Center for Oldest Ice Exploration

ANNUAL REPORT

July 19, 2022

I. GENERAL INFORMATION

Date submitted:	July 19, 2022
Reporting period:	October 1, 2021 - September 30, 2022
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	Wendy Abshire
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.

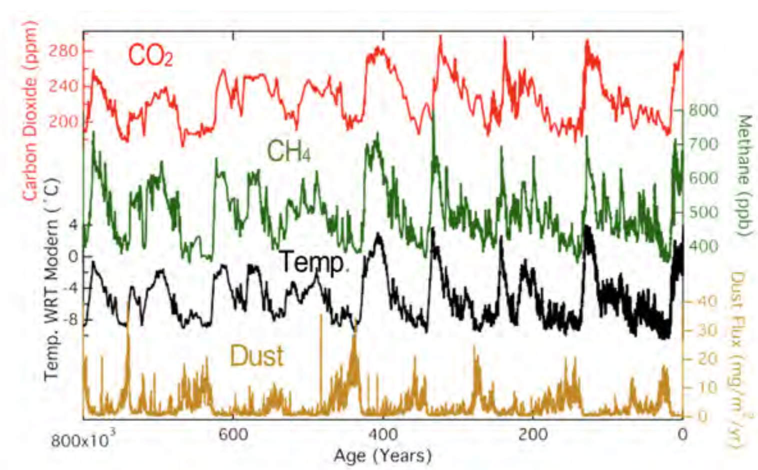

Figure I-1. Existing continuous history of atmospheric carbon dioxide, methane, Antarctic temperature, and dust, from EPICA Dome C and other ice cores.

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 very new data described in this report, provides a tantalizing view of a few older time periods back to 2.7 Ma B.P.

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 15 U.S. institutions 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. More details are available in the COLDEX Strategic and Implementation Plan.

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 sample archive for 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 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

During this reporting period, the Center made significant progress in planning research coordination and logistics, specifically the creation of a workflow document that plans for interdependencies between instrument development, data collection, and modeling (still in progress) and extensive planning both internally and with the Antarctic Support Contract (ASC) planners assigned to COLDEX to produce the COLDEX Operational Notice for Antarctic field work (complete but in final review). Design revisions for Ice Diver, a key piece of equipment for COLDEX research efforts, are progressing well as is design and fabrication of new radar systems. Design and fabrication of new radar systems will be complete for flight texting in August. Glaciological modeling is underway.

Research: Ice Coring and Ice Analysis

New data from 2019/20 ice cores collected at Allan Hills, a shallow drill site, are being used to inform site selection for the 2022/23 field season. Significantly, these new data suggest that the oldest samples so far from these ice cores are 4.1 million years old, highlighting the importance of this area for COLDEX research. Work is in progress on the centralized COLDEX laboratory at Oregon State University, and several analytical technologies are being improved, including argon and krypton isotope dating, hyperspectral imaging, and electrical conductivity measurements that can discern orientation of stratigraphic layers. Additional analyses on the 2019/20 ice cores are in progress. Efforts to develop a publicly accessible database and internal database are on track.

Diversity, Equity, and Inclusion

Director for DEI Erin Pettit has established mechanisms for regular community building during COLDEX meetings and events, and is working on a “sense of belonging” survey for members. A COLDEX DEI committee has been established, and plans for a COLDEX DEI Ambassador Team are in development. A survey to collect demographic data on COLDEX membership and has been distributed and response data will be compiled by September 2022. Leadership and cultural competency workshops are planned for summer 2022 and the September COLDEX meeting. A mechanism for reporting feedback and requesting mediation is in development. An equity in admissions and hiring workshop was held Fall 2021, and used to inform strategies for advertising graduate student admissions. COLDEX held an open “office hours” to support interested prospective students in the application process. The first stage of relationship building with MSI faculty outside of COLDEX is underway.

Education and Leadership Opportunities

The 2022 COLDEX-supported “School of Ice” (SOI), a professional development workshop for faculty from minority-serving institutions (MSIs) in collaboration with the Ice Drilling Program, is underway. Development of the “Project Ice” K-12 teacher education program, in collaboration with the American Meteorological Society is in progress, with the first event to be held in summer 2023. A pilot program of the COLDEX Research Experiences for Undergraduates (REU) program is underway in summer 2022, with a series of workshops coordinated by Director for Education Kristen Rahilly. The COLDEX Early Career Researcher (ECR) group has been formed and holds monthly meetings. The ECR group is also planning professional development activities. Progress is being made in a number of initiatives to integrate COLDEX research and education. Plans to evaluate COLDEX educational activities are underway but undergoing some revision (see below).

Knowledge Transfer

The Knowledge Transfer team, led by Director for Knowledge Transfer Heidi Roop, distributed and analyzed the results of the first Social Network Analysis of COLDEX participants, which will continue on a regular basis. A Strategic Communications Plan for the Center is in development. The creation of communication materials and assets to increase COLDEX Center participants' knowledge of COLDEX-related climate, education, knowledge transfer and other key research approaches and findings is in progress.

Management and Integration

The management structure of the Center has been established, including the hiring of three Director-level personnel (Director for Education Kristen Rahilly, Managing Director Danielle Whittaker, and Director for Field Research Data Peter Neff), and the establishment of regular meetings, report deadlines, and financial tracking systems. A search for an administrative assistant is near conclusion. The Executive Committee's role has been clearly defined. Communication systems have been established within the center and regular communication is maintained. The External Advisory Committee has been established and the charter finalized. Several Center policies are drafted or finalized, including the Integrity and Professional Ethics Policy, the Data Management Policy, and the Intellectual Property Plan.

II. RESEARCH

1a. 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 area of Exploration and Ice Sheet Modeling, and four in the area 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.

1b. Performance and management indicators.

Below, we list our performance and management indicators developed to assess our progress towards our Research objectives, and briefly note our progress towards these goals. For more details on progress, please see section 2.

Objective	Milestones	Progress
Exploration and Ice Sheet Modeling		
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	Develop a comprehensive and traceable workflow that plans for interdependencies between instrument development, data collection,	Workflow document in progress (M Koutnik, UW and Duncan Young, UTIG). Goal to complete by September 2022.

in situ information from Ice Diver, integrated with ice sheet modeling.	and modeling in order to clarify how multiple instruments and activities contribute to achieving the objectives.	
	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.	Relevant planning for logistics Operational Notice complete. Year 1 planning for airborne field campaign complete but see comments on risks and mitigation below. Test of new radar systems and integration of KU and UTIG radar scheduled for Calgary in August 2022.
	Acquire, process, and interpret ground-based radar and geophysical data in regions of interest.	Completed relevant planning for operational notice for ground-based field seasons in years 4 and 5 and planning for scope contingency ground-based season. Plans for new equipment acquisition complete.
	Construct, test and deploy Ice Diver vehicle for age vs. depth information in ground-based survey regions.	Design revisions from previous versions to operate at 4000V and 3000 m depth. Design revisions to incorporate dust logger. Detailed planning for commissioning and field operations. Construction begins in summer 2022.
	Conduct glaciological modeling that integrates geophysical and Ice Diver information to assess possible ice core sites.	Modeling CO_2 diffusion to understand preservation of signals. Planning for data-model integration in progress.
	Maintain connection with Rapid Access Ice Drill (RAID)	Ongoing discussions with COLDEX participants and

	project to identify possible use of RAID in COLDEX site selection.	RAID PIs John Goodge and Jeff Severinghaus.
	Integrate all available information to choose a site or sites for a deep ice core.	Workflow for model-data integration in progress.
Ice Coring and Ice Analysis		
1. Collect ice cores at ice margin sites.	Develop a set of site selection criteria for the Allan Hills and Elephant Moraine shallow drill sites, drill, and return ice cores.	Site selection discussions for the I-165 (Princeton) drilling in 22/23 at La Jolla ice core meeting, informed by new data from 2019-2020 cores. Final coring plan in progress. Existing radar data for Elephant Moraine obtained from Korean Polar Research Institute.
	Intermediate depth core drilled at Allan Hills (scope contingency in logistics planning as of April 2022).	Planning for ground-based radar acquisition relevant to site selection in 2022/23 field season. Extensive logistics planning for this possible activity.
2. Establish a workflow for building paleoclimate records in disturbed basal and ice margin samples.	Create centralized COLDEX laboratory for analyzing chemical parameters in COLDEX cores.	Laboratory infrastructure upgrades complete except for walk-in freezer (on order). New custom laser spectrometer specified in collaboration with Aerodyne technologies and ordered. Purchase of other equipment and set up of laboratory systems in progress.
	Develop initial ice core chronologies using argon and krypton isotope dating.	New ^{40}Ar atm dates from previously collected ice cores at Allan Hills, including several > 2.5 million years. Improvement of precision of dating.

	Develop hyperspectral imaging capabilities at NSF ICF with new camera equipment acquired by COLDEX.	Purchased hyperspectral camera and associated hardware, installed at NSF ICF. Initial testing complete.
	Refine ice core chronology and assess the stratigraphic orientation of ice samples using a suite of analytical techniques.	Initial tests of electrical conductivity measurements on Allan Hills cores from the last interglacial period (see narrative below).
	Increase throughput of dry extraction ice core CO_2 measurements.	Acquired some needed equipment. Further work begins in year 2.
3. Develop paleoenvironmental records and document sample archive for wider scientific community.	Develop publicly available metadata and data about core sites, analyses, and archived ice core samples.	“Landing page” for COLDEX created at USAP data center. Internal collection of previous field reports and existing data underway, including GPR data and core locations, for public release.
	Develop schedule of ice analysis, including technical and sample requirements for different labs, measurement plan, preliminary data availability, archive plan.	Development of core cutting plans and sample needs underway. Center data policies and archive plan in progress.
	Acquire basic chemical and imagery data for all COLDEX cores (stable isotopes, dust, soluble chemistry).	TBD after 2022/23 field season. Dust measurements for 2019/20 cores in progress at UCSD.
	Acquire records of greenhouse gases, other atmospheric constituents, dust, and radiogenic isotopes for COLDEX cores.	Analyses of previously collected cores from Allan Hills for greenhouse gases, noble gases, dust and radiogenic isotopes underway. Core processing to obtain additional samples for analysis planned for June 2022.

1c. Problems encountered and anticipated.

No major problems were encountered in this reporting period. In our strategic and implementation plan we identified potential barriers to success and outlined strategies to address them, as described in the following table. A more comprehensive analysis of logistics delays, equipment failure impacts and mitigating strategies for work in interior East Antarctica is in progress as part of the workflow analysis described in the strategic plan (Duncan Young, UTIG and Michelle Koutnik, UW), to be completed by September 2022.

Potential Barriers	Mitigating Strategies
Exploration and Ice Sheet Modeling	
Delays in building and testing new technology including supply chain issues, shipping delays and problems.	Frequent communication with Center leadership about possible delays; develop alternative suppliers. One identified risk factor which we do not have a mitigation plan for is not getting the modified antenna fairing for the KU accumulation radar certified by Transport Canada in time for the first season. The impact is that we would not be able to fly the Accumulation Radar in the first season. Based on positive discussions with Kenn Borek Air and their experience with aircraft certifications, we believe the probability is low and that our plan to certify by comparison using the previous supplemental type certificate (STC) will satisfy Transport Canada's requirements to certify the modified antenna fairing. We estimate the overall risk factor as medium risk since we rate the probability as low and the impact as high.
Delays in aircraft certification.	Develop back up plans that deploy a more limited set of instruments. Monitor timing with respect to shipping equipment to Antarctica; advance planning for commercial air shipping if needed.
Delays due to field logistics constraints (weather, COVID, other events).	Develop alternative plans that use more limited airborne and surface-based radar or defer work to later seasons. Maintain dual focus on ice margin and deep interior sites.
Short time for model-data integration.	As possible, develop codes in advance of new data collection and define model-relevant aspects of processed data products in advance.
Instrument failure in field work.	Field and bench testing. Identify back up instruments.
Industry pirating faculty and staff.	Cross training within groups to avoid dependence on one person.
Field participants not physically qualifying for field work.	Cross training within groups to avoid dependence on one person; identification of alternate participants. We have paid

	particular attention to alternate participants for the upcoming field season.
Student wages may not be competitive.	Prioritize access to professional development opportunities, conference travel funds, field opportunities, research seed funding, lab resources, and other grad-program enrichment opportunities. This issue arose in one case with an undergraduate this year.
UTIG's gravimeter (jointly owned by Transparent Earth Geophysics) has Russian origins, leading to issues of support and sustainability going forward given the ongoing conflict in Ukraine.	We are working with Transparent Earth Geophysics on identifying paths forward.
Quality and reliability of the Basler autopilot as a limitation on the likely success of the repeat interferometry technique.	We are working with KBA, NSF and other contacts on ways to mitigate this problem. We identified a low cost solution for a pilot guidance system that has been used before on Operation IceBridge and are moving forward with that.
USAP has released their FY23 Continental Acquisition plan - which puts the need date for cargo for our field season very close to our test flight in Canada.	May require more equipment being added to the COMAIR request list due to limited time for rework after the test flights. This situation is being monitored.
Ice Coring and Ice Analysis	
Delays due to field logistics constraints (weather, COVID, other events).	Shift analysis to existing samples. Prioritize coring sites within seasons to insure highest quality old ice sites are drilled first. Maintain communication with field teams. We are developing core site priorities for year 1 field work.
Poor ice core quality from margin sites.	Discrete sampling and analysis (water isotopes, chemistry, gas analysis) capabilities will be maintained. Attempt drilling with small column of drill liquid. Experiment with different types of cutters in drilling systems. Work with US Ice Drilling Program to experiment with other drilling methods to improve quality. Ongoing discussions about preparations for discrete measurements.
Stratigraphic disturbances are too severe to decipher.	Perform "paired" discrete analyses of ages, gas concentrations, and water isotopes. Initial work on spatial variability on small scales underway in summer 2022.
Lack of redundancy in analytical techniques required to develop	Identify colleagues outside and within COLDEX with comparable analytical capabilities. Maintain older equipment

paleoclimate archives.	to use as back up instruments.
Instrument failure.	Develop clear priority protocol for continuous flow analysis that determines when and how to proceed in case of instrument failure. Identify colleagues with comparable analytical capabilities. In progress.

2a. Research areas.

Exploration and Ice Sheet Modeling

Overview. Optimal outcomes for the Exploration and Modeling components of COLDEX are described above. Year 1 activities to date have largely been focused on preparing for field work taking place in the 2022/23 field season and following seasons, developing instrumentation to be used in COLDEX, and initial interpretations of existing radar and other data relevant to planning field activities and ultimately interpreting data and choosing core sites. 2022/23 field work in the Exploration component of COLDEX will include a broad airborne geophysical survey between South Pole and Dome A (operated from the South Pole Station), radar surveys in the Allan Hills focused on refining the core site for an intermediate depth ice core, and radar surveys in the Elephant Moraine region.

Specific activities and outcomes in year 1 are described further below for each Milestone listed in the performance and management indicators table (above).

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: 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.

Michelle Kountik (UW) and Duncan Young (UTIG) are leading the effort to create this workflow analysis. A more detailed analysis of risks associated with field delays and equipment failures will be incorporated in this effort, to be completed by the end of year 1.

Milestone: 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.

Airborne radar
Logistics planning leading to the Operational Notice that describes COLDEX field work was a major effort for the airborne geophysics groups led by John Paden (KU) and Duncan Young (UTIG). This effort included an extensive set of Zoom meetings with planners to refine and

define field logistics needs. These groups were also extensively involved in the Strategic and Implementation Plan process. Specific field preparations including Support Information Packages were completed. UTIG and KU implemented regular meetings to discuss joint concerns and planning for test flights with Ken Borek Air. UTIG and Jamin Greenbaum (Scripps Institution of Oceanography) are working on gravimeter instrumentation for airborne work. Flight line planning has continued and the current version of the broad survey flight line plan (Duncan Young, UTIG) is shown in Figure II-1. This plan will be refined to better align with flow lines for modeling purposes.

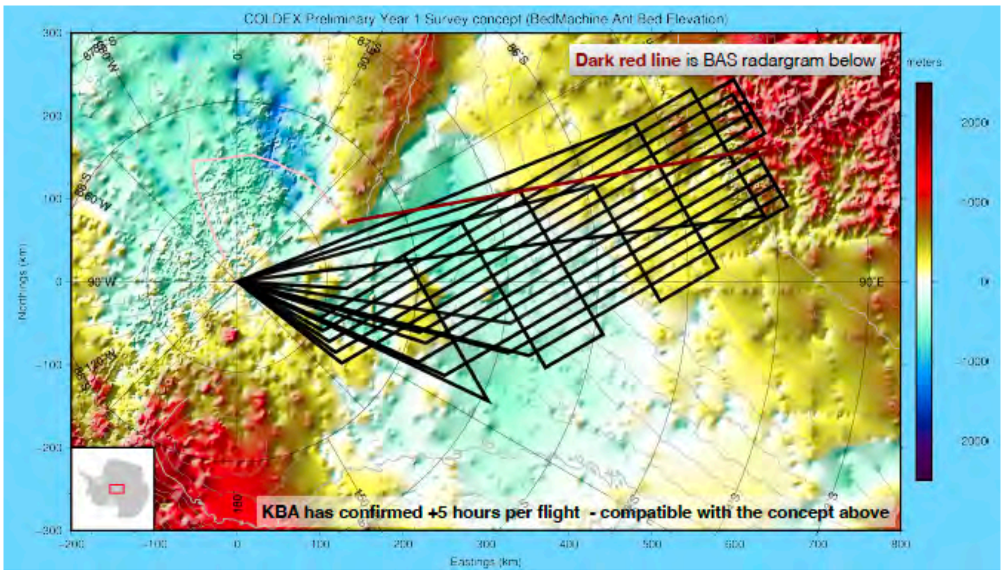

Figure II-1. COLDEX Preliminary year 1 broad survey flight line concept overlay on bed elevation. BAS radargram referred to in figure not shown here.

Part of COLDEX Exploration work involves building a new airborne radar system at the University of Kansas (KU) — a novel phase sensitive system deployed from the air (hereafter called “accumulation radar”) to be combined with the more traditional University of Texas systems for deployment in 2022/23 and 2023/24. Primary work involved planning and work on critical efforts in the KU radar development timeline, led by John Paden. KU contributed to the Operational Notice, Strategic Plan, and Support Information Package that are relevant to all of KU’s activities. KU made initial contact with Kenn Borek Air, who are handling aircraft operations. Critical issues with aircraft integration and test flights have been or are being addressed. KU also completed preliminary work on a link budget and system architecture for the Accumulation Radar, the primary instrument that KU is developing. Tasks with critical paths are the antenna fairing and the power amplifiers; more detail is provided below. KU also made progress on the field processing equipment (all parts have been acquired) and on the radar receiver design (design and part selection completed).

A primary engineering objective during the reporting period was the development of a detailed conceptual design of a UHF radar antenna array in the existing BT-67 or Basler aircraft fairing. The team is modifying this previous antenna fairing to fit a newly designed antenna array for COLDEX. They defined antenna element placement within the fairing as well as mechanical and electrical attachments. They developed several high-fidelity computer electromagnetic simulation models to perform trade studies geared toward achieving a good electrical performance while meeting airworthiness requirements. Figure II-2 shows some of these computer models detailing the distribution of the antenna elements and their mounting within the fairing structure. 64 dual-polarized antenna elements were accommodated into eight separate fairing bays. The antenna elements were grouped into 16 sets, each with 4 elements, resulting in 16 separate radar channels for a single polarization.

