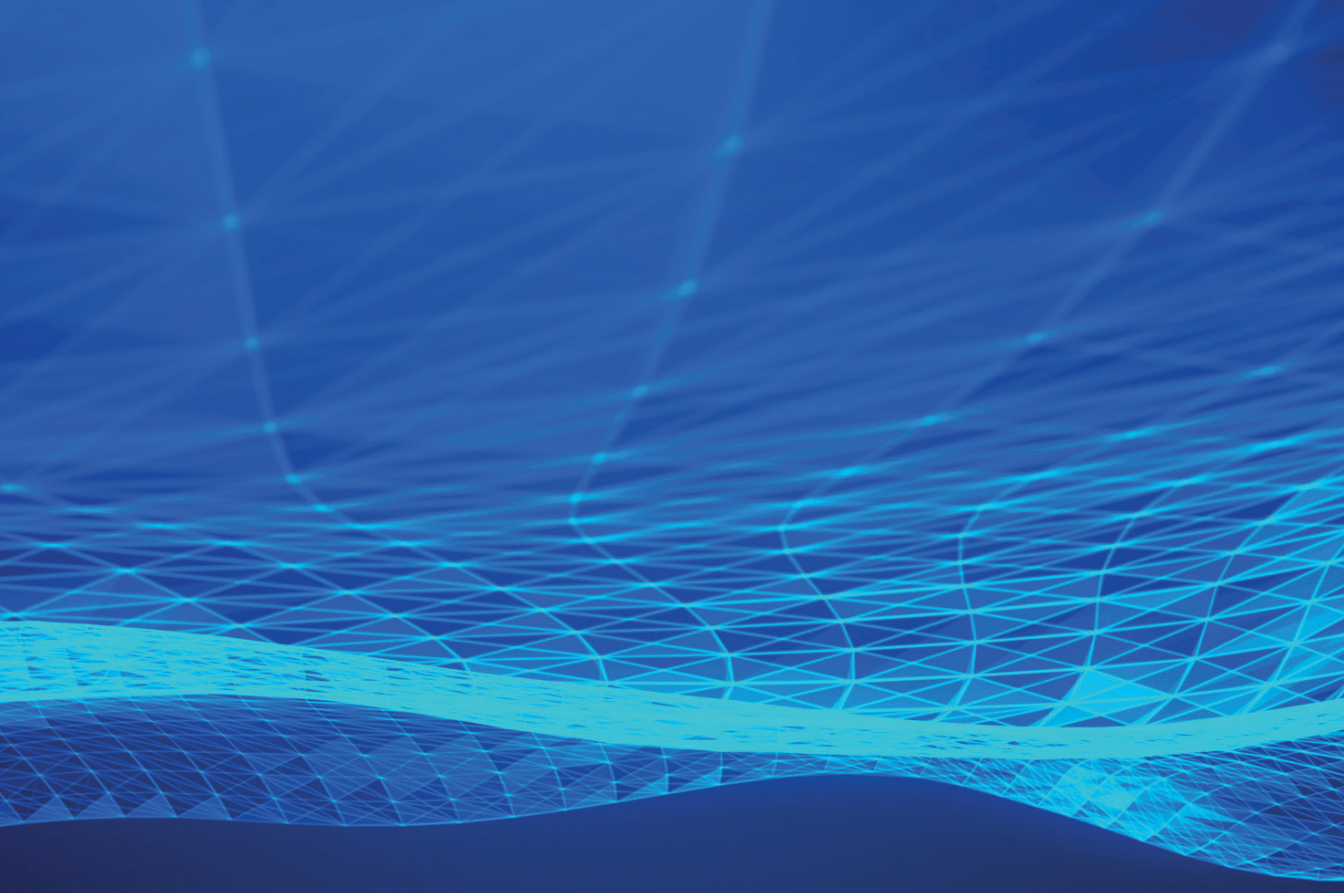


The Canadian Integrated Ocean Observing System

Background, Current Status, and Future Scenarios

by Kelley Santos, Alexa Reedman, and Douglas Wallace

The long relationship between humankind and the ocean is intensifying and growing in complexity globally due to rapid expansion of economic use of the ocean and growing inter-dependence of human society with the ocean's ecosystems and with its role for weather and climate. While there is only one, globally inter-connected ocean, it has enormous geographic diversity. Canada, with the longest coastline in the world, has a complex and diversified relationship with the ocean because its vast ocean spaces are particularly diverse in their biological, physiographic, climatic, and socio-economic characteristics.

