Remote Sensing of Canada's New Arctic Frontier

Project Leader

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Abstract

Rapid climate change and industrialization are unlocking the natural resources of the vast Canadian Arctic and increasingly impacting its ecosystems. The stewardship of these ecosystems, the environmentally sustainable development of arctic resources, and the adaptation of northern communities to their rapidly changing world require a massive intensification of scientific observations. Furthermore, these observations must be organized into geo-referenced data banks and models that will provide stakeholders in government, industry and communities with the knowledge needed to inform their decisions. The objectives of this project are aligned with the targeted achievements of the Canada Excellence Research Chair on “Remote Sensing of Canada’s New Arctic Frontier” to: (1) Augment in time and space the observation of arctic marine ecosystems by implementing new algorithms for the remote-sensing of phytoplankton, particulate matter, dissolved organic carbon and seawater optical properties in the surface layer of the Canadian Arctic Ocean, from which primary production, bacterial growth, and organic matter photo-oxidation will be derived; (2) Develop, validate, and implement the urgently-needed ecosystem models that will help anticipate the impacts of climate change and industrialization on the resources and services (fisheries, navigation, minerals, energy, tourism) provided now and in the near future by the ecosystems of the Canadian Arctic Ocean; (3) Adapt existing and future new observing technologies to the extreme conditions of the Arctic Ocean, with emphasis on the field deployment of Profiling Floats, Autonomous Underwater Vehicles, and Ocean Gliders, and on the use of optical sensors; (4) In collaboration with the Canadian Cryospheric Information Network (CCIN), Centre d’études nordiques (CEN) and other national and international partners, mesh the respective expertise of ArcticNet and GEOIDE, two pan-Canadian NCE, into the development of state-of-the-art geo-referenced data archiving systems that can be accessed online by scientific, industrial and government stakeholders to produce maps and analyses of the transforming Canadian Arctic. The scientific broad objectives of this ambitious program are: (1) To understand the functioning of the arctic marine ecosystems. What is the composition of the microbial communities (biocenoses)? Who are the main players among phytoplankters and bacteria in terms of energy and biomass transfer to higher trophic levels? What are the main ecologically distinct environments (biotopes)? Where do critical biological processes really happen in this environment? What are the interactions between the biocenoses and biotopes? How does the ecosystem work? (2) To determine the carbon fluxes (rivers ? coastal environment ? ocean), with special emphasis on those affected by light. What is the impact of bacterial activity and photo-oxidation on mineralizing organic carbon? What is the extent of new organic carbon production by primary production? What are the chemical and physical factors controlling those three carbon fluxes affected by light: primary production, bacterial activity and photo-oxidation? What is the spatial and temporal variability of those three processes? What large-scale physical phenomena control that variability? (3) To determine the impact of current and near-future changes in the Arctic environment on marine ecosystems and biogeochemical fluxes. How will CO2 production from the mineralization of old organic carbon be compensated by the new sequestration of carbon? Will the Arctic Ocean experience a major shift biotopes and biocenoses? What will be the impact on higher trophic levels?

Briefly, the milestones are, for 2011-2014: (i) Develop the CERC technical team and implement the necessary land-base research facilities; (ii) adapt autonomous platforms and in situ sensors for operation in the Arctic Ocean; (iii) identify and isolate the key Arctic phytoplankton species during oceanographic cruises; (iv) characterize in the laboratory their optical and physiological properties, and derive relevant model parameters, (v) archive and process all available ocean color data and other relevant remote sensing data for the Arctic Ocean; (vi) conduct intensive sampling in key region of the Arctic Ocean with regard to biological production, using various platforms (ship, AUV, gliders and profiling floats) ; and (vii) analyze time series derived from remote sensing data and diagnostic models to identify the main drivers of biological production.

Key Messages

- Rapid climate change and industialization are impacting Canadian arctic ecosystems
- Intensification of scientific observation is required to document the effects of these changes.
- In regions where access is difficult, remote sensing is one of the most appropriate tools to offer synoptic observation of ecosystems.
- The use of ocean color remote sensing will allow assessing the response of arctic marine ecosystems to climate change.

Objectives

The objectives of the CERC in remote sensing of the Canada's new Arctic's frontier are to:

- Augment, in time and space, the observation of arctic marine ecosystems;
- Develop, validate, and implement urgently needed ecosystem models;
- Adapt existing and future new observation technologies to the extreme conditions of the Arctic Ocean;
- Develop state-of-the-art geo-referenced data archiving systems that can be accessed online.

