP).*
    - The DMP is active and always open for revision by COLDEX members in consultation with the Executive Committee.

- *Milestone 8B: Develop and track internal data sharing mechanism*.
    - This milestone was met by early 2023. The data repository for internal use is currently located on Google Drive and is working well for internal data sharing. COLDEX participants must agree to conform to the COLDEX Data Management Policies before being granted access. The Director and Director for Field Research have access to upload data and ensure the appropriate metadata is included; all other participants are normally granted view-only access. Transition to an OSU-based Globus platform is planned for later in 2023. This mechanism is in development by the OSU CEOAS Research and Academic Computing group, which has experience with similar data serving needs and has the physical resources and time available to develop and help maintain this resource.

- *Milestone 8C: Create centralized location for long-term public archive of COLDEX data, metadata, model results and engineering designs.* This milestone has been met through the following activities:
    - COLDEX USAP-DC page is active and being contributed to. https://www.usap-dc.org/view/project/p0010321
    - We have worked with the ice core analysis group and the NSF Ice Core Facility on archiving standards, and have established a Sample Allocation Committee to streamline this work.
    - Methods for rapid sharing of airborne radar data are well established by CRESIS.
    - Radar data will be stored on the Open Polar Server at University of Kansas and COLDEX will maintain a record of COLDEX related data sets stored there. This is in progress for the first field season's data sets, pending adjustment of file formats to match the CRESIS system. After this first post-fieldwork cycle is complete, we will evaluate the success of current infrastructure and consider any needed changes.

- *Milestone 8D: Investigate how new concepts of Open Science can be incorporated in COLDEX data streams and management*. Work towards this milestone is underway, including:
    - We gave a preliminary summary at the first annual COLDEX meeting in September 2022.
    - We are currently working on adding COLDEX 22/23 radar data to Open Polar Server.

Objective 9: Implement program of ethics training.

- *Milestone 9A: Establish an ethics policy and engage all members of COLDEX in ethics training.* This milestone was met by summer 2022 with the following actions:

- We created a Center-wide Integrity and Professional Ethics Plan modeled after the 2017 principles adopted by the American Geophysical Union.
- We provided access to research ethics on-line training modules through OSU for participants at institutions without similar systems and requirements.
- We provided access to third-party reporting system for reporting ethics issues to OSU Office of Audit, Risk, and Compliance.
- We provided contact information for reporting both research integrity and equity and sexual harassment issues for all COLDEX institutions in the Integrity and Professional Ethics Plan.

- *Milestone 9B: Deliver first training module on ethical behavior during field research before first COLDEX field season*. This milestone was met in Fall 2022, with the following activities led by the Director for DEI and the Director for Field Research and Data:
  - Field team best practices document adapted from the International Thwaites Glacier collaboration.
  - Field team inclusive leadership and culture pre-field meetings for each field team held in October 2022.
  - Bystander training provided prior to field deployment on October 11, 2022.
  - Post field survey, adapted from the International Thwaites Glacier collaboration, to provide feedback on success of these approaches was distributed to field team members (including alternates) on February 24, 2023.

Objective 10: Create and maintain COLDEX Intellectual Property Plan.

- *Milestone 10A: Engage OSU IP and Licensing Office for assistance.* This milestone has been met, with the following activities:
  - Draft plan created, agreement and ratification obtained from all relevant participating institutions by mid-2022.
  - We plan to review and update the plan as needed.

6. Problems encountered and anticipated

No major problems were encountered in this reporting period.

VIII. CENTER-WIDE OUTPUTS AND ISSUES

1a. Publications

Published

1. Davidge, L., Steig, E. J., and Schauer, A. J.: Improving continuous-flow analysis of triple oxygen isotopes in ice cores: insights from replicate measurements. *Atmospheric Measurement Techniques* 15, 7337–7351, 2022. https://doi.org/10.5194/amt-15-7337-2022
2. Karplus, M.S., T.J. Young, S. Anandakrishnan, J.N. Bassis, E.H. Case, A.J. Crawford, Gold, L. Henry, J. Kingslake, A.A. Lehrmann, P.A. Montano, E.C. Pettit, T.A. Scambos, E.M. Sheffield, E.C. Smith, M. Turrin, and J.S. Wellner. 2023. Strategies to build a positive and inclusive Antarctic field work environment. *Annals of Glaciology*, 1-7. doi:10.1017/aog.2023.32
3. Z. Liu; C. He; M. Yan; C. Buizert; B. Otto-Bliesner; F. Lu; C. Zeng: Reconstruction of past Antarctica temperature using present seasonal d18O-inversion layer temperature: Unified Slope Equations and Applications, Journal of Climate 36:2933-2957, 2023.
4. Ng, J. (2023). Climate insights from below and to the left: Noble gas constraints on groundwater recharge, dating Antarctic Oldest Ice, and colonial geoscience in the energy transition [Doctoral dissertation, University of California San Diego]. ProQuest Dissertations Publishing.
5. Roop, H.A. (2023). The Climate Action Handbook: A visual guide to 100 climate solutions for everyone. Penguin Random House. Pp272
6. Shuai Yan, Donald D. Blankenship, Jamin S. Greenbaum, Duncan A. Young, Lin Li, Anja Rutishauser, Jingxue Guo, Jason L. Roberts, Tas D. van Ommen, Martin J. Siegert, Bo Sun; A newly discovered subglacial lake in East Antarctica likely hosts a valuable sedimentary record of ice and climate change. *Geology* 2022; doi: https://doi.org/10.1130/G50009.1

