Progress Report to NSERC

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Research Network Grant
Progress Report

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Project Name	Canadian Arctic Shelf Exchange Study (CASES)
File no.	
Co-Applicants' Names/Affiliations	See annex 1 - Canadian co-applicants and affiliation
Partners: • name of organization	See annex 2 – Main Partners

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1. PROGRESS TOWARDS OBJECTIVES / MILESTONES

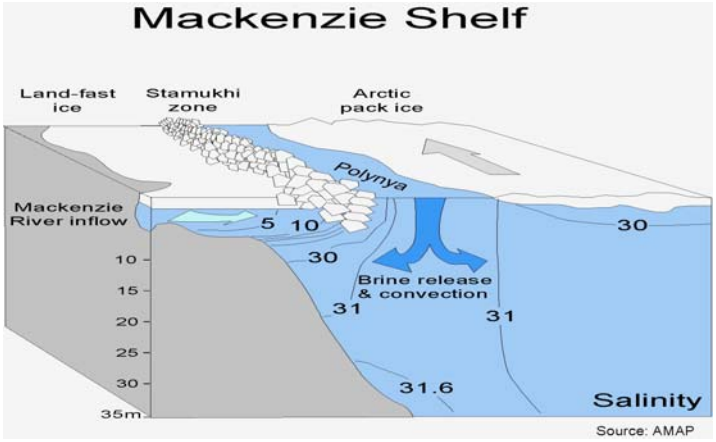
At the time of the preparation of the proposal in 2000, numerical simulations of future climate by different General Circulation Models (GCM) were converging on one scenario: climate warming will start and be most intense at arctic latitudes (e.g. Stouffer et al. 1989; Shindell et al. 1999; Flato et al. 2000). For a doubling of atmospheric CO_2 by 2070, the average output of 19 independent GCMs indicated an increase of 3.5^{o}C in mean atmospheric temperature north of the Arctic Circle. In November 2004, the release of the Arctic Climate Impact Assessment (ACIA, 2004) confirmed the numerous and often spectacular symptoms of an arctic amplification of climate warming: glaciers and ice shelves are regressing, the vegetation is changing, precipitation and river runoff are increasing, the melting of the Greenland Inlandsis is accelerating, the extent of Arctic sea ice is shrinking and the salinity of the deep thermohaline circulation is decreasing. While some scientific debate persists on the causes (natural versus anthropogenic) of these changes, the convergence between observations and model predictions clearly indicates that we cannot reject the possibility that the climate of the Northern Hemisphere is rapidly shifting towards a new equilibrium in response to increased atmospheric concentrations of greenhouse gases.

Among the numerous consequences of a warmer Arctic, the on-going reduction of the Arctic Ocean sea ice cover will have profound environmental impacts. Both simulations and observations confirm that by 2050 the Arctic Ocean could be nearly free of ice during the summer months (Comiso, 2002, Johannessen et al. 2004, Stroeve et al. 2005). By increasing photosynthetic fixation of atmospheric carbon through a reduction of ice cover, climate warming may profoundly alter biogeochemical fluxes on Arctic shelves, therefore affecting the export of carbon to the pelagic and benthic food webs, and to the deep basins where it can be sequestered. The assessment of the role of a seasonally ice-free Arctic Ocean as a future sink or source of atmospheric CO_2 requires a significant improvement of our understanding of the processes and feedbacks linking freshwater and sea ice, sea ice and climate, and sea-ice, biological productivity and biogeochemical cycles in the Arctic Ocean in general and on Arctic shelves in particular.

Toward that goal, the central objective of CASES is to understand and model the response of the Mackenzie Shelf ecosystem to atmospheric, oceanic and continental forcing of sea ice cover variability. The objective of the first phase of CASES (2002-2004) was to deploy an ambitious field program in support of a highly integrated multidisciplinary study of the eastern Beaufort Sea ecosystem on an annual cycle. Because of the influence of the Mackenzie River, this system is the only North-American analog of the immense Siberian Shelves that characterize the Arctic Ocean and where the regression of the ice cover has been intense recently.

The scientific program of CASES is underpinned by the simple central hypothesis that the atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes on and at the edge of the Mackenzie Shelf.

1.1 Study area and proposed field program.



The Mackenzie Shelf is covered with ice from October until May to early August, depending on the year. In late summer, the nearshore zone of the ice-free shelf is dominated by the Mackenzie River plume (Macdonald et al. 1995). Typically, ice starts forming in October in shallow areas and, by late fall, the freshwater plume extends immediately beneath the growing landfast ice cover. The ice-free channel that separates the landfast ice from the central ice pack forms the flaw lead polynya (Figure 1, above). Throughout winter, floe rafting at the edge of the landfast ice builds the "stamukhi", a thick ice ridge parallel to the coast forming in waters between 15 and 50 m deep. In spring, the containment of the river plume by the stamukhi forms the seasonal Lake Mackenzie. Beyond the stamukhi, the flaw polynya that stretches along the entire Arctic Shelf widens in summer to form the Cape Bathurst polynya in the Amundsen Gulf. Offshore of the polynya begins the central Arctic ice pack.

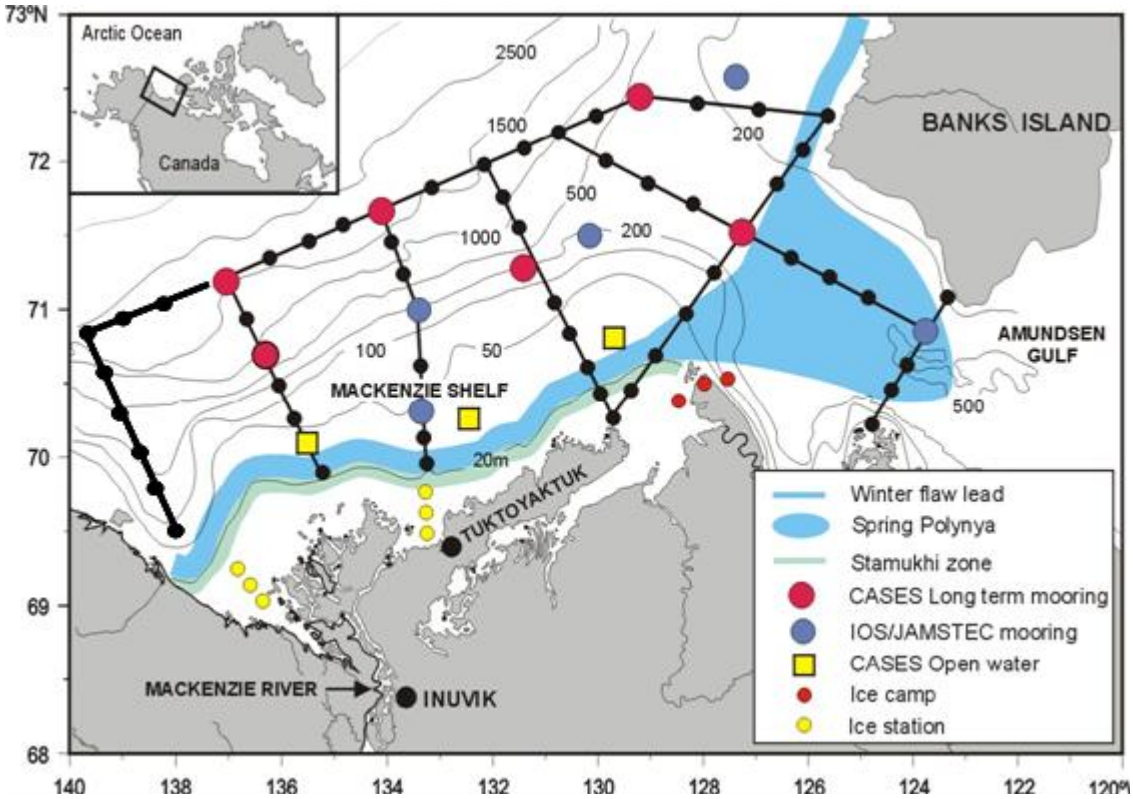


Figure 2: Proposed sampling plan as presented at the site visit in Ottawa.

The field program proposed by CASES was designed to contrast the annual cycle of the arctic marine ecosystem in three regions of the study area: (1) the Cape Bathurst polynya; (2) the Mackenzie Shelf and (3) the edge and slope of the Shelf (Figure 2). Field operations were centered on the deployment of the 100-m long icebreakers *Radisson* and *Amundsen* (from Quebec City through the NW Passage) and the 80-m long icebreaker Laurier (from Victoria through the Bering Strait). These main expeditions were to be complemented by several missions on other vessels, on a charter or opportunity basis. Subprojects 2.4, 2.7 and 2.8 planned to use the *Nahidik*, a 53-m long shallow draft vessel operated by DFO, to access the Mackenzie delta and the inshore waters of the Mackenzie Shelf, either as a direct CASES operation or as part of the satellite program ARDEX (Arctic River Delta Experiment). Subproject 2.7 and 2.8 intended to join the expedition of the ice-reinforced 128-m long *Mirai*, a Japanese ship deployed in the offshore region of the study area from 20 September to 10 October 2002. Finally, Subproject 2.5 planned to participate in the annual expedition of the *Kapitan Dranytsin*, a 132-m Polar class Russian icebreaker, to the Laptev Sea as part of an exchange program between CASES and NABOS (Nansen-Amundsen Basin Observatory Study).

1.2 Completed field program. We are happy to report that all the major elements of the field program have been successfully completed (Table 1). The initial 35-d preliminary expedition of the *Radisson* in September 2002 enabled us to complete a preliminary synoptic spatial survey of the oceanography, biology and biogeochemistry of the area (Figure 3). This was complemented by the deployment for one year of 8 oceanographic moorings during the September 2002 expedition of the *Laurier* to the study area. The main thrust of the planned field program was the one-year expedition of the *Amundsen* to the study area, starting in September 2003 (Figure 4). This arctic mission of unprecedented scope comprised three major parts: (1) a fall survey covering the entire region from September to December 2003, including the recovery of the 8 moorings deployed during the preparatory mission of the *Laurier* in 2002 and the deployment of 17 new mooring arrays; (2) the over-wintering of the ship in Franklin Bay for the monitoring of the winter evolution of the ecosystem; and (3) the spring/summer spatial survey of the region to monitor the break-up of the stamukhi, the opening of the Cape Bathurst polynya and the development of the summer ecosystem, including the recovery and redeployment in August of 7 of the 17 the oceanographic moorings. Again, the annual mission of the *Laurier* to the area was the opportunity to recover the remaining 10 moorings and to extend the sampling of the ecosystem into September 2004.

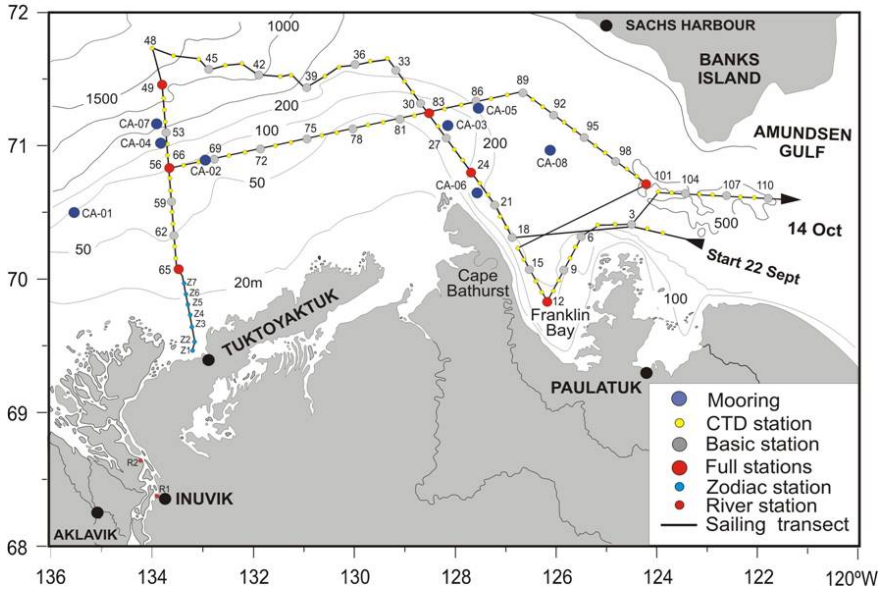


Figure 3. Map of the study area with ship track and sampling stations for the CASES 2002 mission on board *Radisson*. The science complement boarded the ship in Resolute on 18 September and disembarked in Quebec City on 26 October 2002.

The planned deployment of an ice camp on the Mackenzie Shelf in the spring of 2004 had to be abandoned as logistics proved more difficult than expected. To palliate this, the *Nahidik* was used to access the inner Mackenzie Shelf and Delta ecosystems in spring and summer, and complementary sampling of inshore waters was conducted from Tuktuyaktuk (Table 1).

The successful participation of CASES teams in parallel international efforts also represented a major contribution to CASES. Work on the *Mirai* complemented the CASES field program in the Beaufort Sea, while participation in the NABOS missions on the *Kapitan Dranytsin* provided a unique opportunity to compare the shallow shelf ecosystems of the Beaufort and Laptev Seas.

Several of the missions that prepared or complemented the one-year expedition of the *Amundsen* represent a direct contribution to CASES by our main partners the Department of Fisheries and Oceans and the Department of Natural Resources.

Overall, the CASES field program logged 543 days at sea on 6 different vessels, 377 of these days being directly chartered by CASES and 166 being contributed by national and international partners. This corresponded to a total of 14 544 day-scientists at sea, which makes the CASES field program the largest and most comprehensive international effort ever to decipher the functioning of the Arctic Ocean shelf ecosystem.

Most importantly, some elements of the CASES field program are being continued within the framework of the Network of Centres of Excellence ArcticNet (Table 1). In particular, ArcticNet will be re-deploying annually four of the original CASES mooring arrays in the study area, as part of an oceanographic observatory to monitor the evolution of the coastal region in response to climate change. The annual mission of the *Amundsen* to the region will be the opportunity to measure key indicators of the state of the ecosystem, in continuity with the three-year interannual comparison (2002, 2003, and 2004) initiated during CASES. By 2005, four oceanographic observatories of this kind will be operated by ArcticNet and NABOS (Beaufort Sea, North Water, Laptev Sea, and Hudson Bay) and we intend to increase this network of observatories as part of the Canadian contribution to the International Polar Year (see also **Benefits to Canada**).

Table 1. Chronological summary of the main elements of the field program of CASES, with notes on level of achievement.

Planned field program element	**Level of achievement**
September 2002. Annual mission of the *Laurier* to the Beaufort Sea (6-24 September). An in-kind shiptime contribution to CASES from the Department of Fisheries and Oceans.	Completed as planned. Eight (8) oceanographic moorings deployed at key locations in the study area. The arrays of instruments included salinity-temperature probes, acoustic and mechanical currentmeters, and sediments traps. The moorings recorded over an annual cycle the oceanographic circumstances that conditioned the ecosystem before the one-year expedition of the *Amundsen*.
August-September 2002. Mobilisation of the *Radisson* and expedition to the Beaufort Sea (20 September to 14 October). Thirty-five (35) days including NW Passage and return.	Completed as planned. Full spatial coverage of the three oceanographic regions of the study area with sampling of physics, biology and biogeochemistry. In addition to valuable data for the interannual comparison (2002-2003-2004) of the ecosystem status in the fall, this expedition provided the background information needed to prepare the one-year expedition. Complete mission report available at www.cases.quebec-ocean.ulaval.ca/Radisson2002report.pdf

Table 1. Continued

September 2002. Participation of CASES subprojects 2.4, 2.7 and 2.8 in the *Mirai* expedition to northwest region of the study area (20 September to 10 October)	Completed as planned. On board the *Mirai*, Subproject 2.4 completed some preliminary sampling of microbial life in the study area. Subprojects 2.7 and 2.8 acquired the first multibean survey of the Mackenzie Trough. The information helped plan the multibeam survey and sampling of bottom sediments by the *Amundsen* in 2004.
Aug-September 2003. Participation of CASES Subproject 2.7 in the operations of the *Nahidik* (24 August to 19 September). An in-kind shiptime contribution to CASES from the Departments of Fisheries and Oceans and Natural Resources.	Completed as planned. Subproject 2.7 carried out a complementary sampling on the impact of sea ice scouring on benthic community structure on the shallow inner shelf.
Aug-September 2003. Participation of CASES Subproject 2.5 in the mission of the *Kapitan Dranytsin* to the Laptev Sea (26 August – 18 September)	Completed as planned. Subproject 2.5 sampled oceanographic conditions, zooplankton and the juvenile stages of Arctic cod. The data will allow us to compare the evolution of the marine arctic ecosystem in the Laptev and Beaufort Seas.
February-Aug 2003. Mobilisation of the CCGS *Amundsen* in preparation for the one-year expedition to the Beaufort Sea. A direct contribution to the CASES program and to future Canadian-led international programs in the Canadian Arctic (e.g. ArcticNet).	Completed as planned. With major funding from the Canada Foundation for Innovation ($27.5M) and the Department of Fisheries and Oceans ($3.2M) and with major in-kind contribution of expertise and services from the Canadian Coast Guard (DFO), the *Amundsen* (formerly the *Sir John Franklin*) is transformed into a dedicated research icebreaker. In addition to major structural transformations, the ship is fully equipped with the latest generation of oceanographic instrumentation.
September-December 2003. Part one of the one-year expedition of the *Amundsen* to the Beaufort Sea: mooring deployment and spatial survey.	Completed as planned. Recovery of the 8 moorings deployed in September 2002. Deployment of 17 moorings. Complete spatial sampling of the three oceanographic regions of the study area, including atmosphere and ocean physics, water column chemistry, biogeochemistry and biology, plankton, benthos and fish.
December 2003-May 2004. Part two of the one-year expedition of the *Amundsen* to the Beaufort Sea: over-wintering in Franklin Bay.	Completed as planned. Over-wintering as planned in Franklin Bay in water depth of 236 m. Regular sampling of the water column (physics, chemistry, biochemistry, microbiology, plankton) through the ship's moonpool and at satellite stations on the ice (from 100 m to 20 km from ship). Sampling of atmosphere, snow and ice covers, mesozooplankton, fish and bottom sediments. Spring ice-camp on the Mackenzie Shelf abandoned and replaced by ARDEX coastal work with *Nahidik*.

Table 1. Continued

May-June 2004. Ice camp on the western side of Cape Bathurst.	Abandoned because of logistics. Replaced by sampling of shallow inner shelf with *Nahidik* (see below)
June-August 2004. Part three of the one-year expedition of the *Amundsen* to the Beaufort Sea: spring-summer study of the unfolding ecosystem in the three oceanographic areas.	Completed as planned. The flaw lead polynya and the Cape Bathurst polynya opened widely (as hoped for) in 2004 (Figure 3). The *Amundsen* leaves the landfast ice on schedule to complete two consecutive full spatial survey of the study area.
July-August 2004. Operations of the *Nahidik* in the Mackenzie Delta and inner Mackenzie Shelf (26 July to 3 August). ARDEX program.	Completed as planned. Within the framework of the CASES satellite program ARDEX (Arctic River Delta Experiment), shallow draft vessel CCGS *Nahidik* was used to make parallel measurements of carbon cycling in the Mackenzie River and freshwater-saltwater transition zone. A separate cruise report is available for ARDEX (Vincent & Osburn 2004).
August 2004. ArcticNet mission to continue some aspects of the CASES field program (13-25 August).	Completed as planned. Recovery of 8 of the 17 CASES moorings and redeployment of 4 within the framework of ArcticNet.
August-September 2004. Participation of CASES Subproject 2.7 in the operations of the *Nahidik* (23 August to 20 September). An in-kind shiptime contribution to CASES from the Departments of Fisheries and Oceans and Natural Resources.	Completed as planned. As in 2003, Subproject 2.7 carried out a complementary sampling on the impact of sea ice scouring on benthic community structure on the shallow inner shelf.
September 2004. Annual mission of the *Laurier* to the Beaufort Sea (3-22 September). An in-kind shiptime contribution to CASES from the Department of Fisheries and Oceans.	Partially completed. Complementary sampling of the biology (phytoplankton/zooplankton) to extend the CASES annual cycle and allow for a tri-annual comparison of ecosystem maturity in the fall. Recovery of 7 of the 9 remaining CASES moorings. Ice conditions prevented the recovery of two moorings in the north-eastern part of the sampling area.
Aug-September 2004. Participation of CASES Subproject 2.5 in the mission of the *Kapitan Dranytsin* to the Laptev Sea (5 - 27 September)	Completed as planned. In addition to sampling oceanographic conditions, zooplankton and the juvenile stages of Arctic cod as in 2003, CASES Subprojects 2.1 and 2.5 moored one array of instruments (including sediment traps) and contributed ADCP currentmeters on two Russian moorings. This CASES-NABOS collaboration is quickly expanding.