More specifically, we hope to:

- Adapt autonomous platforms and in situ sensors for operation in the Arctic Ocean;
- Identify and isolate the key Arctic phytoplankton species during oceanographic cruises;
- Characterize the optical and physiological properties of these phytoplankon species in the laboratory and derive relevant model parameters;
- Archive and process all available ocean color data and other relevant remote sensing data for the Arctic Ocean;
- Conduct intensive sampling in key regions of the Arctic Ocean with regards to biological production, using various platforms (ship, AUV, gliders and profiling floats);
- Analyze time series derived from remote sensing data and diagnostic models to identify the main drivers of biological production;
- Provide stakeholders in government, industry and communities with the knowledge to make informed decisions.

Introduction

Nowhere else on Earth are the effects of climate change more evident than in the Arctic. The Arctic is warming twice as fast as the rest of the planet and a rise in global temperature of 4°C could imply anomalies of over 10°C in the Arctic. Climate change alters air-sea circulation patterns and sea ice should disappear in summer months over the next 3 decades. At the same time, the Greenland ice sheet may vanish and 80% of the permafrost could thaw. The Arctic is on the verge of a permanent shift, with unknown consequences for its biological capacity, for societies that rely on it for their subsistence and economy, and for feedback to global climate.

More particulate matter in river runoff, less atmospheric ozone above the Arctic, increasing UV radiation and declining pluriannual sea-ice cover are all contributing to an abrupt shift in the light regime of the surface layer of the Arctic Ocean. These changes have major implications for the most fundamental properties of Arctic marine ecosystems, including: light-driven processes, nutrients, and temperature. Impacts are especially strong in the upper trophic levels of the food chain and the consequences on the culture and way of life of northern communities seem unavoidable. The scientific community faces the major challenge of documenting and anticipating (1) the evolution of marine ecosystems; (2) the fate of the associated fauna and flora; (3) modifications in carbon fluxes and energy transfer across trophic levels;

and (4) changes in the services provided by Arctic marine ecosystems resulting from climate change and industrialization. It is within this context that our program aims to track the response of Arctic marine ecosystems to climate variability and change.

Activities

Activities described here are organized to follow the 2010-14 milestones:

1. Develop the CERC technical team and implement the necessary land-based research facilities:

Our state-of-the-art laboratory facilities are being used by all research groups affiliated with the Canada Excellence Research Chair in Remote Sensing of Canada's Arctic Frontier and the Takuvik Joint International Laboratory. Two new research associates, Gilles Ratté and José Lagunas, were hired in October and December, respectively, to complement our current expertise in electronics and instrumentation. Gilles was hired on a six month contract to complete the development and construction of the bioreactor and will most likely leave the group at the end of March when the system is operational. José is working on the under-ice detection system for our profiling floats and will hopefully stay with us until the end of the project.

Marti Gali-Tapais, a Spanish post-doctoral fellow (PDF) joined the group in October to work on remote sensing of DMSP (dimethylsulfoniopropionate) production. Two other PDF, Alexandre Forest and Chaoyu Yang left in December. No graduate students were recruited in 2013-2014. Pierre Luc Grondin and Philippe-Israel Morin, two students who joined our team during their 'initiation à la recherche' course in 2012-2013, received NSERC undergraduate scholarships for the summer 2013 session and continue to work part-time in our labs. Theo Sciandra, an undergraduate from UQAM, did a 9-week internship in our ecophysiology lab in the summer of 2013. Another three undergraduates, Claudia Roy, Constance Marty and Claude-Anne Blouin, work part-time doing analysis of high-performance liquid chromatography (HPLC) data, laboratory tasks and data management, respectively.

Julie Sansoulet joined the coordination team early in 2013. She is primarily responsible for the administration of Takuvik and the Chantier Arctique Francais projects.

2. Adapt autonomous platforms and in situ sensors for operation in the Arctic Ocean:

The CERC/Takuvik team has been working in close collaboration with the Laboratoire d'Océanographie de Villefranche (LOV, www.obs-vlfr.fr/LOV, CNRS-UMR #7093, Villefranche-sur-Mer, France) to develop an innovative sea ice detection system that will be part of its autonomous platforms, especially the profiling floats. The sea ice detection system is currently under development, but it will most likely be based on the concomitant use of various techniques like passive/active acoustic, optics, temperature and salinity based algorithms, etc. Takuvik is responsible for developing the optical sea-ice sensor and continues its collaboration with Defence Research and Development Canada (DRDC, www.valcartier.drdc-rddc.gc.ca, Valcartier, Canada), and the Laboratoire de Recherche en Ingénierie Optique (LRIO, www.lrio.copl.ulaval.ca), which is part of the Centre d'Optique, Photonique et Laser (COPL, www.copl.ulaval.ca, Quebec City, Canada), located on the Université Laval campus.

