Whitepaper summarizing the 2022 Polar Radar Science and Technology Conference

Virtual - April 4-6, 2022

https://climatechange.umaine.edu/prstconference/

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NOTE: This White Paper Report was compiled from pre-conference communications with the community as well as from notes collected from all conference participants which were written in the breakout sessions during the conference. The team members above (conference organizers, committee, moderator, and additional report contributors) provided critical grammatical, organizational, and language contributions to the final report with a goal of merging comments from all conference participants into an organized summary.

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1. Overview

Ground-penetrating radar (GPR) and related ground-based radar technologies are commonly used within Polar environments for scientific research and logistical operations. Technical hardware and software research and development have generated more widespread use of GPR over the past few decades. Radar applications in polar environments include but are not limited to glaciology, permafrost and periglacial environments, near-surface geology and geomorphology, fluvial environments, engineering and more. The wide applicability of radar for answering geoscience or polar science questions results in relatively high demand as new applications are developed annually. Unfortunately, radar systems are often expensive or cost-prohibitive for single scientists to acquire. It is currently challenging for broader potential end users, outside of well-funded institutions, to gain access to radar instrumentation or software for research, to develop the in-house expertise to collect, analyze, and quantitatively interpret radar results, or to stay up-to-date in these methodologies, particularly if radar is just a tool for specific science questions of interest. This has resulted in the need to assess the current state and future potential of radar within the science community, including: 1) science questions which could be answered in part or whole by radar techniques, 2) technical capabilities and limitations of radar systems, 3) equipment and software, and 4) engineering or technical resources which should be made available to the Polar science community. The U.S. National Science Foundation (NSF) has established facilities and organizations which support equipment pools, engineering expertise, and large-scale data collection, storage, or analysis capabilities for a range of geodetic and geophysical instrumentation (e.g., EarthScope, UNAVCO, Passcal-IRIS; CReSIS). Unfortunately, the Polar science community currently lacks a coherent assessment of future science or logistical interests which may incorporate radar into their needs, despite significantly increased use of radar over the past two decades.

To address this, we held a three-day conference in April of 2022, hosted by the Climate Change Institute at the University of Maine, to discuss ground-penetrating radar, related technologies, and software use and needs within the Polar community. This conference was founded by the National Science Foundation (Award # 2113032). Its focus was to address:

1) current and future science and logistical drivers which may require or benefit from radar hardware and software;

2) current commercial (off-the-shelf), modified, and user-specific radar systems available to the science community;

3) ongoing radar technology R&D;

4) equipment and software community access;

5) radar education and training needs and options;

6) facilitating radar usage in the broader science and logistics community.

In addition, this conference aimed to determine current and future needs of ground-based radar technology in, glaciology, permafrost and periglacial environments, sea ice, and Polar geology or geomorphology fields. Over the course of three days, presentations from 12 speakers were provided on a range of topics, including available software, ongoing radar research, and innovative technologies in the radar field. Following each day's talks, conference participants broke off into smaller groups to discuss questions related to the 'theme of the day.' Following smaller discussions, all participants reconvened in the main zoom room to discuss key takeaways as a group. This approach was designed to give everyone at the conference a chance to share ideas and thoughts.

2. Pre-Conference

In advance of the conference, we created an online questionnaire open to anyone interested in participating. The focus of the questionnaire was to gauge the professional backgrounds of all participants, the radar-related topics that they would most like to discuss as a community, and which topics participants would be most interested in presenting on. We received 72 responses to the questionnaire, which provided valuable feedback for planning daily discussions.

2.1 Advertising and Participant Professional Backgrounds

The conference was advertised on cryosphere-related listservs such as cryolist, and ArcticInfo, and on social media (e.g., twitter) because of the international reach due to active science engagement on these platforms and listservs. To encourage broader international, early career, and underrepresented community participation, we also advertised through the Association for

Polar Early Career Scientists (APECS), Earth Science Women's Network, IARPC, UArctic, and classical Polar workshops (WAIS Workshop, Arctic Workshop, and AGU Cryosphere Discussions). We hoped to encourage early career engagement with this advertising approach and were successful. Based on an online questionnaire emailed to all registered participants, nearly 32% were graduate students (masters/PhD), ~28% were Professors (Assistant/Associate/Full), 11% Postdoctoral researchers, and 11% were government employees. The remaining participants came from a range of backgrounds (Figure 1).

