# Community-based mini-observatories for Arctic ocean science and outreach

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## 1.0 Introduction

The paper describes a concept for near-shore, internet-connected marine observatories that can be deployed at relatively low cost throughout the Arctic, providing near-real-time data on seawater properties, ice thickness, and meteorological conditions, as well as imagery of benthic organisms, and underwater sound. Ocean Networks Canada (ONC), which developed the concept, currently operates mini-observatories in two locations, one in coastal British Columbia and the other in Cambridge Bay, Nunavut. In addition to providing observational and research data, both of these mini-observatories have close connections to local schools where they can support science education. Prior to technical considerations we examine how cabled observatories could contribute to current and future scientific requirements for observation and monitoring in Arctic marine environments, and to the development of community-based environmental stewardship.

## 2.0 Arctic Science Requirements

Arctic science requirements for Canada have been articulated in several documents over the past few years including, for example: Indian and Northern Affairs' "Northern Strategy" (2008); the Canadian Council of Academies' "Vision for the Canadian Arctic Research Initiative; Assessing the Opportunities" (2008); Hik and Douglas (2008) "Planning for a Canadian High Arctic Research Station (CHARS) – A Synthesis of the Arctic Science Needs Scoping Papers Prepared by Federal Departments and Agencies". Several international organizations have also recently considered broader Arctic science needs; e.g., International Conference on Arctic Research Planning (ICARP II, 2007); The World Meteorological Organization's "The State of Polar Research: A Statement from the International Council for Science/World Meteorological Organization Joint Committee for the International Polar Year 2008-2009"; the Sustaining Arctic Observing Networks' (SAON) "Final Report of the Sustaining Arctic Observing Networks (SAON) Initiating Group" (2009); the Intergovernmental Oceanographic Commission's "Why Monitor the Arctic Ocean" (2010); the International Study of Arctic Change's "Science Plan" (2010) which follows on from the International Polar Year (2010) programs.

The rationale for a network of ocean observatories in the Arctic is, in large measure, a mirror of many of the justifications put forward for the Canadian High Arctic Research Station (CHARS) (Hik and Douglas, 2008):

- "Enhanced, coordinated and sustained observing sites, systems and networks in the Arctic will provide data on the magnitude, variation and rate of current and past environmental change, and for the initialization, calibration and validation of computer models that allow simulation of the Arctic environmental system and its

global connections. Combined, these will provide strength to predictions of future Arctic environmental conditions and enhance our ability to adapt.
- A strong science and implementation plan with an explicit and long-term observing component is a fundamental basis for implementing an Arctic monitoring program, and would build on the international SAON and ICARP II planning exercises that Canada has contributed considerable resources to.
- Long-term records are essential to answer today's science and research questions."

## 2.1 Supporting climate change research in the Arctic

At the forefront of science issues in the Arctic are climate change and its impacts on a wide variety of ecosystems, both terrestrial and marine. Despite its key role in the global ocean-climate system, knowledge about the Arctic Ocean and adjacent waters is limited, in large measure as a result of difficult access during most of the year, remoteness, long periods of darkness in the winter, and limited coverage by satellites. The region requires an integrated, international effort if we are to understand the Arctic System and how it will react to global climate changes (IOC, 2010).

The Arctic has already experienced significant climate-related changes with far-reaching consequences for biological, physical and socio-economic systems. Thus, climate change science in the Arctic needs to focus on a better understanding of the linkages between the atmosphere, the land, the ocean and the cryosphere. Examples include: impacts on the carbon cycle as a result of both terrestrial and marine changes; changes in oceanic circulation and productivity through modifications to freshwater inputs and warmer waters from the Pacific and Atlantic Oceans; marine productivity changes due to a greater prevalence of open water conditions; sea ice changes and their effects on the distribution and survival of marine mammals.

The International Study of Arctic Change Science Plan (2010) identifies nine broad science questions framing Arctic change research programs; many of these have a significant marine component:

- How is the Arctic linked to global change?
- How persistent is the presently observed Arctic change and is it unique?
- How large is the anthropogenic component of observed Arctic change compared to natural variability?
- Why are so many aspects of Arctic change amplified with respect to global conditions?
- How well can Arctic change be projected and what is needed to improve projections?
- What are the adaptive capacities and resilience of Arctic ecological systems?
- To what extent are social and ecological systems able to adapt to the effects of Arctic change?
- How does environmental change in the Arctic affect resilience, adaptive capacity, and, ultimately, viability of human communities?

- How can new insight into Arctic change and its impacts be translated into solutions for adaptation, management and mitigation?

