

Canadian Research Icebreaker CCGS Amundsen Platform Outcome Measurement Study (POMS) report

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endeavours such as the International North Water Polynya Study (NOW, 1997-2001) was a complicated and costly affair. The situation became acute on 22 January 2001, when CCG announced to the CASES proponents and to NSERC representatives that they could not provide the icebreaker initially pledged for the multi-million dollar international project in spite of all their good will. This development was particularly embarrassing since an international committee of distinguished specialists was meeting the following day in Ottawa to assess CASES. The NSERC officers took the extraordinary decision to let the proponents present the project to the evaluation committee, just as if a suitable icebreaker was actually available. Eventually, NSERC approved the CASES project conditional on the proponents securing an icebreaker. CASES PI Louis Fortier immediately met with senior CFI officers to explore funding avenues for the permanent scientific mobilization of a research icebreaker. At that time, the CFI was designing its IJVF program to fund major scientific infrastructure with an international mandate. The \$27.5M IJVF proposal to mobilize for science the decommissioned icebreaker Hull-2000-02 (formerly CCGS *Sir John Franklin*) was accepted in June 2002. The Department of Fisheries and Oceans (DFO) contributed the ship itself plus \$2.8M for its refit.

The positive funding decision triggered an 10-month engineering marathon during which Hull-2000-02 underwent a complete refurbishing, the re-activation of its 9 engines, the replacement of the heating and electrical systems and major transformations to receive state-of-the-art scientific equipment (Figure 1). Researchers from the 15 applicant universities of the Science Consortium selected, purchased and adapted the 53 initial scientific equipment systems to be attached to the ship. In close consultation with the scientists, the CCG engineers supervised the installation in dry dock of major equipment systems such as the EM300 multi-beam sonar and the internal access well (moon pool). Rechristened CCGS *Amundsen* in honor of Roald Amundsen, the revamped icebreaker was inaugurated on 26 August 2003 and immediately left for the Arctic on her maiden scientific voyage in support of the CASES program.

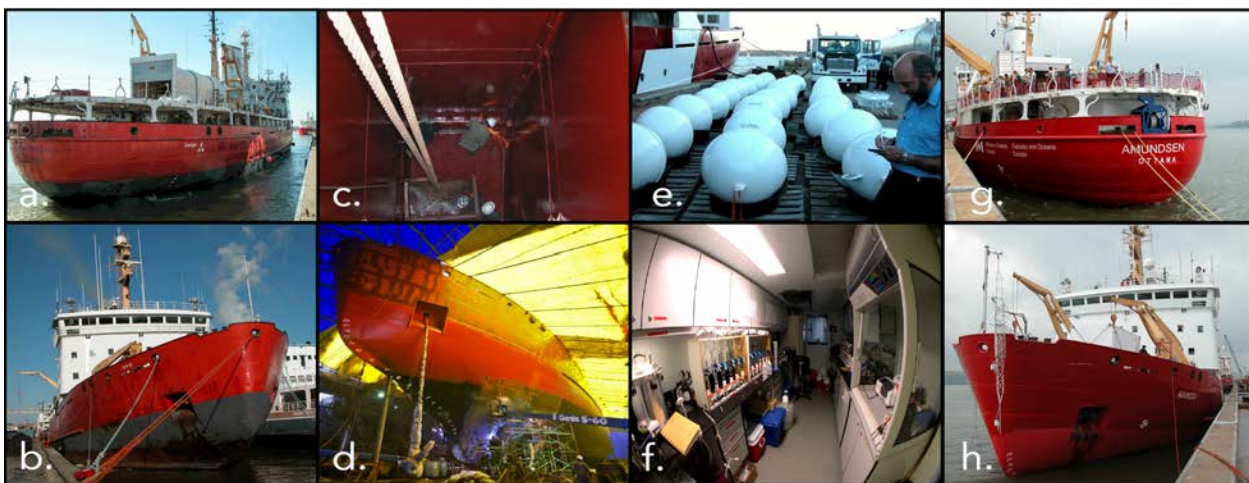


Figure 1. Not just a paint job. Some steps in the marathon refit of the icebreaker in 2003: a and b, the much battered Hull 2000-02 (formerly CCGS *Sir John Franklin*) is towed from St. John's to Quebec City; c and d, major modifications such as the moon pool are completed in dry dock at the Les Méchins shipyard, QC; e and f, the ship is equipped with state-of-the-art oceanographic equipment and laboratories at the Coast Guard base in Quebec City; g and h, the fully revamped CCGS *Amundsen* ready for its inaugural overwintering expedition in the Canadian Beaufort Sea.

Hosted at Université Laval, the *Amundsen* is made accessible in priority to university-based researchers and their partners in government, the private sector, and abroad, thanks to an innovative Cost Sharing Arrangement between U Laval (for the Science Consortium) and the CCG. CCG manages the ship all year long and uses it in winter-spring for icebreaking and escort operations. The icebreaker is part of the fleet and remains a federal asset, thus avoiding insurance costs that would defeat any science budget. The yearlong management of the ship and its periodic modernization by CCG represent major in-kind contributions to Canada's research effort in the Arctic. The ship is available for science on a full cost-recovery basis from May to November or longer if the research program requires overwintering in the Arctic such as in 2003-2004 and 2007-2008. The Consortium and its scientific partners secure the funds to cover the large operation costs of the ship (\$57,500 per day in 2014). These costs encompass the salaries of the crew, fuel and lubricants, air travel for the exchange of personnel, and food and supplies. They represent the recoverable costs or user fees.

In addition to the ship itself and its navigational capacities, the Platform includes a comprehensive pool of scientific instrumentation and facilities valued at over \$36.5M. The ship's transformations and the pool of scientific equipment can accommodate the needs of physical, chemical, and biological oceanographers, paleo-oceanographers, marine geologists and geophysicists, marine ecologists, atmosphere and ocean color specialists, and epidemiologists studying Inuit health. Overall, the *Amundsen* is now equipped with 65 scientific systems divided into 7 major components (see Section 2). Several of the *Amundsen*'s scientific systems can be deployed from other CCG ships that can act as nodes of the Platform. For example, the decks of the CCGS *Pierre Radisson* (sister ship of the *Amundsen*) have been modified to receive winches, A-frames and container-laboratories from the equipment pool for missions in Hudson Bay.

The management, deployment, maintenance and troubleshooting on land and at sea of the *Amundsen*'s overall pool of collective equipment is under the responsibility of a small team of 14 managers, engineers and technicians (Section 2) located at U Laval (ArcticNet, Québec-Océan[†], and Laboratoire de géosciences marines, LGM), U Manitoba (Center for Earth Observation Science, CEOS), and U New Brunswick (Ocean Mapping Group, OMG). Personnel from the Canadian Scientific Submersible Facility (CSSF at U Victoria) are contracted to service and operate the Remotely Operated Vehicle (ROV). Two complements of 38 CCG crew (76 persons) operate the *Amundsen* while at sea, alternating on 6-week rotations.

From 2003 to 2011, the *Amundsen* operated for science for an average of 158.5 days at sea per season. The objective of Management is to maintain operations on average at 152 days per year in the coming years for an annual operating budget of \$9.1M. Adding the projected \$1.7M budget for the maintenance of the equipment pool and the administration of the Platform brings the projected total annual O&M budget to ca. \$10.8M.

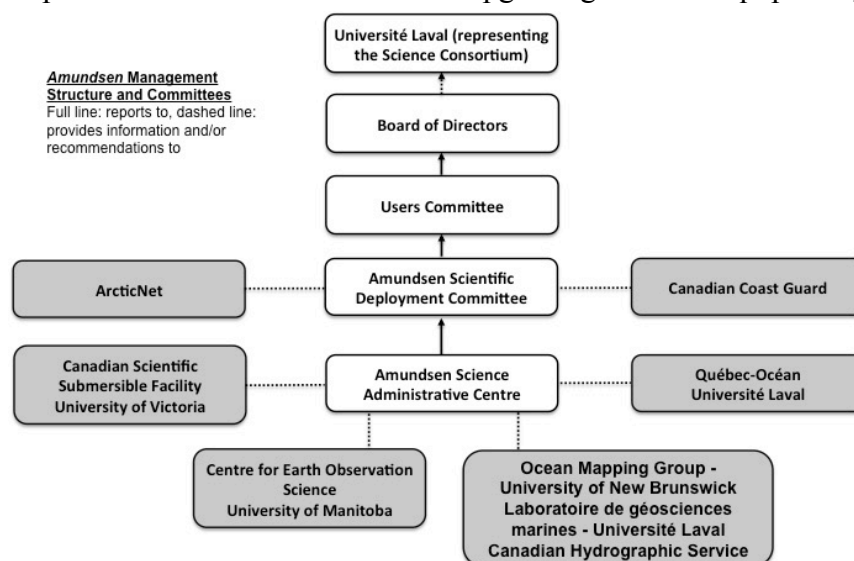
1.2 Governance, management and advisory structure

[†] In operation since 1970, the Regroupement Stratégique Québec-Océan coordinates the activities of 33 oceanographers, 51 collaborators, and over 130 HQP in 6 universities in Québec (U Laval, UQAR, INRS, UQAC, McGill, Concordia) (<http://www.quebec-ocean.ulaval.ca/>)

The linkages between the Platform, U Laval (who represents the Consortium of Canadian Universities) and the Canadian Coast Guard (CCG) are defined in the Cost Sharing Arrangement. U Laval through the offices of ArcticNet coordinates demands for the Platform from different users (academic, private sector, international), manages the flow of operation funds, supervises the maintenance of the scientific equipment, and prepares the annual schedule of deployment of the icebreaker. This way, CCG essentially deals with a single representative of the user community, namely U Laval/ArcticNet.

Among organizational stakeholders, the CCG manages and maintains the icebreaker itself and physically hosts it at its Quebec City operation base. The Science Consortium is responsible for securing operational funds, coordinating operations at sea, and for the maintenance and deployment of the scientific equipment. It retains full control over the planning and management of scientific operations but, for sake of efficiency, delegates the day-to-day coordination of user programs to ArcticNet. Academic and private sector users from Canada and abroad request access to the Platform through the offices of ArcticNet, which negotiate and prepare the MOUs for fund transfer, and liaise with the CCG. Private sector partners can use the Platform only as part of research collaborations with academia. They often contribute directly to the recapitalization of the equipment pool.

Governance and management structure (Figure below). A Board of Directors with members from academia, government and the private sector oversees the Platform (Appendix 2). The *Amundsen* Science Administrative Centre (ASAC) hosts the Ship Science Operations Manager, the Equipment Manager, the Communications Officer and the Data Coordinator in the offices of ArcticNet at U Laval. The ASAC manages the equipment pool, coordinates efforts among the three research units involved in the maintenance of the equipment (Québec-Océan, CEOS, OMG/LGM) and liaises with the CSSF. It reports to the *Amundsen* Scientific Deployment Committee (ASDC), which supervises the maintenance and upgrading of the equipment, recommends investments in recapitalization to the Board, and coordinates science operations with CCG based on the requests from the different user programs. The Users Committee, which brings together the scientific users, CCG and all interested parties, meets annually with the ASDC to coordinate science operations among the different programs, to define the schedule of the ship, and to plan mobilization. The Administrative Centre and the two Committees report to the Board of Directors through the Scientific Leader.



The *Amundsen* is a core infrastructure of the NCE ArcticNet, which provides continuity in operation funding and substantial support for the management of the Platform. Accordingly, the

Board of Directors of ArcticNet plays a significant advisory role in overseeing the Platform through the cross-appointment of two Directors with the Board of the *Amundsen*.

Impacts of structures. The management and deployment of the multi-stakeholder Platform and its extensive pool of equipment for multidisciplinary endeavors in the remote and extreme environment of the Arctic are no easy tasks. Thanks to the talent and dedication of the Directors, managers, engineers and technicians, the relatively small organizational structures in place play a pivotal role in orchestrating operations, liaising with CCG, maintaining the pool of scientific equipment, scheduling the complex expeditions, obtaining scientific licenses and permits, responding to severe crises (e.g. the fatal helicopter crash in 2013), answering the never ending requests from scientific users, helping promote new national and international programs and private-sector collaborations, and managing outreach and communications. The successful completion of 18 major national and international programs by 106 user teams since 2003 is testament to the versatility and competence of the organizational structures in achieving the mission and goals of the Platform.

1.3 Platform planning process

The supervision, management and operation of the Platform are rooted in two main plans: the Strategic Plan and the Equipment Management Plan. The objectives of the **Strategic Plan** and the SMART metrics used to measure progress (*in parentheses*) are:

- To maximize days at sea in support of Canadian-led international arctic science (*interannual trend in number of days above or over the annual target of 152 days excluding mobilization and demobilization, nautical miles logged*);
- To coordinate operations at sea among the different user programs (*mission reports for each user program including a mandatory section providing recommendations on the unfolding of the annual mission*);
- To develop the community of Canadian users (*diversity of user programs, interannual trend in the number of different teams boarding the ship and utilizing the data, HQP trained, the number of new researchers established in Canadian universities and Federal departments*);
- To facilitate international participation in the Platform (*trend in percent participation of foreign researchers, number of foreign teams, new countries using the Platform*);
- To foster research collaborations with the private sector (*number and magnitude of new collaborations with the private sector*);
- Continuously, to improve the safety of operations at sea and on the ice (*number of safety training courses offered, number of personnel enrolling and completing courses, changes in protocols at sea*);
- To explore new avenues for the funding of operations at sea and equipment maintenance (*success in developing Citizen Scientist pilot program, revenues from foundations and philanthropists*);
- To recapitalize existing equipment and to expand the equipment pool with new technologies including at this time: two Autonomous Underwater Vehicles (AUV) with geophysical and oceanographic payloads for under-ice deployment; two helicopter-type Unmanned Aerial Vehicles (UAV or drones) with scientific payload for ice and marine ecosystem surveys; a Calypso Long Coring System to increase coring capacity from 8 m to 30 m to satisfy the common needs of geophysicists and the Petroleum Exploration sector; and an array of

community-based, cabled observatories (*interannual trends in investment and equipment inventory; success in acquiring the 4 new components listed above*);

- To implement the Communications and Outreach Plan including the Schools on Board program and the production of an annual report.

The **Equipment Management Plan** aims to maximize the scientific return of operations at sea by maintaining the equipment pool in optimal condition and continuously improving technical support at sea. Since a re-organization of the technical team in 2012, the management plan has focused on (1) increasing the team's expertise by recruiting highly qualified research professionals and engineers trained in ocean sciences; (2) reducing duty time at sea of core technical personnel, for example by hiring trainees to assist on board; (3) conducting 4 days of sea trials before the annual mission for the testing of the equipment and the joint rehearsing of equipment deployment by our technicians and the ship's crews; and (4) improving all aspects of safety linked to operations at sea. An important element of the plan has been to consolidate links between managers and technicians by multiplying meetings and social activities, by sharing details of the financial situation of the Platform with the technical team, and by fostering respectful relationships between the team and their clients, the scientists. Overall, these measures have improved the corporate culture of the Platform and fostered a feeling of belonging to the organization that may have been wanting before 2012. The indicators used to measure progress in implementing the Equipment Management Plan are: *interannual trends in equipment failure frequency, percentage of successful repairs at sea, number of operation days lost due to equipment failure, user satisfaction with equipment performance and technical services, trends in the number of data sets registered in the Polar Data Catalogue*.

	<i>Role in the planning process</i>
<i>Amundsen</i> Board of Directors	Annually discusses and approves the Strategic Plan and Equipment Management Plan and oversees their implementation. Approves the Annual Deployment Schedule.
<i>Amundsen</i> Scientific Leader	Based on input from stakeholders and users, continuously amend the Strategic Plan, proposing the main avenues of development and funding of the Platform. Leads the implementation of the Equipment Management Plan with support from the Ship Operation Manager.
Science Administrative Centre	Implements the Strategic Plan, the Equipment Management Plan and prepares the Annual Deployment Schedule.
Academic research users	Develop new research programs using the Platform, that contribute to the Canadian and international effort in the study of the Arctic Ocean. Continuously inform the Equipment Management Plan with their needs and suggestions. Contribute to the Strategic Plan with, for instance, ideas for international collaborations and partnerships with the private sector.

Government-based research users	Typically, participate in the planning and deployment of academia-led research programs as members of research teams. Mainly from the Departments of Fisheries and Oceans, Environment, and Natural Resources.
Private sector research users	Private sector research users (e.g. Imperial Oil, BP, Manitoba Hydro) jointly plan collaborations with the academic sector to answer their research needs. Contribute to the development of the equipment pool and to improve safety on board the icebreaker.
Academic stakeholders	U Laval, U Manitoba, U New Brunswick and U Victoria are the main academic stakeholders responsible for the management, maintenance and deployment of the scientific equipment of the Platform.
Canadian Coast Guard	Participates in the planning and costing of operations at sea. Provides logistical expertise for deployment of the Platform and technical expertise for the adaptation of science systems to the ship. Manages, maintains and modernizes the icebreaker.
Private-sector stakeholders	Some consulting companies (e.g. Golder Associates, ASL) participate as team members in the planning and implementation of academia-led proposals (e.g. BREA and ESRF).
Visitors	In addition to High School students participating in the Schools on Board program, Media, diplomats, elected representatives, artists etc. are sometime invited to join the <i>Amundsen</i> Arctic expeditions. They participate in the mission planning process, adapting their needs to the science plan. They contribute to the Communication and Outreach Plan (part of the Strategic Plan) of the Platform.

