A Canadian Contribution to an Integrated Atlantic Ocean Observing System (IAOOS)

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***Abstract*— We review opportunities, impediments, regional scope and principles for a Canadian contribution to an Integrated Atlantic Ocean Observing System (IAOOS) in the context of the Galway Alliance. This contribution should build on what exists, plan ahead for data management and data access, be flexible and sustainable, encourage international involvement, be science-led, foster research aggregation, and have close links to remote sensing, data assimilation and prediction programs. Existing programs that can contribute are described, and new initiatives that will broaden relevance of the Observing System are identified, including biological/ ecosystem observations. Specific platforms and technologies for both near-shore and offshore waters are listed, together with areas where new developments are needed. Finally, we outline a strategy for the development of an Atlantic Canada Regional Ocean Observing System (ACROOS).**

Keywords—Ocean observing systems, Northwest Atlantic, operational oceanography, Galway Alliance

I. The Galway Statement and Research Alliance

On the 24th May, 2013, at a workshop held in Galway, Ireland, representatives of the governments of Canada and the United States as well as the European Union (EU) signed the "Galway Statement on Atlantic Ocean Cooperation". The Statement recognised "the importance of the Atlantic Ocean to our citizens, prosperity, human health and well-being, adaptation to climate and other environmental change, and security". The workshop established a new Research Alliance (herein referred to as the Galway Alliance) to "increase knowledge of the Atlantic Ocean and its dynamic systems – including interlinks with the portion of the Arctic region that border the Atlantic". Key activities identified for the Galway Alliance included alignment and development of mechanisms for financial support of observation efforts, coordination of data sharing, interoperability and coordination of observing infrastructures as well as seabed and benthic habitat mapping. The workshop report promoted a "fit for purpose North Atlantic multi-platform ocean observing and forecasting system driven by science and societal needs and providing real time data and long term time series". The system envisaged would address not only physical and chemical monitoring, but would also fill gaps in biological monitoring.

In addition to ocean observation, the Galway Alliance set goals for cooperation in the areas of: ocean stressors; aquaculture; seabed mapping, marine microbial ecology and ocean literacy. Coordination of the Alliance is in the hands of US-EU and Canada-EU Working Groups that support information exchange, setting joint priorities and joint actions.

Following the Galway workshop, the EU implemented calls for proposals under the "Blue Growth" component of the Horizon 2020 research programme, some of which are designed to support initiatives of the Galway Alliance. This included a call for research towards "deployment of an Integrated Atlantic Ocean Observing System (IAOOS) building on existing capacities on both sides of the Atlantic". The IAOOS should include "use of new ocean observation technologies which would allow the costs of in-situ ocean observation to be reduced and allow for integration of the "biological dimension" into the observing systems". The calls related to Galway noted that research would benefit from inclusion of US and Canadian partners.

Whereas observations form the basis for understanding of the ocean, realization of social and economic benefits requires information be made available to users, not only as unprocessed data but also as targeted knowledge, data products and predictions. Notably, reanalysis and prediction systems combine observations with available knowledge of ocean behaviour in order to provide products and predictions to guide safe, responsible and efficient use of the ocean environment. We envision observation systems discussed here as a foundation for services that deliver Atlantic Ocean information products to end users, for both scientific and operational applications.

II. The Galway Alliance and Canada

The Galway Statement and associated Horizon 2020 calls provide opportunities and challenges for Canada. On the one hand, knowledge of Canada's vast expanse of Atlantic coastline can benefit from access to observing infrastructure and research supported through Horizon 2020. The EU is assigning major funds to Atlantic Ocean research. This builds on a history of support for marine research infrastructure and data management, through both ESFRI (European Strategy Forum on Research Infrastructures) as well as Framework 7 projects.

On the Canadian side of the Atlantic, there is room for improvement in planning and coordination of marine infrastructure and observations in order to respond effectively. A "coordination gap" was noted in a report of the Ocean Science and Technology Partnership (2011):

"To date, the various Ocean Observing System activities represent isolated, regional, and often technology driven projects. No national framework exists for developing long term, coordinated objectives and for sharing expertise. This fragmented approach decreases the potential value, at a national level, of the investments made and it decreases Canada's potential effectiveness at the international level."

This coordination issue was further highlighted by the Canadian Council of Academies Expert Panel on Canadian Ocean Science (CCA, 2013). Canada was noted to be strong in ocean sciences, and playing a global leadership role in development of physical and biological observing systems. However, the Panel also noted that Canada's "dispersed network of regional clusters of diverse organizations" can "create challenges for certain kinds of collaboration, alignment of research strategies, and coordination and use of large-scale infrastructure investments". Specifically, with respect to ocean observation and monitoring, the report noted "challenges exist in achieving geographical coverage and integration of data management" and a "coordination gap in key areas, such as ocean observation" and that this gap "hinders the sharing of resources and knowledge at the international level". The CCA Report should stimulate, eventually, new mechanisms of coordination for ocean science at the national level. However immediate action addressing Canada's Atlantic Ocean research seems urgent given the opportunities presented by the Galway Alliance, and the Horizon 2020 research programme.

In this paper we present principles and a strategy that we feel should guide the Canadian response to the Galway Statement, with particular reference to the in-situ observation. The paper builds on discussions at the Galway workshop, at a subsequent workshop on "Arctic and Marine Infrastructures" organized by the Canada Foundation for Innovation and hosted by the Canadian Embassy in Rome, workshops organised by the MEOPAR Network of Centres of Excellence, as well as an international meeting in Arlington, VA hosted by the US Ocean Carbon and Biogeochemistry program.

