Freshwater Resources of the Eastern Canadian Arctic

Project Leader

Warwick Vincent (Université Laval)

Network Investigators

Derek Mueller (Carleton University); Yves Bégin, Isabelle Laurion (Institut national de la recherche scientifique - Eau, Terre et Environnement); Connie Lovejoy, Reinhard Pienitz (Université Laval); Luke Copland (University of Ottawa); Kathy Young (York University)

Collaborators

Antoine Nicault, Denis Sarrazin (Centre d'études nordiques); Joël Guiot (Centre national de recherche scientifique); Luc Perreault (Hydro-Québec); Pierre Francus (Institut national de la recherche scientifique - Eau, Terre et Environnement); Christian Bégin, Martine M. Savard (Natural Resources Canada - Geological Survey of Canada (Québec)); René Roy (Ouranos); Scott Lamoureux (Queen's University); Jean-Jacques Boreux (Université de Liège); Hubert Morin;Danielle Laprise (Université du Québec à Chicoutimi); Etienne Boucher (Université du Québec à Montréal); Dominique Arseneault (Université du Québec à Rimouski); Michel Allard, Dermot Antoniades, Pierre Galand, Anne-Dorothee Jungblut, Julie Veillette (Université Laval); Bernard Laval (University of British Columbia); Derek Muir (University of Guelph); Antonio Quesada

Post-Doctoral Fellows

Frédéric Bouchard, Sophie Charvet, André Comeau, Jérôme Comte (Université Laval)

PhD Students

Anna Crawford (Carleton University); Sandy Erni, Maud Naulier, Karita Negandhi, Toni Roiha (Institut national de la recherche scientifique - Eau, Terre et Environnement); Alex Matveev (Université du Québec à Montréal); Fabio Gennaretti (Université du Québec à Rimouski); Sophie Crevecoeur, Bethany Deshpande, Biljana Narancic, Anna Przytulska-Bartosiewicz, David Velazquez (Université Laval); Andrew Hamilton (University of British Columbia); Nicole Schaffer, Laura Thomson, Wesley Van Wychen, Adrienne White (University of Ottawa); Hilary White (University of Waterloo); Anna Abnizova (York University)

MSc Students

Gregory Lewis-Paley (Carleton University); Melissa Nacke (Dalhousie University); Cristian Alvarez, Nanie Ayotte, Paschale Noël Bégin, Yves Bouthillier, Marie-Janick Robitaille, Gabriel Rodrigue (Institut national de la recherche scientifique - Eau, Terre et Environnement); Marie-Josée Girard; (Université du Québec à Chicoutimi), Anne Beaudoin, Valentin Proult (Université Laval); Tyler de Jong, Larissa Pizzolato, Miriam Richer McCallum (University of Ottawa); Elizabeth Miller (York University)

Undergraduate Students

Adam Garbo, Undergraduate Student (Carleton University); Catherine Girard, Pénélope Leclerc, Gabrielle Lupien, Simon Williams (Institut national de la recherche scientifique - Eau, Terre et Environnement); Alison Milan (York University)

Technical Staff

Luc Cournoyer, Claudia Zimmermann (Centre d'études nordiques); Marie-Josée Martineau, Marianne Potvin (Université Laval); Gudjon Kristinsson (University of Iceland); John Siferd (York University)

Abstract

Freshwater lakes and wetlands are abundant in the circumpolar Arctic, and still more freshwater is present in the form of glaciers and ice shelves. These freshwater environments provide many essential services including habitats for aquatic wildlife, drinking water for northern residents, and hydroelectricity. Inuit communities and northern scientists have increasingly observed that these resources are highly vulnerable to ongoing climate change. This project extends our observations on lakes and wetlands at key sites in the eastern Canadian Arctic, to identify and measure aquatic indicators of environmental change in the past and present. These studies are allowing us to make assessments of future changes in northern freshwater ecosystems to help guide the formulation of environmental management and monitoring policies. We are continuing our research on lakes, ice shelves and contaminants along the northern Ellesmere Island coastline based out of Ward Hunt Island Observatory, where we work with Parks Canada to develop facilities, indicators and protocols for long term monitoring. This coastline lies at latitude 83°N, at the northern limit of Nunavut and thus North America, and it is characterized by many climate-sensitive aquatic ecosystems that are highly dependent on ice. Discharge from glaciers also contributes to iceberg flux, which is important for shipping. We are extending our research to wetlands by assessing the snow storage and melt patterns in Polar Bear Pass on Bathurst Island (75°N). This Wildlife Sanctuary is composed of a mosaic of lakes and ponds, and seasonal snowmelt is considered the most important source of water to this wetland. The resultant models and understanding should be of broad application to arctic wetland wildlife habitats that have begun to respond strongly to climate change. Permafrost thaw lakes are a prominent component of northern wetland ecosystems, and we are working at several sites including Bylot Island (73°N) and Kuujjuarapik (55°N), to determine the environmental factors that control their ecosystem metabolism and net production of greenhouse gases in the present and future. This ArcticNet research is in collaboration with the Discovery Frontiers program ADAPT (Arctic Development and Adaptation to Permafrost in Transition), which involves 15 laboratories across Canada. We are analyzing sediment cores from northern waters in the Foxe Basin region (65-70°N), as well as on both sides of Hudson Bay, to assess the natural climate variability in arctic and subarctic Canada, and to identify regional variations in climate sensitivity. Additionally, we are documenting past climate changes in the eastern Canadian subarctic by way of an extensive network of tree-ring analysis sites. Finally we are developing and applying new DNA-based techniques to assess the diversity and function of microscopic life in lakes and wetlands and to develop state-of-the-art molecular indicators of climate responses by northern aquatic ecosystems. We are contributing our findings and expertise on Canadian arctic water resources to the ArcticNet IRISs, Canadian and panArctic climate impact assessments (for example, the SWIPA report), government agencies such as Transport Canada and the Canadian Wildlife Services, and circumpolar initiatives such as the 'Arctic Freshwater Synthesis' under the auspices of the International Arctic Science Committee (IASC). Furthermore, we will document past climate change in the eastern Canadian Subarctic by means of a vast network of millennial dendroclimatic series.

Key Messages

- Freshwater ecosystems (lakes, ponds, streams, wetlands) are a key element of permafrost landscapes in terms of biodiversity, water resources, biogeochemical activity and landscape change. These permafrost environments are responding rapidly to climate change, and the prediction and management of such environments requires an integrated permafrost systems perspective that couples together different types of data from different disciplines on all features of the landscape, including human activities.
- Our microbiological analyses at Ward Hunt Island show that the surface soil crusts that

stabilize the landscape harbor diverse bacterial communities, in fact as diverse as temperate latitude communities. The water tracks over the permafrost at these sites also contain a rich community of microscopic life, despite the severe high latitude climate.

- There is evidence of ongoing dramatic change in the ice-dependent ecosystems along the northern coast of Ellesmere Island, at the northern limit of Nunavut. Our ArcticNet automated camera captured the complete collapse and breakout of the Ward Hunt Ice Shelf in August 2012 (data downloaded in July 2013), with open water extending from Disraeli Fjord to the Arctic Ocean, perhaps for the first time in millennia. We discovered a new record of glacial retreat in this region, among many other indicators of change.
- Hillslope streamflow regimes continue to be dominated by snowmelt but summer rainfall is becoming more important at some sites in generating flow. Seasonal water budgets for hillslope basins differ across scale, from one island to the next (i.e. Bathurst Island versus Melville Island) and when compared with earlier QEI streamflow studies (timing of runoff, peak runoff, and runoff ratios etc). This makes it still difficult to simulate runoff in ungauged basins for sites draining into the Northwest Passage, particularly ones considered for water and oil/gas pipeline crossings.
- Extreme events particularly warm versus cold years and their affect on basin response (snowmelt, streamflow initiation, total discharge) should be examined in tandem to observe similarities and differences in responses.
- Greenhouse gases emitted from small arctic ponds (Bylot Island, Nunavut) are substantial, and in some cases from old carbon sources. Different types of permafrost thaw ecosystems use different types of organic carbon substrates and differ in their magnitude of greenhouse gas emissions. Ice wedge ponds around the edge of tundra polygons are particularly strong emittors.
- Canadian High Arctic glaciers currently discharge 2.6 +/- 0.8 Gt a^{-1} of icebergs to the oceans, representing ~7.5% of pan-Arctic iceberg discharge outside of Greenland. However, iceberg losses provide only a small proportion (~3%) of total annual runoff from the Canadian High Arctic as melt dominates this component.
- Ice island surface ablation represents a large component of their deterioration as compared to typical icebergs and to model this process adequately an energy balance approach should be used with high quality wind data.
- Milne Fiord has a complex bathymetry and Atlantic water at the fiord's bottom is responsible for basal melt of the Milne Glacier tongue. The Milne Fiord epishelf lake continues to thin and the southern third of the Milne Ice Shelf is now broken up.
- Subarctic lakes exert a climatic influence on their periphery and islands to a distance equal to the thermal air gradient that they cause, which varies according to season. No influence is evident from meteorological station and dendrometric data obtained in mid summer, but there are strong gradients exist in early summer and fall. Simulation modelling analyses applied to such gradients will provide insights into the biological effect of climate change across latitudinal gradients.
- Hydrological changes in thermokarst lakes have profound effects on wildlife habitat, carbon cycling, and other ecosystem processes. Similarly, snow accumulation and meltwater discharge processes in the catchment of thermokarst lakes have strong impacts on their hydrological and limnological properties, and vary along a vegetational and ecoclimatic gradients from south to north. Surface sediment geology and soil substrate type determine many characteristics of thermokarst lakes and the evolution of these characterstics through time.
- Paleolimnological studies show that glacial meltwaters from the Penny Ice Cap on Baffin

Island leave a climate-modulated signal in the sedimentary record from Nettilling Lake. Major postglacial geophysical and paleoenvironmental changes in the Foxe Basin region are clearly documented in the sediment archives from the Nettilling Lake basin.