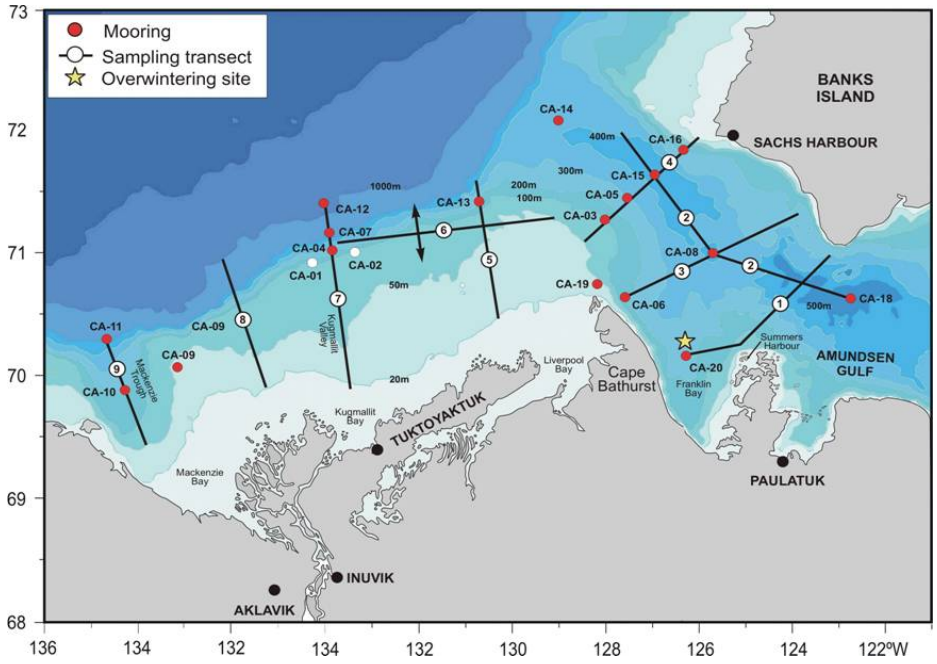


Figure 4. Map of the study area with position of moorings and sampling transects covered by the *Amundsen* in the fall of 2003 and the spring/summer of 2004. The over-wintering position of the ship in Franklin Bay is indicated by a yellow star.

Satellite coverage (SSM/I, AMSR, ENVISAT, RADARSAT, SeaWiFS and MODIS) before, during and after the field program has been extensive, with real-time data received on the ship to assist field operations. For example, the MODIS image presented below was used to optimize the ship track to study the large plumes of turbid surface waters that formed when the stamukhi broke up, releasing Lake Mackenzie waters in the surface layer of the Arctic Ocean.

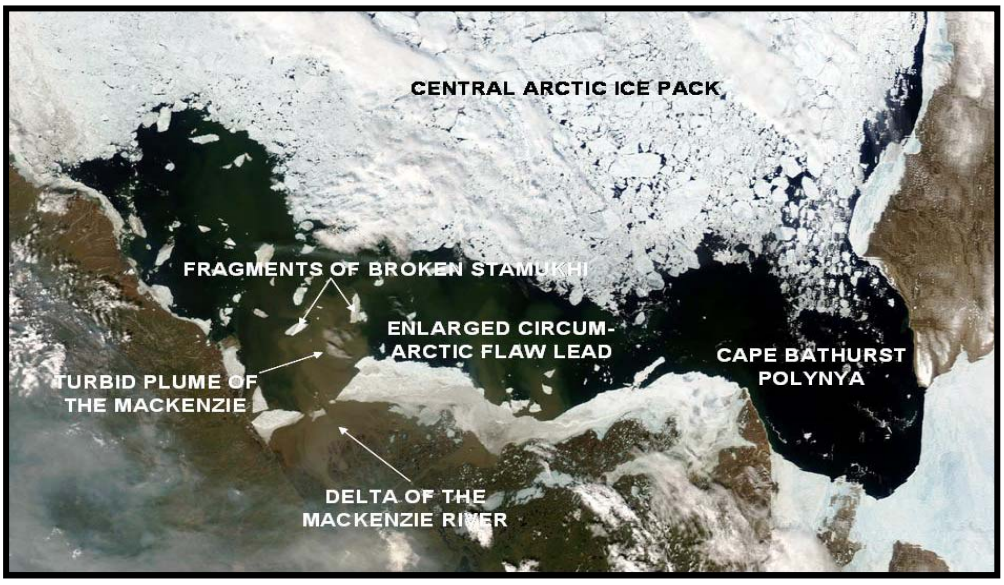


Figure 5. MODIS satellite image of the study area in June 2004, showing the release of the turbid waters of the Mackenzie after the break-up of the stamukhi.

1.3 Network integration of research results

As described in the proposal, the scientific program of CASES consists of 9 highly integrated subprojects. Each subproject is dependent to some extent on the data gathered by several other projects. The design of the subprojects around the same central hypothesis and sampling from the same platform ensured that the sampling of the different variables was coordinated in time and space and that the data sets are compatible.

A first pass at integrating the colossal amount of data collected during CASES took place during a 3-d workshop in Montreal in October 2004. There, the different subprojects presented the data sets available and preliminary findings. This allowed the different teams to exchange information and data, to further the planned collaborations described in the proposal and to initiate new ones based on unexpected findings. The Montreal meeting was also the opportunity to plan the publication of joint papers, in particular the preparation of the several special issues that we intend to publish in different journals.

Six months after completion of an extremely intensive field program, it is still early to report on the full integration of the research results as most teams are in the process of analysing data and samples. The next CASES data and publication workshop is scheduled for February 2006 in Winnipeg. At that time, the analysis of the data is expected to be advanced enough to enable us to draft the content of the different special issues planned in Montreal.

1.4 Significance of the results: highlights and key findings.

As mentioned above, the full significance of the results will emerge with the analysis of the extensive data sets collected during CASES. Already, the preliminary findings reported at Montreal workshop clearly indicated the richness and novelty of the information generated by the Canadian Arctic Shelf Exchange Study. Among the several preliminary findings and scientific premières reported, a selection covering the main disciplines is presented here in bullet form. Other examples are given in the subproject progress reports.

- Up to now, sea ice was believed to be impermeable to gases. Collaborations between Canadian and Danish scientists during CASES revealed that the ice pack actually absorbs large amounts of carbon dioxide during the winter months. This surprising result may bring some modification to present coupled ocean-ice-atmosphere climate models.
- Among several premières, the one-year expedition has enabled us to describe the annual cycle of transformation of the snow over the sea-ice cover. This information is crucial not only to calibrate our interpretation of satellite images of sea-ice, but also to understand the climatic control of the photosynthetically available radiation reaching the ice bottom and the water column.
- The application of molecular approaches to the study of arctic life has revealed a whole suite of new viral, bacterial, unicellular and metazoan organisms. In particular, we discovered the unsuspected importance of Archaea in the arctic microbial community.
- Several lines of evidence point to the development of some limited amount of microalgal biomass under the ice as early as in February, during the Polar night when virtually no light is available for photosynthesis. Could mixotrophs be responsible for the production of photosynthetic pigments before any light becomes available? This conundrum has raised much debate among the different teams.
- Until CASES, the immense concentrations of Arctic cod that must exist in order to feed the numerous arctic predators (seals, whales, birds) that prey almost exclusively on this small fish remained undetected. The deployment of sophisticated echo-sounders over an annual cycle

enabled us to discover the missing cod which form extremely dense aggregations with its copepod prey at depth on the shallow arctic shelf in winter.

- Contrary to common wisdom, the zooplankton and the Arctic cod that congregate at depth on the shelf in winter do not go into hibernation but remain very much active, despite the sub-zero temperatures, the complete absence of sunlight and the weakness of primary production. These animals respire the organic matter formed in summer (either as internal reserves or as prey), a potentially important mechanism for the sequestration of carbon dioxide at depth.
- The preliminary analysis of the annual cycle of sedimentation from the time-series sediment traps indicate that the particulate flux of carbon was as large in the Cape Bathurst polynya in 2002 than in the North Water polynya in 1998. This confirms that primary production and the sequestration of atmospheric CO_2 over the immense Arctic Shelves will increase significantly with a climate-induced regression of the ice cover.
- The deployment of the multi-beam sonar and other instruments has produced the first detailed bathymetry of the region, revealing a suite of geological features such as ice scouring, intense glacial erosion down to 400 m depth, and a major slump of the shelf edge. This unique information is providing new insight into the geodynamics of the northern margin of Canada.
- Combined to detailed surveys of sediment depth by the sub-bottom profiler sonar, the successful deployment of the piston core has allowed us to recover a series of sediment cores from which the paleoceanography of the region will be reconstructed over the last several millennia.

1.5 Benefits to Canada.

The environmental, socio-economic and geopolitical consequences of a reduction of the Arctic sea ice cover will be major. They include the disruption of marine Arctic ecosystems and the displacement (or even extinction) of the unique Arctic megafauna; the acceleration of climate warming through the albedo effect; the potential disruption of the oceanic thermohaline circulation; the opening of the NW Passage to trans-continental shipping; the opening of the Canadian Arctic Shelf (including the Canadian Archipelago) to the exploitation of its natural resources (fisheries, minerals, petroleum); and the disruption of Inuit travel routes and traditional activities linked to sea ice.

Several reports have pointed to the weakness of Canada's stewardship of its Arctic territories and seas and to the need to re-affirm Canadian sovereignty in the Canadian Arctic. The new geopolitical situation brought about by the freeing of the Arctic Ocean could renew assaults on this sovereignty. This threat is amplified by the increasing disparity between foreign and Canadian scientific presence in the Arctic, as Arctic programs of Federal Departments are cut back and foreign programs develop.

The many significant benefits of CASES to Canada include:

- **A significant consolidation of the Canadian scientific presence in the Arctic**. As a Canadian-led international program of unprecedented magnitude, CASES has clearly signalled to the scientific community that Canada is back as a major player in the study of the Arctic Ocean. Being the first scientific mission of the *Amundsen*, CASES also showcased to our international collaborators the new dedicated research icebreaker and its state-of-the-art facilities and equipment. The international invitation to join the Canadian effort in the study of the Arctic contained in CASES has resulted in collaboration with the best foreign teams and is prompting new offers of international collaboration.
- **A significant contribution to the re-affirmation of the Canada's sovereignty in the Arctic**. The participation in CASES of a large contingent of researchers from 8 foreign countries is certainly one of the best way to inform the world of the increasing role that

Canada intend to play in the stewardship of its arctic territories. This foreign participation has been publicized abroad in newspaper and magazine articles, as well as in radio and television interviews. In addition, at least three television documentaries (two focusing on CASES and one featuring CASES activities) have been aired in Europe, Africa, Asia and the United-States. This wide and ongoing national and international broadcast of the scientific objectives and field program of CASES has been tremendously helped by the recent focus of the media on issues linked to climate change. As the general public in Canada and abroad learn of the issues linked to climate warming, it also learns about the Canadian efforts to study the Arctic and, as a consequence, witnesses the renewed interest of Canada for its arctic provinces.

- **Training the next generation of Canadian specialists of the Arctic in a multidisciplinary and international environment**. After 20 years of downsizing its scientific effort in the North, Canada is missing a complete generation of the field scientists painfully needed to study and monitor the present transformation of the Arctic Ocean. CASES has provided a unique scientific environment for the training of young arctic oceanographers. Over 127 Canadian and foreign students trained in Canadian universities have been exposed to the multidisciplinary and international science needed to address the ecosystem-level issues raised by the reduction of the arctic sea-ice cover. Most importantly, on board the *Amundsen* and the other ships used in CASES intensive field program, Canadian students have collaborated closely with foreign students and with the best specialist of the Arctic Ocean in Canada and abroad. International arctic meetings and CASES workshops are regular occasions to revive and strengthen these links. As a result, young Canadian researchers and their foreign counterparts have formed a dynamic international network that is likely to lead future international efforts to study the Arctic Ocean.
- **Building continuity and knowledge transfer in the Canadian arctic program: CASES as a cornerstone for ArcticNet.** The consortium of researchers that developed CASES and the *Amundsen* project has recently expanded to form ArcticNet, Canada's first arctic Network of Centres of Excellence. The central objective of ArcticNet is to bring together the best arctic specialists in the natural, health and social sciences and their Inuit partners to conduct an integrated study of the changing coastal Canadian Arctic. ArcticNet will generate the cross-sector knowledge needed to formulate the policies and adaptation strategies that will enable Canada to minimize the negative impacts and maximize the positive outcomes of the present transformation of the Arctic.

  The NSERC-funded Research Networks NOW (the International North Water Polynya Study, 1997-2001) and CASES have set the stage for ArcticNet by enabling Canadian arctic specialists and their foreign collaborators (1) to merge into a dynamic international network; (2) to develop some of the infrastructure (ship and instrumentation) needed to support the Canadian arctic program; and (3) to provide a substantial fraction of the detailed knowledge of the functioning and recent evolution of the western an eastern Canadian marine ecosystems on which the scientific program of ArcticNet is based. In turn, by using this knowledge to develop adaptation strategies and policies, ArcticNet will ensure that the major scientific advances made by NOW and CASES are brought to full use for the benefit of Canada.
- **Building research capacity in preparation for the International Polar Year.** The International Polar Year in 2007-2008 will be the opportunity to coalesce national programs into international circum-polar synthesis in the study of the rate and consequences of the present mutation of the Arctic. Canada must play a central role in this process. But participation in the IPY requires careful planning and long-term preparation if the Canadian effort is to ramp-up into a significant contribution. The present uncertainty in the political landscape has resulted in serous delays in the funding of the Canadian IPY program. As a consequence, if later funded, the Canadian IPY program will have to rely on existing and already operational networks and infrastructure to kick start its contribution to the international effort. Through the creation of such a network and infrastructure, the NOW and

CASES Research Networks have provided Canada with a significant research capacity on which to develop a Canadian contribution to IPY.

More specifically, a central objective of the international community for IPY is the development of a network of oceanic and terrestrial observatories to monitor the present mutation of the Arctic. Through the past and on-going deployment of oceanographic moorings and with the availability of the *Amundsen*, Canada is in an excellent position to take the lead in the development of the oceanic network of observatories. The long-term moorings deployed in the Beaufort Sea during CASES (2002-2004) have been redeployed in 2004 and will be redeployed annually at least until 2010 by ArcticNet. Starting in 2005, ArcticNet will revive the NOW time series of moorings (1997-1999) in the North Water and deploy a new observatory in Hudson Bay. Adding our participation since 2003 in the NABOS long-term observatory in the Laptev Sea, our consortium is presently operating four long-term coastal arctic observatories. Through IPY funding and international collaboration, and with the logistical support provided by the *Amundsen*, our goal is to expand these four nodes into a circum-polar network of observatories that will document the expected transformation of the Circum-arctic Shelf in response to global warming. For Canada, to lead the organization of such an international network of oceanic observatories would represent a tremendous contribution to the IPY.

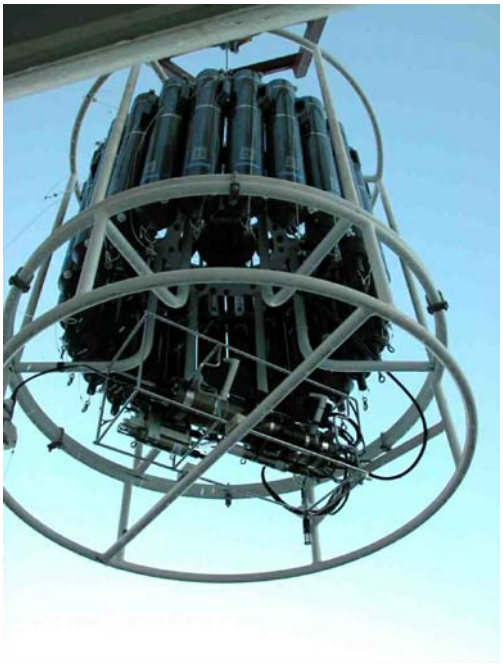
2. SUBPROJECT PROGRESS REPORTS

2.1 Atmospheric and Sea Ice Forcing of Coastal Circulation on the Mackenzie Shelf (Ingram)

The physical oceanographic component of the CASES network proposed to examine the physical processes responsible for the observed water mass and circulation characteristics on the Mackenzie Shelf from an area east of the Mackenzie River mouth to the Amundsen Gulf. An intensive integrated study of the Mackenzie shelf was carried out to help understand the causes and ecological consequences of climate variability in the western Canadian Arctic. The field work included standard vertical (CTD) and horizontal (MVP) measurements during different seasons, as well as current meter moorings. Sediment traps were deployed on the moorings to measure the vertical carbon fluxes. Theses measurements will allow us to (1) investigate the role of upper later stratification, meteorological forcing, and sea ice conditions on the variability of circulation and T-S properties in the eastern Mackenzie shelf area over the annual cycle; (2) to determine the relative importance of hydrodynamic conditions, sea ice characteristics and meteorological factors influencing the generation and maintenance of the Cape Bathurst polynya and to (3) to understand the spatial and temporal variability of marine biological populations in relation to changes in circulation, water mass, and sea ice conditions in the study area.

Progress report

Our research has focused on exchange of water masses across the shelf-break of the Mackenzie Shelf, vertical mixing within the CASES study area, and the water mass characteristics of the Amundsen Gulf polynya. This work addresses the core CASES questions of how nutrient-rich deeper water upwells onto the shelf and subsequently reaches the euphotic zone, how advection of carbon and sediment occurs from the shelf to the Beaufort Sea, and an understanding of the processes forming and maintaining the polynya.



Mackenzie Canyon at the western end of the Mackenzie Shelf is a large (60km wide, 400m deep) cross-shelf canyon that experiences enhanced upwelling during times of westward surface-stress due to wind and ice motion. To characterize flow within the canyon, we analyzed moored current meter mooring, temperature and salinity data and correlated these with concurrent wind and ice velocity data. The results, which show dramatic upwelling events within Mackenzie Canyon and their relation to wind-stress and ice motion, were presented at the joint meeting of the American Society of Limnology and Oceanography and The Oceanography Society in February of 2004 and have been submitted to the journal of Continental Shelf Research for review.

At the eastern end of the Mackenzie Shelf is a region of tidal resonance which may lead to enhanced vertical mixing and an increased nitrate flux to the euphotic zone. CASES moored ADCP, current meter, salinity and temperature data has been used to describe the tidal environment in this region and estimate the vertical mixing. Results for this study were presented at an assembly of the European Geophysical Union in May 2004 and are now being extended, using the whole CASES 2002-2003 moored array data set, for a manuscript that is currently in preparation.

The main CASES ship-based sampling program consisted of ten cruises or legs (Table 1) of *in situ* sampling in the Amundsen Gulf and the Beaufort Sea. Leg 0 was conducted in September 2002, while legs 1 to 9 were conducted between September 2003 and August 2004. The equipment used to sample the physical parameters consisted of a Conductivity, Temperature and Depth (CTD) profiler located on the rosette (right), a 150 kHz Acoustic Doppler Current Profiler (ADCP) located under the ship's hull, the Moving Vehicle Profiler (MVP, a towed profiler; below left) and the thermo-salinometer (basically another CTD) located in the engine room and fed by the ship's cooling system.

A comprehensive study of sea ice ridging in the study area was completed. The link between wind, ocean currents, and sea ice properties, both during growth and melt ice periods, was modelled. One paper published in JGR and another submitted.

In addition to the near year long field program aboard the Amundsen, which required extensive and detailed planning of personnel, data collection, and equipment, much of the last year has been spent processing and quality controlling of the CASES 2002-2003 mooring data prior to its use in research and to enable these data to be distributed to other groups within CASES. Analysis and calibration of CTD data has also taken much of the past year.

We have undertaken a study of pan-arctic shelf/basin/ice interactions for presentations highlighting the importance of the arctic shelves and their ecosystems and the influence of climate change and the associated projected retreat of the ice edge. Also, review papers entitled "The Oceanography of the Northwest Passage" and "Polar Ocean Coastal Boundaries" have been submitted to a volume of the The Sea entitled The Global Coastal Ocean. Four abstracts have

been submitted for consideration at the June 2005 Oceanography Society International Conference session on physical-biological interactions in Arctic Shelf areas. Our work will also be presented at the 2005 CMOS Annual Congress and the 2005 ASLO meeting in Spain.

Future activities include a description of upwelling in Kugmallit Valley, in the central Mackenzie Shelf, and a comparison of this narrow and shallow arctic canyon to the wide and deep Mackenzie Canyon, modelling of the shelf physical processes, and comparison of ADCP derived bioacoustics data with zooplankton observations. In Amundsen Gulf, studies of the generation and maintenance of the polynya, as well as the importance of vertical mixing along the gulf boundaries on observed properties in the interior will be undertaken. Continuing analysis of the CTD, rosette, MVP, and the 2003-04 moored current meter data will be done.

In regard to specific objectives in the original application, we respond as follows. The first objective required an investigation of the physical factors controlling the variability of circulation and T-S properties in the eastern Mackenzie shelf area over the annual cycle. We have the necessary field data (8 moorings in 02-03, 17 moorings in 03-04, and extensive ship based observations over an annual cycle) to respond to this goal. Incorporating the observations into models will provide greater insight into the dominant processes at work in the study area. Use of historical data (and journal articles) from the area has allowed us to take the first step in understanding local shelf dynamics (ms. Subm. Cont Shelf Res). The only uncertainty comes from two moorings in critical areas that we were unable to recover in 2004 (poor ice conditions), and some errors in data recording using the new Aanderaa RCM-11 equipment. Two graduate students (at UBC) and a visiting Norwegian graduate student are studying different aspects of this research, in addition to the PDF and principal investigators. A co-op student will be hired in summer 2005 to examine the bio-acoustics data. We hope to recover the moorings in summer 2005. Overall we feel there has been excellent progress.

Our second objective was to determine the relative importance of hydrodynamic conditions, sea ice characteristics and meteorological factors influencing the generation and maintenance of the Cape Bathurst polynya. Two graduate students (at INRS) are using both a modelling approach and data analysis to determine the dominant processes in the polynya area. A number of current meter moorings and extensive CTD/MVP data will also be used in this study. Excellent progress.

The final objective included a goal of linking the spatial and temporal variability of marine biological populations to changes in circulation, water mass, and sea ice conditions in the CASES study area. Collaborative discussions between the physics group and researchers looking at biology, chemistry, and sedimentology took place early in our program and were used in planning instrument deployment and sampling rates. Most of the physical observations will become available in mid-2005 which will allow us to advance the joint work. The initial focus, as established at the October 2004 CASES workshop, will be on the influence of sea ice ridging on sediment resuspension, characterizing carbon fluxes on the shelf, understanding vertical zooplankton migration, estimating nutrient fluxes, understanding the primary production spatial distribution, and linking sea ice and upper ocean characteristics. Progress on these aspects is in the early stages, but we foresee no major limits to accomplishing our goals.