Figure 1 The primary region of interest for Canadian contributions to an IAOOS

III. Region Definition

The Galway Statement and Alliance promotes international research with a focus on the Atlantic Ocean including "interlinks with the portion of the Arctic region that border the Atlantic". As such, it is expected that other alliances will form to address the Central Arctic Ocean or the European marginal seas such as the North Sea, Baltic and Mediterranean. From a Canadian perspective, the analogous focus area for Galway-related observations includes, logically, waters along the coast of Canada that border directly on the open Atlantic Ocean (i.e. shelf, slope and ocean waters of the Gulf of Maine, Scotian Shelf, Newfoundland and Labrador, Baffin Bay). The exclusion of European marginal seas from the region addressed by the Galway Statement constrains Canada from including its own marginal seas (the Canadian Arctic Archipelago, Hudson Bay and the Gulf of St. Lawrence) within the main focus area. Nevertheless, observations in these areas form an important context for a Canadian contribution to an IAOOS. Ocean connectivity makes it illogical to set firm offshore boundaries. For logistical reasons, it may make sense to refer to Fisheries and Oceans Canada's (DFO) identification of a "Canadian primary area of interest" between 35 and 90°N and 40 to 180°W (although DFO notes that for specialized data types and programmes the area of interest remains global). Figure 1 shows the region of priority interest for Canadian contributions to an IAOOS. It extends from Baffin Bay in the north, east to the mid-Atlantic Ridge and south to 35°N, and includes the Irminger Sea. The region is not exclusive: we expect Canada to contribute to Atlantic observation well beyond this, and many nations contribute observations within this region.

IV. Principles of a Canadian Strategy towards an Integrated Atlantic Ocean Observation System.

A Canadian contribution to an IAOOS must consider that the ocean off Canada's east coast includes globally significant ecosystems, major commercial fish stocks, processes of major importance for the global environment and growing and varied economic activities (Table 1). The strategy must recognize Canada's internationally-competitive ocean technology sector and that maintenance of high-quality observations over the long-term requires commitment of a broad community of users and data providers. Involvement of scientists, in particular, provides for definition of key science questions, methodologies, essential ocean variables, critical review of data quality, development and introduction of new technologies, and training of Highly Qualified Personnel (HQP). However a successful observing system must balance "push" from the scientific community with the "pull", or demand for products, from a diverse user community. This implies that considerations of investments in observing infrastructure should consider, simultaneously, policy-relevant questions, data requirements of ocean management and offshore operations as well as scientific research. Ideally, infrastructure should also provide opportunities for Canada's ocean technology sector to develop, test, implement and showcase their innovations. Consultation with a broad community of stakeholders and users, from multiple sectors of society, will be essential for maximizing the value of observation infrastructure for ocean research, technology development, offshore operations and management.

The Galway Statement and report, and the Horizon 2020 call for proposals, highlighted several key principles to consider during the design process:

* *The observation efforts of partners should be aligned strategically with consideration of interoperability of systems and coordination of data sharing (nationally and internationally)*

* *The IAOOS should be fit-for-purpose, and incorporate multi-platform observations, be driven by science and societal needs and provide real time data and long-term time series*

* *The system should build on existing capacities on both sides of the Atlantic Ocean through international cooperation*

* *The system should encourage integration of new ocean observation technologies to reduce the costs and improve the quality of in-situ ocean observations*

* *The biological dimension should be integrated into the observing systems*

Additional principles were identified at the Canadian Foundation for Innovation led Rome workshop on Arctic and Marine Infrastructure. These included:

* *Multi-disciplinary, multi-user, multi-sectoral and multinational (the 4 "M's"):* efficient use of limited resources implies that observing systems should serve the needs of as many communities and users as possible. Prospects for sustainability of the observing systems improve with a broad user base. Hence observing infrastructure planning should be coordinated with needs of policy and governance via Integrated Ocean Management, and contribute information and data of value to ocean industries.

* *Science-linked:* long-term usability of observations, development of new technological approaches, renewal and sustainability will be promoted if observation systems move beyond "monitoring" and involve scientists in data collection, analysis and interpretation. Infrastructure that can address critical scientific questions as well as operational data needs is key to maximizing utility at the same time as encouraging involvement of highly qualified personnel (HQP e.g. graduate students) in data collection/dissemination.

* *Flexible, interoperable and relocatable:* In-situ systems require regular maintenance and upgrading. Resource limitations will prevent Canada from maintaining measurements at all key locations along its Atlantic coastline and priorities concerning geographic regions and properties to measure are likely to change over time. Hence, systems should be designed for economical maintenance, be upgradable, adaptable to new applications, interoperable, and capable of cost-effective relocation.

Table 1

Ocean-related Economic Activities in Atlantic Canada

- *Major exploited ecosystems*
- *Ocean-related tourism*
- *Shipbuilding*
- *Maritime defense*
- *Major international shipping routes*
- *New shipping routes (to Arctic)*
- *Expanding resource export (LNG, minerals)*
- *Growing deepwater oil/gas development*
- *Increasing aquaculture development*
- *Ocean observation technology*

Globally significant processes in Canada's Atlantic waters:

- *Sea-ice cover change*
- *Changing freshwater input / storage*
- *Ocean acidification / lysocline uplift*
- *Variable deep water formation*
- *Large, variable atmosphere-ocean heat exchange*
- *Meridional overturning circulation*

* *Plan ahead for data management, and data access:* observing system design should be based on a realistic view

of the manpower, infrastructure and funding required to assemble and quality-control resulting data streams, make data available readily to users, and allow for long-term archiving of data.