Objectives

- Maintain automated weather station for Centre d'études nordiques (CEN) SILA Network in Nunavut (Bylot Island; Ward Hunt Island, Nettilling Lake) and Nunavik, and improve data access; continue to develop the CEN Network of Arctic terrestrial monitoring/research stations with its Community Science Centre hub at Kuujjuarapik-Whapmagoostui for knowledge exchange with northern communities, Inuit school science program, winter schools for graduate students, etc.
- Continue to develop an integrated permafrost systems approach in which freshwater ecosystems can be incorporated within a broad, multidisciplinary landscape perspective.
- Evaluate the microbial biodiversity and function of freshwater ecosystems (lakes, ponds, rivers, water tracks, wetlands) on permafrost landscapes in Northern Canada using molecular techniques based on DNA and RNA, HPLC pigment analysis and in situ methods.
- Estimate thaw lake contribution to atmospheric greenhouse gases in eastern Canadian Arctic.
- Describe the limnological and biodiversity of arctic thaw ponds, identify functional microbes, and determine if specific microbial assemblages are associated with specific types of aquatic ecosystems or limnological conditions.
- Determine major limnological features of subarctic thaw lakes as bioreactors and biodiversity hotspots in the forest tundra zone: evaluate the seasonal dynamics of oxygen as a master control in these waters on greenhouse gas production and loss processes; assess the microbial biodiversity and local versus long range patterns; analyze zooplankton community structure and their potential influence on the microbial communities; evaluate the capacity of these waters to grow harmful algal blooms, now and in the future.
- Determine the source of carbon and its availability to microbes using 13C, 14C, and incubation experiments on disolved organic carbon (DOC) reactivity to sunlight and microbial degradation.
- Analyze bio- and lithostratigraphic data and complete production of illustrations for diatom publications.
- Contribute to ArcticNet syntheses and interpretations for the IRIS assessments and International Arctic Science Committee (IASC) Freshwater Synthesis.
- Synthesize information on Arctic ice shelves as extreme habitats for life and as sentinels of climate change in the Arctic.
- Examine the degradation of Ellesmere Island ice shelves with respect to changes in thickness and extent (mass balance) and determine the climatological (air temperature, precipitation and solar radiation) and oceanographic (stratification and mixing of heat and salt) influence on this process. Evaluate these changes in the context of long term variability in ice conditions, over the last 8000 years.
- Examine the inter, and intra-seasonal runoff processes from extensive low-lying wetlands: Polar Bear Pass (PBP)-central Bathurst Island and Alison Inlet (AI)-SW Bathurst Island into neighbouring seawater channels and relate it to seasonal changes in wetland snowcover, inputs of hillslope streamflow, evaporation and storage using both field and modelling strategies.
- Quantify and compare CH_4 emission by ebullition and diffusion from arctic ponds in the continuous permafrost area.

- Determine the source of the carbon used by microbes and emitted as greenhouse gases using ^{14}C dating.
- Determine current and past mass balance of Milne Ice Shelf, and climate-related changes in the hydrography of Milne Fjord.
- Continue running the northernmost weather station in Canada with near real time data access at Purple Valley, Ellesmere Island.
- Investigate the processes of drift and deterioration of ice islands in Arctic waters as well as their ecological impact.
- Map velocity structure of all glaciers and ice caps in the Canadian High Arctic, and determine the importance of dynamic ice discharge to the oceans (i.e., iceberg discharge) as a mechanism of mass loss.
- Determine the climatic effect of large waterbodies on island and periphery forest growth.
- Provide an improved understanding of thermokarst lake hydrological processes in the eastern Hudson Bay region and the potential hydrological responses of these aquatic systems to climate warming.
- Examine the geochemical and isotopic characteristics of the lake sediments and the lake waters to better understand their hydrological settings and behavior. Specific objectives include: Infer lake-specific input water isotopic compositions that will be used to differentiate the relative roles of primary source waters (e.g., rainfall and snowmelt); Calculate lake-specific evaporation-to-inflow ratios to evaluate the influence of vapor loss.
- Gain insights into the evolution (or “life cycle”) of thermokarst freshwater ecosystems through the recovery of sediment cores that will serve to establish the temporal framework for the reconstruction of the limnological conditions over past centuries; Determine the present-day sedimentological and geochemical dynamics in the water column of these systems by analyzing the settling particles (mineral and organic) collected in sediment traps; Develop an inventory of the different substrate and habitat types that exist in these small water bodies to characterize the composition and biodiversity of their algal (diatom) communities.
- Determine the past and recent natural environmental climate variability of the Foxe Basin region and central Baffin Island; Quantitatively track long-term environmental changes during the last postglacial period, which covers approximately the last 6500 years; Provide oxygen isotope record from diatoms in paleoclimatological study of the lake region; Determine lake water isotopic composition and precipitation-specific isotopic signals.

Introduction

This project examines the range of aquatic resources of the eastern Subarctic and Arctic Canada, their biodiversity (with emphasis on microbial communities), ecosystem structure, hydrological and biological functioning and potential ecological responses to climate change. Additionally this project includes studies of glaciers, fjords and ice shelves of High Arctic Nunavut, which are sentinels of climate change and that also play a major role as aquatic environments for unique ecosystems. Via the close collaboration in ADAPT (Arctic Development and Adaptation to Permafrost in Transition), the project is developing an integrated systems perspective on freshwater ecosystems in landscapes underlain by permafrost. Via the contribution ARCHIVES, this project includes studies on the paleohydrology of high latitude environments, specifically by the use of tree ring analysis (dendrochronology) from wood samples retrieved from subarctic lakes.

In the far North, Ward Hunt Island, at the northern limit of the Canadian High Arctic, has proven to be a strategic site for the detection and analysis of environmental change given the diversity of freshwater and marine ecosystems, their extreme sensitivity to perturbations of the cryosphere (snow and ice-containing environments), and the current trend of accelerated warming at this far northern latitude. Our ongoing research program NEIGE (Northern Ellesmere Island in the Global Environment) within ArcticNet seeks to understand the structure, biodiversity and function of these ecosystems and to evaluate their environmental responses as sentinels of global change.

Over the last decade there have been substantial changes to the ice shelves of northern Ellesmere Island. A lack of regeneration suggests that ice shelf loss is irreversible (Copland et al., 2007), after being in largely in place for millennia (Antoniades et al., 2011). Since 2002, ice shelf break-up has led to the loss of layers of freshwater that have been held in place between coastal ice and the shore (Mueller et al., 2003). The Milne Fiord epishelf lake is the last of its kind, and it is opportune to study the properties of an intact lake to draw conclusions regarding former epishelf lakes in the region. Our research focuses on the past and current state of the ice shelves and the epishelf lakes and examines the link between their recent decline and climate as well as oceanographic warming/change.

The trajectory and distribution of ice islands (large tabular icebergs) is relevant to the operational mandate of the Canadian Ice Service (CIS), and this information is used in turn by Transport Canada and industry. Calving rates of glacier ice tongues and ice shelves are increasing dramatically (Mueller et al., 2008; Peterson, 2005) at a time of increased Arctic marine traffic creating an increased demand for ice hazard information. Operational models of iceberg drift and deterioration must therefore be extended to the ice island case with appropriate parameters such as geometric characteristics and model outputs must be validated against observations. In order to improve models and to better understand the ice island deterioration process, we have been instrumenting ice islands to follow their drift and melt. Research is also being conducted to examine ice island deterioration using remote sensing, improving the detection of ice islands using polarimetric synthetic aperture radar and examining the ecological implications of ice islands.

Wetlands are important ecological niches in High Arctic environments providing habitats for fauna and migratory birds (Vincent et al., 2012 and 2013, in the first ArcticNet IRIS volume in English, and French, respectively). However, these sites are sensitive to disturbance and can constrain northern development. To date, the hydrogeomorphology (Woo and Young, 2003) and the hydrology of small patchy wetlands in polar desert environments are well documented (e.g. Woo et al., 2006). More recent studies have started to focus on wetland complexes at the meso-scale (ca. 20-25 km^2) under diverse climatic conditions (Woo et al., 2008; Abnizova and Young, 2010) and at the regional scale. To address the latter we have been conducting ArcticNet studies at Polar Bear Pass, located in the central part of Bathurst Island. This 100 km^2 area has been designated a wildlife sanctuary providing food and shelter for migratory birds, and grazing caribou and muskox. It is an important hunting ground for Inuit. Polar bears den in the pass and often travel through the area to get to feeding grounds on the western coast of Bathurst Island. While the biology is well known (see Nettleship and Smith, 1975), its hydrology is less understood. Detailed hydrology studies initiated in 2007 have sought to improve understanding of the snowcover and melt patterns of this wetland, seasonal pond water storage, hillslope-wetland hydrologic linkages and terrestrial carbon movement. We are continuing to apply novel approaches (e.g. remote sensing imagery, a physically-based snowmelt model, DOC techniques) and the emerging results will help to assess its present hydrology and future sustainability under a warmer climate.

Although signs of recent climate change are more compelling in circumpolar regions, we have limited knowledge of Arctic climates and environments and their past variability. In order to better understand and anticipate the extent and nature of future changes in the Arctic, it is necessary to increase our capacity to model past environmental changes. Instrumental monitoring using high technology in circumpolar regions has been implemented only over recent decades. Hence, to extend the climate record in time, we use a multi-proxy paleolimnological approach to study the sedimentary records preserved in Nettilling Lake, the largest lake in the Canadian Arctic Archipelago. The main objective is to reconstruct the postglacial environmental history of the Nettilling Lake watershed using a vast array of biological and geochemical proxies.

Rapid permafrost degradation and thaw due to climate warming in circumpolar regions has resulted in the development of numerous shallow thermokarst lakes. Climate-driven changes in these aquatic systems across vast regions of the Canadian Arctic and Subarctic have major impacts on regional landscape hydrology. For example, thermokarst lakes may evaporate and desiccate due to longer ice-free seasons, or coalesce with other waterbodies to form larger basins and then drain directly into rivers as a result of lake expansion caused by permafrost thaw. Such profound changes in surface water conditions and overall distribution of lakes bring about ecological consequences as they provide vital habitat for northern wildlife. Our ongoing investigations on various aspects of thermokarst lake hydrology, limnology and paleolimnology in the eastern Hudson Bay region of Nunavik aim at providing a better understanding of hydrological processes in this region and the potential hydrological response of these aquatic systems to climate warming.

The ARCHIVES project led by Yves Bégin and his group was included in the Freshwater project to provide an assessment of climatic variables during historical times. Base on tree-ring analysis, Bégin et al. created a vast dendrochronological network from the James-Hudson Bays coastline to the outer edge of Labrador, from lat 52 to 56° North. Made of over 200 reference chronologies, several marginal works were conducted to document the various indicators of climate variations and changes. For exemple, a network of band dendrometers along with meteo stations are operating in this vast area. The data covering at least 5 years, and up to 18 years in some stations, are now available for a systhesis. Overall, the project was undertaken with Hydro-Quebec and Ouranos and aims to identify variables that significantly affect hydro-electric power production.

