1. Understanding the oceanography of the western NW passage: influence of ice and freshwater on water circulation, stratification, and ecosystems

Primary Investigators

Drs. C.J. Mundy[*,1,2] (CJ.Mundy@umanitoba.ca)
J.K. Ehn[1,2] (Jens.Ehn@umanitoba.ca),
J. Peyton[2] (Jonathan.Peyton@umanitoba.ca)
W.J. Williams[3] (Bill.Williams@dfo-mpo.gc.ca)

[*] Lead Investigator, 582 Wallace Building, Office: 204-272-1571, Fax: 204-272-1532

[1] Centre for Earth Observation Science (CEOS), Clayton H. Riddell Faculty of Environment, Earth, and Resources, 535 Wallace Building, University of Manitoba, Winnipeg, MB, R3T 2N2

[2] Department of Environment and Geography, Clayton H. Riddell Faculty of Environment, Earth, and Resources, 220 Sinnott Building, University of Manitoba, Winnipeg, MB, R3T 2N2

[3] Institute of Ocean Sciences (IOS), Fisheries and Oceans Canada, 9860 W. Saanich Rd., Sidney, BC, V8L 4B2

2. Project Summary:

The impacts of global climate change are most pronounced in the Canadian Arctic Archipelago (CAA) through sensitive feedbacks associated with local river discharge and the growth/melt cycle of sea ice. As the ice cover retreats, the CAA is opening up for resource extraction, tourism, and shipping, which inevitably will increase the risk of environmental accidents. To set in place appropriate management and regulatory strategies for sustainable development, a better understanding of the functioning, variability, and change of the marine system in the CAA is critically needed.

This project focuses on the marine region from Queen Maud Gulf through Dease Strait to Coronation Gulf (hereinafter QMC). It is the narrowest section of the Northwest Passage, with the lowest surface salinities due to three large rivers, and a stable landfast ice cover that is present for half of the year. For these reasons, QMC has for thousands of years been used for travel, fishing (Arctic char), hunting of wildlife (caribou) along migratory paths that cross the ice, and even today hosts one of Nunavut's largest communities, Cambridge Bay.

The objectives of this interdisciplinary multi-scale long-term oceanographic program are to:
1) Develop new methods and technologies to study the oceanography and monitor the changing marine environment of seasonally ice-covered regions, which are characterized by an immobile sea ice cover for half the year, and open water conditions for the other half; 2) understand the trends and variability in the physical, chemical and biological system, and how this has influenced the ways the marine environment has been and is used by the local culture; and 3) enhance community resilience and development potential through the collection and dissemination of oceanographic knowledge.

The proposed research and instrumentation will be used in the training of at least 10 HQP in addition to local community members (DND-Rangers) in state-of-the-art environmental research techniques. In situ real-time sensors are the new generation of analytical techniques with a wide range of application both in government and industry, and their application in the Arctic Ocean is an emerging field of research and technological development. Innovation of the proposed research falls under the following two broad envelopes: (1) development and application of novel oceanographic observational techniques for the seasonally ice-covered environments in the CAA, thereby providing a powerful tool to detect and improve our understanding of variability and change in critical physical, biological, and environmental components; and (2) use of inter- and multi-disciplinary approaches to synergistically develop unique HQP and response capabilities, thereby answering an expected requirement of provincial, territorial, and federal governments as the human footprint continues its rise in the Arctic. HQP with a comprehensive understanding of the Arctic marine system are in high demand, not only for academic sectors, but to meet upcoming needs of our government, industry, and northern stakeholders to understand and better confront challenges associated with the changing Arctic marine ecosystem.

3. Alignment with MEOPAR Strategic Objectives:

This proposed project will address the significant knowledge gap of the QMC through the collection of oceanographic data and knowledge that will further our understanding of, and capabilities to predict, climate related marine ecosystem processes, while incorporating local knowledge and uses of the marine environment. We will develop and use new techniques specific for Canada's Arctic landfast ice-covered marine environment in an effort to provide near real-time data on the state of the ice cover and ocean currents. We will directly involve the successful Canadian Rangers Ocean Watch (CROW), which is a Department of Fisheries and Oceans (DFO) and National Defense (DND) collaborative program, to establish a locally driven sampling program, while contributing to DND-Ranger patrols. A strong and direct collaboration with the Canadian High Arctic Research Station (CHARS) of the Aboriginal Affairs and Northern Development Canada (AANDC) will also ensure that near real-time data and information gathered as part of this project will be provided directly to stakeholders and policy makers where it will assist in decision making processes, model development, and risk response strategies. Therefore, by meeting the stated objectives, the project will directly contribute to the **MEOPAR vision** to, "*inspire and enable Canadian leadership in marine environmental observation, prediction, and response*".

Our planned work connects with at least five of the seven **MEOPAR goals** by: supporting the expansion of the operational network for marine observations to the QMC region; promoting information and knowledge exchange between academia, governmental agencies (DFO and AANDC), non-governmental organizations (Arctic Research Foundation and Oceanetic Measurement Ltd.) and local residents of Cambridge Bay (CROW program and social-cultural component); providing near real-time information in order to deliver regular assessments of major hazards to shipping and travel (sea ice) and dispersal vectors (ocean currents) of potential industrial spills in the region; working with the private sector (Oceanetic Measurement Ltd.) to develop new technology; and contributing to fundamental oceanographic research. Similarly, our project closely aligns with most of the **MEOPAR strategic objectives**:

- The project focuses on a strategically important location (the QMC region) which comprises: the narrowest point in the NW Passage, representing a major hazard to maritime shipping through the area; one of Nunavut's largest communities, Cambridge Bay, which is a regional transportation centre; and the site of CHARS (operational in 2017).
- The project will see the development of a new ice-tethered transceiver for near real-time mooring observations in landfast ice-covered waters.
- Information derived from the project will feed into the development, as led by CHARS, of a social-ecological terrestrial-marine model of the region.
- New information and knowledge gained by the project will be directly accessible to stake-holders and end-users where they will be able to make more informed decisions related to resource management, regulation, and policy in the face of a rapidly changing Arctic.
- The project will provide interdisciplinary training to new HQP by improved integration of social and natural sciences into their degree programs.
- New methods will be developed to study *cultural oceanography* of the QMC with ultimate goals to mold new understandings of the social-cultural, physical, and biological oceanographic system as a whole and to disseminate this knowledge to end-users and stakeholders alike.

