Long-Term Observatories in Canadian Arctic Waters

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Abstract

In the past decade, we have witnessed a spectacular reduction of Arctic sea ice (Maslanik et al. 2011), culminating in September 2012 when both extent (-50%) and volume (-82%) reached all time record lows relative to the recent climatology (last 1500 years). The ice cover insulates the ocean from the atmosphere. A shrinking ice cover means that more light and heat enter the surface Arctic Ocean, drastically changing the temperature, storm, and ice regimes, as well as conditions for life. The objective of this project is to track such changes in the physical, biological and geochemical properties of Canadian Arctic waters. In the past, we have deployed ocean observatories in Hudson Bay, Hudson Strait, Baffin Bay, Beaufort Sea and the Eastern Arctic Ocean. These observatories are the oceanic equivalent of atmospheric meteorological stations. They are deployed every fall and recovered one year later. While moored, they record temperature, salinity, water velocity, dissolved oxygen, nutrients, light intensity, fluorescence (an indicator of micro-algae biomass), the vertical flux of particles, and ice motion. In addition, hydrophones record the vocalization of whales and other marine mammals. The data is used to describe seasonal, annual and interannual variations in the Arctic environment and its local ecosystems. This, in turn, enables us to understand how global warming is affecting the Arctic and how fast.

Key Messages

- The circulation under the ice is very active in the southern Beaufort Sea: there are numerous eddies and current pulses with velocities up to 0.90 m s-1, compared to a background mean current of 0.05 m s-1.
- Sediment trap data confirms that the ongoing decline in Arctic sea ice promotes the growth of pelagic communities in the Amundsen Gulf. However, it is unlikely that the increase in the productivity of lower food web could support new harvestable fishery resources in the offshore Beaufort Sea domain.
- The massive death of female Calanus hyperboreus and Paraeuchaeta glacialis after spawning in February triggers a large increase in the vertical fluxes of particles as the carcasses of these large copepods sink towards the bottom. This significant contribution of the Arctic Ocean to the sequestration of CO2 is documented for the first time.
- Climate change will strongly affect the pattern of the underwater ambient noise levels experienced by whales, seals and fish over the annual cycle. The recent analysis of a 13-month broadband acoustic record from the ArcticNet observatory in central Amundsen Gulf evidences large changes in soundscape during the open water season compared to the ice-covered season. The melting of the ice will result in a longer influence of wind forcing on ambient noise, increasing the levels by several dB over a large frequency bandwidth compared to under-ice levels.

Objectives

The overarching objective of the Moorings project is to track decadal changes in the Arctic Ocean using moored arrays of different oceanographic instruments. We focus on ocean climate and circulation, sea-ice cover, tides, the origin of water masses, soundscapes, the vertical and horizontal fluxes of biogenic carbon and particles, nutrients, primary production, and marine mammal vocalizations. Specific scientific objectives include:

- In collaboration with the Nansen-Amundsen Basins Observatory System (NABOS) and other international programs, to track the penetration and circulation of Atlantic water into and around the Arctic Ocean. We also quantify the Pacific water transport, variability and water masses transformation mechanism as it reaches the Mackenzie shelf and then bifurcates into the Amundsen Gulf. Knowing what is coming will help us understand how (and when) this water is flowing through the different straits in the

Canadian Archipelago. This data is also essential to validate the circumpolar Arctic models that produce the boundary conditions for our IRIS regional models;

- In close collaboration with the Hotspots project, to document fall-to-spring conditions in identified regional biological hotspots with emphasis on interannual variability in productivity and frequentation by top predators. In particular, we want to monitor changes in nutrients availability and biological production in relation to sea-ice cover reduction and warming of the surface layer;
- To monitor the seasonal variability in the timing and magnitude of vertical carbon fluxes. In the past, it was observed that the sedimentation rates (from sediment traps) are highly seasonal and sometimes influenced by current pulses. We plan to relate the changes in vertical carbon fluxes to the reduction in sea ice cover and increasing sea water temperature that dictate changes in primary and secondary productions;
- To develop, adapt to Arctic conditions, and exploit Passive Acoustic Monitoring (PAM) technologies to monitor the frequentation of Arctic biological hot spots by marine mammals over their annual migration to feeding and breeding grounds. We hope to relate variations in habitat use to changes in ecosystem productivity, community composition, and spatial organization as climate changes;
- As part of an international effort on ocean noise and to anticipate the impacts of an eventual increase in Arctic shipping, to characterize the underwater noise patterns of the pristine Arctic Ocean and compare this soundscape to that of the lower latitude belt already strongly affected by anthropic activities.