Subproject 2.1 progress report summary table.

Subproject 2.1	2002	2003	To date	Progress by Mid-Year
1.1. Role of the upper layer stratification, meteorological forcing and sea ice forcing on the circulation variability	X	X	X	All the necessary data have been collected from Sept. 2002 to Sept. 2004. Two grad student in addition to the PDF and principal investigator. Excellent progress.
1.2. Relative importance of the hydrodynamic conditions in the generation and maintenance of the polynya	X	X	X	Modelling and data analysis approach using CTD and MVP dataset. Excellent progress
1.3. Spatial and temporal variability of marine biological populations in relation to circulation, water masses and ice condition			X	Collaborative discussion with almost every other group in order to link atmospherical and physical oceanographic data. Progress is in the early stage

2.2 Ice-atmosphere interactions and biological linkages (Barber)

Changes in the physical environment affect biological processes in the Arctic. This statement predicates the work of project 2.2 of CASES. Our goal was to examine how changes in the physical environment links to biological processes for those elements of the marine ecosystem connected to sea ice. Our focus was on ocean-sea ice-atmosphere physical processes at spatial scales from the cm to hemispheric and temporal scales from decadal to diurnal. Our science plan coupled physical process studies directly to biological studies in an attempt to ascertain the sensitivities of change in one of either the physical or biological realm on the other.

Various types of data were collected on the first-year sea ice environment within the western Arctic during CASES 2003-2004. The basic requirement for data collection was to provide a baseline data set, which is representative of the various environments of the region. Primary data collected during CASES 2003-2004 included micrometeorological and microclimatological data such as relative humidity, air temperature, wind speed and direction, solar and long-wave radiation, etc. The instrumentation used to collect this data was mounted on a tower in proximity of the ship's overwintering location (approximately 1.6 km East of the ship) as well as one tower installed on the front deck. Cloud observations, including visual observations, cloud height and occurrence of precipitation, as well as atmospheric profiles (pressure, temperature, relative humidity etc.) were collected throughout the field campaign. Snow and sea ice geophysical, optical and microwave (passive and active) measurements were taken in both mobile and stationary periods of the project. This data was collected in order to develop methods at which

the surface energy balance and/or snow geophysical properties can be remotely acquired. The final component of the data collected as part of CASES 2003-2004 consisted of remotely sensed data set. Satellite imagery, aerial surveys and surface based radiometry were acquired over the field site location for the duration of the project. These data sets will be used to attempt to scale-up the observations made within the field to a more regional scale. As a complement to remotely sensed data, Global Positioning System (GPS) coordinates of field sampling locations were collected. A suite of GPS coordinates was collected during the aerial surveys.

Subproject 2.2 progress report summary table.

Subproject 2.2	2002	2003	To date	Progress by Mid-Year
	X	X	X	• Sampling completed • Sea Ice historical study completed providing context for the CASES network. • Blowing snow study completed; papers in preparation. • Subice primary production study completed one paper completed (see list) and others in preparation. • Mixed layer depth project completed; papers in preparation. • Gas flux study completed; papers in preparation. • Meteorological forcing project completed papers in preparation. • Sea ice as a habitat for polar bears completed and papers in preparation. • Sea ice as a habitat for Arctic Cod completed and papers in preparation. • Sea Ice remote sensing studies completed and several papers have already been produced (see list) with others in preparation. • Sea ice mass balance project completed with papers in preparation. • Sea ice Motion and Polynya dynamics project completed and papers are in preparation. Dive program completed and papers are in preparation.

Following are highlights and “première” performed by the group 2 in the last two years of field work in a nutshell:

- Identification of the substantive reduction in the aerial extent of sea ice in the CASES study region over the period 1978 to 2001 (Barber and Hanesiak, 2004).

- Detection of atmospheric surface stress causing upwelling to occur along the continental shelf as a feature for causing reduction in sea ice (Lukovich and Barber, 2005).
- Snow history being an important element in the transmission of photosynthetically active radiation (PAR) and the subsequent development of subice primary production (Mundy et al. 2005).
- We collected the first-ever full winter dataset on snow microstructure over landfast first-year sea ice. This dataset is being used to improve models of snow geophysics and the transmission of microwave and optical wavelength energy within snow covered sea ice.
- We collected the first-ever annual cycle of microwave emission and scattering over landfast-first-year sea ice. These data were made possible with substantive input in capital equipment to purchase both microwave radiometers and scatterometers. These data are being used to improve algorithms in passive microwave remote sensing and retrievals from Radarsat I and II.
- We collected a unique dataset of very young ice passive microwave signatures which resulted in a thorough evaluation of competing algorithms being used to retrieve geophysical and thermodynamic state information from operational satellite systems required for climate change studies (Hwang and Barber, 2005).
- We collected the first dataset that chronicles the evolution of the surface heat budget and surface exchanges of heat and mass over the shelf environment over the winter season (Papakyriakou et al., 2004a) and the first data set that covers temporal and geographical variation in the heat budget throughout the annual cycle over the coastal sea.
- We have the only dataset in existence of the air-surface CO2 exchange over a polar marine environment and are the first to demonstrate an air-surface exchange of CO2 in the presence of an ice-cover (Papakyriakou et al., 2004b).
- We have the only existing data set that shows the evolution of sea ice carbon biogeochemistry, a resource that will shed light on the mechanism of wintertime atmosphere-ocean carbon exchange dynamics and on drivers of the sea ice autotrophic and heterotrophic biological communities.
- We collected a unique set of microwave scattering data from a variety of snow thickness classes. These data will help develop a snow-water equivalence algorithm for smooth first-year sea ice which will have utility in modeling the available PAR to the ice bottom and freshwater flux (through snow and ice melt) to the upper ocean layer during the winter to spring transition.
- We collected a unique set of in situ measured sea ice deformation (rough and deformed sea ice) data and are using another unique set of high resolution, multi-polarization and multi-incidence angle satellite based microwave remote sensing data to classify deformation.
- We have utilized a time series of Radarsat I data to upscale a technique of detecting spring melt transitions over landfast first-year sea ice using QuickScat data allowing regional and hemispheric estimates to be made (Howell et al., 2005)
- We collected the first-ever full winter dataset on blowing snow processes over first-year sea ice. This dataset will be used to improve our predictive capabilities of severe blowing snow events in the Arctic and improve our understanding of the Arctic water budget through the measurement of mass and energy flows during these events.
- We designed, constructed and deployed a new imaging, Sagnac-interferometric spectro-radiometer to measure the reflectivity of Arctic snow and ice (Minnett and Sellar, 2005).

- We deployed a Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) on the Pierre Radisson (2002) and the Amundsen (2003) to provide measurements for the validation of retrievals of surface temperature and atmospheric profiles of temperature and humidity derive from satellite-borne infrared spectroradiometers.
- We developed algorithms for measuring near surface air temperature, and air-sea and air-ice temperature differences from infrared surface and atmospheric emission spectra (Minnett, 2003; Minnett et al., 2005).
- We deployed instruments for the measurement of variables related to cloud radiative forcing over the ice and mixed ice and open water surfaces.

2.3 Light, nutrients, primary and export production in ice-free waters (Demers)

The ***Biological Ice Program*** characterized the communities in newly formed ice, the seasonal trends in autotrophic and heterotrophic processes in first-year ice and finally the spatial heterogeneity in ice communities. The ***Light Program*** monitored the optical and bio-optical characteristics of the water column and used satellite images to assess phytoplankton distribution. The ***Nutrients Program*** measured nutrient levels within the water column and examined the biological and physical factors which drive fluctuations. The ***Primary Production Program*** determined the spatial and temporal variations in biomass, productivity, community structure, as well as other characteristics of phytoplankton. The ***Vertical Export Program*** looked at the amount and type of organic material sinking out of the euphotic zone and assessed seasonal changes in the amount and composition of the sinking flux of organic material under first-year ice. The ***Meiofauna Program*** studied the composition, distribution and factors susceptible of determining the structure of the meiofaunic communities and assessed the grazing impact of the meiofauna on the benthic microalgae.

Areas sampled varied throughout the year due to changing ice conditions and sampling activities were adjusted accordingly (see in section 1.2 for details). During the open water sampling periods, rosette operation allowed for nutrients (nitrate, nitrite, phosphate, silicate, ammonium, and DON), phytoplankton (size-fractionated chl *a* (total, >5µm and >20µm), phaeopigments, HPLC, absorption, POC, PON, BioSi, species composition), bio-optical properties (flow cytometry, CDOM, SPM, mineral composition, particle absorption, inherent and apparent optical properties) of the water column to be investigated. Newly forming ice and unconsolidated slush were sampled using an ice coring system, a saw, a spoon or a strainer for various biological parameters (size-fractionated chl *a* (total and >5µm), bacterial and protists communities quantification, exopolymeric substances, enumeration of algal cells, POC, PON, BioSi, TOC, DOC, nutrients, viruses, salinity, and pH). Other samples were collected using free-drifting sediment traps deployed for ca. 24h at 7 depths, i.e. 15, 25, 50, 75, 100, 125, and 150 m, to determine chl *a*, phaeopigments, POC, PIC, PIN, BioSi, lithogenic silica, cell identification and counts, faeces counts, and in some cases dry weight of sinking material. Finally, surface sediments were sampled for total chl *a*, species composition, microphytobenthic biomass, meiofauna (abundance, biomass, and grazing). Additional experiments were also performed such as: short (PI curves) and long term (^{14}C-assimilation method) phytoplankton incubations; grazing, nutrient recycling, and primary production experiments using newly formed ice samples; incubations to measure the total uptake of nitrate, ammonium and urea by the microbial community as well as to measure the contribution of bacteria and phytoplankton to nitrogen uptake; short term (PI curves) incubations using surface sediment samples.

Overwintering at a fixed station in Franklin Bay began in December 2003 and lasted until May 2004. During that period, focus was given to temporal monitoring of water column related variables and biological ice processes. Water column sampling was maintained such that nutrient levels (nitrate, nitrite, phosphate, silicate) and phytoplankton characteristics (same variables as in open water sampling) were determined throughout this period. From mid-February to mid-June, ice cores of first-year sea ice were collected under low and high snow cover using an ice coring system (same variables as for newly forming ice). Finally, under-ice sediment trap lines were deployed to do measurements and counts of faecal pellets, and determine the organic and inorganic sinking fluxes (same variables as free-drifting sediment traps). Spatial heterogeneity of ice algae during its vernal growth season and following the break-up period was also investigated (salinity, chl *a,* phaeopigments, and the enumeration of bottom ice algae). In addition, a sampling transect was carried out to investigate the influence of a salinity gradient from the ship to the mouth of the Horton River on the distribution of ice organisms.

Open water activities were reintroduced in June when the ship broke out of the ice to sample the Amundsen Gulf and Cape Bathurst polynya areas. July and August saw an expansion of the areas studied which resembled September 2002 and September-October 2003. Finally, as the ship got ready to leave the CASES study site, stations in the Amundsen Gulf and Cape Bathurst polynya were briefly revisited. Variables sampled during those periods were the same as those described for open water periods.

Preliminary results from the overwintering period

Biological ice program

Ice algae biomasses remained low during February and March, increasing in early April under thin snow cover (fig. 1). The increase was delayed by ca. one week under thick snow cover, with chl *a* concentrations remaining < 1 mg m^{-2} until 10 April. Maximum chl *a* were observed during the third week of May and were comparable in both snow cover conditions. A rapid decline in chl *a* biomass was observed during June.

The bottom ice microalgal community was dominated by diatoms (Bacillariophyta) which were mainly represented at 95% by pennate forms most often forming arborescent or ribbon-shaped colonies. The population was mainly composed of diatoms of the genera: *Nitzschia*,

Navicula and *Entomoneis*. Most species exhibited a colonial life form such as taxa: *Nitzschia frigida*, *Nitzschia neofridiga*, *Navicula pelagica*, *Navicula septentrionalis*, *Navicula vanhoeffenii*, *Entomoneis kjellmanii*, and *Pauliella taeniata*.

Primary production

The annual monitoring of phytoplankton biomass (chl *a*) at the overwintering station showed slow decreases in October and November with stable and low levels maintained until the beginning of June. Strong increases were observed at a period when ice cover was strongly disintegrating followed by lower values later on in the summer season, although values were higher than in the previous fall.

Under-ice trap time-series

Fluxes of chl *a* at 1 m underneath the ice increased from February to June (fig 3). Maximum chl *a* sinking fluxes observed during this period were ca. 0.4 mg chl *a* m^{-2} d^{-1}. Phaeopigments fluxes at 1 m underneath the ice remained very low ($\leq$ 0.05 mg m^{-2} d^{-1}).

Detailed analysis of the complete suite of variables from the sediment trap material will provide insights into pelagic-benthic coupling processes on the Mackenzie Shelf, including the export of primary production from ice algae and phytoplankton in the form of algal cells and faecal pellets, as well as processes that influence the transformation and recycling of material during its export to depth.

These previous preliminary results are only a subsample of results obtained to date. Furthermore, several other analyses are underway and results from all programs will become available in the months to come. Collaborative work with other subprojects is expected to flourish as well within the next years.

The analysis of phytoplankton has been very slow progressing due to lack of recruitment. The analysis of phytoplankton populations will be done before June 2005 on a priority basis established by Demers group. Sea ice algae analysis is ongoing by Ph.D. student, M. Rozanska (UQAR).

Subproject 2.3 progress report summary table

Subproject 2.3	2002	2003	To date	Progress by Mid-Year
Taxonomic composition of sea ice algae in Franklin Bay (Poulin - Gosselin)	X	X	X	Sampling completed; analysis in progress;3 conferences presented; 2 posters presented
Phytoplankton taxomonic composition in Beaufort Sea (Poulin - Demers)	X	X	X	Sampling done; analysis of sample will be done between March and May 2005.
Remote Sensing of phytoplankton biomass in the Beaufort Sea (Larouche)	X	X	X	Progressing slowly due to difficulty in recruiting graduate student
Sedimentation rates in open and ice-covered waters determined with short-term particule interceptor traps (Michel - Gosselin)	X	X	X	Sampling completed; analysis in progress
Dynamics of the microbial community (Michel - Gosselin)	X	X	X	Sampling completed; analysis in progress
Primary and export production (Demers)	X	X	X	Sampling completed; analysis in progress; 2 conferences presented; 2 posters presented

Nutrients and new production (Neil Price)	X	X	X	Sampling completed; analyses in progress. 1 conference presented

2.4 Microbial communities and heterotrophy (Vincent)

The central hypothesis in CASES concerns the processing of organic matter in the Mackenzie delta versus offshore waters and its relationships with sea ice conditions. Micro-organisms are likely to be major contributors to the biological carbon stocks throughout this region, and to play a leading role in the biogeochemical fluxes of organic matter. The microbial ecology subprogram was formulated to measure microbial community structure and production dynamics in the CASES study region, with sea ice and water column studies offshore as well as comparative measurements in the inshore delta and Mackenzie River source waters.

Initial sampling took place during the CASES 2002 cruise and this led to the formulation of appropriate sampling strategies for the subsequent full year program from CCGS *Amundsen* (CASES 2003/4), and modification of some methods (e.g., bacterial production protocols) to adjust to the environmental conditions found in this freshwater-influenced region of the Arctic Ocean. It also led to the formulation of the CASES satellite program ARDEX (Arctic River Delta Experiment) in which the shallow draft vessel CCGS *Nahidik* was used to make parallel measurements of carbon cycling in the Mackenzie River and freshwater-saltwater transition zone. A separate cruise report is available for ARDEX (Vincent & Osburn 2004).

We have now entered the phase of sample analysis and laboratory data production for this subprogram. Molecular genetic studies are being undertaken on DNA extracts from CASES samples by laboratories around the world specializing in different groups of marine microbiota including viruses (Suttle, UBC), picocyanobacteria (Wilmotte, U Liège, Belgium), pico-eukaryotes (Lovejoy ULaval and Pedrós-Alió, ICM, Spain) and bacterial heterotrophs. Pigment signatures of the microbial autotrophs are being analyzed by High Performance Liquid Chromatography at U Laval and ISMER (Bonilla and Roy) and are showing a surprisingly large contribution by Chlorophyll *b*-containing microbes (see below).

Seasonal changes in microbial rate and state variables are now being analyzed, and the resultant data base should lead to a greatly improved level of understanding about the microbial structure and functioning of the coastal Arctic ecosystem. In addition, a variety of experiments have been undertaken by CASES PIs (including Jody Deming on Archaea, sea ice microbiota and enzymes, U Washington; Osburn, Naval Research Laboratory Washington DC, on CDOM and photochemistry; Vaqué, ICM Spain, on microzooplankton grazing; Vincent, U Laval, on DOM) and their students, postdocs, technicians and collaborators, to provide new insights into the controls on Arctic microbiota and carbon fluxes).

It will be several months of laboratory and data analysis before even a preliminary overview can be made of the ensemble of information from this subprogram. However several features are already emerging. One is that a fully functional microbial food web and microbial processes continued throughout winter in these arctic seas, albeit at slow rates of activity and low standing stocks of biomass. Secondly, the planktonic microbial phototrophic communities began to grow rapidly much earlier in the year than expected (February-March), then slowed with the development of the overlying sea ice algae, before a subsequent maximum. The microbial biodiversity studies show the importance of all three domains of life in this region of the Arctic:

Bacteria, Archaea and Eukaryota, plus viruses. DNA analyses are showing a diversity of pigmented and non-pigmented pico-eukaryotes in the < 3 μm size fraction. Complementary HPLC determinations (Fig. 1) show that picophototrophs in this size class often dominate the total autotrophic biomass. More detailed carotenoid and DNA analyses indicate that picocyanobacteria (including prochlorophytes) contribute a relatively small part of this community biomass and are mostly composed of freshwater-derived genotypes. Various 1.5-3 μm diameter prasinophytes appear to major components of the plankton, and occur throughout the seasonal cycle. These results are now being compared with data from programs elsewhere in the Arctic, for example JWACS in the Canada Basin (Carmack, Lovejoy et al) and the Norwegian Sea program off Svalbard (Pedrós-Alió et al.).

Viruses have been found to be abundant throughout the study region and at all depths sampled, with highest concentrations in the near surface waters where bacterial biomass is also maximal. Molecular and microscopic analyses are continuing for these and other microbiota.

Subproject 2.4 progress report summary table

Subproject 2.4	2002	2003	To date	Progress by Mid-Year
4.1. Determine the seasonal dynamics of bacterial production	X	X	X	CASES 2002, 2003 and 2004 cruises completed; all samples analyzed; data analysis well underway.
4.2. Assess the size distribution of microbial heterotrophy	X	X	X	All fractionation experiments completed; sample analysis in progress; 1 paper in draft stage (Garneau et al.).
4.3. Define the seasonal dynamics of the microbial communities	X	X	X	Sample analysis in progress; Preliminary results presented at conferences by students (Garneau won 'best student oral paper' award at the CEN Annual symposium for presentation of her CASES work).
4.4. Define the gradients in microbial community structure (including viral abundance)	X	X	X	Sample analysis in progress; preliminary results presented at the 2004 CASES workshop by students; 3 papers in preparation (Waleron, Waleron, Lovejoy) and 1 submitted (Wells et al.), another published (Wells & Deming). Additional work through the CASES satellite program ARDEX (cruise in 2004)
4.5. Evaluate microbial production-loss processes	X	X	X	Microzooplankton grazing estimates made by collaborators from Spain and Japan. Collaboration with Theme 3; exchange of data at the CASES workshop;
4.6. Evaluate viral lysis versus grazing	X	X	X	Shipboard experiments completed. Sample analysis in progress; information exchange at the CASES workshop.

Others. Many other objectives were formulated by our	X	X	X	Shipboard experiments completed. Sample analysis in progress; information exchange at the CASES workshop.

2.5 Pelagic food web: structure, function & contaminants (Deibel)

Our objectives were to determine, over an annual cycle a) the abundance, vertical distribution and vertical migration of the zooplankton community, including juvenile and adult fish; b) respiration, grazing, faecal pellet and egg production rates of copepods and appendicularians; c) feeding rates of macrozooplankton predators; d) feeding, growth and survival rates of larval and juvenile Arctic cod; e) seasonal variability in the trophic structure of the pelagic food web using stable isotopes; f) the trophic flux of contaminants in the ecosystem.