4. Research Plan, Approach, & Outcomes:

4.1 Problem(s) to be addressed and state-of-the-art:

The impacts of global climate change are most pronounced in the marine environment of the Canadian Arctic Archipelago (CAA) through sensitive feedbacks associated with local river discharge and the growth/melt cycle of sea ice. Throughout the history of Canada's north, climatic changes have resulted in major shifts in both ecosystems and cultural frameworks. For example, it has been hypothesized that during the Medieval Warm Period a shift in the distribution of bowhead whales drove the west to east migration of Thule (early Inuit peoples) across the CAA. This period was followed centuries later by the Little Ice Age that likely influenced cultural development and the greater use of sea ice for subsistence hunting by Canada's Inuit *[1]*. Presently, climate perturbations are causing unprecedented change in the sea ice cover towards earlier melt onset, enhanced summer melt, and delays in freeze-up. Statistically significant delays of 5-6 days per decade in ice cover formation in the QMC region during fall have been reported for the period 1983-2009 *[2]*. Such changes have potentially profound implications that can cascade through the Arctic marine food web *[3, 4]*. Furthermore, the coincident migration of caribou herds between Victoria Island and mainland with the annual formation and melt onset of sea ice *[5]* implies a possible influence of the changing ice regime on the terrestrial system and hunting practices of the region. Presently, the changing icescape is bringing to the foreground key policy issues facing Nunavut and Canada's northern regions, including: sovereignty and security; increasing industrial presence; and the well-being and socio-economic development of an Inuit culture under severe pressures from globalization and climate change.

The QMC region has a complex marine environment characterized by: (i) the narrowest point in the NW Passage, representing a major hazard to maritime shipping through the area; (ii) input from 3 large northern rivers, which results in some of the lowest salinities found in the NW Passage *[6]*; (iii) a consistent landfast sea ice cover from November to July *[2]*, providing a stable platform for travel, fishing, hunting, wildlife migrations, and scientific investigations; and (iv) Nunavut's fifth largest community, Cambridge Bay, whose residents depend on the local marine/ice environment for subsistence hunting, transportation (including ice roads for leisure and sealift/barge re-supply), and an Arctic Char fishery (in fact, the traditional name, Iqaluktuuttiaq, translates into 'fair fishing place'). However, the QMC marine environment remains poorly characterized due to a lack of natural and social scientific studies. **We propose here, the creation of an interdisciplinary multi-scale long-term oceanographic summary, observation, and prediction program along this critical section of the Northwest (NW) Passage**. More specifically, our objectives are to:

1) Develop new methods and technologies to study the oceanography of the QMC region, which include
    a) development of a data receiver/transmitter specific for near real-time monitoring of oceanographic moorings beneath landfast sea ice (i.e., applicable for other regions in the NW Passage);
    b) supporting the implementation of a marine observational network specific for the QMC with an emphasis on Dease Strait near Cambridge Bay, Nunavut; and

   c) development of research methodologies to investigate the region's Traditional Ecological Knowledge and current material and cultural uses of the marine region by Cambridge Bay residents, which we define as *cultural oceanography*.

2) Understand trends and variability in the oceanography of the QMC region, through investigations of
   a) cultural oceanography as related to historical knowledge and contemporary uses of the region; and
   b) regional hydrology and biological productivity in QMC as a function of sea ice conditions and river discharge.

3) Enhance community resilience through the collection and dissemination of oceanographic knowledge through
   a) investigations of common interests and concerns between natural science and cultural oceanography and with local, regional, and national governance officials and businesses who engage directly with the marine environment (hereinafter stakeholders);
   b) establishment of meaningful partnerships with stakeholders; and
   c) improvement of collaborative research methods with stakeholders.

The flow of water through the CAA is generally directed from the Arctic Ocean towards the Atlantic. However, the barotropicity of the QMC indicates outflow of water from the area due to the large regional freshwater input *[6]*. It is significant to note that the main subsistence foods of the local region are caribou, muskox, Arctic char, lake trout, and to a lesser extent, ringed seal *[7].* Caribou, in particular, have been hunted for thousands of years along their migratory paths that cross the QMC ice cover *[8]*. However, marine mammals, such as polar bears and whales, scarcely frequent the region, with locals often travelling hundreds of kilometers east towards Victoria Strait to hunt bears *[personal communication, Ekaluktutiak Hunters and Trappers Organization (HTO) board]*. We hypothesize that this lack of major Arctic marine mammals in the vicinity and abundance of Arctic char can be connected to the low salinities of the QMC region and their influence on nutrients and biological productivity. Yet the salinity structure, with minimum surface salinities of >20 and bottom salinities of 29 show that Arctic Ocean waters (>31) reach across and mix in the QMC. How the baroclinic flow structure and tidal mixing affect water transport through QMC is not well-known nor easy to estimate without direct observations. Expected trends in sea ice coverage *[9]* and river runoff *[10]* will also have a significant effect on local circulation. As resource extraction, shipping, and tourism industries increase their access to the NW Passage, the risk of shipping-related accidents will increase. Therefore, a better understanding of the complex natural science and cultural oceanography in the QMC is critical to assist in predicting how, for example, a spill could disperse, or how a significant change in the ice cover could affect caribou populations. We will reach these needs and others by meeting our stated objectives through the collaboration of academic, government, private sector, and local community partners.

4.2 Research Approach:

Our research will take a tiered approach, carrying out multidisciplinary research (working within subject areas; Objectives 1-2), while cross-fertilizing natural and social science research

that will culminate in a truly interdisciplinary study (Objective 3). The natural science component of Objectives 1-2 will be tackled through a multi-scale temporal through spatial approach.

(1) A mooring observatory will be installed in the centre of Dease Strait for high temporal resolution point measurements. The mooring will be constructed with typical instrumentation to observe water column structure, circulation, and tidal amplitudes. It will also have the capacity to monitor change in ice thickness and its drift. A unique aspect of the mooring will be a multispectral radiometer to monitor transmitted light through the ice cover, which can be used to estimate light levels and integrated algal biomass above the sensor *[11]*, and potentially relative pigment composition (an indicator of photoacclimation *[12]*), non algal particles, and coloured dissolved organic matter *[13]*. Furthermore, in collaboration with Oceanetic Measurement Ltd., we will develop an acoustic transmitter that will dump data to a transceiver deployed by the CROW program on the ice surface once the landfast ice has formed (December-January) and then retrieved prior to the ice breaking up in June.