* *Plan for sustainability:* Historically, Canadian funding for ocean observation, outside the Federal government, has not been planned with sustainability in mind. In some cases, a focus on short-term scientific or technological advances may have been coupled with underestimation of the difficulty of sourcing long-term financing. The relative availability of funds for operations and equipment is one issue: funds to purchase hardware and initiate observations are usually not matched, at the outset, by long-term funding for operations. Scientists and engineers are often focussed on establishing "something new". Interest can wane before the value of long-term data becomes evident. Proposed infrastructure must have a business plan, and risk management strategy, that identifies opportunities for long-term operational support. This implies a need for dialogue across sectors and disciplines prior to embarking on a major program. Sustainability can also benefit from international support that should be possible via the Galway Alliance.

* *Promote RADs (Researcher Aggregating Devices):* As noted, a key aspect of sustainability is maintaining commitment of scientists. Long-term observations risk being taken for granted and losing the active support of the scientific community. "Monitoring" is sometimes viewed as "routine" and hence not "innovative": in turn, this reduces interest of science funding agencies in supporting such observations. This is especially true if observing systems are viewed as competing with, rather than supporting, cutting edge research targeted at new ideas. Sustained observations, by themselves, do allow new questions to be addressed as the amount and duration of data collection grows. However, utility for scientific investigation can be increased further if the program is designed as the context for testing of new technologies, training of HQP and support of discovery-type research. This requires prior dialogue to ensure that an observing system will sustain scientific interest and generate a succession of shorter-term research projects. In other words, observing infrastructure should be designed to act as a "Researcher Aggregating Device" or RAD where investigators choose to work due to availability of useful data, logistical support and the suitability of the location and system for addressing research questions. A well-designed RAD should attract national and international researchers.

* *Build on what exists:* Canada's Atlantic coast hosts several relevant observation programs, some of which have operated for decades. Most are led by government (e.g. DFO and Environment Canada (EC)). These have stood the test of time and form a natural basis for enhancement and upgrading; for example by adding a more comprehensive set of measurements, expansion to higher-frequency observation, testing and development of new technologies, or broadening of geographical coverage. An example of enhancement is the Ocean Tracking Network's (OTN) choice of DFO's "Halifax Line" (part of the AZMP, see Section V*A*) as a location for expanded oceanographic measurement using additional platforms (e.g. gliders) and new sensors (acoustic tracking of animals). Another example is NSERC's VITALS (Ventilation, Interactions and Transport across the Labrador Sea) project that builds on DFO's AZOMP monitoring in the Labrador Sea.

* *Encourage international involvement:* Table 1 notes that waters off Canada's Atlantic coast play central roles for the Earth's climate, biogeochemical and ecosystems. Further, eastern Canadian shelf waters are an upstream boundary condition for US shelf ecosystems. These are the reasons for a long history of international oceanographic and climate research conducted in these waters. The international scientific interest and activity creates opportunities for joint support and operation of long-term observations, including funding, data sharing and ship-time.

Finally, any in-situ ocean observing program needs to be connected to broader geographical and temporal scales and include consideration of the future evolution of properties (e.g. sea-ice extent). Hence a Canadian contribution to IAOOS should include:

* *Link to data assimilation and prediction programs.* Observational data are essential inputs to data assimilation and ocean modelling that produces assessments and predictions. Data assimilation melds sparse observations with mathematical and statistical depictions of oceanographic processes (e.g. circulation). Oceanographic models and data assimilation extend the utility of observations for end users including provision of quantities and rates that cannot be observed directly, or at all locations. The design of an observing system must therefore be linked closely to assimilation and prediction systems. In Canada, this implies joint planning with the prediction capacity being developed under the Federal Government's CONCEPTS initiative, which is, itself, linked to related developments in Europe (e.g. Mercator / MyOcean).

* *Link to remote sensing products and missions:* most in-situ observing systems discussed here are of direct relevance to remotely-sensed observations and vice-versa. In-situ observations provide validation/calibration capability for remotely-sensed observations and allow for testing and improvement of algorithms which relate remotely-sensed quantities to "real-ocean" variables. Remote sensing also allows spatially-restricted in-situ observations to be extended to regional and even global scales. The in-situ and remotely sensed observing systems complement each other. Hence, in-situ observing systems should be developed in coordination with projects backed jointly by space agencies (e.g. Canadian Space Agency, European Space Agency and National Aeronautical and Space Agency).

V. Existing and Planned Programmes and Projects

The following programmes can contribute to Canada's contribution to an IAOOS. The focus is on programs that resolve temporal-variability (i.e. ≥2 occupations per year).

A. Sustained Observations

1) AZMP and AZOMP (Figure 2)

The Atlantic Zone Monitoring Program (AZMP) was implemented by DFO in 1998 with the aim of: (1) increasing

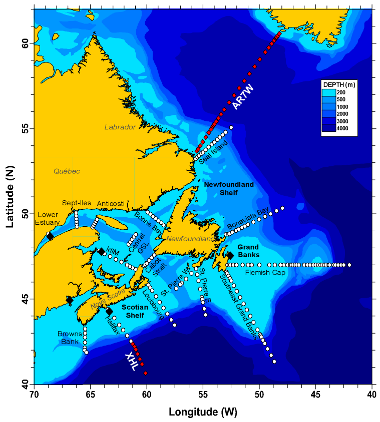

Figure 2 Bathymetric map showing the sections sampled by AZMP and AZOMP

DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and (2) quantifying changes in physical, chemical, and biological properties of the ocean. The program provides annual assessment of physical properties, nutrients, oxygen, as well as phytoplankton and zooplankton. These variables provide key information on: trends in ocean climate; water-mass movements and ocean circulation; and locations, timing, and magnitude of biological production. The AZMP collects data at sampling locations, cross-shelf sections, and regional ecosystem surveys with a frequency of bi-weekly to annually on the Newfoundland Shelf, Gulf of St. Lawrence and Scotian Shelf (Figure 2). Trawl (ecosystem) surveys and cross-shelf sections provide detailed geographic information, but are more limited in temporal coverage.

