Canadian Integrated Ocean Observing System

Investigative Evaluations: Observations and Data

2017-11-30

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EXECUTIVE SUMMARY

Canada has the largest coastline of any nation in the world, making the ocean of great cultural and economic importance nationwide. To meet diverse needs for data, ocean science is conducted by numerous sectors in Canada, including government, academia, industry, non-governmental organizations (NGO), and the general public through citizen science. Using a variety of platforms and sensors, these groups collect considerable amounts of data. However, Canada lacks a national vision and strategy for ocean observation, resulting in overlap and gaps in research efforts. To effectively and efficiently monitor the ocean, Canada needs an integrated ocean observing system to bring Canadian investigators together.

This current Investigative Evaluation (IE) makes recommendations regarding the structure of a national observing system, with a focus on data and observations. This IE reviews and assesses existing assets and activities, and provides recommendations on Canadian core variables, a data management plan, and stewardship and interoperability, following the principles outlined in the Global Ocean Observing Systems Framework for Ocean Observing. This was accomplished by completing a survey of the Canadian ocean community, by engaging the assistance of ocean observing system expert Dr. Zdenka Willis, as well as through consulting with international operators of observing systems. Finally, existing integrated observing systems were analyzed and their successful practices were evaluated for their potential to meet Canada's needs.

Twenty potential core variables for a Canadian Integrated Ocean Observing System (CIOOS) were identified based on their relevance, feasibility, and cost effectiveness. Variable readiness, categorized as mature, pilot, or concept, varied among regions. Overall, maturity is high in the Pacific, Atlantic, and St. Lawrence, while in the Arctic, technology is often mature but coverage is limited. Large coverage gaps exist in the Great Lakes; no data was discoverable for the majority of variables in this region. However, the data characterized for this report is not a comprehensive collection of all data in Canada, only that which was discoverable.

With diverse data sources, CIOOS will require an extensive data management plan to ensure interoperability among regional nodes and datasets. A comprehensive and well-documented process-oriented quality assurance model combined with a product-oriented data quality control model is necessary. Furthermore, the development of detailed data and metadata standards will create a framework to allow for data to work together, foster data reuse, and move CIOOS towards fully reproducible datasets. It has been noted in existing integrated observing systems, that it is in an observing systems best interest to establish these standards early on in its development.

Recommendations are made to allow for a CIOOS to scale up incrementally. From the low-service to high-service models, additional core variables can be added, more rigorous and consistent QA/QC models can be used, and data and metadata can become more homogenous and accessible. This report also highlights the importance of acting early and creating a data policy to foster an open data culture in Canada across all sectors and to promote excellence in digital data management and data stewardship.

1. INTRODUCTION

Canada is an ocean nation. Its extensive coastline of 244 000 km, the largest of any nation on earth, spans from the temperate North Pacific Ocean, through the Arctic, and down the Atlantic seaboard to the USA. The Gulf of St. Lawrence and Hudson's Bay, two of the earth's great inland seas, are wholly contained within Canada's land mass. The Laurentian Great Lakes are another shared coastline between Canada and the USA.

About 40% of the Canadian population lives within 100 km of these coastlines (Manson et al. 2005). Both historically and currently, Canadians have turned to the ocean for their livelihoods and well-being. Canada's ocean economy is diverse, and includes transportation, offshore energy, marine technology, defense, tourism, conservation and fisheries. The ocean economy accounts for about $26 billion, approximately 5% of Canada's annual GDP, and provides employment to more than 315 000 workers (DFO 2009). The marine environment and the Great Lakes are also critically important for Indigenous Peoples' subsistence, social and ceremonial uses, and are the backbone of the socioeconomic well-being of Canada's coastal communities.

Advances in marine technology are providing unprecedented access to the ocean and are spawning a myriad of new economic and scientific activities. Emerging, well-paying employment opportunities will bring many more people out to work on the ocean as this "Blue economy", or "ocean industrial revolution" (McCauley et al. 2015) accelerates. It will also add pressure to the ocean systems that provide essential ecosystem services and currently support the existing fisheries, tourism, and other sectors that are major engines of the Canadian economy. To understand and sustainably manage this development, Canada needs an ocean observing and high-quality research capacity that will provide the integrated information needed to inform policy development and evidence-based management decisions.

The ocean drives planetary systems such as weather and water cycles, and while the environmental characteristics and fauna of the ocean may differ considerably among regions, the ocean is still an interconnected whole, as exemplified in the One Ocean concept (O'Dor et al. 2009). What happens in one part of the global ocean can have important impacts on other, distant regions. The species on which our fisheries depend are mobile and not constrained by national borders. Interconnectivity applies to environmental threats such as oil spills, invasive species, or rising sea level, temperature, and acidity. Consequently, humans have the shared global burden to provide the ocean science needed to plot a sustainable future. One mechanism through which coastal nations are addressing this challenge is by signing international agreements to collect and exchange ocean data and knowledge, and to mutually address shared problems.

In Canada, ocean science is conducted by government, academia, industry, non-governmental organizations (NGOs), and the general public through citizen science. Fisheries and Oceans Canada (DFO) has by far the greatest investment and capacity for ocean science; while DFO's science sector pursues fundamental science, its core responsibilities lie in generating high quality stock assessments enabling best fisheries management practices, and the provision of advice to its programs related to ocean protection, such as Marine Protected Areas (MPA), species at risk, and aquaculture. DFO's work also supports development of ocean economic opportunities such as aquaculture, and assists operations including search-and-rescue for the Coast Guard. The Canadian government is strongly committed to ocean science, as evidenced by the Mandate Letter issued by the government for the Minister of Fisheries and Oceans and the Canadian Coast Guard, which directs the Minister to:

1) *"Restore funding to support federal ocean science and monitoring programs",*

2) *"Ensure that decisions are based on science, facts, and evidence, and serve the public interest", and*

3) *"Work with the provinces, territories, Indigenous Peoples, and other stakeholders to better co-manage our three oceans."*

In parallel, and supported by Canada's national academic funding agencies, our university and college sectors also have strong capabilities in ocean science. Academics undertake a variety of research, ranging from narrowly focused short-term projects conducted by individual investigators, to large national networks (e.g. Canadian Healthy Oceans Network, Ocean Networks Canada, Ocean Tracking Network, MEOPAR, ArcticNet, etc.) that have the supporting infrastructure to sustain interdisciplinary research and the associated data management for longer (~ 5 year) periods.

Industry, Indigenous governments, NGOs and the public undertake more limited ocean research which is generally tied to specific interests or values of their organization(s). Many of these programs frequently address issues in which the public is strongly engaged. With the advent of user-friendly ocean observing sensors, these groups can rapidly generate large volumes of high-quality data from geographic areas of great interest to a diversity of stakeholders.

To efficiently meet Canada's needs in ocean science, it is essential that Canadian investigators from all sectors coordinate their data collection efforts to avoid duplication or lost opportunities, and ensure that data collected is discoverable, usable, and shareable by Canadians to the benefit of all Canadians. This issue, highlighted in the Mandate Letter to the Minister of Fisheries and Oceans, was the subject of two reports commissioned by DFO and its partners (DFO 2010, OSTP 2011) and was a key finding of two reports issued by the Canadian Council of Academies (CCA) which examined the Canadian ocean science sector (CCA 2012; Expert Panel on Canadian Ocean Sciences 2013). In addition, CCA (2013) identified 40 priority ocean sciences questions for Canada. Of those, two questions specifically addressed Canada's ocean information needs:

#24) How can a network of Canadian ocean observations be established, operated and maintained to identify environmental change, and its impacts?

#25) What indicators are available to assess the state of the ocean, what is the significance of changes observed in those indicators, and what additional indicators need to be deployed?

In the Expert Panel on Canadian Ocean Science (2013), which examined how Canadian ocean science research is currently structured, the panel concluded that the country faced three primary gaps:

> **Vision**
> *Canada lacks a national vision and strategy for the oceans.*
>
> **Coordination**
> *We need to pool efforts from the local to the international scale to address our ocean science needs.*
>
> **Information**
> *We lack information about the scale and scope of ocean research being carried out nationally, and on the availability and comparability of our existing research activity and of the data being generated.*

Canada requires a coordinated, integrated, ocean observing system to meet the ocean information needs of government, academia, industry, and the public. Such a system will directly support our international ocean commitments, and permit Canada to play a global leadership role in multidisciplinary ocean science. This ocean observing system will help coordinate the collection of ocean data on a national scale, will be adaptable in the face of changing needs and a changing environment, and will provide access to valuable data currently not discoverable, especially within the extensive holdings of the federal government.

The international and national context both offer favorable conditions for the establishment of a national ocean observing system in Canada. Internationally, a growing number of countries and organizations worldwide have well-established ocean observing systems. Canada's positive global reputation makes it well-positioned to sustain engagement in international efforts (such as UNCLOS, ESPOO, CBD, OSPAR, MARPOL 73/78, GEOOS, GOOS, etc.). Nationally, the amount of information and data generated by Canada's existing ocean observing assets distributed across the country (provincial and federal ministries, research organizations, universities, Indigenous Nations, NGOs, etc.), is already considerable and provides a solid foundation for the establishment of regional associations within an overarching Canadian Integrated Ocean Observing System (CIOOS) able to address Canada's national priorities.

Such a system will require engaging in pan-Canadian efforts to achieve shared standards and practices among the existing organizations (Wilson et al., 2016). Each organization will operate at its own level of sustainability, maturity, scope, and funding and will require investment and support in different areas (for example, the St. Lawrence Global Observatory, established in 2005, integrates multi-disciplinary and multi-partner data, and in many ways is a model for future regional associations). To this end, in 2016, Fisheries and Oceans Canada re-initiated a consultation process with stakeholder groups across the country to continue past discussions and move forward with the creation of a CIOOS. In 2017, DFO commissioned three Investigative Evaluations (IEs) to make recommendations regarding the structure of a national observing system. The three IEs addressed issues within the topics of *Data and Observations*, *Visualization*, and *Cyberinfrastructure*.

Canada faces rising oceanographic data challenges and needs at a time when it lacks a national data system. Challenges include:

1) Increased data volume;
2) Increased data types and observing instrument diversity;
3) Demand for timely access to data of known quality, information and knowledge, in user-friendly formats and applications;
4) The absence of collaboration mechanisms/structures to foster data standardization, integration, discovery and visualization; and
5) The need for coordinated, global, sustained (long-term) data collection.

Many in the scientific community, even those who are actively involved in the collection of ocean data, are not aware of these existing and looming challenges. The community needs to understand the scale and scope of these issues in order to begin work on strong data standardization schemes, coordination and collaboration in data collection and processing, and on developing effective communication channels and tools so that evidence-based decision-making is enabled. As such, the establishment of a CIOOS must rest on existing national and regional strengths, as well as the integration of innovative technologies and national/ international best practices. A CIOOS provides an opportunity to address the challenges Canada faces, and to improve our knowledge of the ocean.

The current investigative evaluation (IE) focuses on ocean data and observations. The report reviews, assesses and provides recommendations on the following key items:

1) **Identification and characterization of a baseline of required Canadian core ocean variables, inspired by the GOOS essential ocean variables and based on Canada's needs and regional node capabilities. Specifically:**
    1.1. *An assessment of each core variable's regional readiness levels (concept, pilot, mature); and*
    1.2. *A first edition of the Specification sheets, identifying the current observing activities for each core variable, sub-variables, supporting variables, temporal and spatial scale, as well as their possible gaps and/or overlaps.*

2) **Data management plan, stewardship and interoperability. Specifically:**
    2.1. *Management, storage, documentation, security, long term sharing and preservation plans for nodes, taking into account other international observing systems; and*
    2.2. *Standardization and interoperability.*

3) **Recommendations for a phased-in approach:**

Finally, this IE provides recommendations for three levels of implementation. This provides options and flexibility in the face of uncertain resource availability and differential readiness levels in different parts of the country. By adopting this flexible approach, the CIOOS will be able to initiate the building of a resilient system that will be capable of scaling up incrementally as capabilities and conditions improve.

2. CORE OCEAN VARIABLES

The Canadian coast scape is vast, diverse, and frequently remote, encompassing the Pacific, Atlantic and Arctic Oceans, and including the Great Lakes. As such, Canadian scientists have collected, and continue to gather diverse observations, sometimes in specific regions, and often with sparse coverage over vast geographic areas. A CIOOS aims to integrate and provide broad access to historic data, to key existing and real-time observations, to forecasts and model scenarios, and to be prepared to support future marine data sources. A critical first step is the identification of core ocean variables relevant to Canada. From a global observing perspective, the Global Ocean Observing System Expert Panels[1] identified Essential Ocean Variables (EOVs): a data type was considered essential if it had high relevance, was feasible to collect, and could be obtained cost effectively. EOVs were also categorized based on the readiness of the technology associated with collecting the data, as either mature, in pilot testing, or still in concept/development.

Canada's needs differ for those of GOOS, and consequently the information collected in a CIOOS will in some cases overlap with that collected by GOOS, as well as will differ in important ways. We therefore refer to the variables recommended for inclusion in CIOOS as "Core Ocean Variables (COV)", to distinguish them from, and to avoid confusion with, the GOOS system. Here we summarize a first assessment of the possible COV for CIOOS based on the above criteria, as well as what Canadian investigators are currently collecting to meet national needs, what is currently feasible to collect, and what a Canadian ocean observing system should make available to support evidence-based decision making.

The Data and Observations IE team identified potential COV through:

1) *An evaluation of Canada's monitoring needs to meet international and national commitments;*
2) *A survey of the ocean community;*
3) *A web-based ground-truthing exercise;*
4) *Expert advice from Zdenka Willis, former Director of the United States Integrated Ocean Observing System; and*

[1] Description of GOOS Expert Panels and their responsibilities: http://goosocean.org/index.php?option=com_content&view=article&id=11&Itemid=111

5) *Calls to Tim Moltmann, Executive Director of the Australian Integrated Marine Observing System, and to Samantha Simmons and Patricia Miloslavich with regards to the Global Ocean Observing System.*

2.1. MEETING CANADA'S NATIONAL AND INTERNATIONAL COMMITMENTS

Canada has national and international commitments for ocean conservation and sustainable use through government and organizational mandates. The following (non-exhaustive) list of commitments pertains to the work a CIOOS could accomplish in helping Canada meet its commitments with regards to ocean monitoring.

2.1.1. Government of Canada

In 2016, the Government of Canada established three foundational principles guiding marine conservation in the country:

Science-based decision making

1) *Ensure ecosystem monitoring data are originating from diverse and complex sources, based on reliable and peer reviewed science; and*
2) *Promote Indigenous Peoples as a source of fisheries and ecological information through their traditional knowledge for ecosystem monitoring.*

Transparency

1) *Include many stakeholders (at the government, industry, Indigenous, academic and non-government levels) in achieving national marine conservation targets, knowing an "all in" approach is necessary and that consultation and collaboration are key to do so.*

Advancing reconciliation with Indigenous groups

1) *Make traditional knowledge a priority in determining ecologically important marine areas based on their culture, economy and traditions.*

2.1.1.1. Canada's Ocean Act

The 1997 Oceans Act made Canada the first country in the world to enact a comprehensive and integrated ocean management initiative in its legislation. The Act calls for the development of a national ocean management strategy guided by principles of sustainable development, the precautionary approach and integrated management for estuaries, coastal and marine waters. This strategy requires coordination among all stakeholders and decision makers, and relies on a continuous flow of verified, reliable and accessible scientific information.