Subproject 2.5 progress report summary table

Subproject 2.5	2002	2003	To date	Progress by Mid-Year
5.1. Vertical & geographical distribution of mesozooplankton and juvenile and adult fish	X	X	X	Mesozooplankton and Arctic cod larvae and juveniles were sampled over the transect grid in the fall of 2002, fall of 2003, spring of 2004 and summer of 2004. On-going analyses suggest three distinct assemblages corresponding roughly to the three oceanographic regions. Vertical distribution was monitored over the winter months using the Hydrobios multiple net system. The vertical distribution of the zooplankton and Arctic cod larvae in relation to the plume of the Mackenzie was sampled in the spring of 2004. Forty BIONESS casts were successfully completed at different stations. Analysis progressing well but could be slowed down by the cancellation of DFO's S&T training program. Poster presented at 27th Symposium on Polar Biology (Tokyo). The continuous operation of the EK-60 yielded a unique data set on the vertical and spatial distribution and abundance of Arctic cod. Analysis is progressing well. Posters presented at Québec-Océan and ArcticNet Annual Meetings.
5.2. Respiration, lipids and ingestion rates of dominant mesozooplankton	X	X	X	The respiration rate of the main copepod species was determined by 87 direct respirometry experiments and 53 indirect measurements of ETS. Gut fluorescence content, lipid and stable isotopes analyses have been conducted on the main copepod species by our Japanese collaborators. The Canadian team assessed gut passage time for *Themisto libellula*. Three posters presented or planned: ArcticNet and Québec-

				Océan annual meetings, ASLO summer 2005 meeting in Spain.
5.3. Reproductive condition and egg production rate of dominant mesozooplankton	X	X	X	The reproductive condition of the main copepods and *Themisto libellula* will be determined from preserved samples collected over the annual cycle. A total of 131 egg production experiments were conducted over the 2003-2004 cycle. Analyses progressing at the expected rate.
5.4. Contribution of copepods and appendicularians to the carbon vertical flux	X	X	X	In 2003-2003, 4 traps were successfully deployed as a preliminary experiment. The analysis of the zooplankton fecal flux indicates that copepods are the main contributors to the flux everywhere, but that an important flux by appendicularians occurs at the shelf break. In 2003-2004, 24 traps were deployed on 17 moorings (2 moorings still to recover). The 10 pps3 French-made sub-surface traps stalled on the second cup, a major draw-back to the program. This failure can be traced back directly to a malfunction of the new hardware used by the maker. Two pps5 and 9 Japanese made traps deployed at depth (> 200 m) worked properly. Analysis of the 2003-2004 fecal flux is progressing well. POC and PON analyses progressing thanks to the purchase and set up of a CHN analyser in Fortier's laboratory (CRC-FCI grant). Three posters presented or planned: ArcticNet and Québec-Océan annual meetings, ASLO summer 2005 meeting in Spain. The sediment trap data will be completed by Vertical Plankton Recorder data on marine snow. Analysis on-going.
5.5. Feeding, growth and hatch-date frequency distribution of larval/juvenile Arctic cod	X	X	X	Over 4000 larval and juvenile arctic cod were collected in 2002 and over the annual cycle 2003-2004, measured and preserved in individual vials. A stratified subsample is being analysed for gut content and age (otolith). Preliminary results tend to confirm the production of early (spring, under-ice) and late (summer, open-water) cohorts. Analysis is progressing satisfactorily but could be slowed by a lack of manpower due to the cancellation of DFO's S&T training program. Posters presented at CASES workshop and ArcticNet annual meeting.
5.6. Stable isotopes composition and bioaccumulation of	X	X	X	In addition to the plankton compartment (see above), the hyperbenthos and the nekton were sampled successfully. Exchange of specimens

contaminants from hyperbenthos to vertebrate predators				within subproject 2.5 and with other subprojects will enable us to determine the isotopic composition (and hence trophic level) and contaminant loads in most species. Analysis progressing according to schedule.
Others.	X	X	X	As described below, progress was made on several new fronts that developed during the field program.

Integration. To achieve these objectives Subproject 2.5 is working closely with several other subprojects, particularly 2.1 (Physics), 2.3 (Primary production), 2.6 (Export flux), 2.4 (Microbes) and 2.7 (Benthic processes). Integration took the form of planning joint sampling at common stations at sea, shared sample analyses following the expedition, and data exchange. Joint papers have been planned at the Montreal workshop.

Deviations from original objectives. There have been few significant deviations from the objectives proposed initially. We are particularly happy to report that most of the needed information was collected over the entire annual cycle. Due to limits of wire time and manpower, respiration and egg production rates of appendicularians could not be determined on live animals during the expedition. However, many hundreds of net and video plankton recorder samples were taken from which the abundance and body size of appendicularians will be determined. We will then apply allometric relationships between body size and respiration (literature) and egg production rates (our own) to determine these rates. The egg production rate relationships were determined on the same species at the same water temperatures on Newfoundland appendicularian populations. These allometric relationships are robust and can be applied with a high level of confidence.

Some new objectives were added to the proposed work. For example, fatty acid biomarkers were used to determine the contribution of marine and terrestrial source material to the diets of water column and benthopelagic zooplankton (Ph.D. Thesis projects of Businski and Connelly) to complement Objective 5.4. This will allow comparative analyses with NEW and NOW and will contribute to the objectives of some of the other subprojects with interests in the impact of outflow from the Mackenzie River on the Beaufort Sea Shelf (2.4, 2.6).

Significance of the results. The EK-60 data set solved the mystery of the missing Arctic cod by revealing for the first time the large aggregations needed to feed its numerous predators. The deployment of under-ice plankton sampler established the date of the first emergence of Arctic cod larvae. Sampling throughout the winter from the moonpool with the Hydrobios provided the first glimpse at the vertical distribution of the zooplankton in winter. Direct and indirect measurements of the respiration of the main copepods and *T. libellula* will enable us to assess the contribution of the mesozooplankton to the transport of CO_2 at depth. We now have the material and data needed to elucidate the trophic structure of the food web and to assess the fluxes of contaminants in the three oceanographic regions. Despite the failure of some of the sediment traps, we have secured one of the most complete data set on the deep particle flux in the Arctic and, most importantly, have rebuild some of the lost Canadian expertise in this crucial field. Fatty acid biomarker studies have confirmed predictions from earlier work by Parsons et al., that there are separate zooplankton food webs on the Beaufort Sea shelf, one from marine source materials through copepods to arctic cod, and the other from a mixture of marine and terrestrial source

materials through appendicularian tunicates to smelt. VPR work has revealed thin layers of particles and zooplankton at many times and places, as well as aggregations of zooplankton in deep waters during the winter. The data will contribute to much more accurate modeling of the carbon cycle of the Beaufort Sea shelf than could have been done otherwise. Copepod production was about twice as high in the Gulf of Amundsen polynya as at the overwintering station, suggesting that there are significant regional differences in the productivity of the water column food web. Feeding by copepods seemed to increase under the ice with advancing season even though food resources did not increase. The copepods remained deep and depleted their oil reserves over the winter, releasing potentially significant amounts of CO_2 that will be assessed with the data sets now available. In 2004, mercury concentration in the Mackenzie Delta during the spring freshet was found to be ~10x higher than later in the summer (from 2.46 ng/L to 0.28 ng/L). Over 70% of the mercury that entered the Beaufort Sea in 2004 entered during the spring freshet. Flux calculations suggest that the Mackenzie River carried a total of 1.5 tons of mercury to the Beaufort Sea in 2004, with about 85% associated with suspended particles.

Collaboration among researchers from Canadian universities, Federal institutes (DFO-IML, DFO-FWI) and foreign teams (Japan, Norway, Russia) was particularly fruitful within subproject 2.5 and resulted in the participation of Canadian researchers in the NABOS program in the Laptev Sea. The comparison of mesozooplankton and juvenile Arctic cod dynamics as well as deep particle fluxes between the two regions will provide unique insight into the impacts of ice reduction on the biological productivity and biogeochemistry of the Arctic Shelves.

2.6 Organic and inorganic fluxes (Hill et al)

The specific objectives of Subproject 2.6 were to 1) Characterize seasonal and interannual variations in carbon distributions (terrestrial and marine) within the water column of the Mackenzie Shelf region and use information on currents, diffusivity, water mass formation, and sediment composition to estimate physical carbon transports and the rate of carbon burial in the sediments, 2) Estimate air-sea CO_2 fluxes and their spatial and temporal variability throughout the study period, 3) Determine the annual cycle and synoptic variation in the horizontal fluxes of total suspended sediment, POC and DOC from the inner shelf to the Cape Bathurst polynya and Arctic basin in relation to sea ice conditions and punctual storm events, 4) Determine the changes in flocculation particle size and composition in the shelf water column as the shelf waters evolve from winter to spring conditions, 5) Determine the vertical distribution of suspended biomass such as phytoplankton and species-specific faecal pellets and measure their retention and vertical export from the upper layer, 6) Compare the physical and biological estimates of carbon export and determine possible mechanistic links between them and 7) Determine the importance of denitrification in Mackenzie Shelf sediments.

Determination of material fluxes requires a time series of measurements over the entire year in as three-dimensional manner as possible. The minimum requirement specified in the proposal was to sample the water column from surface water to the bottom boundary layer and the sediment column through winter and summer along the inshore-offshore transect, from the inner shelf to the deep basin. This has been achieved. To fulfill the above objectives subgroup six consists of 6 teams (listed alphabetically by PI):

1. Radionuclide tracers for nutrient fluxes (Cochran, Amiel)

2. Particle dynamics and flocculation on the Mackenzie shelf (Grant, Walker)

3. Storm resuspension and reworking on the Mackenzie Shelf (Hill, Lintern)

4. Air-Sea-Ice Carbon cycling (Mucci, Miller)

5. Sediment Geochemistry, early diagenesis and sedimentary record (Sundby, Chaillou)

6. Biogeochemical sampling of carbon monoxide (Xie)

Deviation from the original plan:

In subproject 6 there have been few significant deviations from the original objectives both in terms of the proposed milestones and the sampling protocols. The most important deviations are as follows:

- The carbon contents of and fluxes in sea ice were assessed, which was not part of the original project plan.
- Due to financial and logistical constraints it has not been possible to collect data during all seasons in the near shore area of the Mackenzie River plume. Instead intensive sampling was conducted in this area during late winter and late summer.
- The original objectives for the sediment geochemistry team were to determine the role of sediments in the carbon and nitrogen cycles. The objectives were established without much previous knowledge of the sedimentation regime of the Mackenzie shelf region. The discovery that neither the eastern Mackenzie Shelf nor the Amundsen Gulf appear to accumulate significant quantities of modern sediment has prompted us to expand our original objectives to include an in-depth study of sediment chemistry and diagenetic processes. Also, the focus has been shifted away from the shelf region to the Mackenzie Canyon and the flanks of the Shelf, which appear to be sites of sediment accumulation.

The goals of team 1 are to understand carbon and overall particle cycling in the study area using the naturally occurring radionuclides 234Th and 210Pb. The capacity of 234Th to sorb onto particles of biological and lithogenic origin, coupled with its 24 day half life, make it useful to elucidate particle production and sinking events on a seasonal time scale. 234Th is being applied in two ways. The first is to use in situ pumps to obtain the flux (dpm/m2/d) of 234Th through 0-30m and 0-100m depth horizons. These fluxes are then coupled to the ratio of POC (on our best estimate of sinking particles):234Th to obtain carbon fluxes. These carbon fluxes can then be compared with estimates of primary production (subproject 3), nutrient uptake (subproject 3), and other measurements in the water column to elucidate patterns of carbon production, transport and sinking throughout the region, results that will be useful to most subprojects. In addition, these fluxes can also be compared to estimates of carbon fluxes in floating traps (subproject 1) that should yield information on the importance of advective effects on sinking particles. The second application of 234Th is to compare water column deficits of 234Th with respect to equilibrium with 238U with inventories of 234Th obtained from sediments at the same location and time in order to determine whether sediment removal or sediment deposition occurs in an area. To examine net patterns in sediment movement versus accumulation we are using the longer lived isotope, 210Pb. These seasonal to decadal indicators will reveal important linkages between short time scale (several subprojects) and long time scale (subproject 7) processes.

Augmenting the radionuclide data is the measurement of the stable isotope D13C on the same samples as those collected for radionuclides (Table). The tandem of radiogenic and stable isotopes ought to elucidate a broad array of particle phenomena but perhaps most importantly to

evaluate the influence of the Mackenzie River on carbon and elemental cycling within this narrow Arctic shelf, greatly enhancing the data collected by researchers in this and other subprojects.

Teams 2 and 3 have focused on flocculation, sediment dynamics and storm resuspension as well as sediment properties. There are strong collaborations between these teams especially with respect to the characterisation of SPM concentrations along an inshore to offshore transect. Particle interactions and vertical fluxes were investigated using a set of water column profiles taken with a CTD-current meter fluorometer-side scatter instrument collected along an shore normal transect. The Acrobat (Acrobat LTV-50, Sea Sciences, Inc.) was used as a multi-sensor 'fish' capable of vertical undulation for 3D surveying of Kugmallit Bay (operated and supplied by Peter Cranford, a collaborating colleague from the Bedford Institute of Oceanography). Storm resuspension and floc properties have been monitored using optical backscatter sensors, filtration techniques and video image analysis. Sediment properties, including sediment strength and erodibility have been measured at several locations in Kugmallit Bay. Team 2 has collected samples in the Mackenzie Delta for use by the carbon geochemists. These will be used in conjunction with samples collected by the Ardex project (Vincent) to determine CO_2 partial pressures in the river, at the river mouth and out to the middle shelf. Combined with the samples collected simultaneously aboard the CCGS *Amundsen* this will allow the CO_2 fluxes between the sea and the atmosphere to be calculated and characterized in terms of the Mackenzie River Plume, and to determine the influence of the cold dense shelf water on the deeper water beyond the shelf.

The relationship of particle characteristics, including their biological components, salinity, and wave/current climate to settling rate is essential in formulating predictive relationships for the budgeting of suspended particulate matter on the Mackenzie Shelf. The timing of spring melt, exposure of shelf waters to light (ie. primary production), the timing of peak river discharge and flushing of river-borne organic material onto the shelf is critical information for determining the behaviour and fate of mineral and biological materials in the shelf waters. Preliminary results show significant horizontal and vertical gradients in salinity and turbidity. Storm resuspension appears to be a very important mechanism for the off-shelf transport of sediment.

The investigation of air sea ice carbon cycling has been conducted mainly by collaborations between McGill University (Mucci), the Institute of Ocean Sciences (Miller) and Université du Québec à Rimouski (Xie), teams 4 and 6. The integration of results is in its early phase since data acquisition was recently completed and field data have not yet been fully processed. There are multiple possibilities of integration of the team 4 results, from estimating the sign and strength of the CO_2 flux at the air-sea interface to determining the extent of benthic respiration. These goals of assessing the carbon fluxes throughout the system involves directly integrating the carbon data collected specifically by this group with the atmospheric and ice biogeophysics studied by group 2, the oceanographic circulation and mixing studied by group 1, the microbial production and respiration in the water and in the ice studied by group 4, and the benthic ecology studied by group 7.

Subproject 2.6 progress report summary table

Subproject 2.6	2002	2003	To date	Progress by Mid-Year
6.1. Seasonal and interannual variations in carbon distributions within the water column (Mucci, Miller)	X	X	X	All of the 2002 and about 2/3 from 2003-04 samples have been analyzed, Quality control has been begun, as has preliminary interpretation.
6.2. Air-sea CO_2 fluxes and spatial and temporal variability (Mucci, Miller, Papakyriakou)	X	X	X	Some 2002 data are fully processed, several presentations have been given at meetings, and a publication is in preparation (cross reference: group 2). Remainder of data processing from 2002-4 is underway.
6.3. Annual cycle and variation in the horizontal fluxes of total suspended sediment, POC and DOC	X	X	X	DOC samples from 2003-04 are currently being analyzed, Quality control has been begun (based on 2002 samples), by cross reference with groups 3 and 5 for POC.
6.4. Flocculation particle size and composition in the shelf water column during transition from winter to spring conditions (Hill, Grant).	X	X	X	Fieldwork completed. Publications in preparation on the calibration methods of the erosion device, the comparisons of sediment erosion in cores collected by box cores and divers, Particle properties and plume characteristics in Kugmallit Bay and bed strength and storm resuspension in Kugmallit Bay.
6.5. Vertical distribution of suspended biomass and role of the upper layer (many PI's).	X	X	X	Awaiting compilation of complete data set.
6.6. Physical and biological estimates of carbon export (many PI's)	X	X	X	Awaiting compilation of complete data set.
6.7 Importance of denitrification in the sediments. (Sundby, Mucci)	X	X	X	Awaiting compilation of complete data set. Early indications show that shelf sediments are highly diagenetically active, and basin sediments are less so.
Natural Radionuclides as tracers of the cycling and fate of particulate				Funded by US National Science Foundation; field work and analyses complete; project has no-cost extension through February, 2006

organic carbon (Cochran)				
Seasonal and interannual variations in carbon distributions within the water column (Xie)				All samples were analyzed; all data processed; part of data published/submitted. Currently waiting for supporting data: CTD (leg 7), wind speed and insolation (legs 1 and 7)
Sediment geochemistry (Sundby, Mucci)	X	X	X	Analysis of sediment samples for a total of 24 boxcores

Preliminary results reveals that the low salinity ($21 < S < 28$) but cold surface waters ($-1.52ºC < t < -0.87ºC$) sampled on the Mackenzie shelf are undersaturated ($235\ \mu atm < pCO_2 < 310\ \mu atm$) with respect to the overlying atmosphere and serve as a sink for atmospheric CO_2, at least during this sampling period (i.e., late September to early December, 2003).

Carbon monoxide biogeochemistry (Xie), is closely linked with theme area 4 air-sea-ice C exchange) and aims at characterizing the spatial and temporal distributions of CO in the Canadian Beaufort Sea, and assessing the CO production and loss terms in this region. CO has is being used as a proxy species to estimate the rates of photoproduction of dissolved inorganic carbon (DIC), the major carbon photoproduct of CDOM; photoproduction of DIC is arguably one of the major terms in the ocean carbon cycle. CO is particularly interesting in the Arctic Ocean due to large inputs of freshwater and terrestrial organic matter, low yearly-averaged insolation, extremely uneven daylength/nightlength in summer and winter, low temperatures, large and variable ice and snow cover. Preliminary results from legs 1 and 7 are showing strong dependencies on these unique polar conditions. Further data processing and collaboration with other CASES research teams are underway to quantify the production and loss processes of CO in the study area.

Sediment Geochemistry, early diagenesis and sedimentary records are under investigation with collaborations between teams 4 and 5 and 1. The network has allowed the collection of sediment samples from an area from which little or no geochemical information is available. The box cores collected during the CASES experiment (Leg 2 and Leg 8) reveal that surfacial Mackenzie Shelf sediments consist of a stiff glacial clay overlain by about 10 cm of postglacial mud. The light grey mud is organic rich, oxygen penetration is less than 1.5 cm, nitrate disappears rapidly, and dissolved Mn appears less than 1 cm below the sediment-water interface. Mud from the Mackenzie River appears mostly to bypass the shallow shelf, likely aided by ice induced erosion of ephemeral mud deposits, to accumulate on the flanks of the shelf and in the Mackenzie canyon. In contrast, the sediment in the adjacent 5-600 m deep Amundsen Gulf consists of 40 cm of postglacial mud overlying glacial till. The chocolate brown mud appears to have low reactivity, oxygen penetrates as deep as 4 cm, and dissolved Mn only appears 10 cm below the sediment-water interface. Sediments on the Mackenzie shelf and in the Amundsen Gulf are not an important sink for organic carbon.

The geochemical work has confirmed the work by this and other subgroups that the shelf sediment is highly mobile. The most striking comparisons appear to be with the radionuclide data

of team 1 that also show net erosion on the inner shelf. The work of teams 2 and 3 confirm the existence of weak bed strengths and highly mobile sediment on the inner shelf. Future collaborations will be made with the palaeo-oceangraphers in subproject 7, who have shown ice scour to also play an important role in sediment removal from the shelf.

2.7 Benthic processes and carbon cycling (Aitken et al)

Benthic Processes and Carbon Cycling is a collaborative research project that involves the study of the ecology of marine organisms that inhabit the seafloor, the *benthic environment*, on the Mackenzie Shelf and within the Amundsen Gulf polynya. This project consists of four separate but inter-related components: 7.1) the responses of benthic community structure to seasonal variations in sedimentation on an Arctic continental shelf; 7.2) the responses of benthic community structure to variations in the magnitude and frequency of ice scour on an Arctic continental shelf; 7.3) the impact of 1) and 2) on the rate of carbon remineralization in Arctic shelf sediments; 7.4) an examination of the utility of biogeochemical "markers" in invertebrate skeletons as proxies for the various sources of organic materials consumed by Arctic shelf benthos. The structure of the benthos is critical for determining the fate of carbon in continental shelf ecosystems: how much carbon is stored in the tissues of marine organisms, how much is released from the seafloor into ocean waters as carbon dioxide, and how much is stored in the sediments. Our work onboard *CCGS Amundsen* involves the acquisition of various types of information about the seafloor; water depth, seafloor topography and sediment texture, the nature and quantity of organic matter stored within seafloor sediments, the distribution, abundance and biomass of benthic organisms, the productivity of selected taxa, and rates of benthic respiration to determine rates of carbon mineralization at the seafloor.

The research activities described below have been undertaken over the course of the summer (August-September, 2002, September, 2003 and June-August, 2004), fall (October-November, 2003), winter (February-March, 2004) and spring (April-May, 2004) seasons. This sampling program will facilitate comparisons of seasonal and interannual variations in benthic community structure and benthic respiration in relation to the flux of inorganic and organic materials within the study area (see 7.1 and 7.3 above). A complementary sampling program undertaken from *CCGS Nahidik* during the summers of 2002, 2003 and 2004 is focused on understanding the impact of sea ice scouring on benthic community structure at water depths less than 50 metres on the Mackenzie Shelf (see 7.2 and 7.3 above). Steve Blasco (GSC), Kathy Conlan (CMN), Ed Hendrycks (CMN) and our research associates Christine McClelland (CMN) and Karen McKendry (CMN) have pursued this research program. The Department of Fisheries and Oceans fund this research program independently.

CCGS Amundsen is equipped with two main acoustic instruments, the Simrad EM300 and the Knudsen 320R. The Simrad EM300 is a multibeam sonar system that provides information for ocean bathymetry, the nature of seafloor sediments (based on acoustic reflectivity or backscattering), and the intensity of sea ice scouring (Figures 1 and 3). The Knudsen 320R is a low frequency sub-bottom profiler which provides high-resolution imagery of sediment thickness and internal structure up to 70 metres below the seafloor. The data acquired by these two systems can be combined to create a three-dimensional perspective of the seafloor and the underlying sediment structure. This information is essential to our research program as it allows us to avoid sampling 'hard' bottoms (i.e. stony substrates) that cannot be sampled adequately by the box coring equipment onboard CCGS *Amundsen*. Information acquired by these instruments will

allow us to assess the relative ages of prominent ice scours on the inner Mackenzie Shelf: in combination with the box coring program, this information will allow us to assess the impact of sea ice scouring on benthic community structure (see 7.2 above).