Introduction

The Arctic is changing more rapidly than predicted by the most pessimistic climate models. In the past decade, we have witnessed a spectacular reduction of Arctic sea ice (Maslanik et al. 2011), culminating in September 2012 when both extent (-50%) and volume (-82%) reached all time record lows relative to the recent climatology. The Canadian Arctic Straits and Fram Strait connect the waters of the Arctic Ocean to those of the Atlantic. Arctic surface water moves via these straits into the Labrador Sea, thereby stabilizing a global imbalance in precipitation minus evaporation between the Pacific and Atlantic Oceans (Wijffels et al.1992). Fluctuations in the fluxes of freshwater through the Archipelago may have global significance for climate through their influence on deep convection in the Atlantic sector (Melling, 2000). The ice cover, i.e. the insulation between the atmosphere and the ocean, is shrinking and modifying the heat and momentum fluxes between the two. This freshwater will ultimately condition the surface waters of the Labrador Sea and, in the worst case scenario, will contribute to slow down the global conveyor belt circulation. In the best case scenario it will modify the oceanographic conditions on the Grand Banks (Myers, 2005). Another major change is the increase in the heat transported into the Arctic Ocean by the Atlantic waters (Walczowski and Piechura 2006). Observations from the NABOS program have also shown that the temperature of North Atlantic water entering the Arctic has increased in recent years and that pulses of ocean heat occur (Polyakov et al., 2005). All these changes are linked to the global climate system and the scarcity of observations is impeding our ability to understand the linkages.

We also critically need to better understand the connections between the ecosystems and their environment in ice-covered regions to anticipate the impacts of global warming. The increase in the duration of the ice-free season will have major consequences for the marine environment. First, marine mammals relying on presence of ice to complete their annual life cycle, such as seals, belugas, narwhals, bowheads and polar bears will be directly affected by the changes in timing and duration of the ice period and indirectly by the associated ecosystem changes. Second, this region could become as productive as the Barents Sea and see the emergence of new fisheries. Third, some areas of the

Canadian Arctic Ocean could contribute increasingly to the sequestration of atmospheric carbon via an acceleration of the physical, chemical and biological carbon pumps.

Activities

Time frame and study area. Mooring operations have been curtailed since 2009 by accumulating losses of equipment. In 2012, the limited planned mooring operations were further impacted by the non-availability of the NGCC Amundsen, our main platform for deployment of instruments. A mooring was successfully recovered and redeployed in western Hudson Bay using the NGCC Radisson. As part of the Beaufort Regional Environmental Assessment (BREA) our partner mooring program Southern and Northeastern Beaufort Sea Marine Observatories led by ArcticNet and IMG-Golder successfully recovered and redeployed all of its moorings in the Beaufort Sea using the NGCC Laurier. Activities in 2012-2013 essentially focused on data analysis and the successful re-organization of the project (see Discussion section below).

Research activities in 2012-2013

Physics. Jessy Barette completed his M.Sc. thesis on the observations of eddies in Amundsen Gulf. He identified fourteen anticyclonic and four cyclonic eddies in the CASES and CFL data, as well as in the MMP 2007-2008 data. Barette and Gratton prepared a formal report on the quality control process of the 2007-2008 MMP data. McLane research Laboratories Inc. published our report on their website as an example of how the data from their profiler should be processed. Finally, we reprocessed the 2008-2009 and 2009-2010 MMP data. We were unable to salvage any of the 2008-2009 data, but most of the 2009-2010 data was recovered after a lot of efforts.

Nutrients and primary production. Two theses were completed in 2012-2013. Johannie Martin has submitted her Ph.D. thesis on subsurface chlorophyll maxima in the Canadian Arctic Archipelago (defense scheduled for April 9th). In particular, she used the 2008 mooring chlorophyll time series to constrain her 1-D model. Professor Jean-Éric Tremblay gave an invited talk at the IPY meeting in Montreal (Tremblay et al, 2012) where he presented the first observations (Figure 1 and 2) of subsurface chlorophyll maximum as recorded by the MMP (McLane Moored Profiler).

Gravitational particulate fluxes. Sediment trap fieldwork in 2012-13 comprised the successful deployment of a new trap array in the Mackenzie Canyon in partnership with BREA. Laboratory analyses and processing of data collected over 2007-09 in the Beaufort Sea (partly from the exploration claims of BP and IOL) resulted in two publications from post-doc fellows. Makoto Sampei confirmed the unsuspected role of zooplankton carcasses in fostering carbon export during winter. Alexandre Forest proceeded with an integrative analysis of the spatial variability and biophysical forcing of particle fluxes across the Mackenzie Shelf by combining trap data with results from an underwater camera deployed during the ArcticNet-Malina campaign in 2009.