In review

1. Bruns, C. J., & Andersen, I. V. The Worth of Nature: Valuations of Glaciers in Alaskan and Norwegian Media Discourse. Currently R&R at *Environmental Communication*, due for re-submission July 1.
2. Fudge, T. J., Sauvage, R., Vu, L., Hills, B. H., Severi, M., and Waddington, E. D.: Effective diffusivity of sulfuric acid in Antarctic ice cores, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-1219, 2022.
3. Ng, J., Bay, R, Severinghaus, J. Evaluating marine dust records as templates for optical dating of Oldest Ice. *Climate of the Past*, submitted.
4. Patterson, J.D., M. Aydin, A.M. Crotwell, G. Pétron, J.P. Severinghaus, P. B. Krummel, R.L. Langenfelds, V.V. Petrenko, and E.S. Saltzman, Reconstructing atmospheric H2 over the past century from bi-polar firn air records, *Climate of the Past*, submitted

1b. Conference Presentations

1. W. Abshire, E. A. Baugher, E. Mills, and B. Blair, 2022: Climate Education Resources and Opportunities for Faculty, Undergraduate Students and K-12 Teachers! AGU Fall Meeting. Paper Number: ED15C-0373
2. Murat Aydin, Methyl chloride measurements from Antarctic ice cores covering the last 55 thousand years, US Open Science Ice Core Meeting, 2023
3. E.Brook, C.Buizert, D.Whittaker, E.Pettit, H.Roop, J.Severinghaus, J.Higgins, M.Koutnik, P.Neff, and K.Rahilly: The Center for Oldest Ice Exploration (COLDEX) and Opportunities for International Collaboration, IPICS 3rd open science conference, Oct 2-7 2022, Crans-Montana, Switzerland
4. E.Brook, C.Buizert, D.Whittaker, E.Pettit, H.Roop, J.Severinghaus, J.Higgins, M.Koutnik, P.Neff, and K.Rahilly: The Center for Oldest Ice Exploration (COLDEX): Science plans and opportunities for community involvement, AGU Fall meeting, Dec 12-16, Chicago IL. C36B-05.
5. Brown, Noah. Preliminary ice fabric interpretations of polarimetric ApRES acquisitions at the Allan Hills, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023
6. Bruns, C. J., & Andersen, I. V. The Worths of Nature: Valuations of Glaciers in U.S. and Norwegian Media Discourse. European Communication Research and Education Association, Aarhus, Denmark, October 2022.
7. Bruns, C. J., Roop, H. A., & Huffman, D. Mapping the Future: Establishing a Relational Baseline for COLDEX Knowledge Exchange. American Geophysical Union. Virtual, December 2022.
8. Bruns, C. J. Reflections from the (Grape) Field: Integrating Community Wine and Climate Knowledge in Bottom-Up Research Design. American Geophysical Union. Virtual, December 2022.
9. Bruns, C. J. Wine, Water, and Ways of Life: Mapping Community Wine Knowledge in Andalucía, Spain. International Environmental Communication Association. Harrisonburg, VA, June 2023.
10. Bruns, C. J., Roop, H. A., & Huffman, D. Storying Polar Landscapes: U.S. Newspaper Discourses of Antarctica in the 21st Century. International Environmental Communication Association. Harrisonburg, VA, June 2023.
11. Buizert, Liu and He: Reconciling the Antarctic temperature – d18O relationship on different time- and spatial scales, IPICS 3rd open science conference (Oct 2-7, 2022), Crans Montana, Switzerland.
12. Buizert, Liu and He: Reconciling the Antarctic temperature – d18O relationship on different time- and spatial scales, INQUA Congress (July 14-20, 2022), Rome, Italy
13. Jenn Campos Ayala, Biomass Burning throughout the Holocene: an acetylene record from Greenland and Antarctica, US Open Science Ice Core Meeting, 2023
14. Carter, Austin. Ice core record of mineral dust variability across the MIS 6 to 5e transition at the Allan Hills, East Antarctica. 2nd US Ice Core Open Science Meeting, May 2023.