Sound knowledge and understanding of the ocean as a basis for prediction and future projection is now essential for safe and sustainable management of ocean resources and use, as well as for mitigation of risk to ecosystems and human populations. Knowledge and understanding, in turn, depend on accurate, rich, and integrated ocean observations and access to the associated data. Despite having developed and deployed examples of world-class technology for ocean observation, Canada has, until recently, lacked a national vision and strategy for coordination of ocean observation and the resulting data. This led to major gaps and inconsistencies in observation capacity and data availability. A national ocean observing system, based on a coordinated and cooperative approach across Canada, was urgently needed to effectively and efficiently observe Canada's diverse ocean spaces.

Laying a Foundation Based on Cooperation

The launch of the Canadian Integrated Ocean Observing System (see "Further Reading" – Stewart et al.) on March 7, 2019, was the outcome of several years of nationwide consultation and planning. Early discussions provided both the impetus for the movement towards greater coordination, as well as a mechanism to bring Canada's ocean observing community together. A Marine Environmental Observation, Prediction and Response Network (MEOPAR) initiated whitepaper (see "Further Reading" – Wallace et al.) proposed a regionally-coordinated, integrated ocean observing system (Figure 1). While focused on the Atlantic Ocean, this whitepaper noted that "Several new data streams envisioned for an IAOOS [integrated Atlantic Ocean observing system] 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." The conception of a "Community of Practice on Ocean Data Management (CoP ODM)" followed shortly at a MEOPAR-supported workshop on ocean data management (Montreal, March 2014) and initiated a movement of the ocean observing community across Canada towards development of a coordinated national strategy. The CoP ODM was supported by MEOPAR, and connected the various existing ocean data centres across Canada for the first time, allowing them to share and mobilize expertise and best practices, promote cooperation and alignment, and start to develop a shared vision for ocean data management. The CoP provided the framework for an "Expert Forum on Ocean Data Management" (Montreal, November 2015), which brought together over fifty participants from government, academia, and industry who offered their perspectives and shared best practices. The workshop summary, *Towards a Unified Vision for Ocean Data Management in Canada: Results of an Expert Forum* (see "Further Reading" – Wilson et al.), represented a fundamental contribution to the growing national dialogue about the integration of ocean data management in Canada.

The vision that emerged from the Expert Forum was unambiguous, with participants "ready for the federal government to take a leadership and support role" in the formation of a coordinated national system. The consensus was that a "federated model of regional nodes with central coordination and incentives would make best use of existing expertise and experience." Building on this