(2) An annual field program called Ice Covered Ecosystem - CAMbridge bay Process Studies (ICE-CAMPS) will conduct high temporal resolution measurements based on the sea ice while collecting pertinent spatial data within the local region of the mooring between April through the end of June (ice break-up). In particular, the Arctic Biogeochemical Optics Laboratory (supported through a CFI-LOF grant to Mundy and Ehn), will deploy a remotely operated vehicle (ROV) under the ice on a regular basis to make detailed hydrographic, ice morphological and bio-optical observations in an effort to further develop techniques to extract information from transmitted irradiance measurements made from the long-term mooring.

(3) The CROW program will both conduct bi-monthly hydrographic transects across Dease Strait and larger-scale oceanographic sampling across the southern archipelago as part of their wintertime patrols. To do this they will use DFO-provided 'CROW-kits', which contain a CTD (with additional fluorescence and dissolved oxygen sensors), auger, and downrigger. The Rangers receive training on the use of these kits as part of the CROW program. The bi-monthly transects across Dease Strait will provide an unprecedented view of the seasonal cycle of water properties in the strait.

(4) A summertime hydrographic survey will cover the entire QMC region to better understand the distribution of freshwater and ice melt to help extrapolate the temporal observations in Dease Strait to a regional setting.

The cultural oceanography component (Objectives 1c. and 2b.) will be accomplished through a series of interviews, consultations and focus groups with Elders, hunters, and other community partners from the hamlet of Cambridge Bay. We will employ a mixed methods approach that will be grounded in community action research in order to encourage the research partnership with the community. Peyton and the MA student will travel to Cambridge Bay to engage community members directly in interviews and on the ground learning. We also envision using a rich but mostly underutilized data set of relevant policy information (from local sources and territorial and federal governments) and, in particular, a wealth of archival data located in the Hudson's Bay Company Archives in Winnipeg, the National Archives in Ottawa, and Territorial Archives in Iqaluit and Yellowknife. This knowledge mobilization will contribute to the ability of local communities to communicate their interests and experience accrued over centuries. Interactions and interviews with local stakeholders will allow us to better understand both the long and short-term use implications of changing local ice and marine environments.

Objective 3 will be met through integration of the cultural and natural science oceanography components of the project in an effort to provide and disseminate new knowledge required to meet the burgeoning needs of the HTO, hamlet, territorial and national government, and private business as they encounter changes in the marine system. A modified approach of that discussed in *[14]* will be taken. Principal Investigators (PI), Mundy, Ehn, and Peyton, will all sit on the thesis committees of new students directly involved in the project. Discussion, development, and finalization of theses will thus incorporate viewpoints from both natural and social sciences, allowing for the investigation of common interests and/or concerns derived from the different sciences. This first step will provide a direct avenue for results and analyses to feedback into further molding of the research approach to meet Objectives 1 and 2, while fostering discussions and plans on how to best summarize and disseminate knowledge gained. Furthermore, annual in-person meetings and more frequent calls will be held with partner representatives from the Ekaluktutiak HTO, DFO, CHARS, and interested stakeholders in an effort to establish meaningful partnerships that will be able to make use of the knowledge gained, while providing feedback on how to improve collaborative research methods. By meeting Objective 3, we hope to establish a collaborative framework for undertaking interdisciplinary oceanographic research in the region that will continue beyond the funding of this particular program.

4.3 Outcomes and Long-term perspectives:

This project is expected to build a new and strong relationship between the central partners, which include members from academia, government, Ekaluktutiak HTO, Arctic Research Foundation, Oceanetic Measurement Ltd., and local residents of Cambridge Bay, that will connect closely with the commencement of the Canadian High Arctic Research Station (CHARS). As CHARS is expected to be fully operational by summer 2017, and with a successful MEOPAR NCE renewal, we would expect the project to continue to occur and evolve beyond the proposed 3-year timeline. We foresee development of the sea ice based transceiver by Oceanetic Measurement Ltd. to be applied across the CAA and potentially coupled to mass balance buoys that will provide a wealth of near real-time sea ice and oceanographic information during winter to the various stakeholders. Through CHARS, the data will be linked to a national network that will build upon the work accomplished by colleagues at Ocean Networks Canada (ONC). The interdisciplinary nature of the project and dissemination of new knowledge gained will help build new understandings of QMC oceanography providing the basis needed for stakeholders to adapt to a changing climate. In particular, data and new information will contribute towards the development of a social-ecological coupled terrestrial-marine model that is being headed by CHARS. We also foresee the development of new relationships within Cambridge Bay where new understandings of QMC oceanography will be useful to local industry such as Kitikmeot Foods Ltd. and Ekaluktutiak HTO guiding businesses. Our project is committed to increasing awareness of oceanographic research, while contributing to the training of highly qualified personnel (HQP) to help meet upcoming needs of our government, industry, and northern stakeholders to understand and better confront challenges associated with the changing Arctic marine ecosystem.

4.4 Project Timeline:

Table 4.1 Gantt chart describing timing of specific field programs and outcomes expected to arise from the project.

			2014/15									2015/16				
	Programs/Outcomes	**Obj.**	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	Transceiver development	1a.														
2	Distributed oceanographic sampling (*R/V Martin Bergmann)*	1b., 2b.														
3	CROW program bi-monthly sampling (Dease Str. Transect)	1b., 2b.														
4	Cultural oceanography field study	1c., 2a.														
5	Annual report to MEOPAR and partners	all														
6	ICE-CAMPS field sampling program (on sea ice)	1b., 2b.										**1, 2**		**3**		
7	Projected thesis defense *[see Table 7.1]*	1., 2.														
8	Bridging study - cultural oceanography and natural science	1c., 3.														
9	Peer-reviewed publications expected	all														
10	Final report of 3-year project to MEOPAR and partners	all														

	2015/16							2016/17												2017/18*				
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1																								
2											**4**												**4**	
3			**2**												**2**									
4																								
5																								
6										**3**												**3**		
7										**MSc-1-3; MA-1; PhD-1**													**PhD-2, -3**	
8																								
9																								
10																								

*Sampling and mooring deployment beyond 3-year project will depend on securing new funds

1 - Mooring deployment through sea ice

2 - Transceiver deployment on sea ice

3 - Transceiver recovery

4 - Mooring turnover/recovery

***5. Excellence & Interdisciplinary Balance of the Research Team*:**

5.1 Composition and qualifications of the proposed Research Team:

The proposed research team includes 4 outstanding young researchers from the fields of human geography and biological and physical oceanography. This team provides the necessary specialization to meet all of the stated objectives within the time period allotted including specific expertise to carry out the field programs required.