Major external influences on the Strategic Plan, the Equipment Management Plan and the scientific program of the Platform have come from ArcticNet, the International Polar Year, offshore exploration for petroleum in the Beaufort Sea, the Canada Excellence Research Chairs program that funded two CERC using the *Amundsen*, international programs (e.g., Malina, Green Edge) and federal initiatives such as the Beaufort Region Environmental Assessment (BREA) of Aboriginal Affairs and Northern Development Canada, and the Environmental Study Research Fund (ESRF) of Natural Resources Canada. In coming years, new collaborations with the private sector, and initiatives such as France's Chantier Arctique, and Europe's Horizon 2020 are expected to shape in part the mission of the *Amundsen*.

2. Research Capacity

In addition to the expertise of the crew in navigating the remote, ice-infested, poorly chartered waters of the Canadian Arctic, the unique technical capabilities of the *Amundsen* reside in its specialized pool of equipment adapted to arctic conditions. Many elements of this pool such as the Dynamic Positioning System, the internal access well (moon pool), the Bombardier tractor, the fast-launch Miranda davit, the multi-beam sonar, the air-boats, the ultraclean container, the arrays of radiometers, the battery of sonars, the ROV etc. are either exclusive to the *Amundsen* or seldom found on other Canadian research ships. At this time the overall \$36.5M (before depreciation) pool of equipment comprises 7 main components (described below) that can accommodate the most specialized needs of physical, chemical, and biological oceanographers, paleoceanographers, geologists, atmospheric science and remote-sensing specialists.

Component 1: Internal/external laboratories and instrumentation. Nearly 300 m² of dry and wet laboratory space, including 6 external container-laboratories, equipped with fume hoods, refrigeration, -80°C freezers, temperature- and light-controlled incubators, liquid nitrogen and purified water plants, multi-channel nutrient analyser, microscopes and stereoscopic microscopes, ship-track water monitoring system, CTD-rosette deployment station on starboard boat deck, internal CTD-rosette and Remotely Operated Vehicle (ROV) deployment station with moon pool, a portable ultra-clean in-situ laboratory for mercury speciation and contaminants studies.

Component 2: Deck equipment, oceanographic samplers and ice equipment. Six oceanographic winches and three A-frames, two CTD-rosette systems with fluorometers, PAR sensors, transmissometers, and nitrate probes, two new *in situ* zooplankton optical counters and imagers, ROV with 1500-m diving capacity, moving vessel CTD profiler, vertical and horizontal multi-net zooplankton samplers, rectangular mid-water trawl, experimental fish trawl, beam trawl, Agassiz trawls, trammel nets, piston core, box cores, Miranda davit with fast launch, scientific barge, two air boats for deployment on the melting ice pack, ice camp equipment including fully-equipped arctic shelters, Bombardier tractor, snowmobiles.

Component 3: Oceanographic mooring instrumentation. Instrumentation for 26 oceanographic moorings including Acoustic Doppler Current Profilers, sediment traps, CTDs, passive acoustic hydrophones, nitrate probes, upward looking sonars, vertical profilers, location beacons, floatation and acoustic releases.

Component 4: Atmospheric sciences instrumentation. Dual field spectrometers (350-1050nm), extended range spectrometer, 37 & 89 Ghz microwave radiometers, optical spectrometers, polarimetric radar scatterometers, Digicora radiosonde system, APT satellite reception antenna, open path infrared gas analyzer, sea ice microstructure equipment, 19-GHz radiometer, aerosonde, profiling SeaWifs compatible spectrometer, water vapour profiling radiometer, ice buoys, ice beacons.

Component 5: Sonars and associated facilities. EM-302 multibeam sonar, K320R Sub-bottom profiler (K320R), EK-60 scientific echo sounder, Ocean Surveyor hull-mounted ADCPs, Dynamic Positioning System, acoustic well, SX90 fisheries sonar and gate-valve.

Component 6: Ocean color near and remote sensing. Dual-beam spectrophotometer, spectrofluorometer, particle counter, fluorescence-induction meter, *in situ* spectral absorption-, scattering- and backscattering-meters, two fluorometers, miniature CTD, underwater spectro-radiometer for downward and upward irradiance, above-water hyperspectral spectroradiometer for water-leaving radiance, fifteen autonomous satellite-linked profiling floats each with T, S,

NO₃, O₂, suspended particles, chlorophyll and organic fluorescence, irradiance, and ice detection.

Component 7: Equipment calibration and data quality control/logging/archiving systems.

Ship-based salinometer, ship data logging and internal communications network with repeaters in each cabin and laboratory, onshore metrology laboratory for maintenance of the overall equipment pool (U Laval), meteorology laboratory for maintenance and development of atmospheric instrumentation (U Manitoba). The Polar Data Catalogue, an arctic data portal with geo-referenced data banks.



2.1 Capital investment value

After the initial massive investments by the CFI and the Canadian Coast Guard, the capital value of the Platform continued to increase by about \$3M per year from 2006 to 2014, thanks to the regular addition of new equipment from granting agencies, stakeholders, and user programs (Figure 2). This renewal of the equipment pool compensates in part the intense wear of most instruments and the frequent losses at sea of some components (e.g. mooring instruments). But the recapitalization of the scientific equipment of the *Amundsen* remains a major challenge.

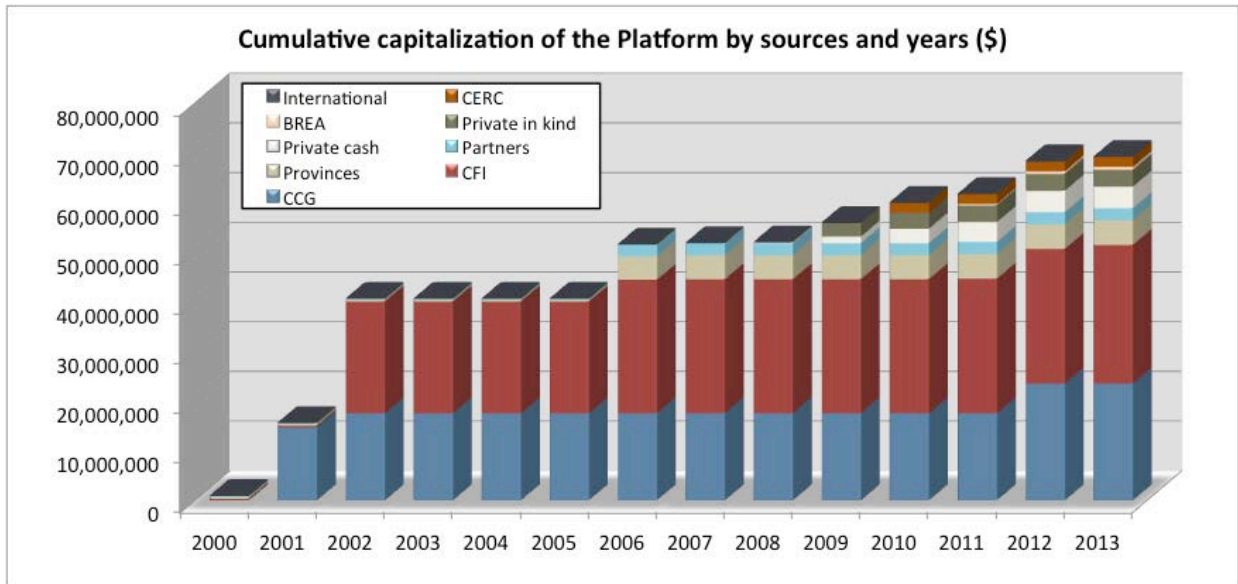


Figure 2. Evolution over the years of the cumulative capital value of the Platform (*Amundsen* icebreaker and scientific equipment pool). The principal contributors are color-coded: CCG: Canadian Coast Guard; CFI: Canada Foundation for Innovation; BREA: Beaufort Region Environmental Assessment; CERC: Canada Excellence Research Chairs program.

Current infrastructure. Because of the extreme conditions of the Arctic, the intense use, and losses at sea, the depreciation of the overall pool of equipment is severe. On average, equipment needs to be replaced after 7 years of deployment. Hence, the recapitalization of the pool of equipment of the *Amundsen* is a challenge. The financial and human capacity to maintain the equipment was stretched during the International Polar Year when the *Amundsen* operated for 450 consecutive days in support of science in the Canadian Arctic. By the end of IPY operations, the state of the pool of equipment and the dedication of the technical team had reached a low. Since then, most of the 53 initial systems have been replaced, refurbished, or upgraded thanks to new investments, donations, insurance reimbursements, or revenues from partnerships with the private sector. In addition, no less than 12 new systems have been acquired. All of these 65 science systems are fully operational and under the competent supervision of a renewed technical team (see next section), making the *Amundsen* arguably the most complete and versatile oceanographic platform in Canada and one of the best-equipped research icebreaker internationally.

2.2 Resources and services of the Platform

Investments. The overall operation and maintenance of the icebreaker for science entails three main expenditures. First, the costs of operating the *Amundsen* at sea (salaries of crew, fuel, lubricants, household supplies, food, plane charter for the exchange of personnel, communications, etc.), which are charged as user fees to the different national and international research programs. Second, the costs of managing, maintaining, and modernizing the icebreaker itself, which are shouldered by the Canadian Coast Guard (a major contribution to the *Amundsen* scientific program). Third, the costs of maintenance and deployment at sea of the complex pool of collective scientific equipment, to which several funding sources and organizations contribute. The costs of recapitalization of the equipment to offset losses and

deterioration are listed as enhancements to the initial capitalization in Section 2.1 and are not considered in this section.

Operation costs. At \$57.5K per day at sea, the costs of operation of the Platform (or user fees) represent the largest expenditure in the overall O&M budget of the platform and are presented as a separate graph to illustrate the main sources of funding (Figure 3). These costs vary considerably from year to year depending on the summed demand from the different research programs. Even before the *Amundsen* became available in 2003, her sister ship the CCGS *Radisson* equipped with the first components of the future equipment pool (CFI-2554) was deployed in the Beaufort Sea in support of the CASES program. Then the CASES overwintering expedition (fall 2003 to late summer 2004) monopolized the *Amundsen* during its first two years of operation. Starting in 2004, the oceanography and epidemiology programs of ArcticNet provided the funding that would guarantee the annual deployment of the *Amundsen* in the Canadian Arctic for a minimum of 84 days per year. In 2007-2008, major investments from the Canadian International Polar Year program funded a record deployment of the ship for 450 consecutive days (16.5 months) without touching port, in support of Canadian-led international research in the Canadian Arctic. From 2009 to 2011, major research collaborations with the Oil Exploration sector built up the use of the Platform. In 2012, the *Amundsen* was out of commission for the replacement of its engines, and different alternative platforms were chartered, including the *Radisson* and several small vessels for coastal work, to fulfill the most urgent demand of the user community for support at sea.

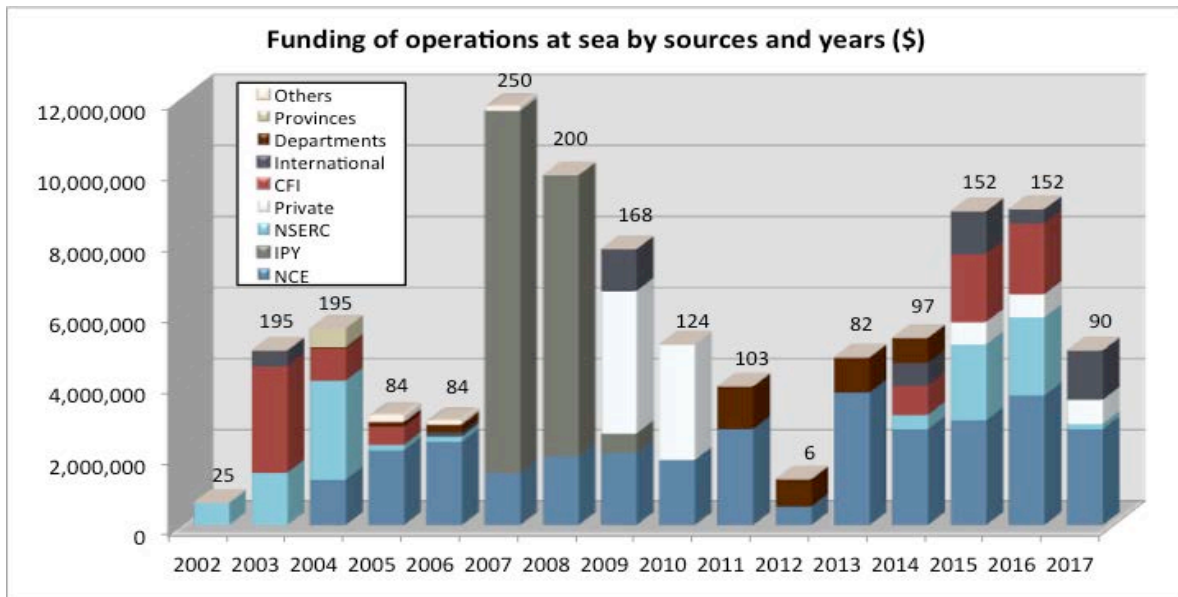


Figure 3. Contributions (CAD\$) to the **operation** of the Platform by fiscal year. The principal funding sources are color-coded: NCE: Network of Centres of Excellence (ArcticNet); IPY: International Polar Year; NSERC: Natural Sciences and Engineering Research Council; CFI: Canada Foundation for Innovation; International: primarily France, Japan, USA. Federal departments: primarily Environment Canada, Natural Resources Canada and Aboriginal Affairs and Northern Development Canada. Numbers above bars indicate the number of days at sea. Projected contributions for the period 2015/16 to 2017/18 are secured at a level of 65%.

Ship maintenance costs. Coast Guard covers the costs of managing, maintaining and modernizing the icebreaker itself as part of its fleet maintenance budget. These expenditures include the large costs of the periodical revision of the ship in dry dock on a ≈ 4 -year basis. In Figure 4, the costs of dry docks are spread over these 4-y periods. To guarantee security at sea in the harsh arctic environment, the standards of Coast Guard in maintaining the hull, the engines and the overall condition of the ship are extremely high. As a result, the ship-shape *Amundsen* is an excellent ambassador to the international Arctic science community that proclaims Canada's dedication to the stewardship of its arctic seas and territories. In recent years the overall costs of maintaining the ship to such high standards have exceeded \$2M per year (Figure 4).

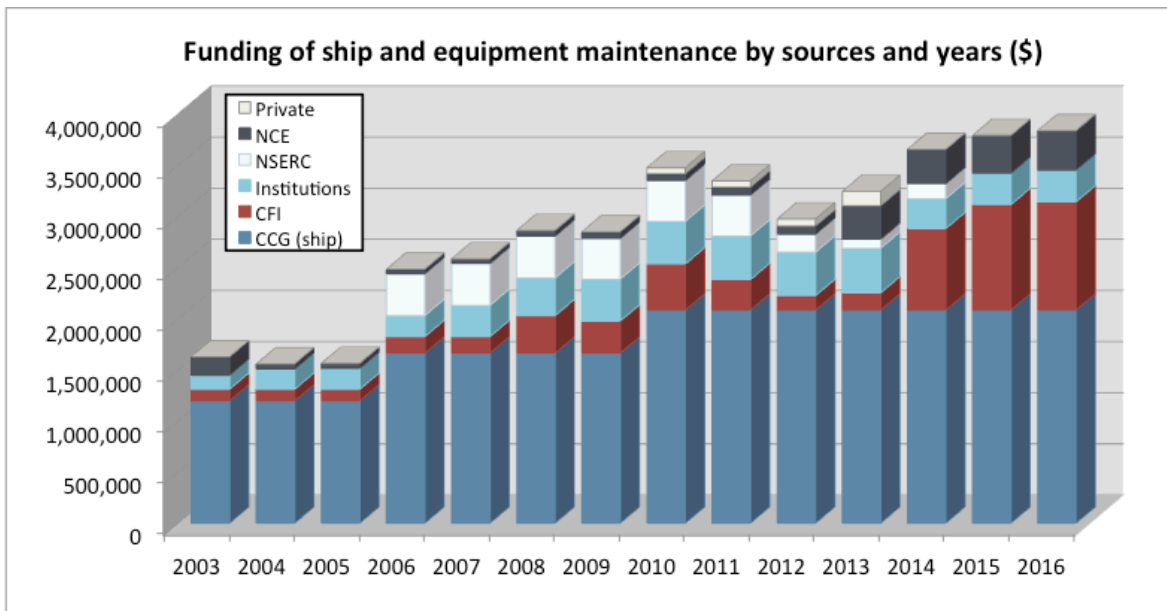
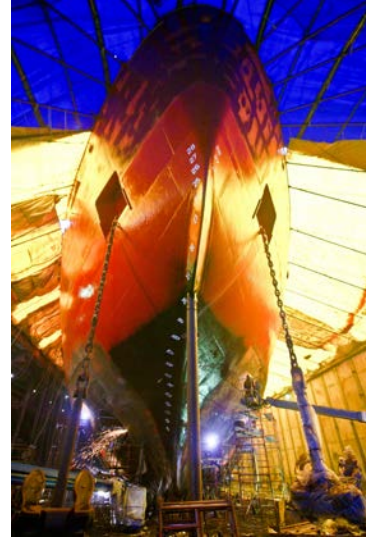


Figure 4. Investments (CAD\$) by funding sources for the **maintenance** of the platform (ship and scientific equipment) by fiscal year. CCG: Canadian Coast Guard; CFI: Canada Foundation for Innovation; NSERC: Natural Sciences and Engineering Research Council of Canada; NCE: Network of Centres of Excellence. The large contribution of the CCG is towards the maintenance of the icebreaker itself only. All other sources contribute to the maintenance of the scientific equipment only. The projected contribution of CFI beyond 2014 is based on a positive outcome of our application to the Major Science Initiatives Special Competition.