2.1.1.2. Transport Canada

The 2016 Oceans Protection Plan by Transport Canada outlined several goals, including:

1) *"Real-time awareness of marine traffic in Canadian waters.*

1.1. *The Government of Canada will work with Indigenous and coastal communities to design new information-sharing systems and platforms so they have access to real-time information on marine shipping activities in their local waters."*

2) *"Work with partners to implement a real-time whale detection system in specific areas of the species' habitat to alert mariners to the presence of whales, which will allow them to better avoid interactions with this and other marine animal species."*

3) *"Take action to better understand and address the cumulative effects of shipping on marine mammals, such as the southern resident killer whale pods, belugas, and northern right whales. This includes work to better establish baselines for noise and consideration of options to mitigate these effects."*

2.1.1.3. Minister of Environment and Climate Change Mandate Letter

As stated in the Minister of Environment and Climate Change Mandate Letter, the Government of Canada promises to:

1) *"Work in collaboration with the Minister of Fisheries, Oceans and the Canadian Coast Guard and the Minister of Science to examine the implications of climate change on Arctic marine ecosystems."*
2) *"Treat our freshwater as a precious resource that deserves protection and careful stewardship, including by working with other orders of government to protect Canada's freshwater using education, geo-mapping, watershed protection, and investments in the best wastewater treatment technologies."*

2.1.2. Convention on Biological Diversity

Canada has set National Targets to be met by 2020 under the Convention on Biological Diversity's Related Strategic Goals/Aichi Targets. Each related strategic goal includes targets and specific indicators which mark the achievement of a National Target. Those pertaining to the CIOOS project include:

Goal B: "Direct and indirect pressures as well as cumulative effects on biodiversity are reduced, and production and consumption of Canada's biological resources are more sustainable."

1) *Target 12: "customary use by Aboriginal peoples of biological resources is maintained, compatible with their conservation and sustainable use."*

   Indicators of Target 12 include "number of households participating in traditional activities", "consumption of traditional food", and "case studies illustrating customary use of biological resources."

Goal C: "Canadians have adequate and relevant information about biodiversity and ecosystem services to support conservation planning and decision-making."

2) *Target 14: "the science base for biodiversity is enhanced and knowledge of biodiversity is better integrated and more accessible."*

   Indicators for Target 14 include the "number of biodiversity monitoring programs contributing information to a national or provincial web portal."

3) *Target 15: "By 2020, Aboriginal traditional knowledge is respected, promoted and, where made available by Aboriginal peoples, regularly, meaningfully and effectively informing biodiversity conservation and management decision-making."*

   Indicators for Target 15 include the "extent of native habitat types…[and] degradation and restoration metrics."

2.1.3. Intergovernmental Oceanographic Commission (IOC)

Some national goals for ocean monitoring were adopted by Canada as a member of international groups. As a member of the Intergovernmental Oceanographic Commission (IOC), Canada aims to develop early warning systems for marine hazards and enhance knowledge of emerging ocean science issues by 2021. Although dated, Canada's Ocean Action Plan (2005-2007), which was created through the IOC's Marine Spatial Planning program, encourages international leadership and ocean management for sustainable development, promotes health of the oceans, and highlights ocean science and technology.

2.1.4 United Nations Sustainable Development Goals

10 targets, along with their associated indicators, were listed for the UN Sustainable Development Goal (SDG) #14, "Life Below Water". This goal must be applied in the government and private sectors, civil society and the general public. Target 14.3 stipulates increasing scientific knowledge while minimizing and addressing impacts of ocean acidification by 2020. Other targets include reducing nutrient and plastic pollution (14.1), using ecosystem-based approaches in managing and protecting marine and coastal ecosystems (14.2), and increasing scientific knowledge while developing research capacity and transferring marine technology (14.A). Global Compact Network Canada (GCNC) is the main organization in Canada raising awareness about, and supporting the implementation of the SDGs.

2.1.5 International Arctic Science Committee (IASC)

Canada has commitments to the Arctic through the Marine Working Group of the International Arctic Science Committee (IASC). As a member, Canada helps to improve global understanding of sea ice structure dynamics and the Arctic system.

2.1.6. Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM)

As a member of the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), Canada commits to:

1) *"Enhance the provision of marine meteorological and oceanographic services in support of the safety of life and property at sea and in coastal areas";*
2) *To coordinate the development, enhancement and delivery of climate services related to the marine atmosphere and coastal and deep oceans, based on the core competencies within the Commission in marine meteorology and oceanography, as a contribution by COMM to the Global Framework for Climate Services (GFCS)";*
3) *To coordinate the enhancement and long-term maintenance of an integrated global marine meteorological and oceanographic observing and data management system, as part of the Global Ocean Observing System (GOOS), the World Weather Watch (WWW), other operational programs, and in support of the GFCS".*

2.2. SURVEY

In mid-September, 2017, a planning survey was completed by 19 respondents (of 54 queried), 14 of whom represented Canadian organizations (of 23 queried). The survey included questions on ocean variables collected and managed by responding organizations and grouped by broad categories (climate/physical, carbon/biogeochemistry, biodiversity/ecosystem, sediment, other). The survey also assessed the ranges of sampling rates, geographic regions, observing platforms, data access and delivery tools and data products encompassed by each facility. Additional questions examined data/metadata and quality control standards, as well as the kinds of challenges faced by organizations in the storage, processing and operation of data archival and delivery services.

Survey findings were used as an important, but not exclusive input to recommendations on core ocean variables listed in this report. For a detailed report on the compiled survey results, please see CIOOS Planning Survey Results.[2]

In addition, the Canadian Survey of Atlantic, Pacific, Arctic, and Great Lakes Observing Systems (April 2011) was consulted. This report summarized results of a survey sponsored by Fisheries and Oceans Canada (DFO), Canadian Space Agency (CSA), and the Ocean Science and Technology Partnership (OSTP).

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[2] CIOOS planning survey results:
https://docs.google.com/document/d/1AzAkdso8apHHG3V3V7aojX5bZN_FsQt6GAAaYi-Za_M/edit?pli=1#heading=h.e78tnmvnet0a

2.3. GROUND-TRUTHING

A ground-truthing analysis was conducted in conjunction with the online survey, in order to determine the current availability of oceanographic variables, and to support CIOOS' preliminary ranking of Core Ocean Variables. Lists of potential partners and existing ocean observing systems were analyzed to assess public availability of their currently monitored variables. Variable data were generally found on data portals, in data catalogues, in lists of publications, and on online apps. Variable data were considered 'present' if they were visibly evident on the website (e.g. listed in a table), or available from a "download data" option, or by data request form. Organizations were first screened for the presence or absence of any publicly available ocean variable data, and if the data were present we then looked for specific variables. A set of 57 oceanographic variables (covering the physical, biological, chemical and geological oceanographic fields) were evaluated for presence/absence on the websites (the results are listed in Appendix 7.3 and summarized in Table 1). The results of the online survey were then compared to those of the ground-truthing, to evaluate the difference between currently monitored variable per organization, versus the discoverable public data found during the ground-truthing.

Table 1. Ground-truthing assessment results. The number of organizations where each variable was found on their website (bolded) during the ground-truthing, ordered according to physical (blue), biological (green), and chemical (red) variables, from most available to least available variable.

Physical	Chemical	Biological
Temperature (subsurface) **(26)**	Dissolved oxygen **(22)**	Chlorophyll **(28)**
Current (surface) **(25)**	CO2 **(16)**	Fish (diversity, abundance, migration, stocks) **(21)**
Salinity (surface, <10m) **(24)**	Silicate **(10)**	Ocean Biota **(20)**
SST **(24)**	Phosphate **(12)**	Phytoplankton (biomass/diversity) **(17)**
Sea surface stress **(23)**	Carbon (other than CO2) **(8)**	Marine mammals **(16)**
Wave height **(23)**	Alkalinity **(8)**	Nutrients **(16)**
Salinity (subsurface, >10m) **(19)**	Iron **(4)**	Live coral **(13)**
Sea surface height **(18)**	Calcite **(4)**	Zooplankton (biomass/diversity) **(12)**
Currents (subsurface) **(16)**	Methane **(3)**	Suspended particulate material **(9)**
Turbidity **(16)**		Pigment **(7)**
Depth **(14)**		Seagrass **(7)**
Bathymetry **(14)**		CDOM **(6)**
Backsattering **(13)**		Mangrove **(5)**
Water pressure **(13)**		Water color **(3)**
pH **(12)**		
Fluorescence **(11)**		
Ice (cover, movement) **(11)**		
PAR radiation **(11)**		
Wave period **(10)**		
Acoustics (tracking, ambient noise) **(9)**		
Density **(9)**		
Optical properties **(9)**		
Conductivity **(7)**		
Air-Sea Fluxes **(5)**		
Irradiance **(5)**		
Sigma-t **(5)**		

Physical	Chemical	Biological
Salinity (depth not specified) **(5)**		
Absorption **(4)**		
Sound velocity **(4)**		
Water visibility **(4)**		
Erosion **(2)**		

2.4. REGIONAL AVAILABILITY AND READINESS

2.1.2. Regional availability

The regional availability of publicly available ocean variable data (excluding forecasts and models) from potential DFO and Canadian partners' websites was assessed to estimate the current monitoring coverage of the proposed CIOOS core variables. The assessment was conducted by listing the organizations providing data as determined from the ground-truthing assessment, by variable and by region (Pacific, St. Lawrence, Atlantic, Great Lakes, East/West Arctic). All the results of this assessment with lists of all organisations per region can be found in Appendix 7.3, Table 2, which summarizes general trends per region.

Ocean variable monitoring coverage varied based on region (Pacific, St. Lawrence, Atlantic, Great Lakes, East/West Arctic). The goal of this assessment was to determine a baseline of variable monitoring in Canada. It should be noted that regional availability is most likely incomplete as many organizations have additional core variable data not currently available on their websites. This is discussed further at the end of this section.

The Atlantic Region currently provides the largest variety of monitoring sources for the core variables. MEOPAR and the Ocean Tracking Network (OTN), DFO's Atlantic Zone Monitoring Program (AZMP) and Atlantic Zone Off-Shelf Monitoring Program (AZOMP), Ocean Networks Canada (ONC), and the St. Lawrence Global Observatory (SLGO) are all recording and/or providing varied and continuous ocean variable data along Atlantic Canada. The Pacific and Gulf of Saint Lawrence regions show a similar diversity in terms of number of variables monitored and quantity and diversity of publicly available data. Other Atlantic institutions have smaller offerings. Although few organizations monitor oceanographic variables in the Arctic, Ocean Networks Canada, the Polar Data Catalogue, and DFO record a large proportion of the recommended CIOOS core variables in both the Eastern and Western Arctic. The Eastern Arctic has more monitoring sources; however, most organizations doing monitoring in the Arctic conduct work in both the Western and Eastern Arctic.

Temperature, salinity (with the exception of the Great Lakes), surface stress, sea surface height, sea state, ice, phytoplankton (fluorescence and chlorophyll), fish abundance, marine mammals (with the exception of the Great Lakes), and bathymetry have the most diverse set of sources. These variables are monitored in each region, with most variables having three or more sources per region.

Coverage gaps occur for core variables in some regions. Current monitoring of ambient sound, water currents, oxygen, inorganic carbon, nutrients, zooplankton, and live coral would be need to be augmented to fill current information gaps. These variables lack coverage in one or more regions and have fewer sources per region. The Great Lakes region has the biggest coverage gap, with no currently known systemic monitoring in Canadian waters for surface heat flux, ambient sound, bottom type, currents, inorganic carbon, oxygen, nutrients, and zooplankton.

Although recognized as being an important variable in future ocean studies, ambient sound is not currently monitored by many Canadian organizations. Ocean Networks Canada records sound in the Arctic and Pacific and provides the data publicly, but data from organizations such as Jasco, Eastern Charlotte Waterways and the Bedford Institute of Oceanography (DFO), who monitor ambient noise in the Atlantic, are not currently publicly available. This appears to be a recurring pattern, where oceanographic parameters are monitored regionally or nationally, but are not available in the public domain. For example, the Great Lakes Fishery Commission conducts research on fish abundance and distribution, but does not make its data publicly available. In addition, a query to BioChem was not answered by the date of report submission. Thus, the results of this assessment are a baseline in terms of available oceanographic data that could be catalogued by the CIOOS, as opposed to all potential data. Active requests for data and partnerships with organizations not assessed through the ground-truthing and survey could lead to supplementary information. In the case of Eastern Charlotte Waterways, they are interested in sharing their data, but lack the internal data management capabilities.

No monitoring of ocean surface heat flux could be found in a public domain, for any regions. This was the only variable for which no publicly available data could be found.

Thus, this assessment provides a baseline description of available data surrounding a suite of pre-identified oceanographic variables that could be catalogued by the CIOOS, as opposed to all the data that is available. Requests for data and partnerships with organizations not assessed through the ground-truthing and survey could lead to the provision of supplementary information about the pre-identified variables, and about other variables.

Table 2. Summary table of Regional Availability for CIOOS core variables (complete table listed in the Appendices), as of November 2017. Total number of national organizations and Canadian partners providing core variable data publicly on their website, per variable and region. Colour shading indicates whether variables are well monitored (green: all regions have ≥1 source per region), have some coverage gaps (yellow: one or more regions with no sources), or have no current sources of public data (red: no sources in all regions).

	Region				
Variable	**Pacific**	**St. Lawrence**	**Atlantic**	**Great Lakes**	**Arctic E/W**
Ambient Sound	1	0	0	0	E:1 W:0
Bathymetry	3	2	3	2	E:2 W:2
Bottom Type	1	0	0	0	E:0 W:0
Currents	4	1	5	0	E:3 W:2
Fish Abundance and Distribution	4	3	2	1	E:3 W:2
Ice	1	4	4	3	E:4 W:3
Inorganic Carbon	3	1	3	0	E:2 W:0
Live Coral	1	1	1	0	E:1 W:0
Marine Mammals	2	2	3	0	E:3 W:2
Nutrients	2	2	4	0	E:2 W:1
Oxygen	4	1	5	0	E:3 W:2
Phytoplankton	6	4	7	2	E:4 W:3
Salinity	5	4	7	0	E:3 W:2
Sea State	5	4	5	5	E:3 W:3
Sea Surface Height	2	3	3	2	E:1 W:1
Seagrass Cover	2	0	0	0	E:0 W:0
Surface Heat Flux	0	0	0	0	E:0 W:0
Surface Stress	4	6	4	4	E:3 W:3
Temperature	8	7	10	4	E:5 W:4
Zooplankton	2	1	4	0	E:1 W:1

2.1.3. Core variable readiness

The available core variables being measured in Canada as determined from the ground-truthing and regional availability assessments, were evaluated for their readiness for GOOS compliance. Readiness, as stated by the GOOS, is the observing component's level of maturity in terms of requirement processes, coordination of observations elements, and data management and information products. GOOS categorizes an observing component's readiness by three levels:

1) *Mature: "Products are well understood, documented, consistently available, and of societal benefit."*
2) *Pilot: "Planning, negotiating, testing, and approval within appropriate local, regional, global arenas."*
3) *Concept: "Peer review of ideas and studies at science, engineering, and data management community level."*

Each organization listed in the Regional Availability assessment was evaluated on the readiness level of each of their monitored (and publicly available) core variables. Results of this evaluation can be found in Appendix 7.4.

This assessment showed that the proposed CIOOS Core Ocean Variables are nearly completely up to GOOS monitoring standards. Nearly all have ample sources at a high level of readiness. All but one variable (ocean surface heat flux) showed at least one Mature or Pilot level of Readiness as it is monitored within Canadian waters by national and international partners.

Temperature accounted for the largest number and widest variety of Mature- and Pilot-level sources of monitoring in Canada. Salinity, sea state, currents (surface and subsurface), phytoplankton, and marine mammals were the next set of variables originating from mature-level readiness sources, followed by ice, inorganic carbon, sea surface height, nutrients, zooplankton, fish and ambient sound. Mature and Pilot-level data for bathymetry, live coral and seagrass cover could only be found under one source each; however, as was mentioned in the previous subsection, further research would most likely determine additional sources of information not currently publicly available that could fill coverage gaps.