Dr. Mundy (*Project Leader*) is a biological oceanographer specializing in the investigation of processes that control the timing, concentration, and fate of primary producers in ice-covered and open oceans. He has played a leading role in research investigating primary producers in ice-covered oceans. He was the first to extensively show the influence of ice algal biomass on the spectral distribution of transmitted irradiance, developing a calibration method to remotely estimate ice algal biomass. His under-ice camera technique designed to observe the microscale distribution of algae in their sea ice habitat was also the first to document in situ brine channel distribution and geophysical properties of the ice bottom. Mundy's more recent work has been on the investigation of phytoplankton production under an ice cover, where he has demonstrated that ample light penetrates the ice cover permitting a, previously assumed non-existent, bloom to occur. These results are currently fueling new research across the Arctic and Antarctic. His documentation, inferred through absorption measurements, of a considerable contribution of UV-absorbing mycosporine-like amino acids produced by ice melt water algae, has also helped re-invigorate research on this important yet little known algal community. Furthermore, Mundy is the lead PI of two international (participants from across Canada, UK, Germany, USA, Denmark, France, and Belgium) projects called Arctic-ICE (Ice Covered Ecosystem; 2010-2012) and ICE-CAMPS (CAMbridge bay Process Studies; 2014-present) based out of Resolute Bay and Cambridge Bay, respectively.

Dr. Ehn is a physical oceanographer whose research focuses on understanding how solar radiation propagates in sea ice covered environments and how sea ice and water column physical, biological, and chemical properties are affected through light-matter interactions. He was the first to describe the importance of horizontal propagation of light through a melting sea ice cover, resulting in a push towards a better understanding of the complex influence a variegated surface has on the under-ice light field. Ehn was also the first to show through an inverse modeling approach that key biogeochemical properties in sea ice such as brine volume, ice structure and particle characteristics can be estimated from spectral transmitted irradiance measurements. He has worked extensively on the optical properties and energy balance of sea ice throughout the Arctic, during all seasons of the year, and covering all ice types from nilas with frost flowers to melting multi-year ice. The research proposed here is an expansion of this work, contributing to an understanding of inherent and changing variability governing radiative transfer in the Arctic Ocean. His work in the Baltic Sea remains the foremost optical study of sea ice formed from brackish and CDOM-rich water. His ongoing work includes characterizing particle assemblages in the Arctic shelf seas in terms of their dynamics, concentration, composition, size distribution, and how these properties affect light propagation, radiative heating rates and consequently circulation and stratification.

Dr. Peyton is an environmental geographer whose work develops a cultural and historical approach to the analysis of resource conflicts and the new extractive economies built around minerals and hydrocarbons. His research has examined a series of resource development conflicts in the Stikine region of northwest British Columbia, an area that is currently the site of intense mineral exploration and speculation over potential energy projects. He has developed a unique methodological approach, termed *unbuilt environments*, to the analysis of the environmental and socio-economic effects of development schemes in remote geographical areas. Interactions with the local Tahltan communities through ethnographic interviews, formal leadership interviews and informal community conversation was at the centre of this research, which also analyzed relevant scientific data, public policy and grey literature, environmental impact assessment data, and corporate archival information. His current research interrogates the policy implications of northern energy infrastructure megaprojects in Arctic and subarctic North America through an underlying question of how envisioned northern energy projects influence the course of North American energy policy. It is northern in focus but will place the north in relation to broader continental energy policy and geopolitics.

Dr. Williams is a Research Scientist with Fisheries and Oceans Canada at the Institute of Ocean Sciences in Sidney, British Columbia, and is currently applying for adjunct status at the University of Manitoba. He is a physical oceanographer specializing in the Arctic Ocean, particularly on the circulation patterns observed in the Beaufort Gyre region of Canada Basin, the Canadian Beaufort Shelf, and the Canadian Arctic Archipelago. His research focuses on how physical processes, such as shelf-break exchange, contribute to the functioning of Arctic marine ecosystems and how these processes are affected by a changing climate. He has led many expeditions to the Canadian Beaufort Shelf and now leads the Joint Ocean Ice Studies program to the Beaufort Gyre Region of the Canada Basin aboard the *CCGS Louis S. St-Laurent*. He also leads the Canadian Rangers Ocean Watch (CROW) a DFO-DND collaboration in which the DND-Rangers in the Canadian Arctic Archipelago collect oceanographic data during their wintertime snowmobile patrols. The CROW monitoring program thus complements the goals of this proposal.

5.2 Social/policy issues addressed:

Understanding and directly monitoring in near real-time the ocean's circulation and structure along the NW Passage is a key information gap to be tackled by this work in an effort to better prepare government and local stakeholders should incidents related to increasing transportation through the region occur. Furthermore, a central outcome of the project will be a direct engagement with the local dimensions of northern policy-making, specifically around resource mobilization, community development, sovereignty and security, and the expected growth of new transportation channels. We will identify and help to mitigate against environmental and socioeconomic vulnerabilities that can accompany new resource development economies in order to ensure that the residents of Cambridge Bay are able to benefit from the corresponding opportunities. We will also engage directly with the community and involve them in research that directly contributes to the improved understanding of their local environment and ecosystem.

