PUSHING REMOTE SENSING CAPACITY FOR CLIMATE CHANGE RESEARCH IN CANADA'S NORTH:

POLAR's contributions to NASA's Arctic-Boreal Vulnerability Experiment

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Abstract

NASA's Arctic-Boreal Vulnerability Experiment (ABoVE) is a ten-year study of ecosystem response to environmental change across Alaska and northwestern Canada, utilizing and testing space-based and airborne remote sensing technologies. Consultations at the planning stages of the project included a concerted push by Polar Knowledge Canada (POLAR) to extend the domain to High Arctic landscapes. POLAR now participates with NASA in the ABoVE Coordinating Group, aiding in the coordination of Canadian research, data management, and the acquisition of RADARSAT-2 satellite imagery with the Canadian Space Agency (CSA). POLAR is also leading ecosystem studies at the Canadian High Arctic Research Station (CHARS) campus, one of the few High Arctic sites within the study domain. POLAR also funds several projects associated with the ABoVE program, across several of the thematic working groups.

The first ABoVE Airborne Campaign (AAC) finished in 2017, with remote sensing instruments measuring a diverse suite of environmental variables. These technologies were intended to align with field researchers for ground calibration and validation. At the CHARS study site, both the AVIRIS-ng and ASCENDS jet-based instrumentation suites surveyed the Greiner watershed component of the CHARS Experimental and Reference Area (ERA) for vegetation and CO_2 respectively.

ABoVE education activities have also been coordinated in northern communities. The Earth to Sky course held in Yellowknife in April 2017 brought US and Canadian scientists together with educators and representatives of First Nations to share in how they observe, understand, and interpret environmental change. Then, during the airborne campaign in May and August of 2017, NASA and the Government of the Northwest Territories (GNWT) organized open houses at the Yellowknife airport, where youth and the public were able to see several of the jets and sensors, and receive an overview of ecosystem and remote sensing sciences.

Suggested citation:

Houben, A., McLennan, D., Goetz, S., Miller, C.E., Griffith, P., Hoy, E., and Larson, E. 2018. Pushing remote sensing capacity for climate change research in Canada's North: POLAR's contributions to NASA's Arctic-Boreal Vulnerability Experiment (ABoVE). Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 53–62. DOI: 10.35298/pkc.2018.07*

Résumé

L'expérience de la NASA sur la vulnérabilité de la région boréale de l'Arctique (ABoVE) est une étude de dix ans sur la réaction des écosystèmes aux changements environnementaux en Alaska et dans le nord-ouest du Canada, qui utilise et met à l'essai des technologies de télédétection spatiales et aériennes. Les consultations menées aux étapes de la planification du projet comprenaient un effort concerté de Savoir polaire Canada (POLAIRE) pour étendre le domaine aux paysages de l'Extrême-Arctique. POLAIRE participe maintenant avec la NASA au Groupe de coordination ABoVE, aidant à la coordination de la recherche canadienne, à la gestion des données et à l'acquisition d'images satellites Radarsat-2 avec l'Agence spatiale canadienne (ASC). POLAIRE mène également des études des écosystèmes au campus de la Station canadienne de recherche dans l'Extrême-Arctique (SCREA), l'un des rares sites de l'Extrême-Arctique dans le domaine d'étude. POLAIRE finance également plusieurs projets associés au programme ABoVE, dans plusieurs des groupes de travail thématiques.

La première campagne aérienne d'ABoVE (ACC) s'est terminée en 2017 avec des instruments de télédétection mesurant un ensemble diversifié de variables environnementales. Ces technologies devaient être harmonisées avec les chercheurs sur le terrain pour l'étalonnage et la validation au sol. Au site d'étude de la SCREA, les ensembles d'instruments à réaction AVIRIS-NG et ASCENDS ont étudié le bassin hydrographique Greiner situé dans la zone d'expérimentation et de référence de la SCREA pour la végétation et le CO2 respectivement.