The OTN/MEOPAR/DFO profiling glider programs and project-based research are promising in terms of providing temperature, salinity, sea state, inorganic carbon, and marine mammal (abundance, distribution, etc.); however, these monitoring sources are currently listed as Pilot-level. Similarly, Ocean Networks Canada is observing surface currents and waves, with a readiness at the Pilot level.

Overall regional readiness was also assessed for each Core Ocean Variable by compiling data available from all sources (Figure 1).

Phytoplankton, sea state, sea surface height, surface stress, and temperature are mature in all five regions. There is a high proportion of mature readiness in the Atlantic, Pacific, St. Lawrence, and Arctic in particular. Fish abundance and distribution, marine mammals, nutrients, oxygen, salinity, and zooplankton are also mature in all four of these regions.

The Atlantic and the Pacific have the highest number of mature variables, with fifteen each. In the Atlantic, a variable is typically either mature or not covered at all, with the exception of live coral (pilot). Surface heat flux is the sole variable not covered in the Pacific. The Gulf of St. Lawrence has a similar number of mature variables (fourteen).

Only two variables are not covered in the Arctic; however, multiple variables in the Arctic have limited coverage. This is attributable in part to fewer monitoring sources and the vast area that needs to be covered. Data from BioChem would likely fill in some of the gaps in biological and chemical variables, as there is not a specific DFO web-based access page for Arctic data like there are for the Atlantic and Pacific.

A majority of the core variables are **not** covered in the Great Lakes. As discussed above, some data from research being conducted in the Great Lakes is not available publicly, which could fill some of the coverage gaps. Additionally, the low coverage in the Great Lakes Region is a system artifact, mainly due to several variables being irrelevant to a freshwater region, such as: marine mammals, live coral, salinity, and seagrass cover. Similarly, the low level of ice research in the Pacific region reflects the low level of ice that occurs there annually. Many physical variables are mature in the Great Lakes: bathymetry, ice, sea surface height, sea state, surface stress, and temperature. Only two biological variables are covered in the Great Lakes, and there is no systemic coverage of chemical variables.

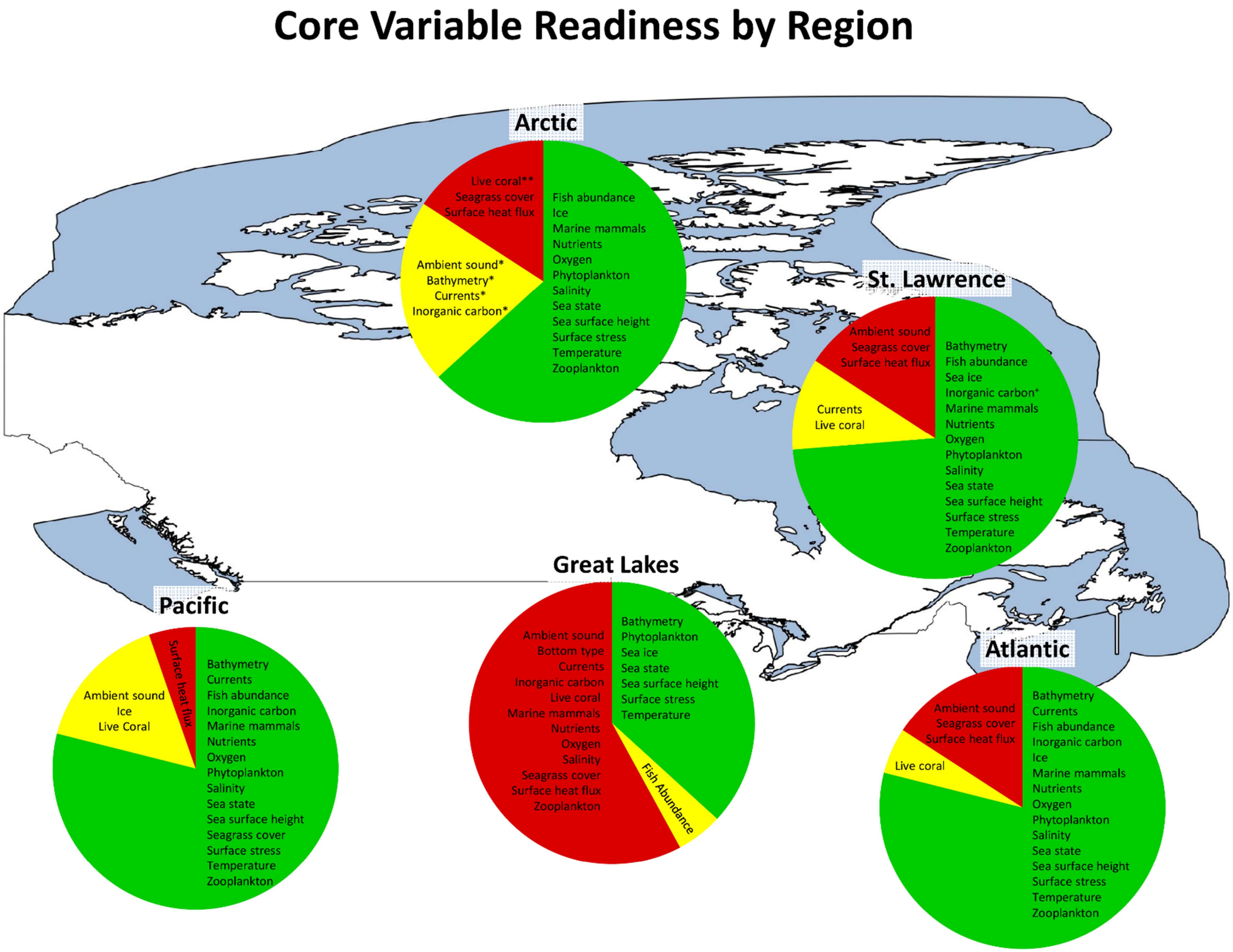

*Figure 1. Proportion of core variables that are, Mature (green), Pilot (yellow), and Concept or have No Coverage (red) in each region. *Mature technology, but low coverage. **Pilot, but low coverage. +Mature technology, but inconsistent sampling.*

2.5. EXPERT ADVICE

Dr. Z. Willis provided expert advice to the team on three aspects:

1) An assessment of the state of core variables in observing systems internationally - this was a detailed document providing a number of key references for selecting core variables. It is included as Appendix 7.2 in this report.
2) A preliminary list of suggested core variables for CIOOS, which included:
    2.1. General recommendations:
        i. CIOOS should determine the focus of the system, and choose variables based on what services the system is required to deliver;
        ii. CIOOS should take the approach of characterizing the system as focused on sustained observations to support public services **and** research for public interest;
        iii. It is important for CIOOS to determine upfront who is part of CIOOS, who is external to CIOOS and what the relationship between the two groups will be;
        iv. It is important to understand where CIOOS can add value. CIOOS determines where an integrated observing system can improve services, further scientific knowledge and advance technologies.
    2.2. Specific variables to include were recommended based on missions of the various organizations that have been identified as being the foundation of CIOOS: DFO, Ocean Tracking Network (OTN); MEOPAR; St. Lawrence Global Observatory (SLGO) and Ocean Networks Canada (ONC). The scientific themes of IMOS and their appropriateness to CIOOS were evaluated. U.S. IOOS has not defined a specific list of services to offer, but broadly supports seven societal benefit areas.
3. Development of Specification sheets - Dr. Willis recommended developing a modified, shortened CIOOS form based on the GOOS Essential Ocean Variables specification sheets. This mirrors the US IOOS approach to developing specification sheets for its core variables. NOAA has a fully developed system for validating observing requirements, identifying systems that collect required data, and assessing how well the observing systems meet the requirements; this is accomplished with a staff of only 15 people. As such, shortened core variable specification sheets are appropriate for CIOOS at this point, recognizing also that they are living documents and will evolve over time.

2.6. ASSESSMENT AND RECOMMENDATIONS

An initial list of core variables has been compiled. The list was informed by the variables identified in the survey, the ground-truthing exercise, Dr. Willis' advice, and on meeting Canada's national and international commitments including complying with GOOS EOV's. This list was then reviewed and revised in discussion among the members of the three IE's. Twenty variables are proposed as initial Core Ocean Variables for CIOOS (Table 3). These would comprise the offering for a low-service model of CIOOS. Additional variables were also identified that could be added to the list for the moderate and high-service models of CIOOS (Table 4).

Bathymetry: Although bathymetry meets the criteria of a core variable, and is widely collected and used by the community, it is currently well curated and served by the Canadian Hydrographic Service (CHS). As CHS already has an established route for submission and curation of bathymetric data, it will not be further examined in this report. Users of CIOOS who have bathymetry data will be directed to submit their data to the CHS.

Table 3. Proposed base model variables for inclusion in CIOOS, including an evaluation of their availability and readiness. Availability is listed as High (monitored in each region, with a minimum of one source per region), Moderate (lack of coverage in one or more regions and have fewer sources per region), Low (limited public availability) or None (no public sources found). Readiness follows the GOOS definitions of Mature (products are well understood, documented, consistently available and of societal benefit), Pilot (planning, negotiating, testing, and approval within appropriate local, regional, global arenas) and Concept (peer review of ideas and studies at science, engineering, and data management community level).

Variable	Availability	Readiness
Ambient Sound	Low	Pilot
Bathymetry	High	Mature
Bottom Type	Low	Concept
Currents (surface & subsurface)	Moderate	Mature technology, limited coverage
Fish Abundance and Distribution	High	Mature
Ice	High	Mature
Inorganic Carbon	Moderate	Mature
Live Coral	Moderate	Mature technology, limited coverage
Marine Mammals	Moderate	Mature
Nutrients	Moderate	Mature, some gaps
Oxygen	Moderate	Mature, some gaps
Phytoplankton	High	Mature
Salinity (surface & subsurface)	High	Mature
Sea State	High	Mature
Sea Surface Height	High	Mature
Seagrass Cover	Moderate	Limited coverage
Surface Heat Flux	None	No coverage
Surface Stress	High	Mature
Temperature (surface & subsurface)	High	Mature
Zooplankton	Moderate	Mature

Table 4. Proposed additional variables for inclusion in CIOOS moderate and high service models

Moderate Service	High Service
Coastal development and climate change adaptation (ex. erosion) Coastal development and climate change Colored Dissolved Organic Matter (CDOM) Invasive species (abundance and distribution) Macroalgal canopy Ocean Color Species at risks Suspended Particles (backscattering, chlorophyll, turbidity)	Fluorescences (chlorophyll) Marine birds abundance and distribution, migrations, essential habitats Marine turtles abundance and distribution, essential habitats Nitrous Oxide Protected areas Stable Carbon Isotope Transient Tracers

2.7. DEVELOPMENT OF SPECIFICATION SHEETS

Specification sheets were created with the goal of mapping current ocean observing activities and identifying any potential gaps or areas of overlap. While the CIOOS specification sheets were based on those created by GOOS, their focus is an assessment of the current state of the variable, not providing recommendations or guidelines like those created by GOOS. Proposed initial CIOOS specification sheets for each core variable can be found in appendix 7.1.

Dr. Z. Willis provided guidance on specification sheet development. Following her recommendations, the CIOOS sheets are shortened forms modified from the GOOS specification sheets. Each specification sheet contains the following information that is also present in the variable's corresponding GOOS specification sheet:

1) Variable information: variable name, sub-variables, derived variables, phenomena to capture; and
2) GOOS requirements by phenomena: phenomena to capture, temporal scales of phenomena, horizontal resolution, vertical resolution.

CIOOS specification sheets also contain the following information on variable observing in Canada:

1) CIOOS current observing elements: observing elements, regions where observation of the variable is underway, organizations displaying data, phenomena addressed, horizontal resolution, vertical resolution, and temporal scale;
2) Regional readiness map (readiness assessed using the methods described in the section above); and
3) References.

Ambient sound does not have a corresponding GOOS specification sheet, hence there is no GOOS link in this CIOOS specification sheet.

Information on the methods behind data collection was frequently unavailable online; however, most organizations were quick to respond to requests for information. Because accuracy is to a degree instrument-specific, and information about this is not widely available, accuracy was not included on CIOOS specification sheets. The greatest difficulties in creating the CIOOS specification sheers arose when defining horizontal and vertical resolution for a variety of variables. In some instances, such as ADCP current meters, resolution varies among instrument types and configurations. In the case of hydrophones, horizontal resolution is highly variable. Both the frequency of a sound and the location of the hydrophone in the water can influence the distance at which a hydrophone can detect a sound. When it was not possible to determine the horizontal or vertical resolution of an observing element, it was left blank or described as "varies."

The variables which are measured by the greatest number of observable elements are fish abundance and distribution (8), marine mammals (6), currents (5), salinity (5), and temperature (5). A significant amount of data collected by Canadian organizations are point observations derived from buoys or other fixed stations. Sea surface height, surface stress, and sea state measurements are exclusively point observations. Inorganic carbon, nutrients, and zooplankton are also mostly measured only with point observations, however, some work on these is also done using other methods (ship/CTD). Importantly, the number of observable elements or methods measuring a variable does not necessarily indicate maturity. Sea surface height and sea state are well measured by buoys/fixed stations, and they are mature across all five regions.

CIOOS does not currently include models or forecasts. MEOPAR and SLGO (the model used by SLGO was produced by DFO and ECCC) have model data for currents, wind, waves, chlorophyll and ice that could be included in future iterations. In addition, our assessments of data about ocean currents only include holdings within DFO, other Canadian organizations, and international organizations with a Canadian regional node (e.g., OBIS). There are numerous international organizations with data on core variables in Canadian waters: e.g. AOOS, NOAA, Ocean Color, UN-WCMC, SCCOOS. Including this data would fill in some of the coverage gaps in Canadian data. For example, UN-WCMC has data on seagrass and live coral occurrences globally.

2.8. FEASIBILITY AND IMPACT ANALYSIS

As referenced in the statement of work, and earlier in this report, a number of organizations have undertaken to define what variables are most important for ocean observing, and also what variables are the most feasible. Notably, IOOS recently released the results of their extensive feasibility and impact analysis. IOOS began with the concept that ocean observing cannot be exhaustive nor does it need to be. Rather, IOOS suggested variables should be "driven by requirements" and "rooted in reality". From the CIOOS perspective, the requirements are defined by meeting Canada's national and international needs, the expert advice received from Dr. Willis, the survey of Canada's observing priorities, and alignment with GOOS and other ocean observing systems. Feasibility is well captured by the variable readiness, and the availability of data has already been summarized in this report. For the Feasibility and Impact analysis, variables were divided into three categories:

1) Least challenging - have both a high availability and readiness;
2) Most challenging - either availability is low or readiness is very weak; and
3) Moderately challenging - those variables not having both high availability and readiness and/or either availability is low or readiness is very weak.

More difficult is evaluating the impact, as 'impact' can be highly subjective. Although IOOS employed a scoring process in their evaluation of impact, this scoring process was not ultimately used in the final recommendations to prioritize variables. IOOS recommended instead 'taking a step back' and taking a high-level approach. For the purposes of this report, therefore, quantitative scores were not engaged - rather, variables were ranked within their respective feasibilities by their likely impact (Table 5). This impact was determined by combining the requirement to meet Canada's national and international needs and Dr. Willis' survey of Canadian observing priority.

Table 5. Feasibility & Impact of Core Variables. Variables were divided into three categories:
Least challenging - have both a high availability and readiness; most challenging - either availability is low or readiness is very weak; and moderately challenging- those variables not having both high availability and readiness and/or either availability is low or readiness is very weak. Variables in each column are ranked according to impact, with a score of 1 being the highest impact.
**not a GOOS EOV*

Least challenging	Moderately challenging	More challenging
1. Temperature 2. Surface Stress 3. Sea State 4. Ice 5. Phytoplankton 6. Sea Surface Height	1. Salinity 2. Inorganic Carbon 3. Oxygen 4. Currents 5. Fish abundance and distribution 6. Marine mammals 7. Nutrients 8. Zooplankton 9. Live Coral	1. Ambient Sound* 2. Surface Heat Flux 3. Seagrass Cover

3. DATA MANAGEMENT

3.1. ASSESSMENT OF STEWARDSHIP OF DATA AND METADATA

The following assessments have been made to evaluate and outline a framework for interoperability between the Central CIOOS, the Regional Associations, the data nodes, and partner organizations within the global ocean observing system.