15. Carter, Austin. Ice core record of mineral dust variability across the MIS 6 to 5e transition at the Allan Hills, East Antarctica. International Partnerships in Ice Core Sciences. October 2022, Crans-Montana, Switzerland (Oral).
16. Conway, Howard. COLDEX site selection for a continuous deep ice core dating back to +1 Ma at the Allan Hills. 2nd US Ice Core Open Science Meeting, May 2023.
17. Lindsey Davidge et al. Developing a continuous-flow method for triple oxygen isotope analysis by laser absorption spectroscopy. International Partnerships in Ice Core Science (IPICS) Meeting 2022
18. Davidge, Lindsey. High-resolution water isotope variability in a >1Ma discontinuous blue-ice core from the Allan Hills, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023.
19. Eves, D., et al. (2022). Examining Fine-Scale Greenhouse Gas and Water Isotopic Variability in Shallow Drill Core Samples from the Allan Hills Blue Ice Area. Fall Meeting 2022, AGU. C32D-0859.
20. T.J. Fudge, Raphael Sauvage, Linh Vu, Benjamin Hills, Mirko Severi, and Ed Waddington, Effective diffusivity of sulfate in Antarctic ice cores, International Partners in Ice Core Science Open Science Meeting, 2022
21. Shahzad Gani et al. including H.A. Roop. The shadowlands of science communication in academia – definitions, problems, and possible solutions. EGU General Assembly, April 2023.
22. John Goodge: Participant and invited Keynote Speaker at the 3rd International Partnerships in Ice Core Sciences meeting, Crans-Montana, Switzerland, Oct 2-7. Title of presentation: “Beyond ice coring — wide aperture exploration of the deep ice sheets”
23. Nicholas Holschuh, Gordon Ariho, Knut Christianson, Andrew Hoffman, John Paden. Catchment-Scale Measurement of Englacial Deformation in Greenland. AGU Fall Meeting, 2022.
24. Kerr, M., D. Young, T. G. Richter, D. D. Blankenship, D. Buhl, K. Chan, J. Greenbaum, S. Kaundinya, S. Kempf, M. Liu-Schiaffini, G. Ng, J. Paden and S. Yan, 2023, Geophysical mapping of the southern flank of Dome A, Antarctica: Initial results from the inaugural COLDEX airborne survey, INStabilities and Thresholds in ANTarctica Conference 2023
25. Kerr, M., D. Young, T. G. Richter, D. D. Blankenship, D. Buhl, K. Chan, J. Greenbaum, S. Kaundinya, S. Kempf, M. Liu-Schiaffini, G. Ng, J. Paden and S. Yan, 2023, Geophysical mapping of the southern flank of Dome A, Antarctica: Initial results from the inaugural COLDEX airborne survey, IUGG Berlin 2023
26. Kerr, Megan. COLDEX geophysical mapping of the southern flank of Dome A, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023.
27. Kirkpatrick, Liam. Next Generation Electrical Conductivity Measurements of Thin and Disturbed Layering. 2nd US Ice Core Open Science Meeting, May 2023.
28. Lowes-Bicay, Haley. Water isotope variability between two sides of a deformed and stratigraphically complex ice core from the Allan Hills, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023.
29. Manos, John-Morgan. Using Distributed Temperature Sensing for Ice Borehole Thermometry. 2nd US Ice Core Open Science Meeting, May 2023.

30. Ellen Mutter and Nicholas Holschuh. Comparing Radar Data from Deep Ice Core Sites with Observed Physical Ice Core Properties to Evaluate How Subsurface Scattering Reflects Ice Core Site Suitability. AGU Fall Meeting, 2022.
31. Jessica Ng, Jeffrey Severinghaus, Ryan Bay. "Marine dust records as templates to date 1.5 Ma ice", AGU Fall Meeting, 2022
32. John Patterson, Reconstructing atmospheric H2 over the past century from bi-polar firn air records, US Open Science Ice Core Meeting, 2023
33. Julia Marks-Peterson et al, “Greenhouse gas record from the Allan Hills Blue Ice Area for the penultimate deglaciation and last interglacial period”. International Partnerships in Ice Core Science (IPICS), Oct. 2022, Switzerland.
34. Peterson, J. M., et al. (2022). New early Pleistocene atmospheric carbon dioxide and methane data from the Allan Hills Blue Ice Area, Antarctica. Fall Meeting 2022, AGU. C36B-06
35. Peterson, Julia Marks. New early Pleistocene atmospheric carbon dioxide and methane data from the Allan Hills Blue Ice Area, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023.
36. Powers, L., Kurbatov, A., Kershaw, C., Hargreaves, G., Labombard, C., and Fudge, T. J.: The next generation U.S. National Science Foundation Ice Core Facility: supporting state-of-the-art science., EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-1684, https://doi.org/10.5194/egusphere-egu23-1684, 2023.
37. Priestly, R., Roop, H.A., & Salmon, R. Public engagement with Antarctica in a changing climate. (session convened at SCAR Open Science Meeting 2022)
38. Rahilly, K. E., et al. (2022). Bringing the Search for Oldest Ice to Classrooms and Early Career Researchers Through COLDEX, a new NSF Science and Technology Center. Fall Meeting 2022, AGU. ED52A-02
39. Roop, H. A. "From Science to Action and Implementation: A Coordinated, Community-based Climate Resilience Extension Program in Minnesota (Union Session)," American Geophysical Union Fall Meeting American Geophysical Union, Chicago, Illinois. (December 15, 2022).
40. Roop, H.A. and Bruns, C.J. Media Engagement at the Ice Core Open Science Meeting. May 2023. Seattle, Washington, USA
41. Shaya, Marguerite. Preliminary ice fabric interpretations of polarimetric ApRES acquisitions at the Allan Hills, Antarctica. 2nd US Ice Core Open Science Meeting, May 2023
42. Shackleton, S., et al. (2022). Pliocene ice preserved in the Allan Hills Blue Ice Area (BIA), East Antarctica. Fall Meeting 2022, AGU. C32D-0858
43. Shackleton, Sarah. Molecular dynamics simulations of noble gas permeation in ice. 2nd US Ice Core Open Science Meeting, May 2023.
44. Singh, Shivangini. Linking South Pole and Dome A using englacial stratigraphy: A COLDEX perspective. 2nd US Ice Core Open Science Meeting, May 2023.
45. Shivangini Singh. Englacial stratigraphy at Dome A, Antarctica derived using airborne radar-sounding surveys: A COLDEX perspective. National Conference on Polar Sciences 2023, Goa, India