Active acoustic and temperature/salinity techniques will be field-tested soon, as well as a first prototype of a miniaturized optical sea-ice sensor. Field trials of these platforms are scheduled for the spring of 2014.

Two floats are also scheduled to be deployed during the 2014 ArcticNet cruise in the Baffin Bay, and they will drift throughout the winter of 2014-15.

Two submarine gliders were received during the summer of 2013. Guislain Becu attended the glider piloting training that was provided by Teledyne during the fall of 2013. A second research associate is scheduled to attend the same training during the spring of 2014 (no training is proposed during the winter), and some field trials and missions are scheduled during the spring of 2014 and the summer of 2014 (respectively), as far as the other field duties allow. The technical directorate of l'Institut National des Sciences de l'Univers (www.dt.insu.cnrs.fr, La Seyne-sur-Mer, France), and especially its French national glider fleet team (www.dt.insu.cnrs.fr/gliders/gliders.php), has been contacted to consider a piloting support for the Takuvik glider missions. Indeed, this unit supports French laboratories in their gliders missions, and Takuvik, because it is a French laboratory on foreign soil, is eligible for this service.

3. Identify and isolate the key Arctic phytoplankton species during oceanographic cruises:

Several phytoplankton cultures have been isolated from the Arctic environment in the past few years (including during the MALINA cruise) and have been sent for transcriptomic sequencing. Ecophysiological studies of Arctic phytoplankton species under controlled conditions are currently being conducted.

4. Characterize the optical and physiological properties of Arctic phytoplankton under laboratory conditions, and derive relevant model parameters:

The construction of a fully automated culture system for studying plankton physiology will be complete in the spring of 2014. Fully computer controlled, this system will continuously monitor several critical parameters, thus allowing phytoplankton growth to be controlled and parameters such as light level and pH to be tightly regulated while maintaining a high level of quality control.

The construction of two photosynthetrons in 2011 has allowed us to efficiently obtain precise measurements of important photosynthetic parameters using 14°C fixation for the three major culture experiments we have conducted to date.

Experiments involving arctic phytoplankton cultures began in November 2012 and are still undergoing. Because semi-continuous culture is a long-term process, a series of measurements for different projects are collected simultaneously for optical and physiological properties: particulate absorption, chlorophyll a fluorescence, pigment content, particulate organic carbon and nitrogen, Fv/Fm, photosynthetic parameters derived from 14 fixation, oxygen production, and rubisco content.

Thomas Lacour (PDF) is experimenting the adaptation and acclimation of the Arctic diatoms *Chaetoceros neogracile* and *Thalasssioira gravida* to light and temperature. For his undergraduate 'initiation à la recherche' project, Philippe-Israël Morin (BSc candidate) studied the effect of these stresses on the rubisco content of *Chaetoceros neogracile* as an indicator of carbon fixation. Meanwhile, Pierre-Luc Grondin (BSc candidate) studied oxygen production as an innovative method to measure primary production of *Chaetoceros neogracile*. The method proposed by Dubinsky et al. (1987) was adapted to experimental conditions.

Jade Larivière (MSc candidate) is studying the effect of photoperiod on the growth of *Thalasssioira gravida*, simulating early spring to late spring light cycles. Michel Lavoie (PDF) also participated in the project and measured the intracellular and extracellular concentrations of DMSP in the algal cultures.

These experiments share the objective studying the physiological capacities of these phytoplankton species to predict their spatial and temporal distribution under conditions of increased light availability in the Arctic Ocean as the sea ice recedes.

5. Archive and process all available ocean color data and other relevant remote sensing data for the Arctic Ocean:

During the current fiscal year, the remote sensing group (RSG) at Takuvik focused on maintaining and extending the satellite archive as well as improving the pan-Arctic Primary Production model. In addition to data described in previous reports, the RSG added data from other sensors (MODIS for the atmosphere, AMSRE for sea-ice concentration) either to continue ongoing time series or to increase spatial resolution. Modifications to the primary production (PP) model include the research results from Ph.D. students and Post-doctoral fellows. For example, the work of Mathieu Ardyna on phytoplankton phenology (in preparation, 2013) and vertical profiles (Ardyna et al. 2013) has been implemented in the PP model to increase the accuracy of the estimations.