Des activités d'éducation d'ABoVE ont également été coordonnées dans les collectivités du Nord. Le cours « Earth to Sky » (de la terre au ciel), qui a eu lieu à Yellowknife en avril 2017, a réuni des scientifiques américains et canadiens ainsi que des éducateurs et des représentants des Premières Nations pour qu'ils puissent expliquer comment ils observent, comprennent et interprètent les changements environnementaux. Puis, au cours de la campagne aérienne en mai et août 2017, la NASA et le gouvernement des Territoires du Nord-Ouest (GTNO) ont organisé des journées portes ouvertes à l'aéroport de Yellowknife, où les jeunes et le public ont pu voir plusieurs des avions à réaction et des capteurs et recevoir un aperçu des sciences des écosystèmes et de la télédétection.

Introduction and ABoVE overview

Polar Knowledge Canada (POLAR) is developing a strong research presence in the Arctic, based out of the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay, Nunavut, to serve Canada and the world. Its mission is to advance knowledge of the Arctic in order to improve economic opportunities, environmental stewardship, and quality of life for northerners and all Canadians. One of the ways that this mission will be achieved is through strengthening of monitoring activities designed to provide important baseline environmental information, as well as sponsoring research to fill critical knowledge gaps.

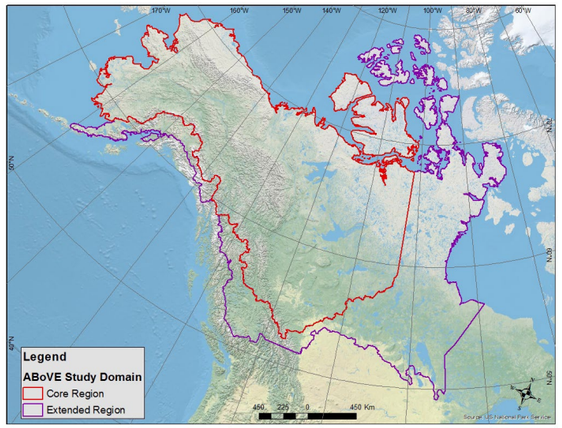

Figure 1: The ABoVE study domain includes Arctic and boreal terrestrial landscapes in Alaska and much of western Canada. The core region of the study domain captures the regional-scale variations in surface and atmospheric conditions, necessary to address the science questions and objectives. It includes landscapes and ecoregions that are rapidly changing in complex ways, as well as others that are not — a combination that allows for studies on both vulnerability and resilience. The study domain includes an extended region outside of the core region, which allows for studies focused on a subset of important changes that are not occurring in the core region (e.g., insect outbreaks and forest dieback in the southern boreal forest). The extended region includes areas where research focuses on environmental conditions that are considered to be antecedent to those in the core region. Studies conducted in the extended region also provide opportunities for collaboration with existing or planned research.

NASA is implementing the Arctic-Boreal Vulnerability Experiment (ABoVE), a large-scale study of ecosystem responses to environmental change in the Arctic and boreal regions of northwestern North America (Fig. 1) and the implications for social-ecological systems (above.nasa.gov). ABoVE's science objectives focus on (1) developing a fuller understanding of the vulnerability and resilience of Arctic and boreal ecosystems to environmental change in western North America, and (2) providing the scientific basis for informed decision-making to guide societal responses from local to international levels.

There is significant overlap between the scientific objectives and geographic domains for POLAR and ABoVE; the geographic domains include much of Yukon, the Northwest Territories, and Nunavut in northwestern Canada, encompassing boreal and tundra landscapes. In addition, both POLAR and ABoVE will focus on the monitoring and research needed to understand how terrestrial and freshwater ecosystems and permafrost are responding to environmental change, and how these responses alter the ecosystem services that are provided to society within and beyond this region. The research and monitoring activities carried out through POLAR and ABoVE will include the collection, synthesis, and analyses of in situ and remote sensing data, and the use of models to effectively integrate and extrapolate observational data to describe large-area processes and to communicate information required by decision makers and stakeholders. These common areas of interest provide the foundation for collaborations between POLAR and ABoVE in pursuing their common goals.