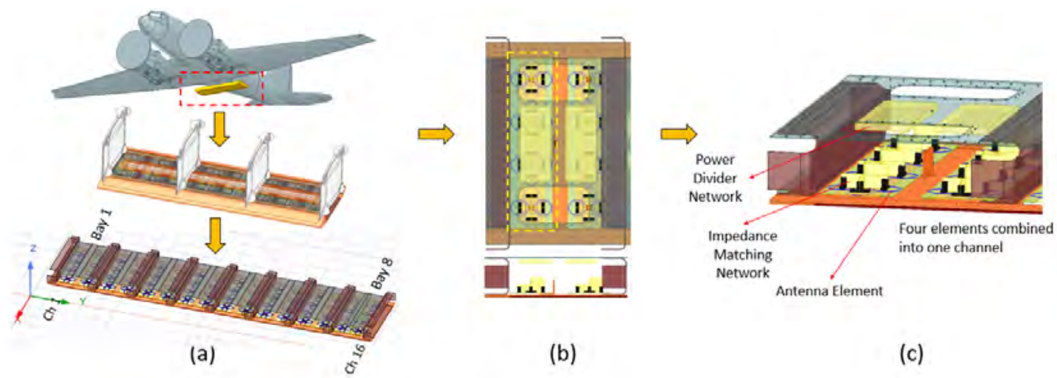

Figure II-2. Antenna array design showing the conceptual integration of the antenna elements inside the center fairing of the BT-67 aircraft (a). Model of the internal antenna placement within one bay with eight antenna elements (b); and detailed view of component.

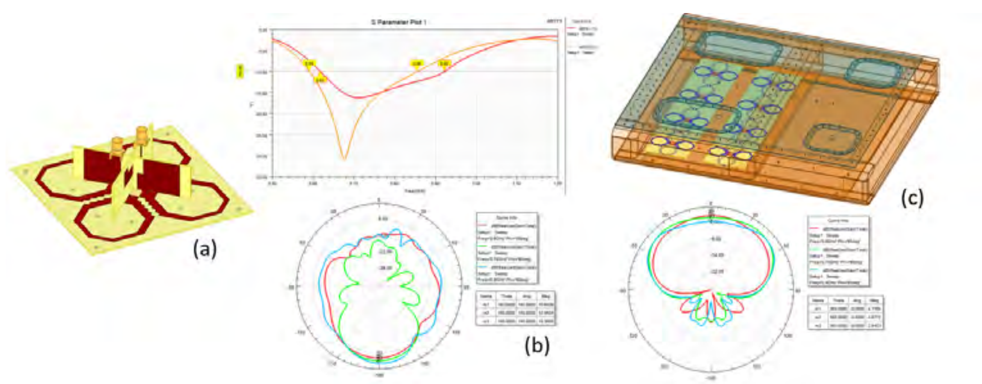

Figure II- 3. Electromagnetic simulation model for a single antenna element (a); with its simulated return loss and radiation pattern in free space (b). Model for an 8-element sub-array within the fairing and the simulated cross-track radiation pattern (c).

The left inset of Figure II-3 shows the model used for initial full-wave electromagnetic simulations on a single antenna element (a) and the results produced with this configuration (b). The right inset of Figure II-3 shows the model for an 8-element sub-array and the radiation pattern predicted by simulations, showing satisfactory beam formation within one bay. The initial simulation results point toward the feasibility of using our base antenna design after some adaptations. Further work continued toward implementation of the radar's antenna array and radar electronics. As for the antenna, slight modifications were made to the base design for a single element to fit inside the smallest access panel on the fairing and facilitate integration while maintaining good electrical performance. The design of a power divider to combine/split the signals within the 4-element sub-arrays was initiated. This component has to be custom made because of connector placement and size restrictions for installation within the fairing.

KU also test fitted a set of prototype antennas to mock up the element placement within the fairing (Figure II-4).

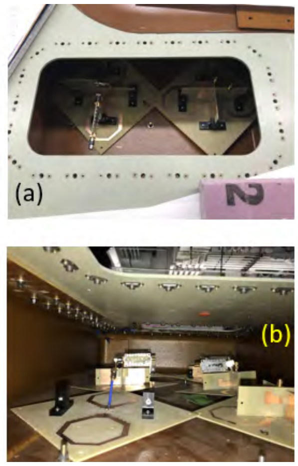

Figure II-4.Photograph of the base design antenna prototypes fitted within one bay of the fairing (a); detailed view of the same elements inside the fairing showing the tentative placing of the impedance matching networks (b).

On the structural side, Shravan Kaundinya (KU graduate student in EE) familiarized himself with previous structural models of the fairing and worked on solidifying a revised antenna and antenna-integration design to enable certification through equivalence to the previously flown system. This work requires extensive collaboration between the Aerospace and Electrical Engineering (AE) students and faculty, to maximize the RF efficiency of the proposed antenna array while minimizing structural modifications to allow for this certification by comparison.

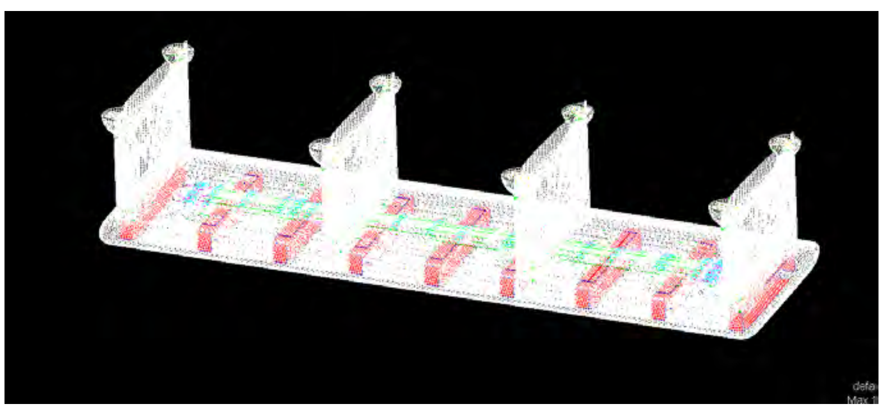

Figure II-5. Previous PATRAN model.

The AE team began with reviewing the previous PATRAN model, shown in Figure II-5, associated with the BT-67 center array fairing and determining the parameters of modification allowed and specifying the restrictions the Electrical Engineering (EE) team had with their design. The finite element model has 137,844 elements and 120,281 nodes. The number of degrees of freedom estimated by Nastran is 601,846. This model captures 12 different loading cases, ranging over the likely situations the aircraft would encounter. Understanding this model took a considerable amount of time for Skyler Jacob (KU graduate student in AE) due to the complexity of the model and familiarization with boundary conditions, loads, and elements used. Such familiarization is essential for proper usage of the predictive model, leading to the informed redesign.

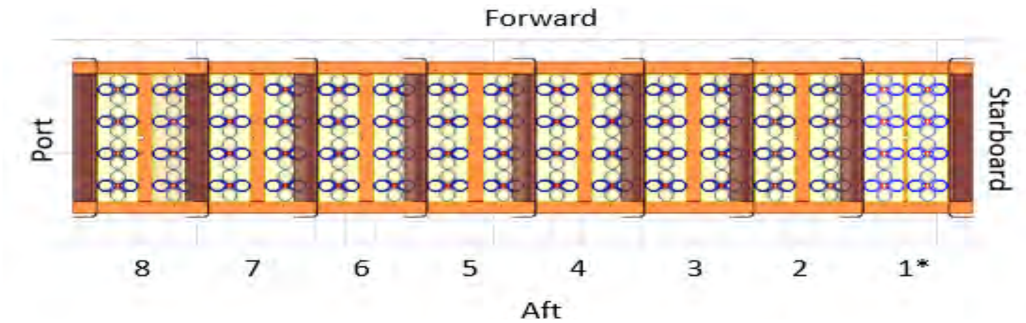

Figure II-6. New antenna concept for integration into the fuselage fairing.

After familiarization with the model, Skyler Jacob modified and analyzed the design for the inclusion of the new antenna array shown in Figure II-6. This modification included changes to the lower skins to remove the previous antenna panels that the original fairing was designed for and the slightly different cable fairing that COLDEX will use.

The CAD image of the antenna design, shown in Figure II-7, was provided by the electrical engineering team. This was used to create the proposed design, shown to the left in Figure II-8, which shows the design of the critical bay (bay with the least space and smallest access panels). This shows 8 antennas arranged within a 4x2 pattern with the light blue sections being the location of doubler plates that would be used to hold the antennas at the appropriate height off the bottom skin. The design includes the capacity for the entire assembly to be bolted to the current lower skin structure, index antenna locations, and prevent detrimental vibrations. This design is a modification to the antennas, rather than the fairing itself, thus increasing the likelihood of certification by comparison.

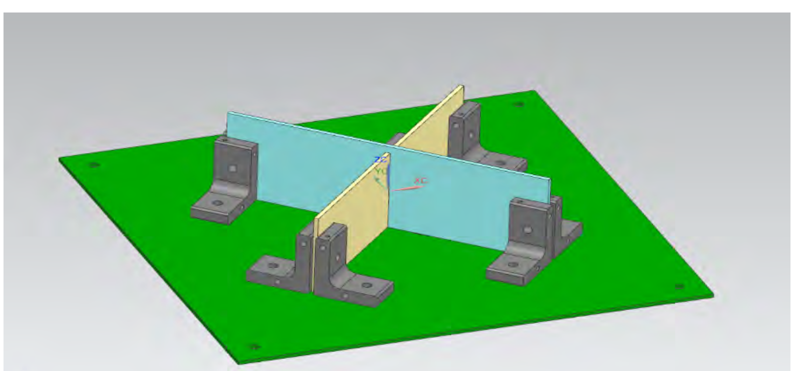

Figure II-7. New antenna concept details.

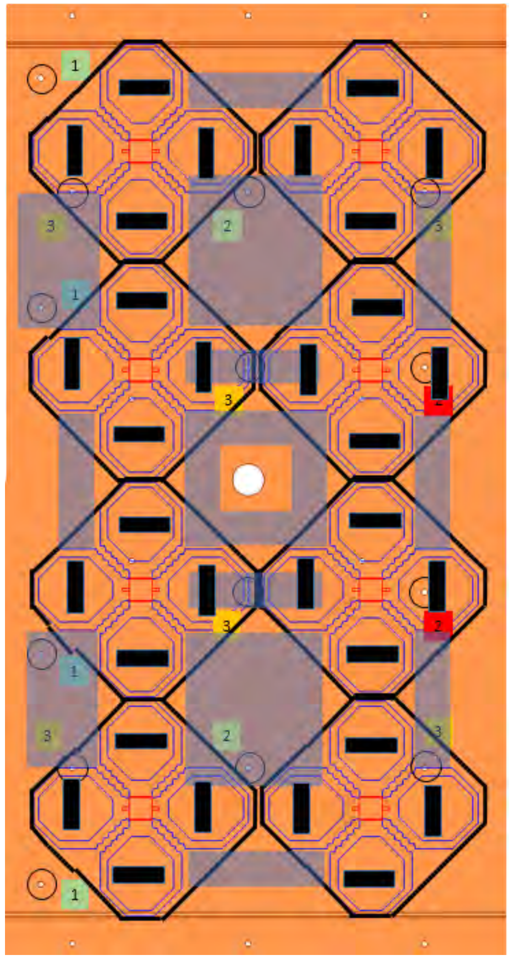

Figure II- 8. Antenna support concept.

An additional model for analyzing the vibratory modes of the antenna arrays is currently being produced from the combination of these models for proper validation of the design. This iteration will match the changes made to the antennas by the EE team. A few meetings have been held with Kenn Borek Air and Lake Central to discuss the number of cables that can be fed to the aircraft and other mounting and timeline details. This new design has more than twice as many cable runs as the prior design, with the plan to run these to the aircraft through the two central pylons (rather than one pylon as in the certified design).

The KU team has thus made notable progress to the aforementioned strategic plan activities of finalizing the antenna design for certification this summer. Meeting the timeline for a summer test flight may still prove to be difficult depending on certification requirements given the limited responses from the Canadian Aircraft certification process during summer months.

<u>Power Amplifier</u>

The second engineering objective during the reporting period was the identification and selection of some of the RF components for the radar electronics. KU procured some RF parts, including power limiters and two 800-W power amplifier pallets (Figure II-9). The KU team will characterize the performance of these parts and use them to develop transmit/receive (T/R) modules for the radar based on the link budget requirements.

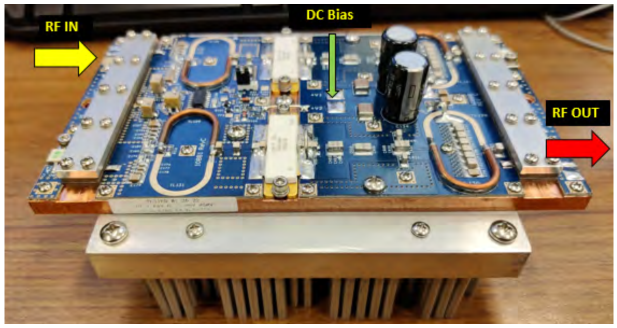

Figure II-9. 800-W power amplifier pallet for 1.6 kW T/R module development mounted on its heat sink prior to testing.

KU has also been working toward the implementation of the initial transmitter and receiver prototypes before production of the radar chassis; mechanical design of the radar enclosure; and GPS receiver integration.

<u>Interpretation of deepest sections of radar images</u>
Interpreting the deepest sections of radar images is important for old ice studies and has been a long standing problem. Nick Holschuh at Amherst College (with Ellen Mutter, post-baccalaureate student) initiated an investigation of this problem. Their work includes an exhaustive review of the ice coring literature, identifying (a) all areas where directly sampled ice was either disturbed or otherwise unusable for climate reconstruction, and (b) all transitions in physical or chemical properties that may be detectable using radar. The second focus of their work is comparing known depths of disturbance or property change with all available radar data collected at those ice core sites. Their goal is to determine the reasonable expectations for knowledge in advance of drilling, relative to what we may want to know in advance of drilling. An example of preliminary work is shown in Figure II-10, with two radar images (collected nearly orthogonal to one another) for several Greenland cores, with labeling indicative of depths of interest in the core.

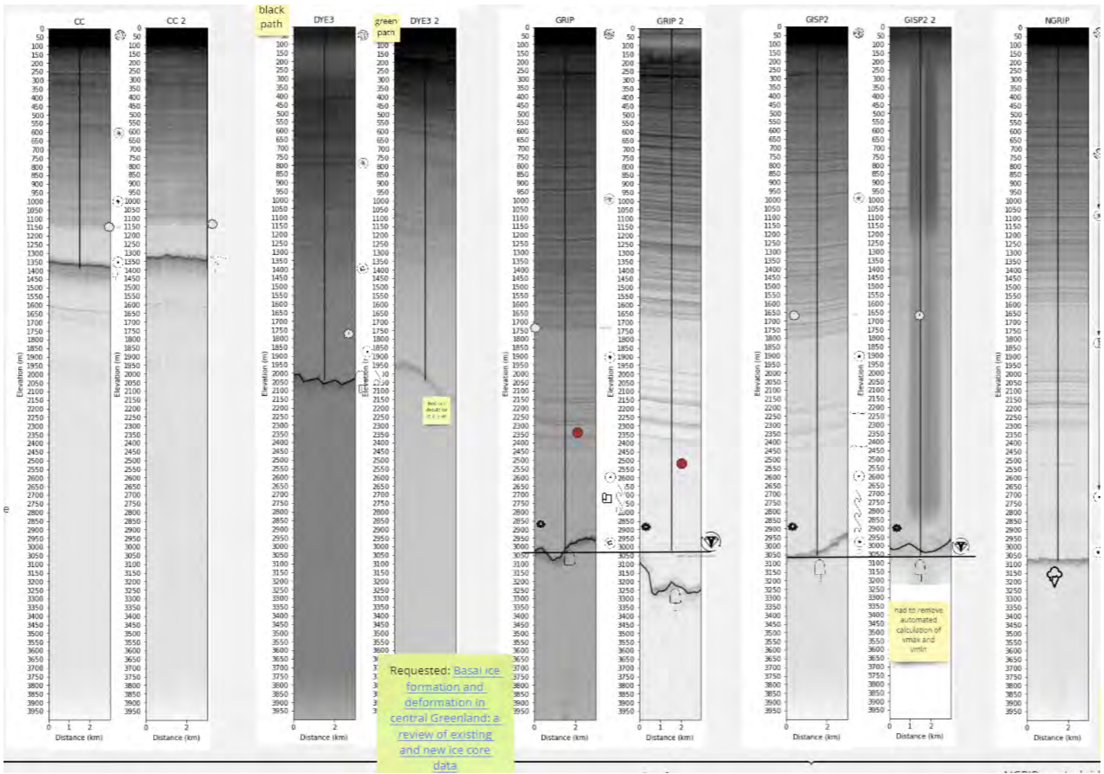

Figure II-10. Example images for several Greenland ice cores used to examine the nature of near-basal layering.

That work is ongoing, as they continue to assemble radar imagery and relevant literature that can inform interpretation. Figure II-11 below provides some sense for the way they are organizing this work, as Mutter and Holschuh work together on this project using "MIRO," a storyboarding and brainstorming facilitation tool. The work reported here is preliminary but the goal is to assemble this work as a review paper by the end of year 1.

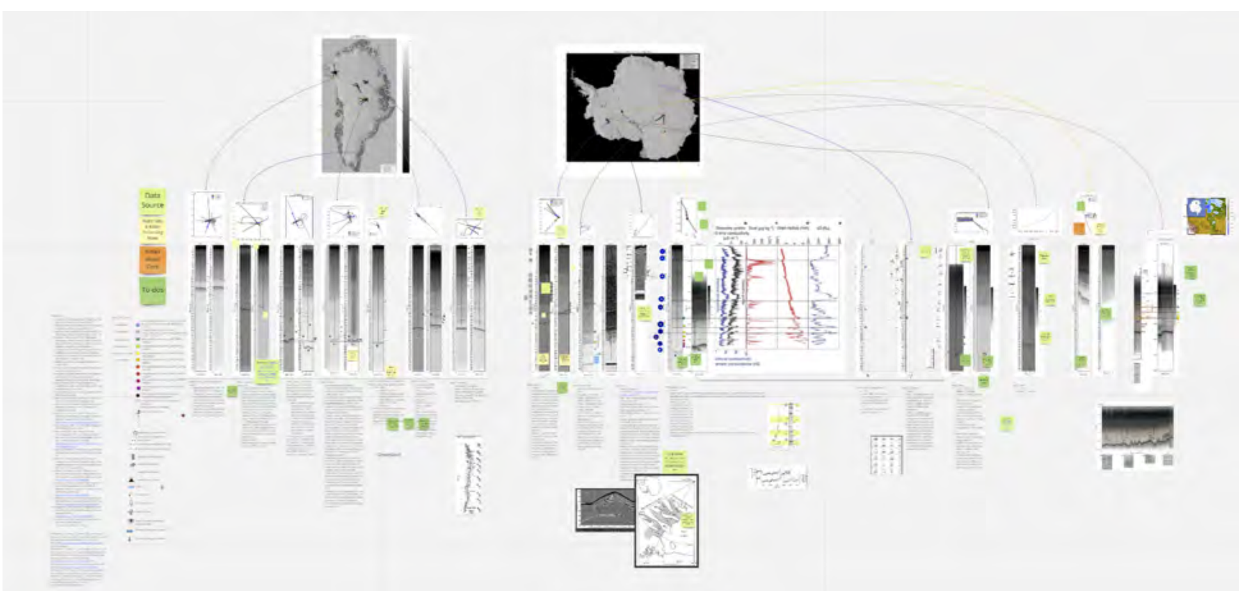

Figure II-11. MIRO storyboard brainstorming image used to examine basal layering in radar images.

