Project number **39573**
Innovation Fund 2020
Proposal

Project information

Project title	Multidisciplinary Observatory for Arctic Climate Change and Extreme Events Monitoring (MOACC)
Applicant institution	Université de Sherbrooke
Collaborating institutions	The University of Western Ontario, University of Toronto, Université de Montréal
Team leader(s)	Langlois, Alexandre
	Strong, Kimberly

Project funding

Total project cost	$4,262,997
Amount requested from the CFI	$1,601,614
Percentage of the total project cost requested from the CFI (maximum 40%):	37.6%

Disciplines

Primary discipline	Geophysics
Primary sub-discipline	Environmental geophysics
Secondary discipline	Atmospheric science
Secondary sub-discipline	Climatology
Tertiary discipline	Geographical information
Tertiary sub-discipline	Remote sensing

Areas of application

Primary	Other research on the environment
Secondary	Atmosphere

Keywords

Research or technology development	Arctic extreme events, Snow, permafrost, atmospheric processes, hydrology, ecology, remote sensing, modeling
Specific infrastructure	Permanent site, outdoor, permanent instrumentation, fenced

Project summary

This summary will not be used in the review process. Should the project be funded, it may be used in the CFI's communications products and CFI's website.

The Multidisciplinary Observatory for Arctic Climate Change and Extreme Events Monitoring (MOACC) proposal is submitted by the Université de Sherbrooke (lead institution-UdeS), University of Toronto (UofT), Western University (WU) and Université de Montréal (UM). The main objective of our project is to develop a permanent multidisciplinary scientific infrastructure that enables long-term observations of Arctic climate change, bringing together experts from a wide range of expertise and institutions. The project is led by Prof. Alexandre Langlois (UdeS) and Prof. Kimberley Strong (UofT) and responds to a consensus on the lack of temporal observations that are crucial to understand feedback processes and to promote model development in the Arctic. The innovative aspect of this proposal resides in its multidisciplinary approach while enabling long-term Arctic measurements spanning several disciplines. The proposed observatory will be located at the Canadian High Arctic Research Station (CHARS) in Cambridge Bay, Nunavut, while enhancing the reach of CHARS with linkages to the Environment and Climate Change Canada supersite in Iqaluit. Our ambition is to establish the site as one of the largest instrumented high Arctic observatories dedicated to the monitoring of key indicators that drive climate change. The site will generate and enhance partnerships, not only with Canadian research centers and organizations, but also with international research partners and networks.

Team

The CVs for each of the team leader(s) and members are appended to the proposal.

Name	**Institution**	**Department**
Langlois, Alexandre	Université de Sherbrooke	Géomatique appliquée
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Ayotte, Patrick	Université de Sherbrooke	
Fortier, Daniel	Université de Montréal	
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Sica, Robert	The University of Western Ontario	Department of Physics and Astronomy

Enhancing and optimizing the capacity of institutions and research communities

The main objective of our project is to develop a long-term *Multidisciplinary Observatory for Arctic Climate Change and Extreme Events Monitoring (MOACC)*, including key atmospheric radiative forcing constituents such as greenhouse gases (GHGs), aerosols, and clouds. During the past decade, numerous projects and intensive field activities were carried out in several regions of the Arctic and across a variety of disciplines including health, atmosphere, cryospheric processes, ecology, and remote sensing. These projects have led to significant progress in our empirical understanding of the various processes governing climate change in the Arctic. However, there is now a consensus on the lack of temporal observations that are crucial to the level of monitoring needed to understand feedback processes or to promote model development, whether they are radiative transfer models for remote sensing applications, surface-state-variable-based models or high-resolution atmospheric models. The innovative aspect of this proposal resides in its multidisciplinary approach while enabling long-term Arctic measurements spanning several disciplines. The proposed observatory will be located at the Canadian High Arctic Research Station (CHARS, Government of Canada), enabling new and much needed measurements capabilities, accessible at much lower costs when compared to other permanent Arctic stations that are not multidisciplinary and for which the logistical and financial constraints are high.

From an operational perspective and for the delivery of near-real-time information crucial to supporting algorithm development and satellite observations (especially for new missions, such as the RADARSAT Constellation Mission – RCM and the Sentinels atmospheric missions of the Copernicus program) there is an urgent need for a permanent deployment of instrumentation in the Arctic. To address this gap, the CHARS station was built and has been operational since 2017 in Cambridge Bay, Nunavut. The station includes laboratory spaces, triplexes for scientists, meeting and seminar facilities as well as logistical support resources, and local staff who are permanently on site. Its location will represent an important atmospheric monitoring site, along a transect linking Alert and Eureka (PEARL) to Cambridge Bay and Cambridge Bay to Whitehorse in a sparsely instrumented region of the Arctic and sub-Arctic. CHARS represents a unique opportunity to build a permanent multidisciplinary study site, owned and managed by a network of Canadian Universities through the Canada Foundation for Innovation (CFI) program.

The CHARS MOACC measurement park will be protected and fenced in, with internet access, electricity and daily maintenance by CHARS staff. The mandate we have given ourselves addresses the core applications of numerous research projects in collaboration with CHARS, while providing an advanced networking platform that will facilitate international research efforts conducted in the Canadian Arctic. The proposed site will be one of the largest multidisciplinary, permanently instrumented high Arctic sites dedicated to the monitoring and analysis of key indicators that drive climate change. Several communities do have large meteorological stations (Iqaluit and Eureka for example), but our project aims to deploy a world-leading, High Arctic reference site, equipped with an instrumentation suite (including an array of microwave to optical, surface and atmospheric, passive and active measurements) that will be largely unique in its diversity. Furthermore, some instrumentation such as the TCCON and the UV-VIS Pandora spectrometer are available at other Arctic sites (Eureka, Iqaluit), but the proposed site in Cambridge Bay will fill a gap in the lower Canadian Arctic Archipelago while expanding existing networks. The site will also support space missions for snow and permafrost studies: RCM, Sentinel, Snow Mass Mission project, MetOp-SG Sat B for multi-frequency active/passive synergy (WMO Polar Space Task Group). The measurements of greenhouse gases (GHGs) and other trace gases along with aerosols and clouds will contribute to the validation of missions such as GOSAT-2, TROPOMI on Sentinel 5P, and potential missions such as AIM-North. This proposal initiative thus represents a unique logistical and financial opportunity while expanding the multidisciplinary nature of CHARS.

Our proposal mandate will incorporate passive and active microwave measurements as well as optical reflectance measurements of snow and soil state variables for satellite remote sensing algorithm development, facilitate the development of unmanned aerial vehicle (UAV) technology applicable in Arctic conditions, enable atmospheric measurements of GHGs (including water vapour), aerosols, clouds and stratospheric ozone depletion using both passive and active techniques as well as in situ measurements of aerosol composition and microphysical properties from mobile platforms including UAVs. This will be complemented by in situ measurements of active layer and permafrost temperature, unfrozen water content, thermal conductivity, ground heat loss and ground surface movement to evaluate climate change and interannual weather variability. This monitoring strategy will be applied within a context of four research themes: Snow remote sensing and ecological applications-TH1; Snow modeling and Hydrology-TH2; Atmosphere-TH3 and Permafrost-TH4.

Enabling global leadership

The site will also be used for HQP training as part of the multidisciplinary research projects of co-applicants, while collaborative activities with CHARS would include field training/scientific seminars and workshops in the classrooms and accommodations already available for such activities. The proposed observatory will provide a world class networking platform to promote the well-established expertise in cryospheric and climate modeling from the applicant’s universities, while contributing to their unifying priorities as well as targeted research orientations. The acquisition of the proposed state-of-the-art instruments will open the door to many new opportunities for its researchers and students alike, supporting specific strategic-plan objectives of promoting international collaborations. Moreover, we expect that the multidisciplinary nature of the research program will create a stimulating HQP training environment, provide leverage for NSERC CREATE proposals and attract high-quality undergraduate and graduate students while significantly increasing the applicant’s universities visibility at national and international venues.

The site will also generate and/or enhance partnerships, not only with Canadian research centers and organizations but also with research centers and organizations in France (Laboratoire de Glaciologie et Géophysique de l’Environnement, Centre d’Étude de la Neige), Switzerland (Swiss Federal Institute for Snow and Avalanche Research, MeteoSwiss), Germany (Alfred Wegner Institute), Norway (Norwegian Polar Institute), US (NASA), Italy (NAtioanl Research Coucil), T-MOSAiC (Terrestrial Multidisciplinary distributed Observatories for the Study of Arctic Connections) that already conduct or will conduct work in the Arctic, but not specifically in the Kitikmeot region and/or not in collaboration with CHARS. We aim for a very strong multidisciplinary approach with substantial proposal team research links in: Health, Atmospheric sciences, Ecology, Hydrology, Snow, Permafrost and Technology development.

Benefits for Canadians

The anticipated results are (1) new knowledge of the impact of climate change and extreme events on the Atmosphere-Snow-Ground interface (ASGint) of the Arctic, (2) improved understanding of the ability of models and remote sensing retrievals to simulate key surface state and atmospheric variables affecting surface energy balance, ground thermal regime, ground surface topography, melt dynamics and hydrological processes, and (3) new knowledge about the frequency of extreme events and the sensitivity of the local climate response to ASGint specification under such circumstances. These results will be relevant for the ongoing development of climate, atmospheric, permafrost and snow models and for increased understanding of sources of uncertainty in climate scenario construction. Hence, understanding the impact of climate change on the ASGint conditions in arctic regions is critical for native, traditional resource users, scientists and other stakeholders in order to develop mitigative responses and adaptive strategies in a changing environment. The proposed infrastructure will address a resolution from the World Meteorological Organization that not only highlights the significant gaps in observations capacities but suggests supporting efforts enhancing our '*understanding of the Earth system and environmental processes and interactions in polar regions*'. The results will also support ongoing development of global climate models while representing a reference dataset for numerous satellite missions (current and future).

Hence, the research program is of particular relevance from the scientific, economic and social perspectives: Scientific: This study will provide the scientific community with new knowledge about changing ASGint under extreme events in the cryosphere as well as information on the sensitivity of the local climate response to parameterizations of these processes in climate models. Our project also addresses two of the key recommendations of the World Climate Research Program (WCRP) Cryosphere and Climate Project: *(1) Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of CC; and (2) Improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system.* Social: Arctic environments are an integral part of Inuit life and the projected increased occurrence of extreme events will have a strong impact on the harvesting of traditional foods for the Inuit as well as community life and native industries by affecting infrastructure development in melting permafrost regions. Economic: Industry partners have a strong interest in understanding how extreme events related to climate change may affect the ASGint. The knowledge and methods developed in the project will help develop strategic decision-making in resource exploitation, transportation, recreation and infrastructure development. Better quality long-term planning information on extreme events will contribute to competitive advantages and environmentally sound decision-making while providing an improved empirical understanding on the state and fate of the cryosphere.

Other users

Name and title/position	Institution and department
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1. Research or Technology Development

1.1. Rationale

The Arctic has warmed at twice the global average over recent decades [1] due to a number of processes and feedbacks [2; 3]. A direct consequence of this critical climate change tendency (Arctic amplification) is the increased occurrence of climate-change-induced extreme events such as rain-on-snow and blizzards [4; 5] and a longer melt season that have significant impacts on how the cryosphere responds to climate change [6]. Patterns in the spatial extent and mass balance of snow, and permafrost show a statistically significant trend towards negative anomalies [7]. These patterns impact the transport, health, safety and economic condition of Arctic communities. As such, communities across the cryosphere require accurate and timely information on the state of snow, atmosphere and permafrost for a range of needs, which are currently not available owing to a lack of observations networks. There is also a need for information on the potential paths of projected warming to generate climate scenarios.

There have been numerous calls for improved atmospheric and surface observing systems in the Arctic. Resolution 57 of the World Meteorological Organisation's 16th World Meteorological Congress notes key gaps in observational capabilities and scientific understanding related to the Arctic atmosphere and "Requests Members: (1) To support efforts to address the key gaps in scientific understanding of the Earth system and environmental processes and interactions in polar regions; (2) To promote and/or establish national research programmes towards this endeavour" [8]. This proposal responds directly to this resolution and to this call from "Integrating Arctic Research - a Roadmap for the Future" [9]: "Focus should be given to … Establishing flagship observatories as part of this observing system of systems to provide comprehensive measurements over the entire Arctic region." Yet, large uncertainties remain with regard to the effect of climate change on climatological cooling and heating patterns [10]. Observed extreme events at southern latitudes during the current winter have been linked to the breakdown of the polar vortex: a breakdown that is the consequence of changing stratospheric dynamics that are, in turn, linked to the warming Arctic troposphere. The direct and indirect (cloud nucleating) effects of aerosols represent the greatest source of short-term tropospheric radiative forcing uncertainty, while the longer-term greenhouse (GHG) trends represent the greatest source of concern in terms of the uncertainty generated by the precarious state of global mitigation efforts. Further, uncertainties in input information from the atmosphere-snow-ground interface (ASGint) within global circulation models (GCMs) lead to uncertainties in climate predictions [e.g., 11]. Uncertainties are larger for Arctic latitudes owing to a lack of in-situ temporal observations of the ASGint as a system used to drive the models and satellite retrieval algorithms. This was reported by Richardson et al. [2016, 12] who suggested that lack of historical data has led to an underestimation of global-mean warming. Mitigation strategies [13] related to reducing the Arctic warming effects of short-lived climate-forcing pollutants (SLCPs) such as black carbon and ozone (and the intricately linked cooling SLCPs such as particulate sulphate and nitrate) require carefully monitoring of SLCPs in addition to the long-term climate-forcing pollutants.

This proposal describes a new initiative, the Multidisciplinary Observatory for Arctic Climate Change and Extreme Events Monitoring (MOACC), which will be located at the Canadian High Arctic Research Station (CHARS) in Cambridge Bay, Nunavut. MOACC will bring together a multidisciplinary team to make long-term measurements that will establish baseline data regarding the cryosphere, hydrology, the atmosphere, and permafrost. The requested infrastructure will enable new measurement capabilities in the Canadian Arctic for world-class research across a range of disciplines. It will address the infrastructure needs of several research programs whose common whole-system goal is to improve our empirical understanding of the ASGint and fundamentally to better understand current and future Arctic changes. Results from MOACC will thus be relevant for the ongoing development of climate and snow models that are not yet well adapted to Arctic conditions [14; 15] and for increased understanding of sources of uncertainty in climate scenario construction. Furthermore, in many Arctic regions, an increase in tourist activity and accessibility to natural resources is observed, which emphasizes the need for a better understanding of trends of the ASGint to provide decision-makers with essential information relevant to infrastructure development in the North, environmental protection and public safety. For example, mining and transportation industries will be interested in knowing when and how permafrost will thaw in order to adopt mitigative strategies in infrastructure development (e.g., elevating structures, isolating soil beneath, use helical piers, wind-induced cooling systems, etc.). Another example of a benefit would be better predictions of future extreme precipitation that could be used to avoid snow-related building collapse. Increased knowledge of these events will allow communities and industries to improve existing infrastructure (i.e., increase snow-load resistance). Hence, understanding the impact of extreme events on the ASGint conditions in Arctic regions is critical for indigenous peoples, traditional resource users, communities, scientists and other stakeholders in order to develop mitigative responses and adaptive strategies in a changing environment.

1.2. Proposed research

The site is to be based in Cambridge Bay, Nunavut with the Canadian High Arctic Research Station (CHARS). MOACC's monitoring strategy involves establishment of baseline Arctic datasets at the leading edge of current measurement capabilities, which may be generalized to the wider Arctic. Our monitoring strategy will be applied within the context of four research themes: TH1-Snow Remote Sensing and Ecological Applications; TH2-Snow Modeling and Hydrology; TH3-Atmosphere, and TH4-Permafrost. While each theme has its own motivation and objectives, they are inevitably linked together by climate change and impacts that transcend the ASGint system.

TH1-Snow Remote Sensing and Ecological Applications

Motivation: Despite recent progress in identifying the occurrence of extreme events from space in the Arctic [16; 17], very little is known about their spatial and temporal patterns, while their cumulative impact on the surface energy balance remains an open question. The densification of the snowpack though the formation of ice crusts or wind slabs will affect the survival of ungulates (caribou, muskoxen) by blocking their access to food [18; 19; 20; 21]. Peary caribou, in particular, were listed under the federal Species at Risk Act (SARA) in Canada in 2011 as endangered. Understanding how changing snow conditions influence the distribution and survival of Peary caribou will be important to the species' recovery. While the literature clearly demonstrates that snow conditions influence caribou survival [22; 4], no studies have investigated the potential for snow to influence or explain the distribution of Peary caribou across different seasons owing to a lack of temporal high-quality snow observations [23] which this proposal will enable. The challenges posed by the lack of temporal data motivated the focus of this theme on remote sensing and modeling approaches that will be enabled with the proposed infrastructure in a context where food security in the Arctic is very fragile (e.g., caribou can account for up to 65% of the traditional diet). Recent work has highlighted the impact of climate and topography on caribou survival [23] using the MaxEnt model, but large uncertainties remain in explaining presence/absence during critical survival periods due to the quasi-absence of temporal monitoring. The proposed site will allow continuous measurements of snow along with detailed meteorology and enable the development of surface state variables retrieval algorithms (i.e. rain-on-snow occurrence, ice layer presence, wind slab density) that can in turn be applied to the whole Canadian Arctic.

Objectives: The main objectives of this theme are: (1) to develop new techniques to derive snow water equivalent (SWE) and stratigraphy using passive and active microwave data; and (2) to quantify the processes governing snow spatial distribution using innovative photogrammetric approaches (Structure-for-Motion) at the in-situ and airborne scales. Snow retrievals approaches from (1) and (2) will be used (3) to map snow properties at various scales to assess ungulates foraging conditions. Finally, we will (4) continue our development of remote sensing algorithms capable of monitoring extreme events using satellite passive microwave data and in-situ Frequency Modulated Continuous Wave (FMCW) radars that will enable us, along with results from (3), (5) to develop an ungulate habitat quality index based on surface snow conditions and extreme event occurrence. The theme will also aim at developing a methodology to retrieve high-resolution snow information from unmanned aerial vehicle-UAVs (small scale).

Research activities: The field data from the proposed site will allow calibration and development of both the snow simulation and satellite retrievals for characterizing surface state variables. Meteorological station and radiometric measurements combined with stratigraphic measurements of snow (to be conducted inside a dedicated disturbed area periodically) will be used to develop satellite-based retrieval approaches for long-term operational monitoring. More specifically, we will use the rain-on-snow detection approach developed by Dolant et al. [2016, 16] and Montpetit [2015, 24] that use passive microwaves to detect rain-on-snow and icing event occurrence and implement measurements from visibility sensor that provides precipitation rate and phase information. This will address the main limitations identified in Dolant et al. [2017, 17] and is the last step in applying this method globally and operationally using satellite data. Furthermore, Langlois et al. [2017, 4] highlighted that more data are needed to improve the detection statistics, so this project will create a rain-on-snow/ice/wind slabs database extracted from the site, which will be used to improve and develop satellite retrievals. Finally, the method described in Kramer et al. [2019, 25] will be adapted to the needs of Arctic conditions to retrieve 3D snow depths from UAV flights. Our group will develop 24/7 flying capabilities for a UAV that will be able to map snow depth spatial variability at small scales in order to help resolved unanswered questions on the effect of surface roughness on snow distributions, which is of critical importance in parameterizing soil thermal characteristics required in climate and snow models.

TH2-Snow Modeling

Motivation: An accelerated hydrological cycle, as modeled under an increased CO_2 and aerosol scenario [26], would increase the amount of snowfall and blowing snow events in the Arctic [27], and better ways to monitor these variables from a hydrological perspective have yet to be developed. Of particular relevance, it is known that snow accumulates geochemical elements that reach the marine system during spring melt [28]. Snow can hold up to 50% of the total annual inorganic charge within one drainage unit and the ionic charge can be significant during snowmelt given the contribution of atmospheric particles during accumulation [29]. Tracing geochemical elements in snow allows a proper assessment of the various contribution sources of the hydrological cycle for any given location [30]. This is of particular relevance from a climate change perspective where the hydrological cycle is affected in various ways by the increased occurrence of extreme events but yet, very limited studies have tried to quantify geochemical tracers in snow [31; 32]. It will also help measuring the consequences of climate warming in the cryosphere while providing an understanding of the various atmospheric processes that control precipitation at the regional scale. Pavelsky et al. [2006, 33] demonstrated that increasing precipitation plays a significant role in observed discharge increases that will in turn affect thermohaline circulation [34]. The increased transport of atmospheric moisture into the Arctic [35] results in higher precipitation in both liquid and solid phases [36; 37; 38] but their effect on isotope storage remains unknown.

Objectives: The main objectives of the theme will be: (1) to pave the way towards improved model approaches by quantifying isotope values ($\delta^{18}O$, δD) of Arctic snow cover in order (2) to evaluate linkages between physical and geochemical measurements according to snow stratigraphy, weather factors and seasonal evolution providing a nice link to Theme 1. We will also (3) quantify the geochemical components of winter snow cover and spring snowmelt (4) to determine snow contributions to spring flow of the major river systems associated with the Greiner watershed at the MOACC site. These results will allow (5) the development of an isotope routine to be implemented in our snow simulation platform developed by the Université de Sherbrooke team [18] to better understand flow patterns in other important watersheds of the Arctic. Finally, this snow simulation platform will also (6) aim to predict the impact of future changes in snow cover to freshwater export into the marine system.

Research activities: This project will simulate snow conditions at 1-3 km spatial resolution using high-resolution topography from numerical elevation data Canada at 1:50,000 and soil occupation from Circa-2000 vector data produced using the classification of Landsat-5 and Landsat-7 ortho-images. The site will be use as a calibration reference where continuous snow measurements will be made, allowing for a proper treatment of microstructure, which in turn will provide an improved understanding of the scattering processes observed in TH1. Meteorological data for the 2100 horizon will be extracted from the Canadian Regional Climate Model (CRCM; 39) generated in collaboration with the Ouranos consortium, Montréal. The simulations will be utilized to drive the SNOWPACK model using near-real time and continuous forcing data produced by the site. We will also undertake routine geochemical sampling from Freshwater Creek (Greiner Lake, near Cambridge Bay), from ice break-up to freeze-up, and snow observations will be carried out and related to observations of river geochemistry collected by community collaborators from CHARS. This will allow evaluating the "end-member" characteristics of snow melt contributions to river flow, including characterization of snow geochemical fingerprints, and incorporate these observations into a model (e.g., SNOWMOD after Ahluwalia et al., 2013, 40).