Ecosystem change is rapidly occurring across Canada's North because of climate change — from the northward movement of treeline to permafrost degradation and thermokarst expansion, from increased forest fire events and burn severity to accelerating greenhouse gas emissions. Observing these changes across the remote and challenging environments of the North is inherently difficult. Thus, utilizing remote sensing is pivotal to monitoring northern environmental, social, and economic sustainability. This includes novel airborne sensors and orbiting satellites, with concurrent calibration and validation by field researchers on the ground, to answer some of these climate change questions over a ten-year period and beyond.

This paper also describes the partnership with POLAR during the program planning stage. Following that, a description of the first ABoVE Airborne Campaign (2017) outlines the airborne assets, instrumentation, and flight paths taken over the ABoVE domain. A brief summary of POLAR-supported ABoVE projects and field of study is then provided. In conjunction with NASA's airborne fleet, POLAR is also coordinating with the Canadian Space Agency in the tasking and acquisition of RADARSAT-2 imagery over several years to further support instrumentation and field studies. This may lead to additional support from the Polar Space Task Group in subsequent years. Finally, on top of the large-scale scientific focus of ABoVE, a summary of parallel education and outreach activities and community considerations are described, as well as the future phases of ABoVE.

NASA-POLAR consultations at the ABoVE planning stages

Given POLAR's role and jurisdiction for the Canadian Arctic, a POLAR representative joined the NASA ABoVE Science Definition Team while the project was being scoped and designed, at the request of Environment Canada. With an additional representative from the Canadian Forest Service, this was the Canadian component of the ABoVE team that contributed to the development of the NASA ABoVE Concise Experiment Plan (available from https://above.nasa.gov/acep.html) that defined the geographic scope of the project, confirmed project goals, and identified key questions the project would address. Another key development was the generation of a Memorandum of Understanding (MoU) between NASA and POLAR that outlined the roles and responsibilities of the two parties in implementing the ABoVE project in Canada. In this MoU, POLAR's roles included the coordination of work and liaison with communities and governments within the joint study area in Canada, ensuring that airborne operations comply with Government of Canada aircraft operating regulations, providing for the coordination of ground observations in Canada, defining data management approaches, and providing funds as possible to Canadian researchers to complement the NASA funding. The MoU was advanced in preparation for the White House Ministerial Meeting in September 2016, where the NASA-POLAR relationship was included as an example of positive US-Canada science cooperation in the North.

2017 ABoVE Airborne Campaign

The 2017 ABoVE Airborne Campaign (AAC) was one of the largest, most complex airborne science experiments conducted by NASA's Earth Science Division. Between April and November, the AAC involved ten aircraft in more than 200 science flights that conducted surveys across more than 4 million km2 in Alaska and northwestern Canada. Many flights were coordinated with same-day ground-based measurements to link process-level studies with geospatial data products derived from satellite sensors. The AAC collected data spanning the critical intermediate space and time scales that are essential for a comprehensive understanding of scaling across the ABoVE study domain, and ultimately extrapolation to the pan-Arctic, using satellite data and ecosystem models. The AAC provided unique opportunities to validate satellite and airborne remote sensing data and data products for northern high-latitude ecosystems. The science strategy coupled domain-wide sampling with instruments commonly known as "foundational instruments," L-band and P-band synthetic aperture radar (SAR), imaging spectroscopy, full waveform Light Detection and Ranging (LIDAR), and measurements of atmospheric trace gases (including carbon dioxide and methane), as well as PI-led studies using Ka-band SAR and solar-induced chlorophyll fluorescence. Targets of interest included field sites operated by the ABoVE Science Team as well as the intensive and/or long-term sites operated by US and Canadian partners. An example of an airborne instrument configuration is given in Figure 2 — an Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) unit.