Activities

- A successful season was completed at Ward Hunt Island and along the Ellesmere Island coast. We continued our long term measurements from climate stations, permafrost monitoring and automated cameras, and our measurements tracking water column change in the lakes and fjords along the northern Ellesmere Island coastline. Specifically we profiled: Markham Fjord, Disraeli Fjord, Lake A, Ward Hunt Lake, Lake A, Lake B, and Milne Fjord. Our studies continued on the microbial communities and processes in the lakes and fjords of Ward Hunt Island and vicinity as a preliminary to a new set of microbial network studies to be initiated in 2014, with plankton samples from the surface waters of the lakes and fjords for analysis of microbial diversity and activity. Experiments were run to examine carbon cycling in cyanobacterial mat communities. Our geomorphological and hydrological research (GEO-NEIGE) was conducted in the Ward Hunt Lake watershed, to generate information on snow distribution, flow pathways, water quality, sediment movement and the timing of delivery.
- Ground-penetrating radar surveys were completed across the Milne Ice Shelf to map spatial variability in snow accumulation patterns. This information was supplemented with snow depth data downloaded from 3 automatic stations first installed across the ice shelf in summer 2012. Shallow ice cores were drilled in lake ice, glacier ice, sea ice and ice shelf areas to provide validation of satellite imagery, and to provide information on how the ice cover

in this area has changed recently. A total of 4 time-lapse cameras were downloaded and serviced to provide monitoring of snow melt and accumulation patterns across the study site, and to monitor ice shelf breakups when we weren't there. We recovered instruments that recorded temperature and salinity in Milne Fiord over winter and measured the currents in the fiord in an effort to understand how the ice shelf might be influenced by the ocean. The weather station located in Purple Valley (established in 2009) was serviced and downloaded. This station can be accessed by the public at http://tinyurl.com/milnewx. Ground-penetrating radar survey of the Milne Glacier ice tongue along with surface elevation profiles to map the ice freeboard will be used to model the influence of salt and heat on this ice mass. Profiles of current, conductivity and temperature were collected in Milne Fiord to determine the influence of melting ice and infer fiord bathymetry and mixing of water masses.

- A detailed terrain-based snow survey was conducted across Polar Bear Pass (PBP) late May, 2013. We monitored snowmelt directly at PBP using ablation lines and photographed the regional melt pattern, mid-June via helicopter. However, due to a cold season, melt was late, beginning late June. Detailed streamflow and water quality variables (conductivity, temperature, pH) were made at the eastern outlet stream of Polar Bear Pass (end of June to mid July, 2013). Water level was monitored continuously until early August. No helicopter was available after early August, so all water sensors were pulled out at this time. Stream discharge measurements continued at two hillslope catchments (Windy River, Landing Strip Creek), ongoing now since 2007-see Young et al. Hydrology Research, submitted. We downloaded video and climate data from the main Automatic Weather Station (AWS) near the PBP cabin. We continued to monitor water levels in study ponds representative of others across the Pass (linked, isolated). We surveyed small and shallow slope failures;–possibly potential new pathways for water and nutrient flow from upland areas to the low-lying wetland. We first saw these sites in 2012, likely triggered by an exceptionally warm summer.
- Greenhouse gas fluxes were measured using inverted submerged funnels installed in a series of thaw ponds located in the valley of C-79 glacier near the village of Pond Inlet (Bylot Island CEN field station) in July 2013. Gas samples from funnels and dissolved in water were taken to measure gas composition, 14C and stable isotopes in C and H. ^{14}C was also measured from dissolved organic matter, pond sediment and surrounding peat samples. Basic limnological characteristics of ponds were also taken (in water and sediment). This work was done by Gabrielle Lupien and Hilary White. A thermistor chain was installed in one pond to get a full year thermal vertical structure (2013-2014). Pond hydrology was studied by sampling oxygen-18 from a large series of ponds and lakes in the valley and surrounding region, at 3 times from the beginning of July to the end of August 2013. This was done by Hilary White, with the help of Gabrielle Lupien and Audrey Robillard.
- Sediment cores were analyzed by both non-destructive (X-radiography (X-ray), microfluorescence-X (μ-XRF), magnetic susceptibility) and destructive (Loss-On-Ignition, grain size, water content, thin sections, diatoms, foraminifers) techniques. Sedimentological and geochemical changes were analyzed using a Multi Sensor Core Logger and a microfluorescence scanner. Radiometric AMS ^{14}C and $^{210}Pb/^{137}Cs$ age determinations, as well as paleomagnetic measurements, were used to develop the core chronologies. Lake water, lake ice and rain samples were collected and analysed to determine their specific isotopic composition.
- Water samples were collected from thermokarst lakes and ponds located between Whapmagoostui-Kuujjuarapik and Rivière

Nastapoka (Nunavik), at four different “ADAPT super-sites” distributed across an ecoclimatic gradient, from site SAS in the South to site NAS in the North, to analyze molecular micorbial biodiversity; to measure the fluxes of greenhouse gases (methane and CO_2); to determine limnological characteristics including zooplankton community structure; and to perform water oxygen isotope composition (δ^2H, $\delta^{18}O$) analyses. Precipitation samples (rain and snow) were collected at CEN station in Whapmagoostui-Kuujjuarapik as part of a three-year project that determines the isotopic composition of atmospheric precipitation in the region. Sediment cores were retrieved from a thermokarst pond (site ‘SAS-2A’), and settling particles (mineral and organic fractions) were sampled with an automated sediment trap in site BGR-A, all for the purpose of completing paleolimnological and sedimentological analyses to better understand the developmental phases in the “life cycle” of these aquatic ecosystems. A full 12 month record was obtained of oxygen, temperature and conductivity dynamics in a thermokarst lake at the BGR site near Umiujaq.

- In the James Bay-Hudson Bay area, studies were undertaken of ice flood regimes of lakes over the past century in the High Boreal Zone (Masters theses in collaboration with É. Boucher, UQAM). Forest fire regimes were assessed for the northern edge of the boreal continuous forest zone over the past two centuries as an indication of drought periods (PhD thesis of Sandy Erni in collaboration with D. Arseneault UQAR). The installation and maintenance of instruments and data download continued at various locations in the James and Hudson Bay region with a special effort for station servicing and additional environmental measurements in the lake and catchment at Lac à l’eau claire (Clearwater Lake) including in a palsa (collaboration with N. Bhiry).

Results

Our NEIGE contribution to this project in ArcticNet showed that the High Arctic experienced a cooler summer than in previous years. The large year-to-year variation in climate is seen from Fig. 1, updated to July 2013, for maximum air temperature at our SILA station on Ward Hunt Island (Fig. 1). These data are now in the public domain in Nordicana-D. As presented at our ArcticNet plenary (Vincent and Sarrazin 2013), these and related ecosystem and geosystem observations draw attention to ArcticNet’s essential input to multi-year environmental records and reporting for the Canadian Arctic, and the vital need for Canada to assure the ongoing provision of such observations and reporting at this time of rapid change.

Our automated camera (2 images per day) located on the southeastern side Ward Hunt Island was downloaded in July 2013 and captured the final break out of Ward Hunt Ice Shelf in August 2012.

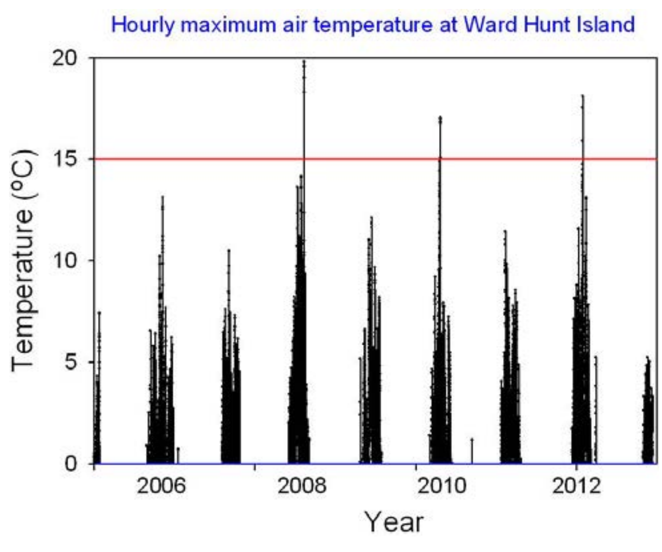


Figure 1. Hourly maximum air temperatures during summer at our ArcticNet-CEN automated climate station on Ward Hunt Island (lat. 83oN). The observations illustrate the strikingly large year-to-year variability, with several recent years of extremely warm conditions. The effects of this variability on the ice-dependent geosystems and ecosystems of this region are further amplified by this warming above the freeze-thaw 0oC line. From: Vincent and Sarrazin (2013).

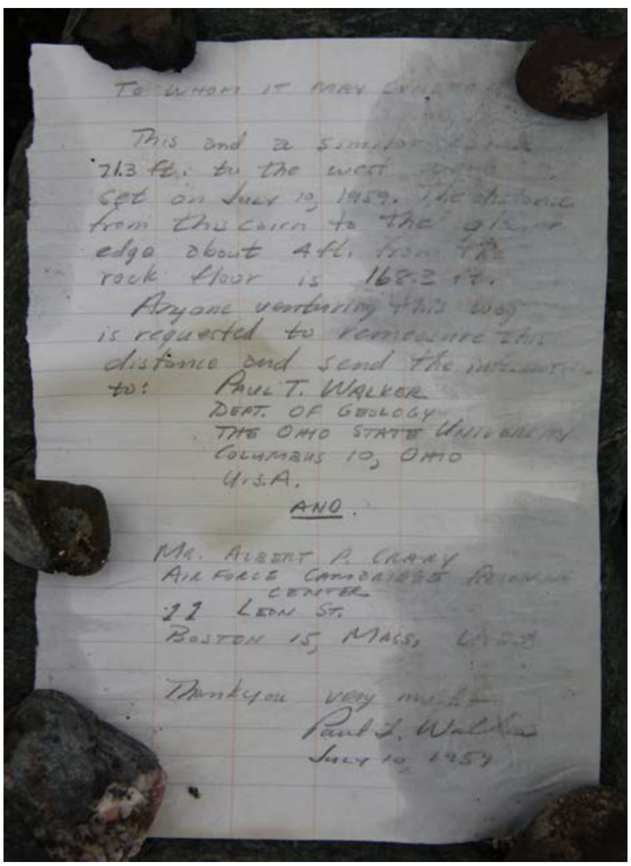
Disraeli Fjord at that time became fully open to the Arctic Ocean, perhaps for the first time in millennia (Fig. 2a, b). Details of the automated camera: Harbortronics time-lapse camera system modified for cold environments. It uses a Digisnap controller with external battery and solar panel enclosed in a fiberglass box. The Digisnap controls a Canon EOS Digital Rebel XS camera that has a CMOS sensor of 10,1 megapixels. The dimensions of the photos are 3888 x 2592 (pixels). Focal stop of F/14, exposure time of 1/320 sec and focal length of 28 mm. Images were programmed to be taken twice per day, 14h45 and 16h45.