TH3-Atmosphere

Motivation: The Arctic tropopause is subject to a variety of seasonal processes: gaseous and aerosol pollution transport to the lower Arctic troposphere during the late winter and early spring (Arctic Haze; 41), polar winter cooling associated with inhibited crystallization of polluted aerosols (the dehydration greenhouse feedback effect), the onset of important photochemical reactions as the sun rises in the spring, the late spring breakdown of the Arctic Haze and the year-round transport of warm pollution and smoke along isentropic lines to the Arctic UTLS (upper tropopause and lower stratosphere). Pressing research questions related to tropospheric ozone chemistry include the impact of rapid Arctic climate change, production of ozone from tropical and mid-latitude emissions of precursors such as methane, transport pathways of pollutants into the Arctic, new sources of local pollution from tourism (e.g., cruise ships), shipping, and oil/gas extraction, changes in local air quality, and deposition of harmful contaminants in snow. Springtime Arctic tropospheric ozone is greatly affected by severe ozone depletion events, recently linked to extremely high concentrations of BrO in bromine explosion events. These are important because they increase the deposition of mercury to snow, causing harmful effects on ecosystems and humans. Tropospheric ozone in the Arctic also acts a SLCP. Long-term trace gas time series, acquired from stations that have been integrated into a pan-Arctic network, are essential, in general, for understanding atmospheric processes and their climate change impacts. This need arises because there is a lack of knowledge about carbon sources and sinks, feedbacks between climate change and carbon reservoirs, and anthropogenic emissions from fossil fuel burning and land use change. An improved understanding of these issues is essential for well-informed policies regarding greenhouse gas (GHG) emissions. They are more acute at high latitudes where measurements are scarce and where the magnitude and distribution of carbon sinks and sources are poorly known. Tropospheric aerosol pollution and aerosol cloud interactions are hot-button areas of atmospheric research in the Arctic. Recently published articles have demonstrated that models are missing important post-Arctic-Haze processes (e.g., nucleation of fine mode aerosols during summertime) [42; 43] and an important mechanism for the creation of planetary boundary layer (PBL) fine mode aerosols during the polar winter [44]. The above-mentioned (Arctic-Haze-induced) DGF effect has been tied to extreme events at southern latitudes [45] while Arctic Haze aerosols have been linked to Arctic warming induced by an increase in cloud emissivity associated with the indirect Twomey effect [46]. Arctic smoke, apparently induced by increases in gaseous and particulate forest fire emissions have been observed as extreme events over the High Arctic [47; 48].

Objectives: Within the context of lower Arctic region of the Canadian Arctic Archipelego, we seek: (1) To quantify the relative importance of regional sources and long-range transport on GHG concentrations and aerosols. (2) To better understand climate change impacts on the regional carbon cycle. (3) To determine what is driving changes in springtime tropospheric Arctic ozone depletion and Arctic Haze aerosols in the PBL (4) To investigate the near-surface microphysics and chemistry of aerosols (notably with respect to aerosol absorption) and relationships with snow/ice surface albedo (5) To characterize the surface to columnar transformation of aerosol microphysics and chemistry across the total PBL. (6) To employ CTMs in order to help understand the high- to low-Arctic transect from Alert to Eureka to Resolute Bay to CHARS. (7) To establish, in general the determinants of Arctic air quality and how they are changing with time.

Research activities: Four instruments, dedicated to the measurement of a suite of trace gases will be installed. Precise and accurate column-averaged dry-mole fractions of the GHGs CO_2 and CH_4 will be measured with a new Fourier transform infrared (FTIR) spectrometer that will be deployed as part of the international Total Carbon Column Observing Network (TCCON). Dual detectors will provide additional information on biomass burning tracers (HCN, C_2H_6) so that C_2H_6:CH_4 ratios can be used to distinguish sources of CH_4 to the Arctic atmosphere. The GHG measurements will be combined with other network data, satellite measurements, and atmospheric models (including the Environment and Climate Change Canada (ECCC) Carbon Assimilation System) to address the first two objectives. Two Pandora UV-visible Spectrometers will be bought for air quality measurements relevant to objectives 3 and 4, one for CHARS and one to complement ECCC's meteorological "super-site" at Iqaluit. These will be used to measure ozone, NO_2, HCHO, H_2O, and SO_2: both will join the new global Pandonia network. To enhance the measurement capabilities of the Pandoras, each instrument will have a mini micro-pulse lidar (MPL) co-located. The aerosol science objectives will be addressed with a unique combination of complementary measurements, as well as providing context and corrective capability for the Pandora measurements. The MPLs will continuously measure backscatter profiles of aerosols, clouds and PBL height. The MPL's capability to measure the polarization of the backscatter signal will facilitate aerosol and cloud classification and, with different levels of complementary information (including CTM simulations), a measure of aerosol sub-type classification. A CIMEL (AEROCAN/AERONET) sunphotometer/sky radiometer/ moonphotometer will enable the division of the aerosol optical depth (AOD) spectra into fine and coarse mode AODs (a separation that is strongly linked with estimates of lidar-derived aerosol and cloud optical depth determined using a threshold approach applied to the depolarization ratio channel). The MPL aerosol / cloud profiles are essentially calibrated by comparing their estimated optical depths with their fine and coarse mode CIMEL-derived analogues. This information, combined with surface extinction coefficients from an existing cavity ring-down spectrometer (Co-I Patrick Ayotte) will enable an optical characterization of the PBL (with the CIMEL in moonphotometer mode during the polar winter). We will also deploy a set of miniaturized aerosol instruments on a drone in order to measure particle size distributions and aerosol light absorption, including black carbon concentration across the lower PBL. The measurements will focus on characterizing the vertical profiles of these properties: they will be used for CTM evaluation, the analysis of surface to column transformations and investigations of correlative links with reflectances acquired by the CRem (Continuous Reflectance Monitor). The will also enable a better understanding of any local-pollution impact on regional aerosol trends.

TH4-Permafrost

Motivation: Permafrost is warming on a global scale [49]. However, the response of Arctic permafrost to future warming and its feedback to the global climate system is a key question that remains unresolved and subject to debate [50; 51; 52; 53]. This is essentially due to the potential feedback generated by the large amount of carbon contained in the permafrost. Indeed, it is estimated that about 800 Pg of organic carbon are strored frozen in the first 3 m of permafrost [54], which is approximately the equivalent of carbon stored in the atmosphere [55]. Thawing of upper permafrost will make carbon accessible to microbial decomposition which in turn could increase Green House Gases (GHG) emissions. Thawing of permafrost is however locally highly variable, mainly due to the differential distribution of ground ice, which increase the thermal resistance of permafrost. In the Arctic, ground ice is the principal component of the ecosystems that ensures landscape stability [56] and it can be pictured as the backbone of tundra ecosystems. Melting of ground ice triggers topographical changes such as differential thaw settlement and subsidence of the ground surface [57; 58]. Where ground ice occurs in excess of the soil porosity, ground ice melting leads to water ponding on flat terrains and mass movements on sloping areas. Sustained ground ice melting (thermokarst) turns terrestrial environments such as ice-wedge polygons field to aquatic environments such as ponds and lakes [59; 60]. These topographical and the associated hydrological changes can have important impacts on infrastructure and ecosystems, and on the emissions of Green House Gases such as carbon dioxide, methane, and nitrous oxide as well as contaminant, such as mercury, and pathogens, such as anthrax [61; 62; 53; 63; 64; 65; 66; 67]. Thawing of permafrost, and how carbon because available for microbial decomposition, is mediated by the *transient layer* of permafrost. This ice-rich layer located at the interface between the active layer and permafrost is formed over decades to centuries as a product of interannual climate variability, which generates differential thawing/freezing depth [68; 69; 70]. The oscillation of the maximum thaw depth then creates an ice-rich layer with volumetric ice-content over 50% and often over 75%. The transient layer acts as a buffer to warming events as the latent heat 'stored' in ground ice of this layer increases the thermal resistance of permafrost. This is important because this layer is present at various stage of development (thickness, ice content) in all the continuous permafrost regions of Canada, yet it is not included in the Canadian Land Surface Scheme model. Despite recent progress in the long-term dynamics of ground ice [71] very little is known on the impact of meteorological events, especially extreme events occurrence, on the dynamics of permafrost. Whether these events are detrimental or not to the transient layer remains unknown. The formation of ice layers in the snow pack or at the surface of the ground and/or wind-packed snow will affect the thermal regime of permafrost but the magnitude and the direction of changes are unknown and require new studies. The proposed site will allow continuous measurements of snow and permafrost cryo-hydro-thermal properties along with detailed meteorological conditions which will be used to model the transient layer dynamics which can be applied to other tundra regions of the Arctic. The results of this research have wide ranging applications and will help to improve the ground ice map of Canada [72] which is currently used as the ground ice base map in the CLASS model simulations but which currently doesn't incorporate the transient layer.

Objectives: The main objectives of this theme will be: 1) to develop a surface energy budget (SEB) to predict the ground surface temperature (GST) and energy fluxes with varying snow regimes and properties; 2) to evaluate the impact of weather events, in particular extremes events, on the thermal regime of permafrost; 3) to evaluate the movement of water in permafrost as a result of thawing and freezing cycles in a context of climate change; 4) to model the dynamics of ground ice in the transient layer to changing climatic conditions; 5) to evaluate the impact of changing climatic conditions and extreme events on surface stability and topographical changes; 6) to evaluate the thermal resistance of permafrost to warming using various ground ice scenarios and simulations of regional climate change; 7) to monitor long-term (beyond the duration of this project) climate change as recorded by deep permafrost temperature.

Research activities: A 20-m long thermistor cable will be installed in the permafrost. This cable will be equipped with several thermistors, more closely spaced near the top to detect short-term temperature changes linked to weather and extreme events. A permafrost core-drill equipped with a cooling system to minimize thermal disturbance will be used to retrieve intact permafrost samples. The drilling operation will be conducted on rubber mats while the active layer is still completely frozen to avoid any surface disturbance such as damage to the vegetation, removal of organics or soil compaction. The permafrost samples will be kept frozen at CHARS facilities. At controlled temperature, they will be cleaned from drill-mud and photographed for cryostructure analysis. They will be weighted and scanned with a laser to precisely determine their volume and calculate the bulk density. Additional boreholes will be done in the near surface permafrost (0-3 m) to document the spatial variation of ground ice and especially the geometry of the transient layer. The permafrost cores from the different boreholes of the proposed site will allow a detailed characterization of the cryostratigraphy (active layer, transient layer, permafrost), which will form the base of the SEB-based numerical thermal model (obj. 1). Thermal conductivity needle probes, heat flux sensors, thermistors, time-domain reflectrometry sensors (volumetric water content above and below 0°C) and electrical conductivity sensors will be deployed in the active layer, above and below the transient layer, and in the permafrost to follow the changing thermal properties and ground temperature and to follow the movement of water in the ground leading to ice segregation (or ice loss) in the transient layer and in the permafrost (obj. 2, 3, 4). Repeated electrical resistivity tomography of the ground will image the phase changes in the near surface and coring will be conducted on a yearly basis to evaluate the impact on the transient layer. In collaboration with TH1, we will retrieve 3D snow depths (winter) and 3D ground surface topography (no snow period) from UAV flights, able to map snow depth/ground surface spatial variability at a small scale in order to feed the SEB (obj. 1), to evaluate the impact of extreme events on snow thermal properties and ultimately on permafrost temperatures (obj. 2), and to evaluate changes in topography due to the dynamics of ground ice (heave/subsidence related to ground ice formation/melt) (obj. 5), which is of critical importance in parameterizing the mechanical response of permafrost to weather events and climate change in permafrost models. These meteorological, nival and permafrost monitoring datasets will be used to calibrate a numerical model of permafrost and ground ice dynamics (obj. 1 and 4). More specifically, we will evaluate how meteorological events affect the thermal diffusivity, the moisture gradient and the thermal gradient in the active layer, the transient layer and the permafrost. These data are crucial to calibrate the numerical model of permafrost and ground ice dynamics. In a subsequent phase, the calibrated numerical SEB-based atmosphere-snow-permafrost model will be used to evaluate the thermal resistance and fate of permafrost to climate change using regional climate scenarios from the Ouranos Consortium (obj. 6). Well-maintained thermistor cables can last for decades and the deep thermistor cable will be used to monitor regional climate change on a longer perspective than the current project (obj. 7).

1.3. Complementarity to existing similar research programs

Several research projects addressing specific parts of the proposed research do exist, but they do not seek to understand the effect of extreme events on the ASGint, which has yet to be done. The proposed site will be one of the largest multidisciplinary, permanently instrumented High Arctic sites dedicated to the monitoring and analysis of key indicators that drive climate change. Several communities/sites do have large meteorological stations (Iqaluit and Eureka for example), but our project aims to deploy a world-leading, High Arctic reference site, equipped with an instrumentation suite (including an array of microwave to optical, surface and atmospheric, passive and active measurements) that will be largely unique in its diversity. Furthermore, although some instrumentation is available at other Arctic sites, the proposed site in Cambridge Bay will fill a gap in the lower Canadian Arctic Archipelago while expanding existing networks. The Arctic is huge, with about 40% of Canada’s landmass above the Arctic Circle, and measurements are sparse. Cambridge Bay (69°N) is located ~1700 km from Iqaluit (63.7°N) in the Low Arctic and ~1300 km from Eureka (80°N) in the extreme High Arctic. Cambridge Bay (population ~1800) is a coastal community that serves as a transportation and administrative centre for the Kitikmeot Region, while Iqaluit (population ~7700) is the capital of Nunavut, and Eureka is a remote site on Ellesmere Island that has a rotating population of eight ECCC Weather Station staff and varying numbers of visitors. Complementary measurements at multiple sites like these, which represent very different conditions, are essential for properly characterizing and understanding the Arctic environment.

2. Team

The MOACC project brings together ten internationally recognized researchers as principal users from four Canadian universities, and includes 20 collaborators and users from nine different universities and research institutes. Team members are experts in atmospheric science, climate science, snow and permafrost, ecology and hydrology, and possess a wide range of experience in modeling, field measurements, Arctic environment and remote sensing. This team is unique in its multidisciplinary expertise while including a variety of early, mid-career researchers, and senior leaders who have demonstrated the expertise needed to deploy the requested infrastructure and exploit it for scientific advancements.

Names and titles of applicants	Affiliations
Prof. Dr. Alexandre Langlois (PI)	Département de géomatique appliquée, U. Sherbrooke
Prof. Dr. Kimberly Strong (Co-PI)	Department of Physics, U. of Toronto
Prof. Dr. Alain Royer	Département de géomatique appliquée, U. Sherbrooke
Prof. Dr. Norm O'Neill	Département de géomatique appliquée, U. Sherbrooke
Prof. Dr. Dominique Gravel	Département de biologie, U. Sherbrooke
Prof. Dr. Patrick Ayotte	Département de chimie, U. Sherbrooke
Prof. Dr. Alexis Lussier-Desbiens	Département de génie mécanique, U. Sherbrooke
Prof. Dr. Daniel Fortier	Département de géographie, U. de Montréal
Prof. Dr. Patrick Hayes	Département de chimie, U. de Montréal
Prof. Dr. Robert Sica	Department of Physics and Astronomy, W. University

Names and titles of collaborators	Affiliations
Marla Limousin (Chief Adm. Off.)	Hamlet of Cambridge Bay
Beverly Maksagak (manager)	Ekaluktutiak Hunters & Trappers Organization (HTO)
Prof. Dr. Richard Arès	Dépt. génie mécanique, U. de Sherbrooke
Dr. Don McLennan	Polar Knowledge Canada
Dr. Cheryl-Ann Johnson	Canadian Wildlife Service, ECCC
Prof. Dr. Debra Wunch	Department of Physics, University of Toronto
Prof. Dr. Kaley Walker	Department of Physics, University of Toronto
Dr. Vitali Fioletov	Air Quality Research Division, ECCC
Dr. Alexander Haefele	Remote Sensing Group, MeteoSwiss
Dr. Stéphanie Coulombe	Polar Knowledge Canada
Dr. Marie Dumont	Météo-France, Grenoble, France
Dr. Isabelle Gouttevin	Météo-France, Grenoble, France
Dr. Emily McCullough	Dept. of Physics and Atm. Science, Dalhousie U.
Prof. Rachael Chang	Dept. of Physics and Atm. Science, Dalhousie U.
Prof. Aldona Wiacek	Dept. of Environmental Science, St-Mary's U.
Dr. Xiaoyi Zhao	Air Quality Research Division, ECCC
Dr. Chris Derksen	Climate Research Division, ECCC
Jean-Francois Mercier	Radiation Protection Bureau, Health Canada
Prof. Dr. Richard Kelly	Dpt. of Geography and Env. Management, U. Waterloo

The expertise is outlined below:

Alexandre Langlois (PI of MOACC, Associate professor, Dépt. de géomatique appliqué, U Sherbrooke) is an expert in snow remote sensing and the geophysical processes that regulate its temporal, spatial and vertical evolution. He has also worked on the close and complex interactions between the cryosphere and the changing climate. His remote sensing research focuses on passive microwaves at various scales, as well as on the development and validation in the Arctic. He has published 54 peer reviewed papers on snow modeling, remote sensing and spent over 500 days in the field since 2000. Of particular relevance, Prof. Langlois owns a unique suite of snow instruments that helped define the needs of a permanent deployment such as proposed in this project. Prof. Langlois has also run a snow monitoring program in Cambridge Bay since 2013 and has developed a relationship with this community and staff from CHARS which is critical to the success of the deployment. He is also the PI of a FRQNT team grant looking at climate drivers affecting snow conditions in the Arctic from a context of caribou habitat. He has received over $2M in research funding as PI since 2013 and graduated ten students. He also received the Canadian Remote Sensing Society Bronze award in 2017. In summary, Prof. Langlois has the community, field, modeling and remote sensing experience to run this project, and the multidisciplinary team he built will ensure its success.

Kimberly Strong, FRSC (Co-PI of MOACC; Professor and Chair, Dept. of Physics, UofT; President, Canadian Meteorological and Oceanographic Society) has more than 25 years' experience in atmospheric remote sounding for studies of ozone, climate, and air quality. She is PI for the CFI-funded UofT Atmospheric Observatory, Co-I for the OSIRIS and ACE satellite missions, and former PI for the Middle Atmosphere Nitrogen TRend Assessment high-altitude balloon program. Strong has been making atmospheric measurements at Eureka since 1999, when she initiated a program of spring campaigns at ECCC's Arctic Stratospheric Observatory. Since 2004, she and Walker have been Co-PIs on a series of annual CSA-supported campaigns at Eureka for validation of ACE and OSIRIS, as well as international missions such as the Japanese GOSAT, NASA's OCO-2, and the European TROPOMI. Strong was a founding member of the Canadian Network for Detection of Atmospheric Change (CANDAC), which established the PEARL facility at Eureka, and completed six years as Director of the NSERC CREATE Training Program in Arctic Atmospheric Science in 2016. More than one-third of her 170 refereed papers are related to Arctic atmospheric science. Strong is currently the Co-PI for PEARL and the Probing the Atmosphere of the High Arctic (PAHA) project, leader of the PAHA Composition Measurements theme, and lead scientist for four PEARL instruments. Strong will be co-mentor for the MOACC TCCON FTIR and Pandora spectrometers.

Norm O'Neill (Professor, Dépt. de géomatique appliqué, U Sherbrooke) is an internationally recognized leader in aerosol optical remote sensing. He is co-founder of the AEROCAN network (a sub-network of AERONET) and the founder of a small Canadian network of starphotometers. He is a CANDAC Co-I, mentor of the PEARL photometry suite, and acting mentor of the lidar suite. He will oversee the key innovations applied to the CRL and Starphotometer, as well as the development and implementation of the IC-CAS. He will continue with his leading role in the processing and analysis of the CRL and Starphotometer data and will co-lead, with Blanchet, the interpretation of the crystal type data in terms of aerosol cloud interactions as well as the analysis of surface to column and speciation links with Strong and Hayes.

Robert J. Sica (Professor and Chair of the Dept. of Physics and Astronomy, Western) is an expert in using lidars to study atmospheric dynamics and its effects on constituent chemistry. He is responsible for Western's Purple Crow Lidar (PCL), which is still a cutting-edge, innovative instrument nearly two decades after first light. The PCL uses a 2.6-m liquid mercury mirror telescope and 30-W Nd:YAG transmitter, making it one of the world's most powerful lidars and allowing temperature measurements into the thermosphere and water vapour measurements above 20 km. Sica is involved in the NDACC Lidar Working Group and has a productive partnership with MeteoSwiss; he and Haefele (see below) recently introduced the application of optimal estimation methods to improve lidar retrievals for temperature, water vapour, and aerosol properties, resulting in their nomination for the WMO Vilho Väisälä Award. He will be mentor for the Ceilometers, managing their operation and liaising with the E-PROFILE network.

Patrick Hayes (Associate Professor, Dept. of Chemistry, U Montréal) is an atmospheric chemist with expertise in field measurements for the characterization of aerosols and collaborates with modelers, including those at the US Environmental Protection Agency. He is currently leading an aerosol modeling project with researchers from ECCC and McGill, and has led collaborative studies on urban aerosols. Since 2010, he has participated in six field experiments including two deployments to PEARL. During these experiments, he operated aerosol instrumentation similar to that requested in this proposal. He has published more than 20 articles on aerosol composition and optical properties with a particular emphasis on organic aerosol. Many of these papers involve collaboration with modellers who have used the measurements to test and improve CTMs. He has been honoured with an Analyst Emerging Investigator Lectureship.