Milestone: Acquire, process, and interpret ground-based radar and geophysical data in regions of interest.

This activity will take place in years 4 and 5 of COLDEX (and possibly additional work in year 3) so there are no details to report in this period. Advance planning for field logistics was conducted in year 1, in cooperation with the USAP planning group, culminating in the current version of the Operational Notice for COLDEX. At present we are on schedule for these activities and await a decision about the possible 2023/24 “Saddle Site” ground-based field season at the South Pole.

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

The ice diver/dust logger is designed to measure dust content of the ice sheet *in situ* with a laser particle analyzer on board a melt probe vehicle that melts its way rapidly through the ice sheet paying out a very thin high voltage wire. Dust profiles will be used to establish the age structure of the ice sheet. Year 1 activities include design and fabrication of vehicles that will be tested at Summit Greenland in year 2. Engineering drawings are nearly complete and the UW group will begin fabrication of the first vehicles shortly. The following summarizes work to date (as of mid-May), which is on schedule.

1. Design revisions to operate at 4000V and 3000 m depth
    a. system modeling to verify requirements on voltage and wiring - *complete*
    b. revision to electronics boards to meet higher voltage and dust logger requirements - *completed design*
    c. testing of new components – in particular cartridge heaters and wiring - *ongoing*
    d. thermal modeling of revised heater configuration - *nearly complete*
    e. mechanical modeling of revised melt head to ensure integrity at 3000 m depth - *nearly complete*
    f. high-voltage power supply and battery backup revisions to ensure sufficient reliability - *complete*
    g. purchase of long-lead components to ensure readiness for commissioning - *in process*

2. Design revisions to incorporate dust-logger
    a. mechanical modeling to incorporate dust-logger components - *70% complete; ongoing*
    b. electrical design to meet dust-logger power and data requirements - *ongoing*

3. Detailed planning for commissioning and field operations
    a. collaboration w/ NSF Antarctic logistics on generator and fuel specifications - *complete*

b. collaboration with NSF Arctic logistics for Greenland Summit commissioning - *ongoing*

Milestone: Conduct glaciological modeling that integrates geophysical and Ice Diver information to assess possible ice core sites.

The leader for modeling in COLDEX (Michelle Koutnik, UW) and others working on this topic (TJ Fudge and Ed Waddington, both UW) have been continuously involved in the design and planning of radar and geophysical data acquisition plans. They made progress on reconciling the gridded model of survey design with the flow line needs of COLDEX's ice sheet modelers. UW recruited an incoming graduate student (Margot Shaya) who will contribute to ice flow modeling objectives. The modeling group contributed to field logistics planning and the Operations Notice. In preparation for the 2022/23 field season at Allan Hills and Elephant Moraine, the UW group assimilated existing radar data and satellite data to guide site selection for future drilling operations; the outcomes have been shared with relevant COLDEX members. They began depth-age, temperature, and diffusion modeling for different potential ice-core sites in the ice-sheet interior.

The latter focused on the magnitude of diffusion of CO_2 for two sites with the same surface temperature, ice thickness, and geothermal flux, but different accumulation rates: 4 cm/yr for South Pole Saddle vs. 2 cm/yr for interior towards Dome A. The team's primary conclusion was that the CO_2 diffusion was similar for two scenarios. The 4cm/yr accumulation case has less diffusion initially due to the thicker ice packets for a given duration and colder ice temperatures; however, the greater ice thinning leads to steeper concentration gradients as the ice gets closer to the bed and has spent longer in the ice sheet. By 1.5Ma, the diffusion is greater in the 4cm/yr case compared to the 2cm/yr case. The primary goal of the preliminary modeling is to develop a framework for discussing trade-offs between potential ice core sites identified with airborne and ground-based geophysics.

Milestone: Maintain connection with Rapid Access Ice Drill (RAID) project to identify possible use of RAID in COLDEX site selection.

Director Edward Brook is in regular communication with RAID PIs John Goodge (UM Duluth) and Jeff Severinghaus (UCSD Scripps) about the status of the RAID Drill platform. The team intends to start long range planning for the future of COLDEX after the first annual COLDEX meeting (September 2022).

Milestone: Integrate all available information to choose a site or sites for a deep ice core.

While COLDEX is not at the site selection stage yet, the workflow analysis described above will inform this effort. Establishing more formal site selection criteria and committees will be a topic at our annual meeting or an upcoming remote meeting before that.

Ice Coring and Ice Core Analysis

During the first five years of COLDEX, we will drill several shallow (~200 m) ice cores in the Allan Hills and Elephant Moraine region of Antarctica, in regions where old (> 800 ka) ice is known to exist. We also have plans for the intermediate depth core (site selection for that core described above) that is currently a scope contingency in the COLDEX planning. A variety of analyses are planned for these cores and a centralized lab facility at Oregon State University that will be used for some of these measurements is has undergone renovation and utilities modifications and existing equipment is moved in and being made operational.

Specific activities and outcomes for Ice Coring and Analysis in year 1 are described further below for each Milestone listed in the performance and management indicators table (above).

Objective 1. Collect ice cores at ice margin sites.

Milestone: Develop a set of site selection criteria for the Allan Hills and Elephant Moraine shallow drill sites, drill, and return ice cores.

Analysis of cores collected in the 2019/20 field season for and dating based on the ^{40}Ar content of trapped air ($^{40}Ar_{atm}$ age) (see results elsewhere in this section) is in progress, providing further information for site selection for additional coring in 2022/23 field season (for details about this method, see Bender, M.L., Barnett, B., Dreyfus, G., Jouzel, J. and Porcelli, D., 2008. The contemporary degassing rate of ^{40}Ar from the solid Earth. Proceedings of the National Academy of Sciences, 105(24), pp.8232-8237). The main criteria for site selection for shallow cores includes depths < 200 m, existing radar imagery and depth to bedrock information and probability of old ice above (rather than at) the ice-bed interface. Core site selection is ongoing and should be complete by September and also aid in developing coring plans for future seasons. The COLDEX team has had preliminary discussions with Dr. Jinho Ahn at Seoul National University in Korea about collaboration in drilling ice cores at Elephant Moraine, which is reachable from the Korean Station. KOPRI (Korean Polar Research Institute) has agreed to share radar data from this location and we are considering a more formal collaboration.

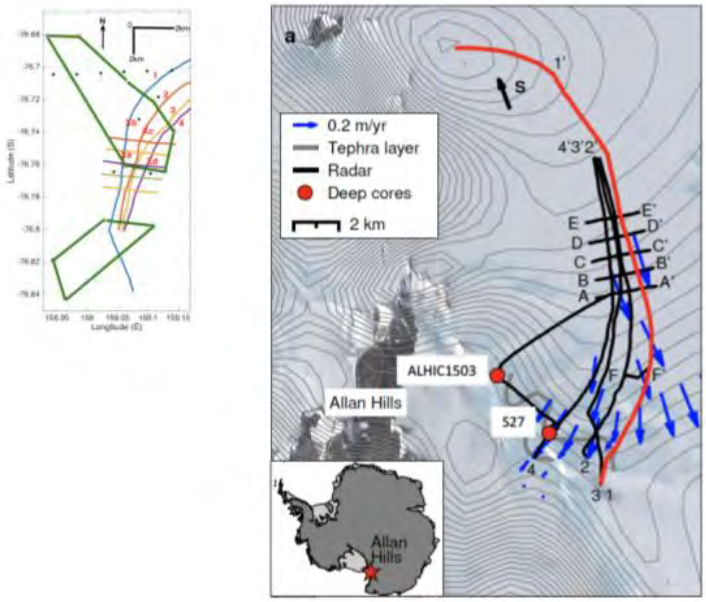

Figure II-12. Allan Hills existing radar lines (Kehrl et al, 2018. Geophys Res Lett 45: 4096-4104) (right); possible core locations (Xa to Xd) including possible LC 130 (Hercules) ski plane landing zones in green (left). Note different orientations of images.

Milestone: Intermediate depth core drilled at Allan Hills (scope contingency in logistics planning as of April 2022).

For Allan Hills intermediate core site selection, drill sites identified in previous work may be suitable given >30 m depth to ice, 205kyr layer at 71% of the ice thickness, and smooth bed. Planning is underway to conduct more surveys to the west and east of current profiles during the 2022/23 season to allow further modeling of age vs. depth profiles. This plan will include a resurvey of existing poles to update horizontal velocity vectors, radar surveys on a tight grid within region of potential coring sites (Xa through Xd in figure II-12), ApRES polarimetry for ice fabric, and initiating ApRES measurements for vertical velocities. COLDEX scientists will be in the field in this region in 2022/23 and will assist with the National Guard evaluation of a possible landing site for cargo aircraft as needed. Probable landing regions have been identified as described above (Figure II-12).

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

Milestone: Create centralized COLDEX laboratory for analyzing chemical parameters in COLDEX cores.

COLDEX has been provided with a modern laboratory in close proximity to the large ice core freezer storage facility at the OSU Marine Geology Repository. Christo Buizert (OSU) is leading the implementation of the lab. Infrastructure changes, including installing a walk-in freezer for the continuous flow analysis (CFA) system and other processes, and some relatively minor reconfiguration of electrical outlets, are ongoing. Needed laboratory furniture has been acquired and installed. The installation of the walk-in freezer has been delayed by supply chain problems (installation anticipated in winter 2023), but in the meantime an existing reach-in freezer will stand in. The existing OSU melter system for gas analysis has been moved to this lab and is being reconfigured and made operational now.

A key piece of hardware, a laser spectrometer for methane measurements, has been ordered. The originally planned acquisition of a new Picarro analyzer was not possible because Picarro was not willing to make an instrument with the desired response time and other specifications (at the time of the COLDEX proposal writing, they had expressed willingness, but market conditions have changed). Luckily, Aerodyne Technologies, another leader in this field, was more than happy to work with us to specify an instrument with even better response time than Picarro would have been capable of, and at a budget point that fit our original estimates. Aerodyne is much more interested in R&D projects in general, so this collaboration may be helpful for COLDEX going forward and will benefit other ice core projects. An existing Picarro CH_4/CO analyzer used on previous ice core projects is available to COLDEX at OSU with a recent software upgrade and is functioning well and being integrated in the lab now.

At University of Washington, Eric Steig and colleagues are focused on developing and optimizing the continuous melting system and vaporizer and analyzer, for eventual deployment at Oregon State University for the continuous water isotope analysis system. The major goal for this reporting period was to understand and quantify the relationship between air and water flow, and the resulting isotopic measurement precision. The UW team has made modifications to the previously existing water vaporization system with an eye for stability, ease of use, maintenance, and remote management. They now have a system capable of uninterrupted week-long runs. They have been using an existing laser spectrometer for this development work and at the same time are testing the new laser spectrometer that will be deployed to OSU. They also continue to develop data processing software in R and Python for rapid assessment of instrument state and performance, as well as long term monitoring of data quality and for calibration to the VSMOW-SLAP scale.

The UW group has also addressed some potential problems with this analysis related to chemical impurities. Two distinct impurity categories were identified, each requiring a different mitigation strategy. The first category of impurities affecting analysis is the dissolved mineral load in standard waters, especially the dissolved calcium carbonate content. Standards developed from polar ice (filtered for entrapped dust particles) are expected to be essentially pure in this regard, whereas standard waters derived from most terrestrial aquifers will contain appreciable amounts of dissolved carbonate matter. For example, the aquifer supplying Seattle with water contains very little dissolved carbonate in comparison with most aquifers in the US (23 mg/L $CaCO3$; Seattle Public Utilities data). The amount present is nonetheless significant from the perspective of multi-day analysis runs, where the vaporization chamber becomes calcified to the point of adversely impacting system performance after only 3 days of continuous (24 hr/day) analysis during stability tests. Week-long stability tests are now being performed with 18 mOhm water (purified by reverse osmosis).

Second, dust in ice requires physical filtration (2 in-line filters with 2 um filter mesh screens). Data from 2 in-line pressure sensors is now integrated in real-time to display alongside the primary isotope data channels, and is also written into the data output files. Live-time pressure sensor monitoring allows us to gauge the clogging state of in-line filters (pressure builds up over time in comparison to the baseline established immediately after deep system cleaning (decalcification of vaporizer assembly, new filter screens, new peristaltic pump tubing, capillary maintenance).

The solutions to these problems described above are an early success - the ability to clean and refresh the system is such that we can reliably return to expected performance based on various settings. Another early success is an increasingly easy-to-use user interface, developed with custom code on our Picarro system.

At UC Irvine, Eric Saltzman and colleagues are testing their electrospray/MS/MS for COLDEX work. A problem with excessive drift in instrument response has been isolated to faulty electronic components and they are currently exploring solutions to that issue.

Milestone: Develop initial ice core chronologies using argon and krypton isotope dating.

While many archives have been examined to document past climate change, arguably the most important are deep sea sediments and ice cores. Deep sea sediments give us access to continuous climate records extending back in time by many millions of years. In comparison, the ice core climate record currently only extends back to 800 ka (thousands of years before present), but it has the great virtue of giving detailed information about the concentrations of greenhouse gases, and detailed information about climate over Antarctica. Because the Greenland and Antarctic ice core records can be accurately correlated, ice core studies also give information about the phasing of climate change in the northern and southern polar domains.

Because of shear associated with the flow of an ice sheet, particularly at the bed, the continuous climate records of glaciers end before ice bottoms out. Below the continuous record, there are typically hundreds of meters of glacial ice that may be geochemically intact, but are no longer in proper stratigraphic order. In all areas studied to date, the discontinuous ice is older than the stratigraphically continuous ice that it underlies, and this is likely to continue to be true. While we hope that current efforts to target continuous records extending back to 1.5 Ma will be successful, we also expect that this continuous old ice will be underlain by older ice that is stratigraphically disturbed. Thus, sampling the deep, disturbed ice will allow us to characterize key climate properties even when continuous records are not accessible. In general, we can access the same climate properties in disturbed ice as in clean ice: the isotopic composition of ice (a proxy for regional temperature); dust content and composition (source areas and aridity); CO_2, CH_4, and other gas properties.

The accessibility of old ice increases greatly in mountainous areas at the margin of ice sheets. Here, deeply buried glacial ice can be guided to or near the surface; by the bedrock topography. Retrieval becomes much easier in these environments, because one can encounter old ice at relatively accessible depths of 100-200 meters, rather than much more challenging drilling to thousands of meters below the surface. To date, the Allan Hills region has yielded the most ice and oldest ice, dated well beyond the oldest continuous ice that has been retrieved. The Allan Hills ice is also older than the greatest plausible extent of continuous records, about 1.5 Ma. This ice has been explored with support of several OPP grants, and is transitioning to a COLDEX component.

Dating candidate samples of old ice is the first step in using this archive for climate reconstructions. Dating ice older than about 1 Ma is accomplished primarily by argon (Ar) isotope geochronology. (COLDEX also will explore applications of ^{81}Kr dating but this has not yet been implemented. Methods for sample preparation are being developed at Princeton). The basis for the Ar method is that ^{40}K is radioactive, decaying to ^{40}Ar (as well as ^{40}Ca, not of interest here). Going forward in time, ^{40}Ar, produced by ^{40}K decay in rocks, leaks out to the atmosphere and increases the atmospheric ^{40}Ar burden. Because there is no such source of other stable Ar isotopes (^{38}Ar and ^{36}Ar), the ratio of ^{40}Ar to ^{38}Ar or ^{36}Ar increases with time and hence decreases with age. The older an ice sample, the lower the ratio of ^{40}Ar/^{38}Ar or ^{40}Ar/^{36}Ar. The resulting age uncertainty is currently about ± 60 kyr, because the Ar isotope ratio of air is changing so slowly.

Figure II-13 shows ^{40}Ar age plotted vs. depth for the most extensively studied core from Allan Hills to date, CMC-1, a 10” diameter hole drilled into blue ice collected in the 2019/20 field season. This laboratory work was done primarily by postdoc Sarah Shackleton at Princeton. In previous work at this site, the ice dates to about 400-800 ka from the surface to a depth about 20 m above bedrock. In this basal interval, ages can be much older. The oldest sample yet studied dates to about 4.1 Ma.

The ages do not increase monotonically with depth, leaving no doubt that the ice is not stratigraphically intact. However, on the scale we have studied (about 1 m sampling interval in the bottom 15 m of the ice), it appears that sample ages cluster within zones of more or less constant age between transitions to older or younger ice. Our results will then allow us to ask 2 questions about past climates. First, what was the range and mean of climate properties during periods of roughly stationary climates in the 40k world, and perhaps beyond? Second, how did climate properties covary (e. g., CO_2 vs. Antarctic temperature) in the 40k world? We report below on initial data from this core relevant to these questions.

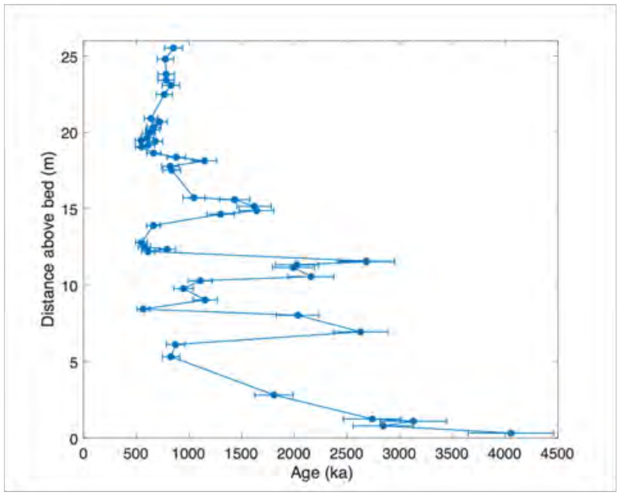

Figure II- 13. New $^{40}Ar_{atm}$ ages as a function of distance from the bed from the CMC-1 ice core at Allan Hills (Sarah Shackleton, John Higgins, Michael Bender; Princeton).

Milestone: Develop hyperspectral imaging capabilities at NSF Ice Core Facility (ICF) with new camera equipment acquired by COLDEX.

The hyperspectral imagery equipment planned for COLDEX has been purchased and installed at the NSF ICF. It has not yet been applied to work on COLDEX cores but its use will be explored further during a visit in June 2022 by TJ Fudge (UW).

Milestone: Refine ice core chronology and assess the stratigraphic orientation of ice samples using a suite of analytical techniques.

TJ Fudge (UW) recently used the ECM (electrical conductivity measurement) system at the NSF Ice Core facility to accomplish what we believe is a first in ice core science, the determination of the dip of layers in an unoriented ice core. The large diameter ice cores from Allan Hills permit ECM to be made on two perpendicular faces (in this case on the CMC-3 ice core, which spans the last interglacial period). The primary face had minimal slope in the layering; however, the layering in the direction perpendicular revealed a slope of about 20% (Figure II-14). This slope matches the slope of the internal radar layers imaged by radar at the core location. This method allows geographic orientation of the core with respect to ice velocities and could further help with comparisons of ice fabric measurements using thin sections on the core and polarimetry measurements using phase sensitive radar.