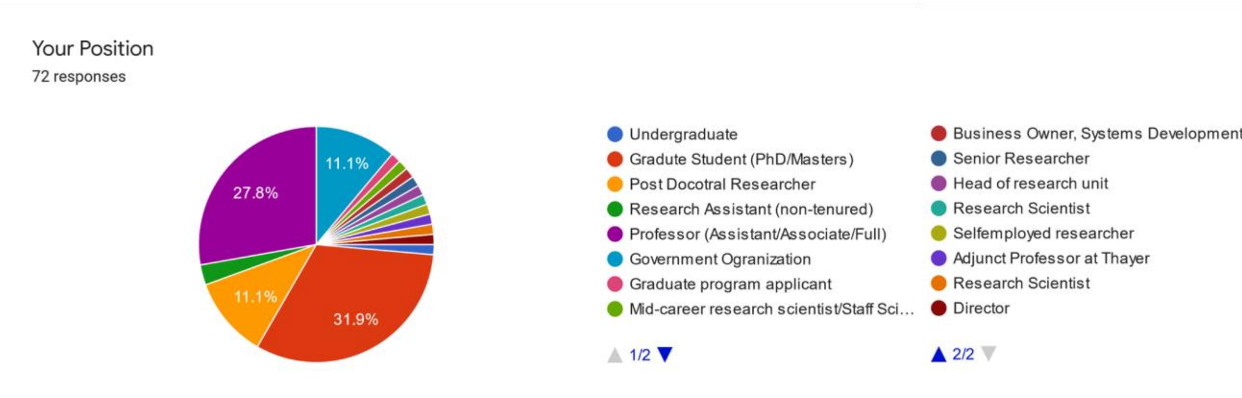

Figure 1. Professional demographics of individuals who responded to the pre-conference questionnaire.

2.2 Participant Topics of Interest

Based on pre-conference feedback (Table 1), most participants were interested in discussing 1) the current and future science and logistics which use radar methods, 2) radar software and data analysis needs and 3) current and future radar systems. The topics selected for planning the conference were topics specifically recommended by community members during a pre-survey. This community feedback helped the committee develop themes and questions that drove daily discussions.

Topic	% Interest
Science Questions & Logistics Requiring Radar & Related Technology in the Future	64 (89%)
Radar Data Software, Analysis, and Interpretation Needs	59 (82%)
Current Polar Science & Logistics using Radar and Related Technology	57 (79%)
Current & Future State-of-the-Art Science Community Radar Systems	54 (75%)
Current Commercial Radar Systems, Research, and Development	43 (60%)
Maximizing Radar Data Access, Sharing, and Standards in the Future	40 (56%)
Current Radar Data Repository and Future Needs	37 (51%)

Radar Science, Engineering, and Technical Support Needs	36 (50%)
Improving Radar Training & Education within the Polar Community	34 (47%)
Community Radar Equipment Pool	31(43%)
Spaceborne Synthetic Aperture Radar	1 (1%)
Establishment of specific working groups to be continued after the conference	1 (1%)
Links between radar, potential field and geological and geomorphology communities	1 (1%)

Table 1. The results from the re-conference questionnaire: topics of interest for the Radar conference.

3. Daily Conference Summaries

Discussions during each of the three days of the conference were driven by the following questions:

Day 1) What *science questions can ground-penetrating radar and related technology help us answer?*

Day 2) *What is the state of our current hardware, software, and other resources for radar technology? (What's out there now?)*

Day 3) *Where are the holes? Current equipment, software and training gaps, future limitations, and emerging areas of need?*

Where possible, the 12 talks for the conference were assigned based on how they aligned with the question of the day. Following daily talks, breakout sessions were created, and each group was provided with the same set of questions to help guide discussions. Responses from participants were recorded in shared Google Slides where participants could respond to questions anonymously. Allowing anonymous responses on Google Slides would, hopefully, reduce reservations for participants and make the venue more amenable to people with opinions that differed from the group (e.g., early-career participants). Below, we summarize the key takeaways from each group. However, the full responses in the Google Slides can be viewed via a link listed on the following webpage, as well as full video recordings of the conference:

https://climatechange.umaine.edu/prstconference/resources/

3.1. Day 1 - What science questions can ground-penetrating radar and related technology help us answer?

Day 1 started with presentations from four speakers to help spark conversations and to share the radar science and technology available to users. The following presenters discussed:

1) Bastien Ruols, Drone-*based GPR system for alpine glacier surveying*

2) Olaf Eisen, *AWI's ultrawideband radar systems – access, technology & science*
3) Sarina Kapai, *AR Focusing of Mobile ApRES Surveys*
4) Joe MacGregor, *Current & future community radar systems*

Following these talks, participants were placed into breakout groups and provided with several questions to help guide discussions. The following questions were formulated: 1) What are people currently working on for projects, and what are the science questions? 2) What do people want to be working on for projects, and what science questions are you interested in the future? 3) What is your most interesting science question, and what hardware do you need to answer it?