Acoustics. Work in 2012-13 was dedicated to the analysis of the annual series of passive acoustic data recorded in Eastern Beaufort Sea and Southeastern Hudson Bay. The levels of background ambient noise over a [0-4 kHz] frequency band and its variation over the annual cycle were determined. The environmental forcings responsible for the ambient noise levels during the ice-covered and open-water periods were identified. The characteristics of transient and non-biological noise events were documented. The annual cycle of frequentation of the area by beluga, bowheads, and bearded seal was assessed and correlated with the ice breakup in spring and the freeze-up in fall.

Results

Long-term measurements of physical, biogeochemical and ecological variables in the Canadian Arctic are critical to our ability to detect significant trends in marine ecosystem change. The LTOO program provides baseline information on sea ice dynamics, ocean circulation, biogeochemical fluxes and marine mammal activities. But several other teams also use our results in second-level analyses and modeling exercises intended to decipher the linkages among the different components of the Arctic System. Although several adverse situations limited field operations in 2012-2013, we have continued to maximize the various datasets collected with the mooring-based instrumentations deployed as part of the LTOO program over the last few years. The following results clearly illustrate how this project forms a vital component of the ArcticNet scientific strategy by providing key insights on marine processes.

The under-ice ambient noise and transient acoustic events during Arctic winter reveal the dynamics of sea ice in response to environmental forcings (Kinda, Simard, Gervaise, Mars, Fortier, 2012, 2013)

Despite being entirely covered by ice of variable thickness and age in winter, the Arctic Ocean is not a static body of water during the polar night. As Arctic sea ice recedes and rejuvenates in response to global warming, the winter ice cover becomes more mobile and moves more freely under the pressure of wind and large-scale circulation patterns. Sea ice drift, fracturing, cracking, colliding, shearing, and ridging generate various acoustic transient events that can be monitored with moored instruments. Within the framework of the ArcticNet LTOO, the underwater ocean noises are investigated through a series of autonomous hydrophones AURAL-M2 and Acoustic Doppler Current Profilers (ADCP). The detailed analysis of transient acoustic events provides key information on the changing sea ice dynamics, especially during the fall-winter-spring period when access to the region is limited.

As part of the year-long recording “sound sessions” conducted in the Beaufort Sea through the LTOO program, a time-series of underwater noise recorded at the mouth of Amundsen Gulf from November 2005 to Mid-June 2006 was thoroughly analyzed with the aim of relating the ambient noise to environmental conditions. During this period, the study area was continuously covered by sea ice at >90% concentration. The time-series of the ambient noise component was computed using an algorithm filtering out transient acoustic events from 7-min hourly recordings of total ocean noise over a [0- 4.1] kHz frequency band. Under-ice ambient noise did not respond to thermal changes but showed consistent correlations with large-scale regional ice drift, wind speed and measured currents in upper water column. The correlation with ice drift peaked at ranges of ~300 km off Amundsen Gulf mouth, within the multi-year ice plume that the large Beaufort Gyre circulation extended westerly along the coast. Some of the transient acoustic events, of variable durations, were FM tones or pulse trains that were sometime repeated with a period corresponding to waves, and can sometimes be confounded with marine mammal songs. The most energetic ice sounds occurring all along the ice-covered period corresponded to leads opening. The Amundsen Gulf appears therefore to act as a large listening cone, where noise from distant sources, collected over a ~200 000-km2 large area is funnelled, as schematically represented in Figure 1. Our results reveal that ambient noise in the eastern Beaufort

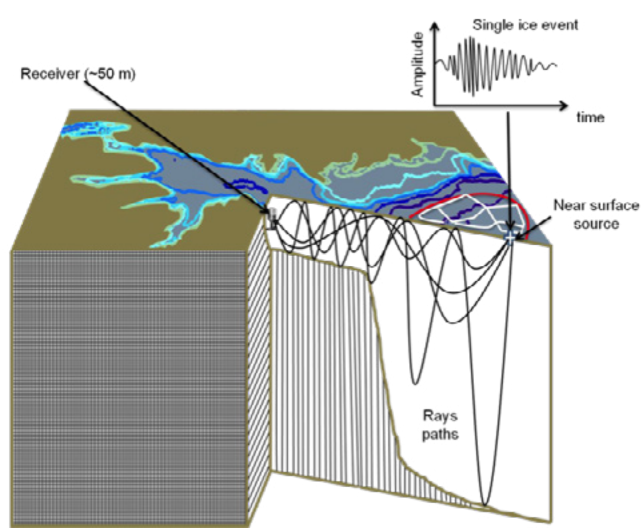

Figure 1. Schematic representation of ocean noise propagation from the multi-year ice plume drifting westerly from offshore Beaufort Sea to the 50-m deep recording location on the shelf in Amundsen Gulf.