A bottom camera was used to acquire images of the seafloor in effort to estimate the densities of epibenthic organisms and to ground-truth acoustic reflectivity data prior to box coring operations. These images are valuable in determining community structure (see 7.1 and 7.2 above), especially of those organisms that are either able to avoid the box corer or are at densities below which they are adequately sampled by box coring. The most common taxa that appear in these photographs: brittle stars, sea stars, soft corals and large isopods (Figure 2), may be important contributors to total community respiration (see 7.3 above), which would suggest a fundamentally different perspective on seafloor cycling in Arctic shelf environments.

A large box core (50 cm x 50 cm x 80 cm) was employed to obtain samples of benthic organisms and seafloor sediments. Triplicate samples were obtained whenever possible. The samples obtained from the box core were subdivided to provide materials to study the distribution, abundance and respiration of benthic macrofaunal organisms (organisms larger than 0.4 mm), the nature and quantity of organic matter present in the seafloor sediments, and the particle size distribution of seafloor sediments (see 7.1 and 7.2 above). Among the macrofauna polychaetes, amphipods and bivalves are most abundant (Figure 3). Preserved specimens were returned to the Canadian Museum of Nature for sorting and identification and determination of biomass, and will provide essential information to support our study of benthic community structure, the productivity of selected taxa, and benthic respiration.

The rate at which benthic communities process organic matter can be used to predict the strength of linkages between pelagic and benthic habitats, the input of inorganic nutrients into bottom waters, and the potential for carbon burial in sediments (see 7.3). Sediment sub-cores extracted from the box corer were filled with near-bottom water collected from a rosette at the same station. The cores were sealed and oxygen depletion was measured every 4 to 6 hours for 1 to 2 days. In addition, respiration rates of

3 species of echinoderms and 3 species of crustaceans were measured by adding animals to sediment cores and running these cores as above (with sediment-only values subtracted to obtain epifaunal respiration rates). Finally, respiration rates of the infaunal community with macrofauna excluded were measured from vial incubations. Generally, sediment oxygen demand was similar to that measured in other shelf areas of the Arctic. The ability to sample the same location on multiple occasions throughout the year was enlightening. Respiration at the overwintering station varied by more than a factor of 10, and showed marked seasonality. Work is underway to calculate the relative contributions of meiofauna, macrofauna, and epibenthic megafauna to total community respiration. This work will be completed in 6 to 8 months.

Our original plan to investigate the use of biochemical markers (lipids, fatty acids) preserved in the organic matrix of calcareous shells to identify potential sources of carbon consumed by the benthos has been delayed as a result of the closure of the biogeochemistry laboratory operated by Dr. Emily CoBabe at the University of Massachusetts-Amherst. We have initiated discussions with subproject 5 researchers to pursue this line of inquiry in the laboratory operated by Dr. Don Deibel, Memorial University. In the interim, stable isotope analysis of biotic components of the pelagic and benthic food webs are being performed to identify the trophic pathways in the southern Beaufort Sea, and how these pathways vary in time and space. This work involves

collaboration with Dr. Keith Hobson, Canadian Wildlife Service, and builds on the success of a similar study completed as part of the North Water Polynya (NOW) study. Combining these measurements with data on contaminants (see collaboration with subproject 5 above: Zou Zou Kuzyk's thesis research is supervised by Dr. Gary Stern, DFO) will provide useful information on the movement of organic and heavy metal pollutants through the food web, potentially up to Arctic residents. Additionally, stable isotope data can elucidate the relative contributions of potential sources of carbon to benthic organisms (see 7.4). These results may allow for prediction of the pathways of consumption and burial of carbon in a changing Arctic marine environment.

Finally, CASES has provided new opportunities to explore the contribution of carbonate shells to the pool of carbon stored in seafloor sediments. The research of Karine Bibeau and Shanshan Cai will examine the biological (e.g. bioerosion), physical (e.g. fragmentation by sea ice scouring of the seafloor) and chemical (e.g. dissolution) processes that affect the preservation of mollusc shells in arctic continental shelf sediments. The examination of modern mollusc assemblages and subfossil shells recovered by box coring (see 7.1 and 7.2) will allow these two researchers to track the post-mortem loss of shell material via fragmentation and bioerosion from seafloor sediments. Collaboration with subproject 6 researchers Dr. Alfonso Mucci, Dr. Bjorn Sundby and their students (Chaillou, Magen) will allow Karine and Shanshan to assess the influence of chemical processes such as dissolution and cementation on shell preservation in seafloor sediments.

Subproject 2.7 progress report summary table

Subproject 2.7	2002	2003	To date	Progress by Mid-Year
7.1. Benthic community structure responses to the seasonal variations in sedimentation.	X	X	X	108 boxcores samples and extensive bathymetric survey. Samples from 2002 are all analysed. The taxonomy, the biomass, particle size and organic matter analysis from the overwintering samples should be done by December 2005. 2 conference paper presentations in 2004
7.2. Benthic community structure responses to the variations in the magnitude and frequency of ice scour.	X	X	X	Progressing well: see reference to box cores in 7.1 above; extensive bathymetric survey completed; sorting and identification of 2003-2004 benthos in progress; analysis of benthic biomass in progress; analysis of particle size and organic matter content of 2002 sediments completed; analysis of 2003-2004 sediments in progress Progressing well: identification of 2003-2004 benthos in progress (to be completed by Dec., 2005); analysis of benthic biomass in progress (to be completed in fall, 2005); analysis of particle size and organic matter content of 2003-2004 sediments in progress (to be

				completed by May, 2005); 2 publications in preparation (see 7.1 above)
7.3. Impact of 1) and 2) on the rate of carbon remineralization.	X	X	X	*In situ* incubations for benthic respiration completed; identification of benthos in progress; determination of benthic biomass in progress; determination of community respiration in progress (to be completed in fall, 2005) Progressing well: identification of benthos in progress; determination of benthic biomass in progress; determination of community respiration in progress (to be completed in fall of 2005); 1 publication submitted
7.4. Biogeochemical markers" in invertebrate skeletons.		X	X	Initiated stable isotope (carbon, nitrogen) analysis to support food web and contaminant pathways research in collaboration with Subproject 5 Progressing well: stable isotope analysis in progress (to be completed in fall of 2005)

2.8. Decadal-millenial variability in sea ice & carbon fluxes (Scott)

Numerical modelling of the response of the Canadian Arctic shelf ecosystem to climate change requires investigation of the geological record in order to set meaningful initial values for conditions warmer or colder than those recorded in historical times (e.g.Vettoretti et al. 2000). This problem in initialising (and validating) climate models is particularly severe in the Mackenzie Delta-Beaufort region where written climate records cover only the past century and oceanographic data cover only the past 30 years. Validation of carbon flux models also requires quantitative measurement of sediment sink values, e.g. changes in rates of carbon burial, amounts of terrigenous vs. marine carbon inputs (Macdonald et al. 1998).

Hypotheses and objectives of group 2.8 were conceived in 2000, we had a number of hypotheses that we wanted to test:

a) Large oscillations in August sea-surface temperature of the order of 2-4ºC have occurred in the Mackenzie Shelf-Beaufort Sea area at decadal to millennial intervals during the past 10,000 yrs, with concomitant reductions in sea ice extent and increased primary productivity.
b) Warmer climate, accelerating sea level rise and more open water conditions may increase the quantity of sediments and particulate organic matter (POM) exported from the inner shelf and coastal embayments to the outer shelf and slope.
c) Changes in direction of surface ice drift in the Beaufort Sea are linked to decadal and millennial climate changes in the AO system.

d) Climate warming in the Mackenzie Valley-Beaufort Sea region may be accompanied by increased freshwater discharge from the Mackenzie River.

All of these hypotheses remain and we have not deviated from our main objectives. However, the methods which will be used to test hypothesis "c" have changed. We had originally planned to perform ice rafted debris (IRD) analyses using a microprobe (Darby and Bischof at Old Dominion University) to determine the composition and the origin of the IRD, and assess changes in the direction of the Arctic Drift related to the Arctic Oscillation. This method is rather expensive and consumes a substantial portion of our annual budget. Due to increasing costs of fuel and logistics, scientific personnel were required to pay their transit to and from the ship, which was not planned in our original budget. In addition, we encountered unforeseen expenses related to the piston coring activities. As a result, we will use other less expensive methods to help achieve our objectives for hypothesis "c", namely, sedimentology, micropaleontology and paleomagnetism. The latter will be performed by a new addition to our team, Dr. Guillaume St-Onge from ISMER.

Scientific significance of results

The seafloor of the Beaufort Sea has been studied since the early 1970s using low-resolution single beam and sidescan sonars, and sub-bottom profiling systems. Only in the late 1990s, early 2000s did we start to see detailed mapping of the seafloor, mainly on the Beaufort Shelf (Blasco, 2001), using a multibeam system. In 2002, some members of our team acquired the first detailed multibeam survey of the Mackenzie Trough area as part of the Joint Western Arctic Climate Study (JWACS) Program, while on board the Japanese research vessel RV Mirai. This survey confirmed some hypotheses relative to sediment deposition and transport from the shelf toward the slope area. Something we did not have proof of until the survey was performed. In autumn 2003, the first multibeam and sub-bottom survey through the NW Passage was done during the transit of the Amundsen from Quebec City to the Beaufort Sea, sometimes in areas where hydrographic data was quasi non-existent. This in itself is a significant contribution. The survey also allowed us to observe potential Holocene (≤ 10,000 years) sediment accumulation areas along the path of the ship. Before 2003, sidescan and sub-bottom surveys were restricted to certain areas along Lancaster Sound and in a few channels connected to Lancaster Sound. It is in summer 2004 during leg 8 of the CASES cruise that the most detailed multibeam surveys were performed in areas where it had not been done before, along the Mackenzie slope and in Amundsen Gulf. This allowed us to observe drumlin-like features of glacial or meltwater origin, relict ice scouring and the maximum depth at which it occurs, potential ice margin features (moraines), none of which have ever been mapped with such details in the past. These results will definitely stimulate the ongoing discussions concerning the position of the ice front during the last glacial maximum, and maybe confirm or refute some of the hypotheses on the matter. A sediment instability feature, or "slump", along the Mackenzie slope, about 176 km off Tuktoyaktuk was also identified using the multibeam echosounder. This feature, which was reported for the first time in 1982 (Hill et al., 1982), generated a lot of publicity and heightened public and government (federal and territorial) awareness to the problem of sea floor stability in relation with the oil and gas industry. Multibeam and sub-bottom profiler data was instrumental in identifying sites of high Holocene sedimentation rate required for high-resolution paleoceanographic research to meet the objectives of this project

For the first time, high-resolution Holocene sediments were recovered from the Mackenzie Trough during the JWACS cruise in 2002. A series of 3 cores, 2 of which are 10 m in length,

have been dated using AMS-^{14}C measurements on shell fragments and comprise up to 8000 years of sedimentation. Preliminary results in one of these cores indicate that there have been significant changes in microfossil assemblages over that time-period, possibly indicating important variations in sea ice cover, but also changes in the origin of water masses. Analyses on these cores are underway and are likely to reveal important information regarding climate variability and oceanic circulation in the western Canadian Arctic throughout the Holocene. A series of piston cores collected during leg 8 of the 2004 cruise also show promising results. Preliminary analyses of the remnant magnetization recorded in the sediment in conjunction with sedimentological analyses show that most of the cores are probably Holocene in age, that they can be correlated with one another, and most importantly, that they may be correlated to lacustrine sequences from Ellesmere Island, which are varved (annual layers). This in itself is a significant contribution, as we will potentially have access to an annual chronology, something that has never been achieved with marine sediments from the Canadian Arctic. More detailed sedimentological studies and AMS-^{14}C dating on shell fragments will be performed to confirm the age of these sequences. In addition to long piston cores, a series of 46 short undisturbed sediment cores (boxcores) were collected throughout the Mackenzie Trough, Shelf and Amundsen Gulf. These will allow for detailed analyses of the historical and pre-historical records of climate change in areas where sediment accumulation rates are high enough, data that are of paramount importance to climate modelers in order to test the regional climate models that are being developed for the Arctic region. Micropaleontological and very high-resolution (0.1 to 1 mm) sedimentological analyses (CAT-scan and microfluorescence-X) are underway for the boxcores collected in the Mackenzie Trough area. ^{210}Pb analysis of one of these boxcores indicates recent sedimentation rates of at least 0.25 cm/yr in the Trough area, allowing the setting of chronologies with at least at decadal resolution. We hope to obtain a detailed record of climate change over the last few centuries or millennia with these short cores. As a first step towards interpreting the micropaleontology of these cores all the surface samples collected in 2004 have been analyzed for foraminifera and tintinnids as well as qualitative analyses of diatom and ostracod content. Each of these proxies will provide us with a unique signal. One promising finding is a species of foraminifera that appears only where there is probably methane discharge (i.e. around mud volcanoes and pingo-like-feature) which may show us where methane discharges were in the past but are no longer present at certain locations. Tintinnids give us indications of the amount of freshwater and SPM in the water column. These surface data, which have collaborating physico-chemical data from CASES allow us to calibrate our prehistoric fossil assemblages.

Subproject 2.8 progress report summary table

Group8	2002	2003	To date	Progress by Mid-Year
2.8 Millenial-decadal variability in sea ice and carbon fluxes	X	X	X	• Sampling completed • Palynological analyses progress slowly due to the nature of the analysis (time-consuming counting of specimens in light microscopy), but publications (poster+presentations) are in preparation nevertheless (35th Arctic Workshop in Edmonton, March 2005; North American

	Paleontology Conference in Halifax, June 2005), a symposium dedicated to polar faunas and floras at the North American Paleontology Convention (NAPC June 2005) • Paleomagnetic and CAT-scan analyses progress rapidly and publications (poster + presentations) are in preparation (35th Arctic Workshop in Edmonton, March 2005; Geological Association of Canada annual meeting in Halifax, May 2005). • Foraminifera analyses progress slowly (time-consuming counting of specimens), but publications (poster+presentations) are in preparation (35th Arctic Workshop in Edmonton, March 2005 and NAPC June 2005) • Development of processing procedures for geophysical data and implementing these procedures; geophysical images have been placed on the internet and initial interpretation of the geophysical data has begun • Sedimentological and stratigraphical analyses of the three Beaufort Trough cores are completed

2.9 Modeling–coupled bio-physical models of the carbon flows on the Canadian arctic shelf (Barber)

The CASES project acknowledged the need for both upstream and downstream modeling in preparation of our ship based field activities. We conducted this study with a team of modelers in preparation for the study. This team (Table 2) remained involved and is now participating in development of improved models, validation of existing models, and data assimilation studies using the field data from the CASES study. The emphasis of the group was to use existing models to steer the experimental plan of the CASES project by examining issues of specific processes within the CASES study area.

The CASES project requires a multidisciplinary approach to investigate the sensitivity of the arctic marine shelf ecosystems to climate variability and change. Our working premise is that we are interested primarily in 'variability' rather than 'change'. We need to understand how various physical and biological processes operate in order to investigate how they respond to variability in the climate system of the CASES region. Carbon export is the central theme being examined by CASES yet the models required to investigate the processes inherent in carbon export cover the full spectrum of physical, biological and biogeochemical processes.

Table 2. Modelling team title and affiliations

Title	Affiliation
Arbetter, T. (Post Doc)	CIRES, University of Colorado, Boulder, CO
Barber, D.G. (Professor and Director)	Centre for Earth Observation Science (CEOS), University of Manitoba
Diebel, D. (Professor)	Ocean Sciences Centre, Memorial University, Newfoundland
Dupont, Frédéric (Research Associate)	Québec-Océan, Department of Biology, University of Laval, Quebec City, PQ.
Fortier, L. (Professor)	Québec-Océan, Department of Biology, University of Laval, Quebec City, PQ.
Hanesiak, J. (Assistant Professor)	Centre for Earth Observation Science (CEOS), University of Manitoba
Holland, D (Associate Professor)	New York University, USA.
MacDonald, R. (Research Scientist)	Institute of Ocean Sciences (IOS), Department of Fisheries and Oceans, Sidney, BC.
Papakyriakou, T. (Assistant Professor)	Centre for Earth Observation Science (CEOS), University of Manitoba
Tian, R. (Post Doc)	Ocean Sciences Centre, Memorial University, Newfoundland
Maslowski, M. (Research Scientist)	Naval Postgraduate School, Monterey, CA

To structure the work in subproject 9, we have divided our models into several generic classes of models: physical model of the ocean-sea ice-atmosphere system (1); detailed ocean-sea ice coupled model (2); one-dimensional thermodynamic atmospheric and thermodynamic sea ice models (3) and finally a model which attempts to couple significant physical processes to the associated biological processes (4). Although this framework has significant overlap, both within and between the various models, it allowed us to compartmentalize the modelling results into the two major sampling regions of CASES: the fast ice region (overwintering location of the Amundsen) and the marginal ice zone/open water region (mobile sampling with the Amundsen). A summery of current activites in each of these regions follows:

- The ARCsym model is being implemented by a US collaborator for the CASES study (Arbetter). The model is being used to examine the general formation and decay of sea ice relative to oceanic and atmospheric forcing. We have also begun to examine how blowing snow may be encapsulated into the ARCsym model through the use of in situ blowing snow studies and a numerical model known as Piektuk.
- The naval post graduate school is also using the CASES data to examine processes of oceanic forcing on the sea ice and studies which couple ocean-ice-atmosphere processes. High resolution runs have been completed for the entire CASES region using a 9km spatial resolution. Discussion are now underway to design specific process studies where in situ CASES data are compared with modeling field in both the marginal and fast ice regions. This model will be particularly useful in examining the relationship between freshwater fluxes and sea ice processes within the CASES study region.

- The use of a 1-D thermodynamic snow/sea ice model is being lead by Hanesiak and Barber. This work seeks to connect atmospheric radiative transfer to the thermodynamics of the snow/sea ice system (fast ice only). The principal focus is on using the University of Manitoba 1-D thermodynamic snow/sea ice model coupled to a radiative transfer model (SBDART). This combined modeling environment is being used to examine the role of clouds on the thermodynamics of the snow/sea ice system and in particular radiative transfer within the atmosphere, through the snow/sea ice system and to the base of the sea ice where initial primary production occurs. Collaborations are also ongoing with Holland in the development of a dedicated fast ice model based on in situ measurements made during CASES.
- The development of physical-biological modeling is underway and remains a priority of the CASES modeling team. Gratton (Subproject 2.1) and Fortier (Subproject 2.5) have received a FQRNT team grant to develop this aspect. Fortier's Senior Canada Research Chair will be devoted to the development of NPZD models and offline coupled biological-physical models of copepods and larval arctic cod life cycles in the CASES study area. The CFI grant associated with the Chair enabled Fortier to purchase and set up a cluster of CPU to support numerical simulation. Dr. Frédéric Dupont, a physical modeller, has been hired through the Regroupement stratégique Québec-Océan and two students with a strong background in physical-biological modelling have been recruited.

3/4. MAIN PROBLEMS ENCOUNTERED IN CARRYING OUT THE RESEARCH

Given the magnitude and complexity of the endeavour, there have been few significant problems related to the execution of the field program of CASES. The myriad of logistical and technical problems encountered were solved on a continuous basis by our specialists and technicians with extraordinary administrative, technical and navigational support from Coast Guard personnel. Our Federal and international partners were fully involved in the research and completed their planned share of the program and more, as reported in the subproject progress reports.

5. NETWORK MANAGEMENT

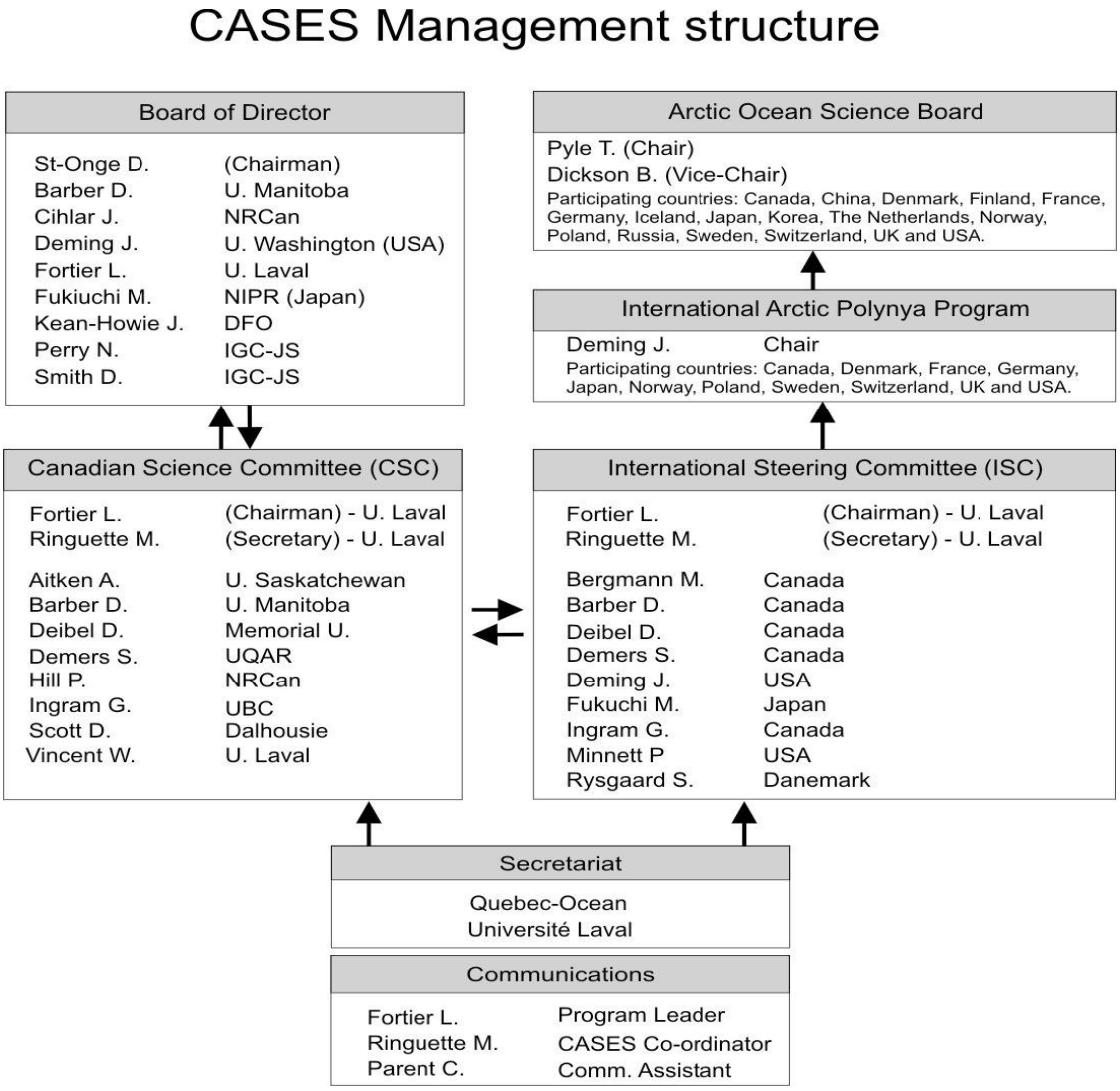


Figure 5. Organisational chart of the CASES Research Network with names and affiliations of elected members. There has been no significant change in the management structure of the CASES Research Network.