The complementary Atlantic Zone Off-shelf Monitoring Program (AZOMP) comprises: (1) the AR7W section across the Labrador Sea and (2) the Extended Halifax Line (XHL) on the slope and rise off the Scotian Shelf (Fig. 2). These surveys cover physical properties, as well as chemical (e.g., total inorganic carbon, pH, nutrients, O_2) and biological measurements (phytoplankton, bacteria, meso-zooplankton).

2) SMARTATLANTIC (Figure 3)

The SmartAtlantic Alliance supports oceanographic and meteorological measurements to improve operational efficiency, situational awareness and safety in the marine environment. This initiative, supported by the Marine Institute of Memorial University's Centre for Applied Ocean Technology (CTec) in St. John's and the Institute for Ocean Research Enterprise (IORE) in Halifax grew out of the Marine Institute's SmartBay program in Placentia Bay. The Alliance deploys oceanographic and meteorological buoys to provide buoy data, forecasts and value-added services for users. Presently, the Alliance maintains buoys in Halifax, St. John's, Placentia Bay, Port aux Basques and Conception Bay and Bay of Islands with additional deployments planned for Bay of Islands and Bay of Exploits. Data are made available in near real-time and historical data can also be accessed

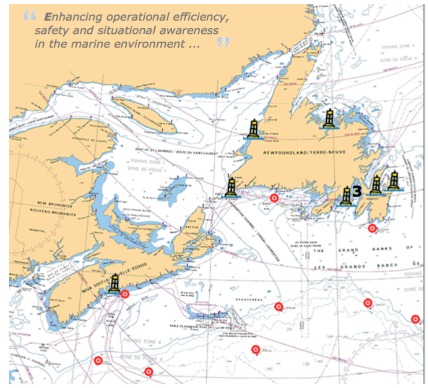

Figure 3 Locations of SmartAtlantic buoys (buoys) and EC weather buoys (red circles).

through the web. The SmartAtlantic Alliance is supported by governmental agencies and departments (e.g. IBRD – NL, DFO, the Atlantic Pilotage Authority and, potentially, Transport Canada) as well as private sector partners such as AMEC, Earth Information Technologies and the Port of Halifax. Plans are being developed to extend the network to Saint John, NB and Canso, NS.

3) ARGO (Figure 4)

Argo floats are robotic devices that drift freely in the ocean over a period of c. 5 years. The floats sink and rise regularly between a predetermined depth (e.g. 1000m or 2000m) and the surface. Presently, the international ARGO program maintains an array of over 3,500 such floats contributed by 30 countries collecting data on temperature and salinity, and providing valuable information on changes to the Earth's climate and hydrological cycle. The floats provide about 100,000 profiles per year with an average spacing of 350 km. All data are publically available in near real-time through two global data centres. DFO is a strong contributor and since 2001 has launched over 340 floats, more than 100 of which are operating presently. Most Canadian ARGO floats are deployed in the NW Atlantic and the North Pacific (see Figure 4).

4) OCEAN TRACKING NETWORK

The Ocean Tracking Network (OTN) is a Canada Foundation for Innovation (CFI) - International Joint Venture Fund global research and technology development project headquartered at Dalhousie University. Starting in 2008, the OTN began deploying Canadian (VEMCO) acoustic receivers and oceanographic monitoring equipment in key

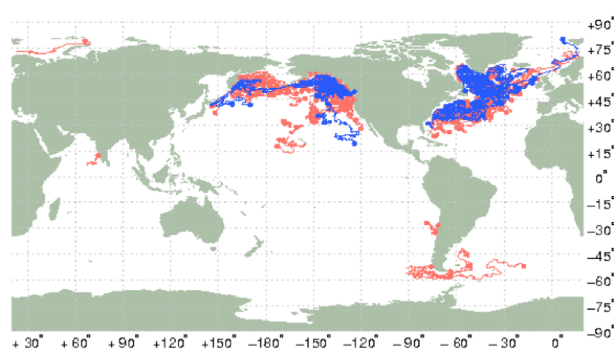

Figure 4 Canadian ARGO floats as of June 2014 when 101 Canadian supplied floats were operational.

locations. These are used to document movements and survival of marine animals carrying acoustic tags ("pingers"), and to document how both are influenced by oceanographic conditions. Animals as small as 5 cm length can be fitted with tags, and species currently tracked include marine mammals, sea turtles, squid, and fishes. The Natural Sciences and Engineering Research Council (NSERC) supports OTN-Canada, a national network of researchers that works with the OTN infrastructure. The Social Sciences and Humanities Research Council of Canada (SSHRC) funds participation of social scientists in OTN. OTN hosts a Data Warehouse that serves as a repository for data collected by OTN researchers, and is working to develop interpretation and visualization tools. OTN also operates a fleet of autonomous vehicles (Slocum gliders and a Wave Glider) in support of oceanographic and tracking research. It maintains moored benthic pods for oceanographic monitoring in various locations in the Canadian Arctic, North West Atlantic Ocean, and the Gulf of St. Lawrence.