46. Dale P. Winebrenner, Justin Burnett, Ben Brand, Ryan Bay, Madison Pickett, and W. Timothy Elam. An Instrumented Melt Probe Scheduled for Deployments to 3 Kilometers Depth in Greenland and Antarctica Starting in Summer 2023. (presented at the Astrobiology Science Conference, May 2022, Atlanta, GA)
47. D.P. Winebrenner, R.C. Bay, and N.E. Bramall. Toward vertical profiling of organics in planetary ices with economical use of spacecraft resources. 2023 Lunar and Planetary Science Conference.
48. D.P. Winebrenner, J. Mikucki, C. Schuler, W.T. Elam, J. Burnett, B. Brand, M. Pickett, M. Smith and S. Howell, Accessing Microhabitats in Ice (In Terrestrial Analogs and On Ocean Worlds), presented at the Keck Institute for Space Studies Workshop on Ice Microhabitats, September 2022, Pasadena, CA.
49. D.P. Winebrenner, J. Burnett, B. Brand, M. Pickett, and W.T. Elam. COLDEX Development and Deployment of the University of Washington Ice Diver, presented at the Jet Propulsion Laboratory Cryobot Workshop, February 2023, Pasadena, CA.
50. Yan, S., D. D. Blankenship, M. Kerr, L. Beem, J. S. Greenbaum and D. A. Young, 2022, Geologic controls on subglacial thermal conditions and old ice preservation from a COLDEX perspective – insights from East Antarctic airborne geophysical surveying, Fall AGU Meeting
51. Yan, Shuai. Constraining past ice flow using englacial radio-stratigraphy and numerical modeling - examples from previous East Antarctic aero-geophysical surveying. 2nd US Ice Core Open Science Meeting, May 2023.
52. Young, D. A., S. Yan, J. D. Paden, J. S. Greenbaum, D. D. Blankenship, D. Buhl, G. Ng, M. Kerr, S. Kaundinya, F. Rodriguez-Morales, R. Hale, E. Arnold, J. W. Goodge, M. Koutnik, T. J. Fudge, K. A. Christianson, H. Conway, D. P. Winebrenner, N. Holschuh, P. D. Neff, J. P. Severinghaus and a. E. J. Brook, 2022, The COLDEX regional aerogeophysical survey for oldest ice core candidate site selection: plans for 2022/23, Fall AGU Meeting
53. Young, D., J. Paden, M. Kerr, S. Singh, S. Kaundinya, D. Buhl, J. Greenbaum, D. Blankenship, G. Ng, S. Kempf, P. Neff, T. Fudge, M. Koutnik, J. Severinghaus and E. Brook, 2023, The initial COLDEX aerogeophysical survey of Southern Dome A: Overview and prospects, INStabilities and Thresholds in ANTarctica Conference 2023
54. Young, D., J. Paden, M. Kerr, S. Singh, S. Kaundinya, D. Buhl, J. Greenbaum, D. Blankenship, G. Ng, S. Kempf, P. Neff, T. Fudge, M. Koutnik, J. Severinghaus and E. Brook, 2023, The initial COLDEX aerogeophysical survey of Southern Dome A: Overview and prospects, IUGG Berlin 2023
55. Young, D., J. Paden, M. Kerr, S. Singh, S. Kaundinya, D. Buhl, J. Greenbaum, D. Blankenship, G. Ng, S. Kempf, P. Neff, T. Fudge, M. Koutnik, J. Severinghaus and E. Brook, 2023, The initial COLDEX aerogeophysical survey of Southern Dome A: Overview and prospects, US Ice Core Open Science Meeting.

1c. Other Dissemination Activities

1. Bay, R. Neutrino astronomy, paleoclimatology and astrobiology in Antarctica. Lawrence Livermore National Laboratory Seminar, February 17, 2023.

2. Brook, E, 2023, Exploring the intersection of deep ice coring and marine based sedimentary records around Antarctica, Future Direction for Southern Ocean and Antarctic Nearshore and Coastal Research, National Academy of Sciences Community Workshop, February 9-10, 2023.
3. Bruns, C. J. Rising Seas: Representations of Climate Change and Antarctica in U.S. Newspaper Coverage. University of Minnesota Water Network. Virtual, May 5, 2023.
4. Bruns, C. J. Chair of the Graduate Student Pre-Conference at the International Environmental Communication Association. Harrisonburg, VA, June 5, 2023.
5. Conway, H., & Brook, E. (2023) "2022-23 Allan Hills Intermediate Ice Core Site Selection Field Report" U.S. Antarctic Program (USAP) Data Center. doi: https://doi.org/10.15784/601697.
6. Nicholas Holschuh. The Dynamics and Deformation History of Earth's Oldest Ice. – UMass Amherst, Geosciences Colloquium, 11/04/2022
7. Nicholas Holschuh. Between the surface and the substrate: measuring glacier deformation and sliding in real time. Five College Geology Faculty Symposium, 11/10/2022 (The Five College Geology Faculty Symposium brings together faculty and students from UMass Amherst, Amherst College, Smith College, Mount Holyoke College, and Hampshire College)
8. Roop, H.A. 21st Climate Change and Emergency Preparedness: Impacts, Actions & Partnership for Improved Health Outcomes. Annual Preparedness Collaborative, Brooklyn Center, MN, March 2023.
9. Roop, H.A. Climate change expert testimony to the State of Minnesota Legislature. 1/4/2023; 3/7/2023
10. Roop, H.A. From Climate Impacts to Action: Working Across the Urban and Rural Landscapes. Keynote Ag/Urban Forum, Saint Cloud, Minnesota. March 2023.
11. Shackleton, S., & Brook, E. (2023) "Allan Hills 2022-23 Shallow Ice Core Field Report" U.S. Antarctic Program (USAP) Data Center. doi: https://doi.org/10.15784/601696.
12. Young, D. A. COLDEX and the Search for Antarctica's Million Year Old Ice, South Pole Station Science Lecture, January 12, 2023, Amundsen-Scott Station, South Pole, Antarctica