The Council of Canadian Academies (CCA) 2008 report highlights the fact that "knowledge of Arctic marine areas, in general, remains very poor, particularly the linkages among seabed topography … ocean currents, sea ice movements and adaptive responses of marine ecosystems". A few examples serve to illustrate the nature of the knowledge gaps and the linkages among the various components of the overall system:

- While there are a great many gaps in our understanding of the Arctic marine system, one particularly significant one is our lack of information on the spatial and temporal variability of sea ice cover and, in particular, its thickness. Very few measurements of ice thickness have been made since the 1990s (ISAC, 2010), a crucial parameter in understanding the energy balance between the atmosphere and ocean.
- It is apparent that there has been an increase in surface flow of warm waters into the Arctic Ocean from the North Pacific and North Atlantic, though less is understood about the consequences, for example, for flow through the Canadian Arctic Archipelago and for marine ecosystems. The CCA (2008) report states: "An important impact of climate change will be the changing nature of Canada's Arctic waterways, particularly the Northwest Passage." Related to these changes in inflows from the Pacific and Atlantic, is the potential, not presently known, for species to migrate northward into the Arctic Ocean with possible implications for marine productivity and entire ecosystems. (IASC, 2010).

- Species impacts from Arctic change fall into four categories: (a) habitat modification; (b) ecosystem alteration; (c) stresses to condition or health; (d) human interaction (ISAC, 2010). The effects of climate change on marine ecosystems are both diverse and profound, with impacts on plants and animals from marine algae to polar bears to humans. Diminished sea ice, for example, means a changing light regime, possibly increasing primary productivity made possible through the addition of enhanced fluvial input adding nutrients to the surface waters. At the same time, primary productivity will likely shift from ice-associated algae to phytoplankton with potential effects through the marine food chain. As has been seen, diminished prevalence of sea ice has modified the distribution of polar bears and promises to threaten their very existence.

## 2.2 Environmental monitoring and stewardship

Improved understanding of the interactions between the physical environment and marine ecosystems in the Arctic is crucial in order to protect often sensitive ecosystems. Resilience of marine ecosystems or particular species to anticipated change is only poorly understood in many cases. How, for example, will marine mammal distributions and numbers be affected by increased shipping as ice free summers become a reality in the

Arctic? What mitigating measures can be instituted to minimize any adverse effects (e.g., alternate shipping routes; limits on shipping during particular seasons)?

Hik and Douglas (2008) summarize, based on a brief from Environment Canada, that there is a need for "an integrated monitoring and science research program" to address these information gaps. Such programs would involve a "reference environmental observatories network (REON supersites), enhancements to coordinate operational monitoring systems, and science programs …" (Hik and Douglas, 2008). Connecting elements of an observatory network to arctic communities provides opportunities for both engaging communities in environmental monitoring and improving science literacy. These two goals are at the core of the ONC mini-observatory concept.

Environmental management under a regime of increasing activity in the North requires solid baseline information and ongoing monitoring to understand the natural variability in Arctic marine systems and to identify anthropogenic impacts. As the CCA (2008) report states: "High quality, science-based evidence is needed to design effective regulations. Therefore there is an urgent need to establish environmental and socio-cultural baseline information to support development of frameworks for environmental impact assessments and strategic environmental assessments against which the potential and actual cumulative impacts of development activities can be measured and judged."

While the CCA (2008) report separates "Observation and Monitoring" as a separate priority, in fact they are integral to all Arctic science requirements. The CCA panel, however, felt the need to explicitly highlight the need for regular collection and monitoring of baseline data "over time and across geography". They point to the international consensus that long-term environmental monitoring "is an indispensable core activity for understanding and managing the global environment" and provides the "… essential building blocks for the kind of robust, evidence-based, regulatory regime that can support sustainable resource development in a highly sensitive environment".

## 3.0 Ocean Observing Technologies

The CCA (2008) panel also highlighted the need for technology development as an additional priority in order to achieve the goals of the primary science activities. They point to the need for autonomous technologies and "high specification broadband communications" and an enhanced northern communications infrastructure in support of northern science. Of specific relevance in this context, they state:

"Monitoring technologies … are continually developing and will enable entirely new kinds of measurements. These developments will generate very large data volumes and create the need for advanced means of organizing, documenting and analyzing data (e.g., data mining)."