Sea in winter is primarily controlled by the same meteorological and oceanographic forcing processes that drive the ice drift and large-scale circulation of the Beaufort Gyre. Hence, the monitoring of ambient noise at the mouth of the Amundsen Gulf could be used as a key indicator of changes in ice drift and circulation patterns that could occur remotely in the Canada Basin.

The detection of mesoscale eddies and their biogeochemical implications for the marine ecosystem (Barrette 2012, Barrette and Gratton 2012)

By transporting heat, nutrients, sediments and plankton, mesoscale eddies are key features of the ocean biophysical system. In low-latitude regions, eddies propagate at the sea surface and can be detected through remote sensing. They are defined as “marine oases” associated with increased biological productivity and commonly provide a rich feeding habitat for higher trophic levels. In the Arctic Ocean, the dynamics of ocean eddies are more complex and their linkages with the marine food web are poorly known. Arctic eddies develop generally at depth as a result of baroclinic instability along the shelf break or density fronts induced by brine rejection/freshwater inputs. They propagate under the consolidated pack ice and could account for a substantial share of the ocean heat that contributes to sea ice decline from underneath. Still, they remain fully undetected and their impacts on physical processes and marine life are not quantified. As a result, the current development of 3-D physical-biological models of the Arctic Ocean system is partly hindered by our poor comprehension of Arctic Ocean eddies.