***6. Multi-sectoral Structure and Support*:**

6.1 Demonstrated linkages to other MEOPAR activities and/or other existing projects:

Much of the research proposed above will be able to link to numerous MEOPAR activities that could both expand some projects to have an Arctic component while directly contributing to data needs of others. For example, the mooring data can contribute towards expanding the geographic focus of MEOPAR projects such as "Building a Network of Fixed Coastal Observing and Forecasts Systems" while the near real-time winter mooring data and distributed samples obtained through the CROW program on snow and ice thickness will be directly applicable to the project, "Improved Sea Ice Forecasts Through Classification and Assimilation of SAR Imagery". Furthermore, our group will bring an expertise of sea ice and under-ice oceanography as well as human geography to MEOPAR.

Led by Mundy, the Arctic-ICE (2010-2012) and ICE-CAMPS (ongoing) are process studies focused on the sea ice and under-ice marine environment of the CAA. The latter program, which currently involves 10 PIs and 16 students from Canada, Denmark, France, USA, and UK, will contribute directly to the project described in this proposal through the participation of Mundy, Ehn, and their students. ICE-CAMPS is also one of 5 main Arctic Science Partnership (ASP; http://asp-net.org) research projects. The ASP provides direct collaboration between participants of the different research projects, bringing together researchers from Canada, Denmark, and Greenland. The data collected to date from Arctic-ICE and ICE-CAMPS have already provided a wealth of new information on the oceanography of the NW Passage and associated metadata reports are being catalogued as part of the ArcticNet NCE on the Polar Data Catalogue where they will be accessible for other MEOPAR participants. The ICE-CAMPS program is also working with Ocean Networks Canada (ONC) to assist in data calibration of their Cambridge Bay mini-observatory. Furthermore, through collaboration with CHARS and working with ONC, this proposed MEOPAR project will seek to provide web portal access to the near real-time winter mooring data.

Mundy and Ehn recently started the Arctic Biogeochemical Optics Laboratory (CFI-LOF funded), which will provide the necessary instrumentation to undertake detailed bio-optical studies of the under-ice marine environment. Mundy and Ehn are both network investigators (NIs) in ArcticNet under Project 2.8, "Arctic Geomicrobiology and Climate Change", which is led by Dr. Rysgaard, the Canada Excellence Research Chair (CERC) at the University of Manitoba. As ArcticNet NIs, their group participates in the annual scientific cruise aboard the *CCGS Amundsen* and have direct access to past oceanographic observations along the entire NW Passage, providing the possibility to geographically expand the oceanographic observations in the QMC to the entire NW Passage. Mundy and Ehn are also part of the CERC unit at the University of Manitoba, which is housed within the Centre for Earth Observation Science (CEOS). Through the CERC unit, they collaborate with most projects ongoing, which include annual process experiments in the Sea-ice Environmental Research Facility (SERF) at the University of Manitoba.

Furthermore, through ArcticNet Mundy and Ehn collaborate closely with the Schools on Board program, which is led by M. Watts. In particular, ICE-CAMPS will be coordinating, with the Schools on Board program, an Arctic Science Day in May 2014 where science students

and teachers from Kiilinik High School will travel out to our ice camp to learn about the science we accomplish through experiential learning practices.

6.2 End-user involvement and external partnerships:

The program will be strongly grounded with partnerships established and to be made in the government (DFO and AANDC) and with local residents of Cambridge Bay, Nunavut. It will also be local residents that make up the rangers of the CROW program in this project. Therefore, end-users will have direct access to the data and information to be used at an operational capacity. In particular, the information derived from this project and ICE-CAMPS will directly contribute towards the development of a social-ecological coupled terrestrial-marine model that is being developed by CHARS. Our collaboration with Oceanetic Measurement Ltd. will also help develop a mooring transceiver technology that could be applied across the Canadian Arctic. This device will have the potential to provide near real-time winter data of variables such as ice thickness and melt state, which can be accessed by end-users (e.g., Canadian Ice Service) who require these types of information for Arctic shipping season forecast model prediction.

***7. HQP Focus*:**

7.1 Description of HQP

The HQP to be trained through our proposed work, including their supervisor/co-supervisor, research topic/focus, expected areas of training, and the contribution of their work to the project's objectives are outlined below (Table 7.1). Training of University-based HQP will involve the development of key skills that include critical scientific thinking and problem-solving, tractable project planning, oceanographic field and analytical techniques, algal culture laboratory experimentation, and scientific writing and communication of research findings. Direct training of at least 2 PDFs, 3 PhD, 1 MA, 3 MSc, and 1 BSc students is planned through the project. Furthermore, DND-Rangers will be trained in oceanographic field sampling techniques.

Table 7.1. A list of HQP that will be trained as part of the MEOPAR project.

HQP	Supervisor	Research Topic/ Focus	Training	Proposal Objective
BSc-1 (S. McDonald)	Mundy/ Koulis (Statistics-UM)	Statistical methods for under-ice optical measurements	Functional regression statistics, Mooring and ROV operations	1b
MSc-1 (A. Elliot)	Mundy/ Wang (CEOS-UM)	Photoprotective strategies of ice-associated algae	HPLC-MS; photophysiology; culture experiments (CE)	2b
MSc-2 (A. Diaz)	Ehn/ Papakyriakou (CEOS-UM)	Sea ice optics and microstructure	Sea ice geophysics and thermodynamics, bio-optics	1b,2b
MSc-3 (C. Quiring)	Mundy/ Ehn	Bio-optical characterization of under-ice primary producers	Marine bio-optics, HPLC, ROV operations	2b
MA-1 (TBD)	Peyton	Cultural Oceanography	Ethnographic methods, community participatory action research	1c,2a
PhD-1 (K. Campbell)	Mundy/ Rysgaard (CEOS-UM)	Sea ice primary production	Sea ice physics, photophysiology, primary production (PP), CE, nutrient dynamics	2b
PhD-2 (A. Delaforge)	Mundy	Under-ice primary production	Photophysiology, PP, CE, algal taxonomy, nutrient dynamics	2b
PhD-3 (V. Petrusevich)	UM	Mixing and particle transport	Oceanographic sampling, Mooring and ROV operations	2b
PDF-1 (K. Brown)	Williams/ Peucker-Ehrenbrink (WHOI-USA)	Geochemical fingerprinting of rivers in the CAA	Stable isotope geochemistry, sea ice and oceanographic sampling, chemical oceanography	2b
PDF-2 (TBD)	Mundy/ Ehn	QMC regional hydrology	Mooring and ROV operations	1a,b,2b
DND-Rangers	Williams	Dease Strait transects	Snow, sea ice, and oceanographic sampling	1b