One component of the 2017 airborne campaign surveyed the CHARS campus and Cambridge Bay area (Fig. 3). This included the Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) suite of instrumentation onboard NASA's DC-8 aircraft and the Airborne Visible/ Infrared Imaging Spectrometer-Next Generation (AVIRIS-ng) onboard an A200 aircraft. A summary of the ABoVE sensors/instruments, what they were used to measure, and platforms used to collect the data is provided in Table 1. One set of flightlines within the CHARS Experimental and Reference Area (ERA) showing data acquisitions from the NASA AVIRIS-ng hyperspectral sensor is shown in Figure 4.

NASA is planning to return to Canada and Alaska in 2018 with two of the instruments deployed in the 2017 airborne campaign. The notional plan as of this writing is to conduct AVIRIS-ng flights in midsummer 2018 and 2019, and L-Band SAR flights in late August of 2018 and 2019. AVIRIS-ng is tentatively scheduled to fly sites around Fairbanks and Barrow, Alaska; the Old Crow Flats, Yukon; and the Mackenzie Delta, Northwest Territories.

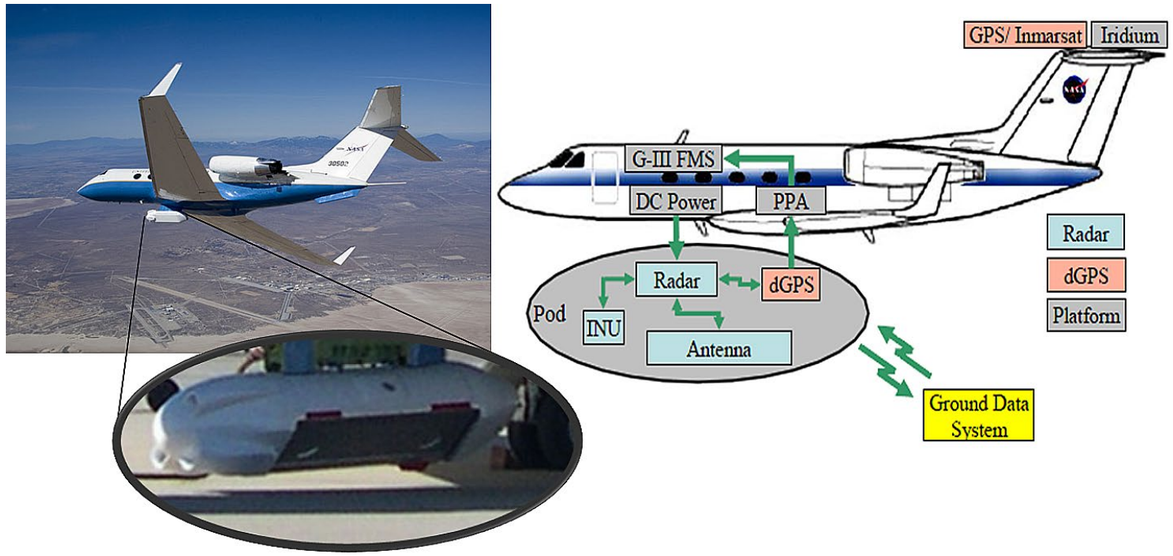

Figure 2: Photos and diagrammatic views of an airborne instrument, the UAVSAR in this example (Lee et al 2007).

Table 1: Instrumentation and aircraft utilized in the 2017 ABoVE Airborne Campaign.