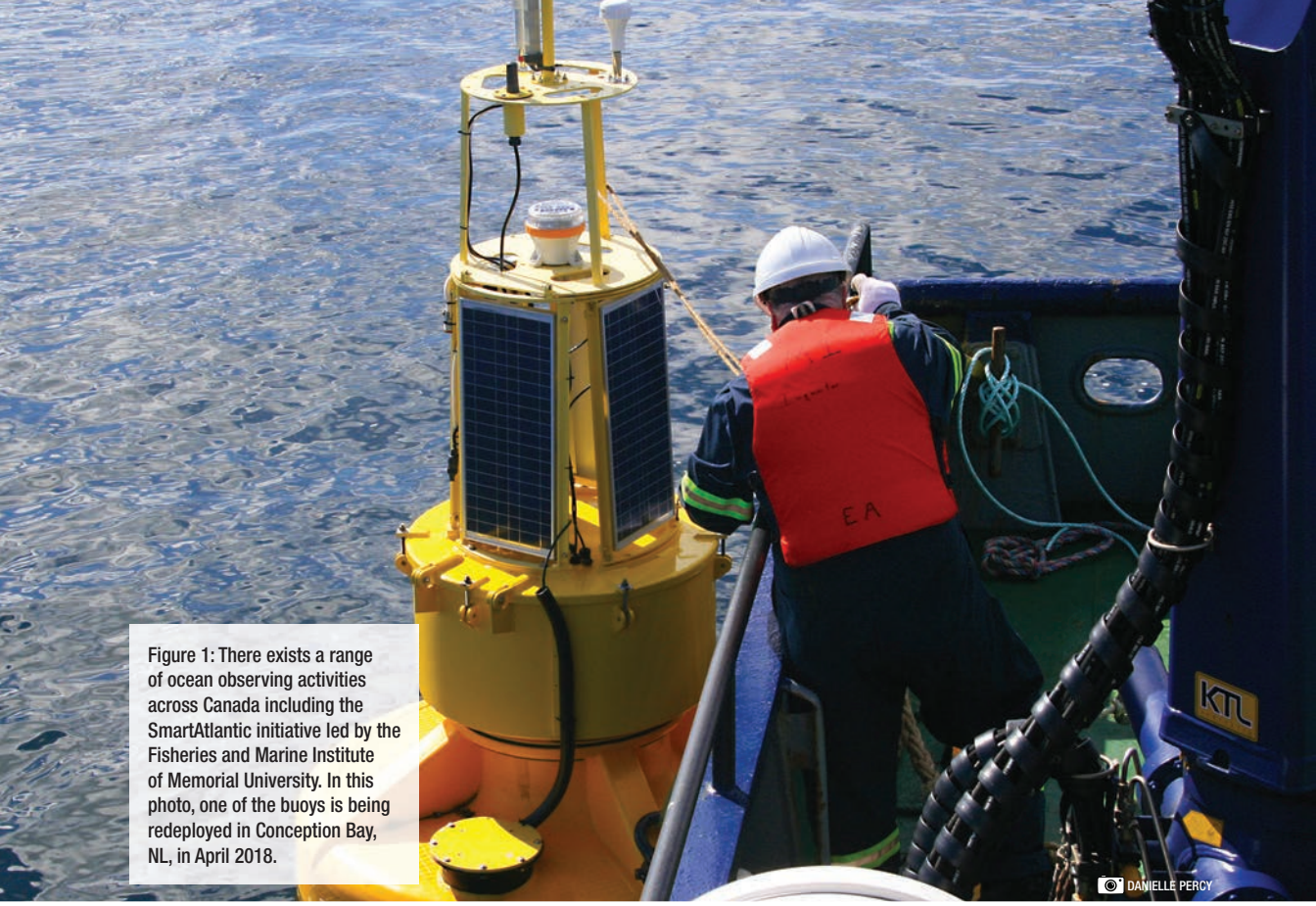


Figure 1: There exists a range of ocean observing activities across Canada including the SmartAtlantic initiative led by the Fisheries and Marine Institute of Memorial University. In this photo, one of the buoys is being redeployed in Conception Bay, NL, in April 2018.

momentum, Fisheries and Oceans Canada (DFO) funded three Investigative Evaluations into data management, cyberinfrastructure, and data visualization to further investigate existing assets and activities and provide recommendations on implementation. These collaborative efforts demonstrated that Canada's distributed ocean research community could cooperate effectively and was therefore well-positioned to undertake an initial roll-out of a national system.

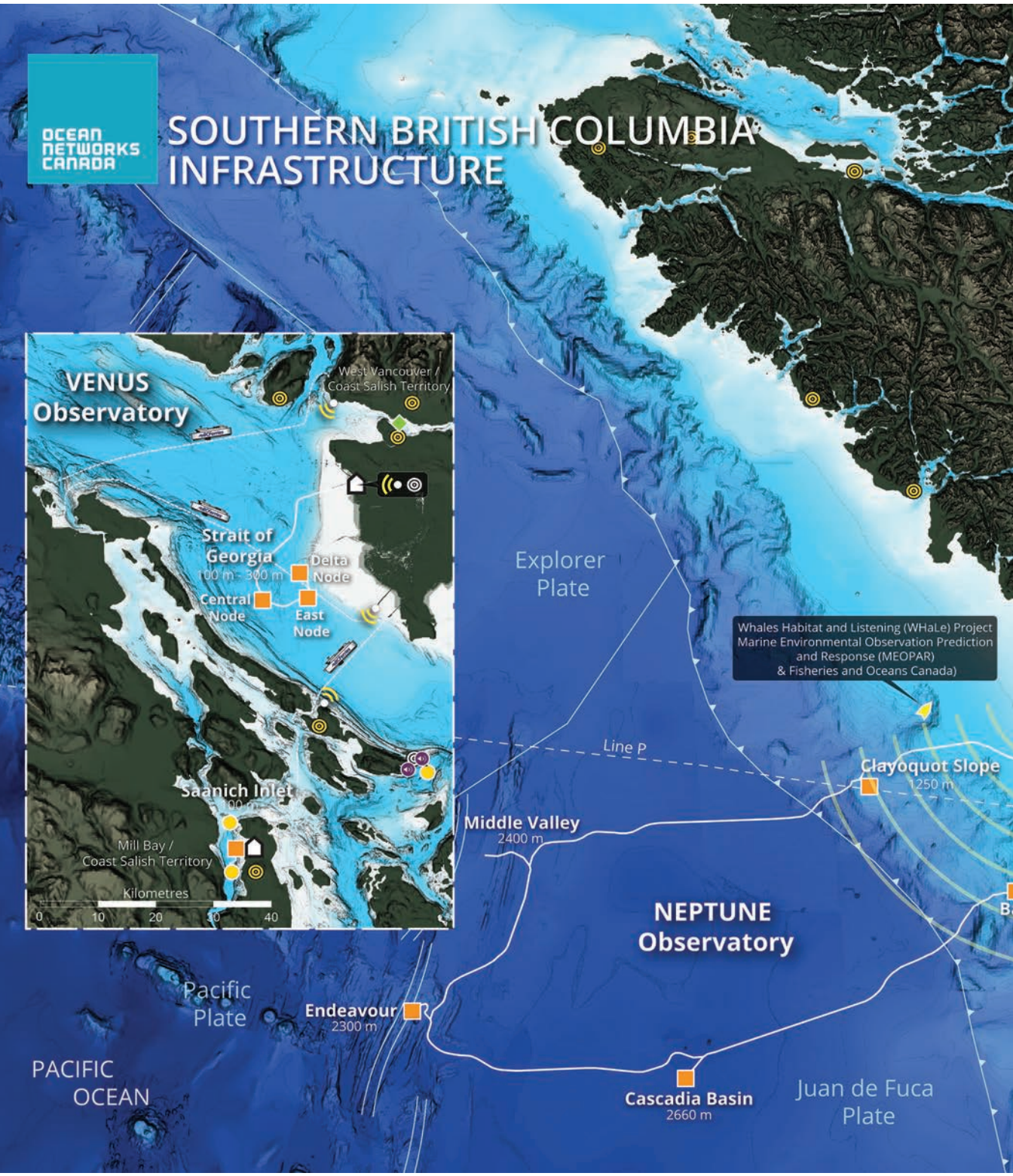
On March 7, 2019, DFO, in partnership with MEOPAR, announced Phase 1.0 of the Canadian Integrated Ocean Observing System (CIOOS). Building on the foundation of the CoP ODM and Investigative Evaluations, DFO and MEOPAR committed more than $2 million annually as well as organizational support to a CIOOS pilot phase focused on development of data infrastructure, management structure, and visualization tools, and treatment of an initially limited number of existing key data streams. The pilot system will be robust and scalable to additional data types and variables. Development of this pilot system has united the knowledge, expertise, and infrastructure of Canada's ocean data management community.