2. Awards and Honors

	Recipient	Award Name and Sponsor	Date	Award Type
1.	Sarah Aarons	Geochemical Society, F. W. Clarke Medal	Feb 2023	Scientific
2.	Donald Blankenship	UTIG Directors Circle of Excellence	May 2022	Scientific
3.	Christo Buizert	Alfred P. Sloan, 2023 Sloan Research Fellow	Feb 2023	Scientific
4.	Catherine J. Bruns	Graduate Student Scholarship Award, Department of Communication Studies, University of Minnesota	May 2023	Education-related
5.	Catherine J. Bruns	Hella Mears Graduate Fellowship, Center for German & European Studies, University of Minnesota	Summer 2023	Fellowship
6.	Catherine J. Bruns	Summer Fellowship, Literacy & Rhetorical Studies, University of Minnesota	Summer 2023	Fellowship
7.	Catherine J. Bruns	Fellowship, Environmental Humanities Initiative, University of Minnesota	AY 2022-23	Fellowship
8.	Kristian Chan	UTIG outstanding graduate student award	Spring 2023	Scientific
9.	Kristian Chan	UTIG graduate student fellowship	Summer 2023	Fellowship
10.	Nick Holschuh	Max and Etta Lazerowitz Lectureship: Amherst College	02/27/23	Other
11.	Nick Holschuh	2022 Outstanding Reviewer Citation - Geophysical Research Letters: American Geophysical Union	05/22/23	Other

	Recipient	Award Name and Sponsor	Date	Award Type
12.	Austin Carter	ARCS Foundation Fellowship Award	Sept. 2023	Scientific

3. Undergraduate, M.S. and Ph.D. students who graduated during the reporting period

- Annika Horlings, University of Washington: PhD, 2023
- Lindsay Davidge, University of Washington: PhD, 2023
- Jessica Ng, University of California San Diego: PhD, 2022
- Jessica Badgeley, University of Washington: PhD, 2022
- Shuai Yan, University of Texas: PhD, 2023

4a. General outputs of knowledge transfer activities

None to report.

4b. Other outputs of knowledge transfer activities

None to report.

5. Participants

	Last Name	First Name	Position	Institution	Department
1	Brown	Noah	a	University of Washington	
2	Bucco	Angelina	a	University of Maine	
3	Choi	Alissa	a	University of Wisconsin Madison	
4	Chu	Hoang	a	Community College of Allegheny County	
5	Eves	Demetria	a	Cal State Long Beach	
6	Fenton	Melyssa	a	Oregon State University	
7	Forshee	Olivia	a	Macalester College/UMN Twin Cities	
8	Fouche	Eads	a	Amherst College	
9	Gollette	Sa'angna	a	University of New Mexico	
10	Goswami	Anusha	a	University of California, San Diego	
11	Leon	Rhys-Jasper	a	University of California, Irvine	
12	Lowes-Bicay	Haley Mayana	a	University of Washington	
13	Mayo	Elizabeth	a	Rutgers University	
14	Miller	Sebastian	a	Oregon State University	
15	Mutter	Ellen	a	Amherst College	
16	O'Reilly	Jamie	a	Red Rocks Community College	
17	Rampton	Ian	a	Pepperdine University	
18	Rice	Emily	a	Oregon State University	
19	Sheth	Trisha	a	University of Kansas	
20	Suen	Kyle	a	University of California, Irvine	
21	Vega	Alejandra	a	University of Puerto Rico	
22	Wexler	Caroline	a	University of Connecticut	
23	Andreasen	Julia	b	University of Minnesota, Twin Cities	Earth and Environmental Sciences