6. DECISION MAKING.

At the national level, a Canadian Science Committee (CSC), formed by the leaders and co-leaders of the 9 sub-projects and chaired by the Program Leader, reports to a Board of Directors. The CSC is responsible for the monitoring of the progress of individual sub-projects and provides the Board with recommendations regarding modification of research priorities and budget allocations. At the international level, the International Steering Committee chaired by the Program Leader regularly reports to the IAPP of the AOSB. The ISC is responsible for the general co-ordination of international collaboration (in particular expedition plans and sampling schedules), the planning of meetings, workshops, symposia and special sessions at international conferences, the co-ordination and edition of special issues of journals, and the solution of scientific issues (e.g. berth allocation on the ship, authorship). To facilitate liaison, the Program Leader and the Program Co-ordinator (Marc Ringuette) are *ex officio* respectively Chairman and non-voting Secretary of both the CSC and the ISC.

The day to day operations, co-ordination and communication to the general public are the responsibility of the Program Leader assisted by the Program Co-ordinator. A Communication Assistant (Christine Parent) managed the CASES Website and initiated contacts with media. As for NEW and NOW, the secretariat of Québec-Océan handles the distribution of funds to investigators in other Canadian universities, the administration of the central budget and the preparation of financial reports.

7/8. MAIN MANAGEMENT ISSUES AND THEIR SOLUTIONS

Ship operation deficit in 2003-2004. The only major management issue encountered was the build-up of a serious deficit in the funding of the operation of the *Amundsen* for CASES0304. The history, causes and solutions to this problem have been fully documented and presented earlier to NSERC. They are summarized here.

The deficit reached $2 300 000 at the end of fiscal year 2003-2004 and seriously threatened to curtail the one-year expedition. The main causes of the deficit in approximate order of importance were:

- In 2001, the decision by Coast Guard to adopt a full costs recovery policy for scientific operations of their icebreakers (versus incremental costs recovery for NOW) roughly doubled the financial pressure on science budgets. This decision was announced after the submission of the full proposal, which explains the initial underestimation of CASES ship operation costs based on the costs for NOW and SHEBA. This situation was resolved by the CFI grant that doubled our operational funds for CASES03-04 (see section 11. for details of this contribution). However, if the full costs had been requested from (and granted by) NSERC right from the start, the deficit accumulated at the end of fiscal year 2003-2004 could have been absorbed by the CFI grant.
- The unforeseen costs of refueling in the spring of 2004 (the barges). Our initial strategy was to have the *Amundsen* refueled in early summer by the *Louis S. St-Laurent* (at the fuel price of ¢42 per liter prevailing in the South), a solution which we could afford within the budget available. Based on the initial estimate of the costs of the barge, it was still possible to proceed for CASES03-04 with a small deficit that was expected to be absorbed by savings on fuel consumption, a large American contribution to operation costs, and reducing the science program. Up to this point, the financial situation for CASES03-04 ship operation costs was

sane. The actual costs of the summer refueling (at the fuel price of ¢72 per liter prevailing in the North + the charter of the barges) is, in essence, what defeated our strategy to balance the ship operation budget and created the bulk of the deficit.

- The general increase of salaries and costs of logistics in recent years. For example, labor contracts of crew and officers have received salary increases of 8.74% since 2000 assorted with substantial holyday premium for the officers. Airfares and aircraft charter rates in the Arctic have easily doubled in recent years.
- The loss of foreign contributions because of the one-year delay in Canadian funding and in the deployment of the one-year expedition ($585 000 for Japan, up to $510 000 for the USA).

In addition to several efforts to reduce operation costs (e.g. transfer of the helicopter costs to users; reduction of ship personnel to a minimum; etc.), our team implemented the following solutions to reduce the deficit and maintain the integrity of the science program.

- A contribution already imposed to Canadian researchers and proposed to foreign researchers, towards the costs of scientist exchange (comprised in the ship operation costs) increased revenues by $250 000.
- Fuel consumption over the winter was significantly less than expected. Savings amounted to $250 000 and Coast Guard bought back $250 000 worth of fuel from CASES, effectively reducing expenses by this amount. Because the polynya opened early and widely, ship movements in the ice in spring was reduced without major consequences on the science program. The reduction in fuel consumption resulted in savings of about $500 000. Part of the saved fuel was sold to the ArcticNet health mission to Nunavik from late August to October ($374 000). The remainder was bought back by Coast Guard as described in the Cost Sharing Arrangement.
- Leg 9 was shortened by a few days, with the expedition ending in Churchill around 25 August instead of Quebec City on 4 September as planned. The reduction in the number of days was compensated by the continuation of CASES operations (water column and plankton sampling, mooring operations) in September during the fall mission of the *Laurier* to the study area. This solution provided by DFO actually extended the duration of the sampling beyond the planned date of termination and allowed us to complete the full annual cycle and prevent any negative impact on the science program.
- A $600 000 contribution from ArcticNet to ship operation costs for the re-mooring of instruments at the end of Leg 8 (as part of the scientific observatory program of Theme 1) was approved by the Network's Board of Directors. This helped maintain the planned CASES science program all the while initiating operations for Theme 1 of ArcticNet (a win-win combination for the two programs).
- After reviewing mobilization expenses, Coast Guard shared some of the mobilizing costs. A net reduction of $85 000 of the overall costs for CASES.
- Our request to NSERC to increase funding for the operation of the ship for CASES has been approved. A net increase of $609 000 in revenues.

The operation deficit was effectively corrected by the implementation of these actions and, as of 31 March 2005, the books for CASES03040 are balanced and closed.

Involvement of Federal partners. A concern of NSERC about CASES has been the perceived lack of contribution of our Federal partners, in particular the Department of Fisheries and Oceans, to the costs of operation of the ships used in the field program. This perception stems from the fact that, contrary to the situation for other Research Networks, the DFO did not make any formal commitment of cash for CASES ship operations. However, the DFO made major and crucial in kind contributions to CASES through the provision of services by DFO-Coast Guard and of ship time by DFO-Science. On the bottom line, these contributions are greater than cash commitments to other research networks. Clearly, CASES would not have happened without that support.

9. TRAINING OF HIGHLY QUALIFIED PERSONNEL (HQPS)

Canadian and foreign Highly Qualified Peoples (HQP's) involved in CASES are listed below by subproject. An asterisk indicates involvement in ARDEX, a satellite program of CASES focussing on the Mackenzie River and Delta.

Central 2.0

Blondeau S	Sea-going technician. Québec-Océan, U. Laval.
Desmeules G	Sea-going technician. ISMER.
Guillot P	Research assistant. Data quality control. Québec-Océan. ISMER.
Massot P	Sea-going technician. Québec-Océan. U. Laval.
Michaud L	Research assistant. Ship manager. Québec-Océan. U. Laval.

Subproject 2.1

Amundrud T	PhD. Sea ice modelling. U. British Columbia.
Belanger C	Research assistant. CTD technician. U. British Columbia.
Eart J	Research assistant. CTD technician. U. British Columbia.
Hamilton A	MSc. Water mass links to phytoplankton. U. British Columbia.
Hardenberg P	Undergraduate. Current meter data analysis. U. Victoria.
Lanos R	PhD. Amundsen Gulf dynamics. INRS-ETE
Martin I	Undergraduate. Data analysis. U. British Columbia.
Rail M-E	MSc. Water mass characteristics. INRS-ETE
Vysotskyy M	MSc. CTD technician. U. Puerto Rico.
Wang Q	PhD. Ocean modelling on Mackenzie Shelf. U. British Columbia.
White R	Undergraduate. Mooring preparation. British Columbia Institute of Technology.
Williams B	PDF. CASES area dynamical processes. U. British Columbia.

Subproject 2.2

Al-Mamun M	MSc. Ship-based air-surface exchanges. U. Manitoba.
Asmus K	Technician. Microwave remote sensing. Canadian Ice Service.
Blouw C	MSc. Sea ice roughness and higher trophic habitats. U. Manitoba.
Breneman C	MSc. Sea ice deformation analysis from remote sensing. U. Calgary.
Butler J	MSc. CASES meteorology and blowing snow project. U. Manitoba.
Ehn J	PhD. Bio-optical modeling in marginal ice zones. U. Manitoba.
Else B	MSc. Carbon flux modeling over snow covered sea ice.U. Calgary.
Fisico T	MSc. CASES meteorology and atmospheric modeling. U. Manitoba.
Galley R	PhD. Sea ice melt and mixed layer depths. U. Manitoba.
Geldsetzer T	PhD. Polarimetric microwave remote sensing of sea ice. U. Calgary.

Granskog M	PDF. Sea ice geophysics. U. Manitoba.
Hodgson R	Technician. Field Support during CASES. U. Manitoba.
Howell S	PhD. Remote sensing data assimilation and fusion. U. Calgary.
Hwang P	PhD. Remote sensing of snow on sea ice. U. Manitoba.
Iacozza J	PhD. Sea ice and Polar Bear Habitat. U. Manitoba.
Key EL	PDF. Surface radiation budget in the Arctic. U. Miami.
Langlois A	PhD. Thermodynamic of snow on sea ice. U. Manitoba.
Lukovich J	PDF. Sea ice and climate change. U. Manitoba.
Mosscrop D	Technician. Computer Support during CASES. U. Manitoba.
Mundy CJ	PhD. Radiative exchange and microwave scattering. U. Manitoba.
Owens O	MSc. Sea ice and CO_2 partial pressure. U. Manitoba.
Peirson R	Undergrad co-op student. meteorology program assistance. U. Alberta.
Scharien R	PhD. Microwave scattering modeling of summer sea ice. U. Calgary.
Szcodrak M	Assistant Scientist. Infrared satellite validation studies. U. Miami.
Tat A	MSc. CASES meteorology assistance. U. Manitoba.
Tivy A	PhD. Statistical modeling of sea ice dynamic processes. U. Calgary.
Woo W	PDF. Hudson Bay Sea Ice. U. Manitoba.
Xin J	PhD. Atmospheric Radiative Transfer Modelling. U. Manitoba.

Subproject 2.3

Bérubé D	Technician. CHN analyses.. ISMER/UQAR.
Bérubé D	Research assistant in chemistry. ISMER/UQAR.
Bessière A	Undergraduate student. Microphytobenthos and meiofauna. ISMER/UQAR.
Brugel S	PhD. Phytoplanctonic community and biogenus flux carbon. ISMER/UQAR.
Caron G	Trainee. Phytoplankton sampling. ISMER/UQAR.
Cherewyck K	Research Technician. Marine Productivity. DFO-FWI.
Côté J	Trainee. Phytoplankton sampling. ISMER/UQAR.
Ferreyra G .	Research associate. Phytoplankton data analysis. ISMER/UQAR.
Furon C	Undergraduate student. Phytoplankton sampling. ISMER/UQAR.
Gauthier M	Research technician. Chemical Oceanography. ISMER/UQAR.
Hamel D	Research technician. Biological Oceanography ISMER/UQAR.
Juul-Pedersen T	PhD. Sedimentation and grazing export of biogenic material. ISMER/UQAR.
Lacoste K	Research associate. Phytoplankton sampling and data analysis. ISMER/UQAR.
LeBlanc B	Research Technician. Marine Productivity. DFO-FWI.
Nozais C	Research associate. Phytoplankton sampling and data analysis. ISMER/UQAR.
Ouellet G	Technician. Cytometry analyses. ISMER/UQAR.
Riedel A	PhD. Grazing and nutrient regeneration by sea-ice microfauna. ISMER/UQAR.
Różańska M	PhD. Species composition of ice algae and abiotic factors. ISMER/UQAR.
Simard M	Research technician. Biological Oceanography. ISMER/UQAR.
Yamamoto S	MSc. Photosynthetic acclimation of ice algae to light. Soka U. Japan.

Subproject 2.4

*Casper A	PhD intern. Food web in the Mackenzie River transition zone. U. Laval.
*Emmerton CA	MSc. River-lake exchange on ocean-bound nutrients. Simon Fraser U.
*Retamal L	PhD. CDOM control of spectral irradiance and primary production. U. Laval.
*Vallières C	MSc. Microbial community structure and carbon fluxes. U. Laval.
Alonso L	PhD. Diversidad filogenética bacteriana. U. Politècnica de Catalunya. Spain

Balagué V	Technician. Molecular techniques. ICM. Spain
Bayer M	PhD. Composición estequiométrica del fitoplancton. U. Bremen. Germany.
Bélanger S	PhD. Satellite estimation of photochemical fluxes. LOV. Villefranche. France.
Bonilla S	PDF. Picoplankton dynamics by HPLC pigment analysis. U. Laval.
Carpenter S	Technician. Sea-ice and microbes sampling and analysis. U. Washington.
Carrière M	BSc undergraduate trainee. Picoplankton dynamics. U. Laval.
Chapenoire A	BSc undergraduate trainee. Experimental study of picoplankton. U. Laval.
Collins E	MSc. Microbial Succession in Arctic Sea Ice. U. Washington.
Comeau A	PhD. Distribution of Vibrio viruses and their hosts. U. British Columbia.
Culley A	PhD. Identification of novel RNA viruses. U. British Columbia.
Felipe J	Technician. Flow cytometry. ICM . Spain.
Galand P	PDF. Molecular biodiversity of Arctic seas. U. Laval.
Garneau M-È	PhD. Bacterial production dynamics. U. Laval
Guadayol O	PhD. Turbulència i el flux de carboni. U. Politècnica de Catalunya. Spain.
Lovejoy C	Research Associate. Molecular ecology of the Arctic Ocean. U. Laval.
Martineau C	Research Assistant. Shipboard sampling and laboratory analyses. U. Laval.
Martineau M-J	Research Assistant. HPLC and other sample analysis. U. Laval.
Noksana M	Intern. Mangilaluk School Tuktoyaktuk. Joint Fisheries Management.
Ortmann A	PhD. Deep sea microbial ecology - Juan de Fuca Ridge. U. British Columbia.
Payet J	PhD. Ecology and diversity of marine viruses. U. British Columbia.
Ramlal P	PDF. pCO_2 dynamics in the Mackenzie River and Delta. FWI. DFO.
Rautio M	Research Associate. Food web relationships. U. Laval.
Roldán C	PhD. Fitoplanctòn y variables ambientals. U. de Barcelona. Spain.
Roy S	MSc. Winter microbial community structure and dynamics. U. Laval.
Sala M	PDF. Functional diversity of bacteria. U. Politècnica de Catalunya. Spain.
Terrado R	MSc/PhD. Dynamics and molecular diversity of picoeukaryotes. U. Laval.
Unrein F	PDF. Mixotrophy in polar flagellates. U. Politècnica de Catalunya. Spain.
Vance S	PhD. Thermochemistry in Europa's Ocean: aqueous $MgSO_4$. U. Washington.
Vila M	PhD. Microorganismes y cyclo de sofre. U. Politècnica de Catalunya. Spain
Waleron M	PDF. Genotypic diversity of picocyanobacteria. U. Gdańsk. Poland.
Wells L	PhD. Low-Temperature Activities of Marine Viruses. U. Washington.
Wen K	Undergraduate. Enumeration of viruses. U. British Columbia.
Yamamoto S	MSc. Ciliate ecology in the Beaufort Sea. Ishinomaki Senshu U. Japan.

Subproject 2.5

Atsushi M	MSc. Ocean color algorithm in the Subarctic and Arctic Oceans. Hokkaido U.
Benoit D	PhD. Distribution of the Arctic cod using hydroacoustic tools. U. Laval.
Bergen D	Volunteer technician. Zooplankton taxonomy and analyses. Memorial U.
Braekevelt E	Research Technician. Field program organization. DFO-FWI.
Bruce J	Undergraduate Student. Video analyses. Memorial U.
Businski T	PhD. Food sources and lipid storage in mesozooplankton. Memorial U.
Connelly T	PhD. Biogeochemistry of the benthic boundary layer. Memorial U.
Coughtrey S	Undergraduate. Mercury loading from the Mackenzie River. DFO-FWI.
Darnis G	MSc. Copepod life cycles. U. Laval.
Forest A	MSc/PhD. Fecal sedimentation and its contribution to carbon flux. U. Laval.
Fortier M	CASES scientific coordination. U. Laval.
Fortin K	Trainee. Field work and taxonomy. U. Laval

Helm P	PDF. CASES contaminants project coordinator. DFO-FWI.
Jackman L	Research Associate. Suspended particulate matter analyses. Memorial U..
Kuzyk ZZ	PhD. Trends of persistent organic pollutants (POPs). DFO-FWI.
Lafrance P	PhD. Arctic cod larval and juvenile feeding and growth. U. Laval.
Lalancette C	Trainee. Field work and taxonomy. U. Laval
Lebel S	Trainee. Field work and taxonomy. U. Laval
Lee S-H	Research Associate. Zooplankton taxonomy. Memorial U..
Leitch D	MSc. Mercury loading from the Mackenzie River. DFO-FWI.
Letourneau L	Research assistant. mesozooplancton sampling and taxonomy. U. Laval.
Loseto L	PhD. Mercury in the Beaufort Sea/Amundsen Gulf food web. DFO-FWI.
Perron V	Research assistant. mesozooplancton sampling and taxonomy. U. Laval.
Pilote M	Trainee. Field work and taxonomy. U. Laval
Prokopowicz A	PhD. *Themisto libellula* life cycle. U. Laval.
Ringuette M	CASES scientific coordination. U. Laval.
Ryosuke M	PhD. Biogenic particle flux in the Canadian Arctic. Sensyu U. Ishinomaki.
Sampei M	PDF. Carbon flux from long term sediment traps. NIPR. Japan/U. Laval.
Sampei M	PDF. Seasonal variability in the flux of particulate organic matter. NIPR. Japan.
Seuthe L	MSc. Production and export of copepod faecal pellets. U. Tromsø. Norway.
Shinpei A	MsC. Annual change in photosynthesis. NIPR. Japan.
Shinya Y	MsC. Photosynthetic Characteristics of ice algae. Soka U. Japan.
Sohei M	PhD. Chaetognaths in the Subarctic and Arctic Oceans. Tohoku U. Japan.
Takahiro N	PDF. 210Pb and sedimentation. Ntnl Institute of Radiological Sciences. Japan.
Trela P	PDF. Fine-scale distribution of mesozooplankton. Memorial U.
Vickers C	Research Associate. Zooplankton taxonomy and sample analyses. Memorial U.

Subproject 2.6

Amiel D	PDF. Natural Radionuclides and POC cycling on the Shelf. State U. New-York.
Arctander E	Undergraduate. Sample analysis. DFO-IOS
Arychuk M	Research technician. Preparation and instrumentation development. DFO-IOS.
Bernier G	Research technician. Cruise participation and sample analyses. McGill
Bowie K	Research Technician, Water column. ice. bed. U. Victoria
Chaillou G	PDF. Sediment geochemistry. McGill University.
Collin P	PDF. Nature and provenance of suspended particulate matter. McGill
Crowe S	MSc. Benthic geochemistry, McGill University
Davelaar M	Research technician. Cruise preparation, sample analyses. DFO-IOS.
Guignard C	Research assistant. Sampling and method development. McGill University.
Hill B	Research Technician. Fieldwork preparation. NRCan.
Lintern G	PDF. Seabed geotechnic and storm resuspension, U of Victoria
Lo T	PhD. Biogeochemical cycling of carbon monoxide. ISMER/UQAR.
Magen C	MSc.Benthic respiration and biogeochemetry, McGill University
Norroy M	Trainee. CO analysis and sampling. ISMER/UQAR.
Percy, D.	Undergraduate. State University of New York, Stony Brook, USA.
Sutherland N	Technician. Sampling and method development. DFO-IOS.
Szlosek J	Research technician, State University of New York, Stony Brook, USA.
Turkington T	Undergraduate,. Modeling, U of Victoria.
Walker T	PDF. River plume sediments dynamics, Dalhousie.