Building on Canada's Strengths

Canada has considerable strength in regional data collection on all three coasts (Pacific, Arctic, Atlantic) and within its major inland seas. The observation activities within each region as well as the end-users for data and information products are, however, highly varied, reflecting the diversity of the regions themselves. Hence, CIOOS was designed as a federated model of regional associations with central coordination (similar to the U.S. Integrated Ocean Observing System or IOOS) in order to reflect this diversity and capitalize on the experience, expertise, and end-user connections of regional networks across the country (Figures 2A, B, and C). Guided and supported by DFO and MEOPAR, the pilot phase established three CIOOS Regional Associations (Atlantic, Gulf of St. Lawrence,

A Figure 2: CIOOS will capitalize on established regional capacity while ensuring an consistent national approach using data from, for example, (A) SmartAtlantic on Canada's east coast; (B) Ocean Networks Canada on Canada's west coast; and (C) St. Lawrence Global Observatory.


Port Hope Simpson
Mary's Harbour
Pidgeon Cove-St. Barbe
St. Anthony
Saint-Augustin
Mutton Bay
Tête-à-la-Baleine
Port au Choix
Roddickton-Bid Arm
Baie Verte
LaScie
Rocky Harbour
Springdale
Stag Harbour
Deer Lake
Corner Brook
Grand Falls-Windsor
Gander
Bishc Falls
Buchans
Stephenville
Bonavista
St. George's
Clarenville
Channel-Port aux Basque
Grand Bruit
Burgeo
Rose Blanche
François
Gaultois
Pool's Cove
Carbonear
Seal Cove
Harbour Bre
Placentia
Grand Bank
Trepassey
SCOTT BRUCE


OCEAN NETWORKS CANADA
SOUTHERN BRITISH COLUMBIA INFRASTRUCTURE
VENUS Observatory
West Vancouver / Coast Salish Territory
Strait of Georgia
100 m - 300 m
Delta Node
Central Node
East Node
Saanich Inlet
100 m
Mill Bay / Coast Salish Territory
Kilometres
0 10 20 30 40
Explorer Plate
Whales Habitat and Listening (WHaLe) Project
Marine Environmental Observation Prediction and Response (MEOPAR)
& Fisheries and Oceans Canada)
Line P
Clayoquot Slope
1250 m
Middle Valley
2400 m
NEPTUNE Observatory
Pacific Plate
Endeavour
2300 m
PACIFIC OCEAN
Cascadia Basin
2660 m
Juan de Fuca Plate