Figure 2. Automated camera images of the final break out of Ward Hunt Ice Shelf in August 2012. Disraeli Fjord at that time became fully open to the Arctic Ocean, perhaps for the first time in millennia. a. 10 July 2012; b. 28 August 2012. From: Vincent and Sarrazin (2013).

We discovered a new site with a luxuriant microbial mat ecosystem: a shallow inland waterbody (unofficially named Walker Pond, Fig. 3a) located near a glacier (Fig. 3b) between Markham and Disraeli Fjords. At that site (lat. 83 00'N; long. 72 12'W) we discovered a cairn containing a bottle, with a message from Paul T. Walker (whose name is given to 'Walker Hill', the highest point on Ward Hunt Island, probably Canada's northernmost peak) dated 10 July 1959 (Fig. 3c). It marked the distance from the cairn to the glacier as 168.3 feet. We re-measured the distance to the glacier and found it to be 401 feet. This large retreat (about 70 m) highlights the pronounced warming of the Ward Hunt region over the last half century, and

Figure 3a. Sampling the microbial mats. ArcticNet sampling in July 2013 in a glacier-blocked coastal valley of northern Ellesmere Island, unofficially named the 'Walker-Crary Valley'. (From Vincent & Sarrazin, 2013).

Figure 3b. The glacier. (From Vincent & Sarrazin, 2013)



TO WHOM IT MAY [illegible]

This and a similar [illegible]
71.3 ft. to the west [illegible]
set on July 10, 1959. The [illegible]
from this cairn to the [illegible]
edge about 4 ft. from the
rock floor is 168.3 ft.
Anyone venturing this way
is requested to remeasure this
distance and send the [illegible]
to: PAUL T. WALKER
DEPT. OF GEOLOGY
THE OHIO STATE UNIVERSITY
COLUMBUS 10, OHIO
U.S.A.
AND
MR. ALBERT P. CRARY
AIR FORCE CAMBRIDGE RESEARCH
CENTER
11 LEON ST.
BOSTON 15, MASS, U.S.A.
Thank you very much
Paul T. Walker
JULY 10, 1959

Figure 3c. The message in the bottle. (From Vincent & Sarrazin, 2013)

the strategic importance of ongoing measurements in this region. We carefully replaced the note in the bottle (along with our own) and replaced the rocks, so as to leave the site undisturbed, consistent with our NRI License and Parks Canada Research Permit, and the usual ethics of polar research and exploration. This discovery of a 54-year old message generated enormous popular interest around the world when we presented it at the ArcticNet meeting in Halifax, December 2013, including CBC North, CBC national radio shows and Radio Canada, LA Times, Fox News, Huffington Post, the Weather Channel, Chicago Tribune, Internet TV channels (AOL, Grind TV, Newsy, etc), Daily Times UK, Mon Quotidien (Paris), Wunderwelt Wissen (Hamburg), Popular Science (New York), Up Here (inflight magazine, Canadian North), the International Business Times, among many others, and on Twitter and Facebook.

Our early results in the geomorphological part of our work (GEO-NEIGE-ADAPT; Fig. 4) show that water is channeled in the coarse sections of sorted nets that form underneath snow drift. These underground “channels” are similar to soil pipes and they favor nutrient and sediment movement through the landscape and into Ward Hunt Lake. The channeled flow also emerges to form “water tracks”, a type of

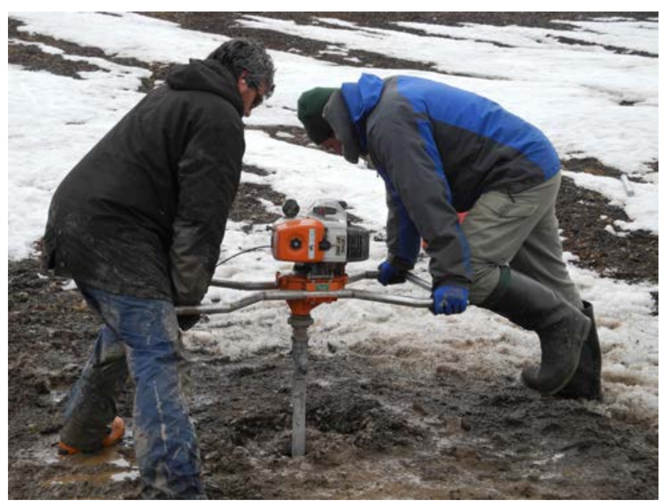


Figure 4. ADAPT permafrost drilling in support of the ArcticNet water track research on Ward Hunt Island. Photo: W.F. Vincent (CEN/ArcticNet).

overland flow whose characteristics have yet to be clearly defined in the literature. One of the effects of these water tracks on the soil is their cooling effect, as the flow of water through them slows down the thawing of the active-layer during early summer. This contrasts with what has been observed in regions of warmer permafrost.

A series of conductivity and temperature profiles were taken by Mueller's team in Milne Fiord (about 100 km to the west of Ward Hunt Island) from the open ocean to the Milne Glacier grounding line. We have been able to elucidate that the inner portion of Milne Fiord (maximum depth: 450 m) is isolated from the ocean from a 265 m sill that lies beneath the Milne Ice Shelf. The profiles also show the distribution and proportion of meltwater in the fiord and indicate that the Milne Glacier tongue is melting the fastest its grounding line (142 m below sea level) where it is closest to relatively warm (up to 2°C above freezing) Atlantic water below. This meltwater plume rises and entrains marine water as it spreads out.

Large fractures were observed across the Milne Ice Shelf in May and in July 2013. These cracks were likely created following open water in the Milne Fiord epishelf lake in August 2012. The southern-most third of the ice shelf appears to have broken into pieces, some drifting south up to 1 km from their original positions. As noted above, this summer, was cool with air temperature along the northern coast of Ellesmere Island being lower than they have been in the past decade (Fig. 1 above and Richer-McCallum, unpublished). Consequently, there was little, if any break-up of ice this past year.

In related work, an energy balance approach was used to examine the surface melt of an ice island adrift in Lancaster Sound during August 2011 (Crawford et al. Submitted). This ice island (unofficially named Berghaus) was instrumented with an automated weather station that telemetered hourly observations via Iridium satellite. The analysis shows that turbulent heat fluxes (in particular sensible heat flux) is responsible for most (82%) of the melt observed, while net radiation is the dominant cause of melt during

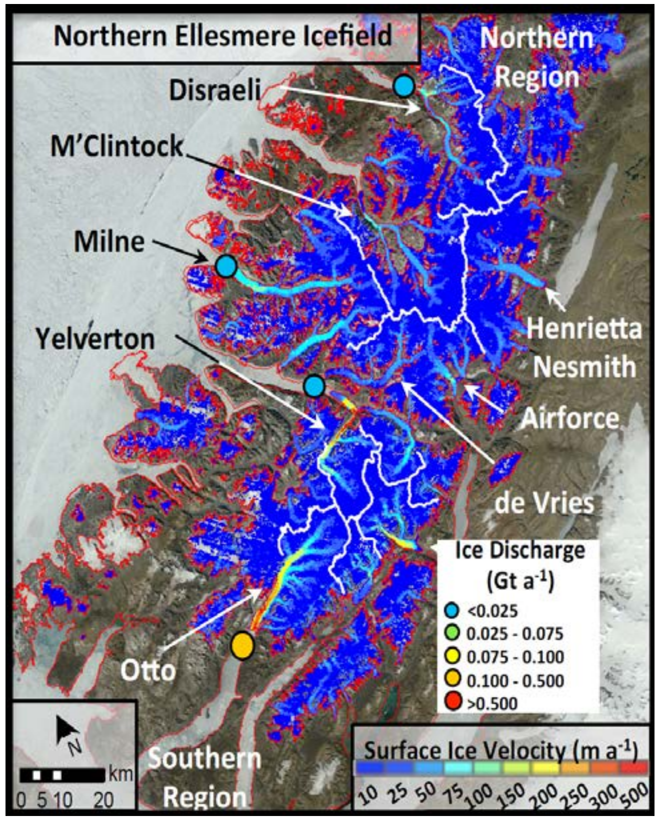


Figure 5. Surface velocity structure of the glaciers and ice caps of northern Ellesmere Island, derived from speckle tracking of pairs of Radarsat-2 imagery from winter 2012. Ice discharge values indicate volumes of ice reaching the ocean from outlet glaciers (excluding ice shelves). Northern Ellesmere Island currently accounts for 0.21 +- 0.06 Gt/yr of glacier discharge to the oceans, which equates to 8.1% of the total for the Queen Elizabeth Islands. This figure provides the first complete ice velocity and discharge map for this region. From: VanWychen et al. (2014).

especially calm conditions. This study also validated a variety of models that predict surface ablation and recommended that future ice island deterioration models use an energy balance approach, in spite of the sensitivity to wind speed which was found to be inaccurately predicted by weather models.

We completed the mapping of the velocity of all ice masses across the Canadian High Arctic, and a paper has just been accepted in Geophysical Research Letters with the detailed results (Fig. 5). Velocities in the interior parts of ice caps are typically <10 m a^{-1}, indicative of ice frozen to its bed. Most tidewater glaciers have velocities of 30-90 m a^{-1}, rising to 300 m a^{-1} at their termini. Land-terminating glaciers are typically slower, with velocities of 20-50 m a^{-1} and a maximum of ~75 m a^{-1} at their termini. Based on the velocity maps, iceberg production from the glaciers and ice caps of the Canadian High Arctic was 2.6 +/- 0.8 Gt a^{-1} in 2012. This equates to about 7.5% of total northern hemisphere iceberg production outside of Greenland. However, iceberg production is relatively unimportant as a source of current mass loss in the Canadian High Arctic, which saw total annual runoff of ~83 Gt a-1 in 2012.

At Polar Bear Pass, the snowmelt pattern in 2013 was quite different from what was observed in 2012. The climatic conditions were much more severe (as also observed by our northern Ellesmere Island teams). In 2012, Thawing Degree Days (TDD) reached 436 and number of thaw days (TD) was 88, and summer precipitation (JJA) reached 58.3 mm. In 2013, summer precipitation was similar (56.7 mm) but TDD were only 139 and TD reached only 45. In the wet meadow snow amount was double that in 2012 (60 mm vs. 30 mm, in snow water equivalent terms), and melt-out was 10 days later than in 2012. Likewise, the plateau area captured more than double the amount of snow in

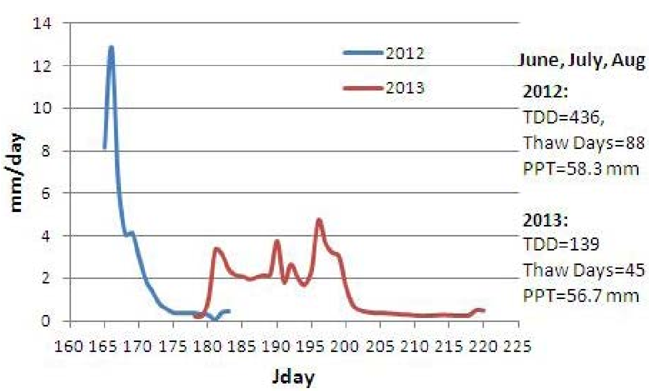


Figure 6. Streamflow out of the eastern part of the pass in 2012 (blue line) versus 2013 (red line). Here we assume that the eastern sector drains half of the Polar Bear Pass wetland area. Climatic conditions in 2012 and 2013 are provided. Note that timing of streamflow in 2013 was later, discharge peaks were lower and runoff was prolonged (K. Young, unpublished).