Key takeaways from breakout sessions:

Group 1 - Discussion focused on the difficulty of working in alpine vs polar environments with GPR. This is due to funding, how well available radar equipment performs in warmer, temperate environments vs cold, dry polar conditions, and logistical/safety concerns. A second discussion focused on the question of how we obtain better spatial coverage of ice thickness and properties in alpine environments.

Group 2 - Some group members discussed how swath mapping is important and that the larger cryosphere community could benefit from more data sets at different frequencies to tease out different ice properties. Group 2 shared the question of collecting data over large regions and obtaining a better spatial resolution for important data sets.

Group 3 - This group had questions related to understanding the differences between using radar systems on wet snow vs ice vs permafrost. Because all of these polar environments exist under different conditions (temperature, elevation, precipitation), there is no one-size-fits-all approach on which hardware works best in each situation. Discussion of the different equipment necessary for each environment highlighted the difficulties for many researchers and early-career scientists that don't have access to different antennas and GPR setups to use in varying environments.

Group 4 - Discussions focused largely on how to link local to regional scale observations and enhance spatial coverage of data sets. The group also discussed which radar systems best answer specific questions in unique environments.

Group 5 - The team was interested in field validation of theoretical solutions and how we can test new equipment in new environments to get the most out of capabilities. For existing technology, the group discussed making sure that ground-truth data exists for the validation of GPR surveys in the field. A second theme was the use of drones. Drones are appealing to the larger community because they may allow improved spatial coverage of collected data sets for teams with limited time and because drones allow access to hazardous and inaccessible areas of glaciers.

Group 6 - Discussions focused on the demand for new radar equipment such as ApRES, multi-polarization/channel GPR systems, and training on how to use such systems and the required software. Because only a limited number of people in the community know how to use certain radar systems, the demand to produce and properly train users is outpacing the time and resources of the few experts who can provide this information.

Group 7 - This group focused on major questions in cryosphere science and was interested in the structural properties of ice sheets and if it's possible to determine past ice flow patterns and ice volume changes from radar surveys.

3.2 Day 2 - What is the state of our current hardware, software, and other resources for radar technology? (What's out there now?)

Day 2 started with presentations from four speakers to help spark conversations and to share the radar science and technology available to users. The following presenters discussed:

1) John Bradford - *Detailed mapping of the internal structure of Arctic pingos using ground-penetrating radar*
2) Riley Culberg - *Improving Geophysical Constraints on Firn Aquifer Total Water Storage by Combining Radar and In Situ Measurements*
3) Laurent Mingo - *IceRadar: a tool for radio-echo sounding of glaciers*
4) Marie Cavitte - *The difficulty of having only access to open source software*

Groups on Day 2 were given the following prompts to discuss: 1) *What hardware/software are people currently using?* 2) *What hardware or software are you currently finding most valuable?* Groups were able to compile a list of the gear they currently use or would like to use in future studies.

Commercial Radar Systems

There are a wide range of commercial GPR systems available which have been used for snow, firn, ice, permafrost, and other polar terrestrial environments. The conference did not summarize all available systems nor all Polar environments that GPR systems have been used in. The discussions only summarized the systems currently being used by attendees of the conference. We also did not summarize what each system has been used for. However, we share the systems below to at least capture the range of systems which the current EM community is using to suggest that these systems are currently the most useful for Polar research applications.

Geophysical Survey Systems Incorporated (GSSI) (USA):

Antennas: 15-80 MHz Multi-frequency antenna, 100 MHz, 200 MHz, 200 MHz digital hyperstacking), 350 MHz (digital hyper-stacking), 400 MHz, 900 MHz, 1 GHz

Control Units: SIR-3000 Controller, SIR-4000 Controller, SIR-30 Multi-channel system, and Panasonic Tablet Controller.

Blue Systems Integration LTD (Canada):

IceRadar: 1 MHz to ~200MHz antennas using Narod to Kentech transmitters and a wide range of digitizers for different applications (stationary radar, snake antennas, drone radar, etc.)