Subproject 2.7

Arsenault M-J	Technician. sampling and analyzing samples. DFO-IML.
Bibeau K	MSc. Taphonomy and shell preservation. McGill University.
Cai S	MSc. Shell preservation on continental shelves. U. Saskatchewan.
Chiuchiolo A	Undergraduate. Benthic respiration. U. Connecticut.
Cusson M	PDF. Macrobenthic community of the Mackenzie Shelf. U. Saskatchewan.
Evans C	Research assistant. Analyzing seafloor sediment. U. Saskatchewan.
Foss M	Co-op Education student. Benthic invertebrates. Canadian Museum of Nature.
Hégeret H	PhD. Benthic respiration experiments. U. Connecticut
Laurie-Bourque S	Contractors. Graphic artist. Ottawa. ON.
McClelland C	Research associate. Benthic respiration. Canadian Museum of Nature.
McKendry K	Research associate. Benthic invertebrates. Canadian Museum of Nature.
Morata N	PhD. Benthic sampling program and respiration experiments. U. Connecticut
Neudorf C	Undegraduate. Technical seafloor sediment sampling. U. Saskatchewan.
Pietroniro E	Contractors. GIS analysis of benthic habitats. GIServices. Saskatoon.
Pocklington P	Contractors. Invertebrate taxonomy. Arenicola Marine. Wolfville. NS.
Simard M	Technician. sampling and analyzing samples. DFO-IML
Wallace K	Co-op Education student. Benthic invertebrates. Canadian Museum of Nature.

Subproject 2.8

Barletta F	PhD. Holocene sub-millennial-scale geomagnetic fields. ISMER-UQAR.
Hanon O	MSc. High-resolution magnetic properties of sediments. ISMER-UQAR.
Hill B	MSc. Foraminiferal assemblages in Baffin Bay and Amundsen Gulf. Dalhousie.
LeDu D	PhD. Paléocéanographie holocène dans la mer de Beaufort. ISMER-UQAR.

Richerol T	MSc. Modern dinoflagellates kyste assemblage in sediments. ISMER-UQAR.
Schell T	PDF. Foraminiferal assemblages and Holocene paleoenvironments. Dalhousie.
Walsh F	MSc. Foraminiferal assemblages from the Kopanoar mud volcano. Dalhousie.

Subproject 2.9

Arbetter T	PDF. CIRES. U. Colorado. USA
Dumas J	MSc. U. Victoria
Dupont F	Research Associate. Coupled modelling. Québec-Océan. U. Laval.
Fortier M	PDF. Centre for Earth Observation Science (CEOS). U. Manitoba
Konig C	PhD. State U. New-York. USA.
Lee C	PhD. NPZD models. U. Laval.
Thanassekos S	PhD. IBM model of juvenile Arctic cod. U. Laval.
Tian R	PDF. Bio-physical coupling. Ocean Sciences Centre. Memorial U.

Table 4. Summary of Highly Qualified Personnel trained within the scientific program of CASES.

Type of HQP	Group 2.1		Group 2.2		Group 2.3		Group 2.4		Group 2.5	
	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant
Undergrad.	3	1	1	0	3		5	1.5	2	
M.Sc.	2	1	8	1	1		5	1.6	3	
Ph.D.	4	3	11	6	6	3.5	16	1.1	7	2
PDF	1	1	4	1			6	0	3	1
Research Associates			1		4	1	7	1		
Technicians			3	0	9				4	
Others: Trainee									4	
Total	10	6	28	8	23	4.5	39	5.2	23	3

Table's continued...

Type of HQP	Group 2.6		Group 2.7		Group 2.8		Group 2.9		CASES	
	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant	Total #	# completely supported by RN grant
Undergrad.	2		4	4	2				22	6.5
M.Sc.	1	1	5	2	2		2	0	29	6.6
Ph.D.	4	1	2		2		2	0	54	16.6
PDF	3	3	1	1	1	1	3	0	22	8
Research Associates	2		2						16	2
Technicians	11	0.9							27	0.9
Others: Trainee	2		2	2					8	2
Total	25	5.9	16	9	7	1	7	0	178	42.6

Table 5. Breakdown of CASES students by nationalities. *Note that foreign students trained in Canada are included in the numbers for Canada.

	Undergrad.	Msc	PhD	PDF	Total
France			1		1
Germany			1		1
Japan		5	2	2	9
Norway		1			1
Poland				1	1
Puerto Rico		1			1
Spain			4	2	6
USA	1	3	3	3	10
Foreign	1	10	11	8	30
Canada*	22	29	54	22	127
Total	23	39	65	30	157

10. EXTENT OF CROSS NETWORK AND PARTNER INVOLVEMENT IN THE TRAINING OF HQP

The high level of integration of the research activities among the different teams from Canadian university, government agencies and foreign institutions has provided students and other HQP with unique access to a varied expertise in all fields of ocean sciences. Among a long list, selected examples of realized and future cross-network collaboration and partner involvement in the training of HQP are provided here in bullet form:

- Sampei completed his PhD on the deep particle fluxes during NOW with the National Institute of Polar Research of Tokyo under Fukuchi. He is now a postdoctoral fellow with Fortier (U. Laval, Subproject 2.5), collaborating closely with Forest (Ph D) and Subprojects 2.1 and 2.6 in the study of particle fluxes in the CASES study area.
- The Ph D work of Lafrance, cosupervised by Fortier (U. Laval) and Gagné (DFO-IML), was featured in one of the television documentaries on CASES.
- After finishing her M Sc at the Sopot Institute in Poland, Prokopowicz is now completing her Ph D with Fortier (U. Laval) on the population dynamics of *Themisto libellula*. She will receive additional training on the determination of lipid classes by HPLC in the laboratory of Stein (DFO-FWI in Winnipeg).
- Technicians at Dalhousie were responsible for building and designing new field equipment (portable erosion device and perspex settling chamber), and for performing various sample

analyses, such as chlorophyll and SPM. There will be an opportunity in the coming months for another technician to perform CHN analysis for Dalhousie.

- Research collaboration between the PDF's Tony Walker (Dalhousie) and Gwyn Lintern (University of Victoria) arose at the beginning of the project and has continued since.
- Lintern is undergoing training in delta process modeling at the University of Colorado, Boulder, and will pass this training on to an undergraduate student (Thea Turkington) for model implementation. Hill and Lintern have hired several undergraduate, recent graduate, local first nations and consultants for the CASES work
- Owens, a M.Sc. student in Subproject 2.2, is attempting to understand the carbon geochemistry within sea ice and is therefore directly synthesizing the data collected and ideas formed within Subprojects 2.2 and 2.6.
- Collin's Ph D work on the provenance of the suspended particulate material on the Mackenzie shelf is directly integrated with the suspended particulate matter work being done in Subprojects 2.2, 2.4, 2.5, and 2.7.
- Amiel from SUNY is writing his PhD thesis on radionuclide tracers in the Beaufort Sea. This work will be used to support carbon transport and sequestration studies by a number of the other groups. Graduate students from SUNY joined David on Legs 1,6 and 7.
- Tao Lou, a PhD student at UQAR, assisted in the field with the sampling for biogeochemical cycling of carbon monoxide.
- Chaillou, a McGill postdoctoral fellow with Sundby, is working on the early digenesis of marine sediment in close collaboration with Mucci.
- Students Brugel (Subproject 2.3), Payet (2.4), Connelly and Kuzyk (2.5), Chaillou, Magen and Amiel (2.6) shared the material sampled by the box core and, as a result, established new research collaborations with PI's in subproject 2.7 that will facilitate a broader examination of the fluxes and fates of inorganic and organic materials.
- Evans and Neudorf (Subproject 2.7) received training from Dr. Andrea Freeman, (archaeology, U. Calgary) on state-of–the-art automated particle size analysis and carbon analyser technology to process sediment samples.
- Extensive exchange involving the training of HQP took place between Subproject 2.4 (U. Laval) and the Institute de Ciencas Marinas of Spain. Terrado (Ph D) has been recruited to U Laval from ICM, with co-direction from both institutions, and several Canadian researchers have worked at ICM Barcelona, including a U Laval PhD student Garneau.
- Liaison between Subproject 2.4 U. Pierre et Marie Curie has led to a successful joint application for France-Canada collaboration funds and to co-direction of Ph D Bélanger.
- Loseto (Stern, DFO-FWI) spent one in week in the laboratory of Sue Budge (Dalhousie University) to develop expertise in the use of fatty acids to study transfer of carbon among trophic levels.
- Many CASES students made contact in the field with the Inuit wildlife observers that participated in each rotation of the one-year expedition. They also participated in the communication of the results to Inuvialuit communities (Aklavik, Tuktoyaktuk and Inuvik).

- At a workshop sponsored by Devon Petroleum and the Joint Fisheries Management Committee, Loseto (Stern, DFO-FWI) presented papers entitled "Beaufort Beluga Whales: Sea Ice and Shelf use in the Eastern Beaufort Sea" and "Trends in Mercury Levels in the Beaufort Sea /Amundsen Gulf Pelagic Foodweb", while Leitch (Stern, DFO-FWI) presented "Mercury Loading from the Mackenzie River to the Beaufort Sea".

11. COLLABORATIONS WITH FEDERAL AND FOREIGN PARTNERS

Federal departments, agencies and foundations have contributed major cash and in-kind support to CASES. Researchers from Federal departments have played and play a critical role in the planning of the scientific program, in the success of the recently completed field program and in the ongoing laboratory analyses of samples and data. They have provided access to physical, human and fiscal resources that have contributed significantly to advancing CASES. They also contribute to the training of HQP. The contributions of our main Federal partners are listed here:

- Major grants from the **Canada Foundation for Innovation** have been crucial to the success of CASES. A first $856 288 grant was obtained to purchase the oceanographic deck equipment needed to mobilize the Radisson in 2002. This equipment was then transferred to the *Amundsen.* A second grant of $22 185 866 was obtained for the refit and transformation of the *Amundsen* and for the oceanographic instrumentation to equip the ship. These investments will support the Canadian national program in the Arctic for the next 14 years, CASES being the first element of this program. When prorated to the duration of CASES (2 years out of the 14 years of the project) this represents a $3 291 736 cash contribution to CASES. In addition, the second CFI grant included funding for the operation of the Amundsen, the bulk of which ($4 132 448) was invested into the operation of the *Amundsen* for CASES. Thus, the overall cash contribution of the CFI to CASES can be assessed conservatively at $7 424 184.
- The **Department of Fisheries and Oceans** is involved in all subprojects and contributes to all aspects of the science from planning to execution of the research, including the training of students. The contribution of DFO includes the indispensable administrative, logistical and navigational expertise of the Coast Guard, as well as the provision of substantial ship time on different vessels (Table 3). The DFO sits on the Board of Directors and the International Steering Committee.
- The **Department of Environment** collaborates intensively with Subprojects 2.2 and 2.7 through the Canadian Ice Service (CIS), the Hydrometeorology and Arctic Laboratory and the Canadian Wildlife Service, all of which provide funding, equipment, personnel and expertise. The CIS also supplied the ice information needed for the day-to-day planning of the ship route during open-water operations as well as some of the satellite imagery used in the research.
- The **Department of Natural Resources** plays a leading role in the geology and paleoceanography components of the scientific program of CASES. NRCan researchers have been involved at all steps in the development of the scientific program and the scientific mobilization of the *Amundsen*. NRCan is represented on the BoD.
- Researchers from the **Canadian Museum of Nature** contribute taxonomical expertise and participate directly in the research programs of Subprojects 2.2 and 2.7.

Foreign partners (universities and government laboratories) have also contributed major financial, human and scientific resources to CASES (see Table 6). Through NSF and the University of Washington, American collaborators have contributed $278 000 in cash for the operation of the *Amundsen*. The cash contribution of our Japanese collaborators for ship operations amounted to $173 000 (through the NIPR).

From the private sector, Devon Petroleum made a $78 000 cash contribution for the study of beluga whales.

13. Dissemination of Network Results and knowledge and technology transfer

Although the intense CASES field program ended as recently as September 2004, the dissemination of the results is already well initiated. Scientific reports related to CASES are listed on the following pages.

In addition to scientific communications, the CASES program has received very much media coverage. This interest has been fuelled by worldwide concerns about incipient global warming and interest in the role played by the Arctic Ocean in the regulation of climate. Dozens of radio and television interviews, as well as articles in newspapers and magazines have reported the often spectacular field activities of CASES. Among these, items with the most impact are listed here in bullet form:

- The christening of the CCGS *Amundsen* and her maiden voyage through the Northwest Passage to the CASES study area in the Beaufort Sea triggered an extensive coverage into the electronic and written media. During the yearlong expedition, Chief Scientists and PI's gave countless interviews to Canadian and foreign networks from the ship or from their home base.
- The *Mission Arctic* series of documentaries produced by the National Film Board (NFB) featured many CASES scientists and CASES field activities. Aired around the world, this series won international prizes.
- In the fall of 2003, Nathan VanderKlippe (Global) joined the ship for produced a series of 4 reportages. After airing on Global News, these documents were published in several newspapers of the Network.
- In the winter 2004, Peter Calamai of the Toronto Star joined the *Amundsen* over-wintering in Franklin Bay to produce a series of 7 articles about CASES, the changing Arctic and the social, economic and geopolitical issues raised in Canada by the warming of the Arctic. Calamai elegantly highlighted the participation of students and young researchers in CASES.
- The Radio-Canada Découverte team joined the ship to produce a wonderful 1-h documentary documenting the extreme winter conditions that challenged the scientific team during the over-wintering of the *Amundsen* in Franklin Bay. The French version was watched by over 700 000 persons on its première on the French Network and then in Europe, Africa and Asia by TV5 the international French network. A shorter English version was aired by CBC on The National and other programs.
- Anemone-Chroma and Marc Tawil produced an excellent 1-h documentary entitled the *"Arctic Odyssey"* on the spring and summer activities of *Amundsen* during CASES. The diffusion of the documentary met with much success. It was broadcast first in Canada by

Grand Reportage of the Réseau de l'Information (RDI) and then on CANAL-D. The English version is in preparation.

- Patricia Bell of CBC-North joined the ship in August for a series of daily reports that summed the scientific findings of CASES and their impacts on Northerners.
- In the wake of CASES, Principal Investigator Louis Fortier was elected "Scientist of the year 2004" by Radio-Canada and named "Lauréat de Québec" by *Le Soleil* and "Personalité de la semaine" by *La Presse*.

13.1. Published book chapters or journal article (* non referred journals)

***Amundrud, T., Melling, H. & R.G. Ingram. 2002.** Modelling the evolution of draft distribution in the sea ice pack of the Beaufort Sea. Proceedings of 16th IAHR International Symposium on Ice, p.115-122, Dunedin, New Zealand.

Amundrud, T., Melling, H. & R.G. Ingram. 2004. Geometrical constraints on the evolution of ridged sea ice, Journal of Geophysical Research. 109, C06005, doi:10.1029/2003JC002251, 12p.

Barber, D., J. Iacozza, and A. Walker. 2003. On the Estimation of Snow Water Equivalent (SWE) using microwave Radiometry over First-Year Sea Ice. Hydrological Processes. 17(17):3503-3517.

Barber, D.G. and J. Hanesiak. 2004. Meteorological forcing of sea ice concentrations in the Southern Beaufort Sea over the period 1978 to 2001. Journal of Geophysical Research. 109, C06014, doi:10.1029/2003JC002027.

Barber, D.G. and J. Iacozza. 2004. Historical analysis of sea ice conditions in M'Clintock Channel and Gulf of Boothia, Nunavut; Implications for Ringed Seal and Polar Bear Habitat. 57(1):1-14.

DeAbreu, R.A., J. Yackel, D. Barber and M. Arkett. 2003. Operational Satellite Sensing of Arctic First Year Sea Ice Melt. Canadian Journal of Remote Sensing. 24:487-501

Howell, S.E.L and J.J. Yackel. 2004. A Vessel Transit Assessment of Sea Ice Variability in the Western Canadian Arctic: Implications for Ship Navigation. Canadian Journal of Remote Sensing, 30(2): 205-215.

***Howell, S.E.L., Yackel, J.J., De Abreu, R.A., Geldsetzer, T., and C., Breneman. 2004.** An evaluation of SeaWinds/QuikSCAT data for the estimation of the decay status of first-year sea ice, Proceedings, IGARSS 2004 Anchorage, Alaska.

Howell, S.E.L., J.J. Yackel, R.A. De Abreu, T. Geldsetzer and C. Breneman. 2005. An evaluation of SeaWinds/QuikSCAT data for the estimation of the decay status of first-year sea ice. IEEE Transactions on Geoscience and Remote Sensing.

Ingram, R.G., Carmack, E., McLaughlin, F. & S. Nicol. 2005. Polar continental shelf boundaries, in The Sea Volume 14, ch. 4 (Harvard University Press).

Marsden, R. & R.G. Ingram. 2004. A method for correcting for beam spread in acoustic Doppler current profiler methods. J. Atmospheric and Oceanic Technology 21, 1491-1498.

McLaughlin, F., Carmack, E., Ingram, R.G, Williams, W. & C. Michel. 2005. Oceanography of the North West Passage, in The Sea volume 14, ch. 30 (Harvard University Press)

Minnett, P. J., K. A. Maillet, J. A. Hanafin and B. J. Osborne. 2005. Infrared interferometric measurements of the near surface air temperature over the oceans. Journal of Atmospheric and Oceanic Technology.

Scharien, R., and J.J. Yackel. 2005. Analysis of Surface Roughness and Morphology of First-year Sea Ice Melt Ponds: Implications for Microwave Backscatter. IEEE Transactions in Geoscience and Remote Sensing.

Xie, H. 2005. Biological carbon monoxide consumption in Delaware Bay, NW Atlantic and Beaufort Sea. Marine Ecology Progress Series.

13.2. Submitted papers to peered reviewed journals

Barber., D.G. Microwave Remote Sensing, Sea Ice and Arctic Climate Processes. Physics in Canada.

Carmack, E., D. Barber, J. Christensen, R. Macdonald, B. Rudels and E. Sakshaug. Climate Variability and Physical Forcing of the Food Webs and the Carbon Budget on Panarctic Shelves. DeepSea Research.

Galley, R., D.G. Barber and J. Yackel. Sea Ice Melt and the Stabilization of Mixed Layer Depth in the North Water Polynya. Journal of Geophysical Research.

Hwang, B. and D. G. Barber. Pixel-scale evaluation of the SSM/I sea ice algorithms in the marginal ice zone during early fall freeze-up. Hydrological Processes.

Jin, X. and D. Barber. On the Sensitivity of cloud related radiative processes on the initiation and rate of melt over snow covered landfast first-year sea ice. Hydrological Processes.

Lukovich, J. and D. Barber. Atmospheric controls on sea ice motion in the Southern Beaufort Sea. Journal of Geophysical Research.

Lukovich, J. and D. Barber. On Sea Ice Concentration Anomaly Coherence in the Southern Beaufort Sea. Geophysical Research Letters.

Mundy, C.J., D. Barber, and C. Michel. On the scale dependent variability of thermophysical, optical and sub-ice microalgae properties in spring season landfast first-year sea ice. Journal of Marine Systems.

O'Sullivan DW, Neale, PJ, Coffin RB, Boyd, TJ and Osburn CL. Photochemical production of hydrogren peroxide and methylhydroperoxide in coastal waters. Marine Chemistry.

Renaud, P. E., Riedel, A., Morata, N., Gosselin, M., Michel, C., and Chiuchiolo, A. Rapid response of the benthic community to an ice algal bloom in the Beaufort Sea, Canadian Arctic. Limnology & Oceanography.

Vincent, W.F., Rautio, M. & Pienitz, R. 2004. Climate control of underwater UV exposure in polar and alpine aquatic ecosystems. In: J.B. Orbaek. Arctic Environmental Change.

Wells, L et al. Archaea in particle-rich waters of the Beaufort Shelf and Franklin Bay, Canadian Arctic: Clues to an allochthonous origin? Limnology & Oceanography.

Williams, W., Carmack, E., Aagaard, K., Macdonald, R. & R. G. Ingram. Upwelling in the Mackenzie Canyon. Continental Shelf Research.

Xie, H. and Gosselin, M. Photoproduction of carbon monoxide in first-year sea ice in Franklin Bay, Beaufort Sea. Geophys. Res. Lett.

Xie. Photoproduction of carbon monoxide in sea ice in Franklin Bay of Beaufort Sea. Geophysical Research Letters

Yackel, J.J., D. G. Barber, T.N. Papakyriakou, and C. Breneman, Utility of time series SAR to provide spatio-temporal information on sea ice spring melt: 1992 to 2002. Hydrological Processes.

Yackel, J.J., D. G. Barber, T.N. Papakyriakou, and C. Breneman. First-year sea ice spring melt transitions in the Canadian Arctic Archipelago from time series SAR data, 1992-2002. Atmosphere-Ocean.

13.3. Technical Report

Lukovich, J and D. G. Barber , 2005. On the relative contributions of dynamic and thermodynamic forcing of sea ice concentration anomalies in the southern Beaufort Sea inferred through spatiotemporal statistical analysis. Centre for Earth Observation Science (CEOS) technical report. CEOS-Tec-05-02-1. Faculty of Environment, Earth and Resources. University of Manitoba.

13.4. Invited Conference

Aitken, A. 2004. At play in the marine realm: A Prairie geographer studies Arctic marine ecology. Geography seminar, University of Saskatchewan, Saskatoon, SK, November 5.

Bonilla, S; Lovejoy, C; Roy, S; Vincent, W F. 2004. Pico-eukaryotic dominance of the Arctic Ocean phytoplankton. Phycological Society of America, Williamsburg, USA. July.

Bonilla, S; Lovejoy, C; Roy, S; Vincent, W F. 2004. Pigments explain the story: Microalgal community structure in subarctic and arctic aquatic ecosystems. Centre d'Études Nordiques invited seminar program, Québec City, Canada, Sept .

Conlan, K., Aitken, A., Hendrycks E. & P. Archambault. 2004. Benthic community structure on a sea-ice affected continental shelf. Proceedings, 11th Biennial Benthic Workshop, Department of Fisheries and Oceans and Huntsman Marine Science Centre, St. Andrews, NB, October 5-6.

