Remote Sensing of Canada's New Arctic Frontier

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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 (CERC) 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 CO_2 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, Autonomous underwater

vehicle (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.

The milestones for ArcticNet 2011-2014 project are to:

- Develop the CERC technical team and implement the necessary land-based research facilities;
- 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

The often spectacular impacts of climate change on the terrestrial and oceanic environments of the Arctic unfold at an accelerating pace (ACIA 2005). During the last few decades, air and ocean temperatures have risen almost twice as fast in the Arctic as in the rest of the world in response to increased atmospheric concentrations of greenhouse gases (Zhang 2005). From 1936 to 1999, freshwater inputs to the Arctic Ocean increased by 7% and are expected to keep increasing over future decades (Peterson et al. 2002, 2006; Holland et al. 2007). River runoff carries increasing large amounts of particulate and dissolved material into the coastal Arctic Ocean. Atmospheric ozone above the Arctic in spring has declined by 10 to 15% since 1979 (e.g. Bélanger et al. 2006), with a parallel increase in ultraviolet radiation. The summer ice cover of the Arctic Ocean has shrunk by 30% over the last 3 decades and is predicted to vanish by the end of the century, or perhaps much earlier (Holland et al. 2006; Serreze et al. 2007; Comiso et al. 2008; Wang and Overland 2009). Combined, these changes are causing an abrupt shift in the light regime of the surface layer of the Arctic Ocean.

Arctic marine ecosystems are therefore experiencing major disruptions in their most fundamental properties: sea-ice cover, light, nutrients, and temperature. Such disruptions are already causing major shifts in ecosystem structure and services in some Arctic and sub-Arctic regions (e.g. Grebmeier et al. 2006). 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 by (1) Increasing, in time and space, observations in Arctic marine ecosystems, (2) Developing, validating, and implementing urgently-needed ecosystem models, (3) Adapting existing and future new observation technologies to the extreme conditions of the Arctic Ocean, and (4) Developing state-of-the-art geo-referenced data archiving systems that can be accessed online and and will provide stakeholders with the needed information for making informed decisions.

Activities

Activities described here are based and organized to follow the 2010-2014 milestones :

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

The CERC technical team is now firmly established. It is composed of four tandems of full-time research associates in addition to two research asssociates from the Takuvik Joint International Laboratory (see list of active members). An additional research associate was hired on a 6-month contract (mid Sept 2012 to mid March 2013) to analyse a paleoceanographic sediment core and we are presenting advertising for a third remote sensing professional to work on the MEOPAR project. Guillaume Massé, a paleoceanographer and Takuvik CNRS scientist, relocated to Université Laval in the fall of 2012.

Our student recruitment efforts were very successful. Five postdoctoral fellows, seven doctoral students and two master's students, from 10 different countries, joined the team over the reporting period. One PDF and two PhD students are working directly on ocean colour remote sensing, while the other students and PDFs are working on complementary projects.

Construction and renovation of the land-based research facilities are now complete. The offices and meeting space are being used at maximum capacity and the laboratories (optic lab, electronic lab, cold lab for phytoplankton cultures, analytical lab and radioactivity lab) are all fully operational.

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), the Insitut National d'Optique (INO, www.ino.ca, Quebec City, Canada), and Defence Research and Development Canada (DRDC, www.valcartier.drdc-rddc.gc.ca, Valcartier, Canada), to develop an innovative sea ice detection system that will be part of its autonomous platforms. 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. Field trials of these platforms are scheduled for the winter of 2013-2014.

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 a fully automated culture system for studying plankton physiology will be complete in the spring of 2013. Fully computer controlled, this system will continuously monitor several critical parameters, thus allowing phytoplankton growth to be controlled. Parameters such as light level and pH will be tightly regulated while maintaining a high level of control.

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

Over the past year, the remote sensing capabilities of the team have increased substantially. Ocean color data products have been organized and archived.

The remote sensing capacity has been extended to include multiple ocean-color sensors (MERIS, MODIS and SeaWiFS), as well as, sea-surface temperature, salinity and relevant atmospheric data. The processing chain has been validated to derive primary production from ocean-colour and ancillary data.

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):

Given that the CCGS Amundsen was not available, no samples were collected during the 2012 field season.

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

The CERC/Takuvik team is currently composed of 10 research associates, 9 post-doctoral fellows and 10 graduate students. Recruitment of students and post-docs through the team's web sites: www.takuvik.ulaval.ca and www.cerc-arctic.ulaval.ca; and our booths at ASLO (Feb 2012) and ArcticNet/IPY (April 2012) meetings was very successful.

Intensive experiments involving arctic phytoplankton cultures began in November 2012. Thomas Lacour (PDF) and Jade Larivière (MSc candidate) are working on *Chaetoceros neogracile* and *Thalasssioira gravida*, respectively. They are subjecting the diatoms to different light intensity treatments in an effort to predict the spatial and temporal distribution of these phytoplankton species under conditions of increased availability in the Arctic Ocean as the sea ice recedes. The experiments will be repeated with additional species. Undergraduate students Pierre Luc Grondin and Philippe Israel Morin are conducting complementary physiological experiments using the same diatom species. No results are presently available, as the data have not yet been analysed.

Validation of the satellite-derived primary production is being conducted by comparison with other satellite-based model of primary production (PP) on a daily basis. Times series of primary production and chlorophyll-a concentrations between January 1, 1998 and December 31, 2012 have been produced. The time-series include ancillary data such as atmospheric optical properties, cloud fraction and sea-ice cover for the same period. Variation in primary production due to change in earth observation data has been studied.

A preliminary study of the impact of ice-retreat and upwelling-favorable wind on phytoplankton productivity showed interesting results - this study is under progress.

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 (this time-series currently expanded).

An investigation of salinity and altimetry products for the Arctic has been conducted. We expect to have these time series available later in 2013. This work has been used in various studies performed by postdoctoral fellow and doctoral candidates.

Development of the sea-ice detection sensor is advancing and prototypes will be available for testing in the fall of 2013. If financing is obtained, floats equipped with the detection system will be launched near the Greenland Institute of Natural Resources' Kobbefjord field station before freeze up and remain under the sea ice until June 2014.

Discussion

Given that the project has yet to produce any publications, it would be inappropriate to discuss the results obtained to date. The CERC/Takuvik remote sensing team is well placed to publish several peer-reviewed papers in the coming year. 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 in 2013.

Conclusion

2011-2012 was the first year that our project was fully functional. Culture of Arctic phytoplankton species is now operational in our laboratories and the expertise of our professionals and students is in demand by other research groups.

Testing and development to adapt autonomous sampling platforms and in situ sensors for operation in the Arctic Ocean is underway and will continue in the future.

The storage and calculation capacity needed for processing ocean color data has been implemented. Algorithm development and updating will remain a priority and near-time archives will continue to be maintained.

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