B. EXISTING SCIENCE PROJECTS

1) VITALS

Funded by NSERC through the Climate Change and Atmospheric (CCAR) network, VITALS addresses how the deep ocean exchanges CO2, O_2 and heat with the atmosphere in the Labrador Sea. The program is a mix of new observations, analysis of historical data and numerical modelling focussed on the Central Labrador Sea and its connection to slope waters. The observation component includes deployment of dissolved gas sensors on moorings and mobile platforms. The program will make use of AZOMP's AR7W section and the moored profiler Sea Cycler that was developed by DFO's Bedford Institute of Oceanography. The SeaCycler is an energy-efficient system for profiling the upper 200m of the water column without requiring a permanent surface float. The multi-disciplinary, multi-institutional team involves researchers across the country (Memorial, Dalhousie, Laval, McGill, University of Alberta and University of Victoria) together with DFO scientists.

2) GREEN EDGE

The objective of the international Green Edge program is to understand the dynamics of the phytoplankton spring bloom (PSB) and determine its role in the Arctic Ocean of tomorrow. Specifically, the goal is to 1) understand key physical, chemical and biological processes governing the PSB, 2) identify phytoplankton species involved in the PSB and model their growth under various environmental conditions, and 3) predict the fate of PSB-associated carbon transfer through the food web and towards the sediments.

A spring bloom event will be monitored during 2015 in Baffin Bay from its onset under melting sea ice in May to its conclusion within the seasonal ice zone in July. The distribution of relevant physical, chemical and biological properties will be measured with profiling floats and gliders and an autonomous underwater vehicle, all equipped with physical and bio-optical sensors. Process studies will be conducted from an ice camp and then from a research icebreaker. Key phytoplankton species will be grown under various conditions to determine their response to environmental factors and understand succession during spring. A coupled physical-biological model will be optimized for simulating the PSB and for predicting changes in phytoplankton and food web dynamics. In parallel, past and present trends in the intensity and spatial distribution of the PSB will be documented using a paleo-oceanographic approach, and from remote sensing. The Green Edge program is led by the Université Laval and involves researchers from France, Denmark, the USA and Germany.

3) OSNAP (Figure 5)

Large-scale ocean circulation is the focus of the "Overturning in the Subpolar North Atlantic Program" (OSNAP) that is led from Duke University (USA) and includes partners from Canada, the UK, France, Germany and the Netherlands. OSNAP aims to provide measurement of full water column, trans-basin fluxes of heat, mass and freshwater across the subpolar North Atlantic. There are two primary legs to the measurement array: one extends from southern Labrador to the south-western tip of Greenland and the other from the south-eastern tip of Greenland to Scotland. In addition to moorings, the observing system includes subsurface floats that will trace the pathways of the overflow waters and describe connectivity across the OSNAP lines. The program aims to understand the drivers of the Atlantic Meridional Overturning Circulation (AMOC), determine pathways of overflow waters and determine deepwater connectivity in the subpolar Atlantic. The measurements will inform design of a long-term monitoring system for measuring the AMOC in the North Atlantic Subpolar Gyre.

C. FUTURE PROJECTS / PROGRAMMES

In addition to the programmes and projects listed above, there are a number of new, ocean-observing related initiatives under discussion for incorporation into Canada's strategy. These include:

1) BIOARGO

BioArgo seeks to extend the concept of the ARGO program in order to characterize processes such as ventilation, photosynthesis and respiration in the ocean. Bio-optical and chemical sensors are now being developed with a size and power requirement suitable for incorporation into ARGO-type profiling floats. An early demonstration of what can be attained was high-frequency measurement of the annual cycle of dissolved oxygen in the central Labrador Sea. More recent demonstrations of the utility of bio-optical measurements are promising and an international working group is advancing the technology and concept of BioArgo. As of February 2014, 219 BioArgo floats carried biogeochemical sensors in addition to physical sensors. Of these, 205 had O_2 sensors, 52 had bio-optics sensors, 44 had NO_3^- sensors, and 3 had pH sensors. In the context of Horizon 2020, European and US partners are likely to conduct deployments in the North Atlantic Subpolar Gyre (Herve Claustre, pers. comm.). A Canadian BioArgo program would provide high value in the context of ARGO, other sustained observations along the Canadian Atlantic coastline and projects such as VITALS and Green Edge.

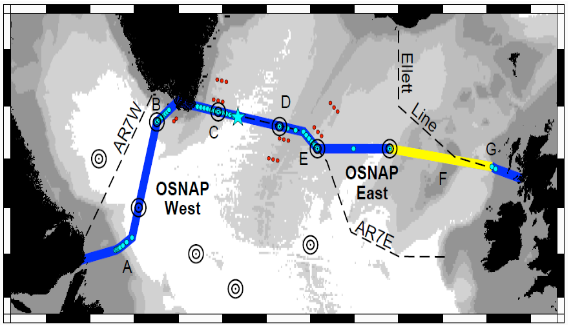

Figure 5 Mooring arrays and hydrographic sections of OSNAP. Repeat sections indicated by dashed lines.

2) Benthic Lander Observatories

The efficacy of in situ observation of benthic organisms has been limited by their small size and variable subsurface distribution. The limited movement of this fauna coupled with technology limitations means that benthic ecology has historically focused more on spatial rather than temporal variability. For epifaunal organisms, high resolution imagery has been used to document feeding rates as well as larval settlement. For infaunal organisms, imagery has been used to characterize bioturbation. The greatest potential application of ocean observatories to understanding seafloor communities relates to characterization of environmental drivers (e.g. phytodetritus supply, or disturbance by predators or sedimentation) and to document contributions of seafloor organisms to key ecosystem functions (e.g. nutrient efflux, remineralization, sediment oxygenation). For these applications, movable and re-deployable observatories based on benthic lander technology offer the best approach for advancing understanding. We envision deployment of benthic lander systems capable of long-term deployment and communication in real time through telemetry. The landers would be equipped with high resolution digital imaging capability with pan and tilt, micro-profiling sensors capable of measuring key sedimentary parameters (oxygen, pH, CO_2 and nutrient efflux) and automated incubation chambers. The deployment of such observatories could be linked to measurements for seafloor characterization related to geohazards associated with seafloor instabilities and mass flow.