3.1.1. Data Sources

The recommended core variables will draw from heterogeneous data sources; this must be accounted for in the data management assessment. Data are based on measurements, calculated values, or annotations which are obtained from instruments, physical samples and observations. Instruments are themselves highly variable, and their deployment scenario (e.g., platform type, location, duration, configuration) often impacts how data should be handled. Physical samples may be biological (e.g., organisms), geological (e.g., sediment, rocks) and fluid (e.g., water), and have numerous options for collection methods, measurement and preservation protocols. Observations may be conducted by experts, citizen scientists, and computer algorithms in the field or extrapolated from other data (e.g., camera video, hydrophone audio). As data for the same variable may originate from different data source types, metadata should fully describe these sources and contexts so that users can make reliable interpretations. For example, zooplankton data can be obtained by numerous methods including net tows, echo sounders, and high-resolution plankton cameras.

3.1.2. Quality Assurance & Quality Control

Both data providers and users benefit from implementation of a comprehensive process-oriented quality assurance (QA) model used in combination with a product-oriented data quality control (QC) model. These models systematically intercept and examine instruments and their data streams at various stages to ensure long-term data quality control and assurance.

3.1.3. The QA/QC Process

QA/QC workflows that minimize human and/or systematic errors can be established to ensure high quality data (JERICO report[3]). QC and QA monitor the performances of data collection systems, which eventually contribute to expedition schedules, equipment maintenance requirements, and process improvements. A customized web-based tool to define, execute and record workflows has proven to be effective and highly valued for operations at ONC[4] (ONC

[3] JERICO report on data management best practice and Generic Data and Metadata models: http://www.oceanbestpractices.net/bitstream/handle/11329/354/JERICO-NEXT-Deliverable_5.9_v2.1.pdf?sequence=1&isAllowed=y
[4] https://ieeexplore.ieee.org/document/7404600/

AGU poster[5]). These two processes are complementary to research and development of improved and new monitoring technologies. This approach is consistent with the GOOS Framework for Ocean Observing[6], in which platform/instrument deployment and maintenance is governed by science-driven requirements.

Distinct stages for data quality control and assurance interventions are suggested for the three main data sources.

3.1.3.1. Instruments

1) Pre-deployment Testing: Includes all data/metadata QA/QC checks performed at the pre-deployment testing point of an instrument up to actual deployment.
2) Post-Deployment Commissioning: Includes all data/metadata QA/QC updates and checks beginning with actual deployment and continuing for a reasonable time period after deployment.
3) During-Deployment Monitoring: Automated quality checks continue to operate, and data specialists routinely conduct manual quality control checks. If issues are identified, specialists are engaged to diagnose the issue and rectify (if possible) remotely.
4) Post-Recovery Servicing: Includes inspecting and cleaning the equipment, conducting post-recovery calibrations and other servicing as per established protocols.

3.1.3.2. Physical Samples

1) Preparation: Includes plans and checks for relevant equipment, collection procedure(s), preservation, processing and storage. Metadata and documentation are also organized.
2) Collection: Includes the gathering of the physical samples and recording of metadata.
3) Processing and Preservation: includes processing, measurements and preservation (if needed). Metadata and data are updated accordingly.
4) Storage: Includes maintaining the samples at a suitable facility, and possibly making it available for future re-use.
5) Review: Metadata and data are checked for adherence to conventions, accuracy and completeness.

3.1.3.3. Observations

1) Preparation: Includes training of personnel or datasets that train computer algorithms, preparing annotation tools and metadata.
2) Annotation: Recording observations according to defined protocols.

[5] ONC AGU poster: https://agu.confex.com/agu/fm15/meetingapp.cgi/Paper/85062
[6] Framework for Ocean Observing: http://www.goosocean.org/index.php?option=com_content&view=article&id=125&Itemid=113

3) Review: Includes reviewing annotations for accuracy and adherence to defined conventions.

3.1.4. Quality Assurance

Data quality assurance (QA) processes are preventive measures implemented to minimize issues in the data streams and inaccuracies, thereby limiting the need for corrective measures to improve data quality. These may include processes to ensure that the instrument sensor network protocols are appropriately developed and adhered to. Examples include adherence to calibration schedules, cleaning to remove biofouling and personnel training.

3.1.5. Quality Control

Data quality control (QC) is a product-oriented process to identify and flag suspect data after they have been generated. QC includes both automated and manual processes to test whether the data meet the necessary requirements for quality outlined by the end users. The QC process may incorporate three components. For real-time data, there can be automated evaluation of data before they are parsed into the database. For near-real time or archived data, there can be automated delayed-mode testing. Additionally, there can be manual review, where an expert inspects the data for quality issues.

3.1.5.1. Automated Real-Time Tests

Real-time, automated data qualification determines the initial validity of data prior to archival. QA/QC test models may follow conventions such as those listed in the Argo quality controls manual with additional tests developed at provider institutions. Qualifying the data prior to archival ensures that every reading with a QA/QC test has an associated QA/QC value.

There may be two types of automatic real-time QC tests: single-sensor range tests and dual-sensor relational tests. These tests are designed to catch instrument failures and erroneous data at regional or site-specific range values that originate from various sources depending on level of the test. In addition, quality flags are propagated to sensor data that exhibit dependence on other sensors to ensure derived data are adequately quality controlled as well.

The Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) Project[7] is an IOOS initiative towards establishing QC procedures for real-time data with tests and quality control flags, in consideration of the various sensing technologies. These tests are divided into required, strongly recommended and suggested categories. The following table indicates which of the recommended essential ocean variables have an existing QARTOD manual of relevance (Table 6).

[7] IOOS QARTOD website: https://ioos.noaa.gov/project/qartod/

Table 6. Relevant QARTOD Manuals

Variable (Low-service model only)	QARTOD Manual
Ambient Sound	Passive Acoustics
Currents (surface & subsurface)	HF Radar Observations, In-situ Current Observations
Marine Mammals	Passive Acoustics
Nutrients	Ocean Optics Data
Oxygen	Dissolved Oxygen Observations in Coastal Oceans
Phytoplankton	Phytoplankton Data
Salinity (surface & subsurface)	In-Situ Salinity
Sea State	HF Radar Observations, In-Situ Surface Wave
Sea Surface Height	Water Level Data
Surface Stress	Wind Data, Ocean Optics Data (for PAR)
Temperature (surface & subsurface)	In-Situ Temperature

3.1.5.2. Automatic Delayed-Mode Testing

Delayed-Mode, automatic testing includes checks on data that are delayed and can be applied in 'near' real-time or batch processed at set intervals. These tests require consecutive data where the central value is compared with surrounding values to determine its validity. In near real-time, quality control values are delayed by a measurement where tests become invalid if the time interval between the data exceeds a set value. In batch processing, the data are pulled from the repository to check for quality control and can be run at scheduled time intervals.

Two examples of delayed-mode quality control tests are: spike detection and gradient steepness. Both tests require three consecutive measurements where the test becomes invalid if the time difference between the measurements exceeds a set time value.

3.1.5.3. Manual Assessments

Automated QC is only a first pass at quality control. Relying solely on automated QC testing creates the risks that real events will be flagged as bad or 'bad' data periods will be considered good. To ensure that data are not flagged inappropriately, data are manually reviewed at regular intervals. This assures users that an expert is regularly checking the data and is adjusting the output quality flags appropriately. Annotations can also be applied for known sensor failures, and data gaps. It is recommended that data providers develop user-friendly interfaces and tools to facilitate the addition of annotations by data specialists and effectively link the annotations through the time domain with corresponding data. Data requests by external users should be fulfilled with inclusion of relevant QA/QC information corresponding to the provided data. Manual QC tests could be designated as superior in validity to automated tests, and supersede all automatic quality control flags.

3.1.6. Quality Flagging

Data quality control models can convey information about the quality of individual data points by integrating the results from multiple types of tests evaluations. The overall quality of the data may be given integer indicators or standardized flags, as outlined in Table 7.

Table 7. QC flagging example.

QC Flag	**Description**
0	No quality control on data.
1	Data passed all tests.
2	Data probably good.
3	Data probably bad. Failed minor tests.
4	Data bad. Failed major tests.
5	*(unused)*
6	*(unused)*
7	Average value.
8	Interpolated value.
9	Missing data.

Overall quality flags can be used to demarcate data that fails one or more QC test. This is achieved by subjecting the data to various levels of testing that generates a quality control vector containing the output for each test.

In addition to using flags as quality indicators, flagging systems can also provide information about how the data were processed, such as flag “7” for averaging and flag “8” for filling gaps via interpolation. Note that averaged and interpolated data only use ‘clean’ data where ‘clean’ data have flags of 1 only. Users can determine the type of tests that have been applied to the data by referring to the Data Quality Information in the accompanying metadata. Quality control test information is based on device and is listed, if available, along with the valid time period of the test as well as the values used in the formula.

3.1.7. Delivery Policies

CIOOS data providers will need to decide how data should be delivered to end users, whether in "raw" (unmanipulated) form or "clean" (compromised data removed and replaced with placeholder values) form. There is a risk that real and potentially important phenomenon will be ignored in fully automated QC models, therefore a CIOOS data delivery policy should consider the need to offer raw un-manipulated data and allow users to choose their preferred format. Great care should also be taken to ensure that valid data are not removed and that all QA/QC processing steps are well documented so that they can be evaluated.

The reliability of the data is based, in part, on its capacity to reproduce data products. To this end, data QA/QC models used by CIOOS organizations should carefully consider how to preserve the original dataset in its raw form for reproducing any subsequent procedures performed on the data. To this end, metadata can act as a resource and presents valuable information regarding all the QC levels performed on the data (i.e. raw data, qualifier flags added, problematic data removed or corrected and the gaps filled). Also included should be all necessary information used to generate the data, such as the source file used, data-rejection criteria, gap-filling method, and model parameters. This information enables the data user to carefully scrutinize the data and determine whether the data-processing methods used by the provider are appropriate for their specific applications.

3.1.8. Data QA/QC Challenges

Development of a comprehensive automated data QAQC strategy is challenging when an organization produces a wide variety of data types. For instance, QA/QC is difficult for complex data types such as 4-dimensional time series of ocean current data from acoustic Doppler current profilers (ADCP), acoustic data from hydrophones, and video from underwater cameras. Although these types of instruments may undergo rigorous QA similar to scalar data instruments, very manual or automated QC may still be quite limited. Data providers do not always have the ability and processing capacity to parse these data types in real time and apply automated QA/QC tests.

A broader challenge is to find a balance between automated QC testing versus manual intervention. With the number of sensors coming online steadily increasing, the volume of data makes it necessary to develop new automated methods for QA/QC to keep the workload to a manageable level.

Technological advancements are allowing sensors to become increasingly smaller and less expensive. This progression should make it financially and logistically feasible for observatory facilities to deploy multiple instruments of a given type at the same site. This sensor redundancy will increase the spatial resolution of the data collected, improve data continuity, and allow for automated inter-comparison and correlation analysis between data types for QC validation.

3.1.9. QA/QC Standardization

CIOOS participants are committed to actively promote interoperability of streaming sensor data among the growing number of sensor networks worldwide (e.g. IRIS[8], PANGAEA[9] and MEDS[10]. In the interest of data sharing and compatibility of data QA/QC standards among these organizations, it is necessary for CIOOS members to regularly review their QA/QC models against other standards and adopt best practices as applicable. Further to this, CIOOS should be actively involved with international organizations such as QARTOD (Quality Assurance of Real Time Ocean Data), and Argo to develop and implement recommended standards and practices for oceanographic data QA/QC.

3.1.10. Standards Used

3.1.10.1. Timestamps and Datums

For timestamp representation, ISO 8601 and UTC time zone are the most widely used at ocean domain data repositories. The precision, accuracy, source of timestamp and the frequency by which clocks are synchronized varies widely by platform and application. For autonomous instruments, this is usually governed by the internal instrument clock and data storage, while instruments that communicate via satellite or cabled networks may have timestamps applied to data upon receipt. While timestamps at receipt are usually based on a more reliable clock, the accuracy is impacted by the lag time in transmission. For physical samples and observations, timestamps may be measured via accompanying collection tools, but may also be based on manual entry by a human. Synchronization of autonomously deployed instruments generally occurs prior to deployment, and timestamps applied to data may or may not be corrected for drift if a time offset is measured at recovery. Networked instruments have the advantage of NTP or PTP time syncing solutions. Sampling frequency for variables is widely varying, ranging from milliseconds to years with some measurements being periodic while others are opportunistic or event-based.

Sampling rates reported by respondents to the planning survey ranged from 512 kHz to decadal, with sampling frequencies from minutes to days mentioned most frequently (Figure 2).

[8] Incorporated Research Institution for Seismology, http://www.iris.edu/hq/

[9] PANGAEA Data Publisher for Earth & Environmental Science, http://www.pangaea.de/

[10] Marine Environmental Data Section, Oceans Science Branch, http://www.isdm-gdsi.gc.ca/isdm-gdsi/index-eng.html

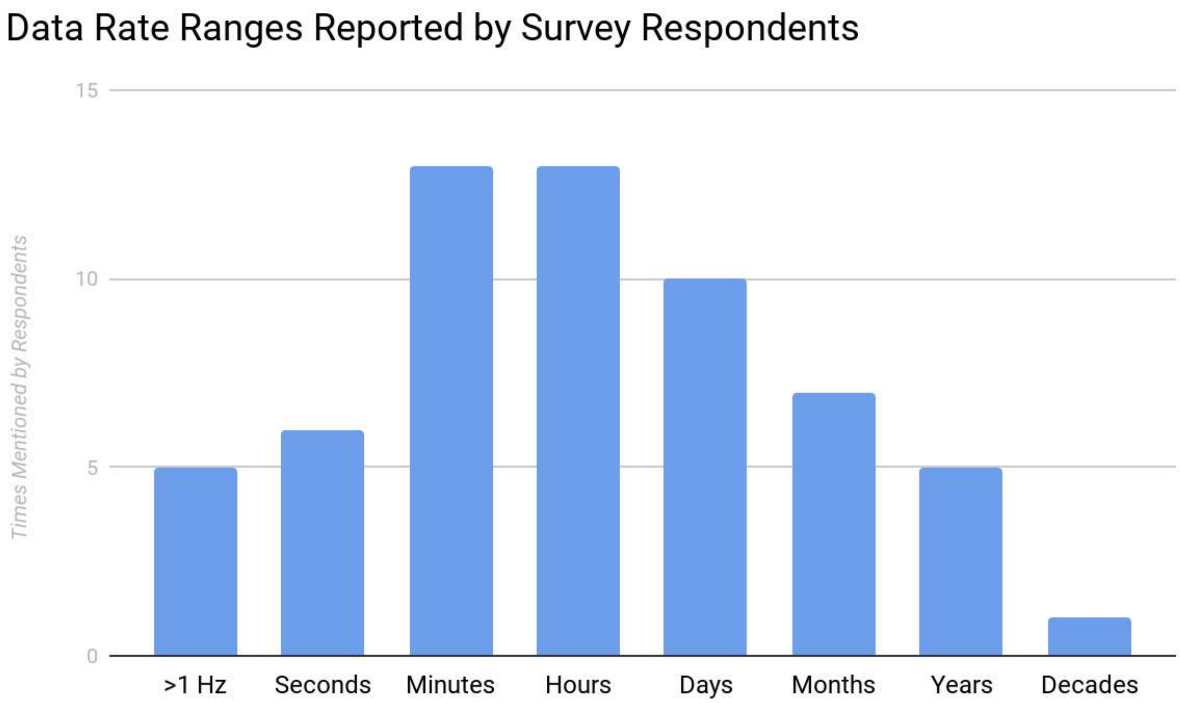

Figure 2. Counts of data sampling frequencies mentioned by 17 respondents to the planning survey. All respondents mentioned more than one range of sampling frequencies.