Alain Royer (Professor, Dépt. de géomatique appliqué, U Sherbrooke) was a Natural Sciences and Engineering Research Council Fellow with the Centre d'Applications et de Recherches en Télédétection (CARTEL), Université de Sherbrooke from 1983 et 1988. Since 1988, he has been a Professor at the Université de Sherbrooke (CARTEL Director 2000-2010), he was involved in Canada's International Polar Year cryosphere project (2008–2011), and now he leads several projects for improving remote sensing of snow using passive microwave radiometry over Arctic, Antarctic and subarctic regions. His research interests are environmental geophysics from space, including the development of surface parameter retrieval algorithms using remote sensing data applied to northern climate change analysis.

Alexis Lussier-Desbiens (Professor, Dept. of Mechanical Engineering, U. de Sherbrooke) is the assistant director of the new undergraduate program in robotics, co-director of NSERC CREATE in Collaborative Robotics in Manufacturing (CoRoM), co-PI of the NSERC Strategic Canadian Robotic Network and co-PI of the NSERC CREATE for Uninhabited aircraft systems Training, Innovation and Leadership Initiative (UTILI). He develops new airborne platforms, including drones for long-term aerial-aquatic operations, for the sampling of tree branches, for landing on vertical surfaces, for the inspection and maintenance of infrastructures, for the robust landing of UAVs on fast-moving vehicles. He collaborates with several companies, including manufacturers (Bell Helicopter, Exo Tactik, Exonetik) and end users (Domtar, Cima+, Corriveau & Asso., mining companies). He holds two patents and has received several international design and best article awards. He has extensive expertise in multidisciplinary design of highly dynamic robots / drones, and advanced manufacturing.

Patrick Ayotte (Professor, Dept. of Chemistry, U. de Sherbrooke) is a physical chemist that develops and applies advanced molecular beam techniques and optical/electronic surface spectroscopy/microscopy as analytical tools to investigate heterogeneous (photo)chemical dynamics of molecular processes on model ice surfaces relevant to atmospheric chemistry. Numerical modeling and atomistic simulations of the interfacial reaction dynamics enables deep insight and detailed molecular-level descriptions of the surface specificity of the elementary processes that govern the physics and chemistry at ice surfaces in the atmosphere and in the polar boundary layer.

Dominique Gravel (Full professor, Dépt. de biologie, U. Sherbrooke and Tier 1 Canada Research Chair in Integrative Ecology) studies biodiversity distribution and changes in response to climate warming. He is director of the Observatoire des Écosystème, a collaborative project with governments, academia, private industries, NGOs and consulting companies. He develops new numerical technologies and services to help monitoring biodiversity and to provide scenarios for stakeholders. He leads BIOS2, a NSERC-CREATE training program in computational biodiversity science and services. His research activities include theoretical modeling, field work in the Canadian Arctic, data syntheses and analyses. His expertise in theoretical ecology is highly appreciated in working groups and therefore he is regularly in international projects to contribute new concepts and promote inter-disciplinary research. He will oversee database management in the project, in particular he will support the development of open access online tools for data upload and download. The database will be linked dynamically to the POSE infrastructure for the Observatoire des Écosystème, allowing real time revision of models and projections. The feedback loop between data collection, management and modelling will promote more efficient ways to collect information, a critical strategy in the Arctic where the logistics of getting on the field requires optimisation of field expeditions.

Daniel Fortier (Associate Professor, Geography Department, Université de Montréal) studies permafrost biogeosystems and northern infrastructure along a 4000-km latitudinal, 5500-km longitudinal transect across North America. Dr Fortier is director of Geocryolab, a research group focused on geotechnical and geomorphological studies of the changing North. He manages the Geocryopshere, a 2M$ CFI-funded laboratory, equipped with large climate and permafrost simulators able to reproduce northern field conditions. He has over 20 years of experience in Arctic and subarctic fieldwork in Canada and Alaska. He regularly contributes to national and international research efforts and synthesis publications due to his expertise in permafrost and landscape changes and provides guidance to Canadian and territorial governments for the development and management of northern infrastructure. He is Co-PI and theme lead for the NSERC Strategic Network PermafrostNet which regroups the majority of permafrost scientists in Canada and lead several other research projects (e.g., within the Canadian Mountain Network programs) in the Canadian North. He will be in charge of evaluating the thermal and mechanical response of permafrost to climate change, climate extremes and changing snow conditions. He will ensure that the results of the research contribute to national circumpolar permafrost monitoring and modelling effort (e.g., NSERC PermafrostNet, IPA-GTNP). He will oversee ground thermal monitoring, ground thermal properties dynamics, surface change, data analysis and numerical thermal modelling in the project.

The MOACC team is committed to ensuring equity, diversity and inclusion in our applicants, collaborators, students, and postdocs, and also in our governance approach. Part of our strategy is to first to create a firm and tangible bond with the community of Cambridge Bay. Our research program will include a large portion of Inuit collaborations from Cambridge Bay with tangible achievements and ongoing data collection in the MOACC site. As such, Indigenous Knowledge (IK) is essential to the overall project. We plan to host community meetings and with the Hunters and Trappers Organizations (HTOs). These meetings would focus on sharing IK related to: changing snow conditions; occurrence of rain-on-snow; water quality and runoff timing/amplitude; areas affected by permafrost thawing and changing sea ice conditions; and changes in space use and movement patterns of caribou. We will use existing collaborative links from A. Langlois' ongoing research that involves snow measurements by Inuit monitors. We plan to expand this effort to the various instrument and measurement needs within our group. This expansion includes the creation of a monitoring initiative that will be co-developed with communities, in collaboration with the NASA ABoVE CHARS-ERA project for monitoring in the Cambridge Bay area and will use the MOACC site as a training facility. We will seek community interest and input how best to develop a community monitoring program (e.g., what aspects of snow, permafrost and atmosphere monitoring are most pertinent? Who should be involved in the initiative?). We want to initiate this work in Year 1 and use the MOACC site to train monitors from other communities, in particular Kugluktuk and Gjoa Haven who already work within Prof. Langlois' network. This monitoring initiative would involve a senior scientist and a junior scientist/graduate student working alongside an elder from the community and someone younger. This training program would then be led by the four partners working together to train interested Inuit youth in measuring environmental variables to support the project. This snow monitoring initiative aligns directly with Polar Knowledge Canada's development of sustained measurements in the Intensive Monitoring Area. For example, Langlois' group is developing new approaches and instrumentation for snow depth measurements that could be used in this initiative as a benchmark. Discussions with Polar Knowledge Canada (POLAR) are planned during this visit to implement these monitoring practices with the CHARS-ERA NASA ABoVE project and the site implementation manager from this proposal. Money planned for 'Fieldwork' (see budget) and 'Inuit community sampling' will get this initiative started, most of which will go towards paying local people and travel.

As far as HQP recruitment, we will work with the newly created Research Equity Service at the Université de Sherbrooke that provides knowledge and guidance in the hiring process for our group. A similar approach will be taken at the other universities, where similar initiatives are underway; for example at UofT, where a commitment to advance equity, diversity, and inclusion is one of the strategic objectives of the new Institutional Strategic Research Plan.

As such, <u>all future HQP opportunity calls leveraged and motivated by MOACC will be compliant with the relevant institutional requirements with regard to inclusivity of racialized persons/persons of colour, women, Indigenous/Aboriginal People of North America, persons with disabilities, LGBTQ persons, and others who may contribute to the further diversification of ideas.</u> University equity offices will also provide insight on how to manage the team in an equitable manner, from lab work to field campaigns, so that everyone feels they can make significant contributions to the program. As such, we will always provide flexible working schedule for both laboratory and fieldwork. We also ensure that additional mentoring can be made by MOACC co-applicants, of senior graduate students on specific aspects of the student's work (e.g., coding difficulties, physics problems, field protocols and instrumentation).

3. Research capacity

3.1. Institutional Capacity and Track Record

This proposal is submitted by the Université de Sherbrooke (UdeS), University of Toronto (UofT), Western University (WU) and Université de Montréal (UM) (hereinafter referred as to STWM). At the **Université de Sherbrooke**, the project is led by CARTEL that has long been, and continues to be, an officially recognized and financially supported centre of research excellence of UdeS. As such, it receives an annual institutional grant that can be used to support graduate students, acquire and maintain research infrastructure, and develop international partnerships. One of the identified research priorities in its strategic plan: 'Climate change and the Environment within a context of sustainable development' enabled support to CARTEL by providing student scholarships, Canada Research Chair allocations, technical services, and infrastructure, including cash contributions to several applications to CFI and other funding agencies. The project builds on past CFI grants awarded to team members that are relevant to the proposed infrastructure and include: Langlois (J. R. Evans Leaders Fund, $372,432); Royer and O'Neill ($1,363,061). The UdeS views this project as a strategic priority and this proposal was selected internally already for the CFI-IF competition 2019. As such, the UdeS will provide a high level of support to the project, including the services of an electrical engineer hired through the university, which is essential to the installation, maintenance and operation of the requested instruments. The UdeS will also contribute the necessary laboratory space for these operations. Of particular relevance, the Site Interdisciplinaire de Recherche en ENvironnement Extérieur (SIRENE) research station, which is located on campus, will be made available for this project. This includes storage and maintenance space and tools.

This infrastructure also aligns with the strategic plans of our three collaborating institutions (WU, UM and UofT). For instance, environmental sciences are a top priority for **Université de Montréal (UdeM)** as demonstrated by its recent investments in research activities and infrastructure in this field. Within their Faculty of Arts and Sciences, the 1st priority in their strategic plan is to create five "knowledge centers" to support interdisciplinary initiatives, with one of these centers focused on Environment and Sustainability. The proposal thus fits perfectly into this new UdeM knowledge center. The substantial institutional commitment to environmental research has been clearly demonstrated by: (i) the construction of a platform for analytical measurements of trace environmental contaminants and a second one for sedimentological analysis in the new UdeM Sciences Campus MIL Building, expected to be completed by the end of 2019; (ii) the substantial past support of faculty in environmental sciences with CFI infrastructure funding (i.e. J.R. Evans Leaders Funds), including co-investigators Fortier ($554,863) and Hayes ($340,259); (iii) the creation at UdeM in 2014 of an Institute for Environment and Sustainability (Institut de l'environnement, du développement durable et de l'économie circulaire); and (iv) the implementation in 2018 of a new Master's degree program in Environment and Sustainability for which Hayes is a member of the graduate studies committee.

This program of research is also well aligned with the **University of Toronto's** Institutional Strategic Research Plan 2018-2023. Under the theme SUSTAIN: *Societies, the Environment, and Natural Resources*, the Global Climate Change sub-theme highlights the importance of measurements: "*Climate change poses a major challenge to humanity. Detecting and quantifying these changes will require developments in remote sensing*." This sub-theme also explicitly emphasizes carbon cycle science and the Canadian Arctic: "U of T's scholars are collaborating to develop measurement concepts, biosphere information retrieval techniques, monitoring tools, and sophisticated computational models for quantifying change and its effects on terrestrial carbon and water cycles". Expertise relevant to this proposal has been developed through four CFI awards at

UofT: The University of Toronto Atmospheric Observatory (#907, PI Kimberly Strong), The Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka (Project #8634, Co-I Kimberly Strong), Laboratory for Atmospheric Spectroscopy And Applications (#16434, PI Kaley Walker), and Constraining Canada's Regional and Urban Carbon Cycle using Atmospheric Greenhouse Gas Measurements (#35278, PI Debra Wunch)".

At **Western University**, Sica is a core member of Western's Centre for Planetary Science and Exploration (CPSX) and a Faculty Affiliate in The Centre for Environment and Sustainability (CES). His research is directly aligned with two of the five major CPSX research themes, Planetary Processes and Earth Observation, Monitoring, and Protection. Established in 2008, CPSX bridges over 50 faculty members and 30 graduate students from 11 different departments across Western's campus, engaged in planetary science and exploration research. Over the last five years, Western has invested $250,000 in CPSX administration, $140,000 in outreach initiatives, and $200,000 in support of research. Western continues to allocate resources and on-going support to CPSX and its members, including through recent applications to the CFI John R. Evans Leaders fund. Sica has growing research collaborations with these projects and the interactions, as well as the partnership high Arctic monitoring projects such as MOACC are all priority items in the Department of Physics & Astronomy's Research Plan. Those past/current grants allowed developing a unique Canadian expertise in surface and atmospheric state variable retrievals that are now mature enough for permanent and operational approaches/deployments rendered possible with the proposed infrastructure.

3.2. Current investments

As for the proposed site to be hosted at CHARS, investments using grants from NSERC ($175,000), FRQNT ($190,000), ECCC ($107,000) and POLAR ($274,000) allowed the development of a 'monitoring network' led by Langlois (PI) in the Kitikmeot region that includes 14 researchers from 11 institutions (UdeS, NASA, ECCC, U Waterloo, UdeM, IRSTEA-France, Meteo-France, Ouranos, Wilfrid Laurier U, Canadian Centre for Inland Waters and UBC). Currently about 70 graduate students (supervised by the our STWM team; see CVs) are working on different aspects of the cryosphere and atmosphere, serving as a great 'task force' to exploit the data that will result from MOACC. Langlois' monitoring network will be renewed in 2019-2020 with funding from NSERC and POLAR, and the proposed infrastructure will be central to the program renewal (2019-2024) while allowing the range of applications to be expanded though new partnerships and collaborations with national and international researchers who have confirmed interest in the proposed infrastructure: SLF in Switzerland, LGGE in Grenoble, France, Northumbria University in Newcastle, England, Norwegian Polar Institute in Norway, Alfred Wegener Institute in Germany and MeteoSwiss. These international collaborations will leverage the proposal herein and there is a strong global interest in expanding the site beyond what is proposed here. Furthermore, it is anticipated that MOACC will complement two existing international networks focussed on trace gas measurements: the Network for the Detection of Atmospheric Composition Change (NDACC) and the Total Carbon Column Observing Network. Membership in these networks is only permitted after extensive validation and quality control of the measurements. Eureka (NU) and East Trout Lake (SK) are currently the only two TCCON stations in Canada, each making precise and accurate measurements of greenhouse gas concentrations using FTIR spectrometers.

These various collaborations have been key to attracting world-class graduate students from both Canada and abroad, including France, Switzerland, Italy and Germany. The above-mentioned funding has also created very productive research environments at all STWM institutions, with groups participating in numerous projects, allowing the development of significant expertise in remote sensing, cryospheric processes, atmospheric science, and climatology. Our team has initiated research projects and partnerships, from urban to alpine to Arctic regions, focusing on cryospheric and atmospheric processes at different scales working on snow, sea ice, hydrology, habitat characterization and atmospheric studies while contributing significantly to peer-review literature with over 200 publications and over 60 students graduating over the past six years.

4. Infrastructure and budget justification

The financial support for the operations and maintenance (other than existing CFI-FEI programs) of the existing infrastructure for STWM includes: site preparation (fence, ground leveling, electricity) covered by Polar Knowledge Canada (confirmed contribution of 435,000$, see 'Installation' section of budget details); on-site permanent staff for site maintenance and monitoring contributed by Polar Knowledge Canada; engineering staff for instrument maintenance and calibration from each institution; and deployment travel costs and field campaigns covered by individual research grants from the applicants. For all requested equipment, original quotations were obtained from qualified suppliers in accordance with STWM Procurement Services procedures. These quotations are obtained in compliance with the CFI pricing format. All admissible costs are in Canadian dollars, and include taxes. All in-kind contributions are also in accordance with STWM Procurement Services procedures. In addition, all quotations are reviewed to ensure completeness for all aspects such as installation, testing, training, documentation, Canadian Standards Association certifications, shipping, facility requirements, etc. Such documentation forms the basis for subsequent open and competitive bidding at the time of grant arrival. The costs are projected to the time of acquisition.

TH1-Snow Remote Sensing and Ecological Applications: Passive microwave radiometers system ($415,288 Item #1) : The system includes L-band and 19 GHz radiometers from supplier Radiometrics Corporation ($379,489) were chosen given our positive past experience with this company. We currently own a suite of radiometers that are now old and lack in reliability. This suite is also used at many locations, so that a permanent deployment would seriously handicap ongoing projects. The complementary 10, 37 and 89GHz GHz antennas we currently own were built by this company so that the complementary radiometers for permanent deployment requested in the proposal herein will be easily blended to the existing system. Furthermore, PI Langlois published a user guide on behalf of Radiometrics on the use of their radiometers for snow applications. The radiometers will be deployed on a scaffolding platform on-site ($25,439) and all instruments controls, computers ($7,526) and software will be hosted inside a container ($2,834). The temporal data collected from the site, combined with ongoing (funded through other sources) continuous meteorological observations will allow a proper parameterization of extreme events detection algorithms such as blizzards, rain-on-snow and heat waves. The punctual nature (spatial and temporal) of those events can only be assess using temporal continuous measurements, which this site will enable. The **Hydrogen Aircraft platform for observations-HAPO ($316,648 Item #2)** aims at developing an aircraft platform for microwave (mw) measurements at different altitudes, i.e. with variable footprints. The problem of downscaling coarse mw satellite data is a key research aspect for snow monitoring over heterogeneous areas (forested cover, mountains, high fraction of lakes, etc.) We propose an innovative approach based on a hydrogen-inflated captive dirigible balloon (HAPO), able to transport ~100 kg payload. The balloon UAV-type is the only alternative for heavy payload lifts in remote areas such as in Arctic. This item includes two main components: 1- a portable hydrogen generator (electrolyser system); 2- the balloon with a basket (envelope, tail, metal structure, landing gear, basket to support the radiometers, etc.). The France-based Voliris company achieved the proof of concept with their V902RC airship prototype, that is a first step toward the development of an "Automatic Air Shuttle for the Transport of Containers system, AASTC) (this company landed in the Guinness Book of World Records for creating the smallest airship in the world). The **UAV permanent base ($141,345 Item #3)** includes a DJ M210 ($18,070) to be powered continuously by the Elistair ground station ($64,162) and allow the temporal retrieval of spatially distributed snow depths, with natural links to TH2 from a model forcing perspective. The six additional UAVs ($59,113) will consist of three fixed-wing

Aeromapper and three DJI Matrice 100 quadcopters for further development and larger-scale application of the approaches developed with the M210 at various sites within the Greiner Lake watershed (near Cambridge Bay).

TH2-Snow Modeling: The **Frequency Modulated Continuous Wave (FMCW) radar ($158,353 Item #5)** are unique set of instruments designed for the specific aspect of this project. Snow cover and ice thickness of northern rivers and lakes are the two main components of the terrestrial cryosphere. The variability in snow water equivalent (SWE), i.e. the snow mass on the ground, is a key parameter in hydrology (modelling and flood forecasting) as well as in climate change impact monitoring. We will develop a innovative approach to monitor these parameters (SWE and ice thickness) using a new light-weight, portable and autonomous bi-frequency 13.5 and 17.5-GHz Frequency-Modulated Continuous-Wave (FMCW) radar system. Surface-based measurements of the snow and ice spatial variability is essential to validate et improved satellite-based retrievals. The chosen frequencies are those optimal for radar monitoring from space and were selected for the future Snow Mass Canadian satellite mission. The **SWE In-Situ Monitoring Station ($22,458 Item #6)** will allow continuous and automatic in-situ snow water equivalent (SWE), snowmelt and runoff measurements. These measurements are often very limited, especially in remote areas, as the snow density cannot be easily measured. The objective is to purchase three newly developed in situ snow monitoring stations based on signals of the Global Navigation Satellite System (GNSS). The novel GPS-based in situ sensor, using two static low-cost antennas with one being mounted on the ground and the other one above the snow cover. This sensor setup enables retrieving SWE and liquid water content (LWC) in the snowpack in parallel, using GNSS carrier phase measurements and signal strength information. The **field spectrometer ($132,114 Item 7)** will be used for precise measurements of surface albedo to identify melt-onset and albedo-related feedback.

TH3-Atmosphere: The **Sun photometer and CRem system (Snow Ice Continuous REflectance Monitor) ($97,160 Item 8)** includes a CIMEL 318-T ($77,950) is the standard AEROCAN & AERONET instrument. It will be installed at the CHARS instrument park (see the CIMEL and CRem requirements document for more detailed information). It acquires atmospheric extinction data in solar or lunar pointing mode (340, 380, 440, 670, 1020 and 1640 nm bands) and sky radiance data in its almucantar scanning mode (380, 440 670, 870 nm bands). AERONET retrieval products include (AOD for all extinction bands), AOD and phase function, particle size distribution and refractive index in sky radiance mode. The extinction mode enables the extraction of high frequency fine and coarse mode optical and microphysical parameters at a frequency compatible with lidar profile sampling while the sky radiance mode enables the extraction of all optical and microphysical parameters associated with spherical (or effectively spherical aerosols) at a sampling frequency (a few retrievals per day) which is more amenable to climatological scale analyses (daily to monthly binned averages). Identical instruments exist as part of the AEROCAN suite of instruments: these will provide the AEROCAN calibration swap out service for the CHARS site. The CRem (Snow Ice Continuous REflectance Monitor) ($19,210) is a three-channel reflectance monitor (860, 1240 and 1640 nm) that will be employed to monitor long-term trends in snow/ice reflectance at the undisturbed site in the CHARS instrument park. The system includes a camera for monitoring snow/ice texture and colour information as well as snow/ice fraction. Our particular research interest, aside from the empirical findings of significant trends in snow/ice reflectance will be to investigate the relationship between surface reflectance and Patrick Hayes' aerosol absorption coefficient measurements as well as the more subtle relationship between surface reflectance and AERONET absorption optical depth. The CIMEL outputs will provide important complementary information for analysis of the robust elements of local and regional pollution (including comparisons with Resolute Bay and Eureka and the relative contribution of different types of aerosols along that high- to low-Arctic transect). They will also be an important source of ground-based validation for satellite sensor retrievals of AOD. The CRem instruments will be part of part of a network of such instruments installed at Ny Alesund (Spitsbergen) and planned for Villum (Greenland).