Ice Map System: 500 MHz center frequency for lake ice and related applications

British Antarctic Survey (United Kingdom):

ApRES: 200-400 MHz (Chirp FMCW)

ApRES: 1 GHz (in development for near surface applications)

Sensors & Software (Canada):

pulseEKKO 50, 100, 200, 500, 1000 MHz; Multi-offset GPR systems available as well (500 and 1000 MHz antennas).

Malå (Australia):

Malå systems were not explicitly summarized. However, attendees were generally aware of the radar system and some attendees have used800 and 1600 MHz Mala antennas and controllers for their snow research.

Software

Similar to the EM hardware summarized above, discussions in the conference primarily summarized software packages currently being used by the Polar EM community to process and analyze GPR and related data. Conference attendees did nearly across the board in discussions show interest in open-source software access as opposed to reliance on commercial software packages to reduce barriers to entry. This said, there was also some concern that open-source packages have their own unique challenges, for example a lack of consistent funding to support software development, barriers to entry for possible users without strong programming or coding skills, and software which is not transferable across platforms (PC, Mac, etc.). We have therefore broken software into commercial and open-source options below for consideration. With all this said, participants noted that it does appear that many scientific groups are trending towards the use of Python as a primary mode of data processing and analysis. It was also noted that Github repositories for working versions of software are commonplace.

Commercial Software Packages:

- MATLAB
- GSSI Radan
- ReflexW
- Sensors & Software EKK_Project

Open-source Software Packages:

- Python
    - Example: ImpDAR
- R
    - Example: RGPR

Key takeaways from breakout sessions:

Group 1 - asked how do teams get access to equipment and expertise when using it in non-standard ways or to test it on theoretical ideas experimentally? Many researchers are restricted in the experiments or measurements they can conduct because they have limited or no access to different radar equipment (antenna frequencies/models/training)

Group 2 - discussed how the use of different brands of radar and software makes collaboration difficult. Much of the commercial hardware needs to be processed with proprietary software. This makes sharing data between groups difficult if another team does not have access to that software. This point emphasizes the need to continue developing and maintaining radar processing software that is open source. Additionally, group 2 noted that multiple radar systems with different antenna frequencies would be necessary if any community pool of equipment were to be purchased.

Group 3 - would like to further explore the use of drones for radar data collection. However, the group acknowledges that Federal Aviation Administration and European Union regulations will likely be a challenge in how they restrict the size and use of drones for research.

Group 4 - Focused on training for different software packages to get the most out of radar data. This is particularly relevant for early career researchers and teams who could borrow radar gear from a communal pool. This team noted it might be beneficial to the wider Polar radar community to host a software conference in future to organize all available software and its best uses. One major issue for existing software, especially those developed in open-source software by individual research groups, is that much of the knowledge on these processing packages are passed from one person to another. This usually occurs from one graduate student to the next and results in the software and training not being recorded in one place.

Group 5 - found that allocating time to train new users on equipment and software is a major concern for research groups who are developing and using new radar systems that are of use to the wider community. Only a few people know how to use certain equipment and software and end up teaching many other people. This is certainly the case with the popular ApRES systems that have been recently developed and used in many Polar environments. Training and workshops are almost always free of charge and come as extra work for research groups and students on top of their existing workloads. Another issue is the lack of long-term maintenance on developed code for radar analysis. There are usually only one or two people who can answer questions on any issues related to code and software.

Group 6 - **agreed** that we need to pool hardware for the community. They also noted that software access and training must accompany access to the hardware to properly process data. One concern for group 6 related to funding a community pool of hardware. Would there be sufficient funding to purchase enough equipment for a community pool, and who would maintain, fix, and upgrade radar units? Another concern from this group and others is who would have access to a communal pool of equipment. Would this only be available to researchers who are funded by an NSF grant? Could equipment be available for international researchers as well? Would early career researchers be prioritized for borrowing equipment?

3.3 Day 3 - Where are the holes? Current equipment, software and training gaps, future limitations, and emerging areas of need.

Day 3 began with four talks and was followed by breakout sessions that focused on the questions of the day. What new or additional instrumentation/software would be useful for your existing projects and likely future projects? What current limitations are you running into with hardware/software in past or present research? What are the accessibility issues for radar hardware/software/data use within the Polar community?