7.2 Innovative training of HQP

The proposed interdisciplinary project will provide a unique training environment bridging natural and social sciences, while providing direct contact with stakeholders and end-users through close collaboration of the research team and their collaborative partners. All research proposed will involve community based work in Cambridge Bay, where HQP and PIs will live and work together, establishing new and lasting relationships and networks beneficial to both the HQP and members of the hamlet. Furthermore, working with HTO guides, HQP will have unique opportunities to exchange knowledge and to learn about the land and ocean from the locals. This experience will provide HQP with a greater appreciation of the Arctic and the work they will be undertaking. Collaborating with Kiilinik High School through an innovative social studies project, senior high school students will interview HQP and the research team on their science, ultimately airing the videos on the Cambridge Bay cable station, Isuma TV. A pilot project is currently underway with grade 11/12 students and the ICE-CAMPS 2014 participants. This innovative project will again provide a two-way exchange of knowledge with a much broader community audience, providing an additional means of knowledge dissemination.

Specific to the natural sciences, ABOL instrumentation, proposed mooring, sea ice and ship-based sampling, and associated laboratory facilities will be unique in Canada, thereby attracting and retaining the very best in both national and international HQP focused on oceanography of the NW Passage and with a specific application of optical methods to investigate biogeochemical processes in the Arctic ice-covered environment. The range of applications for optical techniques to infer physically, biologically, and chemically important properties in aquatic environments is rapidly advancing with technological development. Marine optics is inherently an interdisciplinary field and as such its application requires an in depth understanding across disciplines. Therefore, the proposed project will help develop HQP that cross between the boundaries of traditional natural science disciplines, bridge between field and laboratory-based research methodologies, and take the advantage of state-of-the-art instrumental techniques.

A unique interdisciplinary education is also foreseen to arise through co-supervision of new HQP coming into the project. Discussion, development, and finalization of theses will incorporate viewpoints from both natural and social sciences, allowing for the investigation of common interests and/or concerns derived from the different sciences. Noted in *[section 4.2]*, this experience will provide a direct avenue for results and analyses to feedback into further molding of the research approach to meet Objectives 1 and 2, while fostering discussions and plans on how to best summarize and disseminate knowledge gained. The ultimate goal of this approach is to instill a basic appreciation and understanding of both sciences to each new student involved in the project.

It is expected that the above training of HQP will provide the necessary knowledge base to support jobs in Arctic system science, physical and biological oceanography, environmental science and assessment, climate change, stewardship, and geopolitics. Additionally, there will be demand of new technicians and academic positions focused on Arctic oceanography, particularly associated with the commencement of CHARS in 2017.

***8. Budget Justification*:**

8.1 Detailed budget:

Category	Year 1 ($1000)	Year 2 ($1000)	Year 3 ($1000)	Totals ($1000)
Personnel	85 + 163	85 + 163	69 + 95	660
Materials, Supplies, Dissemination	0 + 10	0 + 10	0 + 10	30
Travel	37.5 + 54	37.5 + 54	35 + 54	272
Equipment	66 + 124	21 + 49	21 + 49	330
Totals	539.5	419.5	333	1,292
Partner funds expected	351	276	208	835
MEOPAR funds requested	**188.5**	**143.5**	**125**	**457**

8.2 Budget notes and justification:

Personnel: We request $45K for partial support of a postdoc to assist in mooring development, deployment, and data analyses in addition to exploring the application of transmitted spectral irradiance to deduce the state of the ice-cover and biological parameters. $24K is requested to hire two DND-Rangers in support of the CROW program for transect sampling across Dease Strait 2 days per month over the entire year. Furthermore, an additional $16K in years 1 and 2 is requested to support MA-1 *[see Table 7.1]*. Expected partner contributions include: $10K for postdoc salary per year (Mundy and Ehn, CFI/NSERC); $6K in year one for BSc-1 (Mundy, NSERC); $60K for PhD-1-3 in years 1 and 2 and $40K for PhD-2-3 in year 3 (Mundy and Ehn, NSERC/UM Graduate Enhancement of Tri-council stipends (GETS)), $48K for MSc-1-3 in years 1 and 2 (Mundy and Ehn, NSERC/UM GETS), $15K per year for partial salary of Williams and technician (Williams, DFO), and $24K per year for matching CROW program support (McLennan, CHARS).

Materials, Supplies, Dissemination: We expect laboratory materials and supplies to cost approximately $10K per year (Mundy and Ehn, NSERC).

Travel: We ask $2.5K to support travel of the Masters student to the field in years 1 and 2, $10K per year to support travel of each of the 4 research team members to Cambridge Bay in support of an annual meeting, and $25K per year for CROW fieldwork, training, and logistics. Expected partner contributions include an estimated $30K per year for fieldwork logistics (Mundy and Ehn, NSERC) and $24K per year for estimated housing in Cambridge Bay (CHARS).

Equipment: In the first year, $30K is requested to support the development of the on-ice transceiver for the Dease Strait mooring and $15K to purchase a multi-wavelength optical radiometer. $21K is requested each year for partial support of an annual 7-day voyage ($6K per day) aboard the *R/V Martin Bergmann* that will accomplish distributed oceanographic sampling in the region and the turn over of the mooring. Expected partner contributions include: $21K in-kind per year for the *R/V Martin Bergmann* (Schimnowski, ARF), $75K in year 1 for mooring equipment including two acoustic releases, an ADCP, three Seabird Microcats, a Seabird Seacat with fluorometer, line, and floats (Williams, DFO), and $28K per year for incremental costs associated with existing instrumentation (Mundy and Ehn, CFI/NSERC).

9. References:

[1] Friesen, T.M. (2010) Dynamic Inuit social strategies in changing environments: A long-term perspective. Danish Journal of Geography 110: 215-225

[2] Galley R.J., Else B.G.T., Howell S.E.L., Lukovich J.V., and Barber D.G. (2012) Landfast sea ice conditions in the Canadian Arctic: 1983-2009. Arctic 65: 133–144

[3] Pipenburg, D. (2005) Recent research on Arctic benthos: common notions need to be revised. Polar Biology, doi:10.1007/s00300-005-0013-5

[4] Leu E., Søreide J.E., Hessen D.O., Falk-Petersen S., and Berge J. (2011) Consequences of changing sea-ice cover for primary and secondary producers in the European Arctic shelf seas: Timing, quantity, and quality. Progress in Oceanography, doi:10.1016/j.pocean.2011.02.004

[5] Poole, K.G., Gunn, A., Patterson, B.R., and Dumond, M. (2010) Sea ice and migration of the Dolphin and Union caribou herd in the Canadian Arctic: An uncertain future. Arctic 63: 414-428.