To complement the remote sensing aerosol measurements, including the CIMEL sunphotometer and LIDAR system, a **UAV aerosol latform (191,391 Item 9)** is required in order to carryout airborne measurements of aerosol properties. Specifically, the UAV-aerosol platform will measure vertically-resolved profiles of aerosol light absorption and particle size distributions, as well as other properties, that will provide a greater level of detail on aerosol properties than can be obtained by remote sensing techniques alone. These measurements will thus support the proposed research by allowing the research team to: (1) better quantify the different types of observed aerosols (e.g., mineral dust vs. sea salt vs. black carbon), (2) more thoroughly evaluate remote sensing data products of aerosols, and (3) compare observed aerosol and cloud properties with greater precision. It is also expected that the UAV-aerosol platform will leverage the expertise of the Université de Sherbrooke team in the use and development of UAVs for environmental observations and create an opportunity to apply this expertise in the domain of atmospheric sciences and aerosols. A small amount of funds for **Engineering services ($30,000 Item 10)** is also requested to assist with the installation of the instruments on the UAV and the initial testing of the platform.

The **TCCON FTIR System ($974,527 Item 11)** will be built to conform to TCCON requirements, recording solar absorption spectra in the near-IR for retrieval of dry-air mole fractions of CO_2, CH_4, H_2O, N_2O, CO, HCN and HF. Equipment selection is based upon the stringent accuracy and precision requirements of TCCON, whose resources (partnership, archiving, quality control, etc.) are essential to successful operation. The primary component is an appropriately-equipped Bruker IFS 125HR FTIR and sun-tracker ($731,099) plus Bruker service/installation charge ($24,818), service engineer travel to Cambridge Bay ($2,585 est.), and packing, freight, and insurance to Toronto ($2,585). Additional components include a weather station from Campbell Scientific ($13,116), a Paroscientific 765-16B field standard barometer from Technel Engineering ($13,433), a NetCam XL 640 All-weather Internet Camera from Stardot Technologies ($1,933), Minco silicone rubber heaters ($2,279), a CaF_2 window from ISP Optics ($2,771), a Norhof LN_2 microdosing autofill system #608 ($9,969), assorted smaller items (optical filters, beamsplitter/dichroic, pump valve: $10,341), and a data analysis computer ($2,068). A customized automation system will be developed ($72,387). A roof-mounted sun-tracker enclosure ($34,420) will be purchased and coupling of the sun-tracker to the container roof will be constructed in-house ($2,585). The system will be installed in a customized container with insulation, electrical, roof support obtained from Martin Container Inc. ($37,511) shipped to Toronto ($9,791) for in-house modifications prior to shipping to CHARS.

Two Pandora UV-Visible Spectrometers ($188,330 Item 12) is a portable spectrometer system developed by NASA and manufactured by SciGlob Instruments & Services. It measures total columns and profile information for ozone, NO_2, HCHO, H_2O, and SO_2, as well as UV and visible AOD. It uses a fiber-fed spectrometer mounted on an azimuth-elevation tracker for direct-sun, zenith-sky, and multi-axis differential optical absorption spectroscopy viewing. We will purchase the Pan2S model, which includes two AvaSpec-2048-64 spectrometers, for 280-530 nm and 400-900 nm, mounted inside a protective housing configured for low temperatures. The system will include a Pan2S Sun Tracker, the SciGlob HSN2-2 Head Sensor with two filter wheels and thermo-electrically cooled detectors. Two Pan2S systems will be bought, one for CHARS and one for ECCC's atmospheric "supersite" at Iqaluit ($186,262), along with a computer for data analysis

($2,068). **Personnel for Instrument Development and Installation (107,000 Item 13)** is needed since a considerable amount of equipment construction, ruggedizing, and other modifications, as well as testing and operational software development, will need to be done "down south" both to avoid incurring excessive costs on-site and for the proximity of workshops and suppliers for the work in hand. Overall, we estimate that the work required for instrument development, installation, and commissioning of the TCCON FTIR and Pandora spectrometers will total two person-years, spread over two years).

The **MiniMPL (micropulse lidars)-532-C-HD ($329,550 Item 14)** operate at a wavelength of 532 nm. The system has a pulse power of 3.5 microJ at a repetition rate of 2500 Hz. The detector package is a single channel photon counting detection, which includes control electronics and a data system package. The unit includes the POL-FS Polarization Control Package, which includes electronic control of polarization state, and two-channel photon counting data acquisition, allowing the lidar returns to be measured in orthogonal planes of polarization. The system is designed for autonomous operation. The unit is housed in an all weather enclosure designed specifically for this system. It allows zenith pointing and includes an optical grade window, climate control, additional heater, network and power interface. Also included are a GPS option for built in location and time information, two days of onsite training at Western plus shipping, insurance and applicant import duties and fees.

The research proposed requires automated lidars that operate 24/7 in all weather conditions. It must automatically send the level 0 measurements via the internet to a data server. This requirement is important as some manufacturers only allow the user to access processed (e.g., level 1 or higher) measurements. The instruments must be able to receive returns in 1 min or less up to at least 15 km altitude in reasonably clear conditions at night (when adjacent range and time bins are added together this height will increase, an important distinction for proposed stratospheric measurements). Most importantly, the lidars must have a digital counting system. Lidars can record the returned photocounts by analog or digital detection. Digital detection is required for all Objectives in this project above the boundary layer, including the cloud science, ozone and trace gas science. Other companies offer lidar systems with similar capabilities, but the price per instrument is at least two or more times more expensive and uses a laser with older flashlamp technology. The flashlamps need to be replaced several times a year, which is not practical at a remote location. The MPL systems uses solid-state diode pumping, which extends the replacement time to years. A lidar capable of measuring polarization in the return signal as opposed to a total backscatter is required, as a total backscatter lidar such as a ceilometer cannot definitely characterize particle type (e.g., smoke versus another aerosol type), nor determine whether a cloud is composed of water, ice, or is mixed-phase. The requested MPLs will be able discern these differences.

The requested infrastructure includes an all weather enclosure for the MPL system, meaning in only needs a small pad, power and internet to be functional. Location and timing are guaranteed using a GPS/GIS system included. The proposed lidar will complement the measurements from Sica's network of five lidars at the following established CASSAVA sites: London (Ontario), Eureka (on Ellesmere Island, Nunavut), Halifax (Dalhousie Ground Station), the UdeS Field Station, and the UofT Atmospheric Observatory (on the downtown UofT campus). The CASSAVA lidars cover a range of urban, rural, and Northern terrains. The synergy of the network is the wide-array of research problems that will be explored due to the other instruments at the CASSAVA sites. What is missing are sites just above and below the Arctic Circle to complement the extreme High Arctic Eureka measurements, and capture the transition from boreal forest to tundra. CHARS is perfectly located for this addition, and Iqaluit is ideal because it is in the transition region between the mid-latitude Sherbrooke site and Eureka. Also, the longitudinal differences between CHARS and Iqaluit, when combined with the power of the Pandora spectrometers, will allow for tracking the extent of features such as the spring ‘ledge’ in ozone.

The CASSAVA lidar network, with the addition of these two instruments, will be dense enough to test smoke tracking algorithms and broad enough to cover a significant portion of Canada. Current commercially available lidars do not have the capability to make polarization measurements like the proposed instruments. This new polarization capability, which is critical for all the Objectives of this program, allows an unambiguous classification of aerosols and water phase. There are a few other high-performance lidar systems in Canada, including Sica’s Purple Crow Lidar at Western, but no other lidar networks exist similar to those available in for instance, E-PROFILE in Europe. High-performance lidar systems are expensive (on the order of $0.5-2M per system or more) instruments and are typically not completely automated, nor do they operate without constant operator intervention. The proposed PANDORA spectrometers bring a full suite of column measurements for many important atmospheric gases.The MPLs will allow aerosols to be characterized as both a function of height and time. In addition, they give information on aerosol type and detect the development of cloud and fog, including the ability to discriminate between ice and water in these regions. The autonomous, near continuous, MPL profiling measurements allows a better context of the atmosphere to be available for interpreting trend measurements from the spectrometers, in addition to their unique aerosol and cloud characterization capability.

TH4-Permafrost: The infrastructure requested here refers to a complete ‘’atmosphere-soil-permafrost’’ monitoring station. It will be deployed in a secured 50x50 m area where the station sits away from the instrumented boreholes. These boreholes will provide high resolution thermo-physical data (see TH-4 activities above) that will be used to develop and calibrate the numerical permafrost thermal model. Funds are required to install an **Automated Data Acquisition System (ADAS) ($74,781 Item 15)** which will include a power system, tripods, enclosures, wiring, wire-casings, supports, cables, and a communication system able to function it the harsh winter climate of Cambridge Bay. It includes equipment required for the surface energy budget such as an air temperature and relative humidity sensor, a barometric pressure sensor and two heated rugged cameras to document surface conditions (e.g. rain/snow storms, snow thickess, snowmelt, water ponding etc) . The main piece of equipment will be a 20-m deep thermistor cable installed in undisturbed permafrost (including the active layer). The borehole to install the thermistor cable will be done using a permafrost core-drill equipped with a cooling system to minimize thermal disturbance (heat during drilling). Funds are required for a **Permafrost coring system ($8,449 Item 16)** that includes coring kit and accessories ($5,554) that will complement Geocryolab’s permafrost coring equipment and which includes a kit of corer and core extractor. The drill rods and adapters ($2,895) needed for the coring operations will be used with the coring kit. The thermistor cable will comprise 28-thermistors installed in a PVC casing filled with silicon oil to avoid heat convection in the borehole. Geocryolab has developed this method in arctic and subarctic conditions in several areas of northern Canada so the level of confidence regarding the monitoring of permafrost temperature is high. One advantage of this system for is the possibility to remove a broken thermistor once installed or thermistors can be removed to be recalibrated if needed, so it is well-suited for long term monitoring. The thermistor cable will be complemented by a surface water level sensor and by 10 moisture/electrical conductivity/temperature probes to follow the movement of water and solutes in the ground, using heat, water geochemistry and moisture variation as indicators of water flow during freezing and thawing of the ground. The **Thermal conductivity sensors ($35,913 Item 17)** includes 10 heat flux plates ($10,985) and 10 thermal conductivity probes ($24,928) will be installed in the active layer, in the transient layer and in the deeper permafrost to document changes in thermal properties and associated heat fluxes. This data is important to parametrize and validate our numerical thermal model. A transect of 150 m (max) that intersects the instrumented boreholes should also be secured for electrical resistivity tomography and active layer probing. The **Electrical tomography system ($109,860 Item 18)** will allow 2D underground profile of the electrical resistivity to document the thermal state of permafrost and phase changes. Finally, **Engineering services ($53,000 Item 19)** is required to implement the set-up.

INSTALLATION: The shipping, installation, test and calibration of the various instruments will be coordinated by the site manager and research professionals. The primary costs will include shipping, airfare, electricity and accommodation on site for which some will be provided in-kind by POLAR. Installation costs include **Research and logistic equipment ($65,000 Item 20)** provided by Polar Knowledge Canada that will consist in assisting ordering and coordinating shipping, storing and local transportation to the site. The **Site preparation ($75,000 Item 21)** includes the actual terrain preparation, fencing and container installation and electricity configuration, provided by Polar Knowledge Canada that will also provide local **Accomodation at CHARS ($175,000 Item 22)** for all co-applicants and collaborators involved in the implementation portion of the project. POLAR will also provide **Site management and monitoring ($120,000 Item 23)** which consist on dedicating POLAR staff to initial setup, calibration and ongoing testing of all instruments while overseeing legal aspects of the installation. The **Shipping ($32,081 Item 24)** will consist of shipping the instrumentation from four institutions to Cambridge Bay. The **Travel expenses for installation ($76,139 Item 25)** include 20 return trips for co-applicants (at $3,000 per return trip) and support staff for the installation period with the associated **Travel per diems** ($16,139) based on 20 per diems of two weeks.

PROJECT PROFESSIONALS: The level of complexity of such multidisciplinary project requires research professionals working across the four themes and not dedicated to specific tasks of individual theme needs. We need staff dedicated to data and logistics coordinating the activities throughout MOACC and also coordinating with other research professionals identified in specific themes. As such, the Université de Sherbrooke will provide the services of an **Engineer ($93,610 Item 4)** as a cash contribution of $18,722/year for five years. The project will hire a full-time **Site implementation officer ($140,000 Item 26)** for years 1-2 at a rate of $70,000/year and a part-time **Database developer ($100,000 Item 27)** for years 2-3 at $50,000/year. Their respective roles are described in more detail in the *Governance Model* section.

OPERATIONS & MAINTENANCE (O&M): Funds from the operations and maintenance (O&M) budget are planned over a period of 10 years and will cover costs associated with the proposed infrastructure detailed above. The total amount planned is at 30% of the CFI asked contribution + an additional 5% for a multi-institution application ($560,419). Those costs include: **MOACC Site Manager** ($80,000/yr, years 3-4-5) for managing the site, measurements and the various teams that will collect data within the site. This person will also manage the community collaborations planned. The **MOACC Data Manager** ($75,000/yr, years 4-5) will manage and coordinate the data collection and distribution to the various project partners. **Maintenance and Repairs** ($10,000 yr 2; $12,000 yrs 3-4; $15,000 yr 5; $21,419 yr 6 and $25,000 for yrs 8-10) are incremental from year 2 to 10 although they are hard to evaluate as troubleshooting of broken instruments is impossible to foresee. However, given the team's experience with their own instruments and past experience in remote regions operations, the needs are evaluated at that amount for UdeS, UofT, WU and UM. As for the MOACC Site Manager and Data Manager, their salary will be covered by contributions from the 10 co-applicants own sources of funding from various sources.

5. Sustainability of the research infrastructure

From the Université de Sherbrooke, CARTEL within the Département de géomatique appliquée will lead the proposed project. CARTEL has long been, and continues to be, one of 25 officially recognized and financially supported centres of research excellence at the Université de Sherbrooke. As such, it receives an annual institutional grant, which is funded by both the Université (70%) and the Faculté des lettres et sciences humaines (30%) and can be used to support graduate students, acquire and maintain research infrastructure, and develop international partnerships. The Université administrative staff is well experienced managing large multi-disciplinary science projects from various sources of funding. More specifically, the Service d'appui à la recherche, à l'innovation et à la création (SARIC), for whom the mandate is to support and coordinate research projects, helps project investigators in the management, reporting of their projects as well as being responsible for all the legal aspects with regards to expenses, contracts, etc. This project is collaborative across a number of universities and the necessary administration of specific purchasing, payroll, and hiring at all sites will be the responsibility of the relevant team members' home institutions and departments.

At the University of Toronto, the Department of Physics will be the administrative lead for MOACC. Team members and the Department's staff have extensive experience in the administration of large multi-user awards of this type. The staff will work with Strong, Walker, and Wunch to ensure that the project finances are administered properly and will liaise with Research Services and the procurement and human resources units of the University of Toronto. With support from multiple sources, including UofT, team members have successfully operated CFI-funded infrastructure similar to MOACC at several locations for many years, including the University of Toronto Atmospheric Observatory (established in 2001), the Polar Environment Atmospheric Research Laboratory (opened in 2006), and the East Trout Lake TCCON station (set up in 2016). Their proven track record at obtaining the resources necessary to maintain these facilities ensures the sustainability of the MOACC research infrastructure purchased at UofT. Anticipated funding sources to operate the UofT equipment include CFI-IOF, NSERC, ECCC, and the Canadian Space Agency. UofT team members have been working in the Arctic since 1999 and supervise a strong team of students, postdocs, and technical staff who will be involved in operating and maintaining the equipment. They will also have access to the Physics machine shop and electronics resource centre, which are heavily subsidized by the Department. MOACC research is directly relevant to the Global Climate Change sub-theme within the SUSTAIN: *Societies, the Environment, and Natural Resources* theme of the University's Institutional Strategic Research Plan. All MOACC team members are affiliated with the University's Centre for Global Change Science (CGCS), which is funded by the Faculty of Arts & Science. Undergraduate and graduate students involved in MOACC will be eligible to apply for CGCS undergraduate summer internships and graduate travel awards, respectively. The University of Toronto also contributes approximately $15,000 towards funding packages for graduate students, with a comparable amount provided from supervisors' research funding (exact amounts depend on the year of study, whether students are domestic or international, and scholarship support).

At Western University, the project will be implemented in partnership with Western's Institute for Earth and Science Exploration (Western Space) through the Faculty of Science . The research proposed in this project is directly aligned with two of the five major Western Space research themes, Planetary Processes and Earth Observation, Monitoring, and Protection. Western continues to allocate resources and on-going support to Western Space. Co-applicant Sica has growing research collaborations with these faculty, for which the interactions and partnerships arising from this proposal are all priority items in the Department of Physics & Astronomy's Research Plan. Western has been committed to support earth observation research by revitalizing contributions to past projects led by Sica including the provision of $92,000 for the purchase of a 1000 mJ/pulse (at 30 Hz, 532 nm) Nd:YAG laser and $325,000 to build and move the lidar to the new facility. Recently they have supported Sica's $500,000 CFI-JELF project to establish the CASSAVA lidar measurement. The multidisciplinary aspect of MOACC and the data management approach also align with the Faculty of Science priority research theme Science of Information. Western has heavily invested in its Big Data infrastructure, as the founder and current administrative home to SHARCNet (a consortium of 18 academic institutions who share a network of high performance computing resources) and a co-founding member of the Southern Ontario Smart Computing Innovation Platform (SOSCIP). As such, the provided expertise and support by Western on data management will ensure a proper development of archive structures and sharing agreements ensuring MOACC legacy.

The proposed research entirely belongs to the theme "Constructing a sustainable future" as described in the Research Action Plan of the Université de Montréal (UdeM). In support of this theme, there are at least 100 researchers at UdeM and its affiliated schools whose research activities are concerned with the environment and climate change. Specifically, at UdeM the sustainability of the requested infrastructure will be ensured by the following three factors: (i) the existing infrastructure already at UdeM that is highly complementary to the equipment requested in this CFI grant, (ii) sufficient operating and maintenance funds and the judicious use of maintenance contracts and (iii) the presence of highly qualified staff to maintain the new equipment. (i) UdeM recently completed construction of a new Science building that will house both Professor Hayes' and Fortier's lab. The building will provide state-of-the-art spaces for preparing equipment before deployment to CHARS and analyzing samples collected in the Arctic. For example, the Platform on Emerging Contaminants includes clean rooms and preparation laboratories that will be used by the Hayes group when analyzing aerosol samples collected at CHARS from an UAV. The Fortier group will use the cold room facilities and the sedimentology lab to characterize permafrost samples. In addition, UdeM has made significant investments in instruments related to the research project including CFI John R. Evans Leaders Fund Grants awarded to Fortier in 2010 ($554,863) and Hayes in 2014 ($340,259), the former of which was used to develop a frozen ground geotechnical laboratory that will be used in this project and the latter of which was used to purchase in situ aerosol instrumentation that could also be deployed to CHARS. The amounts in parentheses correspond to the CFI contribution only. (ii) A number of funding sources have been used to maintain the current infrastructure at UdeM, and we anticipate using a similar mix of sources to finance the operation of the requested equipment including CFI-IOF funds, external grants (e.g., NSERC Discovery, which Hayes and Fortier both hold) and research contracts (e.g., Transport Canada, Yukon Highways and Public Works). Additionally, three-year service contracts have been included in the prices for certain critical instruments. (iii) At UdeM, a team of technical staff and researchers (postdocs, students or technicians) will be assigned to the maintenance of the equipment. This work will be supervised by Professors Hayes and Fortier, who together have extensive field experience in Arctic and remote locations. In addition, the science departments have free access to a fully equipped workshop staffed with two machinists and an electrician that can assist with equipment repair. The labor costs for these staff members are fully assumed by UdeM. From a more general perspective, the acquisition of the state-of-the-art remote sensing instruments requested will open many new opportunities for its researchers and students alike, notably in support of the internationalization objectives of the institutions' respective strategic plans highlighted earlier. Moreover, we expect that the multidisciplinary nature of the research program (civil and electrical engineering, geomatics, chemistry, physics and Earth sciences) that will be enabled by this proposal will create a stimulating environment for the training of HQP and attract high-quality undergraduate and graduate students and provide great visibility for the applicant's institutions at various national and international venues. The four institutions view this project as a strategic priority and will allocate to it a large envelope for the Innovative Fund competition. The recruitment highlighted in the applicants CVs represent yet another step in our different research groups to maintain the highest level of excellence. PIs Langlois and Strong and their team members actively collaborate with international leading networks of researchers in Europe and in the USA, as well as with government bodies such as Environment and Climate Change Canada. To do so, the new infrastructure is needed so that our world-class researchers can remain active in those networks and continue to produce leading edge results.

Governance model: The management plan for MOACC will benefit from, and build on, the existing structure that is in place for CHARS operations and science (Figure-1). CHARS has a complement of permanent staff on site in Cambridge Bay who will contribute to installation, maintenance, trouble shooting and utilization of the proposed infrastructure as well as covering the electricity costs associated with the infrastructure. For the MOACC team, management will be augmented with the hiring of a site officer and a data manager (see budget). The CHARS Director of Science & Technology (A. Leclair) will coordinate three committees (Advisory Committee, Executive Committee and HQP Committee) with the MOACC team (PI Langlois and co-applicants). PI Langlois will have overall responsibility for the administration of the project, which will include communications, budget management and ensuring the communication between the themes. The Advisory Committee will provide support to MOACC by overseeing the project as a whole and will be comprised of two representatives of the MOACC project (Langlois, O'Neill) and major stakeholders from Polar Knowledge Canada, ECCC and two members for the Cambridge Bay community. The Executive Committee will include the PI, theme leaders and our site officer that will oversee the project management while steering the scientific objectives and communications through monthly teleconferences and yearly in-person meetings. The site officer will support field coordination in close collaboration with CHARS' operations manager (G. Redvers), while supporting the data manager ensuring data quality, proper archive while establishing data sharing agreements. The site officer will also coordinate, with the UdeS engineer, field deployment of instruments. The HQP Committee will include existing and future students from MOACC and ensure the maximization of HQP training within the project. The data produced by the project will be hosted at the Université de Sherbrooke on existing data platforms managed by A. Langlois and D. Gravel and managed through the Site officer and a Data manager. Finally, outreach will be integrated through community meetings as well as HTO meetings to ensure the proper inclusion of traditional knowledge in the science objectives while contributing to training through snow/summer schools hosted at CHARS given the existing classrooms and laboratories availability.