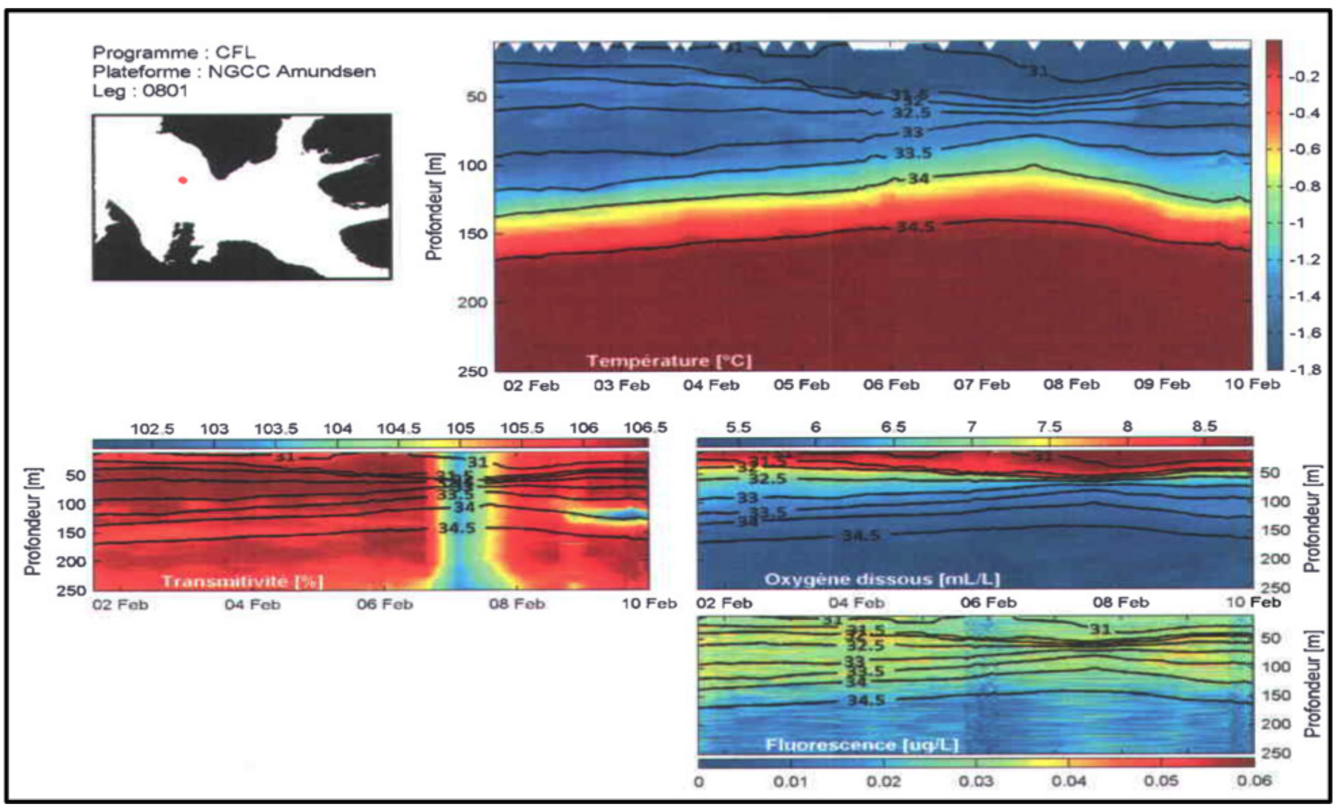

Figure 2. A cyclonic eddy (class 4, characterized by the pinching of isolines) travelling in the center of the Amundsen Gulf in February 2008. The increased suspended matter concentration is shown by the lower transmissivity signal associated with the passage of the eddy (lower left panel).

A pioneer step toward a better understanding of Arctic eddies in the southeast Beaufort Sea has been accomplished through the LTOO program. A detailed analysis of the ocean time-series collected from 2003 to 2008 provided the framework to characterize and classify Arctic Ocean eddies in distinct sub-groups according to their physical and biogeochemical properties (Barrette, 2012). A total of 18 coherent eddy-like features were identified, out of which 16 were characterized as anti-cyclonic (clockwise) while 4 were cyclonic (anti-clockwise; see example in Figure 2). Half of the anti-cyclonic eddies had their origin from instabilities occurring in the Beaufort Shelfbreak Jet that flows on the upper slope. Water properties in these features were similar to those outside, but most of them had an increased suspended matter concentration. The other half of anti-cyclonic eddies were also more turbid at their core, but had a lower temperature (near -1.8°C) and were present at a shallower depth (~50 M). These eddies probably originated from dense water formation occurring over the Mackenzie shelf or in the Cape Bathurst Polynya. Cyclonic eddies also contained more particles, thus confirming their relation with the shallow shelf area, but their exact mechanism of formation remained elusive. Our inventory illustrates that subsurface eddies in the Beaufort Sea are more frequent than initially believed, which underscores the need to monitor ocean circulation in the vicinity of topographical discontinuities, such as at the shelf break.

As part of the present work on Arctic eddies, Barrette and Gratton (2012) prepared a formal report on the quality control process of the 2007-2008 McLane Moored Profiler (MMP) that supported the detection of eddies. McLane research Laboratories Inc. has published the report on their website as an example of how the data from their profiler should be processed.

Geospatial modelling of vertical carbon fluxes as a support for ecosystem-level analyses across the Arctic shelf (Forest et al. 2012a, b, c, d, e, f)

The magnitude and nature of particulate organic carbon (POC) fluxes in marine ecosystems are key indices of biological productivity and ecosystem functioning. Downward POC fluxes drive the transfer of energy from the sunlit surface layer to benthic organisms and eventually support the sequestration of atmospheric carbon dioxide (CO2) in marine sediments. As part of the ArcticNet-Malina Joint Expedition in 2009, we assessed the variability and forcing factors of vertical POC fluxes across the Mackenzie Shelf by combining mooring times-series, ship-based measurements and remote-sensing (Forest et al., 2012a). A geospatial model of vertical POC fluxes was developed with the aim of proceeding to an integrative analysis of their biophysical determinants (Figure 3). Vertical flux data were obtained with sediment traps moored around 125 m and via a regional empirical algorithm applied to particle size-distributions (17 classes from 0.08-4.2 mm) measured by an Underwater Vision Profiler 5 (UVP5; Picheral et al. 2010). The optimization technique of Guidi et al., 2008 was adapted to the dataset to find the best parameters that minimized the differences between sediment trap data and the spectral-estimated POC fluxes within a power-law function. The optimization procedure revealed that the low fractal dimension (1.26 ± 0.34, i.e. indicative of porous, fluffy particles) and the dominance (~77%) of small aggregates (<0.5 mm) in total fluxes were the result of settling material produced through recent aggregation processes between marine detritus, gel-like substances and ballast minerals.