[6] McLaughlin, F.A., Carmack, E.C., Ingram, R.G., Williams, W.J., and Michel, C. (2004) Oceanography of the Northwest Passage, Chapter 31. in The Sea Vol 14: The Global Coastal Ocean, Interdisciplinary Regional Studies and Syntheses, A.R. Robinson and K.H. Brink., eds., Vol.14, Chpt.31

[7] Calihou, C. and Romaine, T. (2010) Cambridge Bay Climate Change Adaptation Action Plan, Municipal Corporation of Cambridge Bay 52 p.

[8] Friesen, T.M. (2013) The impact of weapon technology on caribou drive system variability in the prehistoric Canadian Arctic. Quaternary International doi:10.1016/j.quaint.2012.12.034

[9] Tivy, A., Howell, S.E.L., Alt, B., McCourt, S., Chagnon, R., Crocker, G., Carrieres, T., and Yackel, J. J. (2011) Trends and variability in summer sea ice cover in the Canadian Arctic based on the Canadian Ice Service Digital Archive, 1960–2008 and 1968–2008. Journal of Geophysical Research-Oceans 116: C03007, doi:10.1029/2009JC005855

[10] McClelland, J.W., Déry, S.J., Peterson, B.J., Holmes, R.M., and Wood, E.F. (2006) A pan-arctic evaluation of changes in river discharge during the latter half of the 20th century. Geophysical Research Letters 33: L06715, doi:10.1029/2006GL025753

[11] Mundy, C.J., Ehn, J.K., Barber, D.G., and Michel, C. (2007) Influence of snow cover and algae on the spectral dependence of transmitted irradiance through Arctic landfast first-year sea ice. Journal of Geophysical Research 112: C03007, doi:10.1029/2006JC003683

[12] Alou-Font, E., Mundy, C.J., Roy, S., Gosselin, M., and Agusti, S. (2013) Snow cover affects ice algae pigment composition in the coastal Arctic Ocean during the spring-summer transition. Marine Ecology Progress Series 474: 89-104, doi:10.3354/meps10107

[13] Ehn, J.K., Mundy, C.J., and Barber D.G. (2008) Bio-optical and structural properties inferred from irradiance measurements within the bottommost layers in an Arctic landfast sea ice cover. Journal of Geophysical Research 113: C03S03, doi:10.1029/2007JC004194.

[14] Laidler, G.J. (2006) Inuit and scientific perspectives on the relationship between sea ice and climate change: the ideal complement? Climatic Change doi: 10.1007/s10584-006-9064-z

Ekaluktutiak Hunters & Trappers Organization
P.O. Box 1270 Cambridge Bay, Nunavut X0B 0C0
Telephone #: (867) 983-2426 Facsimile #: (867) 983-2427
Email: ehtocb@qiniq.com

April 25, 2014

CJ Mundy

Biological Oceanographer

University of Manitoba

Dear Mr. Mundy

The Ekaluktutiak Hunters & Trappers Organization would like to thank you for coming to discuss your Project.

The Board has no objections to the proposed work you brought forward. We look forward to hearing From you in regards to progress. Involving the school is one of our priorities when it comes to science And research, as well as traditional knowledge.

We hope all works well for you during project.

Sincerely,

James Panioyak

EHTO Chair

OCEANETIC (2011) Ltd.
MEASUREMENT

14 April 2014

Attn: Dr. C.J. Mundy
Assistant Professor, Department of Environment and Geography
University of Manitoba, 582 Wallace Building
Winnipeg, MB R3T 2N2

Re: Letter of support for C.J. Mundy et.al. MEOPAR grant application- Dease Strait climate monitoring

Dear Dr. Mundy,

Oceanetic Measurement 2011 Ltd (OML) is pleased to provide you with this letter of support for your MEOPAR grant application, and we look forward to working with you on mooring transceiver development to facilitate real-time transfer of critical study data. We appreciate the important climate change monitoring work you and the team are performing in this significant area of the arctic, and we are well positioned to provide you with the arctic oceanographic instrumentation support you require for this unique project.

Since the 1980's, Oceanetic has been in the business of providing customized oceanographic monitoring instruments and field support to the federal government and other public and private organizations. As such, the OML team has extensive expertise in the design and manufacture of environmental sensors and data transmission equipment. Our well-educated team of interdisciplinary experts is a technically skilled and accomplished group, whose disciplines range from ship-based oceanographic scientific sampling and support to electronics to scientific data visualization and communication.

Oceanetic has a long track record of success and expertise which would especially benefit this project, including design and production of oceanographic instrumentation and satellite communications including complex communication protocols. We pride ourselves on design and fabrication of robust electronic instrumentation systems which function reliably over the long term -- even within the harshest environments on earth, such as land-fast sea ice. Our skills at power management and data collection systems ensure reliable data collection, regardless of harsh conditions.

Oceanetic is looking forward to working with the Mundy team to design and develop the mooring-transceiver. We believe there is broader commercial potential for deployment of this equipment across the arctic and other parts of the world currently experiencing unprecedented effects of climate change. As this unique project would represent another global first for Oceanetic, we believe it can help to position our company as a leader in provision of oceanographic equipment for climate change monitoring in harsh environments.

Please contact us if we can provide additional information. We look forward to working with you and trust your grant application will be successful based on its substantive merits.

Yours truly,

Lori Waters, MFA, MScBMC
President, Oceanetic Measurement (2011) Ltd
Oceanographic Instrumentation & Field Support

Arctic Research Foundation

April 12, 2014

Dr. C. J. Mundy
Centre for Earth Observation Science (CEOS)
Department of Environment and Geography
CHR Faculty of Environment, Earth, and Resources
University of Manitoba
Winnipeg, Manitoba
Canada, R3T 2N2

Dear C.J. Mundy,

Subject: MEOPAR proposal

With this letter, as representative of the Arctic Research Foundation (ARF), we are pleased to provide our support for the proposal titled, "Understanding the oceanography of the western NW passage: influence of ice and freshwater on water circulation, stratification, and ecosystems", led by Dr. C.J. Mundy of the University of Manitoba.