Data Observation Network for Earth (DataONE[11]) best practices include describing format for timestamp[12] and spatial location[13], including how to format coordinates and which coordinate characteristics to clarify.

The International Hydrographic Organization (IHO) Standard S-44 recommends using the International Terrestrial Reference System (WGS1984). If positions are referenced to a local horizontal datum, the IHO recommends that the coordinate system used be tied to a reference system based on WGS1984. Older data may be found in NAD83 and NAD27, but these are limited to use on the North American Plate. Many US organizations still use NAD83, but WGS1984 is most widely accepted. Many bathymetric gridded datasets are projected as well while processing on a regional/local basis to be able to work in meters. For example, ONC typically uses UTM, but the projection used varies based on one's location. IHO's S-60 standard provides information on datum transformations using WGS84.

[11] DataONE website: https://www.dataone.org/
[12] DataONE timestamp format: https://www.dataone.org/best-practices/describe-formats-date-and-time
[13] DataONE: spatial location format: https://www.dataone.org/best-practices/describe-format-spatial-location

Vertical datums are progressing in Canada. There is a shift to a geodetic national datum called CGVD 2013. This datum is based on the ellipsoid rather than regional markers and data can be transformed to other datums from this one as a result with known offsets. Prior to this, vertical datum in Canada has largely used "chart datum". This is a local low water datum for each survey area established by benchmarks and tide markers used for making regional charts. Data collected in adjacent areas may not always align vertically when collected under chart datum. However, with the development of a differential surface, these will be able to be converted to CGVD 2013 once released. Work is underway on this at the Canadian Hydrographic Service. For offshore data, often shore-based tide gauge data are not available. The Foreman et al. model[14] allows for correction to mean sea level. Vertical datums are not globally standardized among countries and this is a problem when using cross border data for e.g., tsunami modelling. For governing models on how this could work, the North Sea provides an example where many countries share one water body and have worked together to resolve these discrepancies.

3.1.10.2. Controlled Vocabularies

Vocabularies define the concepts and relationships used to describe a field of interest. They are used to classify terms that can be used in a particular application, characterize relationships, and define possible constraints. Several near-synonyms for 'vocabulary' have been coined, for example, ontology, controlled vocabulary, thesaurus, taxonomy, code list, semantic network. Glossaries, which play a similar role, are a list of terms in a particular domain with associated definitions.

A controlled vocabulary is a list of standardized terminology, words, or phrases, used for indexing or content analysis and information retrieval, usually in a defined information domain (C~~c~~asrai[15]). The World Wide Web Consortium (W3C) recommends the reuse of standardized vocabularies, as this practice "captures and facilitates consensus in communities. It increases interoperability and reduces redundancies, thereby encouraging data reuse. In particular, the use of shared vocabularies for metadata (especially structural, provenance, quality and versioning metadata) helps the comparison and automatic processing of both data and metadata. In addition, referring to codes and terms from standards helps to avoid ambiguity and clashes between similar elements or values." (W3C Data on the Web Best Practices) Within the scientific data and oceanographic communities, there are several controlled vocabularies and glossaries which have reached a mature state of adoption. Rather than providing an exhaustive list, a subset of noteworthy references is described.

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[14] Forman et al. model http://www.bio-iob.gc.ca/science/research-recherche/ocean/webtide/index-en.php
[15] Casrai dictionary: http://dictionary.casrai.org/Controlled_vocabulary

The Natural Environment Research Council (NERC) Vocabulary Server (NVS)[16] has been used to publish controlled vocabularies of terms relevant to marine environmental sciences since 2006, whilst major upgrades to NVS 2.0 made use of the World Wide Web Consortium's Simple Knowledge Organization System (SKOS). As such, it is a highly versatile and machine-readable system, which has integrated controlled vocabularies governed by numerous institutions internationally. NERC NVS 2.0 vocabularies are used by many oceanographic data providers, including the European Commission's SeaDataNet, the Rolling Deck to Repository, the Biological and Chemical Data Management Office and Ocean Networks Canada. Of note, the Ocean Data Interoperability Project II[17] has endorsed the NVS 2.0 as a resource for controlled vocabularies, having submitted a proposal to the IODE/JCOMM Ocean Standard and Best Practices process for approval (ODIP Deliverable D5.5[18]) which is currently under review. These efforts have yielded significant improvements to linking data across organizations (Diviacco, et al., 2017). Within the NVS 2.0, some of the highly used controlled vocabularies include Climate and Forecast Standard Names (P07), Global Change Master Directory Science Keywords (P10), ICES Platform Codes (C17), SeaVoX Device Catalogue (L22), SeaVoX Platform Categories (L06), Unit of Measure (P06). The most authoritative source for taxonomy and names of marine organisms is World Register of Marine Species (WoRMS)[19]. It is the official taxonomic reference for OBIS, and has been adopted by many oceanographic data providers internationally.

The Coastal and Marine Ecological Classification Standard (CMECS)[20] provides a hierarchical controlled vocabulary for four environmental components: water column, geoform, substrate and biotic. It came out of efforts by NOAA, NatureServe, the US EPA and the USGA to address the needs of many stakeholders for a wide range of applications such as marine protected areas, habitat modelling and marine spatial planning. To support transitions to this encompassing standard, 40 existing classification schemes were cross-walked (CMECS spatial data)[21]. Ocean Networks Canada has had positive results in adopting the geoform and substrate components of the standard into its Remotely Operated Vehicle (ROV) dive logging annotation system, and applying these annotations into a geodatabase for DFO to monitor the Endeavour Marine Protected Area.

A number of registries and vocabularies exist for geographical place names and features of interest. A well-established standard for countries is the ISO 3166 Country Codes, which has been recommended by IOC [ISO[22]]. The options for marine regions and features is more

[16] NERC Vocabulary server: http://vocab.nerc.ac.uk/
[17] Ocean Data Interoperability Platform: http://www.odip.eu/
[18] Common ODIP standards: http://www.odip.eu/media/odip/org/documents/odip_wp5_d5.5.pdf
[19] World Register of Marine Species: http://www.marinespecies.org/
[20] CMECS: https://www.cmecscatalog.org/cmecs/
[21] CMECS spatial data: http://northatlanticlcc.org/spatial-data/coastal-and-marine/the-coastal-and-marine-ecological-classification-standard-cmecs
[22] ISO 3116-1 and 3166-3 country codes: http://www.oceanbestpractices.net/handle/11329/202

complex, with resources often being conflicting, ambiguous, or incomplete. However, in Canada, the Advisory Committee on Undersea Feature Names (ACUFN) is considered an authority for undersea and surface maritime features within Canadian waters, and serves Canada's national interest within the General Bathymetric Chart of the Oceans (GEBCO Sub-Committee on Undersea Feature Names (SCUFN). Their output is available as the GEBCO Gazetteer of feature names, general feature types and geographic positions on the seafloor. The Marine Regions[23] standard integrates georeferenced marine names from institutions internationally (including GEBCO), and has been adopted by numerous oceanographic data providers, but determining an appropriate place name is not always straightforward.

There are also several glossaries that serve as particularly useful references in the framework of CIOOS. With regard to research data terms, the CASRAI Iridium Glossary[24] is particularly relevant for providing clear interpretations in the Canadian context as it was developed and maintained by Research Data Canada's (RDC) Standards & Interoperability Committee. The World Wide Web Consortium (W3C) has also published valuable resources such as the Data Catalog Vocabulary (DCAT)[25] and the W3C Data Quality Dictionary[26] . More specific to the oceanographic domain, internationally reputable glossaries include the IHO S-32 Hydrographic Dictionary[27] and the WMO Sea Ice Nomenclature[28].

3.1.10.3. Metadata Format

Standard metadata formats that describe datasets enable interpretation of datasets by humans and machines, production and harvesting of metadata catalogues, discovery and filtering of datasets, in an interoperable way.

The most widely accepted metadata format for geospatial datasets is ISO 19115 (2003 and 2014 versions) and its related standards in the geospatial series (e.g., ISO 19139, ISO 19157). Adherence to the North American Profile of ISO 19115:2003[29] is advantageous for integration into the Federal Geospatial Platform initiative. Published profiles from other major oceanographic data providers such as NOAA[30] and SeaDataNet metadata profile[31] are also worthy of consultation for interoperability in the oceanographic community.

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http://www.oceanbestpractices.net/handle/11329/202
[23] Marine Regions website: http://www.marineregions.org/index.php
[24] CASRAI Iridium Glossary: http://dictionary.casrai.org/Category:Research_Data_Domain
[25] W3C Data catalog vocabulary: https://www.w3.org/TR/vocab-dcat/
[26] W3C Data quality dictionary: https://www.w3.org/TR/vocab-dqv/
[27] IHO S-32 Hydrographic dictionary: http://www.iho.int/iho_pubs/standard/S-32/S-32-eng.pdf
[28] WMO Sea ice nomenclature: http://www.oceanbestpractices.net/handle/11329/328
[29] North American Profile of ISO 19115:2003 http://nap.geogratis.gc.ca/metadata/napMetadata-eng.html
[30] NOAA ISO Explorer: https://geo-ide.noaa.gov/wiki/index.php?title=Category:ISO_Explorer
[31] SeaDataNet metadata profile : http://www.oceanbestpractices.net/handle/11329/285

The Dublin Core initiative has produced a foundational metadata schema comprised of a small set of 15 terms to describe a resource (Dublin Core Metadata Initiative[32]). Of particular relevance for biodiversity data, the Darwin Core (DwC) metadata schema builds upon the Dublin Core to document the occurrences of taxa as documented by observations, specimens, samples and related information (Darwin Core[33]). The DwC has been adopted by major oceanographic data providers such as OBIS, and the OTN. In considering compatibility with IOOS, it is worth noting that the IOOS Biological Data terminology is also based upon this standard (IOOS[34]).

3.1.10.4. Data Formats & File Conventions

Standards for data formats and file conventions are prolific, with proprietary approaches by manufacturers and institutions, as well as community-driven solutions meant to meet the demand for interoperability.

When selecting a data format for distribution, DataONE and the World Wide Web Consortium outline proven best practices (DataONE[35],W3C[36]) such as providing data in a documented, stable and machine-readable format. Data should also be produced in multiple formats, depending on the intended applications. While some format standards include conventions for file-naming, often it is at the discretion of the data repository. Data One has a best practice for file-names[37] which provides helpful suggestions for maximizing utility.

Within the oceanographic data community, there are a number of widely accepted data formats as outlined in Table 8. While community standards for audio and video data are less mature, directions can be taken from the newly formed working groups for the International Quiet Ocean Experiment and the workshop report from the 2016 Workshop on Underwater Video Acquisition, Tagging, Archiving and Access[38].

[32] Dublin Core Metadata Element, Version 1.1 Reference Description: http://dublincore.org/documen
[33] Darwin Core cover page: http://rs.tdwg.org/dwc/
[34] IOOS Biological Observations Data Services: https://ioos.github.io/biological-data-services/biological-observations.html
[35] DataONE file formats: https://www.dataone.org/best-practices/document-and-store-data-using-stable-file-formats
[36] W3C Report on Data on the Web Best Practices: https://www.w3.org/TR/dwbp/
[37] DataONE fine naming: https://www.dataone.org/best-practices/assign-descriptive-file-names
[38] https://www.unols.org/sites/default/files/FINAL_2016VideoWorkshopReport.pdf

Table 8. Data formats

Variable	Format	Comment
All	Raw formats, NetCDF-CF compliant	Raw formats are required to comply with best practices, while the NetCDF-CF format is consistent with international oceanographic data providers.
Fish, Marine Mammals	AAT Marine Metadata	This format was developed by collaborative efforts by IOOS[39], OTN and others involved in animal acoustic telemetry.
Live Coral, Seafloor substrate, fish, zooplankton	Video: mp4 H264, still frame images: PNG	Each video file should contain imagery from only a single camera source and should include a single start time. Raw video files should be "as uncompressed as storage allows," and "proxy video" is recommended to be 1.5 mbps, mp4 H264. Time-stamped frame grabs from the raw video at a frequent interval (> 1/min) are recognized as a valuable resource and are encouraged. The proxy format recommendation is based on the most broadly used open source codec and thus the most likely to remain supported in the near future and of greatest compatibility with modern hardware. There was no consensus on whether codecs should be frame-accurate, but it was recommended that a new detailed study be conducted to review and compare formats, and that a review of formats/codecs should be undertaken routinely.
Ambient Sound	WAV, FFT, MP3, Spectrogram/PNG	MP3 is a good (compressed) web audio format, but not good for scientific analysis (lossy). The raw WAV file format is required for science/analysis (lossless). The spectrogram images should be in PNG image file format.
Temperature, Salinity	Ocean Data View (ODV), Global Telecommunication System (GTS) formats	GTS formats are relevant only for contributing data to GTS, but not expected for public consumption.

[39] IOOS AAT Data Project: https://ioos.github.io/animal-telemetry/aat-data-ioostech-wiki.html

3.1.10.5. Identifiers

Identifiers used in information processing systems can take on many different forms and conventions, which may be representing entities locally up to globally. A persistent identifier or 'PID' is a long-lasting reference to a digital object that gives information about that object regardless what happens to it (Casrai[40]) A globally unique identifier (GUID) or universally unique identifier (UUID) is ensured to be unique via a central or coordinated registration authority, such that entities can be uniquely resolved. Initiatives through entities like the Research Data Alliance (RDA), FORCE 11[41], THOR [42](formerly ODIN, soon to be FREYA), the Research Data Canada IDs Working Group, PIDapalooza[43], have been particularly influential in the research community to advocate for and develop new persistent identifiers.

With regard to the oceanographic and data communities, there are a number of relevant identifier systems at varying levels of maturity, as shown in Table 9.

[40] Casrai persistent identifier definition: http://dictionary.casrai.org/Persistent_identifier
[41] FORCE 11 website: https://www.force11.org/
[42] THOR website: https://project-thor.eu/tag/persistent-identifier/
[43] PIDapalooza website: https://pidapalooza.org/

Table 9. Relevant identifier systems.

Entity	Identifier Systems & Working Groups	Maturity
Individual/ researcher	The Open Researcher and Contributor ID (ORCID)[44] has become widely adopted by publishers, funders and research institutions internationally. ORCID-CA[45]formed in 2017 to provide Canadian institutions access to an API for ORCIDs and to facilitate integration into existing systems.	Mature
Data Citation	See Section 3.1.10.5 for more details.	Mature (static data sets), Pilot (dynamic datasets)
Funders	The Funder Registry[46] , maintained by CrossRef, provides unique identification for grant giving organizations.	Mature
Physical Samples	International Geo Sample Number (IGSN), Ocean Biogeographic Information System (OBIS)	Mature (geological, biological), Pilot (fluids)
Protocols	Protocols IO[47]	Mature
Organization	The European Directory of Marine Organizations (EDMO)[48] , although European in origin has international adoption. An Organization Identifier Working Group[49] was established in 2017 out of collaborative workshops organized by DataCite, ORCID and CrossRef. Given the institutions involved and progress thus far, it is likely to yield a viable solution for integration in the coming years.	Concept/Pilot
Cruise/ Expedition	Rolling Deck to Repository (R2R) has minted DOIs for cruises as a pilot.	Pilot
Platforms	International Council for the Exploration of the Sea (ICES) Codes, World Meteorological Organization (WMO) IDs used for GTS contributions.	Mature

[44] ORCID website: https://orcid.org/
[45] Canadian node of ORCID: https://orcid-ca.org/node/1
[46] Crosref Funder Registry: https://www.crossref.org/services/funder-registry/
[47] Protocols.io website: https://www.protocols.io/
[48] EDMO organizations: https://www.seadatanet.org/Metadata/EDMO-Organizations
[49] ORCID Organization Identifier Working Group: https://orcid.org/content/organization-identifier-working-group

Devices	A new RDA group is being formed to investigate PIDs for instruments (RDA[50]), motivated by use cases from the oceanographic data community.	Concept

3.1.11. Best Practices Used

3.1.11.1. Research Data Management

By adhering to internationally recognized best practices for data management, datasets can be made more comprehensible, easier to automatically process and manipulate, discoverable, reusable, accessible and interoperable.