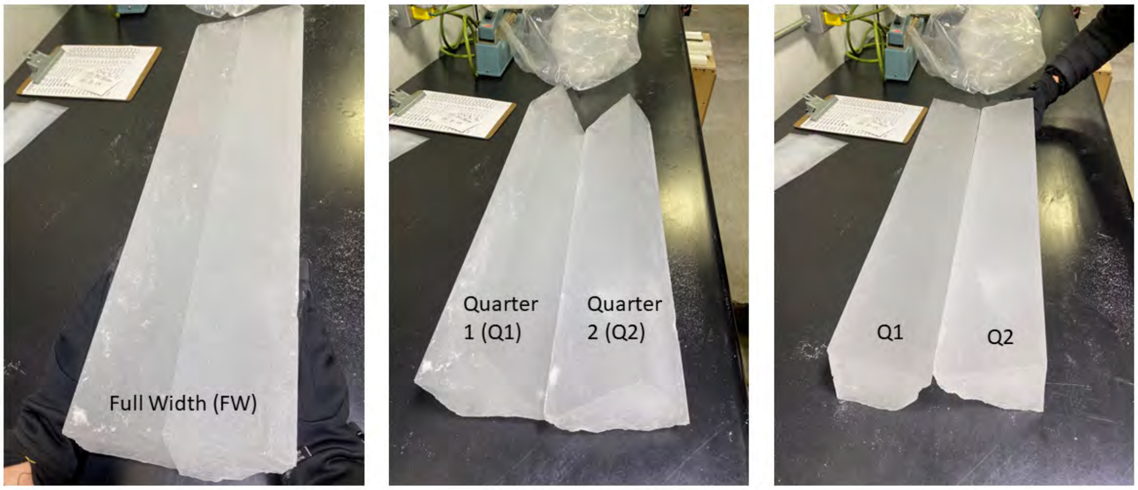

Figure II-14. Allan Hills CMC-3 core sections (~70cm length, at roughly 80m depth) cut for ECM measurements. ECM on three faces: The full width of the half round and the two inside faces when the half round is split into two quarters.

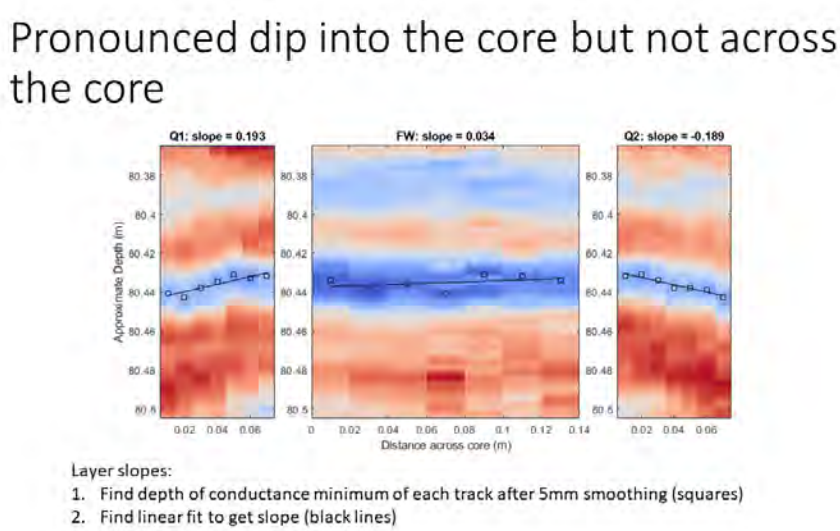

Figure II-15. Multi track ECM measurements (warmer color = higher conductivity) made on three sections from the full width and Q sections shown in Fig. II-14. Dipping layers are evident and can be aligned with layering in radar stratigraphy.

Milestone: Increase throughput of dry extraction ice core CO_2 measurements.

This activity involves building a multiport CO_2 crusher system, planned for year 2. In the current reporting period, we acquired a key piece of equipment, a large capacity recirculating chiller.

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

Milestone: Develop publicly available metadata and data about core sites, analyses, and *archived ice core samples.*

Peter Neff at University of Minnesota was brought on to COLDEX to be the Director for Field Research and Data (~ 5 months per year of Peter's time is supported). Data activities in the current reporting period included contacting leaders at USAP Data Center, Kirsty Tinto and Frank Nitsche. A landing page has been established for COLDEX where datasets will be made public as appropriate according to center and NSF requirements. We also began collecting data and metadata from past projects related to old ice, primarily at Allan Hills, on an internal server. Our plan is to collate and format this material and make it public. This material includes links to existing published data but also several categories of information that are not easily available now, including field reports, core logs, ground penetrating radar data and similar information.

We have also begun initial discussions about how to properly archive and provide metadata for large volume ice samples that are not always contiguous. We are aware that the NSF ICF is considering updating its ice core database procedures and record keeping; we will maintain contact with them to make sure that COLDEX plans are consistent with theirs and to take advantage of their expertise.

Development of COLDEX data policies is also ongoing, including statements about internal use of data in our Ethics and Professional Integrity Policy and the drafting of the COLDEX Data Policies, which follow the data management plan provided in the proposal but will contain more specificity. These policies are planned to be complete by the end of year 1 and ratified by the time of our annual meeting in September.

Milestone: Develop schedule of ice analysis, including technical and sample requirements for different labs, measurement plan, preliminary data availability, archive plan.

Christo Buizert (OSU) is developing a survey of technical and sample needs for all COLDEX partners for planning analysis of future cores. John Higgins (Princeton) is developing "cut plans" for optimal division of samples from existing Allan Hills cores. Both activities will influence the development of more specific plans for new cores we collect starting in the 2022/23 field season.

Milestone: Acquire basic chemical and imagery data for all COLDEX cores (stable isotopes, dust, soluble chemistry).

Sections above describe laboratory progress toward this capability. New cores will likely be available for initial sampling in June 2023 or later, and plans for the more comprehensive analysis will be put in place prior to that time.

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

In this section we report on preliminary data for mean ocean temperature, carbon dioxide and methane concentrations in recently analyzed Allan Hills ice samples from the 2019/20 field campaign which was supported under previous funding to COLDEX investigators at Princeton, University of Maine, UCSD and OSU. This project was delayed by the COVID-19 pandemic and is now being integrated with COLDEX. Figure II-16 shows locations of cores collected in the 2019/20 field season and referred to here.

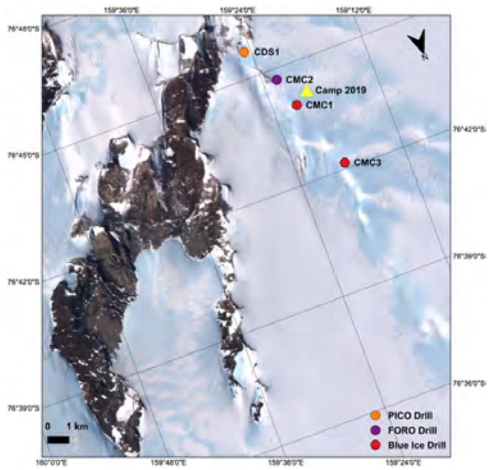

Figure II-16. Map of the Allan Hills area, showing the sites of different ice cores. CMC-3 is centered on the period from 100-250 ka. CMC-1 has ice extending back to at least 4.1 Ma.

Figure II-17 plots mean ocean temperature (MOT) vs. age around the last interglacial (LIG). Orange points are previously published data from Taylor Glacier and EDC ice cores. Blue points represent Allan Hills samples. There is excellent agreement between these two data sets, supporting the idea that Allan Hills ice successfully incorporates ice properties as at other sites. Greenhouse gas concentrations, both previously published and new data from this core (from Julia Marks Peterson and Jenna Epifanio at Oregon State), confirm this conclusion.

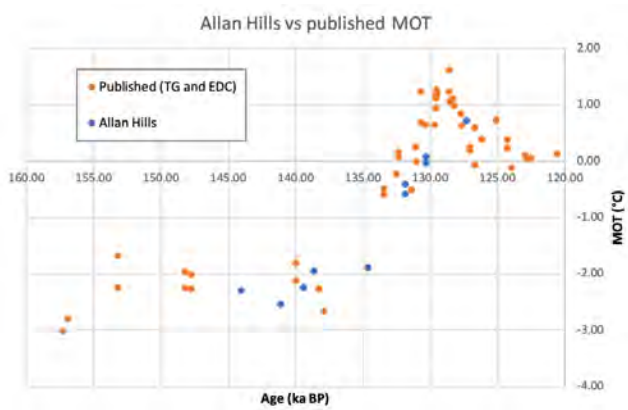

Figure II-17. Mean Ocean Temperature vs. age, around last Interglacial. Orange: published data from Taylor Glacier and EPICA Dome C. Blue: CMC-3 core from the Allan Hills. The good agreement shows that paleoclimate properties can be accurately measured in Allan Hills ice cores.

Mean ocean temperature (MOT) vs. $\delta^{18}O$ of the ice is plotted in Figure II-18. $\delta^{18}O$-ice represents East Antarctic temperature while MOT represents global mean ocean temperature. Age is represented by sample color. While there is significant scatter and 1 or 2 outliers, this plot shows that Antarctic temperature has been linked to MOT in a similar manner over the past 2.7 Myr.

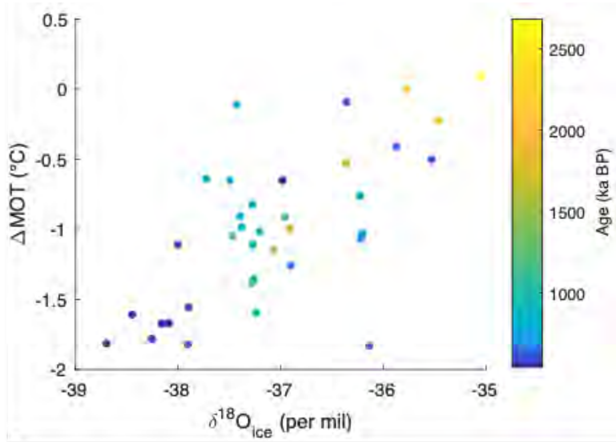

Figure II-18. δ18O of ice vs. Mean Ocean Temperature. Colors indicate age. These data suggest a simple and persistent relationship between East Antarctic temperature (from δ18O) and Mean Ocean Temperature (from Xe/Kr) for nearly 3 Myr.

Finally, mean ocean temperature vs. age is shown in Figure II-19. In this plot, the age uncertainty increases with age because of limitations in the calibration of ^{40}Ar degassing. This plot indicates progressively warmer climate going back in time. Interglacial temperatures vary less; in the present data, they appear coolest around 500-1 Ma, and warm towards younger and older ages. The data are compared to the well- known LR04 marine benthic stable isotope stack. Interpretations are ongoing but agreement in the trends in benthic δ^{18}O and MOT going back to 3.5 Ma is notable.

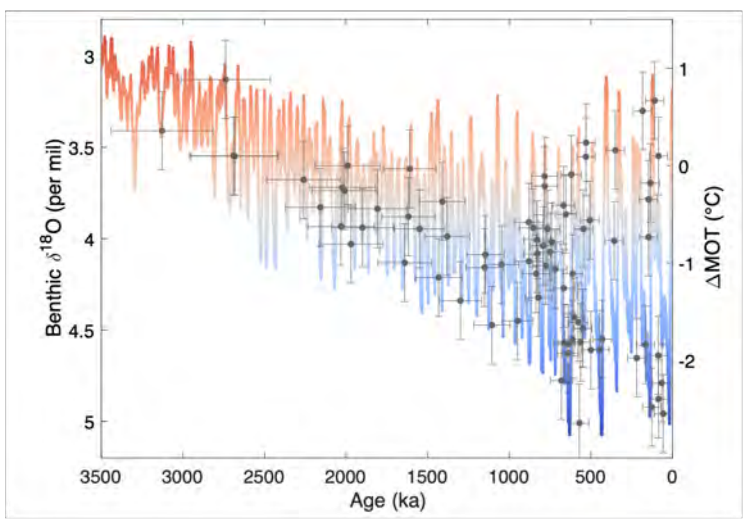

Figure II-19. Mean Ocean Temperature (MOT) estimates from Allan Hills core CMC-1 as a function of age plotted with the LR04 marine benthic isotope stack (Lisiecki & Raymo 2005. Paleoceanography, 20(1).)

Figure II-20 shows CO_2 and CH_4 concentration data from most of the recently dated Allan Hills samples, made by OSU graduate student Julia Marks Peterson and lab technician Mike Kalk. Notable here is the absence of low concentrations of either gas like those that characterize the glacial periods of the last 800 ka. This finding is consistent with the absence of intense glacial periods in other records during and before the mid-Pleistocene transition. Also notable is the absence of higher levels of CO_2 and CH_4 in samples older than 1Ma. This is consistent with previous work in the Allan Hills (Yan, Y., Bender, M.L., Brook, E.J., Clifford, H.M., Kemeny, P.C., Kurbatov, A.V., Mackay, S., Mayewski, P.A., Ng, J., Severinghaus, J.P. and Higgins, J.A., 2019. Two-million-year-old snapshots of atmospheric gases from Antarctic ice. *Nature*, *574*(7780), pp.663-666.). However it is not consistent with many indirect reconstructions of atmospheric CO_2 which have been used to suggest concentrations of 360 to 420 ppm for the mid Pliocene (3.3 to 2.0 Ma).

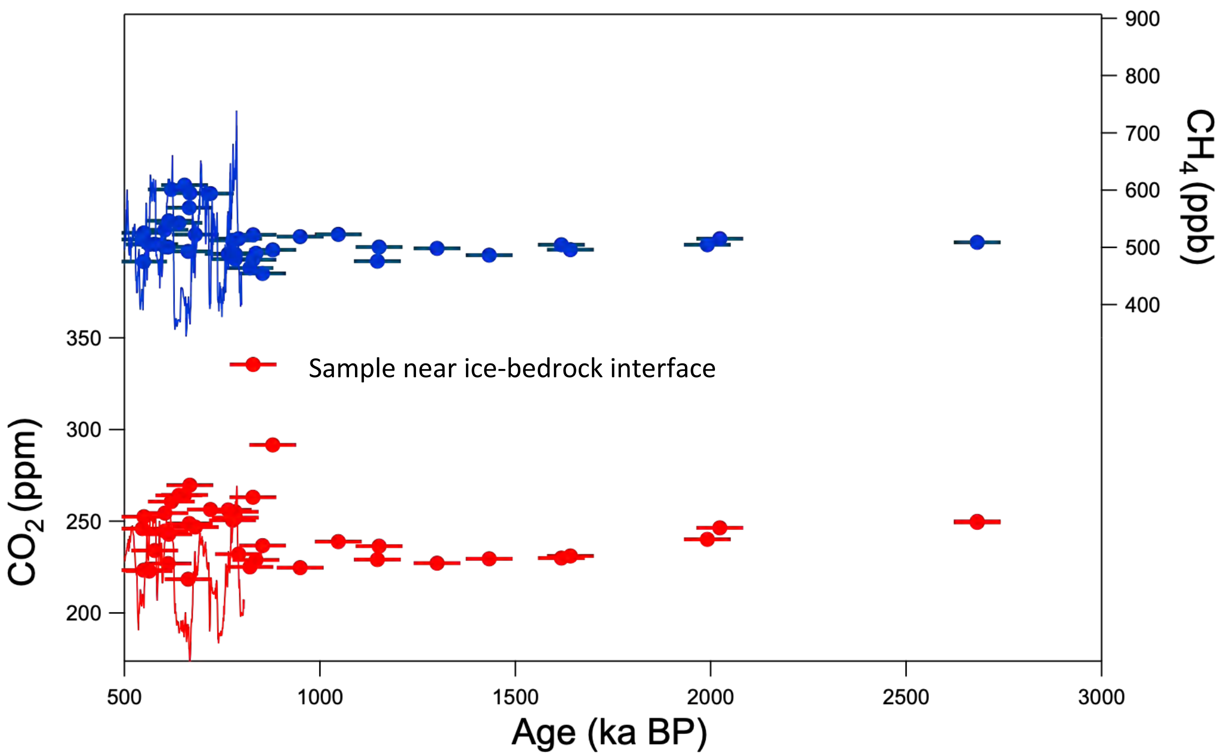

Figure II- 20. CO_2 and CH_4 concentration data from most of the recently dated Allan Hills samples.

Summary table of analyses to be performed. The table below summarizes the various chemical and physical analyses that are planned for the COLDEX ice cores, with details about the techniques to be used, where the instruments are located, and who will oversee the specific analyses. Given that ice returns each year, all analyses will take place each year.

Geochemical properties measured in COLDEX cores				**Analysis Year Analysis Year (Note: *27 in phase 2 of COLDEX)***	
Property	**Objective**	**Investigator (Institution)**	**Instrument (location)**	**Ice Margin Cores**	**Intermediate Core**
Electrical conductivity	Layering, volcanic events, annual layer counting.	Fudge (UW)	Multi-track ECM (NSF-ICF)	23, 24, 25,26	25,26,*27*
Hyperspectral imaging	Layering geometry, bubble, dust, volcanic particles, deformation structures	Fudge (UW), Kurbatov (UMaine)	SPECIM hyper-spectral core scanner (VNIR) (NSF-ICF)	23, 24, 25,26	25,26,*27*
δD, $\delta^{18}O$, $\delta^{17}O$, *d* including continuous measurements	Past temperature, moisture source conditions	Steig (UW)	Picarro L2140-i Isotope and Gas Concentration Analyzer and (centralized OSU lab)	23, 24, 25,26	25,26,*27*
$^{40}Ar_{atm}$ and ^{81}Kr	Gas age	Higgins, Bender (Princeton), Severinghaus (UCSD), Buizert (OSU)	^{40}Ar: Thermo Finnigan MAT 253 plus (Princeton) ^{81}Kr: atom trap trace analysis, University of Science and Technology of China (Hefei, China)	23, 24, 25,26	25,26,*27*
CO_2, CH_4, N_2O and isotopes, including continuous CH_4	Greenhouse forcing, biogeochemical cycles, dating cores younger than 800 ka with stratigraphic matching	Buizert, Brook (OSU)	Gas chromatography (OSU). Stable isotope mass spectrometry (Thermo 253, Thermo Delta V with custom extraction lines). Picarro and Aerodyne (custom) laser gas analyzers.	23, 24, 25,26	25,26,*27*

Ultra-trace gases (ethane, propane, methyl halides, carbonyl sulfide)	Biogeochemical cycles, atmospheric chemistry	Saltzman (UCI)	Gas chromatography with high-resolution mass spectrometry (UCI)	23, 24, 25,26	25,26,*27*
$O_2/N_2/Ar$ ratios and isotopic composition of N_2 and Ar	Past firn depth, gas loss, dating with O_2/N_2 ratio tied to insolation curves	Severinghaus (UCSD), Higgins, Bender (Princeton)	Thermo Finnigan Isotope Ratio Mass Spectrometer (UCSD, Princeton)	23, 24, 25,26	25,26,*27*
$\delta^{18}O_{atm}$	Oxygen biogeochemistry , dating tied to precession cycles.	Higgins, Bender (Princeton), Severinghaus (UCSD), Buizert (OSU)	Thermo Finnigan Isotope Ratio Mass Spectrometer (UCSD, Princeton)	23, 24, 25,26	25,26,*27*
Xe/Kr/Ar ratios	Deep ocean temperature	Severinghaus (UCSD), Higgins, Bender (Princeton)	Thermo Finnigan Isotope Ratio Mass Spectrometer (UCSD, Princeton)	23, 24, 25,26	25,26,*27*
Particle counts	Changes in atmospheric dust deposition	Buizert, Brook (OSU)	Abakus particle counter (centralized OSU lab)	23, 24, 25,26	25,26,*27*
Dust chemistry and isotopic composition	Dust provenance and biogeochemistry	Aarons (UCSD)	Coulter counter, ICPMS (UCSD)	23, 24, 25,26	25,26,*27*
Soluble anions and cations	Aerosol chemistry, dust transport, sea salt transport	Saltzman (UCI)	Quadrupole Mass Spec (centralized OSU lab)	23, 24, 25,26	25,26,*27*
Laser ablation ICPMS analysis	Atmospheric circulation geochemical fingerprinting, detailed layering, dust sources and provenance	Kurbatov, Mayewski (UMaine)	Laser ablation system coupled to ICP-MS (Keck laser facility, UMaine)	23, 24, 25,26	25,26,*27*

2b. Progress toward indicators listed above.