B


BRITISH COLUMBIA
Campbell River / Kwakwaka'wakw / Coast Salish Territory
Strait of Georgia
Squamish / Coast Salish Territory
Salish Sea Marine Survival Project (Pacific Salmon Foundation)
VANCOUVER ISLAND
See Inset Map
Port Alberni / Nuu-chah-nulth Territory
Vancouver / Coast Salish Territory
Tofino / Nuu-chah-nulth Territory
Nanaimo / Coast Salish Territory
Folger Passage
20 m - 100m
Victoria / Coast Salish Territory
arkley Canyon
400 m - 1000 m
Juan de Fuca Strait
WASHINGTON - USA
North American Plate
Automatic Identification System Receiver (Canadian Coast Guard)
Automatic Identification System Receiver (Ocean Networks Canada)
Autonomous Glider/AUV System
Community Observatory
Hydrophone (Saturna Island Marine Research and Education Society)
Mobile Asset
Mooring
Node
Ocean RADAR
Shore Station
Fault Line
Ferry Route
Fibre-optic Cable
Ship-based Observations
Spreading Centre
Subduction Zone
WavE RAdar (WERA) Range
100 km
0
Bathymetry (100 m contour lines)
-3500 m
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AN INITIATIVE OF
University of Victoria
Data Sources: USGS Cascadia, Natural Resources Canada DEM, Canadian Hydrographic Service Bathymetry (license 2015-1001-1260-V), GeoBase Topography (Government of Canada, NOAA Agencies, NGDC, British Columbia Marine Conservation Analysis, Emergency Management BC, Alberni-Clayoquot Regional District, J.R. Delaney, D.S. Kelley, and D. Glickson, University of Washington (TN175Data), Ryan, W.B.F., S.M. Carbotte, J.O. Coplan, S. O'Hara, A. Melkonian, R. Arko, R.A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky (2009), Global Multi-Resolution Topography synthesis, Geochem. Geophys. Geosyst., 10, Q03014, doi: 10.1029/2008GC002332. This product must not be used for navigation.
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Projection: Mercator
Last Updated: 4 September 2019
BRITISH COLUMBIA - CANADA
Vancouver
Seattle
WASHINGTON - USA

and Pacific) linked by an overarching national strategy and governance structure. This multilevel governance model allows for a consistent national approach and opportunity for the sharing of best practices.

Each of the three Regional Associations leverages the national and international expertise of their partner organizations, and can continue to build regionally-specific tools and approaches which will facilitate easy discovery of and access to data of particular value and relevance for each particular region.

St. Lawrence Global Observatory (SLGO): Established in 2005, SLGO has the longest history in Canada of acting as a regional data provider/integrator, and provides integrated and timely access to data, user-friendly interactive visualization tools, and a wide range of multi-disciplinary information from multiple partners. With a membership of over 50 organizations, its concept maximizes the benefits of data integration, discovery, and re-use in order to best enable long-term management of the St. Lawrence's ecosystem. SLGO's mission is to promote and facilitate accessibility, dissemination, and exchange of official and quality data as well as electronic information through consolidation and networking of various producers and data-producing organizations in order to meet both their needs and those of users, and also to improve knowledge and help decision making in areas such as public safety, climate change, transportation, resource management, and biodiversity conservation. Under CIOOS, SLGO will harmonize and align its activities and services with those of other regions, share its expertise and experience, and intensify end-user engagement activities throughout the Gulf region.

CIOOS Atlantic: The Atlantic region houses world-class researchers and centres of expertise in ocean science both in the use of marine autonomous vehicles and sensor systems, and in the curation and analysis of data stemming from particular types of ocean observation. However, prior to CIOOS, there was no organized, region-wide, multi-sectoral approach to the management of diverse ocean datasets. Dalhousie University and Memorial University of Newfoundland (including its Marine Institute campus) are the fulcrums for ocean research and data curation, visualization, and analytics in the region. The Atlantic Regional Association builds on these strengths with a consortium of partners committed to the development of a data management and dissemination approach for the extensive oceanographic data collected along the Atlantic Seaboard, from Labrador to the Gulf of Maine. Hosted by the Ocean Frontier Institute and co-led by Dalhousie and Marine

Institute, the consortium brings together established infrastructure and expertise from COINAtlantic, Memorial University, and the Ocean Tracking Network.

CIOOS Pacific: The Pacific region brings together expertise in ocean monitoring with extensive history and technological expertise in observing both the coastal and open ocean. Hosted at the University of Victoria, this partnership between DFO's Institute of Ocean Sciences, the Hakai Institute, and Ocean Networks Canada elevates the collective monitoring efforts. The Institute of Ocean Sciences has continuously documented change in the northeast Pacific longer than any other monitoring effort in the world, which is proving essential to understanding ocean variability. The Hakai Institute and Ocean Networks Canada each bring a wealth of cutting-edge monitoring techniques to the collaboration. Their myriad of real-time sensors stream data through cabled observatories and telemetry networks taking the pulse of the coastal and offshore ocean and providing timely insights to ocean managers. The collective depth and expertise in CIOOS Pacific allows for comprehension of the past, detection of anomalies in the present, and prediction of future conditions.