The DataONE Best Practices database[51] and the W3C Data on the Web Best Practices[52] provide recommendations on how to effectively work with their data through all stages of the data lifecycle. Ideally, data should be managed so that any researcher can discover, use and interpret the data after a long period of time has passed. A key component of data management is the comprehensive description of the data and contextual information that future researchers need to understand and use the data.

FAIR (Findable, Accessible, Interoperable and Re-usable) Data Principles (FORCE 11[53]) have been recently defined as a minimal set of community-agreed guiding principles and practices that enable data consumers (both human and machine) to more easily discover, access, interoperate, sensibly reuse and properly cite the vast quantities of information being generated by contemporary data-intensive science. These are summarized by the FAIR guiding principles:

1) To be **Findable** any Data Object should be uniquely and persistently identifiable.
2) Data is **Accessible** in that it can be always obtained by machines and humans through a well-defined protocol.
3) Data Objects can be **Interoperable** only if they are machine-actionable, utilize shared vocabularies and contain data that are both syntactically parseable and semantically machine-accessible.
4) For Data Objects to be **Re-usable**, they should be sufficiently well-described and rich that they can be automatically (or with minimal human effort) linked or integrated, like-with-like, with other data sources. Additionally, they should refer to their sources with rich enough metadata and provenance to enable proper citation.

[50] RDA 10th Plenary BoF meeting: https://www.rd-alliance.org/persistent-identification-instruments-rda-10th-plenary-bof-meeting
[51] DataONE Best Practices database: https://www.dataone.org/best-practices
[52] W3C Data on the Web Best Practices: https://www.w3.org/TR/dwbp/
[53] FORCE 11 FAIR data principles: https://www.force11.org/group/fairgroup/fairprinciples

Within Canada, credible groups to consult are the Research Data Canada Best Practices for Scholar Metadata WG[54] and the Portage Curation Expert Group[55].

3.1.11.2. Oceanographic Data Management

Best practices have been produced by many of the major ocean data providers and communities of practice (Table 10). For example, the International Oceanographic Data and Information Exchange (IODE) has published numerous best practice documents such as Monitoring Guidance for Marine Benthic Habitats[56] and the IOC Strategic Plan for Oceanographic Data and Information Management (2017-2022)IOC Strategic Plan for Oceanographic Data and Information Management (2017-2021)[57]. An example of a more targeted approach to best practices is the Alliance for Coastal Technologies[58] which conducts evaluations of sensing technologies and publishes reports based on the outcomes, many of which have been relevant to the recommended essential ocean variables. An essential standard familiar to most oceanographers is the Thermodynamic Equation of Seawater (TEOS) 2010[59] which should be followed for thermodynamic properties of seawater.

One of the most comprehensive collections is by Ocean Best Practices[60] which provides a secure, permanent document repository containing community accepted existing ocean best practices. To more effectively consolidate and propagate best practices, AtlantOS and the Ocean Data Interoperability Platform (ODIP) II have formed a working group on this theme, and hosted a workshop on Evolving and Sustaining Ocean Best Practice in November 2017 at the IOC office in Paris to determine processes for archiving, discovering and assessing ocean observation best practices. The outcomes of this workshop are expected to be presented at OceanObs'19.

Table 10 A review of existing published best practices for oceanographic core variables.

Variable	Best Practices/Collection Methods	Reference links
Temperature, salinity	Calibrated CTD	ICES Guidelines for CTD data[61]
Sea surface height/sea-level	Tide gauge or georeferenced pressure gauge	ICES Guidelines of water level dataICES Guidelines for water

[54] RDC Standards & Interoperability Committee: https://www.rdc-drc.ca/our-work/standards-interoperability/
[55] Portage Curation Expert Group: https://portagenetwork.ca/working-with-portage/network-of-expertise/portage-curation-expert-group/
[56] JNCC Monitoring guidance for marine benthic habitats: http://www.oceanbestpractices.net/handle/11329/332
[57] IOC Strategic Plan for Oceanographic Data and Information Management: http://www.oceanbestpractices.net/handle/11329/345
[58] Alliance for Coastal Technologies website: http://www.act-us.info/index.php
[59] TEOS-10 website: http://www.teos-10.org/
[60] Ocean Best Practices website: http://www.oceanbestpractices.net/
[61] ICES Guidelines for CTD data: http://www.oceanbestpractices.net/handle/11329/244

Variable	Best Practices/Collection Methods	Reference links
		level data[62]
Salinity, oxygen, inorganic carbon, nutrients, phytoplankton, zooplankton	Bottle/water sample (e.g. Rosette) and subsequent sample analysis.	Protocols for the Joint Global Ocean Flux Study Core Measurements[63]
Water sample measurements	Bottle/water sample and analysis	ICES Guidelines for Discrete Water Samples[64]
Currents	Acoustic Doppler Current Profiler, CODAR, Drifter	ICES guidelines for Moored Current Meter Data[65] ICES Guidelines for Surface Drifting Buoy Data[66]
Ice	Remote sensing image, underwater acoustic ice profiler	Sea Ice Information Services of the World (2010)[67]
CO2	pCO2 sensor, Bottle/water sample	Guide to Best Practices for Ocean CO2 Measurements[68]
Plankton	Bottle/water sample, net tows, acoustic echo-sounder	ICES Guidelines for Biological Plankton data [69] Integration of Plankton-Observing Sensor Systems to Existing Global Sampling Programs[70]

[62] ICES Guidelines for water level data: http://www.oceanbestpractices.net/handle/11329/224
[63] Protocols for the JGOFS core measurements: http://www.oceanbestpractices.net/handle/11329/220
[64] ICES Guidelines for discrete water samples: http://www.oceanbestpractices.net/handle/11329/233
[65] ICES Guidelines for moored current meter data: http://www.oceanbestpractices.net/handle/11329/240
[66] ICES Guidelines for surface drifting buoy data: http://www.oceanbestpractices.net/handle/11329/243
[67] Sea-ice information services of the world: http://www.oceanbestpractices.net/handle/11329/283
[68] Guide to best practices for ocean CO2 measurements: http://www.oceanbestpractices.net/handle/11329/249
[69] ICES Guidelines for biological plankton data: http://www.oceanbestpractices.net/handle/11329/245
[70] Integration of plankton-observing sensor systems to existing global sampling programs: http://scor-int.org/Annual%20Meetings/2017EC/P-OBS.pdf

Variable	Best Practices/Collection Methods	Reference links
Imagery-based data	Cameras, Annotation systems	Acquisition of Long-term Monitoring Images near the Deep Seafloor[71] Survey of Best Practices in Digital Image Collection Management[72] Establishing Standards on Underwater Video Acquisition, Tagging, Archiving and Access Workshop, 2016[73]

3.1.11.3. Indigenous Communities and Citizen Scientists

Integrating the knowledge and fulfilling the end-user needs of Indigenous Peoples and citizen scientists has the potential to add immense value to the data assets and derived information.

Indigenous coastal and Arctic communities have a wealth of relevant historical and experiential knowledge, and can directly benefit from environmental monitoring and predictions that affect where they live. Thus, it is important to engage with these communities with certain considerations in mind. First, consult with Indigenous communities to determine which types of instruments and data would be relevant to their local interests, customs and practices; examples may include hydrophones for whale monitoring, acoustics or sampling programs to monitor fish stocks, or sensors to monitor ocean acidification near culturally significant shellfish sites. Second, consider how to present data in ways that can complement their local knowledge and scientific approach. For example, traditional knowledge and practices conveyed through traditional storytelling may be enhanced by integrating data and their knowledge into GIS story maps (arcGIS[74]). "Indigenous science" is also tightly connected with language, culture and history, and may be considered as "an accepted term for inclusion of the beliefs and understandings of non-Western people, acquired through long-term association with a place (Corrigan, 2006[75]). Ogawa (1995), explains Indigenous science as a perception of reality that is

[71] Acquisition of long-term monitoring images near the deep seafloor: http://www.oceanbestpractices.net/handle/11329/326
[72] Survey of best practices in digital image collection management: http://www.oceanbestpractices.net/handle/11329/274?show=full
[73] Underwater video workshop report: https://www.unols.org/sites/default/files/FINAL_2016VideoWorkshopReport.pdf
[74] ArcGIS Story Maps website: https://storymaps.arcgis.com/en/
[75] http://www.chriscorrigan.com/parkinglot/principles-of-indigenous-science/

culturally dependent. Indigenous science might be "tacitly transferred from generation to generation through daily social and cultural events". Snively and Corsiglia's (2000) commenting on Indigenous science noted "Indigenous science…interprets how the world works from a particular cultural perspective". Inclusion of Indigenous scientific approaches can also leverage experience gained from and networks developed by existing research communities and engagement programs. For example, participants of the Polar Data Forum I (2015) and II (2017) have collectively discussed these topics and can bring insights to improve the success of an engagement strategy. Moreover, Ocean Networks Canada has developed its capacity through the work of an Indigenous Liaison and an Indigenous Community Learning coordinator who interface with First Nations in the vicinity of ONC's coastal observatories to plan installations, develop educational resources and collect local knowledge for incorporation.

With the growth of big data and computational resources, scientists do not have the capacity to collect and mine data to their fullest potential. One opportunistic way to improve data coverage is to mobilize more data from species monitoring projects and field observation campaigns (Kissling *et al.,* 2017). This includes citizen science projects (Dickinson *et al.,* 2010) which can have several advantages over traditional field surveys. Assuring the usefulness of citizen-science data for essential biodiversity data products requires careful design of data-input and management procedures and recording of associated information such as sampling effort, species absence and other data-collection variables (Kelling *et al.,* 2015). Citizen science data may also require additional cleaning to protect the privacy of volunteers, and additional metadata documentation to meet conditions of attribution (Kissling, D.W., et al., 2017).

3.1.12. Data Preservation and Sharing

3.1.12.1. Preservation and Repository Certifications

Properly implemented and adequately resourced data repositories ensure secure, long-term metadata and data preservation. This is facilitated by following a planned approach, as outlined in a data management plan. Ideally, data management plans or records are machine actionable and their generation semi-automated so that they contain minimal project metadata. This can be enabled by data management planning tools such as the DMP Assistant, developed by the Portage Preservation Expert Group[76].

DataONE has defined best practices for deciding what data to preserve (DataONE[77]). Raw data are usually worth preserving. Processed data should be preserved if reproduction would be costly and time conserving. Algorithms, software source code and results of analyses cost little to

[76] Portage Preservation Expert Group: https://portagenetwork.ca/working-with-portage/network-of-expertise/portage-preservation-expert-group/

[77] DataONE Decide what data to preserve: https://www.dataone.org/best-practices/decide-what-data-preserve

preserve and can be particularly valuable. In principle, researchers should be able to re-analyze the same data with the same methods in order to test conclusions.

W3C best practices recommends that persistent identifiers be preserved (W3C[78]) such that they remain discoverable and citeable in metadata records. Thus, when selecting identification schemes for adoption, the long-term viability of the identifier should be an important criterion.

As defined within the CASRAI glossary, "Repositories preserve, manage, and provide access to many types of digital materials in a variety of formats. Materials in online repositories are curated to enable search, discovery, and reuse. There must be sufficient control for the digital material to be authentic, reliable, accessible and usable on a continuing basis (CASRAI[79])." Certifications have been established to give credibility to repositories that meet their standards.

In 2017 the ICSU World Data System (WDS) and the Data Seal of Approval (DSA) established a unified standards and certification board, which provides final approval of applicants for Core Trustworthy Data Repositories certification (Edmunds, R., et al., 2016[80] ICSU[81]). Such a designation is a recommended eventual goal for CIOOS. Requirements for certification include:

1) Defined continuity planning to ensure ongoing access to and preservation of holdings.
2) Compliance with disciplinary and ethical norms for data creation, access and curation.
3) Adequate funding, staffing, management and governance.
4) Mechanisms to secure ongoing expert guidance and feedback on data management, as technologies and practices evolve over time.
5) Guaranteed integrity and authenticity of the data.
6) Appraisal and acceptance by the user community of data and metadata relevance and understandability.
7) Documented storage procedures.
8) Documented plan for long-term preservation.
9) Adequate data quality information is provided to end users.
10) Archiving takes place according to defined workflows.
11) Ability for users to discover the data and refer to them in a persistent way through proper citation.
12) Support for data re-use over time, through provision of appropriate and sufficient metadata.
13) Well-supported technical infrastructure technologies and services.

[78] W3C Data on the Web Best Practices: https://www.w3.org/TR/dwbp/
[79] CASRAI repository definition: http://dictionary.casrai.org/Repository
[80] Core Trustworthy Data Repositories Requirements: https://zenodo.org/record/168411#.WhuIwUqnGM9
[81] ICSU New News Archive: https://www.icsu-wds.org/news/news-archive/new-standards-and-certification-entity-on-the-horizon?utm_source=WDS+Newsletter&utm_campaign=00fea7ddba-ICSU_WDS_Newsletter_May_2017&utm_medium=email&utm_term=0_c716199436-00fea7ddba-85321485

14) Adequate protection of the facility, its data, products, services and users.

The International Organization for Standardization (ISO) has defined a recommended practice for assessing the trustworthiness of digital repositories, ISO 16363:2012[82]. It is applicable to the entire range of digital repositories and can be used as a basis for certification. It is recommended that, as detailed plans for implementation are formulated, CIOOS carefully consider certification criteria outlined in this standard.

3.1.12.2. Metadata and Documentation

Metadata must also be considered as an integral component of CIOOS. Metadata is "data about data"; it defines and describes characteristics of data to provide an understanding of the data and related processes. It may be information that describes the contents of archives (such as what data they contain, over what time and space scales) down to detailed information about characteristics of the instrumentation, placement of sensors, or characteristics of the models. It is important to organize and maintain documentation that relates to metadata and data.

Metadata are fundamental for a number of purposes including:

1) Data discovery, access and interpretation;
2) Observatory and expedition operations;
3) Data quality, provenance, versioning and citation records;
4) Contributor attributions and data-related metrics; and
5) Data file and system operations.

DataONE best practices include recognizing data contributors[83] and describing the measurement technique[84] that are highly relevant to oceanographic data. In addition, expedition metadata is an important priority for oceanographic data providers, as demonstrated by Cruise Summary Reports being one of the major priorities within the Ocean Data Interoperability Platform projects.

Documentation that relates to oceanographic data includes, but is not limited to:

1) Instrument manuals and calibration sheets;
2) Expedition plans and reports;
3) Infrastructure diagrams and maps; and
4) Data product documentation.

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[82] ISO 1363:2012 https://www.iso.org/standard/56510.html
[83] DataONE Recognize stakeholders in data ownership: https://www.dataone.org/best-practices/recognize-stakeholders-data-ownership
[84] DataONE Describe measurement techniques: https://www.dataone.org/best-practices/describe-measurement-techniques

Given that complete and consistent metadata is an integrity challenge due to insufficient resources or externally sourced or historical datasets (CIOOS Survey, section 2.2), it is advised that these factors be identified and addressed.