Progress toward each of our goals is summarized in the table in the Performance and Management indicators section, with details reported in the narrative above.

2c. Plans for next reporting period.

In the next reporting period, we will pursue our Year 2 research goals as outlined in the Strategic and Implementation Plan, and complete any Year 1 goals that were delayed. We do not anticipate any major changes in research direction.

III. EDUCATION

1a. Center's overall education goals.

The Center has defined four Optimal Outcomes in the Education and Leadership section of the Strategic Plan.

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.

1b. Performance and management indicators.

Below, we list our performance and management indicators developed to assess our progress towards our Education and Leadership objectives, and briefly note our progress towards these goals. For more details on progress, please see section 2e.

Objective	Milestones	Progress
1. Bring ice core and climate science to K-12 and university curricula.	Incorporate COLDEX research and participants into Ice Drilling Program "School of Ice" (SOI) for faculty at Minority Serving Institutions.	Summer 2022 SOI planning in progress.
	Develop and implement "Project Ice" K-12 teacher education program with the American Meteorological Society, incorporating COLDEX research and scientists.	To begin in Year 2, initial preparation for online modules has begun and in-person dates for summer 2023 have been scheduled.
	Provide opportunities to	To begin in Year 2.

	involve COLDEX students, postdocs, and faculty in formal and informal K-12 outreach.	
2. Develop the next generation of ice core and climate scientists.	Develop and implement a new Research Experiences for Undergraduates (REU) program that engages a diverse group of undergraduate students in COLDEX sponsored research projects.	Students recruited for Year 1 program; currently piloting programming for full deployment in Year 2.
	Create graduate student and postdoc positions at individual COLDEX institutions, successfully recruit and mentor students and postdocs, particularly from underrepresented groups.	Recruited widely on website and listservs, created Zoom "office hours" for interested students to get information about COLDEX and meet each other. Most positions filled.
	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.	To begin in Year 2.
	Develop and maintain an inclusive student/postdoc culture that promotes participation in COLDEX activities.	Database created. ECR group created. IDP template in development. ECR monthly meeting schedule established. Multiple ECRs have volunteered to take part in panels for summer undergraduate workshops. ECR pre-meeting workshop planned for COLDEX annual meeting.
	Provide scholarship funds for	To begin in Year 2.

	graduate student and postdoc research related to COLDEX goals (at COLDEX and non-COLDEX institutions).	
3. Evaluate all COLDEX educational programs.	Create and implement an evaluation framework allowing for summative and formative feedback.	Evaluation frameworks in development to provide feedback for School of Ice, undergraduate research program participants, and COLDEX ECR mentoring effectiveness. Planning to add resources to evaluation in year 2 to create stronger evaluation framework.

1c. Problems encountered and anticipated.

No major problems were encountered in this reporting period. We have identified potential barriers to success and outlined strategies to address them, as described in the following table.

Potential Barriers	Mitigating Strategies
Lack of applicants from historically marginalized identities in science and engineering.	Target recruitment from Minority Serving Institutions, programs in COLDEX institutions, and Community Colleges through School of Ice faculty alumni network and current COLDEX MSI partner institutions.
	Recruit teacher participants with high student populations percentages of those underrepresented in STEM and polar science.
	Recruit at a variety of professional meetings.
	Advertise student and postdoc positions through national and international listservs, particularly those representing underrepresented groups. Seek additional resources for more positions.
Difficulty maintaining strong student and postdoc community across multiple COLDEX and non-COLDEX institutions.	Build REU cohort before, during, and after annual summer research program using remote and in-person team building efforts.
	Develop a multi-tiered network of undergraduate-graduate students, postdocs, and faculty.
	Offer multiple “listening sessions” for current graduate students and postdocs with COLDEX staff and science

	leadership.
	Include undergraduate, graduate students, and postdocs in COLDEX Center annual meetings with options for in-person and virtual attendance. Develop strong ECR cohort in COLDEX, provide remote and in person meeting opportunities, include ECRT member on Executive committee.
Lack of training around mentorship/instruction to encourage participation, success, and persistence of audiences of target.	Provide collaborative opportunities for mentor growth among all COLDEX participants.
	Use outside resources for mentorship growth of COLDEX participants, including the Center for the Improvement of Mentored Experiences in Research (CIMER).
	Open mentoring and leadership workshops to all COLDEX participants (not just students and postdocs) so that mentoring across COLDEX is consistently based in research on best practices.

2a. Internal education activities.

Activity Name	**Early Career Researchers listening session**
Led by	Kristen Rahilly (OSU), Danielle Whittaker (OSU), Meredith Hastings (Brown)
Intended Audience	COLDEX current and incoming graduate students and postdocs
Approx Number of Attendees (if appl.)	14

We held a listening session to begin our programming for early career researchers (ECR) in COLDEX. The first half of the meeting was a brief introduction to the center by Center Director Ed Brook (OSU) as well as a period of open questions and answers about the center for Ed. Following this presentation, we began a closed session with Kristen Rahilly (OSU), Danielle Whittaker (OSU), and Meredith Hastings (Brown University) as moderators. The objective of the closed session was to allow for an environment where ECR participants could feel comfortable making any comments, suggestions, or asking any questions without advising faculty PI present. A total of 12 out of the (then) 19 ECR COLDEX participants came to the meeting with additional participation (before the closed session) of Duncan Young (UTIG) and notetaking by Stephanie Jarvis (OSU). Some of the major themes that came out of this session were: 1) COLDEX ECR participants appreciate the chance to be involved in areas of Center research they may not have expertise in, and scheduling of meetings/research sessions involving different areas of the Center should allow for attendance across participants; 2) It will be important to have an ECR committee with regular meeting times as well as an ECR representative on the COLDEX executive committee; and 3) Career/professional development training is a priority for ECR participants and the highest level of interest centered on writing grants, networking, and science communication (to internal and external audiences).

Activity Name	**Early Career Researcher monthly meetings**
Led by	Catherine Bruns (UMN PhD student), Julia Marks Peterson (OSU PhD student), Shuai Yan (UTIG PhD student), Kristen Rahilly (OSU)
Intended Audience	COLDEX current and incoming graduate students and postdocs
Approx. Number of Attendees (if appl.)	4 - 25

The COLDEX Early Career Researcher (ECR) group holds monthly meetings led by the 3 elected members of the COLDEX ECR executive committee: Catherine Bruns (UMN PhD student), Julia Marks Peterson (OSU PhD student), Shuai Yan (UTIG PhD student). The ECR meetings will occur every month, alternating between “research-themed” and “logistics-themed” meetings. The schedule for summer 2022 is: June 13, 2022 (research), July 11, 2022 (logistics), August 8, 2022 (research). In research meetings, an ECR volunteer will share current developments in their research in an informal presentation or discussion, all members will get to discuss their own current research developments, and problems will be identified. In logistics meetings, ECR participants will discuss planning for activity-wide events such as an ECR training/team building activity the day before the Center annual meeting in September 2022.

Activity Name	**Summer 2022 COLDEX Undergraduate Research Workshops**
Led by	Kristen Rahilly (OSU)
Intended Audience	Undergraduate students working in COLDEX and interested non-COLDEX research groups during summer 2022.
Approx Number of Attendees (if appl.)	10 - 15

Director for Education Kristen Rahilly is organizing weekly zoom meetings for team building, skill building, and research networking with undergraduate students working in COLDEX research groups during summer 2022 or any interested undergraduate student (for example, workshop schedule has been shared with chemistry and environmental studies students at Reed College in Portland, OR, via Mackenzie Grieman, a chemistry instructor and Reed and COLDEX participant). Workshops will include panel discussions with COLDEX Early Career Researchers

Catherine Bruns (PhD student, UMN), Jenn Campos-Ayala (PhD student, UC Irvine), Austin Carter (PhD student, Scripps/UCSD), Lindsey Davidge (PhD student, UW), Annika Horlings (PhD student, UW), Skyler Jacob (MS student, KU), Kaden Martin (PhD student, OSU); a workshop on science communication led by Catherine Bruns (PhD student, UMN); and involvement of COLDEX staff and faculty Ed Brook (OSU), Christo Buizert (OSU), Sarah Aarons (Scripps/UCSD), Erin Pettit (OSU), Nick Holschuh (Amherst College), Heidi Roop (UMN), Peter Neff (UMN), Louise Huffman (Dartmouth/IDP), Danielle Whittaker (OSU), and Kristen Rahilly (OSU).

Activity Name	**Zoom office hours for interested prospective graduate students**
Led by	Christo Buizert (OSU), Erin Pettit (OSU)
Intended Audience	Prospective graduate students interested in applying for a COLDEX graduate student position
Approx Number of Attendees (if appl.)	Approximately 38 came to at least one of the multiple Zoom office hours offered

Zoom office hours were advertised nationally and attended by approximately 38 students. The objective of these office hours was to assist students with questions about COLDEX, graduate school in general, and the application process. Students applied directly to positions at each institution but were told of the additional benefits available for being part of a multi-institution center like COLDEX.

- 9 positions advertised for fully-funded COLDEX graduate student positions beginning in Fall 2022:
    - Ice core gas analysis at Scripps Institution of Oceanography with Jeff Severinghaus (UCSD)
    - Continuous Flow Analysis at Oregon State University with Christo Buizert (OSU) and Ed Brook (OSU)
    - Ice core chemistry at University of California, Irvine with Eric Saltzman (UCI)
    - Ice flow modeling at University of Washington with Michelle Koutnik (UW) and T.J. Fudge (UW)
    - Antarctic Ice sheet geophysics at University of Washington with Knut Christianson (UW) and Michelle Koutnik (UW)
    - Ice core analysis at University of Washington with T.J. Fudge (UW) and Eric Steig (UW)
    - Airborne geophysics at University of Texas at Austin (2 positions) with Duncan Young (UTIG)
    - Science communication research and engagement at University of Minnesota Twin Cities with Heidi Roop (UMN)
- 7 students accepted positions at COLDEX institutions and will be beginning graduate programs in Fall 2022 (several other graduate students who were already enrolled are also supported by COLDEX):
    - Abigail Hudak – OSU
    - Annika Jurgilewicz – UCI

- Margot Shaya – UW
- Liam Kirkpatrick – UW
- Megan Kerr – UTIG
- Shivangini Singh – UTIG
- Demie Huffman - UMN

2b. Professional development activities.

Activity Name	**ECR science communication "distilling your message" activity and team building day**
Led by	Kristen Rahilly (OSU), Heidi Roop (UMN), Catherine Bruns (UMN PhD student), Julia Marks Peterson (OSU PhD student), Shuai Yan (UTIG PhD student)
Intended Audience	All COLDEX graduate students and postdocs
Approx. Number of Attendees (if appl.)	20

Initial plans are in development to have a training/team building day before the COLDEX Center annual meeting in September 2022. Initial meetings between the knowledge transfer and education teams have resulted in a potential "distilling your message" improvisation-based training that will help ECR participants center their research in the broader polar science community as well as identify their own position/place in COLDEX. The optimal outcomes for this day are: 1) ECR participants are able to effectively communicate their research objectives/findings to internal and external stakeholders at upcoming national and international conferences (such as the International Partnerships in Ice Core Sciences meeting in Switzerland in October and the American Geophysical Union conference in December); and 2) ECR participants are given the opportunity to network with other participants to help build an inclusive and collaborative ECR community in COLDEX.

2c. External educational activities.

Activity Name	**School of Ice**
Led by	Louise Huffman (Dartmouth, IDP), Bill Grosser (IDP)
Intended Audience	Faculty from Minority Serving Institutions (MSIs)
Approx Number of Attendees (if appl.)	14 new participants + 1 past participant

School of Ice is a rigorous professional development workshop for faculty from minority-serving institutions (MSIs). This program will train participants to understand paleo-climate evidence derived from ice cores and to acquire the skills necessary to bring this exciting inquiry into new and existing Earth and environmental science classes on their campuses. The experiential nature of this workshop will build background knowledge of cutting edge research and empower participants to communicate authentic paleo-climate research practices, ice core data, and results to their students.

The COLDEX-supported School of Ice will be run at Oregon State University from August 7 - August 11, 2022 with 14 new MSI faculty participants and 1 past MSI faculty participant. Activities, field trips, lectures, and lab tours will provisionally include COLDEX faculty members Edward Brook (OSU), Christo Buizert (OSU), Michelle Koutnik and/or T.J. Fudge (UW), COLDEX Director for Education Kristen Rahilly (OSU), COLDEX ECR participants Jon Edwards (OSU), Ben Riddell-Young (OSU), Julia Marks Peterson (OSU) and COLDEX undergraduate student Sebastian Miller (OSU). The 2022 draft agenda for School of Ice includes field trips to Eliot Glacier on Mt. Hood and the Marine and Geology Repository at Oregon State. Participants will provide summative and formative feedback to evaluate their experiences in the School of Ice program, which will be evaluated by Jana Bouwma-Gearhart (OSU). Longitudinal surveys will also be conducted to evaluate how previous participants use School of Ice content in their undergraduate classrooms. At the June 2022 COLDEX site visit, the panel suggested that SOI use a definition of MSI from the Department of Education that is more restrictive than had previously been employed (25% minority students), a suggestion we will implement.

2d. Integrating research and education.

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

- Facilitate undergraduate research experiences in COLDEX research groups
    - Research mentors, proposed projects and number of undergraduate researchers supported by COLDEX funding in summer 2022 are listed in the table below. Research projects include making high resolution ion measurements of ice cores, measurements of trace gases in ice core bubbles, measuring other gases and stable isotope analyses on Allan Hills ice, chemical analysis of dust in ice cores and training in clean room procedures, and development of the COLDEX strategic communications plan and analysis of audience identification.

Faculty Name	Institution	Project Overview	# students
Sarah Aarons	Scripps Institute of Oceanography	Training in clean lab chemistry and handling of ice cores: from decontamination to melting and filtering; learning and then assisting with the	1

		column chemistry separation procedure.	
Ed Brook	Oregon State	Measure greenhouse gases in old ice from the Allan Hills, Antarctica to establish small scale variability and nitrous oxide concentrations.	2
Heidi Roop, Peter Neff	University of Minnesota Twin Cities	COLDEX audience identification, developing materials for four different audiences, and will assist in the development of the COLDEX strategic communications plan.	1
Eric Saltzman	University of California, Irvine	Training in how to make high resolution ion measurements on COLDEX ice cores and/or analyzing trace gasses in ice core bubbles at UC Irvine.	2
Andrew Schauer, Eric Steig	University of Washington	Training in the development and testing of an ice core melter system design choice and designing a sub-project related to that technology.	1

- Support and acknowledge early career researcher success in research
    - All eight early career researchers that gave talks at the Ice Core Open Science meeting in La Jolla, California were “shouted out” on the Slack early career researcher channel and the main “general” Slack channel with all COLDEX members.
    - Recent published first-author research by Shuai Yan (UTIG, PhD student) “shouted out” on Slack early career researcher channel. Plans to continue to do this for all first-authored research papers by early career researchers (and expansion to other successes).
- Incorporate COLDEX faculty, staff, and early career researchers in School of Ice workshop
    - COLDEX researchers and students are integrally involved in the activities planned for School of Ice 2022, as summarized in the table below.

NAME	COLDEX ROLE	SOI ACTIVITY
Ed Brook	Director of COLDEX	• Provide COLDEX overview to participants, participate in discussions about involvement in COLDEX activities. • Lead participants on a field trip to Elliot Glacier

Kristen Rahilly	Director of COLDEX Ed. and Outreach	● Welcome participants to COLDEX ● Engage with participants throughout the week ● Present COLDEX DEI plans and lead a panel discussion ● Activity: Calculating Glacial Equilibrium
Louise Huffman	Director of the School of Ice and a member of COLDEX Ed. Leadership Team	● Plan, organize and facilitate School of Ice ● Teach Activities and labs
TJ Fudge	COLDEX Faculty - University of Washington	● Presentation: Glacial Dynamics ● Presentation: Sea Level Change
Brodie Pearson	OSU Faculty	● Presentation: Thermohaline Circulation
Andreas Schmittner	OSU Faculty	● Modeling Past and Future Climate
Christo Buizert	COLDEX Faculty	● Lead Gas Lab Tour and isotope activity ● Ice Core Drilling with Barb Birrittella (ice core driller/engineer)- comparing scientists & engineers' practices
Jon Edwards	COLDEX Project Asst-grad student	● Integral to the planning of SOI at OSU ● Demonstrate gas analysis and assist with gas analysis experiment.
Ben Riddell-Young, Katie Wendt, Kaden Martin, Emily Rice, Sebastian Miller, Julia Marks Peterson, and Olivia Williams	COLDEX undergraduates, Grads, and Post Docs TBD–we are meeting next week to determine who will be assisting with SOI this year	● Help with gas lab experience ● Help set up and clean up ● Drive vans ● Assist with hands-on labs and Eliot Glacier field trip
Val Stanley and Cara Fritz	OSU Marine Geology Repository curators	● Tour of facility ● Lead hands-on marine sediment lab ● Compare rock core science to ice core science

- Incorporate COLDEX faculty, staff, and early career researchers into summer undergraduate workshop series (every Wednesday at noon Pacific).

- COLDEX participants are enthusiastically participating in this series. For example:
  - *Social media + Antarctic research Q&A*: Peter Neff
  - *Antarctica "ask me anything" panel*: Sarah Aarons (Scripps), Ed Brook (OSU), Christo Buizert (OSU), Austin Carter (Scripps - ECR), Annika Horlings (UW - ECR), Nick Holschuh (Amherst), Louise Huffman (IDP/Dartmouth).
  - *Science communication workshop:* Led by UMN-TC PhD candidate Cate Bruns; *Science communication panel:* includes COLDEX PhD candidate Cate Bruns and COLDEX Managing Director Danielle Whittaker
  - *COLDEX graduate school panel:* Jenn Campos-Ayala (UC Irvine - ECR), Kaden Martin (OSU - ECR), Skyler Jacob (KU - ECR).

2e. Progress toward metrics described above.

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

- 15 faculty participants from Minority Serving Institutions will take part in School of Ice at Oregon State University from August 7 - 11, 2022. The participants come from the following institutions:
  - 17% from Historically Black Colleges and Universities
  - 33% from Hispanic Serving Institutions
  - 33% from generally defined minority serving institutions (> 25% students from minority identities; but see comments on definition of MSI above)
  - 8% from Alaska Native and Native Hawaiian serving institutions
  - 8% response not reported at time of application

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

- Recruited initial cohort of COLDEX graduate students for positions that start in Fall 2022.
  - Advertised widely through list serves, COLDEX web site, social media.
  - Initiated Zoom office hours for prospective students to learn about the graduate school application process and individual opportunities.

Directly supported graduate students in the COLDEX budget are as follows (note that other students engaged in COLDEX are supported in a variety of ways, e.g., institutional funds, other awards).