Equipment maintenance costs. Over the years, several funding sources and research organizations have contributed to the basic costs of maintenance and deployment at sea of the equipment pool, without ever fully satisfying the demand for support (Figure 4). Through the operation fraction of the IJVF grant (CFI-7079) and then the Infrastructure Operating Fund linked to our Leading-Edge grant (CFI-11393), CFI contributed to the maintenance budget from 2003 to 2013. Through well established research centres, U Laval (Québec-Océan), U Manitoba (Center for Earth Observation Science, CEOS), and U New Brunswick (Ocean Mapping Group)

have supported the maintenance and deployment of the scientific equipment of the *Amundsen* with in kind and cash contributions. From 2006 to 2012, the Major Resource Support program of NSERC provided a significant fraction of the insufficient maintenance budget. In most years, ArcticNet and its private sector partners contributed financial support to help mop up some of the chronic deficit. Starting in 2013, this contribution comprises a tax of \$2,500 per day of operation levied on all user programs including ArcticNet. Starting in 2014, we hope to see the contribution to the maintenance of the equipment increase substantially thanks to a CFI Major Science Initiatives grant that would at last bring this budget to the needed basic level (Figure 4).

Platform Personnel. Each year several dozen technicians and graduate students attached to and paid by the different user teams join the successive 42-day rotations of the *Amundsen* during her Arctic voyage. As part of the research activities, they service and operate the specific instruments of the 65 systems and additional laboratory instruments used on board. But the deployment of the icebreaker for science and the management, maintenance and troubleshooting on land and at sea of the *Amundsen*'s overall pool of collective equipment is under the responsibility of a small team of 14 experts (12 FTE) comprising 8 sea-going engineers/technicians, three operation managers, two data managers, and one communications officer. Their experience in managing large arctic endeavours, their knowledge of the equipment, and their dedication are key to realizing the aims of the Strategic Plan to (1) guarantee the preparedness of the Platform, (2) implement the Annual Deployment Schedule, (3) provide continuous troubleshooting at sea, (4) maximize scientific yield at sea, and (5) minimize costs to the users. Currently, this core team of managers, specialized engineers, and technicians is distributed among five research units. At U Laval (ArcticNet and Québec-Océan) a Ship Operations Manager, a Communications Officer, two Data Managers and four engineers/technicians maintain the oceanographic equipment and supervise the overall scientific mobilization and coordination of the *Amundsen*. One manager and two technicians at the Centre for Earth Observation Science (CEOS, U Manitoba) operate the atmospheric instruments. Until 2013, specialists from the Ocean Mapping Group (OMG, U New Brunswick) took rotations on the ship to maintain and operate the numerous sonars. Starting in 2014, this task was transferred to the Laboratoire de géosciences marines (LGM) at U Laval.

In addition, in close collaboration with the technical team at U Laval, the experienced pilots and engineers of the Canadian Scientific Submersible Facility (CSSF, U Victoria) maintain, upgrade and operate the ROV. Clerical personnel at Québec-Océan, ArcticNet and CEOS provide administrative support for the purchase of equipment and services, contracts, and the management of accounts.

Finally, to enable the research program of the *Amundsen* Coast Guard maintain two sets of 38 officers and crew who are specialized in conducting an array of complex science operations at sea and in catering for the needs of scientists from all over the world.

Training of Platform Personnel: Periodic training of platform personnel is critical to familiarize technical staff with specialized oceanographic instrumentation, to maintain high safety standards and to keep up with changing technologies. Training can be costly and has frequently involved travel either within Canada or internationally. Over the years, technical training was provided to platform personnel on various equipment systems including: ROV (Global Marine, Scotland and CSSF, Canada); McLane Moored Profilers (Romor, Canada and McLane, USA); multibeam, SX90, and EK60 sonars (Kongsberg, Canada and Norway); CTD-rosette (Sea-Bird, USA); and ice-profiling sonars (ASL Environmental, Canada). Safety training

was also provided for field operations such as offshore use of the ship's helicopter (Survival Systems Limited, Canada). Training costs have been covered by a variety of sources including ArcticNet, Québec-Océan, university budgets and private sector collaborations.

2.3 Platform development and sustainability

Technical and operational capability. Prior to the inauguration of the *Amundsen* in 2003, CCG icebreakers were used for science either on an opportunity basis or as chartered platforms. Often, Canadian icebreakers were chartered by foreign organizations to conduct research in the Canadian Arctic with limited or no Canadian participation. Thus, paradoxically, CCG icebreakers provided more support to non-Canadian programs than to Canadian programs in the study of the Canadian Arctic. For instance, from 1997 to 2000, the US-led SHEBA (Surface HEat Budget of the Arctic Ocean) and the Sweden-led Tundra99 altogether chartered the CCGS *Louis S. St-Laurent* and *Des Groseillers* for a total of 512 days. By comparison, over the same period, the Canadian-led international NOW program chartered 189 days of icebreaker time (CCGS *Louis S. St-Laurent* and *Pierre Radisson*).

As well, prior to the *Amundsen*, despite a true willingness to accommodate the needs of the scientists, a request for a platform to support a large international scientific effort over several months, invariably created havoc in the operational schedule of the Coast Guard. A suitable ship had to be identified, freed from its ongoing operations, replaced by another ship, and mobilized for science. A special project unit had to be put together and scientific equipment had to be assembled from all over Canada and fitted to the ship. Similar efforts had to be deployed to de-mobilize the ship. In other words, the wheel had to be re-invented each time again. Until the last minute, the availability of a ship for science remained conditional on unpredictable contingencies such as heavy ice conditions. In 1998 for example, the Coast Guard was able to pledge two icebreakers simultaneously for the US-led SHEBA program and the Canadian-led NOW program thanks to record low ice density in the St. Lawrence Seaway. If ice conditions had been normal, support for NOW likely would have been cancelled or postponed until the completion of SHEBA. Similarly, the fully funded Canadian-led CASES was delayed until a suitable icebreaker became available. Totally re-mobilizing a ship for each expedition was costly and wasteful of time and energy. Delayed availability of a platform was particularly detrimental to the cohesion of international teams and to the career of graduate and postdoctoral students enlisted in the program.

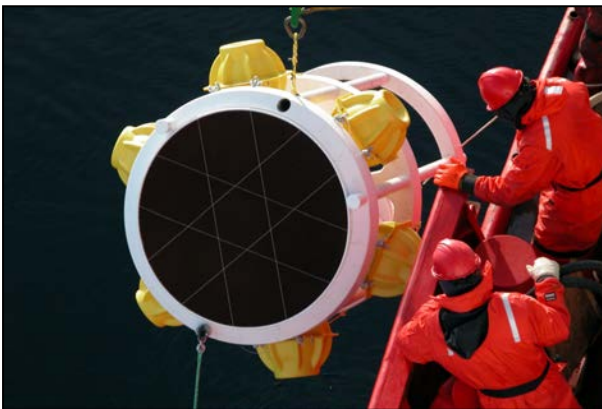
As for the availability of suitable equipment to conduct the science, two Canadian icebreakers provided limited basic support (e.g. laboratory space, scientific winches and A-Frame) on a regular basis: the powerful but prohibitively expensive 120-m *Louis S. St-Laurent* and the 83-m long *Sir Wilfrid Laurier* which has limited icebreaking capacity. The arctic research programs of federal departments such as Fisheries and Oceans Canada and Natural Resources Canada monopolized both ships. University-based specialists seldom used either, and only by piggybacking federal programs.

The Platform and the integration of its operation/management within Coast Guard operations rationalized this situation and opened the field of High Arctic oceanography to Canadian academic researchers. An ideal balance between icebreaking capacity and affordability, major transformations to accommodate science needs, and a remarkably comprehensive pool of scientific instruments, make the *Amundsen* a research platform unmatched by any other Canadian research ship, icebreaker or otherwise. The guaranteed availability of a dedicated icebreaker equipped with state-of-the-art instruments (1) enabled the Canadian science

community to plan projects on the horizon of 3-5 years, a necessary condition for large international efforts; (2) substantially reduced the costs and hurdles of mobilization/demobilization; (3) developed an international “market” for the joint use of the infrastructure; (4) created and maintained the special links with the crew and officers necessary to optimize the scientific yield of operations; (5) increased reciprocal access for Canadian researchers to foreign Arctic infrastructures; (6) guaranteed a reliable access to the Arctic Ocean for the training of highly qualified personnel; and (7) provided international visibility and appeal to Canadian efforts in the Arctic Ocean. The diversified pool of state-of-the-art scientific equipment gave the Canadian and international community the capacity to conduct innovative research under optimal conditions in the extreme environment of the Canadian High Arctic.

O&M Management. Contrary to research icebreakers mobilized by other countries, the *Amundsen* is not supported by a statutory O&M budget. O&M funds are obtained mainly through competitive funding programs. Management and the community of users seized several key opportunities to sustain operations, starting with the successful proposal for the NCE ArcticNet that guaranteed a minimum annual deployment of the icebreaker from 2004 to 2017. The Canadian International Polar Year program was a second key funding opportunity successfully mustered by the community, with major programs such as the Circumpolar Flaw Lead System Study (CFL) and the Inuit Health Surveys bringing utilization to record levels. Under the guidance of the Boards of Directors of both the *Amundsen* and ArcticNet, major research partnerships with the Oil Exploration sector were struck in the years following the IPY, enabling Management to maintain operations. Presently, we are in a phase of diversification of the user base, with several national and international programs lining up over the coming 3 years.

Sustainability (see also Section 1.3). In the medium term (next 5 years), a central objective of Management is to maintain existing research capacity and acquire new capacity to answer the needs of the user community and facilitate new collaborations with the private sector. Our strategy to maintain, renew and expand existing capacity comprises two approaches: (1) to develop new private sector collaborations which provide excess revenues used to recapitalize or acquire new equipment; and (2) a new proposal to CFI in the coming years to maintain the equipment pool at the leading edge. The plan to acquire new capacity focuses on the addition of four equipment components to the existing seven (Section 2. Research Capacity):



Component 8 (projected): Autonomous Underwater Vehicles. Two AUVs with geophysical and oceanographic payloads for under-ice deployment. With Kongsberg and CERC at U Laval.

Component 9 (projected): Unmanned Aerial Vehicle. Two helicopter-type UAVs (drones) with scientific payload for ice and marine ecosystem surveys. With Airbus Group and the Coast Guard.

Component 10 (projected): Calypso Long Coring System to increase coring capacity from 8 m to 30 m to satisfy the common needs of geophysicists and the Petroleum Exploration sector. With the French Polar Institute IPEV.

Component 11 (projected): Low power cabled observatories. Three community-based, cabled observatories in Hudson Bay, deployed and serviced by the *Amundsen*. Québec-Océan, CEOS and Ocean Networks Canada.

As for the maintenance of the equipment, we expect institutional support from Québec-Océan, CEOS, CSSF and now the LGM to be maintained in the foreseeable future. Assuming a positive funding decision for our proposal to the CFI-MSI Special Competition, optimal maintenance of the equipment would enable us to eliminate the \$2,500 per day user tax so as to further increase the competitiveness of new proposals to fund operations. Management is also making sure that new components added to the equipment pool come with additional technical expertise and funding to operate and deploy them, so as to avoid worsening the present pressure on the *Amundsen* technical team.

With support from the Board, the Scientific Leader and Management constantly work at identifying new user programs and exploring new avenues to fund the O&M budgets of the Platform. ArcticNet will continue to provide core funding for operations through its marine program until 2018. After the huge demand from IPY and the collaborations with the private sector ended in 2010, ArcticNet and BREA were the sole users of the ship in 2011. Since then, a clear re-diversification of funding sources has taken place. In 2014, 5 different programs and one project used the icebreaker: ArcticNet (65.5 days), BREA (13 days), JAMSTEC (6 days), NetCare (4.5 days), Green Edge (4.5 days), and the project *Holocene paleoceanography and climate variability in the Western Canadian Arctic Ocean* (2.5 days). Starting in 2015, several new programs are planned to augment this list, including Arctic-Geotraces, ESRF, BaySys, ASP, and H2020. Hopefully, a successful proposal to the CFI-MSI Special Competition will also contribute to fund operations at sea for the coming years.

Previous collaborations with the private sector have proven extremely healthy for the Platform: scientifically, technically, security-wise, and financially. Our plan to build new partnerships with the Petroleum Exploration sector in the Beaufort Sea and Baffin Bay, and with Manitoba Hydro in Hudson Bay should be facilitated by the projected acquisition of Equipment Components 8 to 11 described above.

2.4 Structuring effect on the Canadian research ecosystem

Impact on stakeholders. The Platform had an immediate impact in networking the Canadian Arctic science community, initially among the 15 universities of the Consortium and then beyond that initial Consortium (see **Other structuring effects** below). Most importantly, it attracted massive new research capacity at U Laval, the host institution, and at U Manitoba. At U Laval, the availability of the Platform expanded the Arctic Ocean program of Québec-Océan starting with the successful NSERC Research Network CASES (2002-2007) that developed new collaborations with the USA, Norway, Denmark, Japan, Germany and Spain. The Arctic program of Québec-Océan and the equipment pool it manages were further consolidated during the IPY (2007-2012, CFL and Inuit Health Surveys) and through research collaborations with the Oil Exploration sector (2009-2012). Thanks in great part to the availability of the *Amundsen*, U Laval secured in 2010 the Canada Excellence Research Chair (CERC) in Remote Sensing of Canada's New Arctic Frontier that recruited Professor Marcel Babin and his team from the Laboratoire Océanographique de Villefranche-sur-Mer, in France. Simultaneously, and again thanks to the *Amundsen*, U Laval and the French Centre National de la Recherche Scientifique (CNRS) established the Takuvik Joint Laboratory that recruited 8 French researchers and

engineers, specialists of the Arctic Ocean. Compared to the base year, the availability of the Platform enabled U Laval to quadruple its force of Arctic Ocean specialists from 2 to 8 principal investigators and teams.

The structuring impact of the Platform was similar at U Manitoba, which participated massively in CASES, and led the international CFL program (2007-2012) on board the *Amundsen* with participation from 22 countries. Using the Platform, CEOS developed strong research partnerships with Manitoba-Hydro to study land-ocean interactions in Hudson Bay from 2007 onward. Also thanks to the availability of the *Amundsen*, in 2010 U Manitoba secured its CERC in Arctic Geomicrobiology and Climate Change, recruiting Søren Rysgaard, Professor at Aarhus University (Denmark) and Director of the Greenland Climate Research Centre. In 2012, Canada, Greenland and Denmark struck the Arctic Science Partnership that brings together the research capacity of the Arctic Research Center (Aarhus U), the Centre for Earth Observation Science (U Manitoba) and the Greenland Climate Research Centre. Building on these new structures, U Manitoba further developed its research capacity by establishing on campus the Sea-Ice Environmental Research Facility (SERF), a unique CFI-funded facility where arctic sea-ice and its ecosystem are reproduced.

Overall, the Platform massively increased northern research capacity at U Laval and U Manitoba, creating unique arctic science bridges between Canada and France, and Canada and Denmark/Greenland respectively. This structuring impact is not limited to Laval and Manitoba, but percolates to other universities and organizations in and outside the initial Consortium, which all participate in and benefit from the large international programs supported by the *Amundsen* (see Section 3.2). For example, of the 44 Arctic Ocean specialists recruited in Canadian universities and federal departments thanks to the Platform (Appendix 3), 28 are affiliated to 21 organizations other than Laval and Manitoba.