Since marine ecosystems exhibit physical and biological variability over a wide range of space and time scales (Steele, 1978), no one sampling strategy is suitable to address all phenomena. The four-dimensional nature of the dynamic ocean and its processes make it nearly impossible to obtain a perfect time series of events in the sea from any one platform. A wide variety of moored platforms, including surface and bottom mounted moorings, gliders, unmanned vehicles, drifting buoys, ships, aircrafts, and satellites are currently available, but all have limitations. Satellites provide access to the broadest time and space scales by repeated wide area imaging, over years and even decades, but are limited to monitoring a few properties of the surface ocean. Ships provide the most flexible platforms for sampling throughout the entire water column, but are slow and alias their measurements in time and space. Ship sampling is limited by cost, and in the Arctic by the open water season. Aircraft platforms move faster, and cover more area, but are costly to operate and are mostly limited to a few types of surface imaging or expendable instrumentation. Moored autonomous systems and cabled observatories are the only platforms that can provide long, continuous water-column time-series that are not possible from aircraft, satellites or vessels. Cabled systems offer continuous records covering time scales from decades to microseconds, providing datasets never before possible. Both cabled and moored observing systems are local sampling platforms, but with multiple devices or networks, can provide regional sampling.

## 4.0 Cambridge Bay Observatory

Building on Ocean Networks Canada's experience with large-scale ocean observing systems we have developed a smaller scale community or school based system that collects research grade data. ONC installed one of these small, cabled undersea observatories (approved by the Nunavut Research Institute) in Cambridge Bay, NU in September of 2012. This mini-observatory is the first location in Canada's Arctic for year-round undersea monitoring of the northern environment, offering science-based support for understanding and protection of fragile arctic marine ecosystems.

Prior to the installation of the mini-observatory, Cambridge Bay had been chosen as the location for a feasibility study of a more extensive Arctic cabled observatory, led by Ocean Networks Canada and a team of industry experts. The study, completed for the Department of Indian Affairs and Northern Development in March 2011, examined the use of technologies developed on the VENUS and NEPTUNE Canada cabled ocean

Cambridge Bay was chosen as the site for this first arctic mini-observatory for several reasons including: the existing community and infrastructure (power, airstrip and accessible wharf); the protected location in the bay; the opportunity for science education at the local school; and the outreach potential both to the local community and seasonal visitors. In addition, Cambridge Bay will be the future site of the Canadian High Arctic Research Station (CHARS), projected to open in 2017 http://www.science.gc.ca/Canadian_High_Arctic_Research_Station-WS74E65368-1_En.htm

### 4.1 Mini-observatory development

The miniature ocean observatory was prototyped at Brentwood College on southern Vancouver Island. In the fall of 2011, a mini-observatory was installed at the college where high school students use data collected by underwater instruments for their science classes. The mini-observatory was developed through funding from Canada's Advanced Research and Innovation Network (CANARIE), and with support from the ONC Centre for Enterprise and Engagement (ONCCEE). The Cambridge Bay Observatory (CBO) has a similar design, where the live data and underwater video feeds collected are available to the local school, library and Cambridge Bay Visitor's Centre—for free—via the Internet. These data are also transmitted by satellite for archiving at the University of Victoria, for long-term study of the changing ocean environment in the Arctic.

### 4.2 Cambridge Bay installation

The mini-undersea observatory in Cambridge Bay is designed to operate for a period of five years or more. The underwater instrument platform is located on the ocean floor at a depth of 6.5 metres, and is connected by cables to a nearby wharf. The instrument platform hosts an underwater HD video camera, a suite of sensors to measure seawater properties, plus an instrument to measure ice thickness. On the wharf, a second camera monitors surface ice formation and a small meterological station provides information on current weather conditions. From the wharf, data are transmitted over a wireless link to a nearby government building where a data logging and distribution computer makes data available locally and manages a satellite Internet link to the ONC data centre at the University of Victoria. Data are accessed beyond Cambridge Bay by signing onto the NEPTUNE Canada DMAS web site (https://dmas.uvic.ca/Registration ).

### 4.3 System configuration

Like its Brentwood College School predecessor, the Cambridge Bay Observatory follows the paradigms of VENUS and NEPTUNE networks operated by Ocean Networks Canada: extending the Internet under the ocean and delivering data in near real-time. The system is cabled and placed near a dock for easy access. The dock serves as the closest possible point for providing power and communications to the instruments underwater. The distance from the dock to the underwater instrument platform is limited by the maximum distance for Ethernet transmission over copper cable, about 70 meters total. A wireless antenna on the dock provides a data link to the next point in the topology, a nearby building where computers dialog with the instruments and relay data to the UVic-based data centre via a commercial satellite link.