Location	# students	Years of support provided by COLDEX, and notes on support from other sources
University of Minnesota, Twin Cities	1	Years 1-5. Seeking external support for a second student in Year 2.
University of Maine	1	Years 3-5. Existing funding supports years 1 and 2.

University of Washington	4	Years 1-5 with partial support, existing funding anticipated for remainder.
University of California, Scripps	2	Years 3-5. Existing funding supports remainder. One position open.
OSU	2	Years 2-5, OSU support in year 1.
UCI	1	Years 1-5
KU	1	Years 1-4
UT	1	Years 1-5 with partial support.

- Draft Individual Development Plan (IDP) for COLDEX early career researchers
    - Discussions underway to have COLDEX leadership facilitate plan development between early career researchers and research mentors
    - Draft plan based on the Oregon State University IDP for postdoctoral fellows, with input from Associate Professor of Science Education Jana Bouwma-Gearhart (OSU)
    - Draft plan set up to be a living document, updated each year by the early career researcher, research mentor(s), and the Director for Education
- 11 early career researcher participants attended the virtual “listening session” on April 12, 2022
    - 2 participants were postdoctoral fellows, 9 participants were graduate students
- 5 early career researchers attended the first official COLDEX ECR meeting on May 9, 2022, 6 attended the meeting on June 13, and 9 attended the meeting on July 11
    - All participants at ECR meetings have been current or incoming graduate students
- 8 COLDEX early career researchers presented research talks and 3 COLDEX early career researchers presented research posters at the Ice Core Open Science meeting in La Jolla, California May 24 - May 26, 2022
- Postdoctoral researcher Katie Wendt (OSU) helped organize the ice core session for the fall 2022 American Geophysical Union meeting
- 30 early career researchers are currently members of the COLDEX early career researcher Slack channel, channel is open to all interested early career researchers regardless of funding or location at COLDEX institution
    - 9 early career researchers have engaged with the channel (many multiple times) either through their own posts or reacting to other posts since the channel was created on April 12, 2022.
- Early career researcher attendance at monthly COLDEX meetings (cumulative across 2 - 4 meetings total).
    - Diversity, Equity, and Inclusion = 4 ECR participants (4 PhD students)
    - Education = 2 ECR participants (1 PhD student, 1 undergraduate student)
    - Exploration and Modeling = 4 ECR participants (4 PhD students)

    - Ice Coring and Analysis = 4 ECR participants (3 PhD students, 1 postdoc)
    - Knowledge Transfer = 2 ECR participants (1 PhD student, 1 undergraduate student)
    - Monthly research seminar (July 6, 2022): 13 ECR participants (6 undergraduate students, 5 PhD students, 2 postdocs). Co-presented by 1 PhD student (Austin Carter, UCSD).
    - All-hands monthly meetings and monthly research seminars in April and May = unclear
- Early career researcher participation in panels for summer undergraduate researcher workshop series
    - Antarctica “Ask me anything (AMA)” panel: Austin Carter (Scripps/UCSD, PhD student), Lindsey Davidge (UW, PhD student), Annika Horlings (UW, PhD student)
    - Science communication panel and mini workshop lead: Catherine Bruns (UMN, PhD student)
    - Graduate School panel: Skyler Jacob (KU, MS student), Jenn Campos-Ayala (UC Irvine, PhD student), Kaden Martin (OSU, PhD student)
- Undergraduate student researchers, summer 2022
    - COLDEX funding 7 undergraduate researchers (one part time student) all at their home/local based institutions, except for one who (from Cal State Long Beach) who will be spending the summer at Oregon State
    - Undergraduate student attendance at summer research workshops (as of July 12, 2022): June 15 = 9 students, June 22 = GEO REU network workshop, June 29 = 12 students, July 6 = 9 students

Objective 3. Evaluate all COLDEX educational programs.

- Draft evaluation plan for undergraduate researchers
    - Draft based largely on the Undergraduate Research Student Self-Assessment (URSSA)
    - Draft has been sent to Jana Bouwma-Gearhart (OSU, College of Education) for approval and for input into Qualtrics
    - Inclusion of recent, peer-reviewed evaluation instrument assessing cultural diversity awareness of STEM research mentors (Byars-Winston, A. and Butz, A.R., 2021. Measuring research mentors’ cultural diversity awareness for race/ethnicity in STEM: Validity evidence for a new scale. CBE—Life Sciences Education, 20(2), p.ar15.)
    - Discussion with Louise Huffman (Dartmouth/IDP) and Jana Bouwma-Gearhart (OSU) about School of Ice evaluation needs in April 28, 2022 meeting. Will use School of Ice evaluation instruments used in the past to allow for better data interpretation across years. Adding a longitudinal study to evaluate how previous School of Ice participants are using the curriculum in their classrooms
    - We are collecting demographic on School of Ice participants (both new and past participants) to better understand the impact of this program on increasing diversity in the field of polar sciences.

- Initial discussions about Project Ice evaluation plan
    - Pilot Project Ice set for summer 2023 but will likely use evaluation instrument similar to American Meteorological Society's long-running Project Ocean K-12 teacher development program. Initial draft questions created to collect demographic information about future participants.
- Initial discussions about evaluation instruments to use for effective mentoring of graduate students and postdoctoral fellows
    - Inclusion of recent, peer-reviewed evaluation instrument assessing cultural diversity awareness of STEM research mentors (Byars-Winston and Butz, 2021).
    - Plans developed to collect metrics related to early career researcher graduation rate, peer-reviewed publications, conference abstracts, and inclusion in polar science field work through self-reporting on Individual Development Plan
- We are currently anticipating increasing resources for educational evaluation following comments by the site visitors in year 1, likely by supporting a post-doctoral researcher in the OSU College of Education, or significantly expanded graduate student support, supervised by Professor Jana Bouwma-Gearhart. Carry forward funds from year 1 (savings on salaries because hiring was not complete) can accommodate additional costs in year 2. Later years may require other re-budgeting depending on scope.

2f. Educational plans for next reporting period.

Future internal education activities:

Activity Name	**Research experience for undergraduates - summer 2023**
Led by	Kristen Rahilly (OSU), Danielle Whittaker (OSU), Ed Brook (OSU), Erin Pettit (OSU), COLDEX executive committee, individual COLDEX research mentors.
Intended Audience	All undergraduates, with at least 50% participants from historically minoritized identities in polar science (*note: further decisions to be made regarding prerequisite course requirements, etc.)
Approx Number of Attendees (if appl.)	7 directly funded by COLDEX but we will seek additional support from COLDEX institutions and other sources.

Development and delivery of the official REU program is planned for summer 2023. Applications and recruiting will occur during Fall - Winter 2022/23, including a call for project proposals from potential COLDEX research mentors, following common deadline for student acceptance of program position (March 15, 2023). Pre-orientation will be held in person at Oregon State in summer 2023. The program will consist of a 10-week research experience in individual research labs across COLDEX institutions, weekly COLDEX zoom undergraduate researcher workshops to allow for team building, skill building, and maintaining a strong community across the summer, and finally presentation of research projects at the COLDEX annual meeting in 2023.

Future professional development activities:

Activity Name	**Early career researcher leadership and career development workshop**
Led by	Meredith Hastings (Brown University)
Intended Audience	All early career researchers (open to participants in and outside of COLDEX as well as participants in the broader Earth Science field)
Approx Number of Attendees (if appl.)	30 (15 from COLDEX, 15 outside of COLDEX in the broader Earth Science field)

Development and implementation of leadership and career development workshop aimed at early career researchers is planned for next year. Potential delivery will be in the days prior to the 2023 Ice Core Open Science meeting (date TBD but likely Spring). Example topics include Communication, Negotiation, Leading yourself, Management of different personalities, Creating an inclusive working environment, Networking, Mentoring, Giving and Receiving Feedback.

Future external education activities:

Activity Name	**Project Ice**
Led by	Wendy Abshire (AMS), Beth Mills (AMS)
Intended Audience	K-12 teacher leaders that have already participated in either Project Atmosphere or Project Ocean (during pilot program of summer 2023)
Approx Number of Attendees (if appl.)	9 - 12 (smaller cohort during pilot summer, full cohort in following summer) in month long online program and in-person workshop at OSU

The pilot offering is currently being developed for summer 2023 with a full cohort of K-12 teacher participants beginning summer 2024. COLDEX will provide contributing expert lecturers, host facilities and ice core lab at OSU, and access to new science and technology that teachers are eager to learn about, engage in, and bring back to their students and peers. During summer 2022, Wendy Abshire and Beth Mills (AMS) are working on developing online modules for teacher participants in collaboration with faculty at PennWest University. Kristen Rahilly (OSU) will assist during summer 2022 with testing the first science module and helping to develop or find COLDEX expertise to develop a second online science module.

Plans to develop new educational partnerships

- Create network of K-12 alums from American Meteorological Society K-12 teacher professional development programs Project Ocean/Project Atmosphere/Project Ice to connect COLDEX participants with interested K-12 classrooms
- Investigate working with the new PSECCO (Polar Science Early Career Community Office) to create a partnership for early career researcher community building
- Investigate creating direct partnership with PolarTREC/PolarConnect to connect COLDEX field researchers with K-12 classrooms
- Potential synergy between future Ice Core Early Career Researchers Workshops (ICECReW) sponsored by the U.S. Ice Drilling Program and COLDEX early career researcher workshops as a way to incorporate early career researchers outside COLDEX.
- Potential involvement with Authentic Research through Collaborative Learning (ARC Learn) program through Oregon State University - Kristen Rahilly (OSU)
- Fall 2022 involvement with Career Champions program through Oregon State University (an online professional development opportunity for faculty and instructors to incorporate career connection into courses, while advancing diversity, equity, and inclusion, and examining the barriers to access for students of color, first-generation students, and students with high financial need) - Kristen Rahilly (OSU)

IV. KNOWLEDGE TRANSFER

1a. 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.

1b. Performance and management indicators.

Below, we list our performance and management indicators developed to assess our progress towards our Knowledge Transfer objectives, and briefly note our progress towards these goals. For more details on progress, please see section 2c.

Objective	Milestones	Progress
1. Expand and facilitate connections across the current network of those who engage with COLDEX research, education, and knowledge transfer activities.	Conduct and maintain network mapping research and social network analysis of COLDEX participants over the duration of the Center.	First survey distributed; analysis in progress.
	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.	Networking, relationship building and defining the scope of activities and potential partnerships is in progress.
	Establish a protocol for addressing external COLDEX inquiries and related communication and knowledge needs.	In progress

	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.	In progress.
	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.	Series underway, sharing links and videos with international colleagues.
2. Support effective, consistent communication of polar and climate-related knowledge to diverse audiences.	Develop and execute a Center-wide strategic communications plan with priority external audiences reviewed and updated annually.	In development.
3. Expand impact of COLDEX participants on applied climate science, science communication best practices and actionable science.	Provide annual professional development opportunities for Center participants to engage with applied scientists, practitioners, and communication professionals.	Will provide first live training based on survey feedback in September 2022.
	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.	In progress with the initial suite of products created by August 2022.
	Support development of a graduate student cohort with experience in multidisciplinary research and	In progress. Training being provided in July 2022.

	provide consistent engagement of social and communications-focused graduate students in all COLDEX activities, including field work.	

1c. Problems encountered and anticipated.

We realize that a barrier to our success will be securing sufficient capacity to implement and support our wide-reaching goals. The knowledge transfer team has a large volume of research, center management responsibilities, and fields requests from across the Center team to support diverse communications and knowledge transfer needs. However, we have very limited staff or research time dedicated specifically to Knowledge Transfer and only one point person(PI) engaged in this portion of COLDEX's work. After Year 1, it is clear that we need to consider both budgetary and capacity needs to ensure we can achieve our goals to integrate knowledge transfer activities across the Center's priorities and to support authentic and meaningful engagement with key external audiences. We also learned that we need to develop clear expectations and accountability mechanisms to ensure participation in social network research; we have some clear gaps in participation and our success in this work will depend on identifying ways to ensure complete participation in Center surveys and network analysis data collection. Some specific barriers to success and strategies to address them are described in the table below.

Potential Barriers	Mitigating Strategies
Inconsistent or incomplete participation by Center membership in activities tracking and network analysis reporting collected through quarterly surveys.	COLDEX leadership sets clear expectations that participation in Center evaluation and tracking activities is required.
	Incentivize participation, ensure people can see and understand the value of the evaluation and tracking activities, and consider hosting dedicated sessions during all-hands gatherings to complete surveys and data collection.
Communications plan and approaches lack specificity and attempt to reach too many audiences across too many channels.	Maintain clearly defined priority audiences informed through audience segmentation and message testing.
	Update and evaluate communications plan using analytics and network analysis research to inform gaps and narrow target audiences over the duration of the Center.
	Remain nimble and be willing to add or limit scope where needed to ensure impact for priority audiences and messages.
Inconsistent or insufficient support for implementation of communication plan	Secure additional resources for dedicated communications and knowledge transfer capacity.

priorities.	Leverage existing Public Relations offices and Communications professionals at COLDEX institutions to help amplify COLDEX messages and materials. Ensure the culture of Center supports and empowers all participants to feel responsibility for the success of the communications, engagement, and knowledge transfer work of the Center.

2a. Knowledge transfer activities.

During the current reporting period, Knowledge Transfer efforts were focused primarily on 1) conducting initial social network analysis research; 2) assessing core Center strength in communication and knowledge transfer and professional development needs; 3) initiating the development of a strategic communications plan, and; 4) contributing to the development of the Center, our Center-wide strategic plan, and the Center's norms and operations. Additional details about each of the core activities are below.

1) **Social Network Analysis (SNA) Research:** The Knowledge Transfer team at the University of Minnesota Twin Cities (UMN-TC) worked to establish the research infrastructure for our ongoing social network research and data collection efforts that will take place over the duration of the Center. To support our research, we identified two PhD students to assist with the research. Cate Bruns, a PhD candidate in Environmental Communication at UMN-TC, assisted with initial SNA research and is conducting literature review to assist in the publication of our initial data early in Year 2. A second PhD student was recruited to join UMN-TC in August 2022 to build on this initial research.

   We developed our initial social network analysis data collection protocols needed to understand and characterize relationships across the COLDEX team. The first survey was distributed in April 2022 and early results are currently being analyzed (Figure IV-1). These data will be used, in part, to support establishment of programming and efforts to help support the creation of new collaborations and mentoring relationships. These data are also going to be collected quarterly and will help to track the evolution of participation in COLDEX and the strength and characteristic of connections and collaborations across the COLDEX team.

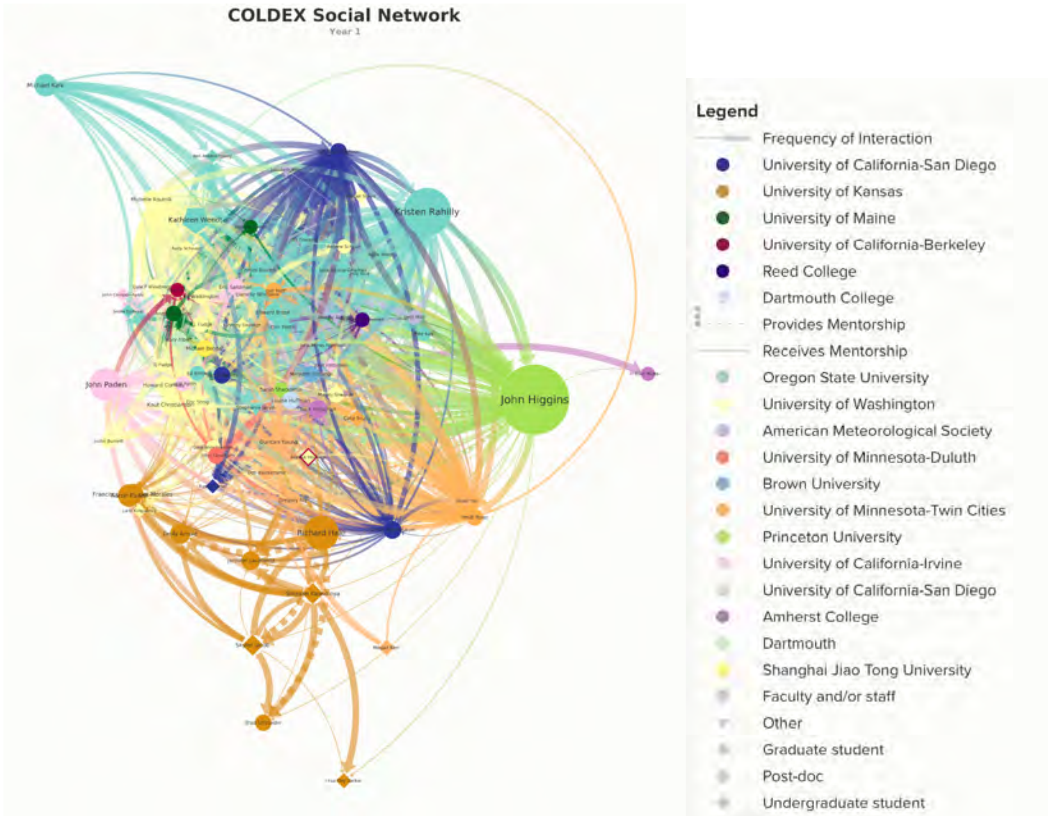

Figure IV-1. Example of the initial networking mapping of the Year 1 COLDEX social network which highlights institutional connectivity, frequency of participant interaction, and mentoring relationships within COLDEX.

2) **Center-wide Knowledge Transfer Audit and Professional Development Needs Identification:** In early May, 2022, we distributed a dedicated Audience Engagement Survey to formally identify needs and current target audiences reached by our Center members, and what the priority training needs are for our professional development programming. An REU student (summer 2022) on the Knowledge Transfer team is assisting with the analysis of these data to inform our strategic communication plan and audience priorities (see below), and to tailor our professional development opportunities for different career stages based on the needs and interests of COLDEX participants. We will provide a dedicated science communication training for the summer student cohort in July 2022.

3) **Strategic Communications Planning and Implementation:** Utilizing the Audience Engagement survey, we have commenced a formal strategic communications planning process to help coordinate and support COLDEX's internal and external communications. This plan, which will be reviewed annually, will help us to target key audiences, identify priority methods for communication and storytelling, and will outline ways to evaluate our impact and reach to our priority audiences. Specific communication outcomes include supporting a dedicated press release about COLDEX, providing several technical and public-facing talks about COLDEX and COLDEX-related science. This includes a collaboration with Hearst Media for a "Forecasting the Future" series that

featured sea level rise science and community engagement efforts that were led by Knowledge Transfer Director, Heidi Roop. Early draft material to populate a COLDEX “press kit” will assist Center participants in broadly sharing about our efforts and promote participation of other researchers, students and teachers in our professional development and educational efforts.

4) **Center Management and Collaboration:** As a member of the Executive Committee, the Knowledge Transfer team dedicated a bulk of early efforts to supporting the establishment of the Center, facilitating needed hiring, and working towards developing workflows and communication channels to support Center-wide engagement.

2b. Other outcomes or impacts of knowledge transfer activities not listed above.