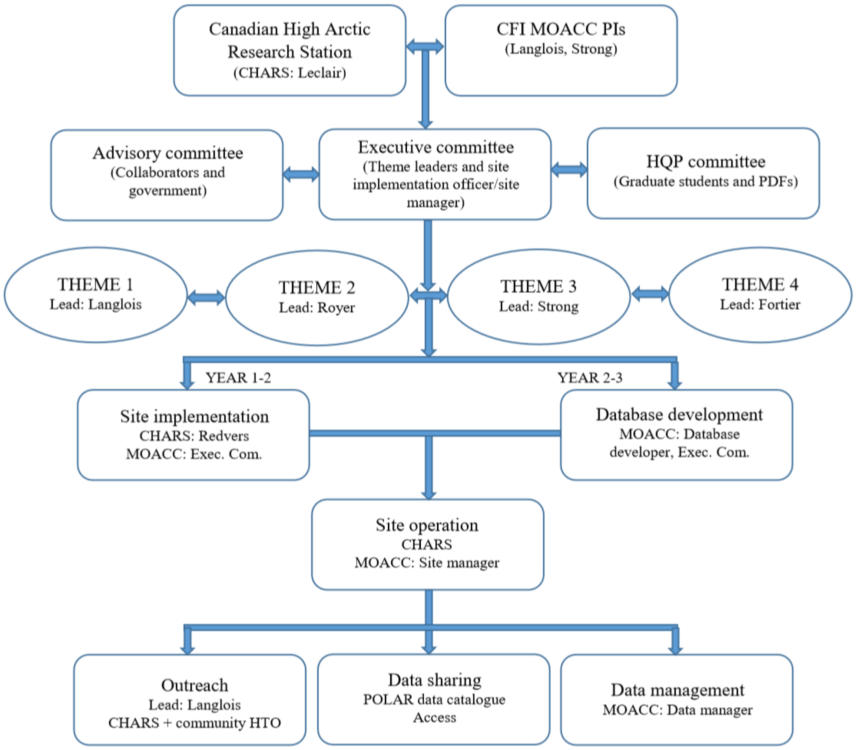

Figure-1: Governance model for MOACC CFI proposal.

6. Benefits to Canadians

The multi-level impacts of climate change on social, economic and environmental aspects are now gaining attention from policymakers, highlighting the need for reliable and permanent monitoring of key surface state variables. As such, the anticipated results from the MOACC research program are (1) new knowledge of the impact of climate change and extreme events on the ASGint of the Arctic, climate variability and change, (2) improved understanding of the ability of models and remote sensing retrievals to simulate key surface state and atmospheric variables affecting surface energy balance, ground thermal regime, melt dynamics and hydrological processes, and (3) new knowledge about the frequency of extreme events and the sensitivity of the local climate response to ASGint specification under such circumstances. These results will be relevant for the ongoing development of climate, atmospheric, permafrost and snow models and for increased understanding of sources of uncertainty in climate scenario construction. Furthermore, in many Arctic regions, an increase in tourist activity and accessibility to natural resources is underway, which stresses the need for a better understanding of trends within the ASGint in order to provide decision-makers with essential information relevant to infrastructure development in the North, existing infrastructure management and maintenance, environmental protection and public safety. For example, mining industries and the transportation sector will be interested in knowing when and how permafrost will thaw in order to adapt mitigative strategies in infrastructure development (e.g., elevating structures, isolating soil beneath, use helical piers, wind-induced air cooling techniques, etc.). Another example of a benefit would be better prediction of extreme precipitation to avoid snow-related building collapse. Increased knowledge on these events will allow communities and industries to improve existing infrastructure (e.g., to increase snow-load resistance). Understanding the impact of climate change on the ASGint conditions in Arctic regions is critical for indigenous peoples, traditional resource users, community leaders, scientists and other stakeholders in order to develop mitigative responses and adaptive strategies in a changing environment.

The proposed research program will aim at gaining a deeper understanding of the effect of climate change on the ASGint, climate in general and the associated feedbacks. The proposed infrastructure will address a resolution from the World Meteorological Organization that not only highlights the significant gaps in observation capacities but suggest supporting efforts enhancing our ‘understanding of the Earth system and environmental processes and interactions in polar regions’. Given the recent changes in northern regions, in particular the significant trends toward negative anomalies in snow and permafrost spatial extent as well as an increased occurrence in extreme events, it is imperative for Canada to claim its sovereignty in the Arctic through scientific research activities and international recognition of its expertise in this region. Those opportunities must be identified and Arctic research can help develop new policies and co-management initiatives in order to adapt to currently observed changes.

MOACC results will also support ongoing development of global climate models while representing a reference dataset for numerous satellite missions (current and future). Of particular relevance, the operational perspective rendered possible with the proposed site will allow the delivery of near-real-time information crucial to supporting algorithm development and satellite observations (especially for new missions, such as the RADARSAT Constellation Mission – RCM and the Sentinel atmospheric missions of the European Copernicus program). The site will also support space missions for snow and permafrost studies: RCM, Sentinel, Snow Mass Mission project, MetOp-SG Sat B for multi-frequency active/passive synergy (WMO Polar Space Task Group). The measurements of GHGs and other trace gases along with aerosols and clouds will contribute to the validation of missions such as GOSAT-2, TROPOMI on Sentinel 5P, and potential missions such as AIM-North.

Hence, the research program is of particular relevance from the scientific, economic and social perspectives: Scientific: This study will provide the scientific community with new knowledge about changing ASGint under extreme events in the cryosphere as well as information on the sensitivity of the local climate response to parameterizations of these processes in climate models. Our project also addresses two of the key recommendations of the World Climate Research Program (WCRP) Cryosphere and Climate Project: (1) Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate change; and (2) Improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system. Social: Arctic environments are an integral part of Inuit life and the projected increased occurrence of extreme events will have a strong impact on the harvesting of traditional foods for the Inuit. Economic: Industry partners have a strong interest in understanding how extreme events related to climate change may affect the ASGint. The knowledge and methods developed in the project will help develop strategic decision-making in resource exploitation, transportation, recreation and infrastructure. Better quality long-term planning information on extreme events will contribute to competitive advantages and environmentally sound decision-making while providing an improved empirical understanding on the state and fate of the cryosphere.

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Financial resources for operation and maintenance

These tables outline the annual costs and sources of support to ensure the effective operation and maintenance of the infrastructure for the first five years after it becomes operational. They do not include costs to coduct the research or technology development. Funding from CFI's Infrastructure Operating fund (IOF) is included in the "Institutional contributions" category. For infrastructure that has a useful life greater than five years, additional information about its operating and maintenance needs is included in the Assessment criteria section.

For a multi-institutional project that brings together three or more CFI-eligible institutions, the lead institution could request up to an additional five percent of the CFI award. This amount is listed in the "Other" category and specified as "additional CFI."

Operation and maintenance budget summary

Costs	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Personnel	0	0	80,000	155,000	155,000	390,000
Supplies	0	0	0	0	0	0
Maintenance and repairs	0	10,000	12,000	12,000	15,000	49,000
Services	0	0	0	0	0	0
Other (specify)	0	0	0	0	0	0
Total	**$0**	**$10,000**	**$92,000**	**$167,000**	**$170,000**	**$439,000**

Funding sources

Funding sources	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Institutional contributions	0	10,000	92,000	167,000	170,000	439,000
Other organizations	0	0	0	0	0	0
User fees	0	0	0	0	0	0
Other (specify)	0	0	0	0	0	0
Total	**$0**	**$10,000**	**$92,000**	**$167,000**	**$170,000**	**$439,000**

Enhancing past CFI investments, core and national facilities (to be completed by the institution)

The Innovation Fund provides investments in infrastructure to help Canada remain at the forefront of exploration and knowledge generation while making meaningful contributions to generating social, health, environmental and economic benefits and addressing global challenges.

The information captured in this section is for statistical purposes only. It will help us to better understand the extent to which proposals enhance capacity in fields previously invested in by CFI as well as the extent to which proposals request funds for infrastructure to be used in core facilities or national research facilities funded under the CFI's Major Science Initiatives (MSI) Fund.

Does this proposal enhance research capacity in a field of research in which the CFI has made past investments at your institution?

- [X] **Yes**
- [ ] No

A core facility provides access to state-of-the-art research services, analyses, instruments and technology, expertise, and training and education that are generally too expensive, complex or specialized for researchers to cost-effectively provide and sustain themselves. A core facility is broadly available to many researchers to conduct their research activities, irrespective of their administrative affiliation and with no requirement for collaboration or co-authorship.
A core facility:- Has dedicated equipment and space serving one or more institutions;- Is recognized and supported by the research institution where it's located;- Has a clearly defined governance and management structure and a sound management plan reflective of its mandate, breadth and complexity; and,- Has dedicated management involving individual(s) with the technical and subject matter expertise necessary to oversee all aspects of the facility.

The percentage of the total project cost of requested infrastructure that will be integrated into a core facility, as defined above.

0%

The percentage of the total project cost of requested infrastructure that will be integrated into a national research facility funded under the CFI's Major Science Initiatives Fund.

0%

Project funding

This table provides a summary of the total contributions and eligible costs for the project.

	Total
Total eligible costs	$4,262,997
Contributions from eligible partners	$2,661,383
Amount requested from the CFI	$1,601,614
Percentage of the total eligible cost requested from the CFI (may not exceed 40%)	37.57%

Summary of eligible costs

This table provides a summary of the total eligible costs for each type of expenditure. Individual items are listed in the 'Cost of individual items' section.

Code	Expenditure type	Total
13	Purchase of equipment (including shipping, taxes and installation)	3,293,248
14	Lease of equipment	0
15	Personnel (for infrastructure acquisition & development)	643,610
16	Components	0
17	Travel (infrastructure related)	76,139
18	Software	0
19	Extended warranties / Service contracts	0
20	Construction/renovation costs	0
21	Initial training of infrastructure personnel	0
22	Other	250,000
	Total eligible costs	**$4,262,997**

Cost of individual items

This table provides the details of eligible infrastructure acquisition and development costs. It shows the full cost of each item, including taxes (net of credits received), shipping and installation. For infrastructure that will be used for multiple purposes, the table includes only the pro-rated research or technology development costs.

The administrative institution was instructed to follow its existing policies and procedures for the preparation of budget estimates. The CFI expects that costs included in this budget are close estimates of fair market value.

				Eligible costs			
Item #	**Type**	**Item description**	**Number of items**	**Cash $**	**In-kind $**	**Total $**	**Date acquired (YYYY/MM) or to be acquired (YYYY)**
1	13	Passive microwave radiometer base (Theme 1)	5	342,431	72,857	415,288	2021
2	13	Hydrogen aircraft platform (Theme 1)	1	256,648	60,000	316,648	2021
3	13	Unmanned-aerial vehicle permanent base (Theme 1)	3	141,345		141,345	2021
4	15	Engineering services for Theme 1 installation (Theme 1)	1	93,610		93,610	2021
5	13	Frequency-Modulated Continuous Wave radar (Theme 2)	1	120,753	37,600	158,353	2021
6	13	Snow Water Equivalent monitoring station (Theme 2)	2	18,263	4,195	22,458	2021
7	13	Field spectroradiometer (Theme 2)	1	105,691	26,423	132,114	2021
8	13	Sun photometer (Theme 3)	3	93,520	3,640	97,160	2021
9	13	Unmanned-aerial vehicle aerosol platform (Theme 3)	3	157,709	33,682	191,391	2021
10	15	Engineering services for item 8 (Theme 3)	1	30,000		30,000	2021
11	13	TCCON FTIR System (Theme 3)	17	832,190	142,337	974,527	2021
12	13	Pandora UV-Visible Spectrometers (Theme 3)	2	170,810	17,520	188,330	2021
13	15	Engineering services for items 10-11 (Theme 3)	1	107,000		107,000	2021
14	13	Micropulse lidar (Theme 3)	1	282,342	47,208	329,550	2021
15	13	Automated data acquisition system (Theme 4)	2	72,106	2,675	74,781	2021
16	13	Permafrost coring system (Theme 4)	3	8,449		8,449	2021

Item #	Type	Item description	Number of items	Eligible costs: Cash $	Eligible costs: In-kind $	Eligible costs: Total $	Date acquired (YYYY/MM) or to be acquired (YYYY)
17	13	Thermal conductivity sensors (Theme 4)	2	29,108	6,805	35,913	2021
18	13	Electrical tomography system (Theme 4)	2	89,064	20,796	109,860	2021
19	15	Engineering services installation items 14-17 (Theme 4	1	53,000		53,000	2021
20	13	Research support and equipment (Installation)	1		65,000	65,000	2021
21	22	Site preparation (Installation)	1		75,000	75,000	2021
22	22	Accomodations at CHARS (Installation)	1		175,000	175,000	2021
23	15	Implementation management-monitoring (Installation)	1		120,000	120,000	2021
24	13	Shipping of instruments (Installation)	1	32,081		32,081	2021
25	17	Travel expenses for installation (Installation)	2	76,139		76,139	2021
26	15	Site implementation officer	1	140,000		140,000	2021
27	15	Database developer	1	100,000		100,000	2021
			Total eligible costs	**$3,352,259**	**$910,738**	**$4,262,997**	

Contributions from eligible partners

The following table provides details of funding from eligible partners. It does not include the amount requested from the CFI.

Partner name	Partner type	Cash $	In-kind $	Total $	Secured or expected
MEI-SIIR (Quebec Government)	Provincial governments (departments or agencies)	914,794		914,794	Secured
ORF-RI (Ontarion Government)	Provincial governments (departments or agencies)	686,820		686,820	Secured
POLAR Knowledge Canada	Federal government (departments or agencies)		435,000	435,000	Secured
The University of Western Ontario	Institutions, trust funds or foundations	18,702		18,702	Secured
Université de Montréal	Institutions, trust funds or foundations	36,719		36,719	Secured
Université de Sherbrooke	Institutions, trust funds or foundations	93,610		93,610	Secured
Vendors rebates (all themes)	Corporations/firms		475,738	475,738	Secured
Total contributions from eligible partners		**$1,750,645**	**$910,738**	**$2,661,383**	

All contributions are secured.

Infrastructure utilization

This table outlines the percentage utilization of the requested infrastructure by category.

Category	Percentage
Research/technology development and associated training	100 %
Education, excluding research / technology development training (not eligible for CFI support)	
Administration	
Clinical or other service function	
Other (specify)	
Total	**100 %**

This section provides a breakdown of eligible costs included in each of the above categories.

If the infrastructure will be used for non CFI-eligible purposes, the administrative institution was instructed to explain the methodology used to estimate the percentage of utilization for each category and how the budget was pro-rated.

Identification

Family Name	Strong
First name and initials	Kimberly
Institution	University of Toronto
Position	Professor and Department Chair
Department/Division	Department of Physics

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Doctorate	1992	Atmospheric Physics	University of Oxford, United Kingdom of Great Britain and Northern Ireland (the)
Bachelor's, Honours	1986	Physics	Memorial University of Newfoundland, Canada

Work experience

Position/Organization	Department/Division	Period	
		Start date	End date
Professor, University of Toronto	Physics	2006	
Chair, University of Toronto	Department of Physics	2019	2024
Director, University of Toronto	School of the Environment	2013	2018
Visiting Fellow, University of Wollongong, Australia	Centre for Atmospheric Chemistry	2010	2010
Associate Professor, University of Toronto	Physics	2001	2006
Assistant Professor, University of Toronto	Physics	1996	2001
Assistant Professor, York University	Earth and Atmospheric Science	1995	1996
Research Associate, York University	Centre for Atmospheric Chemistry	1994	1995
Post-Doctoral Research Associate, University of Cambridge	Chemistry	1992	1994

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Selected list (* indicates my students and PDFs):

Strong K et al., Validation of ACE-FTS N2O measurements. ACP 8:4759, 2008.

*Fraser A et al., The PEARL UV-visible ground-based spectrometer: first measurements of O3, NO2, BrO, and OClO columns. JQSRT 110(12):986, 2009.

*Batchelor RL et al., A new Bruker IFS 125HR FTIR spectrometer for the PEARL at Eureka, Canada - measurements and comparison with the existing Bomem DA8 spectrometer. JAOTech 26(7):1328, 2009.

*Lindenmaier R et al., A study of the Arctic NOy budget above Eureka, Canada. JGR 116:D23302, 2011.

*Mariani Z et al., Infrared measurements in the Arctic using two Atmospheric Emitted Radiance Interferometers. AMT 5:329, 2012.

*Adams C et al., Severe 2011 ozone depletion assessed with 11 years of ozone, NO2, and OClO measurements at 80°N. GRL 39:L05806, 2012.

*Lindenmaier R et al., Unusually low O3, HCl, and HNO3 column measurements at Eureka, Canada during spring 2011. ACP 12:3821, 2012.

*Adams C et al., The spring 2011 final stratospheric warming above Eureka: anomalous dynamics and chemistry. ACP 13:611, 2013.

*Mariani Z et al., Year-round retrievals of trace gases in the Arctic using the Extended-range Atmospheric Emitted Radiance Interferometer. AMT 6:1549, 2013.

*Viatte C et al., Measurements of CO, HCN, and C2H6 total columns in smoke plumes transported from the 2010 Russian boreal forest fires to the Canadian High Arctic. Atmos-Ocean 51(5):522, 2013.

*Whaley C et al., Using FTIR measurements of stratospheric composition to identify mid-latitude polar vortex intrusions over Toronto. JGR 118(D2):12766, 2013.

*Viatte C et al., Five years of CO, HCN, C2H6, C2H2, CH3OH, HCOOH, and H2CO total columns measured in the Canadian High Arctic. AMT 7:1547, 2014.

*Sheese P et al., OH Meinel band nightglow profiles from OSIRIS observations. JGR 119(D19):11417, 2014.

*Viatte C et al., Identifying fire plumes in the Arctic with tropospheric FTIR measurements and transport models. ACP 15:2227, 2015.

*Pendlebury D et al., Comparison of the CMAM30 data set with ACE-FTS and OSIRIS: polar regions, ACP 15:12465, 2015.

List of published contributions

*Zhao X et al., A case study of a transported bromine explosion event in the Canadian high Arctic, JGR 121(D1):457, 2016.

*Mendonca J et al., Improving atmospheric CO_2 retrievals using line mixing and speed dependence when fitting high-resolution ground-based solar spectra. J Mol Spec 323:15, 2016.

*Lutsch E et al., Long-range transport of NH_3, CO, HCN and C_2H_6 from the 2014 Canadian wildfires. GRL 43:8286, 2016.

*Mariani Z et al., Distributions of Downwelling Radiance at 10 and 20 µm in the High Arctic. Atmos-Ocean 54:529, 2016.

*Weaver D et al., Intercomparison of atmospheric water vapour measurements at a Canadian High Arctic site. AMT 10:2851, 2017.

*Olsen KS et al., Comparison of the GOSAT TANSO-FTS TIR CH_4 volume mixing ratio vertical profiles with those measured by ACE-FTS, ESA MIPAS, IMK-IAA MIPAS, and 16 NDACC stations, AMT 10:3697, 2017.

*Zhao X et al., Cyclone-induced surface ozone and HDO depletion in the Arctic. ACP 17:14955 2017.

Pommereau J-P et al., Recent Arctic ozone depletion: Is there an impact of climate change? Comptes Rendus Geoscience 350:347, 2018.

*Byrne B et al., Evaluating GPP and respiration estimates over northern mid-latitude ecosystems using solar induced fluorescence and atmospheric CO_2 measurements. JGR Biogeosciences 123:2976, 2018.

*Mendonca J et al., Using a speed-dependent Voigt line shape to retrieve O_2 from Total Carbon Column Observing Network solar spectra to improve measurements of XCO_2, AMT 12:35, 2019.

*Godin P et al., Conformational analysis and global warming potentials of 1,1,1,2,3,3-hexafluoropropane and 1,1,2,2,3-pentafluoropropane from absorption spectroscopy. JQSRT 225:337, 2019.

*Zhao X et al., Assessing the impact of clouds on ground-based UV-visible total column ozone measurements in the high Arctic, AMT 12:2463, 2019.

160 total + 13 submitted (June 2019)

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
Understanding the Air We Breathe: Atmospheric Composition in Urban and Arctic Environments K. Strong	NSERC Discovery Grant	$61,000	2019	2024
Understanding the Air We Breathe: Atmospheric Composition in the Arctic Environment K. Strong	NSERC Discovery Grant - Northern Research Supplement	$20,000	2019	2024
Extension of the Canadian Arctic ACE/OSIRIS Validation Campaign: Extended Phase-E Validation for 2018-2021 K.A. Walker / K. Strong (co-PIs)	Canadian Space Agency Grants and Contributions Program	$200,000	2018	2021
Validation and interpretation of vertical column density measurements of air pollutants from satellite instruments K. Strong	Environment and Climate Change Canada Grants and Contributions Program	$25,000	2018	2021
CH4 and CO Retrievals in Support of the AIM-North Phase 0 study K. Strong / D. Wunch (Co-PIs)	Canadian Space Agency RFP in support of AIM-North Phase 0 (contract)	$53,000	2018	2019
Operations and Maintenance Support for the Polar Environment Atmospheric Research Laboratory (PEARL) K. Strong	NSERC Research Tools and Instruments - Operations and Maintenance	$150,000	2017	2019
AVATARS : Arctic Validation And Training for Atmospheric Research in Space K. Strong	Canadian Space Agency Flights and Fieldwork for the Advancement of Science and Technology (FAST 2015)	$166,667	2016	2019
Research related to the Polar Environment Atmospheric Research Laboratory (PEARL): Probing the Atmosphere of the High Arctic J.R. Drummond	NSERC Climate Change and Atmospheric Research	$1,000,000	2013	2019
Connaught Summer Institute in Arctic Science: Atmosphere, Cryosphere, and Climate K. Strong	University of Toronto Connaught Fund Connaught Summer Institute	$50,000	2014	2017
NSERC CREATE Training Program in Arctic Atmospheric Science K. Strong	NSERC Collaborative Research and Training Experience	$300,000	2010	2016

Identification

Family Name	Langlois
First name and initials	Alexandre
Institution	Université de Sherbrooke
Position	Associate professor
Department/Division	Géomatique appliquée

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Postdoctorate	2010	Geophysics and remote sensing	Universite de Sherbrooke, Canada
Doctorate	2008	Geophysics	University of Manitoba, Canada
Master's	2003	Physical geography and remote sensing	Universite de Sherbrooke, Canada
Bachelor's	2001	Physical geography	Universite de Sherbrooke, Canada

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Professor, Universite de Sherbrooke	Geomatique Appliquee	2012	
Contract lecturer, Bishop's University	Environment and Geography	2016	2016
Contract researcher, Environment and Climate Change Canada	Wildlife Services	2015	2015
Research Associate, Universite de Sherbrooke	Geomatique Appliquee	2011	2012
Community Based MonitoringScientific Coordinator, Centre for Earth ObservationScience (CEOS), University ofManitoba	Environment andGeography	2006	2007
ArcticNet Theme 3 ScientificCoordinator, Centre for Earth ObservationScience (CEOS), University ofManitoba	Environment andGeography	2006	2007

Position/Organization	Department/Division	Period Start date	 End date
Research Assistant, Centre d'Applications et deRecherches en Teledetection(CARTEL), Universite deSherbrooke	Geographie etTeledetection	2002	2003
Research Contract, HydroQuebec, Centre d'Applications et deRecherches en Teledetection(CARTEL), Universite deSherbrooke	Geographie etTeledetection	2000	2000
Geographer, Gouvernement du Quebec	Ministere des transports du Quebec	2000	2000

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Selected 2016-2019:

Langlois, A., Royer, A., Montpetit, B., Roy, A. and Durocher, M. 2019. Snow grain size and shape distributions in northern Canada. Frontiers, Submitted.