3) Marine Microbial Observatories

Marine microbial communities are composed of metabolically diverse single-cell life forms. Members of these communities act in concert to transform, metabolise and recycle simple and complex molecules with feedback on ocean ecosystem functions and services. Microbes are the microscopic engines that drive the marine food chain and the biogeochemical cycles. Understanding their metabolic function in the context of environmental change is vital for predicting matter and energy flows in natural ecosystems. Our understanding is undergoing a revolution as a result of the use of genomic (sequencing of cultures) and metagenomic (sequencing of community DNA) approaches. Metagenomics, especially, has resulted in an explosion of information on diversity and function of marine microbes in relation to environmental controls. High sample throughput, made possible by next-generation sequencing technologies, offers the potential to vastly increase information on the diversity and function of marine microbes. New in-situ technologies for characterization of microbial populations are also becoming available. Application of these new approaches and technologies will be most informative when coordinated with measurement of physical, chemical and ecological properties. There is a related, urgent need for development of approaches to handle enormous amounts of data that will be produced from such microbial observatories. Advances in cyber-infrastructure, that can combine genomic and metagenomic data with other oceanographic data, will be required to exploit the information from these observatories.

4) Smart Ocean / Smart Industries Regional Node

The World Ocean Council (WOC) is an international, industry leadership alliance on "Corporate Ocean Responsibility" which brings together the ocean business community to collaborate on stewardship of the seas. One WOC initiative is the "Smart Ocean/Smart Industries" program that seeks to establish platforms/portals for efficient, cost effective collaboration of the scientific observing community with shipping and other ocean industries aimed at collection and dissemination of oceanic and atmospheric information. A recent joint MEOPAR-WOC workshop addressed the potential for industry cooperation across Canada. It was agreed that MEOPAR and the WOC would work to establish a first "regional node" of the Smart Ocean / Smart Industries program in Atlantic Canadian waters. Steps were identified that would be required to identify and engage industry partners and move towards a sustainable, industry-based observation effort.

VI. Components Of A Canadian Strategy towards an Integrated Atlantic Ocean Observation System.

The Canadian contribution to an IAOOS would extend from the nearshore, including harbours and bays, to the offshore, open ocean environment. It would comprise meteorological, physical, biological, chemical, and seabed and benthic observations. The ocean observing system must include seabed considerations given the needs of offshore development, transportation and the possible impacts of geo-hazards such as tsunamis and storm surges on coastal communities. In addition to existing, proven platforms and technologies, the observing system should support introduction of technologies that advance the state-of-the-art and supply new data streams. It would include a combination of fixed and mobile observing systems. Some regions will require continuous long-term fixed systems where some others, and some particular issues (e.g. oil spills, harmful algal blooms) would require deployment of mobile systems and platforms. Areas identified for new developments are identified below in ***bold, italic text***.

A. Nearshore and Coastal Components

* Meteorological/wave buoys and/or profiling systems in harbours and near-shore environments. These buoys, installed and operated by the SmartAtlantic Alliance and Environment Canada, offer valuable operational platforms

for advanced measurements. ***Incorporation of pH sensors they could form the basis of a coastal ocean acidification monitoring network.***

* Coastal radars for monitoring of surface currents and, potentially, waves. I***nstallation of new coastal radar with greater range would allow measurement of more than only ocean currents.***

* Coastal, multidisciplinary time-series using regular water sampling from small boats (e.g. Bedford Basin Time-Series). ***This could be extended to include regular collection of metagenomic data***.

* Land- and island-based measurements (e.g. Sable Island) for collection of meteorological, sea-level and air-quality data ***including extension to measurement of aerosols and ocean-derived gases***.

* Collection of temperature, oxygen, and other data (including sediment characteristics) to monitor water quality at aquaculture sites harbours, wharves, etc;

* ***Tracking of animal movement in nearshore and coastal environment using acoustic and satellite tracking technology***.

* ***Citizen oceanography: formalized data collection and reporting by private citizens and organisations (e.g. schools, societies, NGO's).***

B. Coastal and Open Ocean Components

The shelf and open ocean require a different mix of instrumentation, platforms but would share sensors, data management approaches, etc. High costs of maintenance and deployment imply a need for technological development and optimisation of autonomous systems (***bold, italicised text***).

* Meteorological / oceanographic/wave buoys for fixed-location measurements of near-surface and atmospheric conditions; ***explore potential of autonomous, station-keeping, surface vehicles to replace moored buoys***.

* Bottom-anchored moorings for high-frequency, fixed-location, physical, optical and biogeochemical measurements through the water column, current velocities (ADCP), acoustics, fish/animal tracking, etc. ***Instrument mooring arrays with biogeochemical sensors (e.g. O_2) where appropriate; further develop profiling technologies (e.g. IceCycler, SeaCycler) to improve efficiency of multi-parameter profiling; explore potential for under-ice operation, in-situ calibration; in-situ measurement of biodiversity via genomic approaches***.

* Measurements from fixed, offshore platforms (e.g. gas / oil platforms)

* Use of autonomous vehicles (e.g. gliders) for regional measurement of water column physical, optical and biogeochemical properties, acoustics. ***Advance intelligent use of multiplatform, multivehicle observing systems (e.g. "swarms" of gliders carrying differing instrumentation).***

* Argo floats including biogeochemical floats; ***development of a Canadian BioArgo program***

* Research vessel transects for measurement of surface and subsurface waters and surface sediments along fixed hydrographic transects (e.g. DFO's AZMP and associated programs); ***improve use of other regular research vessel transits (e.g. Celtic Explorer, Amundsen); incorporate bottom camera surveys, add metagenomic and other novel biological measurement technologies into these transits***.