COLDEX is active in engaging other research communities through existing collaborations which provide a number of connection points. A few examples of recent and current efforts include:

- COLDEX participated in proposing an ice core themed special session for the Fall 2022 American Geophysical Union (in collaboration with the Hercules Dome project).
- Active engagement and communication across a range of Scientific Committee on Antarctic Research (SCAR) groups including ‘RINGS’, which is an international collaboration to study the margins of the Antarctic ice sheet, INStabilities & Thresholds in ANTarctica (INSTANT) group, the new Public Engagement with Antarctic Research (PEAR) group, the AntArchitecture Action Group focused on continent-wide radiostratigraphy archive for Antarctica, the Antarctic Digital Magnetic Anomaly Project (ADMAP, as well as the SCAR Bedmap3 project.
- Multiple COLDEX members are actively connected and engaged across the planetary science community. For example, the UTIG radar has similarities with the REASON radar on the Europa Clipper mission, which UTIG is managing. Ice Diver technology is also of interest in relation to probing through icy bodies in the solar system with active connections to the NASA research community. And, ice-flow models can be applied to investigate ice-mass evolution on Mars.
- E. Brook and H. Roop serve in advisory roles to the European DEEPICE project, an innovative training network for a new generation of 15 early-stage researchers in instrumentation, ice core analysis, statistical tools and glaciological and climatic modeling.
- Our team is exploring overlap and joint programming opportunities with land and sea grant programs as well as with federal programs/centers, including the DOI Climate Adaptation Science Centers, NOAA Regional Integrated Sciences and Assessments program, and the NSF CoPe Hubs, one of which is co-located at OSU.
- Ed Brook, Jeff Severinghaus, and John Higgins are members of the IPICS (International Partnerships in Ice Core Sciences) steering committee, providing liaison with the broader international ice core community. Director Brook served on the program

committee for the International Partnerships in Ice Core Sciences (IPICS) meeting which takes place Oct. 2-7 2022. Brook will present an overview of COLDEX at that conference, which will be attended by a large fraction of the international ice core community. Brook also worked with the organizers and the US Ice Drilling Program to secure NSF funds for US ECR attendance at the IPICS meeting.

2c. Progress towards indicators listed above.

We have made substantial progress towards all goals over this reporting period. We have started the initial analysis of our baseline social network analysis research, are planning to publish early results, and are using the data to inform our Knowledge Transfer, education and student engagement programing (Objective 1). The team is continuing conversations with several freelance science communication professionals as well as local and national media outlets to plan and coordinate ongoing communication about COLDEX findings and the research and impact of our Center's members (Objective 2). The UMN team is in the process of developing the Center's strategic communication plan (Objectives 1 and 2). The Knowledge Transfer team also provided some individual support to COLDEX team members on communications-related work and are actively engaged in planning for the all-hands meeting in September and creating training and resources for the REU student cohort this summer related to communications and engagement best-practices (Objectives 2 and 3). We have also contributed to overall Center management, hiring processes, Center-wide strategic plan development and provide assistance for the development of Center-wide workflows. The addition of an REU student to the Knowledge Transfer team is leading to the production of a range of communication resources to share about COLDEX to three initial core audiences: 1) general public and researcher awareness about COLDEX and our scope of research, education, DEI and knowledge transfer efforts; 2) policy makers through a policy brief that will be reviewed by policy experts, and; 3) print and multimedia resources targeted for the School of Ice participants and other educators to share with their students (Objective 2 and 3). All of these efforts are supporting increased awareness of COLDEX, increased capacity to effectively engage diverse audiences and ensure our efforts research a range of different researchers, decision makers, and private sector and other public audiences.

2d. Plans for next reporting period.

Our core work will focus on continuing to develop our social network research, including plans to write a peer-reviewed article to share our initial methodology and findings. We will also be welcoming a new PhD student to the University of Minnesota Twin Cities campus, under the supervision of Drs. Heidi Roop and Peter Neff. This student will lead the social network research and will advance some science communication research that will occur in tandem with implementation of our strategic communications plan. We will complete our initial strategic communications plan and continue implementing key communications activities. We will also continue professional development training opportunities for students and all Center participants. We are in the early stages of exploring new partnerships with a national radio station and television news media company to develop a series of dedicated reporting about COLDEX and COLDEX-related research, climate science, impacts and solutions. Given that

that many of our goals are ambitious, we are also working with the OSU administration to more clearly identify existing communications resources available to us.

V. EXTERNAL PARTNERSHIPS

1a. 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.

1b. Performance and management indicators.

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.

1c. 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. We have not successfully re-engaged with ANSEP staff to make further plans for this partnership. We will reach out to them again as we plan the formal REU program.

2a. Partnership activities.

Activity: Broadening participation in polar sciences

Organization(s) involved: Earth Science Women's Network, Inspiring Girls Expeditions

Narrative: 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. These will be initiated in 2023. We are currently exploring the option of holding the first of these workshops in conjunction with the planned 2023 US Ice Core Open Science Meeting, in collaboration with the Hercules Dome project.

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 2022/Winter 2023.

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

Narrative:

- 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 US Ice Core Open Science Meeting (May 24-26, La Jolla, CA, 2022) and initial discussions for 2023 meeting.
- 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).

2b. Other outcomes or impacts of partnership activities not listed elsewhere.

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. Our original plan was to purchase an instrument from Picarro, Inc. but after extensive discussions with Picarro we found that they would not manufacture an instrument with the needed specifications, despite previous willingness to do so.

Aerodyne is much more amenable to a development project and very interested in our application. They 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.

2c. Progress toward goals.

Partnership relationships are proceeding as anticipated with the exception of links to ANSEP described above.

The US Ice Core Open Science meeting attracted 150 participants. Of these, 34 are participants in COLDEX, including 16 early career researchers.

2d. Plans for next reporting period.

We plan to explore new recruiting relationships for undergraduate and graduate students through connections formed as part of the proposal process and later developments. One potential relationship is with the Chemistry and Chemical Technology Department at Bronx Community College, and a second is through the Geology Department at California State University Long Beach.

VI. DIVERSITY

1a. 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.

1b. Performance and management indicators.

Below, we list our performance and management indicators developed to assess our progress towards our Diversity, Equity, and Inclusion objectives, and briefly note our progress towards these goals. For more details on progress, please see section 2c.

Objective	Milestones	Progress
1. Creating a welcoming culture within COLDEX.	Set expectation of open, welcoming community in all team interactions.	● Regular mechanism for relationship building established for meetings. ● Sense of belonging surveys in development. ● Integrity and Professional Ethics Plan drafted. ● Onboarding process created for new COLDEX members.
	Create a COLDEX Equity and Inclusion Committee of 4-6 people across career stages and institutions to provide guidance to the Executive	● Nominations solicited from COLDEX membership. Initial committee formed.

	Committee on all equity and inclusion issues.	
	Create a COLDEX DEI Ambassador Team to encourage conversations and listening.	● Volunteers to be solicited by September 2022. ● Structure for involvement outlined, waiting for input from first team.
2. Provide, and encourage practice of, inclusive leadership skills.	Develop and implement workshops and seminars to help all participants improve their leadership skills with emphasis on inclusive leadership.	● Multiple workshops in development. ● Cultural competency training for all planned for summer 2022. ● Leadership workshop for ALL during annual meeting. ● First field team leadership discussions to take place before teams leave in November 2022. ● Seminar speakers planned (but not confirmed) in fall to keep conversation going.
	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.	● Mechanisms in development. ● Web feedback form is in final stages of editing, based on what has been used by OSU College of Science for the last two year. ● Sense of belonging surveys will go out this summer. ● Listening sessions have happened for early career people and more are planned. ● “Open door policy” for communication available, will need reminder. ● Formalizing mediation and accountability processes still in development. First level of internal mediation through leadership is

		active.
	Create an inclusive leadership award within COLDEX.	● In development for Year 2.
3. Increasing diversity in polar sciences.	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.	● Equity in admissions and hiring workshop held Fall 2021. ● Collaborative announcement of grad student positions with broad reach using social media and other communication mechanisms. ● Open "office hours" to support interested prospective students on the application process. ● First stage of relationship building with MSI faculty outside of COLDEX. ● Outline and draft budget for proposal to fund cohort of graduate students, key partners identified.
	Support career development of participants from historically marginalized identities including appropriate mentoring and career planning.	● Holistic review process for applicants discussed and compared across institutions to ensure consistency as much as possible (each institution has different review system) ● Mentoring workshop planned for annual meeting. ● Listening sessions for early career in spring, more planned, especially for participants from minoritized identities. ● REU activities for summer 2022 designed with DEI lens. ● Independent

		Development Plan in final editing stages, plan for facilitated advisor/advisee workshop in fall.
4. Broaden the reach of polar science content/messaging to the public and other audiences, especially to previously excluded identities and communities.	Assess communication to avoid presenting exclusive narratives in our external (and internal) communication.	● External communication so far has been reviewed. ● Plan for DEI Ambassadors to being this role in September. ● Discussion with OSU STEM Research Center to propose a community workshop on the "hero" narrative.
	Create structure for assessing educational and other workshop material to encourage inclusive content and pedagogy.	● Mechanisms in development.

1c. Problems encountered and anticipated.

No major problems were encountered in this reporting period. We have identified potential barriers to success and outlined strategies to address them, as described in the following table.

Potential Barriers	Mitigating Strategies
The white male "Hero" narrative is deeply embedded in the media culture and within the science culture (even beyond polar science). Changing this narrative will not happen quickly. This narrative sends an exclusive message to students - anyone who doesn't fit the media's view of who is a polar scientist will be hesitant to apply for REU or grad school.	● Be consistent with our alternative narratives. ● Reach out to targeted communities (those who might apply for REU or graduate school) with the alternative narratives. ● Build individual relationships with prospective applicants well before they have to decide to apply when possible. ● Work closely with field teams (especially through the leaders) to ensure that the team dynamics will support those who feel excluded by this narrative.
All of us (COLDEX participants) have implicit bias and limited self-awareness of our own strengths and weaknesses with respect to our ability to practice inclusive mentoring and leadership. Some may be resistant to feedback and change.	● Patience and compassion. Acknowledge mistakes and encourage continued engagement. ● Repeated messaging through ongoing conversations and modeling appropriate behavior can inspire evolving ideas. ● Discuss empirical evidence that implicit bias exists.
Power dynamics exist, despite our	● Be intentional in addressing this and discuss during

best effort to want earlier career participants or those from historically marginalized identities (at any career level) to feel “included.”	leadership workshops. ● Use community building strategies to work to expose the invisible aspects of power dynamics and make the human side of science visible.
	● Create “brave spaces” for anyone to voice their ideas (either through a DEI ambassador or through a confidential process).
Research is taking place at many different institutions and in the field. Any issues within a research group must be brought forward by people within that research group in order to be able to mediate and support.	● DEI Ambassadors will be from all research groups and will do their best to keep conversations going within each group.
MSI faculty and partners can feel “used” if they sense our desire to partner with them is not genuine, but instead to fulfill a requirement from NSF.	● Relationship building, through consistent communication, visits to institutions by COLDEX representatives, DEI Ambassadors, and through attending conferences. ● Partners will be engaged through, science, education, and DEI elements. We plan to listen to each partner for what will help and support their needs and wants out of the partnership.
Mentors may believe there is too much risk in taking particular actions, such as accepting a student that doesn’t fit the image of a perfect graduate student.	● Provide guidance through activities such as a discussion group at the annual COLDEX meeting, where people can share success stories. ● Provide a support network of shared personnel and resources to help research advisors feel less risk because their team’s forward movement in research will depend less on individual student actions, although it will benefit from student’s successes.
Sufficient resources to track and manage DEI activities may not be apparent or allocated.	● We are investigating using OSU support for COLDEX staff to increase capacity in this area. We also plan to track internal spending in more detail to show where staff expenses and other costs directly support DEI goals.

We identified several risk factors in our strategic plan (repeated in the table above) labeled as “potential barriers to success” and related “mitigating strategies.” While all of them are related in some ways to the ultimate goal of increasing participation of underrepresented minorities in the polar sciences, here we will identify a few additional or clarifying risk factors, how we will know they are triggered, and mitigation strategies with respect to each of our three areas of action:

- Retention
    - It is common for an individual to feel isolated or excluded when they are the only person from a marginalized group, this is especially possible because COLDEX comprises numerous small teams focusing on different goals or different field sites. Trigger: Ideally the individual would reach out to a mentor or one of the confidential communication pathways; alternatively, a mentor would notice behaviors and reach out to the individual to check in. Mitigation: a cohort model

has been shown to work well to reduce the feeling of isolation, and we plan to use that whenever possible. If not possible in one small research group, we want to create a cohort across COLDEX and provide the structure and encouragement to take advantage of peer-mentoring groups across polar sciences (for example, we have heard from individuals in other research teams that Polar Impact has been valuable for providing this support).

- Recruitment
  - Our multi-faceted recruitment strategy includes broad and targeted social media, professional societies, and specific relationship building with partner institutions or organizations. Trigger: we are not meeting our recruitment goals. Mitigation: We will reflect on which strategies and which steps in the process to modify to improve. For the initial phases of prospective participants who contact us and consider applying, we seek input and advice from others with expertise in communication to understand if it is that we are not reaching the right audience or if our message is not coming across in the way we intend. For the second phase of the application submission, we review the process and look for cultural or institutional barriers to applying. For the accepting phase, we must also assess how we compare to competing opportunities in terms of providing support and mentoring. One challenge for us in this process is keeping statistical information on each stage of the process, especially when recruiting happens through relationship-building at conferences or through partner organizations.
- Messaging
  - There are significant issues with the historical elevation of white men and the general “hero” message in Antarctic exploration that still permeates our society. In addition, both internal and external messaging more generally can have exclusive elements, even when unintended. And, whether part of direct or indirect communication, this can impact our success rates at recruiting and retaining good participants. Trigger: There are several possible triggers. Feedback from within COLDEX through one of the feedback pathways (e.g. the online portal), feedback through social media responses or from those who interact with our educational material. Mitigation: The DEI Ambassador team will be trained to identify potential messaging issues and bring them up for discussion.

2a. Center activities which contribute to the development of US human resources in science and engineering at the postdoc, grad, undergrad and pre-college levels.

The Diversity, Equity, and Inclusion 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. Specific activities are detailed in section 2c, Progress toward goals.

2b. Impact of these activities on increasing diversity at the Center.

This year, we focused on improving the internal culture of COLDEX community. We do not yet have statistics to show the impact of these activities on increasing diversity at the Center. We are currently gathering demographic data for COLDEX, with an excellent response rate, and will continue to do that for relevant activities such as the REU program, graduate recruiting, and School of Ice, and therefore will be able to track the direct support of people in underrepresented groups in STEM.

2c. Progress toward goals.

1. Creating a welcoming culture within COLDEX.

5-10% of the time in every monthly meeting is dedicated to engaging the community in activities aimed at breaking down barriers and power dynamics.

We are developing an online web portal as a confidential mechanism for reporting concerns. We have been in contact with the OSU Ombuds office and will meet with them this summer to discuss if they can provide ombuds support (which they do for other programs supported by external funding).

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

The COLDEX leadership has committed to and is practicing modeling of inclusive leadership skills. Plans are underway for the first facilitated leadership and mentoring workshops for everyone at the first annual COLDEX meeting in September 2022. We will seek specific feedback from graduate students about these workshops.

3. Increasing diversity in polar sciences.

We are currently collecting demographic data on our current membership, and will evaluate our efforts to increase diversity in the coming years.

Recruitment for the first incoming class of graduate students under the COLDEX award will begin in Fall 2022. We will focus on increasing our efforts to recruit a diverse group of students, by participating in meetings of groups such as SACNAS and the National Association of Black Geoscientists, as well as breaking down barriers to access by holding online office hours for prospective students, providing professional development opportunities for undergraduate researchers, and exploring ways to waive or cover application fees when needed.

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

We have consistently reviewed external material, both pedagogical (e.g. School of Ice) and communication (e.g. graduate position advertising).

2d. Plans for the next reporting period.

Our plans for the next reporting period include:

- Summer
    - Sense of belonging survey
    - Cultural competency training.
    - Prep for annual meeting
    - Attend conferences for partnerships and recruiting
- Fall
    - Annual meeting: building community, leadership, and mentoring workshops
    - New student/post docs facilitated IDP and advisor/advisee agreement workshop
    - Connecting with key HBCUs and MSIs, pursuing connections with minority professional organizations
    - Inclusive field team dynamics facilitated discussions
    - Graduate student recruitment: review equity in admissions and hiring
    - Strengthening relationship with Alaska Native Science and Engineering Program (ANSEP)
- Winter
    - REU recruitment
    - Field season debrief
    - Check in with each lab team
    - Host listening sessions
- Spring
    - Partner relationship development
    - Sense of belonging survey
    - Reviewing external messaging
    - Host listening sessions
    - Connecting with key HBCUs and MSI

VII. MANAGEMENT

1a. Center's organizational strategy and underlying rationale.

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.

Organizational structure. The COLDEX Organizational Chart is provided in Appendix B. Overall leadership is provided by the Center Director (Brook, OSU), who reports to the Dean of the College of Earth, Ocean, and Atmospheric Sciences. The Managing Director (Whittaker, OSU) oversees and facilitates all aspects of Center management, including internal communications, budgeting, financial management, meeting organization, and reporting. The Director for Education (Rahilly, OSU) oversees and facilitates all aspects of COLDEX educational programs and plays a key role in diversity, equity, and inclusion. Directors for Knowledge Transfer (Roop, UMN), Diversity, Equity and Inclusion (Pettit, OSU), and Field Research and Data (Neff, UMN), are faculty members in COLDEX institutions, who oversee these cross-cutting activities. Leads for individual components of COLDEX oversee those areas, and monitor progress and facilitate exchange of information with the rest of the Center. Institutional leads provide points of contact for administrative matters, recruiting and other institutional issues.

The Executive Committee is comprised of the following individuals:

- Director for Diversity, Equity, and Inclusion (Pettit, OSU)
- Director for Education (Rahilly, OSU)
- Director for Field Research and Data (Neff, UMN)
- Director for Knowledge Transfer (Roop, UMN)
- Managing Director (Whittaker, OSU)
- Exploration Lead (Severinghaus, UCSD)
- Modeling and Ice Dynamics Lead (Koutnik, UW)
- Ice Coring Lead (Higgins, Princeton)
- Ice Analysis Lead (Buizert, OSU)
- Early Career Researcher representative (rotates annually; currently Julia Marks Peterson, OSU)
- At-Large Member (TBD, will rotate annually)

The Executive Committee (hereafter "EC") is advisory to the director, who retains overall responsibility for COLDEX. The EC provides advice to COLDEX leadership on strategic decisions and directions for all COLDEX activities; provides advice and leadership on integration of COLDEX themes and activities, consistent with the COLDEX Strategic and Implementation Plan; and is available to assist with mediation of conflicts between COLDEX participants or institutions. Additionally, the EC is responsible for organizing and overseeing evaluation of requests for scholarship funds, selecting REU projects and students, reviewing and making recommendations about requests for changes to COLDEX budgeting, and assisting with development and maintenance of COLDEX policies and plans, including the Strategic and Implementation Plan, Strategic Communications Plan, Integrity and Professional Ethics Policy, Data Policies, and Sample Allocation Policies. Committee members with conflicts of interest related to items under discussion will recuse themselves. Conflicts of interest include direct supervisory or personal relationships with individuals affected by decisions. The committee will endeavors to make decisions and recommendations by consensus. The director may request a recommendation by majority vote of the committee (for example on scholarship or REU decision). The EC meets weekly via Zoom video conference.

1b-1c. Performance and management indicators and progress towards goals.

The Center has articulated 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.

Below, we list our performance and management indicators developed to assess our progress towards our organizational and management objectives, and report our progress towards meeting those goals in the current reporting period.

Objective	Milestones	Progress
1. Establish Center leadership and management.	Hire staff and implement effective Center management structures.	Managing Director, Director for Education, and Program Assistant hired. Executive Committee appointed and weekly meetings initiated. Weekly management meetings initiated. Quarterly reporting and review of subaward activity initiated. Quarterly meetings with CEOAS staff and Research Office staff initiated. CEOAS Business Office point of contact identified. Internal financial reporting and tracking system developed.