24	Badgeley	Jessica	b	University of Washington	Earth and Space Sciences
25	Bruns	Cate	b	University of Minnesota, Twin Cities	Communication Studies
26	Campos-Ayala	Jenn	b	University of California, Irvine	Earth System Science
27	Carter	Austin	b	University of California, San Diego	Scripps Institution of Oceanography
28	Chan	Kristian	b	University of Texas	Institute of Geophysics
29	Davidge	Lindsey	b	University of Washington	Earth and Space Sciences
30	Dey Sarkar	Utsa	b	University of Kansas	Center for Remote Sensing of Ice Sheets
31	Edwards	Jon	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
32	Gadrani	Lela	b	University of Maine	Climate Change Institute
33	Horlings	Annika	b	University of Washington	Earth and Space Sciences
34	Hudak	Abigail	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
35	Huffman	Demie	b	University of Minnesota, Twin Cities	Land and Atmospheric Science
36	Ishraque	Fairuz	b	Princeton University	Geosciences
37	Jacob	Skyler	b	University of Kansas	Aerospace Engineering, Center for Remote Sensing of Ice Sheets
38	Jurgilewicz	Annika	b	University of California, Irvine	Earth System Science
39	Kaundinya	Shravan	b	University of Kansas	Center for Remote Sensing of Ice Sheets
40	Kerr	Megan	b	University of Texas	Institute of Geophysics
41	Kirkpatrick	Liam	b	University of Washington	Earth and Space Sciences
42	Manos	John-Morgan	b	University of Washington	Earth and Space Sciences
43	Marks Peterson	Julia	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
44	Martin	Kaden	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
45	Miranda	Miranda	b	University of California, Irvine	Earth System Science
46	Morgan	Jacob	b	University of California, San Diego	Scripps Institution of Oceanography
47	Ng	Jessica	b	University of California, San Diego	Scripps Institution of Oceanography
48	Riddell-Young	Ben	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
49	Shaya	Margot	b	University of Washington	Earth and Space Sciences
50	Singh	Shivangini	b	University of Texas	Institute of Geophysics

51	Williams	Olivia	b	Oregon State University	College of Earth, Ocean, & Atmospheric Science
52	Yan	Shuai	b	University of Texas	Institute of Geophysics
53	Aarons	Sarah	c	University of California, San Diego	Scripps Institution of Oceanography
54	Abshire	Wendy	c	American Meteorological Society	
55	Albert	Mary	c	Dartmouth College	Thayer School of Engineering
56	Arnold	Emily	c	University of Kansas	Aerospace Engineering
57	Aydin	Murat	c	University of California, Irvine	Earth System Science
58	Bay	Ryan	c	University of California, Berkeley	Physics
59	Bender	Michael	c	Princeton University	Geosciences
60	Blankenship	Don	c	University of Texas	Institute of Geophysics
61	Bouma-Gearhart	Jana	c	Oregon State University	Science Education
62	Brook	Edward	c	Oregon State University - Director	College of Earth, Ocean, & Atmospheric Science
63	Buizert	Christo	c	Oregon State University	College of Earth, Ocean, & Atmospheric Science
64	Christianson	Knut	c	University of Washington	Earth and Space Sciences
65	Conway	Howard	c	University of Washington	Earth and Space Sciences
66	Fudge	TJ	c	University of Washington	Earth and Space Sciences
67	Goodge	John	c	University of Minnesota, Duluth	Earth and Environmental Sciences
68	Greenbaum	Jamin	c	University of California, San Diego	Scripps Institution of Oceanography
69	Hale	Richard	c	University of Kansas	Aerospace Engineering, Center for Remote Sensing of Ice Sheets
70	Hastings	Meredith	c	Brown University	Earth, Environmental, and Planetary Sciences
71	Higgins	John	c	Princeton University	Geosciences
72	Holschuh	Nick	c	Amherst College	Geology
73	Huffman	Louise	c	Dartmouth College	Thayer School of Engineering
74	Kauffman	Chad	c	American Meteorological Society	
75	Koutnik	Michelle	c	University of Washington	Earth and Space Sciences
76	Kurbatov	Andrei	c	University of Maine	Climate Change Institute
77	Mayewski	Paul	c	University of Maine	Climate Change Institute

78	Mills	Beth	c	American Meteorological Society	
79	Neff	Peter	c	University of Minnesota, Twin Cities	Soil, Water, and Climate
80	Paden	John	c	University of Kansas	Center for Remote Sensing of Ice Sheets
81	Pettit	Erin	c	Oregon State University	College of Earth, Ocean, & Atmospheric Science
82	Rahilly	Kristen	c	Oregon State University	College of Earth, Ocean, & Atmospheric Science
83	Rodriguez-Morales	Fernando	c	University of Kansas	Aerospace Engineering, Center for Remote Sensing of Ice Sheets
84	Roop	Heidi	c	University of Minnesota, Twin Cities	Soil, Water, and Climate
85	Saltzman	Eric	c	University of California, Irvine	Earth System Science
86	Severinghaus	Jeff	c	University of California, San Diego	Scripps Institution of Oceanography
87	Steig	Eric	c	University of Washington	Earth and Space Sciences
88	Waddington	Ed	c	University of Washington	Earth and Space Sciences
89	Whittaker	Danielle	c	Oregon State University	College of Earth, Ocean, & Atmospheric Science
90	Winebrenner	Dale	c	University of Washington	Earth and Space Sciences
91	Young	Duncan	c	University of Texas	Institute of Geophysics
92	Buhl	Dillon	e	University of Texas	Institute of Geophysics
93	Burnett	Justin	e	University of Washington	Applied Physics Laboratory
94	Echeverry	Gonzalo	e	University of Texas	Institute of Geophysics
95	Eidsmoe Torris	Patricia	e	Oregon State University	College of Earth, Ocean, & Atmospheric Science
96	Gili	Stefania	e	Princeton University	Geosciences
97	Hayden	Jonathan	e	Princeton University	
98	Hargreaves	Geoffrey	e	NSF Ice Core Facility	
99	Hishamunda	Valens	e	Princeton University	Geosciences
100	Jarvis	Stephanie	e	Oregon State University	College of Earth, Ocean, & Atmospheric Science
101	Jayred	Mike	e	US Ice Drilling Program	
102	Kalk	Mike	e	Oregon State University	College of Earth, Ocean, & Atmospheric Science