* Use of volunteer observing ships (e.g. fishing and offshore supply vessels, ferries, container vessels, freighters): for measurements along repeated transects of physical, optical and biogeochemical properties of the near-surface and atmosphere, current velocities (ADCP), etc. ***Explore potential for deployment of sophisticated measurement systems (e.g. microwave radiometers, lidars, mass spectrometers); bird/mammal observations, etc. Develop unobtrusive methods for water column profiling from VOS***.

* Animals: tracking of animals and use of marine animals (e.g. seals) as carriers of oceanographic sensors. ***Further development of sensors, processing of data as well as acoustic and satellite tracking technologies.***

* ***Develop and deploy benthic observatories for measurement of sediment-water fluxes and long-term changes of benthic biodiversity and metabolism (e.g. in response to ocean acidification and temperature change).***

* AUVs and ROVs for regional surveys and experiments. ***Development of new low-power sensors and operational strategies for deployment.***

C. Data Management and Dissemination

The collection of environmental data carries with it the responsibility to archive data and make it available to others. Historically, the role of data archivist has been played in Canada by the federal government (e.g. DFO, NRCAN). The ability of these departments to partner with new programs and to support new types of data (e.g. from acoustic instruments or ocean gliders) has declined in recent years. Major new programs have tended to develop their own data systems. Ocean Networks Canada, SmartAtlantic and the St. Lawrence Global Observatory have all created data management systems for archival and/or dissemination.

It is expected that environmental data will be made available for scientific and public use, typically after a brief period of quality control or after collectors of the data extract their value from it (in the case of research project data). However data dissemination means more than putting data in an archive that is publically accessible. Increasingly, real-time data initiatives, such as Neptune and Venus on the west coast, SmartAtlantic and the St. Lawrence Global Observatory on the east coast, make data available to all users as soon as possible after collection. Effective dissemination requires creating added value to the data through data analysis and presentation and linking data with numerical models. This can be via analysis tools linked to databases, but typically data products can also be made available that enable less sophisticated users to extract meaningful information. Sharing data at this level expands the pool of users. Several new data streams envisioned for an

IAOOS will challenge existing data management approaches, and will require advances and investments in data infrastructures. There is an urgent need for a national dialogue on these issues, as the needs in Atlantic Canada are likely similar to those elsewhere in Canada.

VII. SENTINEL AREAS

The principles outlined in Section IV included promotion of RADs and encouragement of international involvement. Both imply a need to focus effort, when possible, within common geographic areas where a more complete array of observations can support research and development. We refer to these areas of special focus as "Sentinel Areas".

A. Why Sentinel Areas?

Sentinel Areas create opportunities to: develop infrastructures with broader capabilities and synergies than would otherwise be possible; promote multi-disciplinary scientific interactions; co-locate scientific study and data collection in areas of interest to multiple user groups including industry; provide Canadian focal points for international cooperation; allow a scientific and long-term data "context" for individual project-based investigation of ocean processes; provide a data-rich test-bed for development of new measurement technologies. Sentinel Areas will also create environments within which research towards improvement of data assimilation methods (e.g. to biogeochemical and ecosystem parameters) can be conducted.

B. What are key aspects of Sentinel Areas?

A Sentinel Area should be:

* Suitable for scientific investigation of multiple oceanic phenomena including biological and ecosystem processes. In other words, a Sentinel Area should be able to act as a RAD (Researcher Aggregating Device).

* An area of significance to industry (now or in the future) with potential for linkage to industry activities

* An area suitable for development, testing and demonstration of new observing, data assimilation as well as modelling technologies and approaches.

Sentinel Areas would include:

* Moored arrays supporting multidisciplinary observations at high frequency that extend into deepwater,

* Multidisciplinary observations from regional surveys using research vessels and autonomous vehicles.

* Microbial (e.g. metagenomic) observatories

* Demonstrated interest of international partners

* Ongoing or planned experimental, project-scale investigation of ocean processes, including time-series and spatial characterisation of biological and ecosystem data.

* A focus for oceanographic numerical prediction projects

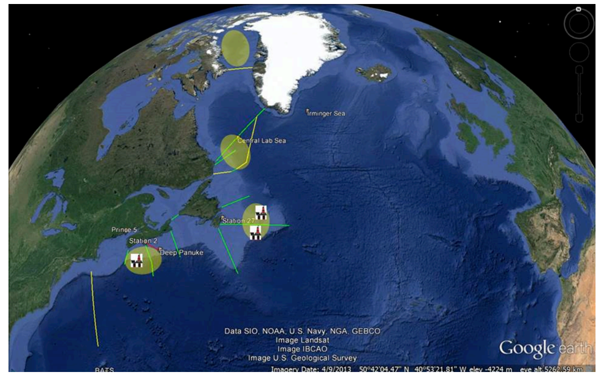

Figure 6 Suggested locations of Sentinel Areas in relation to hydrography lines in the Northwest Atlantic.

C. Where?

Given anticipated funding, the number of Sentinel Areas must be limited. In light of the principles above, consideration is being given to the following locations (Figure 6):

1. **Baffin Bay** is subject to major changes in ice-cover and changes in stratification from changing freshwater input. In some sense it can be considered an "Arctic Ocean Laboratory". The region is the focal area for a major, international research program ("GreenEdge"; Section V*B*). There are links to ARCTICNET and observations along West Greenland (Soeren Rysgaard, Univ. Manitoba) and US programs (Craig Lee, Univ. Washington) in Davis Strait.