Kramer, D., Meloche, J., Langlois, A., McLennan, D., Gauthier-Barrette, C., Royer, A. and Cliche, P. 2019. Designing a DIY-UAV for arctic research purposes and proving its capabilities by retrieving snow depth via structure-from-motion, POLAR Knowledge: Aqhaliat 2019, Submitted, March 2019.

Domine, F., Picard, G., Morin, S., Barrere, M., Madore, J.-B. and Langlois, A. 2018. Major Issues in Simulating some Arctic Snowpack Properties Using Current Detailed Snow Physics Models. Consequences for the Thermal Regime and Water Budget of Permafrost. J. of Adv. in Modeling Earth Sys., Accepted, 2018MS001445.

Prince, M., Roy, A., Royer, A. and Langlois, A. 2018. Timing and Spatial Variability of Fall Soil Freezing in Boreal Forest and its Effect on SMAP L-band Radiometer Measurements. Rem. Sens. of Environ., Accepted, RSE-S-18-02184.

Marchand, N., Royer, A., Krinner, G., Roy, A. and Langlois, A. 2018. Snow-covered ground-temperature retrieval in Canadian arctic permafrost areas using a land surface scheme informed with satellite remote sensing data. Remote Sens., doi: 10.3390/rs1011103.

Dolant, C., Montpetit, B., Langlois, A., Brucker, L., Zolina, O., Johnson, C.A., Royer, A. and Smith, P. 2018. Assessment of the Barren Ground caribou die-off during winter 2015-2016 using passive microwave observations. Geophys. Res. Let., doi.org/10.1029/2017GL076752.

Montpetit, B., Royer, A., Roy, A. and Langois, A. 2018. In-situ passive microwave emission model parameterization of sub-arctic frozen organic soils. Rem. Sens. of Environ, 205, 112-118.

Madore, J.-B., Langlois, A. and Côté, K. 2018. Evaluation of the SNOWPACK model's metamorphism and microstructure in a Canadian context: A case study. Physical Geography, doi.org/10.1080/02723646.2018.1472984.

Dolant, C., Langlois, A., Brucker, L., Royer, A., Roy, A. and Montpetit, B. 2017. Meteorological inventory of Rain-On-Snow events and detection assessment in the Canadian Arctic Archipelago using microwave radiometry. Phys. Geo., DOI:10.1080/02723646.2017.1400339.

Langlois, A., Johnson, C.-A., Montpetit, B., Royer, A., Blukacz-Richards, E.A., Neave, E., Dolant, C., Roy, A., Arhonditsis, G., Kim, D.-K.F, Kaluskar, S., and Brucker, L. 2017. Detection of rain-on-snow (ROS) events and ice layer formation using passive microwave radiometry: A context for the Peary caribou habitat in the Canadian arctic, Rem. Sens. of Environ , 189, 84-95.

List of published contributions

Ouellet, F., Langlois, A., Johnson, C.-A., Richards, A. and Royer, A. 2017. Spatialization of the SNOWPACK Snow Model in the Canadian Arctic for Peary Caribou Winter Grazing conditions Assessment. Phys. Geo., DOI:10.1080/02723646.2016.1274200.

Royer A., A. Roy, B. Montpetit, O. Saint-Jean-Rondeau, G. Picard, L. Brucker, and Langlois, A. 2017. Comparison of commonly-used microwave radiative transfer models for snow remote sensing. Rem. Sens. of Environ, 190, 247-259.

Derksen, C., Xu, X., Scott Dunbar, R., Colliander, A., Kim, Y., Kimball, J., Black, A., Euskirchen, E., Langlois, A., Loranty, M., Marsh, P., Rautiainen, K., Roy, A. and Royer, A.. 2017. Retrieving landscape freeze/thaw state from Soil Moisture Active Passive (SMAP) radar and radiometer measurements, Rem. Sens. of Environ, 194, 48-62.

Larue, F., Royer, A., De Sève, D., Langlois, A., Roy, A. and Brucker, L. 2017. Validation of GlobSnow-2 snow water equivalent over Eastern Canada, Rem. Sens. of Environ, 194, 264-277.

Busseau, B.-C., Royer, A., Langlois, A., Barrère, M. And Domine, F. 2017. Analysis of the Interactions between Snow and Vegetation over low Arctic - Subarctic transition (North Eastern Canada). Phys. Geo., 38, 159-175.

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
Modelling future changes in snow characteristics in the Canadian Arctic to identify priority areas for Peary, Dolphin and Union caribou and Barren ground caribou Alexandre Langlois	Environment and Climate Change Canada Grant and Contribution	$40,000	2018	2021
Développement d'indicateurs spatialisés de qualité d'habitats hivernaux nordiquesà l'aide d'observations satellites et de modélisation du couvert nival : contextepour le caribou barren-ground et Peary Alexandre Langlois	Fonds de Recherche du Québec - Nature et Technologies Projet en équipe	$69,579	2017	2020
Development of a multi-scale cryosphere monitoring network for the Kitikmeot region and Northwest territories using in-situ measurement Alexandre Langlois	POLAR Knowledge Canada POLAR Knowledge Canada	$146,350	2017	2020
Monitoring of winter extreme events in the Arctic Alexandre Langlois	Canadian foundation for innovation Leaders Fund	$74,486	2014	2019
Arctic and subarctic winter extrement events in a changing climate Alexandre Langlois	NSERC Discovery	$28,000	2013	2019
Arctic field measurements of snow physical and radiometric properties for model improvement Alexandre Langlois	NSERC Northern Supplement	$15,000	2013	2019
UNDER REVIEW				
Developing a multi-scale cryosphere monitoring network of winter extreme events in a changing climate Alexandre Langlois	NSERC Discovery	$56,000	2020	2025
Developing a multi-scale cryosphere monitoring network of winter extreme events in a changing climate Alexandre Langlois	NSERC Northern Supplement	$25,000	2020	2025
Multidisciplinary Observatoryfor Arctic Climate Change and Extreme Events Monitoring in the Kitikmeot region Alexandre Langlois	POLAR Knowledge Canada POLAR Knowledge Canada	$149,800	2020	2023
Long-term monitoring of winter extreme events in the arctic and their cumulated effect on snow conditions Alexandre Langlois	NSERC Research Tools and Instruments	$100,406	2020	2021

Identification

Family Name	Sica
First name and initials	Robert J
Institution	The University of Western Ontario
Position	Professor of Physics
Department/Division	Department of Physics and Astronomy

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Doctorate	1985	Geophysics	Geophysical Institute, U. of Alaska-Fairbanks, United States of America (the)
Bachelor's	1978	Physics	Columbia University, New York, United States of America (the)

Work experience

		Period	
Position/Organization	Department/Division	Start date	End date
Professor and Chair, The University of Western Ontario	Physics & Astronomy	2015	
Professor, The University of Western Ontario	Physics & Astronomy	2002	2015
Associate Professor, The University of Western Ontario	Physics & Astronomy	1993	2002
Assistant Professor, The University of Western Ontario	Physics & Astronomy	1988	1993
Assistant Research Professor, Utah State University	Center for Atmosph. & Space Sci.	1986	1988
Postdoctoral Fellow, Utah State University	Center for Atmosph. & Space Sci.	1985	1986

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Trainee indicated by *

1. *McCullough, E. M. et al. Three-channel single-wavelength lidar depolarization calibration. Atmospheric Measurement Techniques 11, 861-879 (2018).
2. *Jalali, A., Sica, R. J. & Haefele, A. A middle latitude Rayleigh-scatter lidar temperature climatology determined using an optimal estimation method. Atmospheric Measurement Techniques Discussions 2018, 1-24 (2018).
3. *McCullough, E. M. et al. Depolarization calibration and measurements using the CANDAC Rayleigh-Mie-Raman lidar at Eureka, Canada. Atmospheric Measurement Techniques 10, 4253-4277 (2017).
4. Sica, R. J. & Haefele, A. Retrieval of water vapor mixing ratio from a multiple channel Raman-scatter lidar using an optimal estimation method. Appl. Opt. 55, 763-777 (2016).
5. Leblanc, T., Sica, R. J. et al. Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms -- Part 3: Temperature uncertainty budget. Atmosph. Measurement Tech. 9, 4079-4101 (2016).
6. Leblanc, T., Sica, R. J. et al. Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms -- Part 2: Ozone DIAL uncertainty budget. Atmosph. Measurement Tech., 9, 4051-4078 (2016).
7. Leblanc, T., Sica, R. J. et al. Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms -- Part 1: Vertical resolution. Atmosph. Measurement Tech., 9, 4029-4049 (2016).
8. Sica, R. J. & Haefele, A. Retrieval of temperature from a multiple-channel Rayleigh-scatter lidar using an optimal estimation method. Applied Optics 54, 1872-1889 (2015).
9. *Argall, P. S. & Sica, R., LIDAR: Atmospheric Sounding Introduction in Encyclopedia of Atmospheric Sciences (eds Pyle, J. & Zang, F.) 262-269, Academic Press (2015).
10. *Fan, Z. Y., Sica, R. J., Walker, K. A., Boone, C. D. & Bernath, P. F. (ed Bernath, P. F.) 215-230 (A. Deepak Publishing, Hampton, Virgina, USA, 2013).
11. *Moss, A., Sica, R. J., *McCullough, E., Strawbridge, K. & Drummond, J. Calibration and validation of water vapour lidar measurements from Eureka, Nunavut, using radiosondes and the Atmospheric Chemistry Experiment Fourier Transform Spectrometer. Atmospheric Measurement Techniques 6, 741-749 (2013).
12. *Iserhienrhien, B., Sica, R. J. & *Argall, P. S. A 7-Year Lidar Temperature Climatology of the Mid-Latitude Upper Troposphere and Stratosphere. Atmosphere-Ocean 1-9 (2013).
13. *Khanna, J., *Bandoro, J., Sica, R. J. & McElroy, C. T. New technique for retrieval of atmospheric temperature profiles from Rayleigh-scatter lidar measurements using nonlinear inversion. Appl. Opt. 51, 7945-7952 (2012).
14. Fromm, M. et al. The Untold Story of Pyrocumulonimbus. Bulletin Of The American Meteorological Soc. 91, 1193-1209 (2010).
15. Sica, R. J., *Izawa, M. et al. Validation of the Atmospheric Chemistry Experiment (ACE) version 2.2 temperature using ground-based and space-borne measurements. Atmos. Chem & Phys., 8, 35-62 (2008).
16. Sica, R. J., *Argall, P. S., Shepherd, T. G. & Koshyk, J. N. Model#measurement comparison of mesospheric temperature inversions, and a simple theory for their occurrence. Geophysical Research Letters 34, (2007).
17. Hocking, W. K., *Argall, P. S., Lowe, R. P., Sica, R. J. & Ellinor, H. Height-dependent meteor temperatures and comparisons with lidar and OH measurements. Can J. of Phys. 85, 173-187 (2007).

List of published contributions

18. *Russell, A. T., St Maurice, J.-P., Sica, R. J. & Noël, J.-M. Composition changes during disturbed conditions: Are mass spectrometers overestimating the concentrations of atomic oxygen? Geophysical Research Letters 34, 1-4 (2007).
19. *Argall, P. S. & Sica, R. J., Lidar (Laser Radar) in The Optics Encyclopedia, Brown, T.H.G et al eds, 1305-1322, Wiley, (2004).
20. Sica, R. J., et al. Modulation of mesospheric temperature inversions due to tidal-gravity wave interactions. J. of Atmosph. & Solar-Terr. Phys. 64, 915-922 (2002).

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period	
			Start date	End date
AWARDED				
Ceilometer and Lidar Measurements of Atmospheric Trends, Coupling BetweenAtmospheric Layers, and Atmospheric Particulates Sica	NSERC Discovery Grant	$27,000	2018	2023
Measurements of Clouds, Aerosols, Forest Fire Smoke, and Volcanic Ash from a Network of Ceilometers Robert Sica	Canada Foundation for Innovation John Edwards Leadership Fund	$500,000	2019	2020
Research Related to the Polar Environment Research Laboratory (PEARL): Probing the atmosphere of the high arctic J. Drummond	NSERC/Environment and Climate Change Canada Climate Change and Atmospheric Research	$546,500	2018	2020
Chair's research supplement Robert Sica	The University of Western Ontario	$20,000	2015	2020
Research related to the Polar Environment Atmospheric Research Laboratory (PEARL): Probing the Atmosphere of the High Arctic K. Strong	NSERC/ECCC Special opportunity; $1,093,000 cash + $372,000 in-kind over 18 months	$879,000	2018	2019
Operations and Maintenance Support for the Polar Environment Atmospheric Research Laboratory (PEARL) K. Strong	NSERC Research Tools and Infrastructure	$150,000	2017	2019
AVATARS: Arctic Validation And Training for Atmospheric Research in Space Strong	CSA Flights and Fieldwork for the Advancement of Science and Technology	$167,000	2016	2019
Probing the Atmosphere of the High Arctic (PAHA) Drummond	NSERC Climate Change and Atmospheric Research	$1,000,000	2013	2018
Dean’s RISC Award Sica	The University of Western Ontario Research Infrastructure	$50,000	2016	2017
CREATE Program Training Program in Arctic Atmospheric Science Strong	NSERC Collaborative Research and Training Experience	$300,000	2010	2016

Identification

Family Name	Royer
First name and initials	Alain
Institution	Université de Sherbrooke
Position	
Department/Division	

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Doctorate Equivalent (PhD)	1981	Géophysique	Laboratoire de glaciologie et géophysique de l'environnement, Université de Grenoble, France

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Chercheur membre, Centre d'Études Nordiques	Regroupement stratégique FRQNT (U. Laval, UQAR, UQTR, U. Sherbrooke, UdeM, McGill, INRS)	2013	2021
Professeur invité , Université Grenoble-Alpes	Institut des Géosciences de l'Environnement	2017	2018
Responsable des programmes de 2e et 3e cycle du Département de géomatique appliquée, Université de Sherbrooke	Dépt. Géomatique appliquée	2012	2017
Président de l'Association Québécoise de Télédétection,		2011	2013

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

(126) Prince M., A. Roy, A. Royer and A. Langlois (2018). Timing and Spatial Variability of Fall Soil Freezing in Boreal Forest and its Effect on SMAP L-band Radiometer Measurements. Remote Sens. Enviro. 18-01532, accepted

(125) Prince M., A. Roy, L. Brucker, A. Royer, Y. Kim and T. Zhao (2018). Intercomparison of Aquarius L-band and Ka-band Surface Freeze/Thaw Products. Earth Syst. Sci. Data, 10, 2055-2067.

(124) Larue F., A. Royer, D. DeSève, A. Roy and E. Cosme (2018). Assimilation of passive microwave AMSR-2 satellite observations in a snowpack evolution model over North-Eastern Canada. Hydrol. Earth Syst. Sci., 22, 5711-5734.

(123) Marchand, N., Royer, A. and 4 co-authors (2018). Snow-Covered Soil Temperature Retrieval in Canadian Arctic Permafrost Areas, Using a Land Surface Scheme Informed with Satellite Remote Sensing Data. Remote Sens., 10(11), 1703.

(122) Roy A., M. Leduc-Leballeur, G. Picard, A. Royer and 6 co-athors (2018). Modelling the L-band snow-covered surface emission in a winter Canadian prairie environment. Remote Sens., 10(9), 1451.

(121) Mavrovic A., A. Roy, A. Royer, B. Filali, F. Boone, C. Pappas and O. Sonnentag (2018). Vegetation dielectric characterization in L-band using an open-ended coaxial probe. Geosci. Instrum. Method. Data Syst., 7, 195-208.

(120) Larue F., A. Royer, D. De Sève, A. Roy, G. Picard, V. Vionnet (2018). Simulation and assimilation of passive microwave data using a snowpack model coupled to a calibrated RTM over North-Eastern Canada, Water Res. Res., 54, 4823-4848.

(119) Dolant C., B. Montpetit, A. Langlois, L. Brucker, O. Zolina, C.A. Johnson, A. Royer and P. Smith (2018). Assessment of the Barren Ground Caribou die-off during winter 2015-2016 using passive microwave observations. Geophysical Research Letter, 45.

(117) Montpetit B., A. Royer, A. Roy and A. Langlois (2018). In-situ passive microwave parameterization of sub-arctic frozen organic soils. Remote Sensing of Environment, 205, 112-118.

(108) Royer A., A. Roy, B. Montpetit, O. Saint-Jean-Rondeau, G. Picard, L. Brucker and A. Langlois (2017). Comparison of commonly-used microwave radiative transfer models for snow remote sensing. Remote Sensing of Environment, 190, 247-259.

(104) Dolant C., A. Langlois, B. Montpetit, L. Brucker, A. Roy and A. Royer (2016). Development of a rain-on-snow detection algorithm using passive microwave radiometry. Hydrol. Process., Published online in Wiley Online Library, DOI: 10.1002/hyp.10828

(102) Roy A., A. Royer and 6 co-authors (2016). Microwave snow emission modeling uncertainties in boreal and subarctic environments, The Cryosphere, 10, 623-638.

(101) Roy A., A. Royer and 5 co-authors (2015). Evaluation of Spaceborne L-band Radiometer Measurements for Terrestrial Freeze/Thaw Retrievals in Canada, IEEE J. of Applied Earth Obs. and Rem. Sens., 8(9), 4442-4459.

(98) André C., C. Ottlé, A. Royer, F. Maignan (2015). Land Surface Temperature Retrieval over circumpolar Arctic using SSM/I-SSMIS and MODIS Data, Rem. Sens. of Enviro., 162, 1-10.

(91) Bergeron J., A. Royer, R. Turcotte (2014), Snow cover estimation using blended MODIS and AMSR-E data for improved watershed-scale spring streamflow simulation in Quebec, Canada. Hydro. Processes, 28, 4626-4639.

(87) Picard and 6 co-authors (2013). Simulation of the microwave emission of multi-layered snowpacks using the Dense Media Radiative transfer theory: the DMRT-ML model, Geosci. Model Dev., 6, 1061-1078.

List of published contributions

(83) Roy, A., Royer, A., Wigneron, J.-P., A. Langlois, J. Bergeron and P. Cliche (2012). A simple parameterization for a boreal forest radiative transfer model at microwave frequencies. Rem. Sens. of Enviro., 124, 371-383.

(69) Royer A. and S. Poirier (2010). Surface temperature spatial and temporal variations in Northern America from homogenized satellite SSMR-SSM/I microwave measurements and reanalysis for 1979-2008. J. Geophysical Res., 115(D08110).

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
Modelling future changes in snow characteristics / caribou habitat A. Langlois	Environnement Canada	$60,000	2018	2021
Géophysique spatiale de l'environnement nordique et variabilité climatique A. Royer	CRSNG Sub. Découverte et Supplément Nord	$53,000	2015	2021
Centre d'études Nordiques G. Gauthier	FRQNT Programme Regroupements stratégiques	$408,000	2015	2021
Géophysique spatiale de l'environnement nordique et variabilité climatique Alain Royer	CRSNG Subvention à la découverte	$43,000	2015	2020
Amélioration des Prévisions de l'Impact de l'évolution du Climat Nordique sur la cryosphère terrestre (APIC-Nord) A. Langlois / A. Royer	Ministère des Relations Internationales du Québec Programme de partenariats stratégiques franco-québécois(CFQCU)	$12,500	2017	2019
Development of a multi-scale cryosphere monitoring network for the Kitikmeot region A. Langlois	Polar Knowledge Canada	$91,000	2017	2019
Centre d'Applications et de recherches en télédétection K. Goita	Université Sherbrooke Soutien Infrastructure Centre d'excellence	$32,000	2017	2019
Développement d'un radar pour la mesure de l'épaisseur de glace et de la neige A. Royer	CRSNG Subventions de recherche et développement coopérative	$63,000	2016	2017
Amélioration de la prévision du couvert de neige et des crues printanières au Québec par assimilation des observations satellites A. Royer	FRQNT Sub. Équipe	$71,000	2014	2017
Spatial snow modeling to assess changing grazing conditions for Peary caribou A. Langlois	Environnement Canada Contrat	$20,000	2014	2016

Identification

Family Name	Gravel
First name and initials	Dominique
Institution	Université de Sherbrooke
Position	
Department/Division	Biologie

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Postdoctorate	2008	Biology	McGill University, Canada
Doctorate	2007	Biologie	Université du Québec à Montréal, Canada
Bachelor's	2003	Aménagement et environnement forestier	Université Laval, Canada

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Canada Research Chair Tier I Integrative Ecology, Université de Sherbrooke	Biologie	2016	2023
Full professor, Université de Sherbrooke	Biolgoie	2016	2019
Assistant professor, Université de Sherbrooke	Biologie	2015	2016
Canada Research Chair Tier IIBiogeography & Metacommunity Ecology, Université du Québec à Rimouski	Biologie, chimie et géographie	2014	2015
Assistant professor, Université du Québec à Rimouski	Biologie, chimie et géographie	2011	2015
Canada Research Chair Tier IIContinental Ecosystem Ecology, Université du Québec à Rimouski	Biologie, chimie et géographie	2009	2014
Associate professor, Université du Québec à Rimouski	Biologie, chimie et géographie	2009	2011

Position/Organization	Department/Division	Period	
		Start date	End date
Visiting researcher, Universtié de Montpellier II	Institut des Sciences de l'Évolution de Montpellier	2008	2009
Postdoctoral researcher, McGill University	Biology	2007	2009

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Total number of publications 2006-present: 130
Total number of publications 2014-2019: 94
Manuscripts currently in evaluation: 17
Number of citations (Google Scholar) since 2014: 4571
h-index (Google Scholar) since 2014: 40

Selected-publications relevant for the proposal:

Massol, F. et al. 2011. Linking ecosystem and community dynamics through spatial ecology. Ecology Letters, 13: 313-323.