Instrument	Description	Instrument Class	Measures	Aircraft
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface	P-band SAR	Repeated flights measure deformations in land, ice, soil moisture	G-III
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar	L/P-band SAR	Repeated flights measure deformations in land, ice, soil moisture imagery	C-20A
AirSWOT	Airborne Surface Water and Ocean Topography	Radar (KaSPAR)	Surface water and ocean topography	B200
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons	CO_2 sounder suite	Gases (carbon): shifts in terrestrial carbon sources/sinks	DC-8
ATM-C	Atmospheric Carbon	CO_2, CH4, CO	Gases (carbon)	Mooney
AVIRIS (NG)	Airborne Visible/ Infrared Imaging Spectrometer (Next Generation)	Spectrometer	Vegetation & atmosphere imagery: high signal:noise imaging in solar reflected spectral range	B200
CFIS	Chlorophyll Fluorescence Imaging Spectrometer	Spectrometer	Vegetation: solar-induced fluorescence	DHC6
LVIS	Land, Vegetation and Ice Sensor	Lidar	Surface topography and vegetation coverage	B200T

Figure 3: Productive lakes are visible on the landscape surrounding Cambridge Bay, Nunavut via AVIRIS-ng imagery, Aug. 2, 2017.

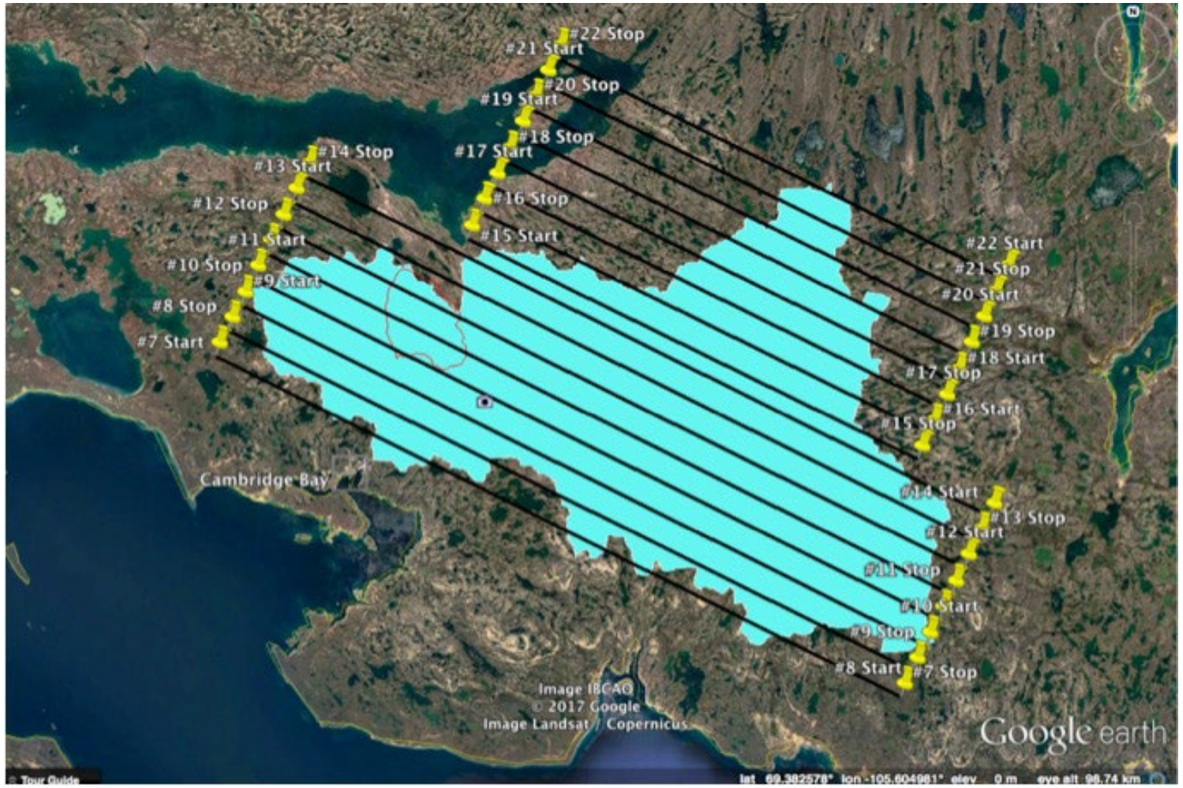

Figure 4: One set of 2017 AVIRIS-ng flightlines (in black) over the CHARS ERA and Greiner watershed (aqua fill colour).