Underwater instruments include a CTD and associated sensors, a video camera with LED lights, an analogue hydrophone and an ASL acoustic ice profiler, all mounted on a simple tripod, easily deployed with a small boat. On the dock, a weather station and seaward looking camera complete the instrument suite.

Table 1. Science instrument complement for Cambridge Bay Observatory.

| Instrument | Sensors |
|---|---|
| Wetlabs Water Quality Monitor | Temperature, conductivity, pressure, oxygen, chlorophyll, turbidity |
| ASL Shallow Water Ice Profiler | Tilt x, tilt y, temperature, pressure, ice thickness uncorrected, ice thickness corrected |
| Ocean Presence Video Camera | PTZ, lights |
| Stationary dock Camera (Axis P1346) | Video and single frames, overlooking the ice |
| Davis Vantage Pro weather station | Air temperature, barometric pressure, relative humidity, rainfall rate, UV index, solar radiation |
| Ocean Sonics HF Hydrophone | 1Hz-100kHz underwater acoustic signals from marine mammals, marine traffic and ice motion |

The schematic drawings below illustrate the overall configuration of a dockside mini-observatory.

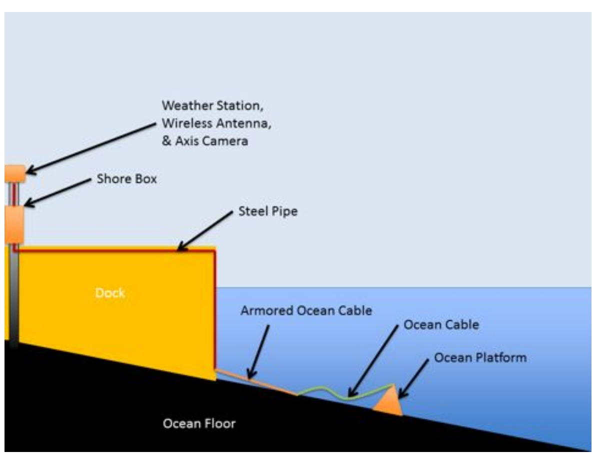

Figure 1 - Cambridge Bay system configuration

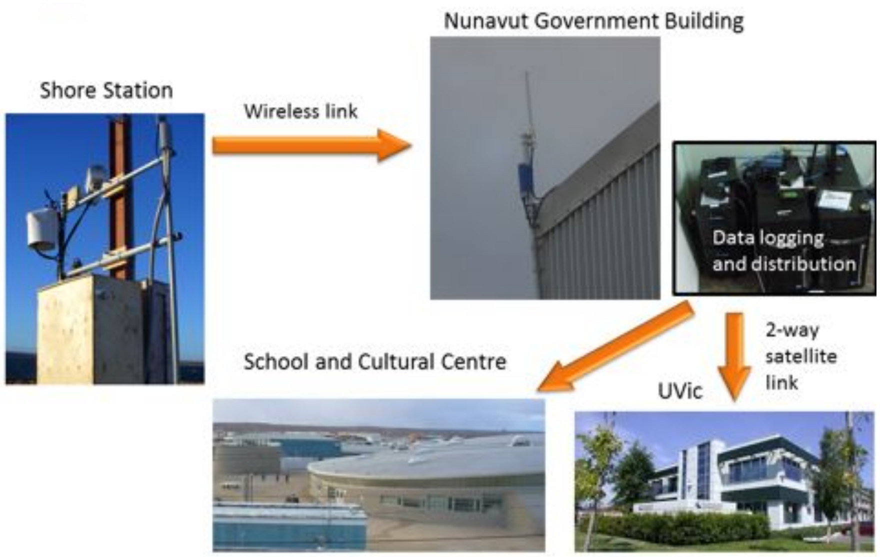


Figure 2 - Cambridge Bay network confirguration

## 4.4 Subsea system

The overall concept has been retained from the Brentwood implementation, but most of the functional components have been changed and replaced by more robust and reliable technologies. In particular, the dockside components have been selected to resist extreme cold and to withstand vandalism. Underwater, a major design and reflection effort went into the traversal of the air-ice-water interfaces with cables and conduits, safely protecting them against ice movements and ice build up and melt. The location of the instrument platform was also selected to avoid most of the boat traffic and anchorage, to secure enough water depth to be well below the maximum ice extent and to provide an interesting environment for the sensors. The system has therefore been deployed roughly 30 meters to the southwest of the dock, at a depth of 6.3 meter.

Figure 3 - Cambridge Bay instrument platform with local science class before deployment

The Cambridge Bay system has been operating since September 2012 and data are freely available to the public and researchers through the NEPTUNE Canada website.