2. The **Labrador Sea and Slope** is the location for the VITALS and OSNAP programs (Section V*B*), as well as DFO's AZOMP monitoring program (Section V*A*) and a long-term mooring maintained by GEOMAR (Germany). The region is one of only a handful of locations for deep water formation, and is responsible for supplying oxygen to large volumes of the ocean interior. There is potential for future deepwater oil exploration along the Labrador Slope.

3. **Flemish Pass, Orphan Basin and Grand Banks**. There is already a DFO AZMP line here and developing plans for oceanographic sampling by offshore oil companies. This is an area of oil exploration and development and a very active year-round fisheries. The region is also characterised by large and variable air-sea fluxes of heat and CO_2.

4. **Scotian Shelf and Slope**. DFO's and OTN's Halifax Line and Extended Halifax Line are located within this area,. The slope water is transited by the Deep Western Boundary Current and impinged by the Gulf Stream. The area supports an important fishery, marine protected areas and the Shelburne Basin is an area of active deepwater oil exploration by BP and Shell.

VIII. A WAY FORWARD

A. Establish a multi-sectoral, regional coordination body for Ocean Observing in Atlantic Canada.

As noted in Section I, there is an urgent need for coordination and planning of ocean observation systems, in order to guide Canadian participation in the Galway Alliance. We propose establishment of a multi-sectoral partnership for coordination of observations along Canada's Atlantic Coast. The organisation would be similar to the Regional Coastal and Ocean Observing Systems of NOAA's Integrated Ocean Observing System (IOOS) in the USA and share similarities with the St. Lawrence Global Observatory (SLGO) in Canada. We refer to this body as "ACROOS" (Atlantic Canada Regional Ocean Observing System). ACROOS would have the following mission:

* To lead coordination, development, implementation, operation, and evaluation of a sustained, multi-sectoral and multi-disciplinary coastal and ocean observing system for Canada's Atlantic Ocean region, in cooperation with oceanographic prediction efforts (e.g. CONCEPTS), other Canadian regional observing networks (e.g. SLGO), the US IOOS program and other international programs (e.g. GOOS and IOC associated programs). ACROOS would lead Canada's contribution to an Integrated Atlantic Ocean Observing System (IAOOS).

* To coordinate with multi-sectoral partners in the development of a business plan model to ensure funding support from multiple "customers" for research, technology development, capitalization and operational support

* To work with national and international partners and users to define a set of key measurements, as well as agreed-upon approaches to data quality control.

* To link ACROOS (and IAOOS) to relevant national and international efforts undertaking ocean monitoring, modelling and remote sensing.

* To work with national and international partners towards mechanisms for management, assessment, and dissemination of data and data products to meet needs of data collectors and end users (see *D* below).

* To establish mechanisms through which observing platforms can be used to accelerate development, testing and introduction of new observing and data dissemination technologies by the Canadian private sector.

* To advocate, through education and outreach, for the regional, national, and global ocean observing system and the application of scientific assessments using environmental data to meet societal needs.

B. Implement specific components of an observing system.

* Support a network of coastal meteorological/wave buoys (or alternative technologies) in key nearshore locations along the Atlantic coast building on the SmartAtlantic initiative and buoys maintained by Environment Canada.

* Integrate and coordinate support of autonomous vehicle platforms operated by multiple universities and agencies.

* Establish a coastal radar network for monitoring currents and waves at key locations along Atlantic coast

* Establish a network of volunteer observing ships (VOS) and other industry platforms for regular measurement of surface ocean and atmospheric properties. Prospective vessels and routes include: Coast Guard vessels, Vessels accessing Labrador and Baffin Island coasts; supply vessels transiting to Flemish Pass, the Grand Banks and Deep Panuke (Scotian Shelf); tankers entering Placentia Bay; ferries across key straits. This activity is compatible with MEOPAR and World Ocean Council plans for a Regional Node of the Smart Industries / Smart Oceans program.

* Expand biological observation, by extending and integrating Ocean Tracking and establishing a number of microbial observatories from Baffin Bay to the Scotian Shelf.

C. Support participation of Canadian ocean technology providers in IAOOS and Galway-related activities.

The development of the technology outlined above requires partnerships between scientists concerned with understanding and measuring the ocean, technology companies interested in developing measurement systems, and users who define needs for data and information. There are many companies in Atlantic Canada with relevant technological capability, including platforms, sensors and communication systems, that can contribute to an IAOOS and that are interested in developing new ocean observation technologies. Coordinated support for ocean tech industry participation in a Canadian observing effort closely linked to IAOOS and the Galway Alliance will enhance Canadian competitiveness in international "blue ocean technology".

D. Data Management.

Work with the SLGO, Ocean Networks Canada, DFO and other data centres and organisations (e.g. MEOPAR, MI/CTec-SmartBay, OTN) and the private sector as well with international partners (e.g. IOOS, Copernicus) to design and implement appropriate approaches to data management, archiving and accessibility that will be interoperable across the IAOOS. Anticipate data requirements of "disruptive observation technologies" such as metagenomic analysis.

E. Define and Populate Sentinel Areas

Promote cooperation between sectors and users, including international partners, to define and instrument a number of "Sentinel Areas" (see Section VII) for diverse, multi-disciplinary, sustained measurement and investigation of atmospheric, oceanographic, biogeochemical, and ecosystem properties as well as animal tracking. Sentinel Areas are envisioned to support long-term scientific research into effects of natural- and human-induced changes of the marine environment and act as "Researcher Aggregating Devices" in order to maximise synergies and cross-fertilisation of efforts based on a wide range of long-term observations.

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