1) Rodrigo Rangel, *Northern lake ice property analysis using ground penetrating radar*
2) Anna Broome, *Development and Initial Field Testing of a Multi-Frequency Ice-Penetrating Radar*
3) Thomas Teisberg, *Development of a fixed-wing UAV-borne frequency-modulated ice-penetrating radar system*
4) William Harcourt, *Millimetre-wave radar at 94 GHz: A new tool for cryosphere research*

Key takeaways from breakout sessions:

Group 1 - This group discussed the ideal equipment for a communal-pool. They suggested that field-proven hardware and easy-to-learn software would be most beneficial. This equipment would ideally be used for intended and proven purposes (ice depth, active layer thickness, stratigraphy) as opposed to lent out for experimental and theoretical studies. An annual equipment and software training workshop might be sufficient to ensure radar users are up-to-date on equipment they might use in the field. One key point the group highlighted was that the benefit of a communal pool of equipment would be greatest for early career researchers and from a (an) diversity/equity/inclusion perspective.

Group 2 - Focused on software and data needs within the radar community. They noted that there seems to be a large gap within the community between people who build/develop radar and software and the people who use them. Continued communication between developers and users is essential. On the data side, group 2 suggests that a greater effort is made to make data more easily accessible and available, particularly with airborne data.

Group 3 - Reemphasized that available equipment is paired with proper training and knowledge so teams get the right gear for the job and produce usable datasets. One approach for the community pool of equipment would be to buy several radar units and discover what the demand is for use. This group also brought up several important questions. Is this a US or international effort, and who would fund these efforts?

Group 4 - Discussed that there is a need for shared equipment and support the idea. They note that members of this group would take advantage of such an equipment pool for their future studies. Like other groups on this day, they concur that training is a must to accompany the use of the equipment and for troubleshooting problems in the field. This group notes that there is at least one organization (i.e., University of Wyoming Geophysics Department) that currently makes radar equipment available for reasonable rental fees. This organization has trained staff to help with equipment training and data processing. Such a group could be studied to model future equipment pools and training resources after.

Group 5 - Suggest that part of the process includes knowing who is liable for damaged shared equipment. Additionally, they suggest that data processed and collected with shared equipment is ultimately shared with the community. Like the previous groups, group 5 would take advantage of using shared equipment and see formalized training as a necessary part of this process.

4. Discussion and Key Takeaways

Over the course of three days, daily attendance averaged 50-60 participants with 103 individuals registered. Our aim of conducting this conference over three days for fewer hours per day (as contrasted with more intensive full two-day schedules common among virtual conferences) was to increase the participation of attendees who might not be able to join the conference over an entire day. We received feedback from a wide range of stakeholders in the radar community, including early-career researchers, established scientists, academic and government scientists, and representatives from private companies that provide radar equipment and services. This combination of participants encouraged discussions that were centered around the need for an organized communal pool of radar equipment hardware and software as well as training and potentially other related resources. Each day was organized around a central theme: Day 1) current science being addressed with radar, Day 2) what radar systems and software are being used by the community, and Day 3) how can we address current needs in the community? These themes produced several key takeaways from the conference that can be summarized:

- A majority of conference attendees agree that a shared pool of equipment and software is beneficial to the radar community, but perhaps an international resource is worth considering,
- A communal pool of radar equipment to include, at the bare minimum, a suite of common offset GPR controller and antennas and Autonomous Phase sensitive radar (ApRES), would be most beneficial for early career researchers and for groups with limited funds,
- It is essential that proper training (towards pre-acquisition operation and post-acquisition processing) accompany any communal pool of radar equipment,
- The creation and access to open-source software are essential for the community because of the barrier created by proprietary software,
- There is a strong interest in drone-based GPR applications, yet there are many FAA and EU regulatory challenges associated with drone systems which must be navigated,
- Many non-commercial radar systems are being developed and lead to innovative radar applications.

5. Future Directions

In regard to next steps for the community, it was discussed that a common pool of radar equipment (commercial and non-commercial) should be a priority for the Polar science community because of limited access to this expensive equipment. This is especially important for undergraduates, graduate students, early career professionals, marginalized community members, or less well-established academic institutions who may not otherwise have access or funding to acquire radar equipment for field campaigns. Accompanying the acquisition of radar instruments, the community emphasized the need for training on proper use of the equipment and troubleshooting for in-field challenges. One suggestion is that training sessions could occur as workshops (bi)annually for interested parties to become familiar with available equipment, proper usage, and best applications for each individual radar and antenna set up. The radar community contains an immense amount of shared knowledge on best use and practices with radar equipment and could benefit from organizing this into a workshop for sharing this knowledge with the broader community. There was discussion about what to do with field data once acquired and access to open software for post-processing and analyzing data sets. A long-term goal for the community may be to create workshops on the use of already-available open software (e.g., ImpDAR or RGPR).