3.1.12.3. Reproducibility, Provenance and Versioning

Reproducibility is a particular challenge facing the research community, with papers being retracted for failure to reproduce results (see recent example[85]). Provenance is a key ingredient to the solution, but approaches to ensuring full end-to-end provenance are in varying degrees of maturity. Versioning of metadata, datasets, and code is another key aspect to enable reproducibility. Metadata may be updated to make corrections, to migrate to evolving standards, or to fill gaps. New versions of data may occur when corrections are applied for calibrations or data processing algorithms. Code that produces data products is also subject to change. For the special case of physical samples, proper storage of any remaining sample can also serve this aim for researchers that may want to duplicate the analysis or perform complementary analysis.

Tracking provenance for research data is vital to science and scholarship, providing answers to common questions researchers pose when sharing and exchanging data: Where did it come from? Who modified it? Is this copy the same as the copy I deposited? In what way is it the same? How do I resolve discrepancies or anomalies?

Best practices have been published and working groups are pursuing the ongoing issues. For instance, DataONE and W3C have best practices for provenance and data versioning (DataONE-1[86], DataONE-2[87], lDataONE-3[88],W3C[89]) that emphasize the need to document methods and processing applied to the data. The research community has also made progress to develop best practices that suite challenges to computational science research (Stodden, V., and Miguez, S., 2014).

W3C has produced a model for tracking provenance[90] that has demonstrated encouraging results [Cox, S.J.D, and Car, N.J, 2015[91];CSIRO[92]] and being further pursued as a viable means within the RDA community (RDA-1[93], RDA-2[94]). Versioning has also undergone a recent study by the

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[85] Retraction Watch article: http://retractionwatch.com/2017/10/26/science-retracts-paper-nobel-laureates-lab-cant-replicate-results/
[86] DataONE - 1: https://www.dataone.org/best-practices/document-steps-used-data-processing
[87] DataONE - 2: https://www.dataone.org/best-practices/describe-method-create-derived-data-products
[88] DataONE - 3: https://www.dataone.org/best-practices/provide-version-information-use-and-discovery-0
[89] W3C Data on the Web Best Practices: https://www.w3.org/TR/dwbp/
[90] W3C PROV-Overview: https://www.w3.org/TR/prov-overview/
[91] Cox and Car, 2015, PROV and Real Things: https://www.mssanz.org.au/modsim2015/C4/cox.pdf
[92] CSRIO Describing geochemistry obsv. using PROV-O https://publications.csiro.au/rpr/pub?pid=csiro:EP156047
[93] RDA-1 Research data provenance: https://www.rd-alliance.org/groups/research-data-provenance.html
[94] RDA-2 Provenance patterns WG: https://www.rd-alliance.org/groups/provenance-patterns-wg

Data Citation Index (Force, M., 2016[95]) which found that 72% out of 322 data repositories studied had no version information for their datasets. When versioning did exist, schemes varied significantly (e.g., how they were numbered or labeled, how they were presented). Until there is a consensus approach to how versioning should be achieved, perhaps through the RDA Data Versioning Interest Group, having some form of versioning is a positive step. Furthermore, if data has been contributed to other distributors or downloaded by users, tracking this history provides a means to provide them with updates or notifications as deemed fit.

Since documentation of processing steps, calibration records, and field operations is a recognized challenge by the community (CIOOS Survey, section 2.2), additional resourcing for cyberinfrastructure developments and data stewardship is prudent. These methodologies should be evaluated to determine appropriate and standardized approaches for provenance and versioning. CIOOS can then use this advice as a basis for recommending appropriate usage on a broad scale.

3.1.12.4. Data Citations

Data citations have the potential to do much more than enable data producers and repositories to receive credit and measure data usage. If persistent identifiers (e.g., DOIs) are applied, version histories are tracked, and citation information is integrated into metadata products, then they serve as a means to improve data provenance, reproducibility, and link data (e.g., associations with Digital Objects Identifiers, contributor PIDs).

In fact, by the CASRAI Iridium Glossary definition, data citations must have all these features: [o]ffers proper recognition to authors as well as permanent identification through the use of global persistent identifiers in place of URLs which can change frequently. Use of universal numerical fingerprints (UNFs) guarantees to the scholarly community that future researchers will be able to verify that data retrieved is identical to that used in a publication decades earlier, even if it has changed storage media, operating systems, hardware, and statistical program format. Data citation is provided in a similar way that researchers routinely include bibliographic references to traditionally published resources. Data citation should include the following elements: (a) Name Principal Investigator/Author/Data Creator; (c) Release Date/Year of Publication - year of release, for a completed dataset; (d) Title of Data Source - formal title of the dataset; (e) Version/Edition Number - the version of the dataset used in the study; (f) Format of the Data - physical format of the data; (g) 3rd Party Data Producer - refers to data accessed from a 3rd party repository; (h) Archive and/or Distributor - the location that holds the dataset; (i) Locator or Identifier - includes Digital Object Identifiers (DOI), Handles, Archival Resource Key (ARK), etc.; (j) Access Date and Time - when data is accessed online; (k) Subset of Data Used -

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[95] Force, M. 2016 Presentation: https://sites.nationalacademies.org/cs/groups/pgasite/documents/webpage/pga_173756.pdf

description based on organization of the larger dataset; (l) Editor or Contributor - reference to a person who compiled data, or performed value-added functions; (m) Publication Place - city, state, and country of the distributor of the data; and, (n) Data within a Larger Work - refers to the use of data in a compilation or a data supplement (such as published in a peer-reviewed paper)."(CASRAI[96])

There are two major dataset citation divisions, static datasets and dynamic datasets. Whilst static datasets may still have version updates, dynamic datasets have data that changes frequently and at asynchronous moments (CASRAI[97]). Examples of dynamic datasets include data collected from live sensor streams, and annotation derived data that have no clear end. Strategies and technologies for static data citations are more mature, while dynamic data citations are evolving through pilot implementations. Working groups and conferences lead by entities like Force11, RDA and the Portage Network, have advanced this topic significantly in recent years.

While various PIDs have been used for data citations, DOIs minted by CrossRef and DataCite are the most widely applied and integrated into linked systems (e.g., publications, ORCID profiles). DataVerse is a tool that has gained wide acceptance in Canada for publishing and minting DOIs for smaller volume static datasets (less than 2GB), while the Portage Network is developing the Federated Research Data Repository (FRDR) to help augment limitations of DataVerse. For dynamic datasets, the RDA has published recommendations[98] and provided guidance to repositories to demonstrate pilot implementations. Their recommendations include versioning, storing individual data query details, and resolving PIDs (e.g., ability to return details about the dataset and query).

Regardless of whether static or dynamic datasets are being published, there does not seem to be any clear consensus of the granularity at which to divide data holdings into datasets. Some publishers consider their entire data holding as one dataset with a single DOI. Others divide datasets by locations, projects, or expeditions. Careful consideration of dataset granularity is prudent for being able to properly validate impact of a dataset by its citations, enabling sensible filtering/harvesting via metadata catalogs, reducing the burden on scientists to cite data used in publications, and updating DOIs for version changes.

3.1.12.5. Data Restrictions

Although there is a shift towards open data policies and researchers are recognizing the value of sharing data, valid reasons to restrict data persist. DataOne includes a sharing data best practice

[96] CASRAI Data citation definition: http://dictionary.casrai.org/Data_citation
[97] CASRAI Dynamic data definition: http://dictionary.casrai.org/Dynamic_data
[98] Identification of reproducible subsets: http://www.ieee-tcdl.org/Bulletin/v12n1/papers/IEEE-TCDL-DC-2016_paper_1.pdf

for legal and policy considerations (DataONE[99]) which acknowledges that data might be required to hide or be obscured if it impacts endangered species, sensitive Indigenous information, or personal information. In the case of oceanographic data, this may arise in the forms of marine mammal tracking, Indigenous knowledge, and individual fishing vessel catch. Unrestricted access to data that may compromise national security such as hydrophone data that may include acoustic signatures of military vessels is another concern. In that realm, ONC has developed agreements with the Canadian and US militaries to screen datasets before they are made public.

Data restrictions can be supported through user-based data access, although this consumes significant resources to maintain agreements with relevant parties, maintain metadata and supporting restrictions, and to develop interfaces and web services that honour these restrictions. Even if data cannot be made publicly available, there is great value in preserving quality data and providing metadata records that contain a direct point of contact for manual data requests.

3.2. DATA MANAGEMENT RECOMMENDATIONS

3.2.1. Introduction

A data management system's purpose is not to simply keep data, but is to foster data reuse. The appropriate management of data from different sources, be they geographically separated or from different types of instruments, provides the ability to offer them with greater ease of access, hiding the intricacies of the initial acquisition conditions. Moreover, a suitable data management system will facilitate the comparison of outputs from various instruments simultaneously – thanks to a single data access protocol, possibly including integrated interactive environment for access, analysis and visualization in a shared, virtual workspace.

A sound data management system is arguably the best way to leverage prior investments in the initial data collection, as it will allow more value to be extracted from previously recorded data by making them available to a much wider audience. The potential for new scientific discovery, or to support public policy through comparing historical baselines with contemporary snapshots is enormous, as has been established numerous times in other areas. It also has been argued elsewhere that the cost of a suitable data management system for science data typically represents 10-20% of the cost of the entire apparatus and of the supporting infrastructure and staff that were necessary to collect the data in the first place (Pirenne 2015).

For the low, moderate and high service recommendations that follow, it is assumed that low-service criteria are included at the moderate-service level, and low and moderate-service criteria are included at the high-service level.

[99] DataONE Sharing data legal and policy considerations: https://www.dataone.org/best-practices/sharing-data-legal-and-policy-considerations

3.2.2. Data Source Recommendation

The multiplicity of data sources producing core variables is described elsewhere in this document. This Investigative Evaluation will not concern itself with actual data acquisition as it is assumed to be managed properly by contributing Regional Associations and data nodes. The data nodes will have to demonstrate their interoperability level (including access, data formats, data description and other metadata) to be able to contribute their holdings to the CIOOS. To that effect, it is expected that Regional Associations will support the data nodes in ensuring quality of service and compliance to adopted standards. Future funding provided to the Regional Associations might help bring some of the data nodes to the required level of maturity.

3.2.3. Quality Assurance & Quality Controls Recommendations

Based on the best practices highlighted in the previous section, we recommend the following approach to ensure that homogeneous data is made available through CIOOS interfaces at either the regional or national level:

Low-service:

1) Nodes have localized QA/QC processes that are documented and available.
2) CIOOS data providers should include relevant QA/QC information corresponding to the provided data.
3) CIOOS data providers implement systematic workflow processes to ensure that the necessary pre-conditions for high-quality data are met.
4) A subset of QARTOD manuals is followed across all nodes with required tests applied.
5) CIOOS data providers should agree upon a common data quality flagging scheme.
6) CIOOS data providers should carefully consider how to preserve the original dataset in its raw form for reproducing any subsequent procedures performed on the data.
7) Data quality flags are contained in data files.

Moderate-service:

1) CIOOS data providers should implement a comprehensive process-oriented quality assurance (QA) model used in combination with a product-oriented data quality control (QC) model.
2) A subset of QARTOD manuals is followed across all nodes with required and strongly recommended tests applied.
3) CIOOS data providers should develop user-friendly interfaces and tools to facilitate the addition of annotations by data specialists, scientists and potentially citizen scientists, and effectively link the annotations through the time domain with corresponding data.
4) CIOOS should be actively involved with international organizations such as QARTOD and Argo to develop and implement recommended standards and practices for oceanographic data QAQC.

5) The CIOOS data delivery policy should require the maintenance of the raw un-manipulated data, while allowing users to choose their preferred format. Great care should also be taken to ensure that valid data are not removed and that all QA/QC processing steps are well documented so that they can be evaluated.

High-service:

1) QARTOD manuals followed across all nodes with required, strongly recommended, and suggested tests applied.
2) A consistent way of representing data quality flags is implemented.
3) ISO 19137 is included in ISO 19115 metadata records.

3.2.4. Best Practice Recommendations

It is recommended that best practices adopted by the CIOOS include mature practices for the low-service implementation, common ones for the moderate-service implementation, and, for the high-service implementation, cutting edge ones that follow on-going developments and improvements in the international community.

3.2.4.1. Research Data Management Recommendations

Low-service:

1) Subset of FAIR Principles supported by all nodes.

Moderate-service:

1) Selected FAIR Principles supported by all nodes in same manner.

High-service:

1) FAIR Principles fully supported by all nodes in the same manner.

3.2.4.2. Oceanographic Data Management Recommendations

Low-service:

1) Nodes locally review best practices and apply if deemed appropriate and feasible.
2) Decisions to source new instruments are evaluated against Alliance for Coastal Technologies outputs.
3) TEOS-10 standard is used.

Moderate-service:

1) CIOOS establishes expert committees to review existing best practices, and provide recommendations for Nodes.
2) Nodes comply with recommendations to the extent that resources permit, providing feedback to the committees that details which ones were applied and provides rationale for those that were not.

High-service:

1) Nodes comply with recommendations from CIOOS expert committees.
2) CIOOS develops, adopts and publishes new best practices where gaps exist.

3.2.4.3. Indigenous Communities and Citizen Scientist Recommendations

Low-service:

1) Data from Indigenous communities, Nations, and governments, while welcome, is not specifically targeted or accommodated. No additional resources are allocated.
2) Citizen scientist data is not supported unless it is routed through another organization which fulfills CIOOS requirements as a data provider (or citizen scientist organization can fulfill the requirements).

Moderate-service:

1) Data from Indigenous communities, Nations, and governments, and citizen scientist data is accepted, and partially accommodated with a support staff at each RA, with appropriate funding.
2) An Indigenous community engagement plan is developed that can harness existing external resources and opportunities.
3) A citizen science engagement plan is developed to ensure that citizen scientist data is of minimal quality and relevance for inclusion.

High-service:

1) Data from Indigenous communities, Nations, and governments, and citizen scientist data is actively sought out and encouraged, with a designated support staff member at each RA.
2) Staff members develop an Indigenous community engagement plan that can extend beyond existing external resources and opportunities.
3) Staff work to remain current on best practices in these field, work to enable modification of services to better support these groups and actively coordinate data from Indigenous communities, Nations, and governments, and citizen scientist data for inclusion.
4) Researchers are engaged to analyze and publish the results of these initiatives, and feedback is provided.

3.2.5. Standards Recommendations

3.2.5.1. Timestamps and Datum Recommendations

Low-service:

1) ISO 8601 timestamp format is used.
2) Nodes locally document the time source details.

3) Datum is specified where known in the metadata record, and coordinates have consistent formatting and decimal places.

Moderate-service:

1) For instruments that are deployed autonomously, it is strongly recommended that record keeping practices be established to synchronize instrument clocks prior to deployment and to measure offsets upon recovery, so that drift can be established.
2) The horizontal datum adopted is WGS1984, the datum is specified where known in metadata record, and coordinates have consistent formatting and decimal places. For projecting grids, a single standard is not recommended, but it would be preferable to select a commonly-used projection that has transformation capabilities.

High-service:

1) Nodes adopt or develop a common metadata framework to disseminate time source details in the metadata records.
2) The horizontal datum is WGS1984, the vertical datum follows CGVD 2013 where possible, all datums are specified where known in metadata record, and coordinates have consistent formatting and decimal places.

3.2.5.2. Controlled Vocabulary Recommendations

Low-service:

1) WoRMS Taxonomy is used
2) ISO 3166 Country codes are used
3) The CASRAI Iridium Glossary is a common reference for research data definitions.

Moderate-service:

1) Nodes agree on which additional controlled vocabularies to implement, prioritizing those that are available from NERC NVS 2.0, and demonstrate uptake of CIOOS materials by the international oceanographic community. Nodes may choose to support additional vocabularies as resources permit.
2) Nodes contribute suggestions for new terms for supported controlled vocabularies as needed through their governance processes.
3) CIOOS evaluates an appropriate vocabulary for substrate classification (such as CMECS), and Nodes apply it to new datasets.