Figure 4 - Cambridge Bay Observatory data search page

Data collected from the observatory are already creating great interest from Arctic researchers and data were recently presented at the ArcticNet 2012 annual meeting in Vancouver.

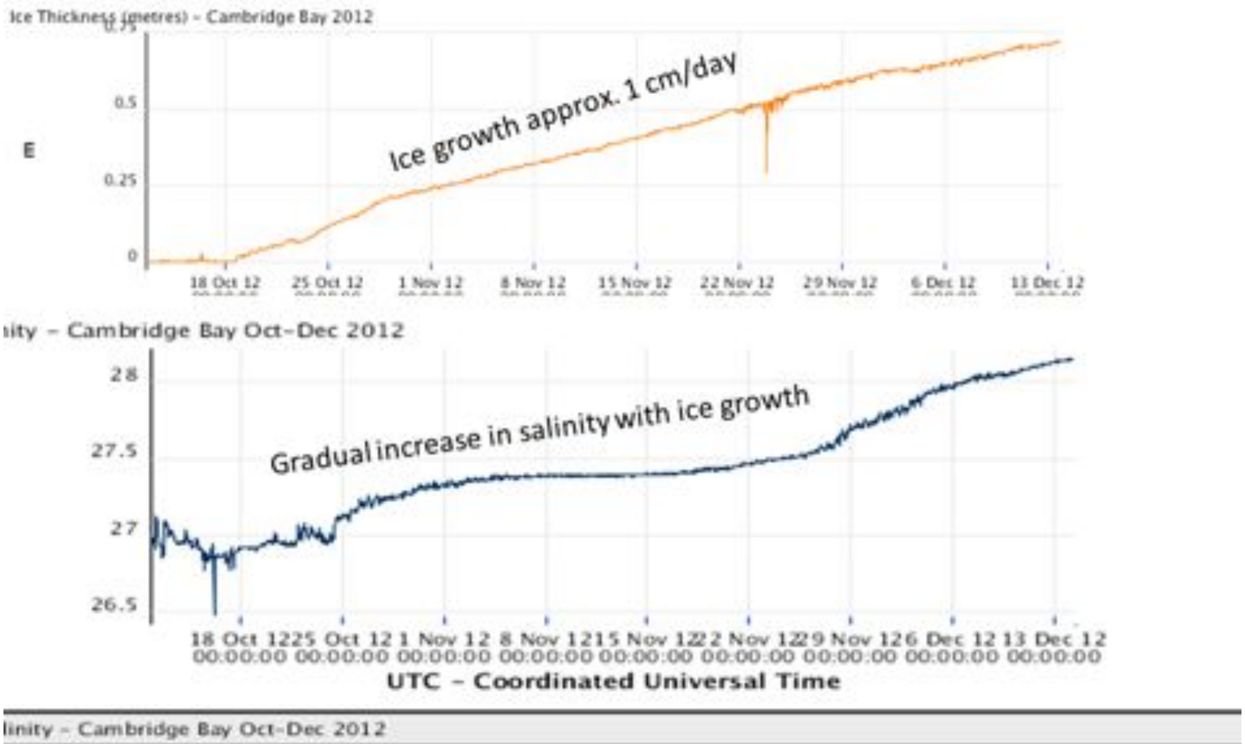


Figure 5 - Ice profiler and salinity data from Cambridge Bay, showing the growth of ice through the fall of 2012 with the corresponding increase of salinity.

A high definition video camera system provides hourly imagery of benthic organisms in Cambridge Bay beneath ice or open water.  A camera on the dock monitors vessel traffic, ice coverage and surface conditions above the subsea platform.  The surface videos can be viewed as daily time-lapse sequences.  All videos can be accessed through the Cambridge Bay data search page.

Figure 6 - Benthic community in Cambridge Bay. Visible are tube dwelling polychaete worms with extended feeding tentacles.

Figure 7 - Winter twilight over Cambridge Bay from dock camera, looking southward.

## 5.0 Applications of Mini-Observatories

Cabled ocean observatories offer continuous monitoring and measurements throughout the year, to complement existing marine research activities. In the Arctic, even mini-observatories such as described here can provide valuable baseline information on the ocean environment and human impacts, against which we can compare future change. The information streaming from the mini-observatory is shared over the Internet with the Cambridge Bay community for education, weather forecasting and other purposes. Several research groups are already using the data from the first year of observatories for studies that range from modeling of ice growth to documenting responses of marine worms to gradual and abrupt changes in habitat conditions.

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