Other structuring effects. However, without any doubt, the most spectacular and enduring impact of the Platform on the Canadian research ecosystem has been the enabling of the Network of Centres of Excellence ArcticNet. ArcticNet transformed Canadian arctic science along the recommendations of the 2001 NSERC/SSHRC Task Force Report on the state of northern research. It has federated the natural, socio-economic, and human health sectors of northern research, and forged the much-needed alliance of researchers and Inuit in the study of the changing Arctic. Thanks to its core infrastructure the *Amundsen*, the Network has provided Canadian scientists, students and their international and private-sector collaborators with unprecedented access to the coastal Canadian Arctic and its communities. It has introduced to the Canadian Arctic the Big Science needed to answer the ecosystem-level issues raised by climate change, industrialization and modernization, and has connected academia with the private sector in the study of the Arctic. The *Amundsen* supports about 45% of ArcticNet's research. But, through ArcticNet, the highly collaborative nature of oceanographic research has expanded through much of the Canadian Arctic research landscape, encouraging the replacement of the mono-disciplinary project typical of former times by highly integrated, interdisciplinary endeavours that bring several teams together to solve multi-faceted issues. The outcomes and benefits of this new way of doing science in the North are best illustrated by ArcticNet's Integrated Regional Impact Studies (Section 4.6).

Foregone costs. The capitalization needed to refit and equip the *Amundsen* up to its present functionality has been in the order of \$69M, including the book value of the ship (Figure 2). For comparison, CAD\$768M were spent in 2000 to build the US research icebreaker *Healy* (128 m).

And Canada earmarked CAD\$720M for the construction of the multi-task polar icebreaker CCGS *Diefenbaker* (130 m), although experts generally consider this price to be severely underestimated. CCG assess the price tag to build an icebreaker equivalent to the *Amundsen* (100 m long) and to arm it for science at about \$480M. Hence, acquiring the equivalent functionality of the Platform by building a new icebreaker would cost 7 times the \$69M capital investment in the *Amundsen*. Obviously, no academic funding program could afford such an initiative in Canada.

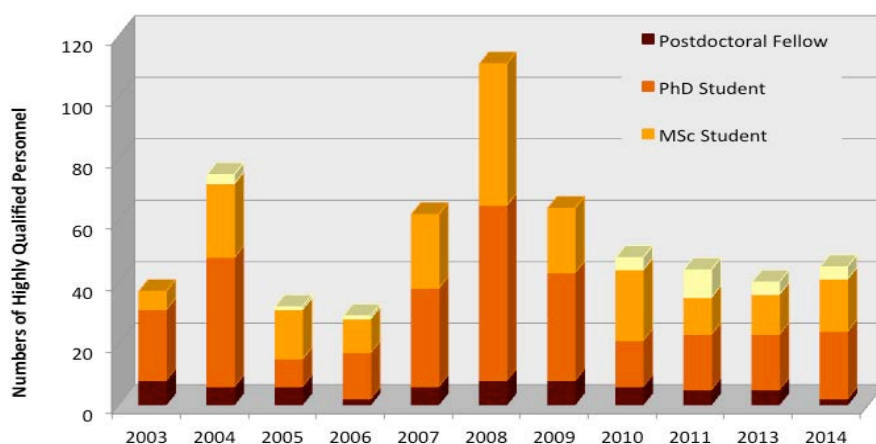
Before the *Amundsen*, Canadian academics sometimes piggybacked the infrequent Arctic missions of Fisheries and Oceans on modestly equipped CG icebreakers, or joined international expeditions as second violins for missions of opportunity on foreign icebreakers. The access to the Arctic Ocean, the equipment pool, and the technical services offered to users by the Platform are immensely superior, and it is somewhat difficult to make a before-and-after comparison of costs. However, thanks to our policy of maintaining academic user fees to a minimum, university-based teams certainly save considerably on (1) technical services at sea; (2) travel and transport costs to board and leave the ship as they can use at minimal costs the flights chartered to exchange the crew; (3) mobilization/demobilization costs; (4) administration and equipment maintenance costs which are centrally supported; and (5) data management.

2.5 Contributions to the training of students and postdoctoral fellows

The evolutionary time series. Over time, the number of research trainees (undergraduate students, graduate students

Number of research trainees in 2014: **46**
Number of research trainees since 2003: **417**

and postdoctoral fellows) boarding the *Amundsen*, using its pool of equipment, and benefiting from the expertise of the core team of technicians/engineers fluctuated primarily according to



the magnitude of the scientific programs supported by the Platform (Figure 5).

Figure 5: Number of HQP trained on the *Amundsen* per year (note that the icebreaker was out of commission in 2012).

Quality and richness of the training. The *Amundsen* provides a unique training environment where HQP are exposed to the complexities of large multinational and multidisciplinary endeavours. They gain experience in the operation of the most recent generation of oceanographic and atmospheric instrumentation. They learn to carefully plan their work and to conduct it safely and efficiently under the extreme conditions of the Arctic. On board the *Amundsen*, Canadian HQP interact closely with foreign HQP and with the best Arctic Ocean specialists from Canada and from abroad. As a result, young Canadian researchers and their international counterparts now form a dynamic international network. Most HQP trained by the Platform are also members of ArcticNet. With ArcticNet, the training environment becomes

trans-sectorial, students being exposed not only to their area of expertise, but also to all sectors of arctic research (natural, health, and social sciences).

On board the *Amundsen*, trainees literally live, eat, work and relax among some of the best specialists in all fields of Arctic Ocean sciences originating from all over the world. They attend the daily science planning meetings and the onboard seminar series where they discuss the most recent advances in arctic oceanography. They also learn important aspects of their trade by interacting with top-level engineers

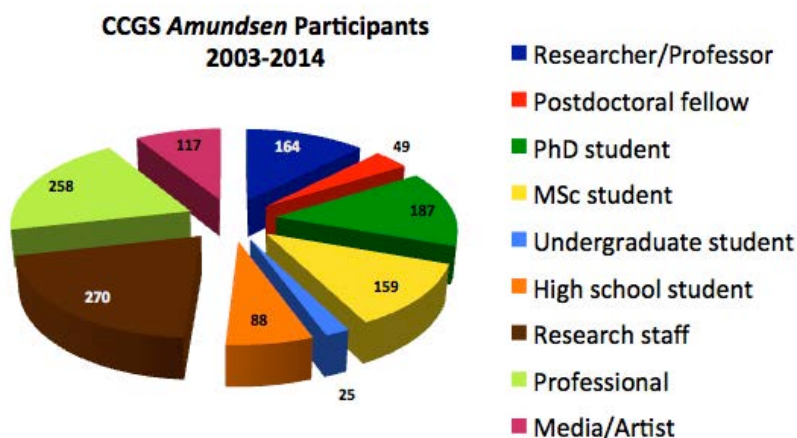


Figure 6. Composition of the community of users of the Platform

and technicians. The ratio of mentor to trainees (1.7) is probably the highest they will ever enjoy: on average since 2003, 213 researchers, professors, and postdoctoral fellows assisted by 528 research staff, technicians and professionals supervised 346 graduate students and 25 undergraduate students (Figure 6).

Attraction and retention. Over 43% of graduate students trained on the *Amundsen* have been awarded excellence scholarships including prestigious Garfield Weston (8), Banting (1), and Vanier (1) scholarships. Most importantly, the Platform is a formidable tool to help establish these exceptional young trainees and some senior researchers as new professors and research team leaders in Canadian universities, federal departments, the private sector and institutions abroad. It has supported the arctic research program of no less than 44 *new* Arctic Ocean specialists since 2003 (Appendix 3). Along with their teams of graduate students and technicians, these new researchers are the building blocks of the workforce acutely needed to study the rapidly changing Canadian Arctic Ocean. They also constitute the community of specialists that will operate, staff and use new arctic research facilities being built by the Federal Government such as the Canadian High Arctic Research Station and the polar icebreaker *Diefenbaker*.

3. Research Enabled

3.1 Access and usage

Policies and mechanisms. The Users Committee meets annually to coordinate science operations among the different programs and to prepare the Annual Deployment Schedule (Section 1.3). The Committee reports to the Board of Directors who has final word on allocation of access to the Platform. The Board has adopted a set of rules for the prioritization of programs in case of an eventual conflict (note that no serious conflict has arisen yet even at the peak of IPY). It is responsible among others for (1) resolving any conflict arising among the users regarding the schedule of ship operation; (2) preventing the monopolization of the Platform by any group; (3) requesting good faith discussions among competing programs to make sure that all options and compromises are explored towards the optimal satisfaction of the needs of the community of users. For example, if competition for access develops among programs with the same priority, the Board will ensure that all avenues to minimize that competition and maximize access are considered (e.g. integration of operations at sea of the two programs, sharing of the same ship time, postponing access for one program all the while guaranteeing access later, etc.); (4) if conflicts for access subsist after discussions among the potential users, the Board is responsible to prioritize the research programs competing for access to the infrastructure. All programs, including those sponsored by the initial Consortium are considered on a par basis for the allocation of access to the Platform. To achieve impartiality and adequate representation, the Users Committee is open to the scientific leader of any program contributing to the charter of the *Amundsen* in a given year and to all users participating in the research program. All users boarding the ship have full access to technical services and to the equipment and the core data relevant to their research.

The Board of Directors has established precise rules to set fees for the different categories of users. Canadian university-based programs are charged the actual costs of operations at sea and have access to all equipment systems at no cost. At the other end of the spectrum of users, university-industry partnerships are charged a significant premium for both operation at sea and the use of the scientific equipment. These revenues are re-invested in the maintenance and recapitalization of the equipment pool. Purely industry programs do not have access to the Platform.

Utilization. From major international programs requiring the overwintering of the ship in the Arctic to small-scale 2-berth projects funded by the NSERC Ship Time Allocation Committee, all programs requesting access since 2003 have been fully accommodated to the best of the capacities of the Platform and according to the funding available, even at peak demand during the IPY when the *Amundsen* was used at over capacity. Whether in the natural, the social or the health sciences, no *funded* program has been refused. Minor schedule conflicts among programs were resolved by mobilizing other ships. This testifies to the efficiency of Management and the flexibility of our partner the Canadian Coast Guard in extending offer to meet demand.

Based on the time needed for the annual maintenance of the ship and the transitions from Coast Guard operations to science operations in the spring and vice-versa in the fall, the Cost Sharing Arrangement fixed the availability of the *Amundsen* for science at 152 days per year **including** science mobilization and demobilization (24 days per year). However, the demand for access to the Arctic Ocean has been so strong that, from 2003 to 2011, the *Amundsen* operated in the Arctic on average **158.5** days per year for science **excluding** mobilization/demobilization. Over

these 9 seasons of operation, the community of users secured \$55,494,807 to deploy the Platform for a total of 1426 days at sea (Figure 3). This level of utilization exceeds the admittedly optimistic 1368 days (152 days per year) anticipated in the original proposal to the CFI. After the 2012 hiatus, the Platform was deployed for 83 days (planned) in 2013 and 96 days in 2014. Overall since 2003, the *Amundsen* has enabled 18 major multidisciplinary and international research programs, providing access to the Arctic Ocean and its ancillary seas to 106 research teams and 1190 scientists (excluding HQP). Funding secured by the different user programs will ensure 111.2 days of operation at sea per year on average over the next three years. If approved by CFI, our proposal to the Major Scientific Initiatives Special Competition would enable Management to raise operations at sea to 152 days per year for 2015 and 2016 (Figure 3).

By comparison, thanks to statutory budgets, Germany is leading a comprehensive Arctic-Antarctic effort by deploying its research icebreaker *Polarstern* for an impressive 320 days per year and the USA operates the research icebreaker *Healy* for science for up to 200 days per year.

National/international usage of the Platform. Excluding Highly Qualified Personnel, the number of usages of the Platform (Grand Total = 1190) varied from as few as 46 in 2013, when operations were curtailed midway by the tragic crash of the ship's helicopter, to as many as 218 in 2008 at the peak of IPY (Table 1). Canadian academics were the most frequent users of the Platform (52%) followed by government researchers (24%), foreign academics (16%) and private sector partners (8%). Not surprisingly, over the years, use of the Platform fluctuated primarily according to the funds available to deploy the *Amundsen* (Figure 3), peaking during major programs such as CASES (2004) and the IPY (2008) (Table 1).

Table 1: Number of times research users (excluding Highly Qualified Personnel) boarded the *Amundsen* for work at sea per year, per category affiliation. Note that the ship was out of commission in 2012. Note also that statistics in this table (number of times the Platform is used) and in Figure 6 (number of users) are not comparable.

<i>Year</i>	<i>Canadian academic</i>	<i>Private sector</i>	<i>Government and not for profit</i>	<i>International academic</i>	<i>Annual Total</i>
2014	45	4	18	10	77
2013	30	5	11	0	46
2011	58	26	28	21	133
2010	47	26	31	4	108
2009	60	25	17	30	132
2008	103	4	46	65	218
2007	102	2	32	21	157
2006	38	1	30	6	75
2005	26	1	24	4	55
2004	94	2	29	23	147
2003	20	0	15	7	42
Total	623	96	281	191	1190

Since 2003, scientific users (including HQP) from 9 of the 10 Canadian provinces and 2 territories and from 22 countries logged 59,025 person-days at sea on the *Amundsen*, reflecting the Platform's truly national and international mandate (see Appendix 4 for a Table of scientist-day at sea by programs, provinces and countries). Overall, the Platform accommodated

individual teams led by 55 Canadian university-based researchers, 30 Canadian government-based researchers, and 38 researchers from abroad. International participation represented 16.5% of overall use, reaching 19.5 and 25.2% in the process-oriented studies CASES and CFL respectively. Adding the officers and crew, the deployment of the *Amundsen* over the 11 seasons of operation represented a total of 120,015 person-days at sea in support of the Canadian-led international effort to study the on-going transformation of the Arctic Ocean.

3.2 Linkages (see also Section 2.4). As outlined in previous sections, networking the Canadian and international Arctic Ocean science community is the trademark of the Platform. Each of the 18 major programs supported by the *Amundsen* is, by definition, a research network bringing together teams from many universities and federal departments into a multidisciplinary initiative to understand the Arctic Ocean or monitor the health of the communities living on its shores. These national and international collaborations have propelled Canada in the leading pack of nations studying the Arctic, as exemplified by the outstanding Canadian contribution to the International Polar Year (\$193M overall, including major programs such as CFL and the Inuit Health Surveys) that culminated with the venue of the IPY closing meeting in Montréal in 2012, where over 3,000 delegates exchanged expertise under the theme From Knowledge to Action.

To illustrate the *Amundsen*'s potential at bringing together researchers, we briefly describe here four networks/programs that span the spectrum of linkages forged through the Platform.

Circumpolar Flaw Lead System Study (CFL). The Circumpolar flaw lead is a linear polynya that extends around the Arctic basin, separating the mobile central ice pack from the fixed landfast ice. As other polynyas studied by the International Arctic Polynya Program, it can be viewed as a model of a future seasonally ice-free Arctic Ocean. The massive CFL program mustered the expertise of 370 researchers from 22 countries during the circum-annual 2007-2008 expedition of the *Amundsen* to decipher the secrets of the Beaufort Sea segment of the CFL in Amundsen Gulf. One of the most productive programs of the International Polar Year, CFL consolidated Canada's position in the study of the Arctic Ocean. An extensive communication plan brought on board 15 science reporters from all over the world to showcase Canadian-led international science.



Qanuippitaa? Co-funded by ArcticNet, the Ministère de la Santé et des Services Sociaux du Québec (MSSS), the Regional Board of Health and Social Services of Nunavik, the Northern Contaminants Program and the Canadian Institutes of Health Research, the *Amundsen*-based health survey *Qanuippitaa?* (*How are we?*) revealed the alarming deterioration of the physical and mental condition of the Inuit of Nunavik. Relative to 1992, suicidal ideation and attempts (35% occurrence), sexual abuse (50% of female respondents), obesity, diabetes, anaemia (40% of women) and high blood pressure (14.5%) had all increased substantially by 2004. Processed food is increasing in the diet: 70% of Inuit consume “junk” food at least thrice a day and 50% of Inuit drink soda pop every day. These and other findings have resulted in several reports and recommendations to the Quebec and Nunavik health authorities. Most importantly, during IPY

the successful approach of *Qanuippitaa?* was expanded to the three other Canadian Inuit regions with the *Amundsen* visiting Nunavut, the Inuvialuit Settlement Region and Nunatsiavut to conduct the IPY-funded *Inuit Health in Transition Studies*.