The ARF is a Canadian private charitable foundation established in 2011. The vision of ARF focuses on long-term sustainability in the Arctic through innovation in research capacity specific to a local/community level. Community resiliency to change is possible through predictive adaptability supported by a thorough knowledge and understanding of the changes taking place.

The *R/V Martin Bergmann* is owned and operated by the ARF. She is a 64ft, shallow draft research vessel now based in Cambridge Bay, Nunavut. The ship is an autonomous platform for performing research in the surrounding area. The project proposed by Mundy et al. is aligned closely with the ARF's vision and we are excited about the potential future research to be undertaken. Towards the project, we will provide in-kind support by way of half the cost of the proposed ship time (3.5 days at sea at a not-for-profit rate of $6000/day) per year during the project's tenure.

Adrian Schimnowski
Operations Manager
Arctic Research Foundation
204-470-5408
1505 Charleswood Road
Winnipeg, Manitoba, R3S 1C2

Fisheries and Oceans Canada | Pêches et Océans Canada

April 25, 2014

Dr. C. J. Mundy
Centre for Earth Observation Science (CEOS)
Department of Environment and Geography
CHR Faculty of Environment, Earth, and Resources
University of Manitoba
Winnipeg, Manitoba
Canada, R3T 2N2

Email: CJ_Mundy@umanitoba.ca

Your file Votre référence

Our file Notre référence

Dear Dr. Mundy:

Subject: MEOPAR proposal

On behalf of the Fisheries and Oceans Canada (DFO), I am writing to express our Department's support for the MEOPAR proposal entitled " Understanding the oceanography of the western NW passage: influence of ice and freshwater on water circulation, stratification, and ecosystems" led by Professor C. J. Mundy at the University of Manitoba.

DFO has had a long-standing interest in conducting integrated management of our oceans. In the case of the Northwest Passage, recent change in ice climate and increased use by shipping has presented a significant challenge in meeting management objectives in an ocean that is undergoing rapid change. Your MEOPAR proposal will contribute to our efforts to collect monitoring data in this sparsely sampled region and, crucially, collect data that is year-round, both through the use of moored instrumentation and repeat transects by the Cambridge Bay Rangers through the DFO/DND Canadian Rangers Ocean Watch. These seasonal data, combined with ecosystem focused intensive field programs will greatly increase our understanding of the regional oceanography of the western Northwest Passage and so provide an oceanographic setting for monitoring time series.

If this project is successful and get the level of funding expected, DFO, CHS&OS expects that all data and information gathered through the project will be open and freely accessible for archiving and distribution via the Marine Environmental Data Service.

We look forward to collaborating with the team Dr. Mundy has assembled.

Denis Hains,
Director General, Canadian Hydrographic Service & Oceanographic Services /
Directeur général, Service hydrographique du Canada & services océanographiques
Hydrographer General of Canada / Hydrographe général du Canada

c.c Rob Young, DFO, C&A
Jill Watkins, DFO, NCR

Ottawa, Canada
K1A 0E6

Canada

Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

www.ainc.gc.ca
www.inac.gc.ca

Votre référence - Your file

Notre référence - Our file

April 28, 2014

Dr. C. J. Mundy
Centre for Earth Observation Science (CEOS)
Department of Environment and Geography
CHR Faculty of Environment, Earth, and Resources
University of Manitoba
Winnipeg, Manitoba
Canada, R3T 2N2

Dear Dr. Mundy:

Subject: CHARS Support for MEOPAR proposal

On behalf of the Canadian High Arctic Research Station (CHARS), I am writing to express our support for the MEOPAR proposal entitled " Understanding the oceanography of the western NW passage: influence of ice and freshwater on water circulation, stratification, and ecosystems" led by Dr. C. J. Mundy at the University of Manitoba.

CHARS' mission is to be a world-class research station in Canada's Arctic that is on the cutting edge of Arctic issues, anchoring a strong research presence in Canada's Arctic that serves Canada and the world, while advancing Canada's knowledge of the Arctic in order to improve economic opportunities, environmental stewardship, and the quality of life of Northerners and all Canadians. The research scope of Dr. Mundy's proposal fits very well with CHARS' five year science priorities (www.science.gc.ca/CHARS), bridging social and natural sciences, while focusing on improving our understanding of the oceanography in Canada's NW passage. The proposed work will directly support our nascent Cambridge Bay research and monitoring programs by providing key data on marine processes. These data that will significantly contribute to the development of a holistic social-ecological framework for the West Kitikmeot that links the dynamics of terrestrial and marine ecosystem change to the human communities and industrial activities that are embedded in them.

CHARS is prepared to support this MEOPAR proposal:

1. by co-contributing to the community –based DND-Canadian Rangers Ocean Watch (CROW) program that directly employs members of the Canadian Rangers and others to carry out ice depth, snow depth and marine profiling sampling – the CHARS contribution will allow for bi-monthly (rather than monthly) sampling across Dease Strait over the next 3 years;
2. by working with this MEOPAR proposal to ensure CHARS' own marine work is planned in concert to support the objectives of this and other projects;

3. to increase the impact of this research by acting as liaison to link this project to local communities, industrial actors, and other researchers, and;
4. by providing logistic support in the form of Cambridge Bay housing for research personnel of the proposal, use of CHARS' launches and other equipment, and access to CHARS' local field personnel as required.

We look forward to collaborating with the research team and collaborative partners that Dr. Mundy has assembled. If you require further information, please contact me at the address below.

Yours truly,

Dr. Martin Raillard,
Chief Scientist
Canadian High Arctic Research Station (CHARS)
Station de recherche du Canada dans l'Extreme-Arctique
Arctic Science Policy Integration/Direction de l'Integration des politique scientifique de l'arctique
15 Eddy, 14ième étage/Floor, piece / Room 1402H
Gatineau, Québec K1A 0H4
(819) 997-9880 bureau/office
martin.raillard@aandc-aadnc.gc.ca