L-Band SAR will be repeating lines flown during the 2017 campaign, with the objective of establishing multiyear time series for ABoVE science investigations, and is tentatively scheduled to fly the Boreal Ecosystem Research and Monitoring Sites (BERMS) in Saskatchewan, road-accessible sites near Yellowknife, Whitehorse, Kluane Lake, and Inuvik, and a subset of sites in Alaska that are of greatest interest to the SAR Working Group. Notional flightlines, subject to modification, will be posted as this planning progresses (available from https://above.nasa.gov/airborne_2017.html).

ABoVE projects and activities led or supported by POLAR

Roughly one quarter of the ~600 researchers in ABoVE are from Canadian organizations. Research is functionally guided by working groups focused on scientific fields that include hydrology and permafrost, vegetation dynamics, fire disturbance, carbon dynamics, wildlife and ecosystem services, modelling, and airborne science. POLAR hosts one of the High Arctic study sites in the CHARS ERA, staged from the CHARS campus (69.121119°N, -105.042189°W), with ecosystem studies scaling from submetre plots to local watershed mapping to the Kitikmeot region level for monitoring. In August 2017, the CHARS campus and town of Cambridge Bay witnessed the first ABoVE airborne campaign's arrival to measure atmospheric carbon dioxide emissions, as well as AVIRIS-ng hyperspectral imaging to assess vegetation characteristics.

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Figure 5: Researchers at High Arctic field sites; contrasting landscapes — alpine (left), tundra plateau (right); wind- and solar-powered monitoring station (centre) for the POLAR-funded Arctic Research Foundation's Cat-Train project.

Table 2: POLAR-supported projects related to the ABoVE program (available from https://www.canada.ca/en/polar-knowledge/advancingpolarknowledge.html*).*

Principal Investigator; Organization	Project Title	Region of Study
Asselin; Université du Québec de Abitibi-Témiscamingue	Impacts of climate change on wildfire risk in boreal forests in Northwest Territories	Communities across NWT
*Calmels; Yukon College	Mapping permafrost vulnerability in Vuntut Gwitchin Traditional Territory: climate change impacts on landscapes and hydrology	Old Crow, Yukon Territory
Stantec & Fraser; NRCan	Shrub Monitoring in Canada's Arctic using Multi-scale Measurements from Field Plots, Unmanned Aerial Vehicle (UAV) Surveys, and Satellite Remote Sensing	Regions in Nunavut & NWT
*Humphreys; Carleton University	Improving Canada's climate change projections by incorporating Arctic shrub feedbacks	Daring Lake Tundra Ecosystem Research Station, NWT
*Langlois; Université du Québec de Sherbrooke	Development of a multi-scale cryosphere monitoring network for the Kitikmeot region and Northwest Territories using modeling and remote sensing	Nunavut (Cambridge Bay, Gjoa Haven, Kugluktuk, Kitikmeot region)
Marsh; Wilfrid Laurier University	Cryosphere, vegetation, and freshwater monitoring in the western Canadian Arctic	Northwest Territories
Marshall; University of Calgary	Cryosphere-climate monitoring	Kluane Lake Research Station, Yukon Territory
*Quinton; Wilfrid Laurier University	Consortium for permafrost ecosystems in transition (CPET)	Scotty Creek & Suhm Creek, NWT
Rautio; Université du Québec à Chicoutimi	Ecosystem health of Arctic freshwaters	Cambridge Bay, Nunavut