Two collaborations have been developed with D. Doxaran (Laboratoire d'optique de Villefranche, France) on remote sensing of suspended particulate matter and particulate organic carbon in the Mackenzie River Delta and plume, and with Nathalie Morata (ECOTAB project, station marine de Brest, France) on effects of climate change on the Arctic benthos. During the latter collaboration, the RGS provide satellite data (e.g., ocean colour and sea-surface temperature).

We participated in a chapter of the future IOCCG report of the Ocean Colour Remote Sensing in Polar Seas working group. The objective of the working group is to compare different primary production algorithms for the polar seas. We used the algorithm of developed by Simon Bélanger (Bélanger 2013). Although the primary production itself was computed in the 2012- 2013 reporting year, we have since supplied the diffuse attenuation coefficient for downwelling irradiance (Kd) used in the Bélanger algorithm in order to understand the differences between it and the other algorithms.

Support to students and researchers:

The RSG has also supported students by installing operating systems and software on students' computer, and also by giving tutorials on data processing on the following occasions:

- Ph.D. Student Sophie Renaut received continuous scientific programming training and support.
- Post-doctoral fellow Atsushi Matsuoka had a private C programming language course of two hours.
- Approximately six graduate students benefitted from a C programming language course of two hours.
- New senior research assistant Eric Rehm received documentation and support on the tools used by the CERC.
- Post-doctoral fellow Alexandre Forest was supplied with documentation and the data on primary productivity in the Beaufort Sea.

The RSG has produced time series of sea-ice concentration for the Antarctic to Dr. G. Massé (Takuvik) to help study the effect of the carving of the Mertz glacier.

The RSG provided daily near real-time data to the scientists aboard the Tara during a circum-Arctic expedition (July to October). The data consisted of chlorophyll-a concentration, sea-surface temperature and sea surface height. The RSG has also provided time series of satellite-derived sea-ice concentration and chlorophyll-a concentration to the scientific project on the Vagabond polar yacht which is presently overwintering in Qikiqyarjuaq.

6. Conduct intensive sampling in key regions of the Arctic Ocean with regard to biological production, using various platforms (ship, AUV, gliders and profiling floats):

Two members of our research group, Joannie Ferland and Claudie Marec took part in the Tara Oceans Polar Circle expedition through the Russian seas. Joannie was responsible for the optical measurements, including imaging (Imaging FlowCytobot and FlowCam), whereas Claudie acted as oceanographic engineer and was responsible for the deployment and maintenance of all oceanographic equipment.

The Tara made a stopover in Québec City in November 2013. The Babin team organized public conferences and visits of the schooner.

The Babin team participated in the ArcticNet expedition 2013 Leg1 (26 July – 5 September) collecting samples for photosynthetic parameters, stock measurements and optical properties of the water column from the Baffin Bay/Labrador Sea and the Northwest Passage area (Lancaster sound). Forty-six stations were visited going from coastal water of the Labrador fjords, thus allowing for the addition of i) highly terrestrial-influenced water to our data set, ii) potentially richer ice edge stations and iii) melting glacier and/or iceberg stations, all of which are of great interest as they represent 'spring type' conditions rarely sampled during ArcticNet cruises. Surface water was always sampled. Six to ten vertical depth profiles were sampled at 24 stations. Two 24 hours Lagrangian studies were achieved on the eastern and western coast of Baffin Bay, sampling every 4 hours. For the first time, sampling from CCGS *Amundsen* was conducted as high as 81°N.

Particle and zooplankton imagery was also performed during the ArcticNet 2013 summer cruise (Legs 1 and 2) using an underwater vision profiler (UVP) instrument, fitted on the Rosette frame. The UVP5 is an instrument designed to take pictures of a slice of water lit by two rows of flashing LEDs while profiling or while being moored (profiling with the Rosette in our case). Image processing performed either onboard while profiling, or in delayed mode after data recovery (at the user's convenience), estimates the particle size distribution and stores vignettes of the particles found in the images. The pixel size of the camera is approximately 150 microns, so that the particles detected by the UVP range from 150 microns up to a few centimeters.

7. Analyze time series derived from remote sensing data and diagnostic models to identify the main drivers of biological production:

The remote sensing group is currently analyzing the outputs of the algorithm to compute primary production using different sensors for ocean-color and atmospheric measurements. Phenology of phytoplankton is being studied using ocean-color remote-sensing data.