Takuvik. On 19 July 2010, a remarkably innovative international partnership was inaugurated with the creation at Université Laval of the Canada-France Unité Mixte Internationale (UMI) *Takuvik: the international centre for the study and modeling of arctic and subarctic ecosystems and geosystems*. The strategic objectives of Takuvik are (1) to provide French polar specialists with access to the Canadian Arctic and Canada's northern research infrastructure, and (2) to enrich the on-going Canadian effort with scientific and engineering expertise from France. Takuvik brings in residence at Université Laval several French experts in arctic sciences and engineers. The salaries, premiums for life abroad, and research budgets of the French participants are covered by the French Centre National de la Recherche Scientifique (CNRS), a major contribution to Canada's arctic effort, which is expected to increase rapidly as the UMI expands. During its first instalment, the highly international Takuvik brought together the expertise of 11 researchers, 26 technicians and engineers, and 36 graduates and postdoctoral fellows from France, Canada and several countries. The Platform is the main infrastructure supporting the marine component of the UMI research program, enabling major Takuvik-led international initiatives such as Malina and Green Edge. (see: www.takuvik.ulaval.ca)

ArcticNet: a Network of Centres of Excellence to study the changing coastal Arctic (2004-2018). ArcticNet is Canada's Network of Centres of Excellence that brings together scientists in the natural, human health and social sciences with their partners in Inuit organizations, northern communities, governments and industry to help Canadians face the impacts and opportunities of climate change and globalization in the Arctic. The multi-sectoral Network involves over 140 researchers and 1000 graduate students, post-doctoral fellows, research associates, technicians and other specialists from 30 Canadian universities; numerous federal, provincial and regional departments; Inuit communities and the private sector and over 150 partner organizations both nationally and internationally. The *Amundsen* and its equipment form ArcticNet's core infrastructure for supporting the large ocean-based component of its research program. Of the 38 core research projects presently funded by ArcticNet, the following 17 rely on the Platform to access the coastal Canadian Arctic and its communities:

- *Climate Change and Contaminant Cycling in the Marine Ecosystem* (U Manitoba)
- *The Canadian Arctic Seabed: Navigation and Resource Mapping* (U New Brunswick)
- *The Law and Politics of Canadian Jurisdiction on Arctic Ocean Seabed* (UBC)
- *The Arctic cod ecosystem, climate change and industrialization* (U Laval)
- *Remote Sensing of Canada's New Arctic Frontier* (U Laval)
- *Climate analysis and scenario for the Canadian Arctic and Subarctic* (EC)
- *Marine Biological Hotspots: Ecosystem Services and Climate Change* (U Laval)
- *Climate Change and Commercial Shipping in the Arctic* (U Laval).
- *Arctic Geomicrobiology and Climate Change* (U Manitoba)
- *Polar Data Management for Northern Science* (U Waterloo)
- *Carbon Exchange Dynamics in Coastal Marine Ecosystems* (U Manitoba)
- *Freshwater-Marine Coupling in Hudson Bay* (U Manitoba)
- *Impacts of Global Warming on Arctic Marine Mammals* (U Manitoba/DFO)
- *Long-Term Observatories in Canadian Arctic Waters* (U Laval/U Manitoba)
- *Sea Ice, Climate Change and the Marine Ecosystem* (U Manitoba)

- *Effects of Climate Change and Modernization in Nunatsiavut* (Memorial U)
- *International Inuit Cohort Study: Developing the Next Phase* (U Laval)

In addition, thanks to the availability of the *Amundsen*, ArcticNet has developed major research partnerships with the Petroleum Exploration and the Hydroelectricity sectors active in the Canadian Arctic. www.arcticnet.ulaval.ca

3.3 Research contributions

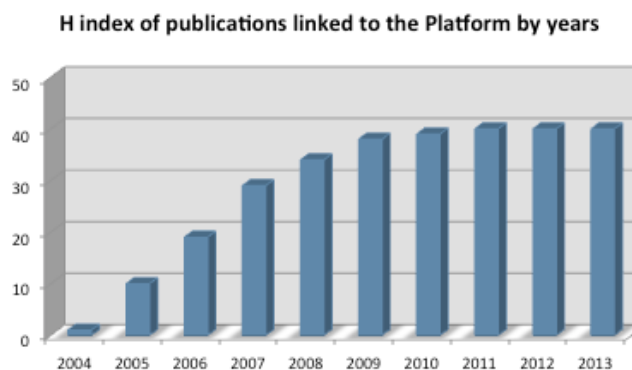
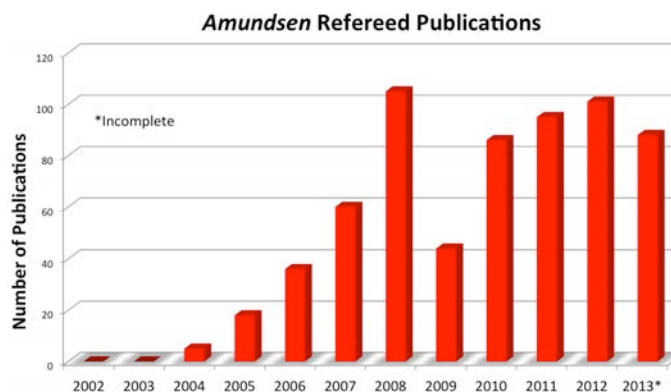
Research achievements. Among hundreds of scientific breakthroughs enabled by the Platform, we present 20 examples to illustrate the scope and quality of the scientific program:

- The first major CDOM photochemistry study in the Arctic Ocean has revealed the role of photo-oxidation in controlling the fate of terrestrial organic matter and the unusual cycle of carbon monoxide in this climatically sensitive region;
- Experimenting on board the *Amundsen*, American exo-biologists explained the winter survival of sea-ice Bacteria and Archaea under extreme temperatures by the production of exopolymeric cryoprotectants that could be used in new biomedical applications;
- A new UK-Canada-France collaboration discovered that the ^{13}C isotopic composition of a monoene hydrocarbon (IP₂₅) specific to sea-ice diatoms and ubiquitous in high latitude sediments can be used as a proxy of past sea ice regime over the last 10,000 years;
- A new collaboration with ROPOS (U Victoria) led to the successful deployment of the Remotely Operated Vehicle (ROV) through the moon pool of the *Amundsen*. From cold water corals to mud volcanoes, from exquisite pelagic ctenophores to ice amphipods, the ROV is providing unique insights into the under-ice pelagic and benthic ecosystems;
- Despite low concentrations of inorganic mercury, the toxic methylated form of mercury is abundant in mid and bottom waters, suggesting that contamination levels high enough to pose health risks in traditional marine food could originate from *in situ* methylation;
- A new algorithm (blue-to-green ratio of the SeaWifs signal) for the remote sensing of surface particulate organic carbon (POC) predicts well the POC flux measured by sediment traps at 100 m ($r^2 = 0.78$), opening the possibility to remotely sense and model over large spatial extents the flux of biogenic carbon out of the euphotic layer under ice-free conditions;
- Safely navigating the rotting summer ice with the Skippy Boat, SCUBA divers equipped with semi-closed re-breathers discovered dense aggregations of zooplankton at the interface between the salt waters and a 30-50 cm thick melt-water layer under the ice;
- Several zooplankton new to science (5 species and 2 genera for copepods alone) were discovered in the benthic boundary layer of the Beaufort Sea. The fatty acids and stable isotopes signatures of these strange critters confirmed the impact of the Mackenzie River on the deep ecosystem;
- Large-volume sea ice samples obtained revealed a surprisingly high diversity of the ice meiofauna with taxa new to this habitat, such as cnidarians, rhabditophore, and plathelminthes, and a first report of abundant rotifers in the sea ice of the Canadian Arctic;
- A German-Canadian collaboration measured the strength of the pelagic-benthic coupling in unprecedented detail to conclude that the influence of the sea ice regime on this key process is more complex than commonly assumed before;
- Zooplankton and fish vertical distributions are monitored continuously with the EK-60 hydroacoustic system of the *Amundsen*. Validation of the echograms by trawls revealed large aggregations of Arctic cod over the slope, solving the mystery of the missing Arctic cod biomass;
- Sediment traps moored at the edge of the Canadian Arctic Shelf elucidated how thermohaline convection due to ice formation, atmospheric cyclones, and underwater storms transport particulate organic carbon and sediments from the shelf to the deep interior ocean;

- The powerful multi-beam mapping sonar of the *Amundsen* has detected active methane seeps in the North West Passage and the ROV explored these structures for possible methane-based ecosystems;
- Circular scours detected by the multi-beam system indicate that the immense glacial lake Agassiz-Ojibway that covered western Hudson Bay 8470 years ago emptied in 24 hours in a cataclysmic event that sent gigantic icebergs waltzing away;
- After sailing the alarmingly ice-free North West Passage on board the *Amundsen*, ArcticNet's specialists of international law reiterated the urgency for Canada to unilaterally declare the Arctic Archipelago as internal waters on the basis of the strait base-lines doctrine;
- Coupled to satellite-born sensors, the sophisticated detectors of the *Amundsen* estimate the air-sea exchange of CO₂ in the Canadian Arctic Ocean, leading to the conclusion that Hudson Bay is a carbon source in summer, in stark contrast with other Arctic seas;
- As part of the Nansen-Amundsen Basin Observational System (NABOS), instruments from the *Amundsen* pool monitored the accelerated intrusion of Atlantic Water (AW) along the Siberian Shelf anticipated by numerical simulations of future climate;
- Mercury levels in the marine arctic ecosystem over the last 60 years have been reconstructed from the analysis of archived beluga teeth. Coal banks along the Mackenzie River have been identified as potential "hot spot" sources of mercury;
- Immense aggregations of Arctic cod have been discovered on the shallow shelves in winter and newly-developed passive acoustic hydrophones revealed the presence of large whales in southern Hudson Bay and the Beaufort Sea in winter;
- The flow of bathymetric data collected by the *Amundsen* is uploaded to the web on a continuous basis providing stakeholders with key products on marine geohazards, new shipping lanes, navigational charting, and past to present evolution of sea-ice regime;
- Satellite imagery validated by observations at sea from the *Amundsen* revealed the recent increase in the frequency of fall phytoplankton bloom in Arctic seas in response to later ice formation and more intense wind mixing that replenish the surface layer in nutrients. This much-mediatized discovery could herald a shift in the ecosystems of the Arctic Ocean.

Overall research influence and reach. After 11 seasons of operation, the massive scientific and technological returns of the Platform are clearly emerging. International arctic meetings are often dominated by Canadian contributions, and the programs supported by the *Amundsen* are producing large numbers of primary publications, communications and special issues. The acquisition of the most advanced versions of oceanographic instruments and their adaptation to the extreme conditions of the ice-covered Arctic Ocean have provided Canadian researchers with a new and extremely valuable expertise. The Platform has also facilitated the development of new instruments such as the underwater hydrophones deployed on moorings to record marine mammal vocalisations, and the adaptation to arctic conditions of several existing systems such as the Underwater Video Profiler for microzooplankton, the LOKI profiling mesozooplankton imager, the Remotely Operated Vehicle, and several instruments (radiometers, scatterometers, etc.) that are deployed on the ship and its launches that provide unique information for the calibration and ground-truthing of satellite signals. As early as 2008, this burgeoning expertise gained much recognition by attracting to Quebec City the prestigious Oceans Conference under the theme: *Oceans, Poles and Climate: Technological Challenges*.

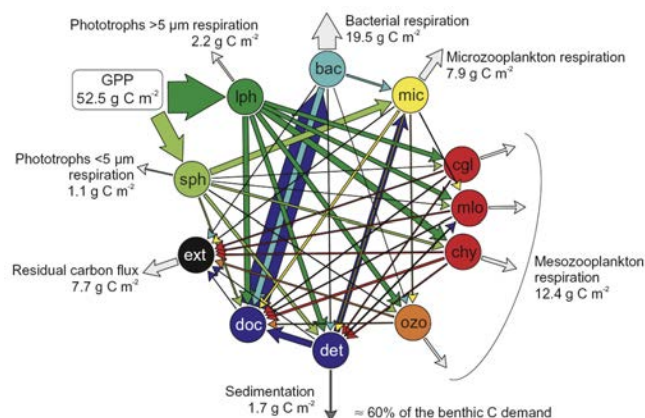
Yet, the most immediate scientific outcome of the Platform and its pool of state-of-the-art equipment has been the production of ever-higher quality peer-reviewed publications (Figure right). Cycles in this production follow the implementation of the large international programs supported by the Platform. It peaked in the aftermath of CASES, and then decreased immediately after the intense fieldwork of the IPY (2007-2008), to grow again in recent years. The impact of the science enabled by the *Amundsen* can be measured by the evolution of the debated but popular H index (number H of publications cited at least H times). The *Amundsen* H index calculated at present (October 2014) increases rapidly by about 10 units per year from the base year to 2007 (Figure right). The progression then slows down and H reaches a plateau of 40 in 2011 because recent papers added to the pool have not yet been fully cited in the literature. Based on the initial slope of the progression (10 H units per year from 2004 to 2007) the *Amundsen* H calculated in the future (say in 2030 when citations have stabilized) for 2014 (one decade after the base year) should reach about 100 (100 articles cited at least 100 times each).



Research approach. As expounded in several sections above, the availability of the Platform has enabled Canada to bring in Big Science to study the ecosystem-level issues raised by climate change and industrialization in the Canadian Arctic. A review of the projects supported by the Polar Continental Shelf Project over the past 30 years clearly indicates that Canadian efforts in the Arctic have been dominated by single-discipline projects, typically involving one or two laboratories and looking at one specific compartment of the Arctic system. With CASES and CFL and many other projects supported by the *Amundsen*, all the major fields of oceanography (geology, sedimentology, paleoclimate, biogeochemistry, biology, ecology, sea-ice and atmospheric sciences, climate and modeling) have come together into highly concerted international efforts to resolve the functioning of the marine arctic ecosystem and its response to climate forcing. With ArcticNet, collaboration now cuts across the traditional boundaries among the natural, health and social sciences as specialists of the arctic environment, the health of Inuit and northern social sciences come together to assess the regional-scale impacts of climate warming and modernisation. Inuit and northern industries are engaged at all steps in the development of Integrated Regional Impact Studies (IRISes) that aim to contribute to the formulation of policies and adaptation strategies that minimize the negative impacts and maximize the positive outcomes of the transformation of the Arctic.

Research opportunities. From the surveys of Inuit health to the detection of deep methane plumes, from the assessment of the risks associated with offshore exploration drilling to the direct observation of cold corals in central Baffin Bay, a myriad of examples of scientific issues that could not be addressed by Canadian specialists before the Platform come to mind. Among the most seminal are (1) the integrative model of the biogeochemical carbon fluxes dictating life in the frigid waters of the Beaufort Sea

(Figure right); (2) the first-time detailed description of the winter ecosystem of the Arctic Ocean thanks to the double overwintering expeditions of the *Amundsen* (2003-2004 and 2007-2008); (3) the exploration of the geophysical processes that formed the seafloor of Canadian arctic seas including for example the spectacular reconstruction of the emptying of the immense Agassiz-Ojibway glacial lake in the early Holocene; (4) solving the mystery of the missing Arctic cod by the offshore deployment of sophisticated sonars; (5) the bathymetric mapping of the Northwest Passage; (6) the discovery of the role of ice-free water in the multiplication of atmospheric cyclones (storms) at the periphery of the Arctic Ocean; etc.



3.4 Leadership and competitiveness.

Global competitiveness. Abroad, a select club of nations conduct polar programs thanks to large and powerful research icebreakers designed for science and funded by statutory operation budgets, such as the German *Polarstern*, the American *Healy*, the Swedish *Oden*, the Korean *Aaron* and the Chinese *Xue Long*. For example, the 118-m double-hulled *Polarstern* can steam through 2 m thick ice at 5 knots and break ice up to 3 m thick. It hosts nine research laboratories for biological, geological, geophysical, glaciological, chemical, oceanographic and meteorological research. Additional laboratory containers may be stored on and below deck. Samples and live marine fauna can be studied in refrigerated rooms and aquaria. A battery of sonars is operated continuously. The layout of the decks is designed for science with most operations conducted from aft thanks to powerful scientific winches hidden below deck, a trawl ramp and a gigantic A-frame. By comparison, the 98-m *Amundsen* was built in 1980 as a normal icebreaker and modified *a posteriori* for science in 2003. Its lesser displacement, ice-breaking capacity and size, as well as the layout of its decks and the deck equipment it can accommodate, cannot rival those of the mighty *Polarstern*. But the comprehensive equipment pool of the *Amundsen* certainly matches that of any research icebreaker.

“Funding from the Canada Foundation for Innovation (CFI) has enabled a complete overhaul and refitting of the CCGS *Sir John Franklin*, renamed the CCGS *Amundsen*, a “state of the science” facility arguably superior to any existing arctic science icebreaker in the world.”

Beacons of the North: Research Infrastructure in Canada’s Arctic and SubArctic
Canadian Polar Commission, June 2008.

Leading-edge research of national and international importance. Combined to modernization, climate change has profound and amplifying impacts on the environment, geopolitics, economy, human health, and societies of the Arctic. Arctic issues have moved to the very forefront of the Canadian and international political agendas: How can we exploit the offshore oil and gas of the Arctic with minimum impact to the environment? When and how will the Northwest Passage open to intercontinental traffic? What role will a seasonally ice-free Arctic Ocean play in the sequestration of atmospheric carbon? Will new, richer fisheries develop over a seasonally ice-free Canadian Arctic Shelf? Will methane released by the warming Arctic shelves further destabilize Earth's climate? How can Inuit societies adapt their crumbling health system to emerging diseases? What new economic opportunities will arise as the Canadian Arctic warms and opens to industrialization?