Figure 7. Early stage of snowmelt discharge at the eastern stream outlet site, June 28, 2013. Note the basal ice on the stream bottom and the trong current. The stage barrel is nearly submerged. Photo: K. Young.

2013 (45 vs. 15 mm). Disappearance of snow here was 16 days later than in 2012. The late-lying snowbeds did not capture more snow but they still persisted well into July. In 2012, most late-lying snowbeds in the vicinity of the PBP cabin melted out by July 1.

Relatively deep snow and cold conditions resulted in a late start to streamflow out of the wetland and discharge did not peak until early July about 3 weeks later than in 2012 (Fig. 6, 7). While melt runoff was 11 days in 2012, it persisted for much longer in 2013 (27 days), and was much lower in magnitude. Multiple peaks in the stream hydrograph follow the pattern where the north side of the Pass melts out first and then is followed by the southern end (Assini and Young, 2012).

On Bylot Island, our ^{14}C dating results reveal an old signature in methane (1910 BP) and CO_2 (1425 BP) from a deep pond, but modern CH_4 and CO_2 with different age (modern to 550 BP) from shallow ponds. Ponds formed over melting ice wedges (Fig. 8) are larger emitters of CH_4 than ponds on top of low-center polygons, and both types of ponds shelter active communities of methanogens (mainly acetotrophs, but hydrogenotrophs are also present). Methanotrophs are more abundant in polygonal ponds, and their activity is

Figure 8. Ponds formed over melting ice wedges, such as this one on Bylot Island, are larger emitters of methane than ponds on top of low-center polygons. Photo: K. Negandhi (CEN/ArcticNet).

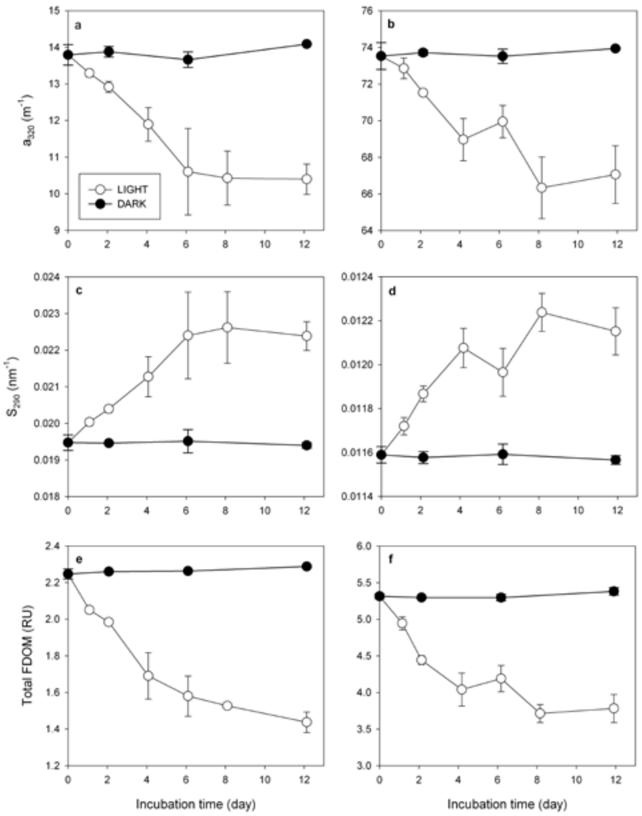


Figure 9. Photochemical degradation of dissolved organic matter (DOM) in thaw ponds of the High Arctic (Bylot Island), expressed as a decrease in the absorption of DOM and an increase in the absorption slope, indicating a modification in the quality of DOM as it is been transformed by sunlight. From Laurion and Mladenov (2013).

apparently more intense, as indicated by the bacterial assemblages (pyrosequencing) and stable isotopes in CO_2 and CH_4. Runnel pond sediment, experimentally subjected to warmer temperatures (+5°C) showed increased production of CO_2 and CH_4. The sediment bacterial communities become more diverse under increased temperature, but with no increase in methanotrophs.

Photochemical transformation of DOC has been described as an important mechanism to generate more labile compounds from large humic DOC molecules, as evidenced by increased bacterial production and bacterial growth efficiency after exposure to sunlight. The present study suggests that coloured dissolved organic matter (CDOM) in both polygon and runnel thaw ponds may contain a large fraction of humic molecules derived from terrestrial sources, with >66 % of fluorescence derived from humic-like molecules. The action of light resulted in significant and quick CDOM loss in our study (Fig. 9), which has the potential to improve the bioavailability of the organic matter mobilized by permafrost thawing and accelerate its mineralization, especially in the abundant shallow aquatic systems of the high Arctic. The length of the ice-free season, the lake mixing regime, and the movement of water and organic matter between terrestrial and aquatic systems are all likely to be affected by climate change; thus they will also influence photolysis rates and have important consequences for microbial mineralization. Photolysis should therefore be taken into account in global estimations of future GHG emissions from inland waters.

Sedimentation rates (0.15 $cm.yr^{-1}$) in Nettilling Lake, Baffin Island (Foxe Basin region, Nunavut) are high compared to other Arctic lakes, due to inputs of highly turbid meltwaters from Penny Ice Cap with high suspended sediment loads. Comparisons of geochemical profiles of Si, Ti, K, Ca in lake sediment

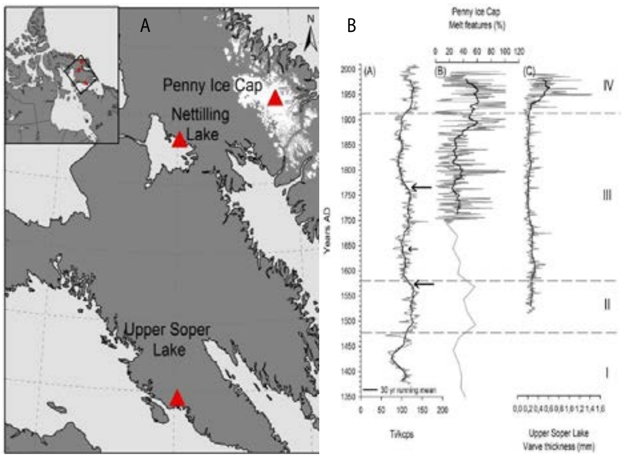


Figure 10. Sediments from Nettilling Lake on Baffin Island are providing a superb paleolimnological record of environmental change over the last 600 years. a. The sedimentology and geochemistry of this lake is intimately connected to the glacial meltwater inflow from the Penny Ice Cap. b. Our detailed geochemical analyses also indicate three periods of reduced melting prior to the present: in 1580, 1650 and 1770 A.D. (Beaudoin et al. in prep), which correspond to cooling events/periods on Baffin Island as suggested by Miller (1973), Locke (1987) and Margreth et al. (in prep.). Thus, the combination of sediment geochemistry with other proxies represents a significant improvement for reconstructions of past climate variability.

cores and melt rates from Penny Ice Cap since the 19th century reveal that variations in detrital elements in Nettilling Lake sediments might be used as an indirect indicator of regional climate fluctuations (e.g., summer temperatures) that determine glacier melt rates (Fig. 10). Long sediment records document the post-glacial marine-lacustrine transition through paleosalinity shifts inferred from core chemistry and composition of fossil diatoms and foraminifers. Shifts in Ca/Ti, Cl and Si/Ti indicate changes in paleosalinity and paleoproductivity, respectively, thereby reflecting marine regression and the end of marine influence. Fossil chironomid remains first appeared in the record after basin isolation from post-glacial marine waters and the establishment of freshwater conditions. Low Mn/Fe element ratios indicate strong anoxic conditions in the lower water column during the saline to freshwater transition.

In the super-region for ADAPT (a satellite program of ArcticNet) we found that thermokarst lakes situated in sporadic permafrost terrain in the south are more isotopically enriched, and thus experience greater evaporation, than those from discontinuous permafrost terrain to the north. Lakes overlying mineral-rich soil (lithalsa) with scarce vegetation are more isotopically enriched due to evaporation than lakes overlying organic-rich soil (palsas) surrounded by forested vegetation, while lakes in close proximity to rivers are isotopically depleted, possibly indicating the influence of river flooding. Our limnological work on these extremely abundant waterbodies is showing that they have large volumes of water that are completely anoxic and thereby conducive to methane emissions, they have diverse assemblages of microbes responsible for greenhouse gas production and loss, and they contain abundant and diverse populations of zooplankton that may exert a control on the functioning of these gas bioreactors in the tundra. This work will now move into its data analysis publication phase, with complementary field measurements in 2014-2016.

Our work in the James Bay-Hudson Bay region is establishing a model of fire extension along with climate variables in the High Boreal Zone. The model shows clearly that the large fires correspond to periods of low hydraulicity of northern lakes and reservoirs. The climatic response of forest growth is closely dependent on tree age and forest density. Open and young forests are more sensitive to temperatures, whereas dense and mature forests are sensitive to variations in humidity. A pronounced split in the data for the Caniapiscau reservoir discriminates the forest response to climate variables: the Hudson-James Bay area trees appear to be more sensitive to humidity and forests that are further inland (eastwards), which react mainly to temperature. Our work at Clearwater Lake shows that the climatic influence of the lake is limited to the cooling effect that water and ice have on the lower atmosphere. In early summer, this cooling effect can be as much as 19°C. It is reduced in late summer, and reappears at the time of ice-up.

Discussion

Our work on freshwater ecosystems and ice throughout the eastern Canadian Arctic is revealing how rapidly the northern environment is changing, and the need to respond proactively and in an integrated, multidisciplinary fashion to monitor, assess and manage these changes. One such approach that we have published on this year is through the development of an Integrated Permafrost Systems perspective, which is the central objective of the ArcticNet satellite program ADAPT. Freshwater resources must be viewed as a vitally important part of the coupled air-land-ice-water-biota-human system. To understand their responses to permafrost change will require integrating a broad spectrum of disciplines, including geomorphology, geophysics, biogeochemistry, microbiology, ecology, and civil engineering to identify the processes that couple environmental change to the rate and state variables of permafrost geosystems and ecosystems.