Gravel, D. et al. 2011. Trophic theory of island biogeography. Ecology Letters 14 : 1010-1016.

Gravel, D. et al. 2011. Experimental niche evolution alters the strength of the diversity-productivity relationship. Nature 469:89-93.

Thuiller, W. et al. A road map for integrating eco-evolutionary processes into biodiversity models. Ecology Letters. 16 : 94-105.

Legagneux, P. et al. 2014. Climate and body-size shape the structure and functioning of arctic ecosystems. Nature Climate Change DOI: 10.1038/NCLIMATE2168

Svenning, J.C et al. 2014. The influence of interspecific interactions on species range expansion rates. Ecography. DOI: 10.1111/j.1600-0587.2013.00574.x

Albouy, C. et al. 2014. From projected species distribution to food web structure under climate change. Global Change Biology 20: 730-741.

Poisot, T., Stouffer, D.B., Gravel, D. 2014. Beyond species : why ecological interactions vary through space and time. OIKOS. DOI: 10.1111/oik.01719

Poisot, T. et al. 2015. mangal - making complex ecological networks analysis simpler. Ecography. doi: http://dx.doi.org/10.1101/002634

Talluto, M. et al. 2015. Cross-scale integration of knowledge for predicting species ranges: a metamodeling framework. Global Ecology and Biogeography. DOI: 10.1111/geb.12395

Morales-Castilla et al. 2015. Inferring biotic interactions from proxies. Trends in Ecology and Evolution

Poisot, T. et al. 2016. Synthetic datasets and community tools for the rapid testing of ecological hypotheses. Ecography. DOI: 10.1111/ecog.01941

List of published contributions

Gravel, D. et al. 2016. The meaning of functional diversity for food weeb structure and dynamics. Philosophical Transactions of the Royal Society B. doi: 10.1098/rstb.2015.0268.

Jacquet, C. et al. 2016. No complexity-stability relationship in natural ecosystems. Nature Communications. doi:10.1038/ncomms12573

Gravel, D. et a. 2016. Stability and complexity of model metaecosystems. 2016. Nature Communications. doi:10.1038/ncomms1245

Cazelles, K. et al. 2016. On the integration of biotic interaction and environmental constraints at the biogeographical scale. Ecography. DOI: 10.1111/ecog.01714

Beauchesne, D. et al. 2017. Thinking outside the box - predicing biotic interactions in data-poor environments. Milieu et Vie, 66: 333-342.

Talluto, M. et al. 2017. Extinction debt and colonization credit delay range shifts of eastern North American trees. Nature Ecology and Evolution 1 : 0182.

Godsoe, W. et al. 2017. Integrating biogeography and community ecology with contemporary niche theory. Trends in Ecology and Evolution 32: 488-499.

Gravel, D, et al. 2018. Bringing Elton and Grinnell together: a quantitative framework to represent the biogeography of ecological interaction networks. Ecography.

Compson, Z.G., et al. In press. Linking DNA Metabarcoding and text mining to create network-based biomonitoring tools : a case study on boreal wetland macroinvertebrate communities. Advances in Ecological Research.

Poisot, T., et al. In press. Open ecological data should not be so hard to find. Trends in Ecologyand Evolution.

Albouy, C. et al. In press. The marine food web is globally connected. Nature Ecology and Evolution.

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	Support Period End date
AWARDED				
BIOS2 training program in computational biodiversity science Dominique Gravel	NSERC CREATE	$30,000	2018	2024
Canada Research Chair in Integrative Ecology Dominique Gravel	Canadian Research Chair CRC Tier I	$200,000	2016	2023
Theoretical and experimental integration of biogeography and ecosystem ecology Dominique Gravel	NSERC Discovery	$58,000	2017	2022
Démystifier l'écosystème immunitaire afin de protéger la santé et l'environnement Alan Cohen	FRQNT Audace	$10,000	2019	2019
Discovery Accelerator Dominique Gravel	NSERC Discovery	$40,000	2016	2019
Infrastructure for the CRC Dominique Gravel	CFI Leaders fund	$185,000	2015	2015
Quantifying and mapping the impact of climate change on forest productivity in Eastern Canada Dominique Gravel	NSERC Strategic	$215,000	2012	2015

Identification

Family Name	Ayotte
First name and initials	Patrick
Institution	Université de Sherbrooke
Position	
Department/Division	

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Doctorate	1999	Chimie physique	Yale University, United States of America (the)
Master's	1995	Radiobiologie/Physique des radiations	Université de Sherbrooke, Canada
Bachelor's	1993	Physique	Université Laval, Canada

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Professeur titulaire, Université de Sherbrooke	Chimie	2012	
Directeur du département, Université de Sherbrooke	Chimie	2016	2019
Professeur invité, Seoul National University	Chemistry	2018	2018
Professeur invité, Hokkaido University	Institute for Low Temperature Science	2017	2017
Professeur invité, Université de Paris VI (P & M Curie)	Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique et Atmosphères	2013	2013
Professeur invité, Université de Lille I (Sci. & Tech.)	PhLAM/CERLA	2012	2012
Professeur invité, Université de Paris VI (P & M Curie)	Laboratoire de Chimie Physique - Matière et rayonnement	2012	2012
Professeur agrégé, Université de Sherbrooke	Chimie	2007	2012
Professeur adjoint, Université de Sherbrooke	Chimie	2002	2007
Postdoctoral fellow , Pacific Northwest National Laboratory	Environmental Molecular Science Laboratory	1999	2001

Position/Organization	Department/Division	Period	
		Start date	End date

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Publications:

J. Maurais, E. Beaumont, J. Bourret, E. Dauphinais, N.-A. Bouchard and P. Ayotte, Thermal Imaging: A Novel Approach To Study Evaporation Kinetics From Mine Tailings, Soumis à Water Ressource Research (Mai 2019).

J. Vermette, I. Braud, P.-A. Turgeon, P. Ayotte, and G. Alexandrowicz, Quantum state-resolved Characterization of a Magnetically-Focused Beam of Ortho-H2O, Soumis à J. Phys. Chem. Lett. (avril 2019).

C. Krüger, et al.z, A magnetically focused molecular beam source for deposition of spin-polarised molecular surface layers, J. Chem. Phys. 149, 164201 (2018).

P.-A. Turgeon, J. Vermette, G. Alexandrowicz, Y. Peperstraete, M. Bertin, L. Philippe, J.-H. Fillion, X. Michaut and P. Ayotte, Confinement effects on the nuclear spin isomer conversion of H2O, J. Phys. Chem. A 121, 1571-1576 (2017).

E. Lisitsin-Baranovsky, et al., In Situ NMR Measurements of Vapor Deposited Ice, J. Phys. Chem. C 120, 25445-25450 (2016).

G. Marcotte, P. Marchand, S. Pronovost, P. Ayotte, C. Laffon and P. Parent, Surface-enhanced nitrates photolysis, J. Phys. Chem. A 119, 1996-2005 (2015).

G. Marcotte, P. Ayotte, A. Bendounan, F. Sirotti, C. Laffon and P. Parent, Dissociative adsorption of nitric acid at the surface of amorphous solid water revealed by X-ray absorption spectroscopy, J. Phys. Chem. Lett. 4, 2643-2648 (2013).

P.-A. Turgeon, P. Ayotte, E. Lisitsin, Y. Meir, T. Kravchuk, and G. Alexandrowicz, Preparation, isolation, storage, and spectroscopic characterization of water vapor enriched in the ortho-H2O nuclear spin isomer, Phys. Rev. A 86, 062710 (2012).

P. Marchand, G. Marcotte, and P. Ayotte, Spectroscopic Study of HNO3 Dissociation on Ice, J. Phys. Chem. A 116, 12112-12122 (2012).

Patrick Ayotte, et al., HCl adsorption and ionization on amorphous and crystalline H2O films below 50K. J. Phys. Chem. A 115, 6002-6014 (2011).

Guillaume Marcotte and Patrick Ayotte, Strong intermolecular coupling between the HF stretching and H2O bending vibrations in HF:H2O binary amorphous solids: Breakdown of the electrostatic description of the hydrogen bond. J. Chem. Phys. 134, 114522 (2011).

Patrick Ayotte, Zohreh Rafiei, François Porzio, and Patrick Marchand, Dissociative adsorption of hydrogen fluoride on amorphous solid water. J. Chem. Phys., 131, 124517 (2009).

List of published contributions

F. Cholette, T. Zubkov, R.S. Smith, Z. Dohnalek, B.D. Kay and P.Ayotte, Infrared spectroscopy and optical constants of porous amorphous solid water. J. Phys. Chem. A 113, 4131-4140 (2009).

P. Ayotte, S. Plessis and P. Marchand, Trapping proton transfer intermediates in the disordered hydrogen-bonded network of cryogenic hydrofluoric acid solutions. Phys. Chem. Chem. Phys. 10, 4785-4792 (2008).

R. Iftimie, V. Thomas, S. Plessis, P. Marchand, and P.Ayotte, Spectral signatures and molecular origin of acid dissociation intermediates. J. Am. Chem. Soc. 130, 5901-5907 (2008).

P. Marchand, S. Riou, and P. Ayotte, Diffusion of methanol in polycrystalline ice. J. Phys. Chem. A 110, 11654-11664 (2006).

P. Ayotte, M. Hébert, and P. Marchand, Why is hydrofluoric acid a weak acid? J. Chem. Phys. 123 184501 (2005).

Proceedings:

J. Maurais, et al. Prevention and mitigation of fugitive dust emission from bauxite residues: aggravating environmental effects, forecasting and risk assessment. Proceedings of the 11th Alumina Quality Workshop, Gladstone, AUSTRALIA, 9-14 Sept. 2018.

Technical reports:

E. Morin, A. Royer et P. Ayotte, Travaux préparatoires pour la modélisation temporelle et spatiale de l'emportement de poussière (Janvier 2018 - Client : Rio Tinto Alcan).

C. Larivière-Loiselle, A. Royer et P. Ayotte, Étude des impacts des émissions de poussières de résidus miniers sur l'albédo du couvert nival (Janvier 2018 - Client : Rio Tinto Alcan).

J. Maurais, A. Royer et P. Ayotte, Incidence des paramètres physico-chimiques sur la génération de poussières des résidus de bauxite (Janvier 2018 - Client : Rio Tinto Alcan).

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period	
			Start date	End date
AWARDED				
Spécificité interfaciale de la chimie atmosphérique et interstellaire sur la glace Patrick Ayotte	NSERC Discovery grant	$28,000	2017	2022
Centre québécois sur les matériaux fonctionnels Armand Soldera	FRQ-NT Regroupements stratégiques	$600,000	2017	2022
Matériaux avancés sous champs électriques extrêmes : effet Stark et états pendules Patrick Ayotte	Ministère des relations internationales et de la francophonie Coopération Québec-Corée du sud	$5,677	2019	2019
Émissions de poussières de résidus miniers-études de l’effet des méthodes et niveaux d’assèchement sur leurs propriétés physico-chimiques et impacts sur l’albédo du couvert nivalFRQ-NT/MERNchimiques et impacts sur l’al Patrick Ayotte	FRQ-NT/MERN/Rio Tinto Alcan Recherche en partenariat sur le Développement durable du secteur minier - 3e concours	$110,000	2016	2019
Centre d’Étude des Matériaux Avancés de l’Université de Sherbrooke - CÉMAUS Armand Soldera	Université de Sherbrooke Programme interne de financement des infrastructures de recherche	$30,000	2016	2019
Effets photo-thermiques d’une fibre textile Patrick Ayotte	NSERC Engage	$25,000	2018	2018
Molecular processes in ice under strong fields Patrick Ayotte	Seoul National University Prestigious foreign scholar program	$6,000	2018	2018
Méthodes d’enrichissement des isomères de spins et applications en RMN Patrick Ayotte	Ministère des relations internationales et de la francophonie Coopération Québec-Israël	$7,000	2017	2018
Heterogeneous atmospheric and interstellar chemistry on ice Patrick Ayotte	Japan Society for the Advancement of Science Invited professor fellowship	$10,000	2017	2017
Modernisation, rénovation et mise aux normes des infrastructures de la faculté des sciences (Pavillons D1 et D2) Patrick Ayotte	Université de Sherbrooke Plan de développement des infrastructures	$7,000,000	2016	2016

Identification

Family Name	O'Neill
First name and initials	Norm T.
Institution	Université de Sherbrooke
Position	Full Professor
Department/Division	Département de géomatique appliquée

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Diploma	1986	Environmental Sciences	CRSNG en milieu industriel: industrie Moniteq Ltd., Canada
Doctorate	1982	Physics	York University, Canada
Master's	1977	Physics	York University, Canada
Bachelor's	1975	Physics	Bishop's University, Canada

Work experience

Position/Organization	Department/Division	Period: Start date	Period: End date
Full Professor, Université de Sherbrooke	géomatique appliquée	1998	
Adjunct Professor, York University	Earth & Space Science	2002	2012
Visiting scientist, University of Maryland (UMBC)	GEST	2003	2004
Visiting scientist, GSFC/NASA	Lab. for terrestrial physics	2002	2002
NRC Senior Associateship, GSFC/NASA	Lab for terrestrial physics	1998	2000
Associate Professor, Université de Sherbrooke	Géographie et télédétection	1992	1998
Assistant Professor, Université de Sherbrooke	Géographie et télédétection	1988	1992
Attaché de recherche CARTEL, Université de Sherbrooke	Géographie et télédétection	1986	1988

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

1.Mateos, D., V. Cachorro, C. Velasco, N. T O'Neill, M. A Burgos, R. Gonzalez, C. Toledano, M. Herreras, A. Calle, Á. M de Frutos, Comparison of three different methodologies for the identification of high atmospheric turbidity episodes, in revision, Atmospheric Research, 2019

2.AboEl Fetouh, Y., N. T. O'Neill, Hayes, K. Ranjbar, I. Abboud, V. Fioletov, Climatological-scale analysis of intensive and semi-intensive aerosol parameters derived from AERONET Arctic retrievals, submitted to JGR, Sept., 2019.

3. Pu, B., P. Ginoux, H. Guo, C. Hsu, J. Kimball, B. Marticorena, S. Malyshev, V. Naik, N. T. O'Neill, et al., Retrieving the global distribution of threshold of wind erosion from satellite data and implementing it into the GFDL model, in revision, ACP, 2019

4.Ranjbar, K., N. T. O'Neill, et al., Extreme smoke event over the high Arctic, accepted for publication in Atmospheric Environment, 2019.

5.Abbatt, J. P. D., et al., New insights into aerosol and climate in the Arctic, ACP, in press, 2019.

6. McKendry, I. G., A. Christen, S.-C. Lee, M. Ferrara, K. B. Strawbridge, N. O'Neill, et al., Impacts of an Intense Wildfire Smoke Episode on Surface Radiation, Energy and Carbon Fluxes in SW BC, Canada, ACP, 19(2), 835-846, 2018

7.Atkinson, D. B., M. Pekour, D. Chand, J. G. Radney, K. R. Kolesar, Q. Zhang, A. Setyan, N. T. O'Neill, and C. D. Cappa, Using spectral methods to obtain particle size information from optical data: applications to measurements from CARES 2010, ACP 18(8), 5499-5514, 2018.

8.Eck, T. F., Holben, B. N., Reid, J. S., Xian, P.,Giles, D. M., Sinyuk, A., A. Smirnov , J. S. Schafer, I. Slutsker, J. Kim , J.-H. Koo, M. Choi, K. C. Kim, I. Sano, A. Arola, A. M. Sayer, R. C. Levy, L. A. Munchak, N. T. O'Neill, et al. (2018). Observations of the interaction and transport of fine mode aerosols with cloud and/or fog in NE Asia from AERONET and satellite RS, JGR, 123(10), 5560-5587.

9.Pérez-Ramírez, D., Andrade-Flores, M., Eck, T. F., Stein, A. F., O'Neill, N. T., et al., Multi year aerosol characterization in the tropical Andes and in adjacent Amazonia using AERONET, AE, 166, 412-432,2017

10.Blanchard, Y., A. Royer, N. T. O'Neill, et al., Thin ice clouds in the Arctic: Cloud optical depth and particle size retrieved from ground-based thermal IR radiometry, ACP, 10, no. 6, 2129-2147, 2017.

11.Hesaraki, S., N. T. O'Neill, et al., Polar summer comparisons of a chemical transport model with a 4-year analysis of fine and coarse mode aerosol optical depth retrievals over the Canadian Arctic, AO, DOI: 10.1080/07055900.2017.1356263, 2017.

12.O'Neill, N. T., et al., "Temporal and spectral cloud screening of polar AOD: impact of homogeneous and inhomogeneous clouds and crystal layers on climatological-scale AODs." ACP, 16, no. 19, 12753-12765, 2016.

13.Baibakov, K., O'Neill, N. T., et al., Synchronous polar winter starphotometry and lidar measurements at a High Arctic station, AMT, 8, 3789-3809, 2015.

14.Proulx-Bourque, J.-S., Magagi, R., O'Neill, N. T., Filtering Global Land and Surface Altimetry Data for Elevation Accuracy Determination, PE&RS, 81, 9, 701-707, 2015.

15.Tomasi, C., A. A. Kokhanovsky, A. Lupi, C. Ritter, A. Smirnov, N. T. O'Neill, et al., Aerosol remote sensing in polar regions, ESR, 140, 108-157, 2015

16.Kaku, K. C., J. S. Reid, N. T. O'Neill,et al., Verification and Application of the Extended SDA+ Methodology to Estimate Aerosol Fine and Coarse Mode Extinction Coefficients in the Marine Boundary Layer, AMT, 7, 3399-3412, 2014

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
Mineral Dust Dynamics and Climate Change at High Latitude Mountainous Regions James King	Networks of Centres of Excellence (NCE) Canadian Mountain Network (CMN)	$140,000	2019	2022
Remote sensing and analysis of 2nd order, Arctic-aerosol parameters Norm O'Neill	NSERC Discovery Grant	$22,000	2017	2022
Analysis of remotely sensed, aerosol-cloud interaction over the Arctic Norm O'Neill	Canadian Space Agency Earth System Science Data Analyses	$77,000	2017	2020
AVATARS - Arctic Validation And Training for Atmospheric Research in Space Kim Strong	Canadian Space Agency Flights and Fieldwork for the Advancement of Science andTechnology	$167,000	2016	2019
Operation and Maintenance Support for Research Equipment Kim Strong	NSERC Research Tools and Instruments	$150,000	2016	2018
Research related to the Polar Atmospheric Research Laboratory (PEARL): Probing theAtmosphere of the High Arctic Jim Drummond	NSERC Climate Change and Atmospheric Research	$1,000,000	2013	2018
NETCARE - Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments Jon Abbat	NSERC Climate Change and Atmospheric Research	$1,000,000	2013	2018
NSERC CREATE Training Program in Arctic Atmospheric Science Kim Strong	NSERC CREATE	$300,000	2011	2017
Remote sensing and analysis of Arctic aerosols: analysis of intensive parameters Norm O'Neill	NSERC Discovery Grant	$32,200	2010	2017
Validation of GOSAT Measurements Using Ground-Based and Satellite Data Kim Strong	Canadian Space Agency Flights and Fieldwork for the Advancement of Science andTechnology	$100,000	2010	2014

Identification

Family Name	Fortier
First name and initials	Daniel
Institution	Université de Montréal
Position	
Department/Division	

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Postdoctorate	2007	Permafrost geomorphological engineering	University of Alaska, United States of America (the)
Doctorate	2005	Geomorphology, paleoclimatology	Laval University, Canada
Master's	2000	Geomorphology	Laval University, Canada
Bachelor's	1997	Geomorphology	Laval University, Canada

Work experience

		Period	
Position/Organization	Department/Division	Start date	End date
Associate Professor, Université de Montréal	Géographie	2014	
Assistant Professor, Université de Montréal	Géographie	2008	2014
Affiliated Research Assistant Professor, University of Alaska	Institute of Northern Engineering	2008	2013
Research Assistant Professor, University of Alaska	Institute of Northern Engineering, Civil and Environmental Engineering Department	2007	2008
Postdoctoral Fellow, University of Alaska	Institute of Northern Engineering	2005	2007
Adjunct Faculty, Université de Moncton	Histoire-géographie	2005	2005
Research Professional, Laval University	Centre d'études nordiques, CEN	2004	2005
Research Assistant, Laval University	Centre d'études nordiques, CEN	1999	2003
Adjunct Faculty, Laval University	Géographie	1998	2003
Teacher Assistant, Laval University	Géographie	1998	2003

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

1.Geocryology: buried glacier ice in permafrost and paleogeography/paleoglaciology
Lacelle D, Fisher D, Coulombe S*, Fortier D, Frappier R. (2018). Buried remnants of the Laurentide Ice Sheet and connections to its surface elevation. Scientific Reports, 8, 13286

Coulombe S*, Fortier D, Lacelle D, Kanevskiy M, Shur Y. (2019). Origin, burial and preservation of late Pleistocene-age glacier ice in Arctic permafrost (Bylot Island, NU, Canada). The Cryosphere, 13, 97-111.