From the start, the Platform aimed to network Canadian arctic specialists and to attract international collaborations in the study of the Canadian Arctic. Hence, the typical user programs are nationally and/or internationally peer-reviewed endeavours of the highest scientific merit that undertake to answer the fundamental questions above in a multidisciplinary, international and logistically coordinated way. Under the close supervision of the Boards of Directors of the *Amundsen* and ArcticNet, academic users and the private sector also use the Platform to conduct research partnerships on the potential risks and impacts of industrial activities. Since the base year, the *Amundsen* has supported internationally reviewed and highly successful endeavours such as the NSERC Canadian Arctic Shelf Exchange Study (CASES, 2002-2008), the Nunavik Inuit Health Study (2004-2007), and the Network of Centres of Excellence ArcticNet (2004-2018). It has played a pivotal role in deploying several projects of the Canadian International Polar Year (2007-2009) including the Circumpolar Flaw Lead System Study, the Inuit Health Surveys of Nunavut, Inuvialuit, and Nunatsiavut, IPY-Geotraces, OASIS-Canada, Arctic-SOLAS, and the Canadian Healthy Oceans Network (CHONe). Since 2009, the icebreaker has been the cornerstone of major research partnerships with the Petroleum Exploration sector to assess the risks of drilling in the offshore Beaufort Sea. It also supports 4 research projects of the Beaufort Regional Environmental Assessment (BREA), NSERC NetCare, Arctic-Geotraces, and Japan's JAMSTEC operations in the Canada Basin.

Technical and research leadership. Perhaps the best indicator of the national and international leadership of the research users of the Platform is the number of Canada Research Chairs (CRC), Canada Excellence Research Chairs (CERC) and other excellence research chairs they hold:

- Babin, M. CERC in remote sensing of Arctic Ocean color (U Laval);
- Barber, D. CRC in Arctic-System Science (U Manitoba);
- Byers, M. CRC in Global Politics and International Law (UBC);
- Chan, L. BC Leadership Chair in Aboriginal Environmental Health (UNBC);
- Egeland, G. CRC in Environment, Nutrition and Health (McGill);
- Fortier, L. CRC in Arctic Marine Ecosystems and Climate Change (U Laval);
- François, R. CRC in Marine Geochemistry for Global Climate Change (UBC);
- Hughes Clarke, J. NSERC Industrial Chair of Ocean Mapping (U New Brunswick);
- Juniper, K. BC Leader Research Chair in Marine Ecosystems and Global Change (U Victoria);
- Levasseur, M. CRC in Plankton-Climate Interaction (U Laval);
- Maldonado, M. CRC in Phytoplankton Trace Metal Physiology (UBC);
- Murphy, J. CRC in Atmospheric and Environmental Chemistry (U Toronto);

- Rysgaard, S. CERC in Arctic Geomicrobiology and Climate (U Manitoba);
- Simard, Y. Fisheries and Oceans Canada Research Chair in Marine Acoustics (UQAR);
- Stern, G. Fisheries and Oceans Canada Research Chair on Arctic contaminants (U Manitoba);
- Thomas, H. CRC in Marine Biogeochemistry (Dalhousie);
- Vincent, W. CRC in Aquatic Ecosystem Studies (U Laval);
- Young, K. TransCanada Pipelines Chair in Aboriginal Health and Wellbeing (U Toronto).

To illustrate the intellectual leadership resulting from the Platform, we present the biographical sketches of six of its main users.

Louis Fortier. CRC Tier 1. Scientific Director – ArcticNet and Takuvik; Scientific Leader – *Amundsen*; Founding Director – Québec-Océan. Led the Canadian participation to the Northeast Water Polynya Study. Led the NOW (International North Water Polynya Study) and CASES NSERC Research Networks. Authored/co-authored over 120 publications on arctic and boreal biogeochemical carbon fluxes, plankton and fish. H = 26. Supervised 16 Ph.D., 13 M.Sc. and 11 postdoctoral fellows. Diplômé émérite du Séminaire St-Joseph 2014. Timothy R. Parsons Award for excellence in Ocean Sciences 2012; Weston Family Prize for Lifetime Achievement in Northern Research 2012; Governor General Northern Medal 2011; Prix Armand-Frappier – Prix du Québec 2010; Stefansson Medal of the Explorers Club 2009; Scientific Personality 2008 – Le Soleil/Radio-Canada; Lauréat de Québec 2008 – Le Soleil/Radio-Canada; Officier de l'Ordre national du Québec 2008; Officer of the Order of Canada 2007; Honorary Ph.D. from the University of Manitoba 2007; Grand Diplômé and Gloire de l'Escolle of Université Laval 2006; Scientific Personality 2005 - La Presse/Radio-Canada; Scientist of Year 2004 - Radio-Canada; Lauréat de Québec 2004 – Le Soleil/Radio-Canada.

David Barber. CRC Tier 1. Founding Director of the Centre for Earth Observation Science (University of Manitoba). Led or co-led several large scale International Arctic Research Programs including IPY-CFL, ArcticNet, CASES, NEXTAW, BaySys, SIMMS, and the Sea Ice Environmental Research Facility (SERF). Published over 200 papers in the peer reviewed literature; H = 34. Has supervised to completion: 6 honours theses; 21 MSc theses; 19 PhD dissertations and 17 postdoctoral fellows/Research Associates. Twenty of his previous students have University positions and 30 work in research, consulting or government. Currently supervises 9 MSc students; 6 PhD students, and 19 Post Doctoral Fellows/Research Associates. Distinguished Professor (University of Manitoba); RH award (Natural Sciences); Fellow - Canadian Geographical Society.

Søren Rysgaard. CERC in Geomicrobiology and Climate Change. Scientific leader - Arctic Science Partnership. Founding Director – Greenland Climate Research Centre (Greenland), Arctic Research Centre (Denmark). Led several large science projects in the arctic (NOG, CAMP, Anoxia, Sea Ice dynamics, FreshLink, GCRC) and initiated two long-term marine monitoring programs (High- and Sub-arctic). Played a key role in science infrastructure build-up in the Arctic. Authored/co-authored over 140 publications on arctic and biogeochemical processes. H = 37. Has supervised 16 Master Students and 21 PhD students.

Gary Stern. Professor, University of Manitoba. Associate Director, Centre for Earth Observation Science. Senior Research Scientist, Fisheries and Oceans Canada (retired). Co-led the IPY funded Circumpolar Flaw Lead (CFL) system study. PI in large multidisciplinary Arctic research programs such as CASES, ArcticNet and BaySys. He leads the ArcticNet

western high Arctic IRIS, Canadian co-Chair of the Beaufort/Bering/Chukchi Regional Implementation Team of the Arctic Council's Adaptation Actions for a Changing Arctic (AACA) initiative. Has published over 140 manuscripts in the peer reviewed literature and 8 book chapters; H = 36, times cited = 4684. Has supervised or co-supervised 5 undergraduates, 10 M.Sc. and 8 PhD students, 8 postdoctoral fellows. Deputy Ministers Distinction Award for outstanding achievements and contributions in furthering the objectives of the Department or the Government of Canada (2013).

Marcel Babin. CERC on Remote sensing of Canada's new Arctic frontier. Founding Director – Takuvik Joint International Laboratory (CNRS and U. Laval). Scientific leader - COASTOOC, HABWatch, Malina and Green Edge major international projects on marine optics and remote sensing in Arctic and elsewhere. Past member of several steering committees of international science programs, including GEOHAB and COOP-GOOS. Current president of the scientific steering committee of the French Arctic science national program. Strong interactions with 4 space agencies (CNES, ESA, CSA and NASA). Authored/co-authored over 90 publications on light-matter interactions in the ocean, cited >5000 times. H = 37. Supervised 12 PhD students, and 14 postdoctoral fellows.

Steve Blasco. Marine Engineering Geophysicist, Geological Survey of Canada; co-lead for ArcticNet Seabed Mapping Project from 2004 to 2014 including annual field programs onboard the CCGS *Amundsen* in the Northwest Passage. Led more than 50 marine scientific field programs on more than 20 research vessels, including as international chief scientist of the joint US-Russia-Canada investigation of the Titanic wreck site. Authored/co-authored over 110 reports and publications related to his research on seafloor and lakebed geological investigations with environmental and engineering applications. Queen Elizabeth Diamond Jubilee Medal for contributions to the nation 2012; Century of Service Gold Award for a career of Achievement, Challenge and Community Service 2012; Distinguished Merit Award, Government of Canada for achievement in the synthesis of Beaufort Sea seabed geohazard research affecting offshore hydrocarbon development 2010; Distinguished Merit Award from the Government of Canada for communicating science to northern communities 2010.

Recognition of the Platform. Thanks to a solid Communications Plan (see Section 4.1), over 550 online/printed news stories and radio and television broadcasts have focused on the Platform and its scientific program since 2003. Nationally, some examples include: Discovery Channel's *Mighty Ships*, *Canadian Geographic*, CBC's *The Nature of Things*, Radio-Canada's *Découverte*, *The Globe and Mail*, *Toronto Star*, *Montreal Gazette*, *Le Devoir* and *Ottawa Citizen* as well as northern news outlets like *Nunatsiaq News* and *Up Here* magazine. Abroad, the *Amundsen* has been featured in over 20 countries on BBC, CNN, *Dan Rather Reports*, NBC's *The Today Show*, *Al Jazeera*, *Nature*, *TIME*, and *GEO*.



The Platform is increasingly used to showcase Canada's growing scientific presence in the Arctic. Since the August 2003 inauguration attended by over 400 political and scientific personalities, many delegations and members of the general public have visited the *Amundsen* on numerous occasions. Several examples to illustrate the diverse aims of these visits include:

- March 2004. With two colleagues, Dr. T. Brzustowski then President of NSERC joins the *Amundsen* during her overwintering in Franklin Bay (Beaufort Sea) to appraise the scope and magnitude of the scientific operations.
- October 2005. As part of discussions to develop a research partnership with Manitoba-Hydro, a delegation of 21 comprising Manitoba Provincial Members of Parliament, Federal Members of Parliament, the University of Manitoba President, Associate VP Research, senior representatives of Manitoba Hydro and the Port of Churchill, and the Mayor of Churchill are welcomed on the *Amundsen* in Churchill for planning.
- December 2005. Docked in Montreal during the 2005 United Nations Climate Change Conference (COP 11), the ship welcomes several dignitaries and nearly 1000 attendees.
- August 2006. CFI President Dr. E. Phillipson and representatives from NSERC and the NCE visit the ship and meet with scientists from participating universities to appraise the research capabilities of the Platform and its newly augmented pool of equipment.
- October 2006. King Carl XVI Gustaf of Sweden and his retinue are welcomed aboard in Quebec City to discuss the threat of climate change and the urgency of using our observations of Arctic warming to stimulate the response of governments to this threat.
- March 2008. High-ranking Inuit representatives from Nunavik, Nunavut and the Inuvialuit Region Settlement join the icebreaker adrift in the ice of Amundsen Gulf as part of the CFL overwintering expedition, to learn about the science capacity of the *Amundsen* and the research program of ArcticNet.
- July 2010. To further develop the research partnership with Manitoba Hydro, a delegation of 17 from the Manitoba and Nunavut governments, University of Manitoba, and industry are welcomed on the *Amundsen* in Churchill.
- August 2011. The International Science Summit hosted in the NW Passage, welcomes Canadian and international dignitaries to exchange information on Arctic geopolitics, and develop and solidify Arctic research partnerships. Among 14 participants: Michel Rocard, former French Prime Minister and current Ambassador to the Poles for France, the Rector of Université Laval, Astronaut Julie Payette (then Quebec's Scientific Delegate to the USA), two ambassadors, and two Quebec Ministers.
- April 2012. As part of the International Polar Year conference in 2012, the *Amundsen* was docked in Montréal for an open house. Over 2000 members of the public, media and international dignitaries visited the ship during the week of the conference.
- May 2014. As India joins the Arctic Council as observer, the High Commissioner to Canada visits the CCGS *Des Groseillers* (the *Amundsen*'s sister ship) to report on the science capabilities of the Platform and the scientific program of ArcticNet.
- June 2014. A delegation of 24 from the International Space University discusses satellite support to the *Amundsen* research program as part of the 27th Space Studies Program (SSP14) Conference.

Finally, the Bank of Canada relies on opinion groups representative of all strata of Canadian society to select the themes that will illustrate new banknotes. That the *Amundsen* was chosen to adorn Canada's new polymer \$50 denomination is perhaps the most spectacular indicator of the importance of the Platform, its research accomplishments, and its visibility in the media. This extraordinary recognition crystallizes the



role of the *Amundsen* as a symbol of the recently renewed awareness of the general public and Canadian authorities for Canada's arctic dimension.

Mechanisms to enhance competitiveness. The national and international community of polar specialists is relatively small and well connected. Moreover, dedicated research icebreakers can be counted on the fingers of two hands. Hence, potential users of the *Amundsen* are generally well aware of its existence and exceptional science capabilities. The availability of the Platform for Canadian and international researchers is advertised on the web site of the *Amundsen* and ArcticNet and through presentations (oral, poster, flyers, and kiosk) at national and international meetings attended by the community of Arctic researchers and research groups. The Scientific Leader regularly organizes or attends international workshops to coordinate Arctic research and the international use of the *Amundsen*. For instance, the international deployment of the *Amundsen* and other arctic platforms was discussed in depth in Rome in 2013 at a meeting initiated by the CFI. Overall in 2013, the Scientific Leader travelled to Tokyo (twice), Seoul, New Delhi, Berlin, Paris, Brussels, and Rome to present the *Amundsen* and its international research mandate.

In addition to these targeted initiatives, we suspect that the wide media coverage of the ship's research activities is perhaps our best tool to help the user community secure the funds needed to charter the Platform. Politicians, decision makers, officers of funding agencies, evaluators of research proposals, and potential users of the Platform in academia, the government and the private sector all watch TV and read newspapers. Hence, we believe that our communications plan has created a general awareness of the Platform, its capabilities, and the urgency of its mission that helps convince national and international agencies to fund projects on the *Amundsen*. By demonstrating that we can lead big multidisciplinary and international science of relevance to fundamental issues in its Arctic territories, the visibility of the *Amundsen* likely influenced Canada's decisions to invest massively in the IPY program (2007-2012), the Canadian High Arctic Station (2018) and the polar-class icebreaker *Diefenbaker* (2023).

4. Extrinsic Benefits - Impact on Local, Regional, and National Innovation

4.1 Mechanisms and strategies for fostering knowledge transfer

Outreach to end-users. The Platform produces scientific knowledge to inform decisions and strategies with the overarching goal of helping Canada respond to climate change and industrialization in the coastal Canadian Arctic. The main end users are northern communities that depend on marine ecosystems services; industries active in the coastal Canadian Arctic (oil exploration, hydropower, shipping, tourism); provincial governments; and several Federal departments with an arctic mandate (Fisheries and Oceans Canada, Natural Resources Canada, Environment Canada, Health Canada, Aboriginal Affairs and Northern Development Canada).

As part of its Strategic Plan, the Platform's approach to connect with the end-users is based on their direct engagement in the research process. First, representatives from the different end-user categories (Inuit officials, industry representatives and government officers) make up the Boards of Directors of the *Amundsen* and ArcticNet where they influence directly the research program supported by the Platform. Second, all programs sponsored by ArcticNet, including the Inuit Health Surveys and the industrial partnerships, are designed from the start to answer the needs for information of end-users. Third, thanks to a recent evolution in the objectives of Canadian and foreign funding agencies, other programs supported by the Platform are increasingly evaluated on their capacity to deliver information that supports socioeconomic innovation.

In addition to scientific primary publications (Section 3.3), the scientific knowledge generated by the Platform is transmitted by various means to end-users: health brochures in Inuktitut reaching individual Inuk; scientific reports to the petroleum exploration industry and other end-users; workshops with end-users; the uploading of bathymetric data on the web for mariners; international panels to discuss the geopolitics of the Arctic, etc. The ArcticNet Annual Science Meeting (ASM) is another extremely popular mechanism where hundreds of arctic specialists and end users gather annually to exchange knowledge and update the research program.

But the most advanced protocol used by the Platform users to make available their often-cryptic science to decision makers and policy makers is ArcticNet's Integrated Regional Impact Study (IRIS) framework (Section 4.3). The IRISes prepared for the four regions of the Canadian Arctic, in which many users of the Platform participate, are developed after a careful analysis of the concerns of end users and are written in layman's terms. Based on climate scenarios for each region they anticipate the general response of geosystems, ecosystems, and ecosystem services to change, and provide non-binding recommendations to adapt to those changes. Chapters on human health, sea-ice, marine ecosystems, coastal erosion, and fisheries are rooted in research conducted on the *Amundsen*.

Public engagement. Thanks to a fascination for the Arctic, its communities and the work of arctic scientists, the general public is an important receptor of the Platform's activities. A first mechanism to communicate the Platform's research program to the public is to allow professionals in the film, television, and printed media to join the annual expedition of the *Amundsen* to the Arctic. Since demand for berths invariably exceeds availability, each year Management evaluates the competing requests from media. The main selection criterion is the expected visibility for the research program of the Platform. Adding radio interviews that do not require presence on board, this first component of the communications plan has resulted in an impressive presence of the Platform in the media (Section 3.4 - Recognition of the Platform).