The 17 POC flux size-classes derived from the UVP5 dataset were further used in a second-level statistical analysis to determine the relationships between POC fluxes and the abiotic/biotic parameters. A suite of redundancy analyses on environmental forcings, linear trends, and spatial structures (i.e. principal coordinates of neighbour matrices, PCNM), was conducted to partition the variation of POC fluxes. POC flux variability was explained at 69.5% by the addition of a temporal trend, 7 significant PCNM and 9 biophysical variables. The first PCNM canonical axis (44.4% of spatial variance) reflected a shelf-basin gradient controlled by bottom depth and sea ice concentration ($p < 0.01$), but a complex

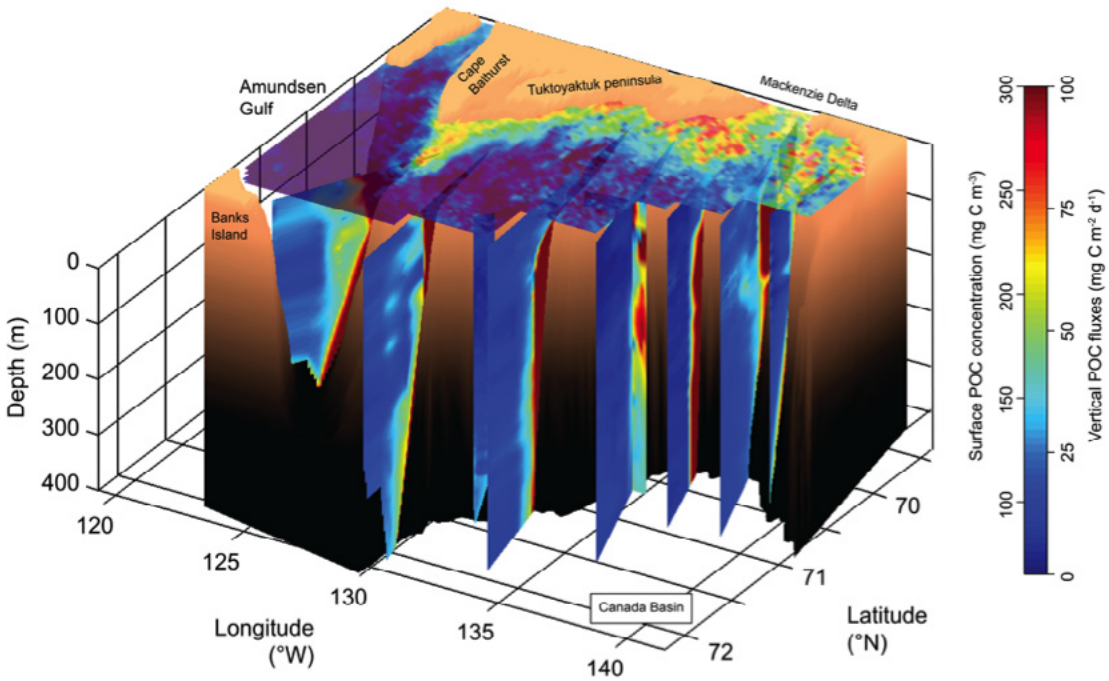

Figure 3. Geospatial model of vertical POC fluxes across the Mackenzie Shelf region as estimated with a transfer function linking sediment trap data and the particle size-distributions as measured by a UVP5 during the ArcticNet-Malina 2009 campaign.

assemblage of fine-to-broad scale patterns was also identified – revealing the patchiness of biological features across the Arctic shelf. Among biophysical parameters, bacterial production and north-easterly wind (upwelling-favorable) were the two strongest explanatory variables (r2 cum. = 0.37), suggesting that bacteria were associated with sinking material, which was itself partly linked to upwelling-induced productivity. The second most important PCNM spatial structure actually corresponded to the two zones across the study area where shelf break upwelling is known to occur under easterlies. Copepod biomass was negatively correlated ($p < 0.05$) with vertical POC fluxes, implying that metazoans played a significant role in the regulation of export fluxes. This study demonstrated convincingly that vertical POC fluxes in Arctic shelf systems are spatially complex, sensitive to environmental forcings, and determined by both physicochemical mechanisms and food web functioning. It further provides a robust case study on how mooring-based measurement can be used in ecosystem-level analyses that extract the backbone information from the multiple and often heterogeneous datasets collected over an oceanographic campaign.

A composite of surface POC concentrations encompassing the period from 18 July-23 August 2009 is superimposed above the vertical POC fluxes.

A substantial export flux of particulate organic carbon linked to sinking dead copepods during winter 2007–2008 in the Amundsen Gulf (Sampei, Sasaki, Forest, Fortier, 2012a)

In the Arctic Ocean, the vertical POC fluxes typically comprised of phyto-detritus, zooplankton fecal pellets and marine snow aggregates remain low during the dark winter period. As a result, the biological carbon pump in Arctic winter is traditionally viewed as non-existent. This is linked to the obvious fact that the main particulate agents that composed the bulk of vertical POC fluxes are ultimately derived from photosynthetic production, which is strongly limited by light during the polar night.