Our ArcticNet work coupled to the project ADAPT places emphasis on identifying the critical places and periods of rapid change in permafrost and snow characteristics that have amplified effects on the Arctic's natural infrastructure and on its ability to provide geo- and ecosystem services. These services in the aquatic environment include wildlife habitat availability, potable water supply, biodiversity (including microbial diversity), fish production, carbon and nitrogen cycling, flood and erosion control, and greenhouse gas consumption. Our work on thermokarst lakes, water tracks and ice-bound lakes is linked to the overarching hypothesis that liquid water and snow cover control heat, sediment, carbon, and microbial transport, and thereby affect thermodynamic stability, geomorphological processes, and the ecology, biogeochemistry, and human use of these aquatic ecosystems on permafrost landscapes. Our approach uses a conceptual model of the permafrost system that, from top to bottom, represents permafrost with three layers and two interfaces as shown in Figure 11: the atmosphere-snow-vegetation layer (the "buffer layer"),

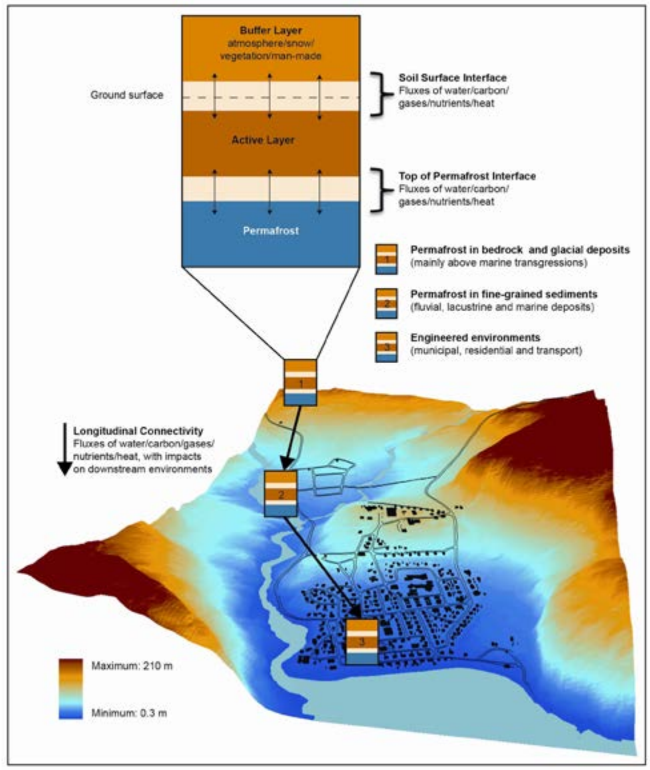


Figure 11. The ADAPT three layer model of permafrost landscapes, and connectivity of the landscape via streams and rivers to the sea. From Vincent et al. (2013).

the soil surface interface, the active layer, the interface between the active and the permafrost layers, and the permafrost layer itself. This three-layer depiction is also relevant in engineered environments, where the buffer layer contains human infrastructure (Fig. 11).

Our oceanographic work in Milne Fiord has revealed that the distribution of heat and salt within this system has implications for the stability of the Milne Glacier tongue via melting at depth. The ice shelf however, has a much shallower draft and is not directly influenced by warm Atlantic water (Hamilton et al., unpublished). The ice shelf does appear to be changing rapidly (it is the last of the six major ice shelves to break up this Century). Changes in the ice shelf are also linked to the ongoing thining of the Milne Fiord epishelf lake. This is the Northern Hemisphere's last epishelf lake and it has thinned by >50 % in the last 3 decades (Mortimer et al., 2012; Hamilton et al., unpublished).

The break-up of its perennial ice cover in summer 2012 was unprecedented and resulted in a large-scale fracturing of the ice shelf.

The analysis of ice island surface melt models (Crawford et al., submitted) shows that it is possible to model ice island surface melt provided that the melt model is forced with output from an accurate weather prediction model. Turbulent fluxes were shown to be important drivers of melt and therefore melt models are sensitive to wind speed. The global environmental multiscale (GEM) model, that was used to test operational surface melt models overpredicted the wind speed by 57 % on average and therefore models run with these inputs had much less skill than those driven by in situ data.

Our work on thermokarst waters is revealing their intense biogeochemical activity, and their role as microbial bioreactors on the tundra. These ecosystems contain a complex mixture of microorganisms form the three domains of life, and as revealed in the 2013 season, have extensive regions of anoxia (zero oxygen) that is conducive to methane production. Our work shows that not only are microbial processes important in organic carbon breakdown in these waters, but photochemical processes also play a role. These issues will be addressed in great detail during the upcoming THAW-2014 international workshop.

The result of variable ^{14}C age in GHG observed from a series of ponds is striking and needs further measurements, notably to check the presence of talik that would explain the old signature from deeper ponds, and more information on carbon lability that could explain why methanogenesis is using young carbon but not other respiration processes. The inverse relationship obtained between the relative abundance of methanotrophs and the concentration of methane in a series of ponds suggests the mitigating action of methanotrophs on emissions. This will need to be done in a larger series of ponds.

The cool 2012 versus warm 2013 field seasons at all our sites in the High Arctic highlight the need to continue to investigate extreme events in Arctic basins. Dramatic shifts in climate from one year to the next alter the timing of ice ablation, snowmelt, runoff and likely water storages, whether this is storage in late-lying snowbeds, groundice accumulation or water levels in ponds and streams at the end of the season. These storages can impact the response of catchment the following year(s) (Woo et al. in press).

Our recent work documents the response of streamflow in hillslope catchments at Polar Bear Pass and Cape Bounty in relation to previous studies across the Queen Elizabeth Islands (70's/80's). This research showed that the timing of runoff, peak response at PBP and CB was significantly earlier than these previous studies and can be tied to a warming climate since 2000. However, if one considers the 2013 preliminary data from the outlet stream at PBP, the timing, runoff duration are more reflective of these earlier basin studies. The 2013 year, may be a one year anomaly as the Arctic continues to warm, but these extreme conditions, whether exceptionally warm or cold deserve more attention as to better understand how they impact on basins (i.e. cumulative responses).

In the southern part of our sector of research activities, our work has continued on tree ring analysis of climate change. Most of the existing tree-ring network are based on the oldest trees found over large areas. The ARCHIVES network was based on a territory that is frequently disturbed by fire, so the forest is a patch mosaic of different tree ages and density. Since we studied tree growth along with the large natural gradients (continentality, altitude and latitude), and by isolating various contribution factors: proximity of large waterbodies that may exert a cooling or warming effect, effects of climate of fire history, and different processes such as ice-floods, summer floods, drunken forest immersed several years, etc., we now have a set of data from which local effects can be interpreted and subtracted from the regional effect of climate. Our climate reconstructions are then ecologically controlled. We plan to finalize this work in 2014-15 by a full analysis of the detailed data obtained from our instrumental dendrometric network. This will bring the ARCHIVES project to completion.

Conclusion

Our results from the High Arctic continue to reveal the diversity of freshwater resources in the eastern Canadian Arctic and Subarctic and their sensitivity to ongoing warming. Our work during the relatively cool 2013 season has underscored the large year-to-year variations in climate in the High Arctic, and the need for continuous monitoring. Inter-annual variation was observed in ice-cover, snow cover, and meltwater generation. Our work highlights the importance of the snow pack as a source of water for lakes, streams and wetlands, and the need to develop an Integrated Permafrost Systems perspective on the role of freshwaters in permafrost landscapes in transition.

We have previously noted that all small surface waters are supersaturated in CO_2 and therefore represent strong sources of this GHG to the atmosphere, however some sites are much more active than others. Our work this season shows that the narrow ice-wedge ponds of the tundra appear to especially active in methane generation, and has also revealed the importance of sunlight in breaking down organic materials by photochemical action in these waters.

The “health” of northern freshwaters is of fundamental importance to northern communities, and our lake, fjord, ice, snow and ice shelf observations contribute to a better understanding of the potential social and economic impacts of global climate change. This suite of observations also provides an “early warning system” for northern aquatic ecosystems to help guide conservation and management measures, and to direct future research initiatives. Our measurements of a wide range of indicators, from glacier and ice shelf observations, to lake ice and mixing dynamics, are showing that a striking recent trend of warming impacts is superimposed upon the large interannual variability. Our paleolimnological research, such as at Nettilling Lake, Nunavut, and on the thaw lakes of Nunavik, and our tree ring studies in the James Bay-Hudson Bay area, are allowing us to place these present-day field observations in a longer term, historical context.

Acknowledgements

We thank ArcticNet, the ArcticNet Aircraft Support Fund, NSERC, PCSP, NSTP, York University, Université Laval, Centre d’études nordiques (CEN), CEN supplement nordique (logistique au Nunavik), INRS-ETE, IBIS, FRQNT, Parks Canada, NSTP (PFSN), CFI, Ontario Research Fund, University of Ottawa, Canadian Space Agency SOAR-E program, Carleton University, NSERC, Canadian Ice Service, Transport Canada, Canadian Space Agency SOAR-E program, EnviroNorth, Nunavut Research Institute and the northern communities of Nunavut and Nunavik.

References

(others are given in the 2013 publication list)

Abnizova, A., Young, K.L. and Lafreniere, M. 2012, Pond hydrology and dissolved carbon dynamics at Polar Bear Pass wetland, Bathurst Island, Nunavut. Ecohydrology.

Abnizova, A., Young, K.L., 2010, Sustainability of High Arctic ponds in a polar desert environment. Arctic 63, 1:67-84

Antoniades, Dermot, P. Francus, R. Pienitz, G. St-Onge, and W. F. Vincent. 2011. “Holocene Dynamics of the Arctic’s Largest Ice Shelf.” Proceedings of the National Academy of Sciences 108 (47): 18899–904.

Copland, L, D R Mueller, and L Weir. 2007. “Rapid Loss of the Ayles Ice Shelf, Ellesmere Island, Canada.” Geophysical Research Letters 34: L21501. doi:10.1029/2007GL031809.

Crawford, Anna, D. R. Mueller, Elyn Humphreys, Tom Carrieres, and Hai Tran. “Surface Ablation Model Evaluation on a Drifting Ice Island in the Canadian Arctic.” Cold Regions Science and Technology: Submitted.

England, John H, Thomas R Lakeman, Donald S Lemmen, Jan Bednarski, Thomas G Stewart, and David J A Evans. 2008. "A Millenial-Scale Record of Arctic Ocean Sea Ice Variability and the Vulnerability of the Ellesmere Island Ice Shelves." Geophysical Research Letters 35: L19502. doi:10.1029/2008GL034470.