A second mechanism to reach out to the public is a small *Artists on Board* program that brings performers in the literary, musical, and visual arts fields on the expeditions. Among several examples, joining the icebreaker in the Beaufort Sea for a week in July 2008 the Composer in Residence of the Winnipeg Symphony Orchestra, Vincent Ho, composed three symphonies about the Arctic and the *Amundsen*. Jazz vocalist Emilie-Claire Barlow and guitarist Reg Schwager gave two memorable recitals during the International Science Summit in August 2011 as the *Amundsen* sailed the NW Passage. In 2013 Schwager released the album *Arctic Passage* inspired by his time spent on the *Amundsen*. The paintings created by George Gartrell during the CFL expedition in the Amundsen Gulf poignantly render the atmosphere of the High Arctic (at right and: <http://wwwapps.cc.umanitoba.ca/faculties/environment/ceos/george-gartrell.html>).



Finally, a third mechanism linking the Platform to the public is the immensely successful *Schools on Board* program that brings High School students and their teachers from schools north and south on board the *Amundsen* in the High Arctic for up to 12 days of immersion in exciting science. Since 2004, 88 High School students were exposed to arctic sciences and Inuit culture through the program. In 2008, students from Greenland, Russia, the USA, China, the UK, Spain, Canada, Scotland, Norway, Germany and Sweden participated in the special international edition of the *SoB* program during the IPY. Each student remains in contact with their school via the ship's communications systems, enabling their colleagues and parents to follow their arctic adventure, and once back, they are required to present the results of their voyage to their classrooms.

Impacts. Our strategy to connect with end-users has revolutionized northern sciences in Canada, making the Platform and ArcticNet the main providers of scientific knowledge specifically tailored to answer the needs and concerns of Inuit, the private-sector and governments. In particular, by involving northerners at all levels of the research process and by distilling scientific results in regional assessments written in layman's terms (Section 4.3), our approach has assuaged the long-standing recrimination of Inuit that arctic science does not benefit them and their communities. Interestingly, the Arctic Council is currently using the IRIS framework developed by ArcticNet, with major contributions from the Platform, as a model to downscale its circumpolar assessments of the Arctic to the regional scale. As part of the Council's Arctic Monitoring and Adaptation Programme (AMAP), the IRIS approach will be applied to assessing the impacts of climate change in three regions of the Arctic (BCB: Beaufort-Chukchi-Bering, BBDS: Baffin Bay-Davis Strait, BS: Barents Sea) <http://www.amap.no/documents/download/1918>. The end result for AMAP should be more targeted assessments that better answer the needs for information of local end-users by focusing on regional issues rather than circumpolar change. This is an example of how the research supported by the Platform influences policy and methodology at the highest levels in international cooperation.

As well, the Platform is the fulcrum of unique research partnerships among academia, the petroleum exploration industry, and the federal government to document the risks and

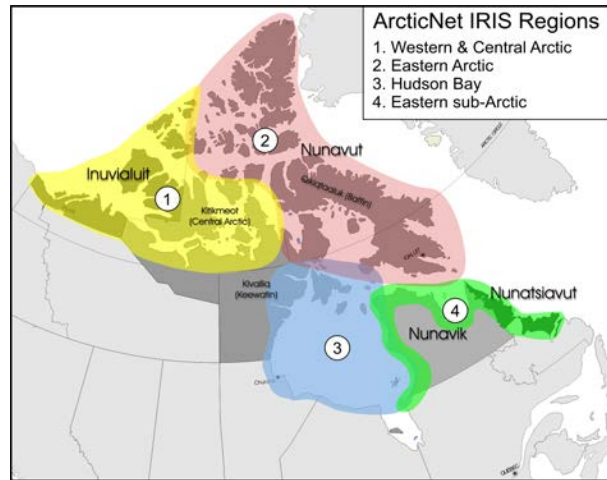
challenges of offshore exploration for oil in the Canadian Beaufort Sea. These partnerships, which have been qualified as “exemplary” by the House of Commons Committee on Fisheries and Oceans, provide all stakeholders with the best scientific data concerning issues such as the stability of the ocean floor, the sea-ice regime, ocean currents, and the regional ecosystems. The non-proprietary knowledge generated by the Platform can be used freely by any party (for example the National Energy Board of Canada, Inuit organizations, NGOs) to inform positions and decisions on the feasibility and safety of exploratory drilling for oil in the offshore Beaufort Sea.

The Platform and its pool of specialized equipment also enable several projects informing programs sponsored by federal departments and provincial governments and utilities. Examples include several components of the BREA (Aboriginal Affairs and Northern Development Canada) and ESRF (Natural Resources Canada), research partnerships with Manitoba Hydro in Hudson Bay, and the Nunavik Health Survey in partnership with Québec Ministère de la Santé et des Services Sociaux (MSSS). The recruitment of HQP in the private sector and in governments is another means by which skills, knowledge and expertise developed on the Platform is transferred to end-users.

Clearly, the success of the Platform’s strategy to foster knowledge transfer to end-users helps maintain and expand the demand for *Amundsen* support: new partnerships are presently being negotiated with other partners in the petroleum exploration sector; the MSSS is investing in a re-edition of the Nunavik longitudinal health survey; iBO (integrated Beaufort Observatory), a partnership among academia, the private sector and government to maintain the monitoring of conditions in the Beaufort Sea, has been retained for funding by the ESRF; BaySys, a partnership with Manitoba Hydro, is in the planning; and the Eeyou Marine Region Workshop in 2014 (<http://www.arcticnetmeetings.ca/EMRS2014/>) could eventually lead to the deployment of the *Amundsen* in James Bay; etc. We are connecting science and action in the Canadian Arctic, and the Platform’s Communication plan helps push Arctic issues to the forefront of the national agenda.

4.2 Partnerships with external end-users. Over the years, the Platform has forged several formal partnerships of different magnitude with end-users. The overall financial contributions (CAD\$) of different end-users to the capitalization of the Platform and the operation at sea of the *Amundsen* are provided in Figures 2 and 3 respectively.

4.3 Knowledge translation and transfer. The Canadian Arctic is a new frontier where the protection of the environment, economic development, and the well being of local communities are sometimes on a collision course. The Platform had a remarkable impact in bringing together local communities and academic-, government-, and private-sector stakeholders into a rich network of collaborations with the aim of informing decisions and policies on a wide spectrum of arctic issues that often lie beyond the immediate research program of the icebreaker. Among many examples, the *Amundsen* was a *sine qua non* ingredient in the creation of ArcticNet and the implementation of its Integrated Regional Impact Study (IRIS) framework. In summary, an IRIS summarizes and combines knowledge and models of relevant aspects of the ecosystems and societies of a region affected by change, with the objective of producing a prognosis of the magnitude and socio-economic costs of the impacts of change. The Network conducts an IRIS in each of the four regions of the Canadian coastal Arctic: Eastern High Arctic, Western High Arctic, the Hudson Bay region and the Nunavik-Nunatsiavut region (Figure above). For each region, an assessment of the present environmental, economic, and public health situation is presented (Figure left). Issues of particular concern to local communities, governments and governance, and the private sector are analysed in a context of climate trends. These include for example the fate of berries production in the tundra, the destabilization of infrastructure by permafrost melt, the future of arctic fisheries, changes in hydraulicity, trends in public health, the future availability of drinking water, etc. Finally, recommendations are made regarding policies and strategies to minimize the negative impacts of change and maximize the positive outcomes. The Platform plays a key role in the ArcticNet's IRIS framework by delivering the marine ecosystem, coastal geosystems, and human health components of the four regional assessments.



4.4 Benefits from knowledge translation and transfer

Among the most important benefits to Canada of the knowledge translation and transfer strategy of the Platform are the impacts of the comprehensive health surveys in all communities of the four Inuit regions of Canada. These not only revealed the alarming health conditions of Canadian Inuit but also led to clear recommendations to improve the situation. For example the *Amundsen*-based health survey *Qanuippitaa? (How are we?)* resulted in several reports and recommendations to the Quebec and Nunavik health authorities and led to the distribution in the communities of 17 information brochures addressing the health concerns of Inuit. The *Amundsen*-based health surveys conducted in the other 3 Inuit regions (Nunavut, Nunatsiavut, Inuvialuit Settlement Region) during IPY are beginning to yield similar benefits, for example an intense campaign to reduce tobacco use.

In the natural sciences, in addition to the impacts of climate change, all the programs supported by the Platform address strategic issues for Canada. For instance, the research partnerships with Imperial Oil and BP, the BREA program, and soon the iBO-ESRF project all document the potential risks and challenges of exploration drilling in the Beaufort Sea, so as to inform positions and decisions by the Petroleum Exploration sector, Inuit communities, and the National Energy Board in the on-going debate on the costs and benefits of offshore drilling in the Arctic (inset right). As well, all 17 *Amundsen*-based projects funded by ArcticNet must contribute to one or several of its four Integrated Regional Impact Studies that aim to inform decisions and policy in northern communities and governances.

In the social sciences, international specialists gathering on the *Amundsen* to explore the Canadian Arctic and discuss its geopolitics are directly informing Canada's position on the NW Passage as well as the position of Canada and other nations involved in boundary disputes in the central Arctic Ocean. Practical results of the research funded by ArcticNet include notably the November 2012 announcement of a tentative Canada-Denmark boundary agreement in the Lincoln Sea based on a solution proposed by our teams on how to extend the boundary beyond 200 nautical miles along or near the Lomonosov Ridge. We also continue to assist the Canadian government with

Following the *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010, the National Energy Board (NEB), Canada's oil and gas regulatory body, was tasked with a review of offshore drilling in the Canadian Arctic (Arctic Offshore Drilling Review 2014). At the request of the NEB and using the vast amount of seabed data (including multibeam bathymetry, sub-bottom, and sediment cores) collected by the *Amundsen* in the Beaufort Sea between 2004 and 2010, the Geological Survey of Canada produced the report, *2010 State of Knowledge: Beaufort Sea Seabed Geohazards Associated with Offshore Hydrocarbon Development* (Blasco et al 2013). The report examines what is and is not known about seabed geohazards (e.g. poor foundation conditions, gas hydrates, permafrost, overpressure in sediments) in the Beaufort Sea region and is currently being used by the NEB for public hearings and community and industry consultations for the purpose of assessing future drilling risks in Canada's North. The seabed data collected from the *Amundsen* is actively contributing to the regulatory process through these consultations and will be used to evaluate future drilling proposals submitted by industry. The state of knowledge report has also been used by industry (IORVL) in preparation of their Environmental Impact Statement, an excellent example of how *Amundsen* data is being used by all stakeholders to ensure that the best possible regulatory decisions are made.

respect to its discussions with the United States over the Beaufort Sea boundary, and with Denmark and Russia over future Central Arctic Ocean boundaries. Our efforts to develop a comprehensive understanding of the issues, including the technical scientific and legal details as well as the geopolitical context, are enabling Canada to identify, explore and explain creative options for win-win solutions that might otherwise not be considered by negotiators.

The mapping of the seafloor using the *Amundsen*'s multibeam sonar and sub-bottom profiler, and the availability of this data on the web, provides precious information for numerous end-users and increases navigational safety in the Canadian Archipelago. Examples of end-users of the bathymetry and sub-bottom data and their region of interest include:

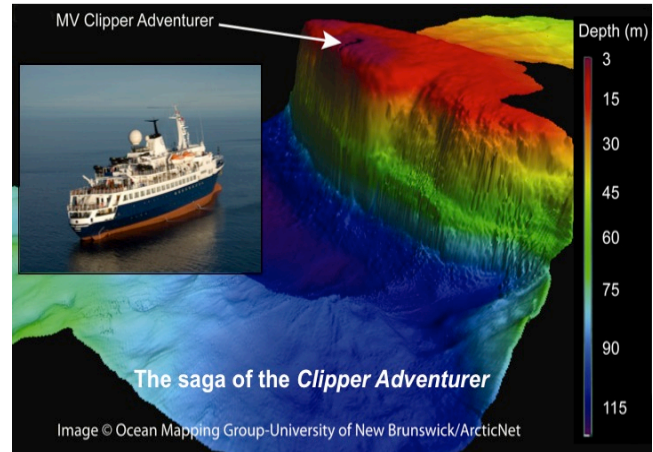
- BP (Beaufort Sea)
- Canada Nunavut Geoscience Office (SE Baffin Island)
- Canadian Hydrographic Service (all data)
- Environment Canada (for Pangnirtung dumpsite)
- Fisheries and Sealing Division, Environment Nunavut (SE Baffin Island)
- Geological Survey of Canada (all data)
- Golder and Associates (Beaufort Sea)
- Imperial Oil (Beaufort Sea)
- Intecsea (Beaufort Sea)
- McGregor Geoscience (Baffin Bay)
- Seaforth Geosurveys (all data)
- U.S. National Geospatial Agency (all data)
- U.S. Naval Oceanographic Office (all data)
- Royal Greenland Fisheries (Baffin Bay)
- Danish Geodata Agency (Baffin Bay)

Among dozens, a few other examples of the societal benefits of the research conducted on the *Amundsen*:

- Assessing Hudson Bay ecosystems in relation to power generation for Manitoba Hydro;
- The Inuit Health in Transition Surveys of Nunavut, Inuvialuit and Nunatsiavut;
- Mapping and modeling coastal erosion and high risk zones along the Arctic Ocean littoral;
- Assessing stocks and trends in fisheries resources in Canadian arctic seas;
- Assessing the impacts of sea-ice regression and ocean acidification on ecosystem services;
- Helping design the science capability of the projected polar icebreaker CCGS *Diefenbaker*;
- Contributing health- and ocean-related chapters in ArcticNet's four Regional Assessments.

Most importantly for Canada, the Platform and its science program have enabled two major multidisciplinary and trans-sector initiatives that have propelled the country in the leading pack of nations that study the ongoing transformation of the Arctic Ocean. First, the *Amundsen* is the cornerstone of ArcticNet, which has transformed the way science is conducted in the Canadian Arctic by involving northerners, the private sector and decision-makers in government, in the research process. Second, the *Amundsen* and ArcticNet provided much of the research capacity that made the Canadian contribution to IPY a spectacular success that culminated with the closing IPY conference in 2012 in Montreal themed “*From Knowledge to Action*”. This theme perfectly mirrors the Consortium’s determination to mobilize the knowledge generated by the Platform to address the arctic challenges faced by Canada.

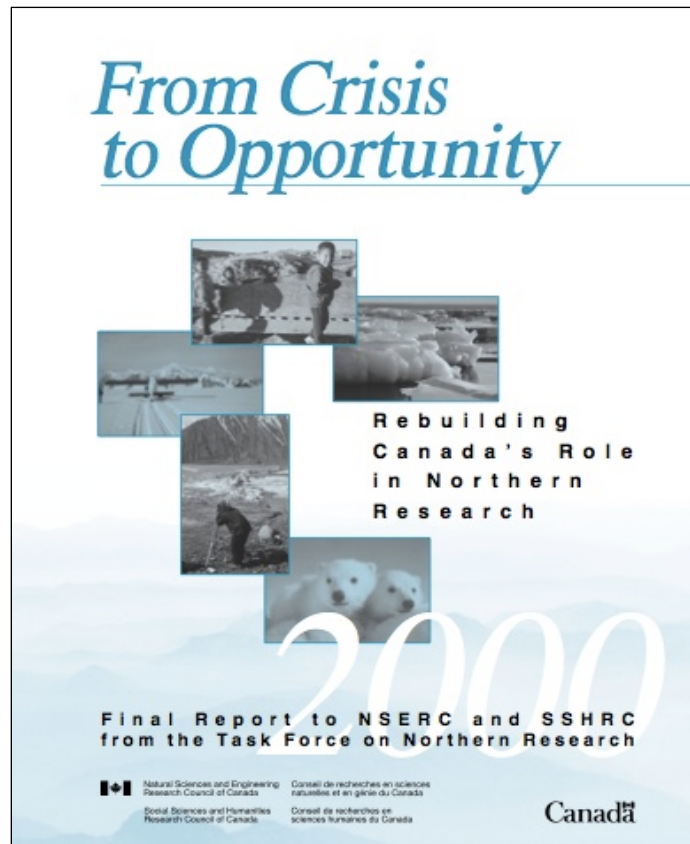
Finally, the research program of the Platform contributes to the scientific basis of all four pillars of Canada’s Northern Strategy. The presence of the *Amundsen*, its vibrant multinational scientific program and the resulting global visibility together forge one of the most convincing affirmations of Canada’s sovereignty on its Arctic waterways (Pillar 1). Sea-floor/geohazards mapping and major research partnerships with industry promote the environmentally safe exploitation of arctic riches and socio-economic development (Pillar 2). The extensive studies and inventories of arctic marine ecosystems and biological hotspots underpin the protection of our environmental heritage in the North (Pillar 3). Inuit Health Surveys and the building of local capacity in the health sector contribute to the improvement and devolution of northern governance (Pillar 4).