103	Kempf	Scott	e	University of Texas	Institute of Geophysics
104	La Bombard	Curtis	e	NSF Ice Core Facility	
105	Laverentz	Jennifer	e	University of Kansas	Center for Remote Sensing of Ice Sheets
106	Morton	Elizabeth	e	US Ice Drilling Program	
107	Ng	Gregory	e	University of Texas	Institute of Geophysics
108	Nunn	Richard	e	NSF Ice Core Facility	
109	Paden	Aaron	e	University of Kansas	Center for Remote Sensing of Ice Sheets
110	Schauer	Andrew	e	University of Washington	Earth and Space Sciences
111	Schroeder	Brad	e	University of Kansas	Aerospace Engineering, Center for Remote Sensing of Ice Sheets
112	Sliwinski	Maciej	e	University of Washington	Earth and Space Sciences
113	Smoak	Erin	e	American Meteorological Society	
114	Stimach	Abby	e	American Meteorological Society	
115	Banerjee	Asmita	f	Oregon State University	College of Earth, Ocean, & Atmospheric Science
116	Berdahl	Mira	f	University of Washington	Earth and Space Sciences
117	Patterson	John	f	University of California, Irvine	Earth System Science
118	Shackleton	Sarah	f	Princeton University	Geosciences
119	Wendt	Katie	f	Oregon State University	College of Earth, Ocean, & Atmospheric Science

6. Summary listing of all the Center's research, education, knowledge and other institutional partners

	Organization Name	Type	Address	Contact Name	Type of Partner	160 hours?
1.	Earth Science Women's Network	Other	https://eswnonline.org/	Meredith Hastings	Diversity, Education	Y
2.	Inspiring Girls Expeditions	Other	https://www.inspiringgirls.org/	Erin Pettit	Diversity, Education	Y
3.	US Ice Drilling Program	Other	https://icedrill.org/	Mary Albert	Research, Education	Y
4.	Hercules Dome Project	Other	https://herculesdome.org/about	Eric Steig	Research, Education	N
5.	Ice Core Working Group	Other	https://icedrill.org/about/science-advisory-board/ice-core-working-group	TJ Fudge	Research	N
6.	International Partnerships in Ice Core Sciences	Other	https://pastglobalchanges.org/science/end-aff/ipics/intro	Ed Brook, John Higgins, Jeff Severinghaus	Research	N
7.	Polar Science Early Career Community Office (PSECCO)	Other	https://psecco.org/	Mariama Dryak-Vallies	Diversity, Education	N
8.	US Association of Polar Early Career Scientists (USAPECS)	Other	https://usapecs.wixsite.com/usapecs	Kristen Rahilly	Diversity, Education	N
9.	Interagency Arctic Research Policy Committee (IARPC)	Other	https://www.iarpccollaborations.org/index.html	Liz Weinberg	Diversity, Education	N

7. Summary Table

1	The number of participating institutions (all academic institutions that participate in activities at the Center) This value should match the number of institutions listed in Section I, Item 1 of the report plus other additional academic institutions that participate in Center activities as listed in the table above.	14
2	The number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center) This value should match the number of partners listed in the table in Section VIII, Item 6 (above)	9
3	The total leveraged support for the current year (sum of funding for the Center from all sources *other* than NSF-STC) [Leveraged funding should include both cash and in-kind support that are related to Center activities, but not funds awarded to individual PIs.] This value should match the total of funds in Section X, Item 4 of "Total" minus "NSF-STC" for cash and in-kind support	$248,750
4	The number of participants (total number of people who utilize center facilities; not just persons directly supported by NSF). Please EXCLUDE affiliates (click for definition) This value should match the total number of participants listed in Section VIII, Item 5 (above)	119

8. Media Publicity

Notable media publicity from this reporting period includes:

- 4/1/23: “Scientists drill for oldest ice to reveal secrets about Earth’s climate.” COLDEX graduate student Julia Marks Peterson’s photo of the Allan Hills field site was featured on the issue cover. Physics Today. https://pubs.aip.org/physicstoday/article/76/4/18/2879453/Scientists-drill-for-oldest-ice-to-reveal-secrets
- 3/12/23: “Why East Antarctica is a ‘sleeping giant’ of sea level rise.” BBC. https://www.bbc.com/future/article/20230309-climate-change-the-sea-level-rise-locked-in-east-antarctica
- 3/1/23: “Can TikTok Save Antarctica? No, but “@Icy_Pete” shows what it CAN do.” Sustain What? Podcast. https://www.youtube.com/watch?v=3tTrdfbX9Pk
- 2/9/23: “Inside the Race to Find Earth’s Oldest Ice.” Scientific American. https://www.scientificamerican.com/article/inside-the-race-to-find-earths-oldest-ice/
- 2/6/23: “As Antarctic Fieldwork Ends, a Sexual Harassment Reckoning Looms.” Undark. https://undark.org/2023/02/06/as-antarctic-fieldwork-ends-a-sexual-harassment-reckoning-looms/
- 1/19/23: “Finding the cold on a warming planet.“ Living Planet, Deutsche Welle. https://www.dw.com/en/finding-the-cold-on-a-warming-planet-balmy-winter-sports-chilly-supermarkets-and-ancient-ice-cores/audio-64454124
- 1/19/23: “OSU student joins team in Antarctica searching for world's oldest piece of ice.” NBC Affiliate KMTR. https://nbc16.com/news/local/osu-student-joins-team-in-antarctica-searching-for-worlds-oldest-piece-of-ice-oregon-state-university-climate-enviornmental-history
- 1/17/23: “Probing Antarctica by Land, Sea, Air, and from Earth Orbit.” UC San Diego Today. https://today.ucsd.edu/story/probing-antarctica-by-land-sea-air-and-from-earth-orbit
- 12/29/22: “Camera plunges down Antarctica borehole to reveal Earth's 'oldest ice.'” Sky News. https://news.sky.com/story/camera-plunges-down-antarctica-borehole-to-reveal-earths-oldest-ice-12776347
- 12/19/22: “Hunt begins for Antarctica's oldest ice.” The Antarctic Sun. https://antarcticsun.usap.gov/science/4742/
- 12/15/22: “What Polar Ice Tells Us About Climate Change with Peter Neff.” KMSU Every Day is Earth Day. https://share.transistor.fm/s/14bfac76
- 12/7/22: “Researchers studying oldest ice on Earth become first Antarctic field camp to use Starlink internet.” Fox Weather. https://www.foxweather.com/extreme-weather/coldex-antarctica-research-base-oldest-ice-starlink-internet-in-extreme-weather
- 12/5/22: “University of Minnesota researcher joins team to study oldest ice on the planet in Antarctica.” 830 WCCO. https://www.audacy.com/wccoradio/news/local/team-of-researchers-studying-oldest-ice-in-antarctica
- 11/23/22: “‘Climate heartbeat’: Scientists hunt for world’s oldest ice.” E&E News Climatewire. https://www.eenews.net/articles/climate-heartbeat-scientists-hunt-for-worlds-oldest-ice/

- 11/20/22: “Oregon State University-led effort to find Earth’s oldest ice begins this month in Antarctica.” Oregon State University press release. https://today.oregonstate.edu/news/oregon-state-university-led-effort-find-earth%E2%80%99s-oldest-ice-begins-month-antarctica
- 11/10/22: “2 Oak Park-River Forest H.S. Seniors are ‘first ever’ in grade level to be mentored by COLDEX: District officials.” Chicago Tribune. https://www.chicagotribune.com/suburbs/oak-park/ct-oak-oprfhs-coldex-mentorship-tl-1110-20221110-yzt43hijfvgerjoy5i72yuvcgi-story.html
- 11/7/22: “Behind the research: What the oldest Antarctic ice can tell us about climate change.” University of Minnesota press release. https://cfans.umn.edu/news/coldex-research
- 7/2/22: “University of Minnesota scientist brings Antarctic work home via TikTok.” Star Tribune. https://www.startribune.com/university-of-minnesota-scientist-brings-antarctic-work-home-via-tiktok/600187253/

IX. INDIRECT/OTHER IMPACTS

1. Please describe any international activities in which the Center has engaged. If they are described elsewhere in the report, highlight them here without going into great detail.

COLDEX participants Ed Brook, Jeff Severinghaus and Katie Wendt are on the steering committee for International Partnerships in Ice Core Sciences (IPICS), an international planning and collaboration network for ice coring. Brook was a member of the organizing committee for the IPICS Open Science Conference in Switzerland in October 2022 and represented COLDEX there. Several COLDEX participants gave oral and poster presentations at the October IPICS meeting. IPICS has an Oldest Ice working group and Brook and Severinghaus are long standing members - this group also met in October to share international plans. Brook is a former co-chair of IPICS.

Ed Brook and Christo Buizert collaborated with the Hercules Dome project, other US ice core researchers, and Canadian ice core researchers (Alison Criscietello at University of Alberta, Anais Orsi at University of British Columbia and Dorthe Dahl Jensen at University of Manitoba) to bid for sponsorship of the 2026 International Partners in Ice Core Science Conference, to be held in Banff, Canada. The bid is likely to be accepted based on informal communications but formal announcement is pending.

We previously reported that Brook has had preliminary discussions with Korean colleagues (Jinho Ahn at Seoul National University is our contact) about possible collaboration in the Elephant Moraine drilling plans in Antarctica (the Korean Antarctic program maintains a base near that location). They have shared some radar data and we are exploring a more formal arrangement - communications continue. Ahn has joined COLDEX as an “international affiliate,” an internal designation that recognizes collaborators with special interests in COLDEX science and active collaborations.

Yuzhen Yan, former Princeton graduate student who did foundational work on Allan Hills ice cores, has also become a COLDEX “international affiliate.” Yan is now a professor at Tongji University in Shanghai, China.

COLDEX director Ed Brook serves on external advisory committees for the Beyond EPICA-Oldest Ice project, the Australian Million Year Ice Program, and the European Deep Ice Training Network.

Christo Buizert and Ed Brook received a $5000 seed award from the OSU Office of International Affairs for internationalization efforts related to COLDEX. We are hosting visits of two graduate students from European/British labs (Ivo Strawson, University of Cambridge and Lison Saintsousssantjean from University of Bern) and one post doc (Andy Menking, CSIRO,

Australia) using these funds and funds the visitors obtained from their home institutions. We will be advertising an opportunity for COLDEX ECR participants to have reciprocal visits.

2. Please use this space to describe other outputs, impacts, or influences related to the Center's progress and achievement during the current reporting period that may not have been captured in another section of the report. (optional)

N/A