A System for All Canadians

Ocean observations form the basis not only for understanding the ocean but also for prediction of its behaviour and impacts. Whereas promotion of the growth of understanding is largely the domain of researchers, large swathes of human society today depend on information, forecasts, and projections of ocean behaviour. The latter are of direct, increasing relevance to coastal communities and industry, and impact livelihoods, safety, and economic performance. The ocean's role for climate change and weather, food supply, and trade impacts all of Canada, indeed all nations. Examples of the use of ocean information range from the mundane to the dramatic and cut across all sectors of society. On the east coast of Canada, holidaymakers and locals alike may want to know seawater temperatures and/or whether fog will disrupt their planned day at the beach; on the Bay of Fundy, tidal forecasts are part of the rhythm of life for many. There are many examples where access to information can produce major economic benefits or mitigate risk. The marine heatwave of 2012 in the northwest Atlantic had major repercussions for fisheries and especially for the lobster industry in eastern Canada. Improved access to observations and ecosystem predictions could have allowed for better management of industry response to this anomaly. In British Columbia, tsunami warning systems based on measurements of seismicity are key to protection of life. Prediction of water movement can allow shellfish hatcheries to avoid the worst impacts of ocean acidification events. Forecasts of sea-ice extent and iceberg drift are critical for fishing, shipping, and offshore operations off Newfoundland and Labrador as well as the Gulf of St. Lawrence. Information concerning ice breakup is of growing importance for hunters and trappers in the Inuit Nunangat. In the Gulf of St. Lawrence, marine ecosystem change has led to shifts in the habitat of the endangered North American right whale with major impacts on the whale population but also on shipping and fishing industries.

There are many benefits that ocean observations can provide for our society and economy as well as for mitigating risk to ecosystems; however, central to these benefits is that information from the observations must be made available in a readily accessible format including presentation as targeted information, data products, and predictions.

Hence CIOOS is aimed at providing data not only to researchers and government agencies but also to a very broad range of end-users, ranging from coastal communities to ocean industries, First Nations, government agencies, and non-governmental organizations. CIOOS will provide data of relevance to industrial sectors as diverse as shipping, defence, ocean-related tourism,

Figure 3: One of the next steps in regional expansion involves exploring how to best connect with the Arctic and Inuit Nunangat.

offshore oil and gas, renewable energy generation, natural resource exploitation and exportation, fishing, aquaculture, and ocean technology development. Many of these same end-user organizations and sectors are potential data providers and a key task of the Regional Associations is to identify and engage with as many potential data providers and information users as possible. Engagement and ongoing communication with users will lead to better understanding of stakeholder needs and likely create new uses for ocean data. The information obtained from these efforts at the regional scale will be shared through CIOOS at the national scale, allowing for rapid dissemination and uptake of promising new ideas and approaches. This includes the dissemination of new tools, web-services, data management practices, expertise, code, and datasets.

With the initiation of CIOOS, a system is now under development that will grant users a wider breadth of information to support predictions and inform decision making, management, and operations. CIOOS brings together a previously fragmented approach to ocean observing, increasing the potential value of the investments made to date and allowing expertise and ideas that arise regionally to be shared nationally. Further, CIOOS will increase Canada's effectiveness at the international level by improving our ability, as a nation, to contribute knowledge on the international stage in the context of global ocean observing systems. CIOOS connects organizational clusters nationwide and, through provision of a single entry point for access to data and forecasts originating from various programs and agencies, the system improves access to data and encourages data reuse. The system, therefore, increases the value of investing in collection of individual datasets by linking them to others, and making them more available. Ultimately CIOOS will facilitate a better understanding of the ocean as a whole, which can generate new opportunities for economic growth, technological development, ecosystem protection, and promote the sustainability of Canada's diverse coastal societies.

A Way Forward

CIOOS is presently a nascent system. Significant progress has been achieved since its inception, including consultations with stakeholders and development of a nationally-consistent approach to data management. Nonetheless, there exist many important next steps to ensure the long-term success and sustainability of the Canadian Integrated Ocean Observing System. And the model established for CIOOS can, potentially, be harnessed for additional applications and to provide further benefits.

Regional Expansion: CIOOS is presently comprised of three Regional Associations (RAs), a National Web Presence, and a Data Stewardship Node. To ensure a truly sustainable and successful system in the long-term, CIOOS needs to expand into new geographic areas. A truly comprehensive Canadian Integrated Ocean Observing System must include, at least, all regions of Canada that touch the ocean directly. Extension to Canada's broader aquatic environment may also make sense. Hence next steps involve consideration of how best to connect existing CIOOS with two new regions: the Arctic (Figure 3) and Inuit Nunangat, and the Great Lakes.