2.Cryosphere: multi-year lake ice dynamics in response to climate change
Paquette M*, Fortier D, Mueller DR, Sarrazin D, Vincent WF. (2015). Rapid disappearance of perennial ice on Canada's most northern lake. Geophysical Research Letters. 42, 1433-1440.

3.High Arctic subsurface hydrology: water tracks
Paquette M*, Fortier D, Vincent WF. (2018). Hillslope water tracks in the High Arctic: Seasonal flow dynamics with changing water sources in preferential flow paths. Hydrological Processes.

Paquette M*, Fortier D, Vincent WF. (2017). Water tracks in the High Arctic: A hydrological network dominated by rapid subsurface flow through patterned ground. Arctic Science. 3, 2, 334-353.

4.Permafrost degradation by convective heat transfer: thermal erosion.
Godin E*, Fortier D, Coulombe S*. (2014). Effects of thermo-erosion gullying on hydrologic flow networks, discharge and soil loss. Environmental Research Letters. 9, 10, 105010

Kanevskiy MZ, Shur Y, Strauss J, Jorgenson T, Fortier D, Stephani* E, Vasiliev A. (2016). Patterns and rates of riverbank erosion in the area of ice-rich permafrost (yedoma) in northern Alaska. Geomorphology. 253, 370-384.

5.Permafrost degradation and feedbacks to biogeosystems
Godin*, E., Fortier, D., Lévesque, E. (2016). Nonlinear thermal and moisture dynamics of high Arctic wetland polygons following permafrost disturbance.Biogeosciences. 13, 1439-1452.

Perreault E*, Lévesque E, Fortier D, Lamarque JL*. (2016). Thermo-erosion gullies boost the transition from wet to mesic vegetation. Biogeosciences. 13, 237-253

6.Permafrost degradation: thermokarst lakes and Green House Gases emissions
Bouchard F*, Laurion I, Préskienis V*, Fortier D, Xu X, Whiticar MJ. (2015). Modern to millennium-old greenhouse gases emitted from freshwater ecosystems of the Eastern Canadian Arctic. Biogeosciences. 12, 7279-7298

7.Dynamics and degradation of marginal sporadic mountain permafrost
Gray JT, Davesne G*, Fortier D, Godin E*. (2017). The thermal regime of mountain permafrost at the summit of Mont Jacques Cartier in the Gaspé Peninsula, Québec, Canada: a 37-year record of fluctuations showing an overall warming trend. Permafrost and Periglacial Processes. 28, 266-274.

List of published contributions

Davesne G*, Fortier D, Dominé F, Gray JT. (2017). Wind driven snow conditions control the occurrence of contemporary marginal mountain permafrost in the Chic-Chocs Mountains, south-eastern Canada- a case study from Mont Jacques-Cartier. The Cryosphere. 11, 1351-1370

8.Permafrost degradation and stability of infrastructure built on permafrost
Chen L*, Fortier D, McKenzie J, Sliger M*. (2019). Quantitative assessment of the impact of heat advection on the thermal regime of roads built on permafrost. Hydrological Processes (under review).

9.Permafrost yedoma circumpolar carbon stock
Strauss J, Schirrmeister L, Grosse G, Fortier D, et al. (2017). Deep Yedoma permafrost: A synthesis of depositional characteristics and carbon vulnerability. Earth-Science Reviews. 172, 75-86

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
NSERC Permafrost Partnership Network for Canada Dr Stephan Gruber (Carleton U)	Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Partnership Grants for Networks (2019-2024)	$2,500,000	2019	2024
Increasing carbon accumulation in Arctic peatlands Dr Angela Gallego-Sala (University of Exeter, UK)	Natural Environment Research Council (NERC) (UK) Standard Grant - NI	$350,000	2019	2022
Design and Implementation of early detection and warning systems for transportation infrastructure impacted by permafrost-related geohazards Dr Fabrice Calmels (YRC)	Transport Canada Northern Transportation Adaptation Initiative Program (NTAI)	$184,068	2019	2021
Breaking down the permafrost carbon feedback enigma: characterizing the composition and lability of dissolved organic carbon (DOC) according to size fractions Dr Melissa Lafreniere (Queen's University)	Natural Sciences and Engineering Research Council of Canada (NSERC) Research Tools and Instruments Grants Program (RTI)	$93,772	2018	2019
Best practices in groundwater monitoring for Northern Canada Dr Daniel Fortier	Government of the Northwest Territories N/A	$75,000	2017	2017
ARQULUK program: Preservation of Canada's northern transportation infrastructure Dr Guy Doré	Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD)	$264,000	2012	2017
Mapping techniques and characterization of ice wedges Dr Daniel Fortier	Transport Canada N/A	$127,000	2014	2016
Geocryosphere Dr Daniel Fortier	Canadian Foundation for Innovation (CFI) John R. Evans Leaders Fund	$300,000	2011	2016
Impact de l'advection de chaleur par ruissellement de surface et écoulement souterrain sur la dégradation du pergélisol Dr Daniel Fortier	Fonds québécois de la recherche sur la nature et les technologies (FQRNT) Établissement de nouveaux chercheurs universitaires	$22,000	2013	2015
ADAPT - Arctic Development and Adaptation to Permafrost in Transition Dr Warwick Vincent	Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Frontiers	$1,000,000	2011	2015

Identification

Family Name	Lussier Desbiens
First name and initials	Alexis
Institution	Université de Sherbrooke
Position	
Department/Division	

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Postdoctorate	2013	Mechanical Engineering	Harvard University, United States of America (the)
Doctorate	2012	Mechanical Engineering	Stanford University, United States of America (the)
Bachelor's	2005	Mechanical Engineering	Université de Sherbrooke, Canada

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Assistant Professor, Université de Sherbrooke	Mechanical Engineering	2013	
Postdoctoral researcher, Harvard University	Harvard Microrobotics Laboratory, School of Engineering and Applied Sciences	2012	2013
Research Assistant, Stanford University	Stanford Biomimetics and Dextrous Manipulation Laboratory, School of Engineering	2007	2012
Teaching Assistant, Stanford University	Mechanical Engineering	2010	2010
Control Engineer, Multimatic Technical Center		2006	2006
Test Engineer, German Aerospace Center	Robotic Group	2005	2005
Space Systems Engineer, Canadian Space Agency	Space Systems Group	2004	2004
Robotic Engineer, Canadian Space Agency	Robotic Group	2003	2003

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

From the last 5 years:

Patents :
[1] David Rancourt, Jean-Sebastien Plante, and Alexis Lussier Desbiens. "Method and embodiments for tethered payload motion control using magneto-rheologial actuators". 2017.
[2] Alexis Lussier Desbiens, C. Brousseau, and J. Truong. "Method and Apparatus for Measuring Rigidity Distribution". 62/268,533. 2015.

Journal articles (peer reviewed):
[1] D. Mehanovic, David Rancourt, and A. Lussier Desbiens. "Fast and Efficient Aerial Climbing of Vertical Surfaces Using Fixed-Wing UAVs". In: IEEE Robotics and Automation Letters (2019).
[2] C. Veroneau, Jean-Philippe Lucking Bigue, A. Lussier Desbiens, and Jean-Sebastien Plante. "A High-Bandwidth Back-Drivable Hydrostatic Power Distribution System for Exoskeletons Based on Magneto-Rheological Clutches". In: IEEE Robotics and Automation Letters (2018).
[3] R.-A. Peloquin, D. Thibault, and A. Lussier Desbiens. "Design of a Passive Vertical Takeoff and Landing Aquatic UAV". In: IEEE Robotics and Automation Letters (2017).
[4] J. Truong, C. Brousseau, and A. Lussier Desbiens. "A Method for Measuring the Bending and Torsional Stiffness Distributions of Alpine Skis". In: Procedia Engineering (2016).
[5] Yufeng Chen, Nick Gravish, A. Lussier Desbiens, R. Malka, and Robert J. Wood. "Experimental and computational studies of the aerodynamic performance of a flapping and passively rotating insect wing". In: Journal of Fluid Mechanics 791 (2016), pp. 1-33.
[6] Alexis Lussier Desbiens, M. Pope, David L Christensen, Elliot W Hawkes, and Mark R Cutkosky. "Design principles for efficient, repeated jumpgliding". In: Bioinspiration & biomimetics 9.2 (2014), p. 025009.

Conference proceedings (all peer reviewed):
[1] C. Brousseau and A. Lussier Desbiens. "Alpine Skiing Recommendation Tool and Performance Prediction". In: Multidisciplinary Digital Publishing Institute Proceedings. 2018.
[2] J. Truong and A. Lussier Desbiens. "Evaluating the directional stability of alpine skis through the simulation of ski deformation during a steady-state turn". In: Multidisciplinary Digital Publishing Institute Proceedings. 2018.
[3] Nicolas Be#langer, A. Lussier Desbiens, T. Courteau, and G. Charron. "The Deleaves drone - A tool for fast and easy sampling of foliage from large trees". In: North American Forest Soil Confer- ence. 2018.
[4] R.-A. Peloquin, D. Thibault, and A. Lussier Desbiens. "Design of a Passive Vertical Takeoff and Landing Aquatic UAV". In: IEEE International Conference on Robotics and Automation (ICRA). (Singapore). 2017.
[5] D. Mehanovic, J. Bass, T. Courteau, David Rancourt, and A. Lussier Desbiens. "Autonomous Thrust-Assisted Perching of a Fixed-Wing UAV on Vertical Surfaces". In: Conference on Biomimetic and Biohybrid Systems. 2017. Best robotics paper.
[6] J.-S. Lauzon, Francois Grondin, A. Lussier Desbiens, and Michaud Francois. "Localization of RW- UAVs Using Particle Filtering Over Distributed Microphone Arrays". In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). 2017.
[7] J. Truong, C. Brousseau, and A. Lussier Desbiens. "A Method for Measuring the Bending and Torsional Stiffness Distributions of Alpine Skis". In: 11th conference of the International Sports Engineering Association. 2016.

List of published contributions

[8] Yufeng Chen, Alexis Lussier Desbiens, and Robert J Wood. "A computational tool to improve flap- ping efficiency of robotic insects". In: IEEE International Conference on Robotics and Automation (ICRA). 2014.
[9] Alexis Lussier Desbiens, R. Malka, Yufeng Chen, and Robert J Wood. "Principles of Microscale Flexure Hinge Design for Enhanced Endurance". In: IEEE/RSJ International Conference on Intelli- gent Robots and Systems (IROS). 2014.

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period Start date	 End date
AWARDED				
Uninhabited aircraft systems Training, Innovation and Leadership Initiative Jeremy Laliberté	NSERC CREATE (Collaborative Research and Training Experience Program)	$300,000	2019	2024
NSERC Canadian Robotics Network Gregory Dudek	NSERC Strategic Network	$600,000	2018	2022
Drone for underground mine mapping Alexis Lussier Desbiens	NSERC Collaborative Research and Development	$200,000	2019	2021
Design of a drone for interior mapping of industrial chimneys Alexis Lussier Desbiens	NSERC Engage	$25,000	2019	2019
Drones for gardens and conservation UBC Botanical Garden Alexis Lussier Desbiens	UBC Botanical Garden Contract	$40,000	2018	2019
Active Haptic Trim Actuators for Rotorcraft Applications Karine Bérubé	CARIC Maturing Technology Program	$800,000	2016	2019
Jump-flying: a Bioinspired Hybrid Locomotion Strategy for Small Mobile Robots Alexis Lussier Desbiens	NSERC Discovery	$23,000	2014	2019
Research infrastructure for the rapid development, fabrication and validation of small multimodal UAVs Alexis Lussier Desbiens	CFI John Edward Leader Fund	$240,000	2018	2018
Improvement of small UAVs aerial performances Meyer Nahon	FRQNT Team project	$63,000	2015	2018
Infrastructure avancée de conception en nano/micro-électronique et mécatronique, et de capture de mouvement haute-fidélité Francois Michaud	Développement Économique Canada	$6,300,000	2015	2015

Identification

Family Name	Hayes
First name and initials	Patrick PLH
Institution	Université de Montréal
Position	Associate Professor
Department/Division	Chemistry

Academic background

Degree type	Year received or expected	Discipline/Field/Speciality	Institution and country
Postdoctorate	2013	Analytical and Atmospheric Chemistry	University of Colorado, Boulder, United States of America (the)
Doctorate	2010	Physical and Environmental Chemistry	Northwestern University, United States of America (the)
Bachelor's, Honours	2004	Chemistry	Oberlin College, United States of America (the)

Work experience

		Period	
Position/Organization	**Department/Division**	**Start date**	**End date**
Associate Professor , Université de Montréal	Department of Chemistry	2018	
Visiting Professor, Harvard University	School of Engineering and Applied Sciences	2019	2019
Assistant Professor, Université de Montréal	Department of Chemistry	2013	2018
Postdoctoral Fellow, University of Colorado & Cooperative Institute for Research in Environmental Sciences	Department of Chemistry and Biochemistry	2010	2013

List of published contributions

This section provides a list of the most significant published contributions (e.g. submitted and/or published articles, patents, technical reports).

Selected list (* indicates my students):

*Bachelder, J., Cadieux, M., *Liu-Kang, C., *Lambert, P., *Filoche, A., Galhardi, J., Hadioui, M., Chaput, A., Bastien-Thibault, M.P., Wilkinson, K.J., King, J., Hayes, P.L. "Chemical and microphysical properties of wind-blown dust near an actively retreating glacier in Yukon, Canada" Aerosol Sci. Tech. 2020, 54, 2.

*Tremblay, S., *Picard, J.-C., *Bachelder, J.O., Lutsch, E., Strong, K., Fogal, P., Leaitch, W.R., Sharma, S., Kolonjari, F., Chang, R.Y.-W., Hayes, P.L. "Characterization of aerosol growth events over Ellesmere Island during the summers of 2015 and 2016" Atmos. Chem. Phys. 2019, 19, 5589.

Croft, B., Martin, R.V. Leaitch, W.R., Burkart, J., Chang, R.Y.-W., Collins, D.B., Hayes, P.L., Hodshire, A.L., Huang, L., Kodros, J.K., Moravek, A., Mungall, E.L., Murphy, J.G., Sharma, S., *Tremblay, S., Wentworth, G.R., Willis, M.D., Abbatt, J.P.D., Pierce, J.R. "Arctic marine secondary organic aerosol contributes significantly to summertime particle size distributions in the Canadian Arctic Archipelago" Atmos. Chem. Phys. 2019, 19, 2787.

Schroder, J.C., Campuzano-Jost, P., Day, D.A., Shah, V., Larson, K., *Sommers, J.M., Sullivan, A.P., Campos, T., Reeves, J.M., Hills, A., Hornbrook, R.S., Blake, N.J., Scheuer, E., Guo, H., Fibiger, D.L., McDuffie, E.E., Hayes, P.L., Weber, R.J., Dibb, J.E., Apel, E.C., Jaeglé, L., Brown, S.S., Thornton, J.A., Jimenez, J.L. "Sources and Secondary Production of Organic Aerosols in the Northeastern US during WINTER" J. Geophys. Res.-Atmos. 2018, 123, 7771.

McDonald, B.C., de Gouw, J.A., Gilman, J.B., Jathar, S.H., Akherati, A., Cappa, C.D., Jimenez, J.L., Lee-Taylor, J., Hayes, P.L., McKeen, S.A., Cui, Y.Y., Kim, S.-W., Gentner, D.R., Isaacman-VanWertz, G., Goldstein, A.H., Harley, R.A., Frost, G.J., Roberts, J.M., Ryerson, T.B., Trainer, M. "Volatile chemical products emerging as largest petrochemical source of urban organic emissions" Science 2018, 359, 760.

Noyhouzer, T., Perry, S.C., *Vicente-Luis, A., Hayes, P.L., Mauzeroll, J. "The best of both worlds: Combining Ultramicroelectrode and Flow Cell Technologies" J. Electrochem. Soc. 2018, 165, H10.

Bzeih, W., *Gheribi, A., Wood-Adams, P.M., Hayes, P.L. "Dependence of the surface structure of polystyrene on chain molecular weight investigated by sum frequency generation spectroscopy" J. Phys. Chem. C 2018, 122, 3838.

*Ma, P.K., Zhao, Y., Robinson, A.L., Worton, D.R., Goldstein, A.H., Ortega, A.M., Jimenez, J.L., Zotter, P., Prévôt, A.S.H., Szidat, S., Hayes, P.L. "Evaluating the impact of new observational constraints on P-S/IVOC emissions, multi-generation oxidation, and chamber wall losses on SOA modeling for Los Angeles, CA" Atmos. Chem. Phys. 2017, 17, 9237.

Hayes, P.L. "Quantification of the sources and composition of particulate matter by field-deployable mass spectrometry: Implications for air quality and public health" Analyst 2017, 142, 687.

List of published contributions

*Torres, L.L., *Chauveau, M., Hayes, P.L. "The macromolecular structure of dodecyltrimethylammonium chloride at the silica/water interface studied by Sum Frequency Generation" J. Phys. Chem. C 2015, 119, 23917.

Hayes, P.L., Carlton, A.G., Baker, K.R., Ahmadov, R., Washenfelder, R.A., Alvarez, S., Rappenglück, B., Gilman, J.B., Kuster, W.C., de Gouw, J.A., Zotter, P., Prévôt, A.S.H., Szidat, S., Kleindienst, T.E., Offenberg, J.H., *Ma, P.K., Jimenez, J.L. "Modeling the formation and aging of secondary organic aerosols in Los Angeles during CalNex 2010" Atmos. Chem. Phys. 2015, 15, 5773.

Hayes et al. "Organic Aerosol Composition and Sources in Pasadena, California during the 2010 CalNex Campaign." J. Geophys. Res.-Atmos. 2013, 118, 9233.

52 total published articles

Research or technology development funding

This table lists support held over the past five years as an applicant or co-applicant for grants and contracts from all sources, including industry and academic/research institutions. Maximum of ten entries.

Title of proposal Name of Principal Applicant / Prinicpal investigator	Funding source Program name	Average amount per year	Support Period	
			Start date	End date
AWARDED				
Mineral Dust Dynamics and Climate Change at High Latitude Mountainous Regions James King (PI), Patrick Hayes (co-I)	Networks of Centres of Excellence Canadian Mountain Network	$130,000	2019	2022
Ultra-trace laboratory for legacy and emerging contaminants Marc Amyot (PI), Patrick Hayes (co-I)	Natural Sciences and Engineering Research Council of Canada (NSERC) Research Tools and Instruments (RTI)	$114,488	2019	2020
Analysis of remotely sensed, aerosol-cloud interaction over the Arctic Norm O'Neill (PI), Patrick Hayes (co-I)	Canadian Space Agency Earth System Science Grants	$76,850	2017	2020
Characterizing the sources and atmospheric chemistry of light-absorbing carbonaceous aerosols using resonance Raman spectroscopy Patrick Hayes	NSERC Discovery Grants Program - Individual	$32,000	2014	2020
Research related to the Polar Environment Atmospheric Research Laboratory (PEARL): Probing the Atmosphere of the High Arctic J.R. Drummond (PI), Patrick Hayes (co-I)	NSERC Climate Change and Atmospheric Research	$924,000	2013	2020
Operations and Maintenance Support for the Polar Environment Atmospheric Research Laboratory (PEARL) Kimberly Strong (PI), Patrick Hayes (co-I)	NSERC RTI Operations and Maintenance Support to Research Facilities	$150,000	2017	2019
AVATARS: Arctic Validation And Training for Atmospheric Research in Space Kimberly Strong (PI), Patrick Hayes (co-I)	Canadian Space Agency Flights and Fieldwork for the Advancement of Science and Technology (FAST 2015)	$166,667	2016	2019
The modeling of secondary organic aerosols arising from the Athabasca Oil Sands Patrick Hayes	Fonds de recherche - Nature et technologies Team Research Project	$48,768	2015	2018
Quantification and mapping of metals in solid phases using laser ablation/laser induced breakdown spectroscopy Kevin Wilkinson (PI), Patrick Hayes (co-I)	NSERC Research Tools and Instruments	$150,000	2016	2017
New spectroscopic tools for quantifying molecular and macromolecular organic structures in environmental systems Patrick Hayes	Canada Foundation for Innovation / Gouvernement du Québec Leaders Opportunity Fund	$680,518	2014	2015

Suggested reviewers

The decision whether to contact the reviewers suggested remains with the CFI.

Name	Uttal, Taneil
Institution/Organization	NOAA
Country	United States of America (the)
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Telephone	1-303-4976409
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	clouds, radiation, aerosols, permafrost

Name	Lazzara, Matthew
Institution/Organization	University of Wisconsin-Madison
Country	United States of America (the)
Email	mattl@ssec.wisc.edu
Telephone	1-608-2620436
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	weather, arctic, automated stations, remote sensing

Name	Notholt, Justus
Institution/Organization	University of Bremmen
Country	Germany
Email	jnotholt@iup.physik.uni-bremen.de
Telephone	49-421-218-62190
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	Trace gases, polar regions, atmospheric composition

Name	Jones, Anna
Institution/Organization	British Antarctic Survey
Country	United Kingdom of Great Britain and Northern Ireland (the)
Email	aejo@bas.ac.uk
Telephone	
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	polar atmosphere, chemical composition, snow, sea ice, ocean

Name	Vincent, Warwick
Institution/Organization	Université Laval
Country	Canada
Email	warwick.vincent@bio.ulaval.ca
Telephone	1-418-6565644
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	Permafrost, arctic, foodwebs

Name	Lemmetyinen, Juha
Institution/Organization	Finnish Meteorological Institute
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Email	juha.lemmetyinen@fmi.fi
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Fax	
Online CV or biography	
Area(s) of expertise (keywords)	snow, microwave, remote sensing, arctic

Name	Macelloni, Giovanni
Institution/Organization	Istituto di fisica applicata
Country	Italy
Email	g.macelloni@ifac.cnr.it
Telephone	
Fax	
Online CV or biography	
Area(s) of expertise (keywords)	cryosphere, remote sensing, snow