Ensuring safety in the Arctic. Before rescuing the 115 passengers of the stranded *Clipper Adventurer*, the *Amundsen* carefully mapped the submarine cliff on which the cruise ship ran aground in the NWP in 2010.

5. Role of the Canada Foundation for Innovation

Scientists from all over the world envy Canada's Network of Centres of Excellence program that encourages synergies among the natural, socio-economic, and health sciences to address complex issues of strategic national and global importance. But many NCEs, including ArcticNet, would not be possible without a central infrastructure around which to rally and coordinate the expertise of the different research sectors to carry out the needed research program. In the case of ArcticNet, this central infrastructure is the *Amundsen* Platform made possible by the CFI. Right from the start, the CFI and its evaluation committees played a crucial role in the development of the Platform and, hence, in the revitalization of Canada's research effort in the Arctic. Starting in 2000 with Grant CFI-2554 (*Equipment for the scientific mobilization of Canadian Coast Guard icebreakers*), followed by the IJVF Grant CFI-7079 (*A Canadian Research Icebreaker to Study the Changing Arctic Ocean*), the Leading-Edge Grant CFI-11393 (*Maintaining Canada at the Leading Edge of Arctic Research: Upgrading and Expanding the Scientific Equipment of the Icebreaker Amundsen*) and several other equipment grants to individual researchers, the CFI played a pivotal role in bestowing Canada with its first dedicated research icebreaker. Operation funds comprised in the IJVF grant were crucial to ensure the deployment of the ship for CASES, while the Infrastructure Operating Fund associated with the Leading-Edge Grant palliated in part the chronic deficit in the equipment maintenance budget.



The importance of the role of the CFI in rebuilding Canadian Arctic Oceanography through these different grants cannot be overstated. First, thanks to CFI, Canadian Arctic specialists were able to realize the vision of a partnership between CCG and academia expressed in the 2000 Report of the Task Force on Northern Research "*From Crisis to Opportunity, Rebuilding Canada's Role in Northern Research*". The Report independently reiterated many of our arguments for a dedicated research icebreaker that would provide university-based researchers with access to the Arctic Ocean. It also recommended the creation of a pan-Canadian Network of Centres of Excellence to study the Canadian Arctic, an objective that was announced in the proposal to CFI for the mobilization of the icebreaker. Hence, the possibility of CFI funding for the icebreaker enabled Canadian academics to think big and to develop collectively a plan to re-invigorate Canadian northern research along the lines of the Report. Given the crucial role of the *Amundsen* and ArcticNet in deploying the Canadian contribution to the International Polar Year, the partnerships with the private sector, ArcticNet's IRIS framework, and many other

programs, our opinion is that the CFI investments have been leveraged well beyond all expectations.

We also believe that the ensuing (1) reconsolidation of Canada's research effort in the Arctic and (2) networking of a formerly fragmented science community, significantly contributed to convince the federal government to invest further in northern research through major initiatives such as the \$185M Arctic Research Infrastructure Fund to revamp northern research stations, the \$142M Canadian High Arctic Research Station, and the \$730M polar icebreaker *Diefenbaker*. Help yourself and the Federal will help you.

Obviously, the Foundation was the only funding agency in Canada with the financial means and the mandate to invest in a research platform of this scale and complexity. The management of an icebreaker falls outside the mandate of universities, which do not have the competences and expertise to crew, maintain and operate large ships in an extreme environment. A pivotal decision by the CFI was its acceptance that the icebreaker remains a federal asset under management by the Coast Guard. Without this decision, the Platform would have been impossible to operate and financially unviable as the costs of insuring and managing the ship would have defeated any academic research budget. This willingness of the CFI to envision the unique win-win academia-government partnership proposed for the management and operation of the *Amundsen* was absolutely key to the success of the Platform.

Appendix 1. Acronyms, abbreviations and their meanings

AACA – Adaptation Actions for a Changing Arctic of AMAP
AAND – Aboriginal Affairs and Northern Development Canada
ABOL – Arctic Biogeochemical Optics Laboratory
ADCP – Acoustic Doppler Current Profiler
AMAP – Arctic Monitoring and Adaptation Programme of the Arctic Council
Anoxia – Anoxia and sea ice
ArcticNet – Canada’s Network of Centres of Excellence on the Arctic (2004-2018)
ASAC – *Amundsen* Science Administrative Centre
ASDC – *Amundsen* Scientific Deployment Committee
ASP – Arctic Science Partnership, a joint Canada-Denmark-Greenland research initiative
AUV – Autonomous Underwater Vehicle
BaySys – Hudson Bay System Study, a collaboration with Manitoba Hydro
BREA – Beaufort Regional Environmental Assessment funded by AANDC
CASES – Canadian Arctic Shelf Exchange Study, an NSERC research network (2002-2007)
CAMP – Change in Arctic Marine Production
CCAR – Canadian Climate and Atmosphere Research program (NSERC)
CCG – Canadian Coast Guard, part of DFO
CCGS – Canadian Coast Guard Ship
CDOM – Colored Dissolved Organic Matter
CEOS – Centre for Earth Observation Science (University of Manitoba)
CERC – Canada Excellence Research Chairs
CFI – Canada Foundation for Innovation
CFL – Circumpolar Flaw Lead system study, a Canadian-led IPY program
CHARS – Canadian High Arctic Research Station
CHONe – Canadian Healthy Oceans Network, NSERC Strategic Res. Network (2008-2014)
CNES – Centre National d’Etudes Spatiales (France)
CNRS – Centre national de la recherche scientifique (National Center for Scientific Research)
COASTOOC – Coastal Surveillance Through Observations of Ocean Colour
COOP-GOOS – Cooperative design panel for Global Ocean Observing System
COP – Conference of the Parties
CSA – Canadian Space Agency
CSSF – Canadian Scientific Submersible Facility at University of Victoria
CTD – Conductivity, temperature, depth
DFO – Department of Fisheries and Oceans Canada
EC – Environment Canada
Ecogreen – West Greenland Ecosystem
ESA – European Space Agency
ESRF – Environmental Studies Research Fund managed by NRCan
FreshLink – Linking ice sheet thinning and changing climate
FTE – Full-Time Equivalent
GEOHAB – Global Ecology and Oceanography of Harmful Algal Blooms
GCRC – Greenland Climate Research Centre
H2020 – Horizon 2020, next phase in the European research plan
HABWatch – Harmful Algal Blooms Watch
HQP – Highly Qualified Personnel

iBO – integrated Beaufort Observatory, a project retained by the ERSF
IJVF – International Joint Venture Fund (CFI)
INRS – Institut national de la recherche scientifique
IOF – Infrastructure Operating Fund (CFI)
IPEV – Institut polaire français Paul Émile Victor
IPY – International Polar Year
IRIS – Integrated Regional Impact Study
JAMSTEC – Japan Agency for Marine-Earth Science and Technology
LGM – Laboratoire de géosciences marines (Université Laval)
LOKI – Lightframe On-sight Keyspecies Investigation System
MEIE – Ministère de l'Économie, de l'Innovation et des Exportations (Province of Quebec)
MRS – Major Resources Support (NSERC)
MSI – Major Science Initiatives fund (CFI)
MSSS – Ministère de la Santé et des Services sociaux (Province of Quebec)
NABOS – Nansen and Amundsen Basins Observational System
NASA – National Aeronautics and Space Administration (USA)
NCE – Network of Centres of Excellence of Canada
NETCARE – Network on Climate and Aerosols, NSERC CCAR Network (2013-2018)
NEXTAW – Network of Expertise on Transportation in Arctic Waters
NOG – Nutrient cycling in Greenland
NOW – International North Water Polynya Study, NSERC Research Network (1997-2001)
NRCan – Natural Resources Canada
NSERC – Natural Sciences and Engineering Research Council of Canada
O&M – Operations and Maintenance
OMG – Ocean Mapping Group (University of New Brunswick)
PDC – Polar Data Catalogue
POC – Particulate organic carbon
ROIS – Japan Research Organization of Information and Systems
ROPOS – Remotely Operated Platform for Ocean Sciences
ROV – Remotely Operated Vehicle
SERF – Sea Ice Environmental Research Facility at University of Manitoba
SHEBA – Surface Heat Budget of the Arctic Ocean, USA-led program (1997-2003)
SIMMS – Seasonal Sea Ice Monitoring and Modeling Site
SSHRC – Social Sciences and Humanities Research Council of Canada
SSP – Space Studies Program (International Space University)
SOLAS – Surface Ocean – Lower Atmosphere Study
UAV – Unmanned Aerial Vehicle
UMI – Unité Mixte Internationale of France's CNRS
UQAC – Université du Québec à Chicoutimi
UQAR – Université du Québec à Rimouski

Appendix 2. *Amundsen* Board of Directors.

Current and past members of the *Amundsen* Board of Directors. Conditional on a positive funding decision for the CFI MSI proposal, 2 new directors will be recruited, one from the international community and one from academia.

Current *Amundsen* Board Members (October 2014)

1. Dave Thomas (**Chair**) – President and Chairman, The Axys Group
2. Louis Fortier – *Amundsen* Project Leader, Scientific Director ArcticNet, Professor, Université Laval
3. Martin Fortier – Executive Director, ArcticNet
4. Tom Paterson – Senior Vice-President, Shipowning, Arctic, and Projects, Fednav
5. Johnny Leclair – Regional Director, Central and Arctic Region, Canadian Coast Guard
6. Denis Mayrand – Deputy Vice Rector, Research and Innovation, Université Laval

Past *Amundsen* Board Members

1. Marian Campbell Jarvis – Director General, Earth Sciences Sector, Natural Resources Canada
2. Bernard Funston – Chair, Canadian Polar Commission
3. Marc Demonceaux – Assistant Commissioner, Canadian Coast Guard
4. René Grenier – Deputy Commissioner, Canadian Coast Guard
5. Claude Langis – Director General, Canadian Coast Guard
6. Irwin Itzkovitch – Assistant Deputy Minister, Natural Resources Canada
7. Monique Carpentier – Director General, Earth Sciences Sector, Natural Resources Canada

Appendix 3. List of researchers that have benefited from the platform

A non-exhaustive list of researchers that have benefited from the Platform to establish their research programs in Canadian universities or federal departments.

- Archambault, Philippe (UQAR) – benthic diversity of arctic seas
- Ayotte, Pierre (INSP/Laval) – Inuit health
- Babin, Marcel (Laval) – CERC in Remote Sensing of Canada’s New Arctic Frontier
- Beaudoin, Jonathan (New Hampshire) – ocean mapping
- Bélanger, Simon (UQAR) – remote-sensing of Arctic seas
- Belt, Simon (Plymouth University) – Arctic paleoceanography and chemistry
- Bentley, Sam (Memorial) – CRC in Seabed Imaging and Seabed Processes
- Bourgault, Daniel (UQAR) – ocean turbulence
- Byers, Michael (UBC) – CRC in Global Politics and International Law
- Church, Ian (Southern Mississippi) – multibeam sonar data collection and processing
- Chateau-Degat, Marie-Ludivine (Laval) – Inuit health and diet
- Cusson, Mathieu (UQAC) – benthic diversity of arctic seas
- Dumont, Dany (INRS) – Arctic Ocean modelling
- Ehn, Jens (Manitoba) – ocean-sea ice interactions
- Else, Brent (Calgary) – air-sea gas exchange processes in Arctic seas
- Hickie, Brendan (Trent) – contaminants in Arctic coastal marine ecosystems
- Hanesiak, John (Manitoba) – atmosphere processes over Arctic and sub-arctic seas
- Hintelmann, Holger (Trent) – arctic contaminants
- Hughes Clarke, John (UNB) – mapping of the Canadian Arctic Ocean
- Kirk, Jane (CCIW) – mercury cycling in arctic ecosystems
- Kuzyk, Zou Zou (Manitoba) – biogeochemical cycles of carbon
- Lajeunesse, Patrick (Laval) – arctic marine geology and paleoceanography
- Lalonde, Suzanne (Montréal) – sovereignty, territorial integrity, self-determination
- Loseto, Lisa (DFO) – Arctic Ecosystems Impacts, Section Head
- Lovejoy, Connie (Laval) – arctic planktonic micro-organisms
- Levasseur, Maurice (Laval) – CRC in Plankton-Climate Interactions
- Massé, Guillaume (CNRS/Laval) – ERC Chair on Arctic Paleoclimate and Biomarkers
- Mueller, Derek (Carleton) – impacts of climate change in the cryosphere
- Muckle, Gina (INSP/Laval) – cognitive development in Inuit infants
- Mundy, Christopher (Manitoba) – ice algae and phytoplankton ecology
- Nozais, Christian (UQAR) – aquatic ecology and biodiversity
- Papakyriakou, Tim (Manitoba) – fluxes of CO₂ in the Arctic Ocean
- Rautio, Milla (UQAC) – CRC in Boreal Aquatic Ecology
- Robert, Dominique (Memorial) – marine fish populations
- Rochon, André (UQAR) – arctic paleoceanography
- Rysgaard, Søren (Manitoba) – CERC in Arctic Geomicrobiology and Climate Change
- Sampei, Makoto (Hiroshima) – Arctic zooplankton and biogeochemical fluxes
- Shadwick, Elizabeth (Virginia Institute Marine Science) – inorganic carbon chemistry
- Stern, Gary (Manitoba) – DFO Research Chair, arctic contaminants and ecosystems
- Suzuki, Keita (Kyoto) – Arctic zooplankton and larval fish dynamics
- Tremblay, Bruno (McGill) – circulation and heat fluxes in the Arctic Ocean

- Tremblay, Jean-Éric (Laval) – nutrient cycling in Arctic seas
- Xie, Huixiang (UQAR) – fluxes of carbon monoxide in Arctic waters
- Yackel, John (Calgary) – sea ice geophysics and cryosphere interactions

Appendix 4. Scientist-Days at Sea

Number of scientist-days at sea (including Highly Qualified Personnel) logged by the main umbrella programs since the inauguration of the Resource in 2003, and tallied by Canadian provinces and territories, and by countries. CASES: Canadian Arctic Shelf Exchange Study; ArcticNet and affiliated projects; IPY-CFL: International Polar Year - Circumpolar Flaw Lead System Study; Inuit Health Surveys; BREa: Beaufort Region Environmental Assessment; JAMSTEC: Japan Agency for Marine-Earth Science and Technology.

	<i>CASES</i>	<i>ArcticNet</i>	<i>IPY-CFL</i>	<i>Health</i>	<i>Geotraces</i>	<i>Malina</i>	<i>BREa</i>	<i>NetCare</i>	<i>Jamstec</i>	<i>Total</i>
Québec	5792	12200	3804	3397	121	341	26	32	32	25713
Manitoba	2287	4567	2925	41	16	44	26	0	0	10227
British Columbia	857	1129	133	134	288	0	0	0	0	2244
Newfoundland	527	618	105	61	64	0	0	0	0	1286
New Brunswick	250	1823	42	36	0	0	0	0	0	2165
Alberta	188	700	63	50	0	0	0	0	0	967
Nova Scotia	183	1730	276	0	16	0	0	0	0	2330
Ontario	138	1278	428	141	0	0	26	0	0	2144
Northwest Terr.	86	500	197	168	0	0	0	0	0	799
Saskatchewan	42	0	74	0	16	0	0	0	0	1065
Nunavut	0	198	20	933	16	0	0	0	0	1317
Canada (sum of above)	10350	24743	8067	4961	537	385	78	32	106	49259
USA	1031	780	643	0	0	128	26	0	0	2606
Japan	592	192	28	0	0	44	0	112	0	968
Spain	359	0	351	0	0	0	0	0	0	710
Poland	168	0	0	0	0	0	0	0	0	168
France	84	705	80	0	0	787	0	0	0	1656
Norway	84	12	147	0	0	0	0	0	0	243
Denmark	51	46	0	0	0	0	0	0	0	97
Russia	42	0	239	0	0	0	0	42	0	323
UK	42	215	248	0	0	0	0	0	0	505
Algeria	0	37	0	0	0	0	0	0	0	37
Belgium	0	0	126	0	0	0	0	0	0	126
China	0	157	278	0	0	0	0	0	0	435
Germany	0	50	294	0	0	0	0	0	0	344
Greenland	0	25	6	0	0	0	0	0	0	31
Guatemala	0	0	22	0	0	0	0	0	0	22
India	0	0	9	0	0	0	0	0	0	9
Iran	0	0	0	0	0	0	0	0	16	16
Italy	0	0	22	0	0	0	0	0	0	22
Lebanon	0	0	16	0	0	0	0	0	0	16
Monaco	0	0	0	0	0	56	0	0	0	56
Netherlands	0	0	99	0	0	0	0	0	0	99
Sweden	0	0	56	0	0	0	0	0	0	56
Switzerland	0	0	8	0	0	0	0	0	0	8
Others*	42	28	42	1099	0	0	0	0	0	1211
Total	12845	26990	10781	6060	537	1400	104	186	122	59025

* Greenland, Italy, Guatemala, Lebanon, Scotland, India, Switzerland