Results

Laboratory

The *Chaetoceros neogracile* culture experiments exhibited fast growth at low temperatures and a great photoacclimation capacity: the species is therefore well adapted for survival in Arctic waters. Temperature strongly affects its growth rate but *C. neogracile* did not acclimate to low temperatures by regulation of either its chlorophyll a or its rubisco content. The experiences demonstrated that the weak rubisco efficiency under low temperature of *C. neogracile* is compensated by a remarkably high concentration of that enzyme.

These important parameters of *C. neogracile* growth and carbon fixation were measured under a large range of temperature and light conditions that can be encountered in Arctic. Such Arctic-specific parameters are essential for improving primary production models for this region.

An additional set of experiments showed that *C. neogracile* could survive for a long period in darkness. Despite very low carbon fixation capacities, very low rubisco concentration, and low photochemical efficiency of PSII, cells are able to reinitiate growth when light become available.

The *Thalassiosira gravida* culture experiments demonstrated adaptation to low light. We observed saturation of photosynthesis at very low light intensity and a low light compensation point for carbon fixation under all four photoperiod regimes. Our results suggest that *T. gravida* is adapted to low light conditions, which may account for its presence when light is highly limited by ice and snow i.e. at the beginning of the seasonal succession of phytoplankton. *T. gravida* showed a strong ability to acclimate to various light regimes by changing its chlorophyll a content, its ability to dissipate energy as heat and the composition of its photoprotective pigments.

The results also suggested that the important DMSP production by *T. gravida* during the "spring bloom" could increase in response to a longer photoperiod associated to an early melting of the arctic ice-cover.

Remote Sensing:

We are in the processes of making significant modifications to a satellite-derived Arctic primary production model to include the vertical resolution of chlorophyll concentration, as it has been shown that persistent deep chlorophyll maxima contribute significantly to Arctic primary production. This work incorporates the research of Mathieu Ardyna and involves the fusion of bathymetry, regional models of chlorophyll depth profiles, and the association of each satellite pixel with a finite state machine to track the state of the bloom at that pixel (i.e., pre-bloom, bloom, post-bloom, post-bloom-deep-chlorophyll max, winter).

We have also been contributing to the analysis of temperature-salinity characteristics of the surface Arctic ocean (Baffin Bay, in particular) in support of the development of a profiling float “ice sensing algorithm”. In particular, we will enhance an existing ice sensing algorithm to estimate the under-ice mixed layer temperature based on both the temperature and salinity using the thermodynamic equations of the state of seawater. Integration of the ice-sensing algorithm with other ice detection/avoidance algorithms will be tested using T-S profiles from various Baffin Bay data sets, including those from the 2013 Tara Expedition.

A full archive of SeaWiFS, MODIS, and MERIS ocean-color product is available. Sea surface temperature measured by satellite is also available from 1879 to present. Sea-ice extent and concentration is available from 2012 to present. Wind data (strength and direction) is available for the entire Arctic between 2006 and present day, as this time-series is currently expended.

Instrumentation:

Two prototypes of the sea-ice detection sensor have been completed. The DRDC prototype is the subject of a published scientific paper that was presented at SPIE Optics and Photonics in August 2013 (Roy et al. 2013). The prototype was tested in a pool. Claudie Marec is hoping to conduct further tests under Arctic conditions while she is doing fieldwork with the crew of the Vagabond near Qikqtarjuaq in May 2014.

Discussion

The CERC/Takuvik team has begun publishing peer-reviewed papers and has contributed several papers to the Malina Special Issue (Biogeosciences vol 10). The phytoplankton and instrumentation teams anticipate publishing technical papers on the automated culture system and the sea ice detector, respectively. The white paper written by the instrumentation team will also be updated later this year.

Conclusion

Lab members participated in Leg 1 of the ArcticNet campaign in July-September 2013. Two members of the group also were involved in the Tara Oceans Polar Circle. cruise.

Given that the automated culture system is still under construction, intensive semi-continuous culture experiments were conducted in our laboratories.
The results we obtained have enabled us to begin characterizing the optical and physiological properties of two Arctic phytoplankton species under laboratory conditions.

Testing and development to adapt autonomous sampling platforms and in situ sensors for operation in the Arctic Ocean are underway and will be a priority in the coming year.

The storage needed for processing ocean color data was increased by 60TB (from 54.5TB to 114.5 TB by purchasing a 48 TB Network Attached Storage (NAS) device DS2413+ Disk Station from Synology and a 12 TB Network Attached Storage (NAS) device ix4-300D StorCenter from Lenovo.

Algorithm development and updating will remain a priority and near-time archives will continue to be maintained.

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