The value of the regionality of CIOOS cannot be overstated. A barrier to early development of a coordinated system was likely reluctance of some regional end-users and data providers to interact with distant or highly-centralized organizations that may or may not be responsive to their priorities and requirements. As CIOOS develops, it is imperative that it remain a national system, but also a decentralized one. The multisectoral nature of CIOOS also appears to be important with, especially, the federal government seen to be working cooperatively with non-government organizations such as universities, again in a decentralized but effective manner.

The Canadian coastline is the world's longest, touching thousands of communities across the country. The myriad of reasons by which communities utilize the ocean for their culture, leisure, and livelihoods underscores the importance of Regional Associations, outside of government, which can retain the ability to be responsive to the needs of individual regions without being under direct, centralized, or political control. The governance model of CIOOS must therefore continue to have a bottom-up approach balanced by a need to share approaches and harmonize best practices efficiently across the country; it must be executed hand in hand with the federal government, but must also remain outside of it.

Discipline Expansion: Also imperative to long-term sustainability of CIOOS is that it remain open and responsive to additional disciplines, emerging needs, and new opportunities. It must be open-minded and support innovation in developing tools and processes to manage and access discipline-specific data, including data that arise from fundamentally new technologies, organizations, and platforms. Concurrently with regional expansion, CIOOS should continue to explore mechanisms that allow integration of data from broader disciplines, so as to further leverage, for the Canadian context, the numerous thematic data repositories that exist globally. Access to worldwide biodiversity and biogeographic data through linkages with systems like the Ocean Biogeographic Information System Canada or acoustic receiver and animal tracking data through the Ocean Tracking Network will broaden the scope of data that researchers and decision makers are able to access.

Encouraging communication and collaboration across emerging systems will ultimately strengthen ocean-related research and capacity throughout Canada. Platforms specifically for underwater acoustic data (such as the Marine Environmental Research Infrastructure for Data Integration and Application Network or Meridian) or for the collection of environmental DNA (eDNA: DNA that can be extracted from environmental samples) or for various "omics" (characterization and quantification of biological molecules that translate into the

structure, function, and dynamics of organisms) are emerging areas that have potential to provide critical contributions to our understanding of the ocean but also guide operations and responsible use. The ability of CIOOS to work constructively and cooperatively with diverse scientific communities involved in such emerging areas, so that they can develop tools and processes in the context of an open and flexible national system, will be imperative to the system's long-term sustainability.

Focused Engagement: The importance of ongoing engagement and dialogue with Indigenous and coastal communities is of utmost importance as CIOOS strives to be a platform that provides recognized value by furnishing access to diverse and high quality ocean data. Careful and early consideration must therefore be given to design a system that can partner powerfully and effectively with Indigenous organizations, and to explore appropriate mechanisms for sharing and preserving ocean-related information collected using both western scientific methods and Traditional Ecological Knowledge.

Ultimately CIOOS must perform focused engagement in order to develop the tools and infrastructure required for interoperability between disparate systems of data collection and use, and between organizations that may have very different priorities. In turn, this will expand CIOOS' ability to connect with both national and international stakeholders. With CIOOS as a central access point, these data repositories will collectively and efficiently be able to provide data users with an as complete and comprehensive picture as possible of what is happening in Canada's highly diverse aquatic environments.

Global Partnerships

Recognition that Canada's ocean spaces and ocean observing activities do not adhere to national boundaries will motivate CIOOS in building international partnerships, and also in better defining Canada's role in global ocean observation and data management. Early consultations with established systems have not only contributed to the design of CIOOS but also ensured alignment of standards and processes which facilitate interoperability of Canadian-sourced data on a global scale. Alignment with the Global Ocean Observing System framework as well as collaborations between CIOOS and other regional and national organizations will facilitate effective global data exchange for mutual benefit.

Participation in regional or basin-scale partnerships such as the Atlantic Ocean Observing Blueprint and its work towards an All-Atlantic Ocean Observing System (AtlantOS) connects multiple partners and countries internationally who are working towards efficient sharing and development of infrastructure, knowledge exchange, and coordination of ocean observing activities. The U.S. Integrated Ocean Observing System (IOOS) is an established model from which CIOOS can continue to learn. Similar to Canada, the U.S. system is challenged with capturing information across a vast and diverse geography. U.S. IOOS is represented by 11 Regional Associations. With four of those RAs sharing waters directly with Canada, a number of collaborations between CIOOS partner organizations and IOOS RAs have been established and will continue to add value to the system going forward.