Principal Investigator; Organization	Project Title	Region of Study
Sharam; Environmental Resource Management	What mechanisms drive habitat choice by caribou? A resource selection function approach using Traditional Knowledge, remote sensing and field surveys	Nunavut, NWT (Hope Bay, Back River, Ekati, Courageous Lake)
Tank; University of Alberta	Fire in the Arctic: The interactive effects of landscape, hydrology, and permafrost	Spence, Notawokha, Scotty, Boundary, and Baker Creeks; Northwest Territories
Zhang; Natural Resources Canada	Mapping and monitoring land surface and permafrost conditions along the Inuvik-Tuktoyaktuk Highway (ITH) corridor using satellite data and process-based modelling	Inuvik-Tuktoyaktuk Highway (ITH) corridor, NWT

* Project funded in POLAR's ABoVE category of the 2017 open call for proposals

Several POLAR researchers are also directly involved with the ABoVE program, and POLAR supports research projects through its grants and contributions program (Fig. 5). The first ABoVE-specific category was created in the most recent call for POLAR proposals (2017–2019 cycle), in which four projects encompassing vegetation, hydrology, permafrost feedbacks and/or responses to climate change were selected. Several other funded projects within the current or past funding cycles at POLAR also have relevance to ABoVE (Table 2).

Space-based coordination with the Canadian Space Agency

POLAR and NASA are coordinating with the Canadian Space Agency, and indirectly with the World Meteorological Organization's Polar Space Task Group, to acquire satellite imagery for the ABoVE field sites, such as PALSAR-2, RADARSAT-2, Sentinel-1, and Terra SAR-X. In 2017, the Canadian Space Agency collected more than 500 swaths of RADARSAT-2 data (Fig. 6) to support research at field sites. The acquisitions had a 66% success rate because of competing national priorities and tasking conflicts. RADARSAT-2 employs C-band synthetic aperture radar (SAR), which can be used to measure the topography of landscapes at high resolution. This imagery is particularly crucial for flat terrain (e.g., the CHARS ERA), where it is often difficult to differentiate watersheds even with the guidance of local knowledge. More than 60 ABoVE researchers plan to use the RADARSAT-2 data for mapping environmental variables such as soil moisture, permafrost and active layer conditions, surface wetness, fire intensity, surface roughness, and vegetation characteristics. In some cases, these images will be used in conjunction with the airborne imagery collected by the 2017 ABoVE Airborne Campaign, while in other cases, the images will be used alongside field data collected in support of ABoVE. Through the use of these data, researchers are investigating rates of permafrost degradation, inundation changes, seasonal subsidence and thaw settlement, the response of lake levels to changes in permafrost conditions, and the detection of inundated vegetation, all in support of understanding the vulnerability and resilience of Arctic and boreal ecosystems to environmental change.

Current activities are planning for additional RADARSAT-2 image acquisitions this summer (2018) to provide repeat acquisitions in most study sites, the inclusion of sites that were not able to be acquired in 2017, and new sites as research questions evolve.

Community considerations

In May 2016, NASA and POLAR co-sponsored a joint workshop, with the assistance and sponsorship of the Northwest Territories government. The workshop was attended by over 100 representatives of First Nations communities, federal and territorial governments, universities, industry, and NGOs. The goals of the workshop were to identify key management and research needs and questions, exchange information on ongoing and planned research and monitoring, solicit feedback on the POLAR Integrated Research and Monitoring Plan, review and discuss best practices for engaging and including communities and Indigenous knowledge