	Establish Executive Committee role in governance and oversight of COLDEX, including written committee charter.	Developed Executive Committee Terms of Reference with guidelines for executive committee decision making and governance. Publications policy developed as part of Integrity and Professional Ethics Plan.
2. Establish effective communication with participants to establish and maintain integration of Center activities and goals.	Establish internal facing communications	Internal website, Slack workspace, and shared Google Drive established, with access for all members. Regular communication with institution leads established. Monthly meetings of subgroups established. Initiated discussions with OSU administrators and staff on supporting COLDEX communications.
	Establish regular COLDEX monthly seminar series featuring both internal and external speakers	Seminar series established; recruitment and scheduling of speakers ongoing.
	Create internal COLDEX data repository linked to website.	In progress, to be completed by September 2022.
3. Facilitate external communications with the media, policymakers, and the general public about COLDEX activities.	Maintain ongoing communication, allocate responsibilities, and set standards and policies	Established regular meetings with the Management team and the Director for Knowledge Transfer. Initiated discussions with OSU administrators and staff on supporting COLDEX communications.
4. Integration of Center science, education, knowledge transfer, and diversity, equity, and inclusion efforts into an enduring Center culture.	Potential new members can easily find information about how to get involved in COLDEX and access resources.	Created an informational website for new and existing members. All aspects of COLDEX represented in annual meetings, seminars, and other Center activities (ongoing).
	Opportunities to exchange information internally.	Monthly all-hands meetings established. Center participants included in annual strategic planning process. COLDEX side meeting held at Ice Core Open Science meeting in La Jolla, CA (May 2022).
	Create opportunities for participants to work across COLDEX themes.	Education Director initiated recruitment of COLDEX researchers in K-12, faculty, and Early Career professional

		development programs. Collective development of COLDEX Integrity and Professional Ethics Plan and mentoring plans underway. Monthly sub group meetings open to all participants.
	Annual Center meetings that integrate all COLDEX themes and provide opportunities for participant connections.	First annual COLDEX meeting being organized for September 2022.
	Diversity, equity, and inclusion activities are valued by COLDEX members and enrich careers.	Training to early career researchers on how to present DEI activities in CVs, job applications to be initiated in Year 2. COLDEX DEI award to be initiated in Year 2.
5. Provide support to COLDEX participants investigating new funding streams and collaborations for COLDEX-related activities.	Serve as a point of contact for COLDEX participants wishing to approach potential donors or funders.	Initial discussions between COLDEX Director Brook and OSU Foundation Officer for CEOAS. List of COLDEX priorities for external support under development.
	Communicate funding opportunities to participants and encourage/facilitate proposals.	Mechanism to distribute announcements about funding opportunities via COLDEX email listserv and Slack workspace established.
	Seek new research partners who can take advantage of COLDEX samples, data, or programs.	Advertising of COLDEX activities and possible research directions through Center website and talks at conferences and workshops (including the US Ice Core Open Science meeting, Ice Crew ECR Workshop,AGU Scientific Drilling in the Polar Regions Town Hall) initiated. Developing plans for sample allocation and advertising
6. Ensure oversight and evaluation of COLDEX by seeking feedback from the External Advisory Committee on an annual basis, and regularly assess progress towards management and integration goals.	Appoint External Advisory Committee (EAC) and develop EAC Charter including roles, responsibilities, and length of service.	Initial committee appointed. EAC terms of reference completed.
	Initiate formal evaluation of educational programs	See details in Education section of report.

	Initiate internal and external evaluation of non-education components of COLDEX.	External Advisory Committee asked to provide annual review of COLDEX progress. Annual Knowledge Transfer network analysis to help improve Center communication in progress. Plan to evaluate different aspects of COLDEX each year is in development.
	Quarterly review of participant activity.	Quarterly review initiated and ongoing.
7. Manage and facilitate field and ice core logistics planning with participants, NSF and USAP logistics providers.	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.	Numerous planning meetings by Zoom in late 2021/early 2022. Director for FRD appointed, COLDEX Operational Memo for field logistics drafted for 2022. Peter Neff appointed as Director of Field Research and Data.
8. Make COLDEX data and technology openly and widely available within and outside of COLDEX.	Finalize and maintain COLDEX Data Management policy.	Planning to get participant input, circulate draft, finalize before COLDEX year 1 meeting (September 2022)
	Develop and track internal data sharing mechanism.	Secure, password-protected internal data archive to be created by September 2022.
	Create centralized location for long-term public archive of COLDEX data, metadata, model results and engineering designs.	COLDEX project registered at USAP Data Center. System will be explored for potential and limitations by September 2022.
	Investigate how new concepts of Open Science can be incorporated in COLDEX data streams and management.	None to report yet; summary to be presented at annual meeting in September 2022.
9. Implement program of ethics training.	Establish an ethics policy and engage all members of COLDEX in ethics training.	Drafted a Center-wide Integrity and Professional Ethics Plan. Developing mechanisms to provide access to research ethics on-line training modules through OSU for participants at institutions without similar systems and requirements. Developing mechanism to provide access to third-party

		reporting system for reporting ethics issues to OSU Office of Audit, Risk, and Compliance. Creating a system to track annual research ethics training compliance (in progress).
	Deliver first training module on ethical behavior during field research before first COLDEX field season.	Planning training module for the first COLDEX-wide meeting (September 2022).
10. Create and maintain COLDEX Intellectual Property Plan	Engage OSU IP and Licensing Office for assistance.	Plan has been drafted, reviewed and adopted by all participating institutions.

1d. Problems encountered and anticipated

No major problems were encountered in this reporting period. We have identified potential barriers to success and outlined strategies to address them, as described in the following table.

Potential Barriers	Mitigating Strategies
Large number of institutions and participants makes communication and progress reporting challenging.	Make communication a high priority.
	Develop internal survey on effectiveness.
Staff resources must match workload.	Review staff workload and responsibilities regularly.
Reconciling early career researcher research plans across the Center, given the academic community's expectations for individual productivity.	Identify overlap, conflicts, and potential opportunities, and facilitate communication and cooperation in cooperation with institutional leads.
	Create a community authorship policy.
	Create a policy of distributing abstracts of papers and talks on COLDEX topics to the entire COLDEX group prior to submission.
	Communicate early on high impact papers in progress.
Unanticipated changes in logistics landscape.	Identify possibilities and refine existing contingency plans.
Leadership unavailability.	Follow procedures in the COLDEX temporary leadership policy and succession plan.
Nonconformance with Center policies	Monitor critical activities and provide ways to report.

in Ethics, Data Management, Mentoring or other areas.	
	Publicize methods for reporting and resolving problems.
	Ensure all participants are aware of policies and consequences of violation.

2. Management and communications systems for 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 group meeting on a monthly basis. All COLDEX members, at all career stages, are welcome and encouraged to attend any meetings that interest them.

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 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.

3. Names and affiliations of the Center's external advisors.

Name	Affiliation
Julie Brigham-Grette	University of Massachusetts Amherst
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

The Executive Committee is working to appoint two additional EAC members.

4. Changes to the Center's strategic plan.

The initial Strategic Plan was submitted to NSF in April 2022. We have made small updates in response to feedback from NSF and the site visit review in June 2022. We will evaluate and update the plan annually.

VIII. CENTER-WIDE OUTPUTS AND ISSUES

1a. Publications

1. Davidge L, Steig EJ, Schauer AJ. Preprint. Improving continuous-flow analysis of triple oxygen isotopes in ice cores: insights from replicate measurements. *Atmospheric Measurement Techniques Discussions*. https://doi.org/10.5194/egusphere-2022-60
2. Yan S, Blankenship DD, Greenbaum JS, Young DA, Li L, Rutishauser A, Guo J, Roberts JL, van Ommen TD, Siegert MJ, Sun B. 2022. A newly discovered subglacial lake in East Antarctica likely hosts a valuable sedimentary record. *Geology*. doi: https://doi.org/10.1130/G50009.1

1b. Conference Presentations

1. Abshire, W, Kauffman, C. AGU Fall Meeting. Innovative approaches in geoscience education via university-K12 partnerships, December 16, 2021.
2. Badgeley, JA, Koutnik M, Steig E. Evaluating the compatibility of thinning and accumulation histories at the WAIS Divide ice core site during the last deglaciation. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
3. Brook E, Buizert C, Higgins J, Koutnik M, Neff P, Pettit E, Rahilly K, Roop H, Severinghaus J, Whittaker D. The Center for Oldest Ice Exploration (COLDEX) and Opportunities for Community Involvement. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
4. Brook E. COLDEX–Search for the Oldest Ice Exploration. Polar Educators International Conference, Iceland, April 2022.
5. Buizert C, Oyabu I, Kawamura K, Severinghaus J, Williams O, Martin K. New quantitative approaches to temperature reconstruction from polar ice cores. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
6. Carter A, Aarons SM, Higgins JA, Shackleton, Epifanio J, Davies Morgan J, Severinghaus JP, Brook EJ, Kurbatov A. 2021/12/16, American Geophysical Union Fall Meeting 2021.
7. Conway H, Christianson K, Horlings A, Holschuh N, Koutnik M. Site selection plans for a stratigraphically continuous record of +2Ma old ice in the Allan Hills. COLDEX meeting at US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
8. Higgins J. The Hunt for Earth's Oldest Ice – Update from the Allan Hills, Antarctica. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
9. Huffman, L. Ice Science Lab - Melting Glaciers. Polar Educators International Conference, Iceland, April 2022.
10. Huffman, L. What Story Does Your Data Tell? Arctic Science Summit Week. March 27, 2022.
11. Neff P, Roop H. Keynote: Stories in Ice: How our frozen world connect us all. Polar Educators International Conference, Iceland, April 2022.
12. Roop H. Minnesota Water Resources Conference. Climate Adaptation Needs in the Water Sector, October 20, 2021.
13. Roop H. AGU Fall Meeting. Science and Society Town Hall, December 13, 2021.
14. Roop H. AGU Fall Meeting. From Risk to Resilience: Connecting Communities to Coastal Hazards Through Interactive & Immersive Design, December 16, 2021.

15. Roop H. AGU Fall Meeting. Ice Core Town Hall Presentation, December 7, 2021.
16. Roop H. AGU Fall Meeting. Geohealth and Equity Innovation Session, December 17, 2021.
17. Yan Y, Blankenship DD, Beem LH, Greenbaum JS, Young DA. Geologic controls on subglacial thermal conditions and old ice preservation – insights from East Antarctic airborne geophysical surveying. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.
18. Young DA, Paden JR, Greenbaum JS, Blankenship DD, Buhl DP, Ng G, Yan S, Gomez D, Kaundinya S, Rodriguez-Morales F, Hale R, Arnold E, Goodge J, Koutnik M, Fudge TJ, Christianson K, Conway H, Winebrenner D, Holschuh ND, Neff P, Severinghaus J, Brook E. The aerogeophysical contribution for COLDEX oldest ice core site selection. US Ice Core Open Science Meeting, La Jolla, CA, May 2022.

1c. Other Dissemination Activities

1. Brook E. COLDEX talk at AGU "Scientific Drilling in the Polar Regions" Town Hall Meeting, December 7, 2021.
2. Brook E. COLDEX talk at ICECReW Ice Drilling Program Early Career Workshop, January 7 2022.
3. Brook E. COLDEX talk at GLASS Sedimentation School, OSU Marine Geology Repository, OSU, Corvallis, May 26 2022.
4. Neff PD. Keynote speaker, Purdue University Ecological Sciences and Engineering Symposium 2022. April 6, 2022. Theme: "The role of social media in environmental movements."
5. Neff PD. Revolutionizing Antarctic Science: the Impact of a Subsea Cable from New Zealand to Antarctica (invited talk, online), International Cable Protection Committee 2022 Virtual Plenary. April 26, 2022. COLDEX was mentioned in introducing Antarctic Science.
6. Neff PD. Invited talk: Purdue University Ecological Sciences and Engineering Symposium keynote speaker, "Antarctic science and social media," April 6, 2022. https://www.purdue.edu/newsroom/purduetoday/releases/2022/Q2/ese-symposium-to-consider-social-media-influence-in-environmental-efforts.html.
7. Neff PD. Podcast: Unrestricted with Ben Leber (former NFL player and Twin Cities media figure) https://www.iheart.com/podcast/1248-unrestricted-with-ben-leb-71814530/episode/dr-peter-neff-ice-core-paleoclimatoligist-95381707/
8. Roop H. Minnesota State Environmental Quality Board. Climate Change - What we know, what it means for Minnesota and the Role of the State, October 20, 2021.
9. Roop H. North Central Climate Collaborative Webinar Series. IPCC AR6 and What it Means for the Midwest. October 25, 2021.
10. Roop H. Alexandria Community College. Climate Change Impacts and Action in Minnesota, October 28, 2021.
11. Roop H. National Webinar for the NOAA Climate Program Office in partnership with the Water Utility Climate Alliance and the Water Research Foundation. Leading Practices in Climate Adaptation: Engineering Case Studies, November 18, 2021.
12. Roop H. Minnesota Corn Growers Association. Climate Change: How We Know, Impacts, and Actions. November 17, 2021.
13. Roop H. Minnesota and Northern Iowa Green Seam. Weather Whiplash: Navigating New Extemes & Embracing Change, December 2, 2021.

14. Roop H. Climate Smart Municipalities MN-Germany Exchange Meeting. Using Climate Data in Decision-making, December 2, 2021.
15. Roop H. UMN Women In Technology. Climate Change, Sustainability, and U (and you), January 26, 2022.
16. Roop H. Minnesota Department of Natural Resources: Learn. Talk. Do. A Western Lake Superior Climate Resilience Forum. Climate Change & Coastal Adaptation, February 9, 2022.
17. Roop H. Minnesota Master Naturalists Program. Climate Change Resources in Minnesota, March 8, 2022
18. Roop H. House Committee Hearing to the Higher Education Finance and Policy Committee. Expert Testimony, March 9, 2022
19. Roop H. American Association of University Women Minnesota Chapter. Climate Change: The Imperative to Act, March 15, 2022.
20. Roop H. VTT Research Finland; Partnership discussion and presentation with VTT Research in Finland. Increasing the Capacity of Communities to Prepare for Changing Climate Extremes, March 22, 2022.
21. Roop H. Washington State Education Service District 113; Teacher Professional Development opportunity for Washington State teachers work on incorporation of Next Generation Science Standards into core curriculum. "What does the future hold? How scientists look back and to the future using different ‘time machines,’" March 24, 2022.
22. Roop H. City of Morris Community Resilience Workshop. Science to Action: Bringing Climate Science into Community Resilience Planning, March 25, 2022.
23. Roop H. University of Minnesota CFANS Alums. Climate Change Action: A Focus on Mitigation & Adaptation (keynote), March 28, 2022.
24. Roop H. MN House of Representatives; House Hearing for the Climate and Energy Finance and Policy Committee. Expert Testimony; Increasing the Capacity of Minnesota Communities to Manage & Prepare for Weather Extremes, March 31, 2022.
25. Roop H. University of Minnesota Duluth. Seminar to Earth and Environmental Sciences Department; Accelerating Climate Resilience in Minnesota and beyond, March 31, 2022.
26. Whittaker D. COLDEX Outreach and Engagement Plans. College of Earth, Ocean, and Atmospheric Sciences Outreach Ignite Session. April 14, 2022.
27. Young D. Presentation at the April 2022 Antarchitecture workshop.
28. Young D. Presentation at UTIG staff meeting on COLDEX.
29. Young D. Presentation to the Northwest Austin Rotary Club, February 18, 2022.

2. Awards and Honors

	Recipient	Award Name and Sponsor	Date	Award Type
1.	Sarah Aarons	Curtis Outstanding Woman in Science Award, Geological Society of America	2021	Scientific
2.	Donald Blankenship	University of Texas Institute for Geophysics Outstanding Researcher	May 2022	Scientific
3.	Edward Brook	William S. and Carelyn Y. Reeburgh Memorial Lecture, American Geophysical Union	December 2021	Scientific
4.	Cate Bruns	MnDRIVE Human in the Data Fellowship, University of Minnesota	June 2022	Fellowship
5.	Austin Carter	Graduate Student Research Grant, Geological Society of America	June 2022	Scientific
6.	Annika Horlings	UW Geophysics Support Fund	May 2022	Scientific
7.	Annika Horlings	UW Kenneth C. Robbins Graduate Fellowship	May 2022	Fellowship
8.	Peter Neff	Harvard Chan School of Public Health C-CHANGE and Pique Action Climate Creator to Watch 2022	January 2022	Education-related
9.	Shuai Yan	University of Texas Institute for Geophysics Outstanding Graduate Student	May 2022	Scientific

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

None to report.

4a. General outputs of knowledge transfer activities

None to report.

4b. Other outputs of knowledge transfer activities

None to report.

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/		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. 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)	6
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	$452,800
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)	80

8. Media Publicity

- 9/9/2021: “New science and technology centers to address vexing societal problems.” NSF Announcements. https://www.nsf.gov/news/special_reports/announcements/090921.jsp
- 9/9/2021: “Oregon State to lead National Science Foundation-funded Center for Oldest Ice Exploration.” Oregon State University press release. https://today.oregonstate.edu/news/oregon-state-lead-national-science-foundation-funded-center-oldest-ice-exploration
- 9/13/2021: “Icy climate clues: University of Minnesota researchers lead in search for 1.5 million-year-old Antarctic ice to transform our understanding of Earth’s climate.” University of Minnesota College of Food, Agricultural and Natural Resources press release. https://cfans.umn.edu/news/earth-climate-coldex
- 9/14/2021: “UW part of $25M NSF-funded effort to retrieve Earth’s oldest ice core.” University of Washington press release. https://www.washington.edu/news/2021/09/14/uw-part-of-25m-nsf-funded-effort-to-retrieve-earths-oldest-ice-core/
- 9/22/2021: “Oregon State to lead effort to find oldest ice in Antarctica.” Interview on Oregon Public Radio show “Think Out Loud.” https://www.opb.org/article/2021/09/22/oregon-state-to-lead-effort-to-find-oldest-ice-in-antarctica/
- 10/20/2021: “Hunt begins for ancient Antarctic ice—and clues to Earth’s response to rising temperatures.” *Science*. https://www.science.org/content/article/hunt-begins-ancient-antarctic-ice-and-clues-earth-s-response-rising-temperatures
- 10/28/2021: “A double dose of climate research.” University of Minnesota press release. https://twin-cities.umn.edu/news-events/double-dose-climate-research
- 12/6/2021: ”COLDEX: The search for Earth’s oldest ice and new climate solutions.” Medill Reports. https://news.medill.northwestern.edu/chicago/coldex-the-search-for-earths-oldest-ice-and-new-climate-solutions/
- 2/8/2022: “As good as a time machine.” *Amherst Magazine*. https://www.amherst.edu/amherst-story/magazine/issues/2022-winter/community-news/as-good-as-a-time-machine
- 4/1/2022: “ESE Symposium to consider social media influence in environmental efforts.” Purdue University press release. https://www.purdue.edu/newsroom/purduetoday/releases/2022/Q2/ese-symposium-to-consider-social-media-influence-in-environmental-efforts.html

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 is a member of the organizing committee for the IPICS Open Science Conference in Switzerland in October 2022 and will represent COLDEX there. IPICS has an Oldest Ice working group and Brook and Severinghaus are long standing members - this group will also meet to share information in October.

Brook has had preliminary discussion 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.

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