Ultimately, international collaboration will ensure that Canada's data is interoperable with global systems, thus increasing its long-term value. It will also position Canada to contribute to and benefit from information on a global level that will further enhance our ability to address marine issues both within our borders and beyond.

Beyond Data Management

Although plentiful, Canada's oceanographic data collection effort is scattered across multiple organizations and initiatives, creating a challenging landscape for conducting comprehensive research and making informed decisions around marine management and

operations. Regional economic differences as well as logistical considerations have led to clear regional differences in the nature of observing systems along Canada's coastline. The ability of Canadians to conduct impactful research and make effective operation and management decisions is heavily impacted by the data to which they have access. Beyond managing data that exist, CIOOS could add value to Canada's ocean sector if it can also provide a vehicle or platform through which ideas for major ocean observing initiatives are planned and operated. Beyond data management, CIOOS has the potential to provide Canada's ocean community with an enhanced level of national coordination of infrastructure, expertise, and data services, which will ultimately encourage broader collaboration and the sharing of ideas and infrastructure across disciplines and across different parts of the country. This role, in providing a platform for national coordination, must be carefully balanced with the need to allow for innovation and creativity. There is an inherent risk that national coordination can stifle or slow down the introduction of new ideas and approaches in the interest of uniformity or regional equity. This is a delicate balance for national networks and organizations such as CIOOS that require considerable self-awareness and/or mechanisms for external evaluation. Advisory and/or external review procedures for CIOOS will, therefore, need to be developed as the system grows in capacity, importance, and power.

Outside of ocean observing, CIOOS' regionally federated structure guided by strong national leadership could serve as a model for other areas of ocean-related research. By providing a common system for government, scientists, and partner organizations to integrate, access, share, and preserve data, CIOOS will facilitate:

- Enhanced modelling work and environmental assessment advice;
- Increased ability to detect changes in ocean conditions, including impacts on fish stocks and distribution;
- Improved resource management decision making, both in the long-term (i.e., environmental and climate change adaptation) and the short term (i.e., ecosystem approach to management);
- Reduced risk to infrastructure by enhancing storm prediction and area of impact, as well as water level rise;
- Capacity to establish integrated baseline data useful for long-term monitoring;
- Generating new opportunities for industry growth/technological development; and
- Advancing Government of Canada commitments to Open Data/Open Science.

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Further Reading

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Wilson et al.
https://dalspace.library.dal.ca/handle/10222/72192

Kelley Santos is a User Engagement Specialist with the Atlantic Regional Association of the Canadian Integrated Ocean Observing System (CIOOS). Her work focuses on the management and administration of multidisciplinary research projects that connect academic and applied research with the private and public sectors. She joined Memorial University in 2009 and has worked with the Office of Research at both the St. John's campus and the Fisheries and Marine Institute. Mrs. Santos' work with CIOOS is focused on promoting the value of FAIR data principles and engaging with data users and providers across all ocean sectors in order to develop an ocean observing system that will have value for all Canadians.

Alexa Reedman currently serves as the national Project Manager for the Canadian Integrated Ocean Observing System. This role is based at the Marine Environmental Observation, Prediction and Response (MEOPAR) Network. Ms. Reedman holds a Bachelor of Management from Dalhousie University. Her work focuses on the development, management, and governance of national Canadian research programs. She joined MEOPAR in 2014, most recently serving as the organization's Research Program Manager; and is currently employed by multiple research institutions, including ArcticNet, the Canadian Arctic Shipping and Transportation Network, and MEOPAR.

Doug Wallace is a Canada Excellence Research Chair Laureate in Ocean Science and Technology as well as the Canada Research Chair (Tier 1) in Ocean Science and Technology in the Oceanography Department at Dalhousie University in Halifax, N.S., Canada. Dr. Wallace also serves as Scientific Director of the Marine Environmental Observation, Prediction and Response Network (MEOPAR; www.meopar.ca), a $5 million/year national research network focused on marine risk. Prior to his appointment at Dalhousie, Dr. Wallace was professor of marine chemistry at the Helmholtz Centre for Ocean Research Kiel. There, he also served as deputy director and head of the Marine Biogeochemistry Research Division. He holds a PhD in chemical oceanography from Dalhousie University and a bachelor's degree in environmental science from the University of East Anglia, United Kingdom.

Dr. Wallace spent more than a decade working as a scientist at the Brookhaven National Laboratory in the United States. He has made significant scientific contributions to his field through the Intergovernmental Panel on Climate Change, and the U.S. Department of Energy, where he developed the first survey to measure the global distribution of fossil-fuel carbon in the oceans. He has contributed to building a number of multidisciplinary research teams and programs in the U.S., Germany, Europe, West Africa, and Canada. His research interests focus on carbon cycle and air-sea exchange of gases.