Mortimer, Colleen A., Luke Copland, and Derek R. Mueller. 2012. "Volume and Area Changes of the Milne Ice Shelf, Ellesmere Island, Nunavut, Canada, since 1950." Journal of Geophysical Research 117 (F4): F04011. doi:10.1029/2011JF002074.

Mueller, D R, M O Jeffries, and W F Vincent. 2003. "Ice Shelf Break-up and Ecosystem Loss in the Canadian High Arctic." Eos, Transactions of the American Geophysical Union 84 (49): 548,552.

Mueller, D R, W F Vincent, and M O Jeffries. 2003. "Break-up of the Largest Arctic Ice Shelf and Associated Loss of an Epishelf Lake." Geophysical Research Letters 30 (20): 2031. doi:10.1029/2003GL017931.

Peterson, I. K. 2005. "Large Tabular Icebergs and Ice Islands off Eastern Canada in 2001-2003 and Their Probable Source." In Proceedings of the 18th International Conference on Port and Ocean Engineering Under Arctic Conditions, 1:143–52. Potsdam, USA.

Vincent, W.F., Fortier, D., Lévesque, E., Boulanger-Lapointe, N., Tremblay, B., Sarrazin, D., Antoniades, D., and Mueller, D.R. (2011) Extreme ecosystems and geosystems in the Canadian High Arctic: Ward Hunt Island and vicinity. Écoscience, 18(3) 1-26.

Woo, M.K., Young, K.L., 2003, Hydrogeomorphology of patchy wetlands in the High Arctic, polar desert environment. Wetlands, 23, 2:291-309.

Woo, M.K.,Young, K.L., 2004, Modelling arctic snow distribution and melt at the 1-km grid scale. Nordic Hydrology, 35, 4:295-307.

Woo, M.K., Young, K.L., Brown, 2006, High Arctic patchy wetlands: Hydrologic variability and their sustainability. Physical Geography, 27, 2:1-11.

Publications

(All ArcticNet refereed publications are available on the ASTIS website (http://www.aina.ucalgary.ca/arcticnet/).

Abnizova, A., Young, K.L. and Lafreniere, M., 2013, Pond Hydrology and Dissolved Carbon Dynamics at Polar Bear Pass Wetland, Bathurst Island, Nunavut, Ecohydrology, doi:10.1002/eco.132,3, 2012

Abnizova, A., Young, K.L. and Lafreniere, M.J., 2013, Hydrologic Connectivity and Dissolved Organic Carbon Fluxes in Low-Gradient High Arctic Wetlands, Polar Bear Pass, Bathurst Island, Canada, 19th International Northern Research Basins Symposium and Workshop, Southcentral Alaska, August 11-17, 2013, 3-14

Arseneault, D., Dy, B., Gennaretti, F., Autin, J. and Bégin, Y., 2013, Developing millennial tree ring chronologies in the North American boreal forest, Journal of Quaternary Science, v.28, 283-292

Beaudoin, A., 2014, Reconstitution paleoenvironnementale de la région du lac Nettilling, (Nunavut) : Une analyse multi-proxy., Thèse M.Sc., 75 pp.

Beaudoin, A., Pienitz, R., Francus, P. and Zdanowicz, C., 2013, Paleoenvironmental reconstructions of Nettilling Lake area (Nunavut): A multi-proxy analysis., CANQUA, Edmonton, Alberta, 18-22 August 2013, x

Beaudoin, A., Pienitz, R., Francus, P., Zdanowicz, C. and St-Onge, G., 2014, Paleoenvironmental reconstructions of Nettilling Lake area (Nunavut): A multi-proxy analysis., European Geophysical Union Annual Meeting, Vienna, x

Beaudoin, A.; Pienitz, R., Francus, P., St-Onge, G. and Zdanowicz, C., 2013, Paleoclimatic reconstructions of Nettilling Lake area (Nunavut): A comparative analysis of lake sediment and ice core records., Ontario-Québec Paleolimnology Symposium (PALS), Ottawa, 15-17 May 2013., x

Bégin C., Gingras, M., Savard, M.M., Marion, J., Nicault, A. and Bégin, Y., 2014, Assessing tree-ring carbon and oxygen stable isotopes for climate reconstruction in the Canadian northeastern boreal forest, Palaeogeography, Palaeoclimatology, Palaeoecology,

Bégin, P.N. and Vincent, W.F., 2013, High Biodiversity of Rotifers in the Permafrost Thaw Lakes of Nunavik and their Potential Role in the Aquatic Food Web., ArcticNet 9th Annual Science Meeting, Halifax, NS,, 9-13 December 2013 (Poster

Bégin, P.N., Przytulska-Bartosiewicz, A., Bartosiewicz, M. and Vincent, W.F., 2013, Les Rotifères Dans les Mares Thermokarstiques : Une Diversité Étonnante, 81e Congrès de l'ACFAS, Quebec City, QC, , May7-8,May, 2013 (Poster)

Berninger F., Nicault, A., Savva, Y., Bégin, C., Dunn, A., Savard, M.M. and Bégin, Y., 2014, Winter climate drives growth of black spruce (Picea mariana (Mill.) B.S.P.) in large areas of North- Eastern Canada, Boreal Environnemental Research,

Bouchard, F., Cassidy, A., Deshpande, B., Malenfant-Lepage, J. , Paquette, M. and Rudy, A., 2013, Sharing knowledge, skills, and experiences: ADAPT Early Career Researchers Association (AECRA), PAGE21 General Assembly, Abisko (Sweden),

Bouchard, F., Francus, P., Pienitz, R., Laurion, I. and Feyte, S., 2014, Subarctic thermokarst ponds: investigating recent landscape evolution and sediment dynamics in thawed permafrost of northern Quebec (Canada), Arctic, Antarctic, and Alpine Research,

Bouchard, F., MacDonald, L.A., White, H., Wolfe, B.B., Hall, R.I. and Pienitz, R., 2013, Isotopic evidence for recent hydrological shifts in source waters of shallow lakes in northern freshwater landscapes, Québec-Ontario Paleolimnology Symposium (PALS), Ottawa (ON),

Bouchard, F., MacDonald, L.A., White, H., Wolfe, B.B., Hall, R.I. and Pienitz, R., 2013, Du stress climatique à la réponse hydrologique: dynamique récente de lacs de thermokarst dans les basses-terres occidentales de la Baie d'Hudson (Wapusk National Park, Manitoba), Colloque annuel du Centre d'études nordiques (CEN), Université Laval, Québec (QC),

Bouchard, F., Pienitz, R., Ortiz, J.D., Francus, P. and Laurion, I., 2013, Palaeolimnological Conditions Inferred from Fossil Diatom Assemblages and Derivative Spectral Properties of Sediments in Thermokarst Ponds of Subarctic Quebec, Canada, Boreas, v.42, 575–595

Bouchard, F., Turner, K.W., MacDonald, L.A., Deakin, C., White, H., Farquharson, N., Medeiros, A.S., Wolfe, B.B., Hall, R.I., Pienitz, R. and Edwards, T.W.D., 2013, Vulnerability of Shallow Subarctic Lakes to Evaporate and Desiccate when Snowmelt Runoff is Low, Geophysical Research Letters, v.40, 6112–6117

Bouchard, F., Turner, K.W., MacDonald, L.A., Deakin, C., White, H., Farquharson, N., Medeiros, A.S., Wolfe, B.B., Hall, R.I., Pienitz, R. and Edwards, T.W.D., 2014, Evaporation and desiccation of shallow tundra lakes under conditions of low snowmelt runoff (Wapusk National Park), Wapusk National Park Research and Monitoring Symposium, Winnipeg (MB),

Bouchard, F., Turner, K.W., MacDonald, L.A., Deakin, C., White, H., Farquharson, N., Medeiros, A.S., Wolfe, B.B., Hall, R.I., Pienitz, R. and Edwards, T.W.D., 2013, The critical role of snowmelt runoff to shallow lakes in permafrost landscapes, ADAPT Workshop, ArcticNet Annual Scientific Meeting (ASM), Halifax (N.-S.),

Bouchard, F., Turner, K.W., MacDonald, L.A., Deakin, C., White, H., Farquharson, N., Medeiros, A.S., Wolfe, B.B., Hall, R.I., Pienitz, R. and Edwards, T.W.D., 2013, Recent shifts in source waters of shallow subarctic lakes: toward widespread desiccation?, ArcticNet Annual Scientific Meeting (ASM), Halifax (N.-S.),

Charvet, S., Vincent, W.F. and Lovejoy, C. 2013., 2013, Effects of Light and Prey Availability on High Arctic Protist Communities Examined by High-Throughput DNA and RNA Sequencing., FEMS Microbiology Ecology,

Charvet, S., Vincent, W.F., Comeau, A. and Lovejoy, C., 2013, Seasonal Changes and DNA Preservation in a High Arctic Meromicric Lake, International Congress on Protistology, Vancouver, BC, 28 July - 2 Aug, 2013

Comte, J., Crevecoeur, S., Monier, A., Lovejoy, C. and Vincent, W. F., 2013, Bacterial Biogeographic Patterns in Permafrost Thaw Ponds and Implications for Greenhouse Gas Emissions., International Biogeography Society, Special Meeting: The Geography of Species Associations, Montreal, QC, 15-17 , November 2013 (Poster)

Copland, L., Mortimer, C., White, A., Richer McCallum, M. and Mueller, D. R., 2014, Controls on the causes and patterns of Arctic ice shelf calving events, International Symposium on Sea Ice in a Changing Environment, Hobart, Tasmania.,

Crawford, A.J., Mueller, D.R., Humphreys, E.R., Carrieres, T. and Tran, H., 2014, Surface ablation model evaluation on a drifting ice island in the Canadian Arctic,, Cold Regions Science and Technology,

Crevecoeur, S., Comte, J., Lovejoy, C., and Vincent, W. F., 2013, Impacts of Permafrost Thawing in the Quebec Subarctic Region and the Micro-organisms Implicated, Francophone Association for Knowledge (ACFAS) 81th Congress and Symposium of Centre d'études nordiques, 6-10 May, 2013 (oral)

Deshpande, B. and Vincent, W.F., 2013, Size-Fractionated Microbial Respiration and Oxygen Dynamics in Thermokarst Thaw Ponds, ArcticNet 9th Annual Scientific Meeting, Halifax, NS, , Decemb10 – 13 December, 2013 (Presentation)

Gennaretti, F., Arseneault, D. and Bégin Y., 2014, Millennial stocks and fluxes of large woody debris in lakes of the North American taiga, Journal of Ecology,

Gennaretti, F., Arseneault, D., Nicault, A., Perreault, L. and Bégin, Y., 2013, Volcano-induced regime shifts in millennial tree ring chronologies from Northeastern North America, Proceedings of the US National Academy of Science,