Using results from a long-term sediment trap moored at 100 m in the Amundsen Gulf over October 2007–July 2008, we nuanced this traditional view by showing that the sinking of zooplankton carcasses can act as an unusual maximum in sinking POC (Sampei et al., 2012a). Surprisingly, the integrated total POC flux for February (466 mg C m-2) was the second highest flux during the study period (the highest was in Jul; 1015 mg C m-2) due to a contribution of 91% from sinking dead copepods. The total POC flux in February 2008 in the Amundsen Gulf was up to two orders of magnitude higher than the previously reported traditional POC winter fluxes that did not include the contribution of sinking dead copepods. Hence, the POC flux in February could only be equivalent to 18% of the quasi-annual traditional POC flux. Our observations suggest that the substantial POC export flux that occurred during winter 2007–2008 was linked to the recent death of female calanoid copepods following egg spawning. Our results underscore that copepod carcasses that are traditionally excluded from POC fluxes estimated with sediment traps could result in the underestimation of the biological pump. They further illustrate how zooplankton life cycle plays an unsuspected role in the biogeochemical cycling of carbon and nitrogen when primary production is low.

A first complete annual time-series of marine mammal frequentation in the Amundsen Gulf from passive acoustic monitoring (Simard, Kinda, Gervaise, Roy, Mars, Fortier)

The steady decreases of the Arctic ice extent and thickness, with the associated lengthening of the ice-free season, are expected to modify the spatial-temporal patterns of frequentation and utilisation of the Arctic marine ecosystems by marine mammals, since ice is used as a platform for some (seals) and as a barrier for others (whales). Monitoring such responses to climate change in the Arctic requires gathering continuous long time-series of marine mammal presence at different locations, especially in intensively used areas and along migration paths. This cannot easily be obtained with traditional visual observations from fixed locations or moving platforms like aircrafts of boats. New PAM (passive acoustic monitoring) technology has been exploited in the Arctic Net Observatory for systematic tracking of presence of phoning marine mammals from their specific vocalisations recorded by passive devices deployed in their habitat.

A 4-kHz bandwidth acoustic dataset was recorded from a moored AURAL autonomous hydrophone at the mouth of Amundsen Gulf from Sept. 2005 to Oct. 2006. A signal-processing algorithm was developed to isolate the biological sounds from the broadband acoustic signal composed of ambient noise, non-biological transient noises (see above), and marine mammal calls. The variety of biological soundscapes representing different phonation activities and "concerts" from the marine mammal community was classified using unsupervised classification. As expected, presence of ice affected the type of biological soundscapes; under-ice soundscapes being dominated by seal sounds and open-water ones by beluga and bowhead whale sounds, especially during ice melting and freeze-up in spring and fall. Duration and timing of the frequentation were estimated for the different species.

Other biophysical results from the LTOO program

Ice stress buoys deployed from the Amundsen were used to show that the internal sea ice stresses are dominated by thermal stresses (rather than mechanical stress because of the reduced fetch of the wind in the CAA). This makes us reconsider the modeling of land fast sea ice in the Canadian Arctic Archipelago and also in the Arctic. The results were presented at a workshop (AOMIP: Arctic Ocean Model Intercomparison Project) at the Woods Hole Oceanographic Institute in October 2012. Ice stress buoy data, ice thickness data and mooring data were also used by Véronique Dansereau to calibrate the sea ice model.

Martin (2013) and Martin et al. (2013) used the data from the fluorometer from mooring CA05 2007-2008 to assess the performance of a 1-D model in simulating the ubiquitous subsurface chlorophyll maxima commonly found in the waters of the Canadian Arctic Archipelago in summer. Similarly, Tremblay (2012) presented at the IPY conference 2012 the first annual time-series in subsurface chlorophyll concentration as recorded with the MMP deployed on the eastern Mackenzie Shelf. Observations made with this instrument revealed the presence of sinking aggregates from the chlorophyll maximum in late summer. This process is likely at the origin of the peak POC fluxes recorded with sediment traps in late summer, but further work is needed to confirm the link between the waning of the chlorophyll maximum and downward export.