Deibel, D. & T. Businski. 2004. Pelagic tunicates: consumers and consumed. American Society of Limnology and Oceanography, Honolulu. February.

Deming JW. 2002. Arctic polynyas poised for change. Project Day, Arctic Science Summit Week, Groningen, The Netherlands, April.

Deming JW. 2002. Arctic polynyas. International Symposium, Nordic Arctic Research Program, Riga, Latvia, November

Deming JW. 2002. The North Water: An Arctic ecosystem poised for change. Invited seminar (included discussion of CASES plans), Arctic Forum, Arlington, Virginia, 17 May.

Deming JW. 2003. Cold-adapted enzymes in sea ice. Invited Seminar (included discussion of CASES plans), International Workshop on Cold-Adapted Microorganisms, Max Planck Institute for Marine Microbiology, Bremen, Germany, May.

Deming JW. 2003. Enzymes from thermally extreme ocean environments. Invited Seminar (included discussion of CASES plans), International Conference on Enzymes in the Environment: Activity, Ecology, and Applications, Prague, July.

Deming JW. 2003. Life in extreme environments with implications for the origins of life. Invited Seminar (included discussion of CASES plans), American Institute of Physics, 2003 Industrial Physics Forum, San Jose, 28 October.

Deming JW. 2003. Microbial life in ice: Implications for possible life elsewhere in the solar system. Science Day, Arctic Science Summit Week, Kiruna, Sweden, April.

Deming JW. 2004. New directions in the study of bacteria inhabiting very cold sea-ice formations. AGU Annual Meeting, San Francisco, December.

Fortier, L. 2004. The Canadian Arctic Shelf Exchange Study (CASES): consolidating Canada's leadership in Arctic research. World Congress of Scientific Journalists. Montreal. 6 October.

Fortier, L. 2004. Réchauffement climatique et Océan Arctique. Forum international de météorologie. Paris. 17 octobre.

Fortier, L. 2004. The Inaugural Voyage of the CCGS *Amundsen*. Northern Canadian Marine Advisory Council. Montreal. 16 November.

Fortier, L. 2004. 2004. CCGS *Amundsen*, the Canadian research icebreaker. UK-Canada workshop on Arctic collaboration. Ottawa. 2 December.

Fortier, L. 2005. The Arctic Meltdown: monitoring the response of arctic ecosystems to climate change. McGill University McCord Museum Conferences. Montreal. 13 January.

Fortier, L. 2005. Canadian contributions to the study of the Arctic Meltdown: the Canadian Arctic Shelf Study (CASES) and beyond. University of Victoria. Victoria. 21 January.

Fortier, L. 2005. Réchauffement climatique: l'Océan Arctique sur la ligne de feu. Université de Montréal. Montréal. 27 janvier.

Fortier, L. 2005. Polynyas: windows on a future, warmer, Arctic Ocean. Third International Arctic Symposium. Tokyo. 23 February.

Fortier, L. 2005. L'Arctique sur la ligne de feu. Ministère de l'environnement du Québec. Groupe sur les changements climatiques. Québec. 5 avril.

Fortier, M. Mundy, CJ. 2005. Canadian Arctic Shelf Exchange Study (CASES) & ArcticNet. Inuvialuit Game Council Meeting. Inuvik. 6 April.

Sasaki, H. Fortier, L. 2005. Early, prolonged and/or high particle fluxes: contrasting the continental slope and the polynya in the Beaufort Sea. International Arctic Polynya Program Symposium. Arctic Science Summit Week. Kunming. 20 April.

Lacoste, K.N. 2005. Un an d'expédition dans l'Arctique canadien: le projet CASES. Conferences presented at the Musée régional de Rimouski

Miller, L.A., T.N. Papakyriakou, O. Owens and C. J. Mundy, 2004. Vertical CO_2 Fluxes over First-Year Sea Ice. Seminar to the Bjerknes Institute of the University of Bergen, Norway, May 10th, 2004.

Minnett, P.J. 2004. Is the climate changing? And how would we know? Miami-Dade MetroZoo. November 6, 2004.

Mucci, A. & L. Miller. 2004. Vertical CO_2 Fluxes Over First-Year Sea Ice/Bjerknes Seminar Series, Bergen, May 10, 2004

Poulin, M and C. McClelland. 2003. Coloris automnal de l'Arctique canadien. Lunch Conference, Canadian Museum of Nature, Gatineau. 18 December.

St-Onge, G., Long, B.F., de Vernal, A., Hillaire-Marcel, C. and Rochon, A. 2005. CAT-scan analysis of sedimentary sequences: a tool to identify millennial- to seasonal-scale climatic oscillations. GAC-MAC Annual Meeting, May 15-18, Halifax

Tremblay, J.-É., Gosselin, M., Poulin, M., and Price, N. 2004. The effects of climate on nutrient supply, CO_2 drawdown and the food chain in the Arctic Ocean. ArcticNet 2004 Annual Scientific Meeting, Quebec City (Quebec), 5-8 December.

Vincent, W.F. & Quesada, A. 2004. Northern aquatic ecosystems as sentinels of global change, IV Iberian Conference of Limnology & XII Conference of the Spanish Limnology Association, Porto, Portugal. July.

Vincent, W.F. 2004. Éclairement spectral sous-marin et les effets des changements climatiques sur la production primaire. ISMER seminar series, Rimouski, Canada. February.

Vincent, W.F. 2004. Arctic microbial ecosystems in a changing climate. Canadian Society of Microbiologists Invited keynote, Annual Symposium, Edmonton, Canada, June.

Vincent, W.F. 2004. Changements écologiques aux bouts du monde: Arctique, Antarctique et Terre boule de neige. Biologie Seminar Series, UQAR, Rimouski, Canada, February.

Vincent, W.F. 2004. Polar ecosystems as sentinels of climate change. University of Maine marine sciences seminar series, Orono, USA. March.

Waleron, K. 2003. Molecular analysis of the Beaufort Sea microbiota based on nifH analyses. CASES microbial ecology workshop, Institut de Ciències del Mar, Barcelona, June.

Waleron, M. 2003. Preliminary molecular analysis of cyanobacteria in the Beaufort Sea region. CASES microbial ecology workshop, Institut de Ciències del Mar, Barcelona, June.

Wilmotte, A. 2004. Diversité et écologie des cyanobactéries dans les lacs et les océans: approches moléculaires. Chaire de recherche du Canada (écosystèmes aquatiques) et Dépt. de biologie joint seminar program, Université Laval, Québec, Canada, 25 mars.

13.5. Non-Invited Conference and poster

Barber, D. G., 2005. The Canadian Arctic Shelf Exchange Study (CASES), American Meteorological Society Meeting, Sand Diego, CA, January, 2005.

Benoit, D., Simard, Y., Fortier, L. 2004. Arctic cod biomass paradigm. Poster, NIPR Symposium on Polar Biology, Tokyo, Japan, December

Blasco, S., Bennett, R., Kostylev, V., MacKillop, K., Bartlett, J. and P. Travaglini, 2004. Beaufort Sea Seabed Environmental and Geotechnical Research Related to Offshore Hydrocarbon Development. NWT Geoscience Forum, Yellowknife 16-18 November, 2004.

Butler, J. and J. Hanesiak, 2005. Use of a blowing snow model for improved prediction on the Canadian Prairies and Arctic, 39th annual CMOS Conference, Vancouver, BC, May 31 – June 3, 2005

Collins RE, Deming JW. 2003. Changes in sea-ice microbial community composition during an Arctic winter. Abstract and Poster, Study of Environmental Arctic Change (SEARCH) Open Science Meeting, Seattle, October.

Collins RE, Deming JW. 2004. Potential changes in sea-ice microbial community composition during an Arctic winter. Abstract and Poster, International Conference on Arctic Microbiology, Rovaniemi, Finland, March.

Collins RE. 2004. Preliminary report from the overwintering CASES expedition: Sampling for microbial succession in Arctic sea ice during winter. Seminar, UW Biological Oceanography Seminar Series, Seattle, April.

Conlan, K. 2004. Submarine gas vents, ice gouges and black pools: benthic community response to change in the Arctic. Department of Fisheries and Oceans and Huntsman Marine Science Centre, St. Andrews, NB. June 11.

Darnis D., Fortier, L. 2004. Respiration and biogenic carbon flux under the mediation of large copepods on the Mackenzie shelf (Beaufort Sea). Poster, NIPR Symposium on Polar Biology, Tokyo, Japan, December

Deming JW, Cochran JK. 2003. Opportunity to develop a US program on Polynyas in the Arctic's Changing Environment (PACE). Presentation at PACE Town Hall Meeting, Study of Environmental Arctic Change (SEARCH) Open Science Meeting, Seattle, October.

Deming JW, Cochran JK. 2004. Opportunity to develop a US-PACE program under SEARCH. Presentation (delivered by Yager PL due to authors' scheduling conflicts), SEARCH Steering Committee Meeting, Washington, DC, 22 September.

Deming JW, Cochran JK. 2004. Opportunity to develop a US-PACE program. Seminar, National Science Foundation, Office of Polar Programs, Arlington, VA, April.

Deming JW. 2004. Annual report on IAPP activities, including CASES overwintering expedition. Presentation to the Arctic Ocean Science Board, Arctic Science Summit Week, Reykjavik, Iceland, 24-30 April.

Deming JW. 2005. International research on Polynyas in the Arctic's Changing Environment (PACE). Presentation, International Polynya Symposium, Arctic Ocean Science Board, Arctic Science Summit Week, Kunming, China, April.

Fisico, T. and J. Hanesiak, 2005.CASES meteorology and atmospheric modeling, 39th annual CMOS Conference, Vancouver, BC, May 31 – June 3, 2005.

Forest, A., Sampei, M., Hattori, H., Sasaki H., Fortier, L. 2004, Faecal pellets & particulate organic carbon export in the CASES long-term sediments traps. Poster, NIPR Symposium on Polar Biology, Tokyo, Japan, December

Fortier, L. Fortier, M. 2004. A Network of Centres of Excellence of Canada to conduct the Integrated Natural/ Human Health/ Social Study of the Changing Coastal Canadian Arctic. Arctic Climate Impact Assessment. Reykjavik. 9 November.

Juul-Pedersen, T., Michel, C., Gosselin, M., and LeBlanc, B. 2005. Vertical flux of particulate organic material on the Mackenzie Shelf (western Canadian Arctic) during fall 2002. Gordon Research Conferences: Polar Marine Science, Ventura, CA, 13-18 March (Poster presentation).

Lafrance,P., Fortier, L. Gagne, J. A. 2004. Feeding dynamics of Arctic cod (*Boreogadus saida*) in the Mackenzie Shelf / Amundsen Gulf study area during Fall 2002. Poster, NIPR Symposium on Polar Biology, Tokyo, Japan, December

Leitch, D., Wang, F., Stern, G.A., Lemes, M., & J. Delaronde 2004. Mercury loading to the Beaufort Sea from the Mackenzie River and potential effects of climate variation. Presented at the COMERN (Collaborative Mercury Research Network), 5th General Congress, Gimi Manitoba, November 2-5.

Leitch, D.; Wang. F.; Stern, G.A.; Lemes, M.; Dick, T. 2004. Impacts on mercury dynamics in the Mackenzie River and Beaufort Sea. Proceedings of the 7th International Conference on Mercury as a Global Pollutant, Ljubljana, June 27th –July 2nd, 2004.

Loseto, L., Ferguson, S., Budge, S. & Stern, G.A. 2004. Trends in mercury in the Beaufort Sea pelagic foodweb. Presented at the COMERN (Collaborative Mercury Research Network), 5th General Congress, Gimi Manitoba, November 2-5, 2004.

Lovejoy, C. 2002. Arctic Ocean microbial ecology and opportunities for international collaboration in CASES. Institut de Ciències del Mar, Barcelona, Oct .

Lovejoy, C., Massana, R., Pedros-Aliò, C., Carmack, E & Vincent, W.F. 2004. Molecular diversity of pico-eukaryotes in the Arctic seas. ASLO Honolulu, USA, February.

Lovejoy, C, R. Massana, C. Pedros-Aliò, S. Bonilla. 2004. Pico-eukaryotes in the Arctic Seas. Poster at Gordon Conference on Marine Microbial Biodiversity, Roskoff, France, June.

Miller, L.A., T.N. Papakyriakou, 2004. Atmospheric CO_2 Drawdown by First-Year Sea Ice. Paper presented at the European Geosciences Union General Assembly, Nice, April 25-30.

Minnett, P.J. 2003. Radio-metric measurements of air-sea and air-ice temperature differences in the Arctic. IEEE International Geo-science and Remote Sensing Symposium (IGARSS'03), July 21-25, 2003, Toulouse, France.

Mucci, A. & L. Miller. 2004. Atmospheric CO_2 Drawdown by First-Year Sea Ice/European Geosciences Union General Assembly, Nice, April 25-30, 2004

Mucci, A. & L. Miller. 2004. CO_2 Exchange Over Sea Ice in the Canadian Arctic/SOLAS Science Conference, Halifax, October 13-16, 2004

Osburn, C. L. and Vincent W. F. 2003. Sunlight Removal of CDOM from the Mackenzie River: Implications for Ocean Color in the Beaufort Sea, SEARCH Open Science Meeting, Seattle, WA, 27 October.

Osburn, C. L., O'Sullivan, D. W., and Vincent, W. F. 2004. Transport and Photochemical Degradation of CDOM in the Mackenzie River-Delta System, ASLO 2004 Ocean Research Conference, Honolulu, HI. February 15-20.

Papakyriakou, T.N., D.G. Barber and L.A. Miller, 2004. On the permeability of sea ice to gas fluxes based on the thermophysical evolution of sea ice. Paper presented at the Bjerkness Centenary, Open Science Conference: Climate Change in High Latitudes, Sept. 1-3, Bergen, Norway.

Papakyriakou, T.N., L.A. Miller O. Owens, 2004. Air-surface CO_2 flux over sea ice in the Canadian Arctic. Annual Meeting of the American Geophysical Union, Montreal, Quebec, Canada, 17-20 May.

Papakyriakou, T.N., O. Owens, C. Mundy, P. Taylor, S. Savelyev, M. Gordon, 2004. Surface Meteorological Measurements Over Arctic First Year Ice During CASES 03-04. Annual Meeting of the American Geophysical Union, Montreal, Quebec, Canada, 17-20 May.

Prokopowicz, A., Fortier, M., Fortier, L. 2004. Compared population structure and trophic role of *Themisto libellula* on the Mackenzie Shelf and the Cape Bathurst Polynya. Poster, NIPR Symposium on Polar Biology, Tokyo, Japan, December

Riedel, A., Michel, C., Gosselin, M., LeBlanc, B. 2005. EPS dynamics in first-year sea ice of Resolute Passage and Franklin Bay (High Canadian Arctic): Implications for carbon transport. Gordon Research Conferences: Polar Marine Science, Ventura, CA, 13-18 March.

Rochon, A. 2004. CASES et l'Arctique canadien en photos: la traversée du Passage du Nord-Ouest. ISMER, UQAR, Rimouski, Canada, Septembre 2004.

Rochon, A., Mudie, P.J., de Vernal, A. and Levac, E. 2004. Holocene records of climate change in northern Baffin Bay: decadal-scale reconstructions from dinoflagellate cysts. GAC-MAC Annual Meeting, May 12-14, Ste-Catharines.

Różańska, M., Poulin, M., Gosselin, M. 2005. Algal entrapment in newly formed sea ice during the fall season. Gordon Research Conferences: Polar Marine Science, Ventura, CA, 13-18 March.

Schell, T., Scott, D.B., Rochon, A., Jenner, K. and Blasco, S. 2004. Recent climate change in the Canadian Arctic, documented through changing microfossil proxies of the Mackenzie shelf, Beaufort Sea. Geological Society of America annual meeting, Denver, USA.

St-Onge, G., Long, B. and Rochon, A. 2004. CAT-Scan analysis of sedimentary sequences: a qualitative and quantitative paleoclimatic tool for low sedimentation rate environments such as the Arctic 32nd International Geological Congress, Program and Abstracts, p. 448, August 20-28, Florence, Italy.

Taylor, P., J. Hanesiak and T. Papakyriakou, 2005. Blowing Snow Studies in CASES (Canadian Arctic Shelf Exchange Study) 03-04, 39th annual CMOS Conference, Vancouver, BC, May 31 – June 3, 2005.

Taylor, P., J. Hanesiak and T. Papakyriakou, 2005. Blowing Snow Studies in CASES (Canadian Arctic Shelf Exchange Study) 03-04, 62nd Eastern Snow Conference, Waterloo, Ontario June 8-10, 2005.

Taylor, P., S. Savelyev, M. Gordon, T.N. Papakyriakou, J. Hanesiak, 2004. Blowing snow studies in CASES (Canadian Arctic Shelf Exchange Study) 03-04. 38th Annual Congress of the Canadian Meteorological and Oceanographic Society, Edmonton, AB, May 31 to June 3, 2004.

Vance S. 2004. Arctic bacteria on Jupiter's second moon? Seminar, UW Astrobiology Seminar Series, Seattle, April.

Vincent, W. 2003. Preliminary microbial results from CASES 2002 and future plans. CASES microbial ecology workshop. Institut de Ciències del Mar, Barcelona, Spain, June.

Wells LE, Deming JW. 2002. Enrichment of Archaea in nepheloid layers of the Northwest Passage: A clue to their physiological potential and biogeochemical role? Abstract and poster, ASLO Ocean Sciences Meeting, Victoria, June.

Wells LE, Deming JW. 2002. Viral abundance, diversity and processes in the cold, oligotrophic Northwest Passage of the Canadian Archipelago. Abstract and poster, ASM Annual Meeting, Salt Lake City, May.

Wells LE. 2004. Monsters, viruses and the history of life. Seminar, UW Biological Oceanography Seminar Series, Seattle, May.

Annex 1: Canadian co-applicants and affiliation:

Family name and Initial(s)	Affiliation
Aitken, A.A.	University of Saskatchewan
Archambault, P.	DFO, Institut Maurice-Lamontagne
Barber, D.G.	University of Manitoba
Blasco, S.	DNR, Bedford Institute of Oceanography
Carmack, E.C.	DFO, Institute of Ocean Sciences
Conlan, K.	Canadian Museum of Nature
DeAbreu, R.A.	DOE, Canadian Ice Service
Deibel, D.	Memorial University
Demers, S.	Université du Québec à Rimouski
Flett, D.G.	DOE, Canadian Ice Service
Gagné, J.A.	DFO, Institut Maurice Lamontagne
Gagnon, J.-M.	Canadian Museum of Nature
Galbraith, P.	DFO, Institut Maurice Lamontagne
Gosselin, M.	Université du Québec à Rimouski
Grant, J.	Dalhousie University
Gratton, Y.	Université du Québec, INRS-ETE
Hanesiak, J.	University of Manitoba
Hill, P.	Dalhousie University
Hill, P. R.	NRCan (IOS)
Hughes Clarke, J.	University of New-Brunswick
Ingram, R.G.	University of British Columbia
Jenner, K.	NRCan (BIO)
Kelley, D.	Dalhousie University
Larouche, P.	DFO, Institut Maurice Lamontagne
Macdonald, R.W.	DFO, Institute of Ocean Sciences
Marsden, R.	Royal Military College
Melling, H.	DFO, Institute of Ocean Sciences
Michel, C.	DFO, Freshwater Institute
Miller, L.A.	DFO, Institute of Ocean Sciences
Mucci, A.	McGill University
Papakyriakou, T.	University of Manitoba
Pienitz, R	Université Laval
Poulin, M.	Canadian Museum of Nature
Price, N.M.	McGill University
Scott, D.B.	Dalhousie University
Solomon, S.	DNR, Bedford Institute of Oceanography
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St-Onge, G.	Université du Québec à Rimouski
Sundby, B.	McGill University
Suttle, C.	University of British Columbia
Vincent, W.	Université Laval
Xie, R.	Université du Québec à Rimouski
Yackel, J.J.	University of Calgary

ANNEX 2: MAIN PARTNERS

Partner
Canadian Museum of Nature
Department of Environment Canada
Department of Fisheries and Ocean (Science)
Department of Fisheries and Ocean (Coast Guard)
Natural Resources Canada
National Institute of Polar Research, (Japan)
Québec-Océan (U Laval)
University of Washington

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Comiso JC (2002) A rapidly declining perennial sea ice cover in the Arctic. Geophysical Research Letters 29:1956.

Flato GM, Boer GJ, Lee WG, et al. (2000) The canadian centre for climate modelling and analysis global coupled model and its climate. Climate Dynamics 16:451-467.

Johannessen OM, Bengtsson L, Miles M, et al (2004) Arctic climate change: observed and modelled temperature and sea-ice variability. TELLUS Series A-Dynamic meteorology and oceanography 56A:328-341.

Macdonald RW, Solomon SM, Cranston RE, et al (1998) A sediment and organic carbon budget for the Canadian Beaufort Shelf. Marine Geology. 144:255-273

Shindell DT, Miller RL, Schmidt GA, et al (1999) Simulation of recent northern winter climate trends by greenhouse-gas forcing. Nature 399:452-455.

Stouffer RJ, Manabe S, Bryan K (1989) Interhemispheric asymmetry in climate response to a gradual increase of atmospheric CO_2. Nature 342:660-662

Stroeve JC, Serreze MC, Fetterer F, et al (2005) Tracking the Arctic's shrinking ice cover: Another extreme September minimum in 2004. Geophysical Research Letters 32:doi:10.1029/2004GL021810

Vettoretti G, Peltier WR, McFarlane NA (2000) Global water balance and atmospheric water vapour transport at last glacial maximum: climate simulations with the Canadian Climate Centre for Modelling and Analysis atmospheric general circulation model. Canadian Journal of Earth Sciences 37:695-723