Henry, G., Lemay, M. and Vincent, W.F, 2013, ADAPTING to Permafrost Change in the Arctic, ArcticNet 9th Annual Scientific Meeting, Halifax, NS, 9-13 December, 2013 (plenary talk)

Laurion, I. and Mladenov, N., 2013, Dissoved organic matter photolysis in Canadian arctic thaw ponds, Environ. Res. Lett., v. 8, 35026

Lewis-Paley G., and Mueller, D.R., 2013, Ice island detection using fine quad polarization RADARSAT-2 imagery: Understanding seasonal, spatial and temporal variability., ArcticNet 9th Annual Science Meeting, Halifax, NS, December 11-13, 2013.,

Luoto, T.P., Salonen, V.-P., Larocque-Tobler, I., Pienitz, R., Hausmann, S., Guyard, H. & St-Onge, G., 2013, Pro- and postglacial invertebrate communities of Pingualuit Crater Lake, Nunavik (Canada), and their paleoenvironmental implications., Freshwater Science, vol.32, no.3, 951-963

Matveev, A., Deshpande, B., Vincent, W.F. and Laurion, I., 2013, Les Champs de Palses en Mutation: une Source Significative de GES vers l'Atmosphère?, ACFAS 81 Congress, Quebec City, QC, 6-10 May, 2013 (Poster)

Matveev, A., Laurion, I. and Vincent, W.F., 2013, Hétérogénéité Spatiale et Contrôle Microbien des Émissions de GES dans les Lacs Thermokarstiques du Nord du Québec, Département des sciences biologiques, GRIL-UQÀM, Montréal, QC, 10 May, 2013 (Invited talk)

Mueller, D.R., Copland, L., White, A and Wohlleben, T., 2014, Recent ice shelf loss, Ellesmere Island, Nunavut, Canada, Workshop on the Dynamics and Mass Budget of Arctic Glaciers, Ottawa, Canada,

Mueller, D.R., Crawford, A., Copland, L, VanWychen, W., 2013, Ice Island and Iceberg Fluxes from Canadian High Arctic Sources, Final Report to Northern Transportation Assessment Initiative, Innovation Policy Branch, Transport Canada, 23

Narancic, B., Pienitz, R. and Wolfe, B.B., 2013, Multi-year landscape-gradient assessment of thermokarst lake hydrology in Nunavik (Quebec, Canada) using water isotope tracers, ArcticNet Annual Scientific Meeting,

Narancic, B., Pienitz, R., Francus, P. and Guilbault, J.-P., 2014, Paleogeography and paleoenvironments of southwestern Baffin Island (Nunavut, Canada): post-glacial isostatic uplift and isolation of Nettilling Lake from marine influence., European Geophysical Union Annual Meeting, Vienna, x

Naulier, M, Savard, M.M., Bégin, C., Marion, J., Arseneault, D. and Bégin, Y., 2013, Carbon and oxygen isotopes of lakeshore black spruce trees in northeastern Canada as proxies for climatic reconstruction, Chemical Geology,

Naulier, M., Savard, M.M., Bégin, C., Marion, J., Nicault, A. and Bégin, Y., 2014, Temporal instability of isotopes-climate statistical relationships- A study of black spruce trees in northeastern Canada, Earth and Planetary Science Letters,

Negandhi, K., Laurion, I. and Lovejoy, C., 2013, Arctic thaw pond morphology influences bacterial communities and associated greenhouse gas emissions, Polar Biology,

Negandhi, K., Laurion, I., Whiticar, M.J., Galand, P.E., Xu, X. and Lovejoy, C., 2013, Small Thaw Ponds: An Unaccounted Source of Methane in the Canadian High Arctic, PLoS ONE, v. 8, no. 11, e78204

Nicault, A., Bégin, Y., Bégin, C., Marion, J., Boucher, E., Guiot, J., Arseneault, D., DesGranges, J.-L., Berninger, F., Tapsoba, D. and Wicha, S., 2013, Spatial analysis of black spruce's (Picea mariana) radial growth response to climate in northern Québec, Canada, Canadian Journal of Forest Research,

Nicault, A., Boucher, É., Bégin, C., Guiot, J., Perreault, L., Roy, R., Savard, M.M. and Bégin, Y., 2013, Hydrological reconstruction from tree-ring multi-proxies over the last two centuries at the Caniapiscau Reservoir, northern Québec, Canada, Journal of Hydrology,

Paquette, M., Fortier, D. and Vincent, W.F., 2013, The Geomorphic and Hydrologic Relation Between Water Track Development and Patterned Ground on a High Arctic Slope, ArcticNet ASM, Halifax, NS, 9-13 December, 2013

Proult, V. and Pienitz, R., 2013, Past and present siliceous algae communities in subarctic thermokarst landscapes, Nunavik (Northern Québec)., Ontario-Québec Paleolimnology Symposium (PALS), Ottawa, 15-17 May 2013., x

Proult, V., Pienitz, R. and Vincent, W.F., 2013, Periglacial origins (palsa-lithalsa) of Nunavik thermokarst lakes and their ecosystemic implications: Analysis of modern and past diatom communities., ArcticNet Annual meeting, Halifax, 8-13 December 2013., x

Richer McCallum, M., Mueller, D. and Copland, L., 2014, An assessment of the causes of open water leads and changes in sea ice conditions along northern Ellesmere Island, Canada, International Symposium on Sea Ice in a Changing Environment, Hobart, Tasmania.,

Rossi, P.-G., Laurion, I. and Lovejoy, C., 2013, Distribution and identity of Bacteria in subarctic permafrost thaw ponds, Aquatic Microbial Ecology, v. 69, 231-245

Steven, B., Kuske, C.R., Lionard, M. and Vincent, W.F., 2013, High Bacterial Diversity of Biological Soil Crusts in Water Tracks over Permafrost in the High Arctic Polar Desert., PLoS ONE, v.8, no.8, e71489.

Stevens, C., Forrest, A.L., Hamilton A.K., Laval, B.E., and Mueller, D.R., 2013, Development of a navigation model for AUVs under ice at high latitudes., ArcticNet 9th Annual Science Meeting, Halifax, NS, December 11-13, 2013.,

Sylvestre, T., Copland, L., Demuth, M.N. and Sharp, M., 2013, Spatial patterns of snow accumulation across Belcher Glacier, Devon Ice Cap, Nunavut, Canada, Journal of Glaciology, v.59, no.217, 874-882

Thomson, L. and Copland, L., 2013, Assessing the role of hypsometry, hydrology, and thermal structure in the dynamics of White Glacier, Axel Heiberg Island, Nunavut., ArcticNet Annual Scientific Meeting, Halifax, Canada., 1

VanWychen, W., Burgess, D.O., Gray, L., Copland, L., Sharp, M., Dowdeswell, J. and Benham, T., 2014, Glacier velocities and dynamic ice discharge from the Queen Elizabeth Islands, Nunavut, Canada, Geophysical Research Letters, doi: 10.1002/2013GL058558,

Vincent, W.F, 2013, Sea Ice – The Biophysical Picture from Microbes to Vertebrates, Workshop on the Last Ice Area, World Wildlife Fund, Iqaluit, 4-5 June, 2013

Vincent, W.F et al., 2013, ADAPT across Canada, ADAPT Workshop, ArcticNet, Halifax, NS, 9-13 December, 2013

Vincent, W.F., 2013, Biodiversity of the Cold Biosphere: From First Freeze-Up to Accelerated Meltdown, Orton K. Stark Public Lecture, Miami University, Oxford, Ohio, USA, 27 March, 2013

Vincent, W.F., 2013, Permafrost Lakes: Global Implications of the Arctic's Most Active Microbial Ecosystems, Orton K. Stark Science Lecture, Miami University, USA, 26 March 2013

Vincent, W.F., 2013, Arctic Terrestrial Ecosystems in Transition, Arctic Science Summit Week, Krakow, Poland, 17-19 April 2013

Vincent, W.F., 2013, Rapid Warming and Limnological Change in the Canadian Arctic, Dartmouth College, Hanover, USA (invited talk), 1 November, 2013

Vincent, W.F. and Sarrazin, D., 2013, Messages from the Far North: Environmental Change at Nunavut's Northern Coast, ArcticNet ASM, Halifax, NS, 9-13 December, 2013 (plenary talk)

Vincent, W.F., Barnard, C. and Bhiry, N., 2013, The CEN Network of Arctic Observing Stations and Nordicana D for Data Dissemination., Arctic Observing Summit, Vancouver, Canada, 30 April 2013

Vincent, W.F., Lemay, M., Allard, M. and Wolfe, B.B., 2013, Adapting to Permafrost Change: A Science Framework, Eos, Transactions of the American Geophysical Union, v.91, 373-375

Vincent, W.F., Pienitz, R., Laurion, I. and Walter Anthony, K., 2013, Climate Impacts on Arctic Lakes., In: Goldman, C.R., Kumagai, M., Robarts, R.D. (eds). Climatic Change and Global Warming of Inland Waters: Impacts and Mitigation for Ecosystems and Societies., 27-42

White, A., Copland, L. and Mueller, D., 2014, Connections between sea ice changes and recent break-ups of Petersen Ice Shelf, Ellesmere Island, Nunavut, Canada, International Symposium on Sea Ice in a Changing Environment, Hobart, Tasmania.,

White, A., Copland, L., Mueller, D. and Van Wychen, W., 2013, Assessment of historical changes (1959-2012) and the causes of recent break ups of the Petersen Ice Shelf, Nunavut, Canada., Annals of Glaciology, v.56, no.69,

Woo, M.K. and Young, K.L., 2014, Disappearing Semi-Permanent Snow in the High Arctic and Its Consequences, Journal of Glaciology, 60, 219, 192-200

Young, K.L., Assini, J., Abnizova, A. and Miller, E., 2013, Snow Cover and Melt Characteristics of Upland/lowland Terrain: Polar Bear Pass, Bathurst Island, Nunavut, Canada., Hydrology Research, v. 44, no. 3, 2-20

Young, K.L., Lafreniere, Lamoureux, S., Abnizova, A. and Miller, E.A., 2013, Seasonal Stream Regimes and Water Budgets of Hillslope Catchments, Polar Bear Pass and Cape Bounty, Nunavut., 19th International Northern Research Basins Symposium and Workshop, Southcentral Alaska, August 11-17, 2013, 217-230

Young, K.L., Lafreniere, M.J., Lamoureux, S., Abnizova, A. and Miller, E.A., 2013, Seasonal Stream Regimes and Water Budgets of Hillslope Catchments, Polar Bear Pass and Cape Bounty, Nunauvt, Hydrology Research,