Discussion

Despite the conjunction of several adverse conditions that affected the field program in 2012-2013 (see Conclusion section below), the LTOO project is coming of age in the analysis of the data recorded by the observatories since 2003 and before ArcticNet (NOW and CASES programs). Progress has been particularly constant in the integration of primary production and sediment trap data from the Beaufort Sea, Laptev Sea, North Water and Hudson Bay. Among the several dozens of articles published by this component of the project, the most recent ones yield an impressive synthesis of the functioning of the arctic pelagic ecosystem, its coupling to the benthic ecosystem, and its potential evolution as the ice cover regresses and the surface layer of the Arctic Ocean warms up. The emerging picture suggests that at least initially (until mid century?), increased stratification of the surface layer linked to an acceleration of the sea-ice freeze/melt cycle could prevent the renewal of nutrients in the surface layer, hence limiting primary production despite an increased availability of light (Tremblay and Babin 2013). This stagnation due to intense stratification could eventually end as mixing by intensifying fall and spring storminess increases as and sea-air exchange of heat and moisture intensify over ice-free areas (Barber et al. 2012).

Another component of the project that made significant advances in 2012-2013 is the Passive Acoustic Monitoring (PAM) of ambient noise and marine mammal vocalizations. The study of the causes of ambient noise unveiled an entirely new approach to study the dynamics and thermodynamics of sea ice by listening to the spectrum of sounds it produces, which ranges from murmur to thunder. In open water, acoustic monitoring could also provide exciting new measures of wind intensity at the surface that could be used in the study of circulation, vertical mixing, and nutrient renewal, thus further connecting the different components of the project, from physics, to PAM, primary production and particle fluxes. Long-term records of marine mammal vocalizations are also yielding the first analyses of the frequentation of biological hotspots by the different species of whales in summer and seals throughout the year.

As well, the identification and classification of eddies at the edge of the continental shelf of the Beaufort Sea represents a significant breakthrough in our understanding of the regional circulation and its potential impacts on ecosystems. The notion that such eddies may be generated by atmospheric pressure gradients as far away as in the Bering Sea provides an interesting example of teleconnections that illustrates the importance of Pacific influences in the Beaufort Sea. The documentation of the frequency and characteristics of such features will help constrain and refine numerical models of the regional oceanic circulation that are needed by the different IRISes to anticipate the evolution of sea-ice and temperature regimes over the coming century.

While further syntheses of physical measurements are needed, it is important to recall that the physical data produced by the LTOO project continue to be timely validated, quality-controlled, and uploaded to the Polar Data Catalogue. These data are used as background information or to test specific hypotheses in a multitude of scientific studies and reports by several ArcticNet projects and by our partners in the oil exploration sector.

Conclusion

Since 2004, the LTOO Moorings project has established Long-Term Oceanic Observatories in the Canadian High Arctic and Subarctic regions in an effort to understand ocean circulation and freshwater inputs, productivity, carbon fluxes and marine mammal activity in each of the 4 ArcticNet IRIS regions. Several collaborations and participation in international scientific programs also enabled us to expand our observational network in the Canadian Artic and even extend its boundaries to include the Laptev and east Siberian Seas and develop a better understanding of the pan-Arctic circulation. The data generated from this project provides the crucial baseline information needed to assess the effects of climate change and rising anthropogenic activities (e.g. oil exploration, shipping) on the Arctic marine ecosystem and has been used in over 35 peer-reviewed articles to date.

Although the time series developed until now provide some insight into the state of the environment, the impacts of climate change in the Arctic will take a few decades to fully emerge. It is therefore mandatory to maintain the observatories to build the long-term dataset needed to answer the ecosystem-level questions raised by climate change.

After years of success, the LTOO Moorings project is now completing a much-needed restructuration. Several major obstacles to our continued success were overcome in 2012-2013. First, retiring Project Leader Gratton was replaced by interim co-leaders Fortier and Tremblay while Dmitrenko, a specialist of arctic moorings, gets established at the University of Manitoba to eventually take lead of the project, including the exploitation of the large set of physical data accumulated over the years. Second, with the cancellation of NSERC's Major Resource Support program in 2011, four out of the 7 technicians in charge of the Amundsen's equipment pool and the mooring operations had to be laid off. Thanks to different funding sources, we have now hired two ocean-going engineers to rebuild part of the team. Third, an epidemic of equipment losses that started in 2008 was traced back to developing weaknesses in the protocols and procedures used to moor the instruments. With help from IGM-Golder, these are being corrected. Fourth, the return of the Amundsen in 2013 will provide the platform needed to deploy new moorings (see Future Work section below). Fifth, as part of the reorganization of the project, responsibility for the operation of the CTD-Rosette systems of the ship is being transferred progressively to the actual users of the data. Finally, we are devising new and promising approaches to the funding of the maintenance and recapitalization of the equipment pool of the Amundsen.

Despite these organizational difficulties, the LTOO Mooring program of ArcticNet has maintained a high scientific productivity in 2012-2013 by working accumulated data sets, completing theses, maintaining an active team, and multiplying collaborations with other projects.

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