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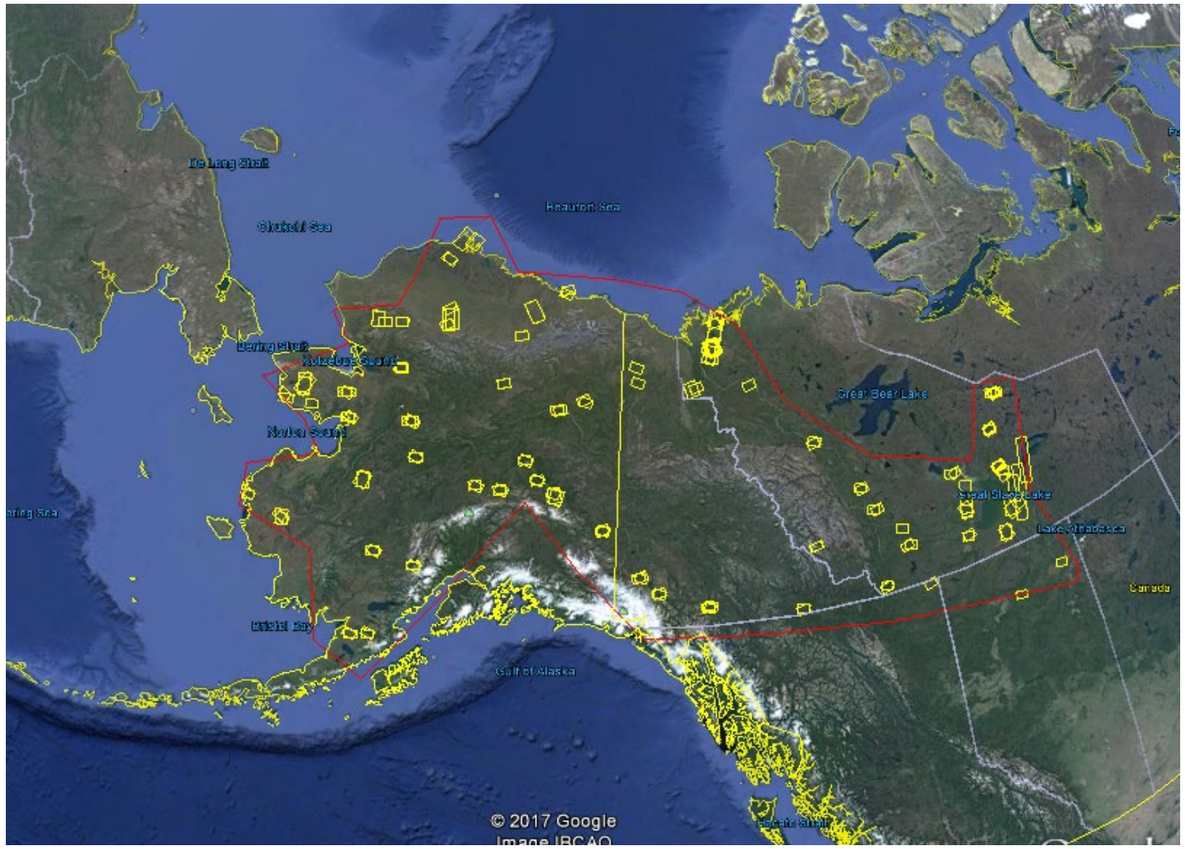

Figure 6: RADARSAT-2 image acquisitions within the ABoVE domain for 2017.

holders in research and monitoring activities, and explore opportunities for collaborations on responding to the identified questions. The workshop was considered by local participants to be an important step in moving the project forward in Canada; workshop proceedings were published in a report available from POLAR (available from https://above.nasa.gov/implementation_plan/ETS_april2017.html).

After the Yellowknife workshop in May 2016, consultations were held with most of the First Nations groups included in the ABoVE domain in the Northwest Territories. These talks and meetings were recognized as demonstrating respect for the First Nations groups, deepening understanding of their needs and concerns, and planning future support through community-based monitoring activities.

Summary and future phases of POLAR and the ABoVE program

The results of this extensive and historic experiment will be used in related computer modelling efforts to help monitor and predict future scenarios across a range of Arctic ecosystems, from Low Arctic boreal forests to High Arctic tundra plateaus. Technology development through ABoVE will enable greater geographic coverage of the vast, remote Arctic landscapes for future monitoring and study. New and evolving partnerships between NASA, POLAR, and the many related organizations will lead to greater leveraging of limited resources to conduct such work in the Arctic.

Acknowledgements

We thank the Canadian Space Agency for its support in providing RADARSAT-2 imagery to ABoVE researchers and coordinating with the World Meteorological Organization's Polar Space Task Group for related satellite resources.

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