High-service:

1) Nodes consult with the ACUFN on a common framework for geographical place names and feature vocabularies.
2) Nodes develop crosswalks for historically used substrate classification vocabularies as needed, and migrate historical datasets to the new standard.

3.2.5.3. Metadata Format Recommendations

Low-service:

1) Nodes contribute ISO 19115 metadata records with partial agreement of profile.

Moderate-service:

1) Nodes contribute ISO 19115 metadata records with common profile.
2) Darwin Core metadata is provided for biological diversity purposes, such as contributions to OBIS.

High-service:

1) Nodes contribute ISO 19115 metadata records with common profile, and seek appropriate catalog harvesters so that datasets are more widely accessible.

3.2.5.4. Data Formats and File Conventions Recommendations

Low-service:

1) File naming is documented and consistent for each node, and adheres to Data One best practice.
2) Raw data formats are archived.
3) NetCDF data files are delivered for all scalar data.

Moderate-service:

1) ODV formats are provided for temperature and salinity.
2) Telemetry data is delivered in the AAT format.
3) Audio is delivered in WAV formats.
4) Video follows recommendations from the 2016 Workshop on Underwater Video Acquisition, Tagging, Archiving and Access.

High-service:

1) GTS formats for surface temperature and salinity data are contributed to the World Meteorological Organization Global Telecommunication System.
2) Passive acoustic data follows conventions that arise from the International Quiet Ocean Experiment working groups.

3.2.5.5. Identifier Recommendations

Low-service:

1) CIOOS becomes a member of ORCID-CA.
2) CIOOS is registered within the European Directory of Marine Organizations.

Moderate-service:

1) Nodes include support for ORCIDs in their metadata framework.
2) Nodes include identifiers from the Funder Registry in their metadata about funders.

3) Nodes include identifiers from the European Directory of Marine Organizations where available, monitoring progress of the Organizational Working Group.
4) Biological samples records are contributed to OBIS.
5) Geological samples are registered with IGSN.
6) Developments from working groups for persistent identifiers are monitored, and continually reviewed for adoption.

High-service:

1) Nodes include ORCIDs in their data management services such as data citations and metadata data products.
2) Nodes include identifiers from the European Directory of Marine Organizations where available, and adopt outcomes of the Organizational Working Group.
3) ICES codes are included in platform metadata, and new platforms are registered.
4) WMO IDs are obtained and included in metadata as needed for GTS contributions.
5) Expedition identifiers are minted if the international community adopts the practice that R2R has started.

3.2.6. Data Preservation and Sharing Recommendations

3.2.6.1. Preservation Recommendations

Long-term data preservation is deemed essential, although the means by which this is achieved and the volume of data that can be accommodated varies at each service level.

Low-service:

1) Nodes act as preservation brokers for both raw and processed formats for datasets that are submitted via an accepted data management plan and relate to one of the essential ocean variables.
2) The rawest form of data provided to repository should be archived following Data One best practice[100] to support reprocessing, reproducibility, avoid loss of information not typically possible to retain within standardized products.
3) All nodes identify which criteria they believe they meet for the CoreTrustSeal (unvetted though).

Moderate-service:

1) Nodes act as preservation brokers for datasets which merit data rescue, as determined by the node.
2) Individual nodes are WDS certified.

[100] DataONE Deciding what data to preserve: https://www.dataone.org/best-practices/decide-what-data-preserve

High-service:

1) Nodes act as preservation brokers as funding permits from additional sources that seek to submit their data, prioritizing datasets by following the DataONE guidelines and CIOOS committee direction.
2) All nodes, entire system is WDS certified (or working towards it).

3.2.6.2. Metadata and Documentation Recommendations

Metadata curation should be conducted by experts who are familiar with domain standards, ideally from the beginning of a project to ensure that proper metadata are identified and recorded.

Low-service:

1) Attributions of contributors are maintained and included in metadata records.
2) Data ONE best practices for describing the measurement technique are followed to the extent possible.
3) Metadata for infrastructure and expeditions maintained by the Node.
4) Calibration records are particularly important for assessing data quality, and thus proper records need to be kept and made accessible.
5) A content management system is used to organize ancillary documentation like instrument manuals and expedition reports.
6) Data products are documented and publicly accessible.
7) A metadata framework supports the needs of all low-service items.

Moderate-service:

1) A calibration landing page is available for each instrument that shows its calibration history, with references to ancillary information such as calibration sheets, formulas, protocols and procedures followed. For example, an oxygen sensor may have a calibration sheet from the manufacturer, benchmark calibration data and computation documents, in-situ water samples with Winkler titration for cross-comparison, formulas and corrections for temperature and salinity applied, and more.
2) Cruise Summary Reports are completed for expeditions executed by the Node.
3) CIOOS forms a metadata committee with representatives from each node that seeks to maximize interoperability, reduce duplication of efforts, and improve metadata content and frameworks.
4) Metadata framework supports the needs of all moderate-service items.

High-service:

1) Metadata framework supports the needs of all high-service items.

3.2.6.3. Reproducibility, Provenance and Versioning Recommendations

Nodes strive towards having fully reproducible datasets by maintaining provenance metadata and versioning records.

Low-service:

1) Best-effort provenance records are maintained.
2) Metadata records contain proper attributions to enable proper crediting when datasets and metadata are redistributed by harvesters or downloaded by users.
3) Database tables for metadata retain their modification dates, modifier names, and histories.
4) Alterations to datasets are tracked.
5) Software code is versioned.

Moderate-service:

1) Data contributed to other distributors such as the GTS, OBIS, is tracked.
2) Data processing steps are described for each data product, and available to end-users.
3) Alterations to datasets are accessible to end-users.
4) Data contributed to other data distributors is tracked, and updates to those contributions are provided if appropriate.

High-service:

1) A common framework to tracking and presenting provenance information is identified and implemented.
2) All provenance information and version histories are accessible to end-users.
3) Users can obtain reproduced datasets if they provide a date or version of origin.

3.2.6.4. Data Citation Recommendations

Low-service:

1) Provide a means to publish and obtain DOIs for publication-related 'static' datasets, and possibly additional curated static datasets as deemed appropriate.
2) A pilot dynamic data citation study is completed by at least one of the nodes.

Moderate-service:

1) Staff receive training on dynamic data citations.
2) Nodes have a local approach to determine granularity for dynamic datasets.
3) Dataset DOIs are produced for dynamic datasets.
4) Use another PID to denote a subset-particular query within a dataset.
5) A subset of the RDA dynamic data citation recommendations is supported.

High-service:

1) Nodes have a shared approach to determine granularity for dynamic datasets.
2) Include dataset DOI in metadata data products (e.g., ISO 19115).
3) Dynamic data citations leverage metadata on provenance, versioning and attributions to automatically populate citation metadata upon minting.
4) Provide a 'resolver' tool that allows users to enter their CIOOS provided doi/subset PID combination to discover citation text, details about the dataset and particular subset query, any subsequent alterations/versioning to that dataset, and retrieve current version of dataset. Linked items like journals and ORCIDS may also be displayed. Even if a dataset is deleted or no longer available, the identifier should still be resolvable and ideally indicate the reason for the change and direct to the newer version of the data.
5) All of the RDA dynamic data citation recommendations are supported.
6) Provide user documentation to explain data citation features and recommendations.

3.2.6.5. Data Restriction Recommendations

This Investigative Evaluation recommends CIOOS does not support restricted access data. Should individual data node already support and manage access to restricted data on behalf of their own stakeholders, those datasets will simply not be made available to CIOOS interfaces.

Low-service:

1) All metadata and data provided to CIOOS are already restriction-free and no further management is required.

Moderate-service:

1) All metadata is restriction-free, but some datasets may be restricted at the discretion of the RA.
2) RAs will have to have a dialog with data providers to work through potential data restriction issues. It is possible that a node will have to refuse data/metadata because of the nature of their data.

High-service:

1) Infrastructure to facilitate permissions-based access to restricted data is considered.

3.2.6.6. Other Recommendations

A part of the complexity of ocean sciences stems from its plurality: the need to serve many different communities (both scientific and public/government), each with different goals and relying on different types of data to achieve their goals. For instance, physical oceanographers and chemists generally use sensors measuring directly phenomena of interest while biologists usually rely on proxies to derive populations, species and abundances. This is reflected in the instrumentation from which data is to be made available under the CIOOS. Typical data types therefore usually fall into one of three categories from a data management point of view (Table11).

Table 11. Types of data and associated instruments and formats.

Category	Instruments	Data format
Scalar	CTDs, chemical sensors, ...	Return one dimensional lists of values at regular intervals or time series as vectors
Complex	ADCP, still cameras, ...	Return n-dimensional (n>1) matrices
Stream	Video cameras, hydrophones	Return uninterrupted streams of bytes

One of the dominant characteristics of ocean observations is the diversity of data types that they produce. To further complicate the problem, users typically need different ways to work with data, including selecting, browsing, retrieving and processing.

Browsing and searching are activities that are typically performed interactively and a rapid response time to keystrokes or mouse clicks must provide a feeling of immediacy. Retrieving and processing can be allowed to take more time, in particular if the user is made aware of the size of the dataset to be transferred or the complexity of the processing to be performed.

To provide adequate response times to queries, typical practices involve the use of database management systems to store metadata and scalar data where an index on time and sensor is provided to speed up searches. Scalar data particularly benefits from being hosted in a database because of the rapid access it affords to quick plot tools and other easily generated preview products.

Even if technically possible, it does not make sense to store all data in traditional relational database management systems (RDBMS) as the issues of backup, space allocation constraints etc. render the use of RDBMS' cumbersome as a mean for storage of large data “blobs”. For datasets produced by complex instruments (n-dimensional matrices, streams) it is often preferable to store those on file systems and simply keep the registry of the files in a database. This is the model used by ONC’s Oceans 2.0. It is also the model that has been in place for many years in other scientific archive systems such as those developed in other fields of science (e.g., astronomy).

This model allows for a clear separation between the data sources, the data storage organization and the data distribution. For instance, a CTD produces data in a vendor-specific format that is captured by parsing and verification software. The internal storage in the data management system can be optimized for the expected use(s) (e.g., quick plots, search and download of random sections of the data). The data delivery system converts selected data sections into either the format desired by the user (e.g., vendor-specific, CSV or other product such as NetCDF) or makes them available in an interoperable way using internationally agreed-upon formats (e.g., SWE-SOS).

Science enablement through historical (and current) data provision can span the spectrum of services from simple data access and basic search capabilities to delivering quick-look/preview products, to supporting science data analysis through tight integration with data processing systems, or to enhancing scientific productivity by offering all matters of advanced analysis tools and collaborative environments. The goal of data management is not to attempt to provide data interpretation as such an activity best rests with the users of the system.

One mandate that will play a significant role in the system design is the possible need for the data to play a public policy role, such as one in which it provides data that is of critical importance in the forecast and mitigation of disasters or other natural phenomena that have an impact on human lives and personal property. It may also simply be used to design legislation that will address an environmental concern, detected in the form of a change of certain parameters in an ocean setting with respect to an earlier baseline.

In such cases, the organization as a whole has to implement tools to provide a highly reliable service to a “client” that is or represents a government agency. The software infrastructure has, in this case, to establish a Service Level Agreement (SLA) with the service recipient and give itself the means and resources to abide by its contractual obligation to provide the service.

3.2.7. Interoperability Recommendations

Interoperability between CIOOS partner organizations requires the adoption of data formats and data exchange standards. Interoperability can be differentiated in different levels: data exchange among data provider nodes (academic, NGO or governmental), CIOOS Regional Associations, and among Regional Associations and the national portal. Depending on the level and the method adopted, ensuring the interoperability of existing systems may require many actions: interfacing systems, modifying existing systems, adding new systems, replacing existing systems. Beyond the choice of a particular standard, a further reflection should address the potential risks related to the compliance of existing systems: semantic conflicts, lexical conflicts, and granularity.

This section is inspired by the Final Strategic Analysis Report[101] submitted as part of the Ocean Data Interoperability Platform project, as well as the needs and concerns of CIOOS.

3.2.7.1. Standards

To ensure interoperability among different systems, they must provide services adhering to one or more recognized standards for data packaging and data access. These standards are defined in section 3.2.5. of this report. This standardization will provide the necessary transparency for a system to access data regardless of the chosen node. To do this, the implementation of these services might require resolving conflicts, listed below.

3.2.7.2. Semantic conflicts

The heterogeneity in the nature of the data and metadata to be aggregated increases the complexity of choosing a single standard as, for example, physical buoy data are inherently different from biological observations data. The option of grouping the data according to their nature, associated with specific theme standard, should be considered.

3.2.7.3. Lexical conflicts

Controlled vocabularies must be adopted to define the encoding and the attributes of the information exchanged between systems. These choices will dispel possible ambiguities between concepts that can be interpreted differently. As an example, speed can be expressed differently if we are talking about current (knots) or wind (m/s). In order to ensure the sustainability of CIOOS, the syntax can evolve over time according to the adopted schemes.

3.2.7.4. Granularity

A consensus should exist as to the standards to adopt according to the granularity of the data to be shared and visualized (basic data point or entire dataset). This definition of the data will make it possible to ensure that the data of the same type will be equivalent from one system to another. Services could offer different access points depending on the granularity of a given data. For example, a OGC Web Feature Service (WFS) protocol could be used to represent a collection of georeferenced data, while the OpenDAP protocol could allow access to sub-set of a collection.

3.2.7.5. Harvesting/Brokering

Since the systems will be interlinked using a net-centric approach, some protocols or formats specific to the web must be considered de facto: for example, services offering a RESTful API, use of the JSON encoding format, CSW / ISO19139, OAI-PMH, and OpenSearch.

[101] http://www.odip.eu/media/odip/org/documents/odip_wp4_d4.2.pdf

3.2.7.6. Recommendations

Low-service:

1) Maintain current systems while developing standards-based interfaces to query or feed these systems. This approach has the advantage of dissociating the interfaces of the underlying systems, which are generally much more complex and evolving.
2) Adopt a generally accepted protocol or data exchange format (RESTful / JSON interfaces, OpenDap, XML, CSW, etc.).
3) Adopt controlled vocabularies and standards that specifically describe the content of data exchanged according to the type of data being harvested (Dublin Core, DCAT, etc.).
4) Restrict the set of attributes in the kernel of the metadata (e.g. unique identifier, title, date of last modification, etc.). These attributes can be increased according to the particularities of the data.
5) To describe data, when applicable, we recommend adopting one of the standards defined by the OGC (Sensor ML, CS-W model, GML, SOS, etc.) or W3C.

Moderate-service:

1) Adopt multiple accepted protocol or data exchange format.
2) Deliver services based on protocols through different access points.

High-service:

1) Standardized existing systems.

4. IMPLEMENTATION

4.1. GOVERNANCE

This section addresses not so much the governance of CIOOS as an organization, but rather the governance of the data management aspects of it. Individual CIOOS nodes or Regional Associations may operate a range of services, from basic metadata management to a comprehensive end-to-end data management environment, covering all aspects from data acquisition to data distribution. In the case of basic metadata, the organization may operate a portal opening a window on a variety of data sources housed in contributing nodes. It is anticipated that they will already have a management structure in place that ensures good practices are followed, and have advisory body(ies) that allows them to progress in the right direction in addressing their users' needs. It should also be sufficiently robust to enable the regional nodes, as well as CIOOS as a whole, to apply for certification with one of the recognized international scientific data organizations, such as ICSU's World Data Systems[102]. The certification would serve as a seal of approval, internationally recognized, that demonstrates that the data management practices in use are indeed standard and audited on a regular basis.

[102] ICSU World Data System website: https://www.icsu-wds.org/

4.2. MODELS OF IMPLEMENTATION

The recommendations for the three service models of implementation are summarized in Table 12.

Table 12. Summary of levels of implementation.

	Low service	**Moderate Service**	**High Service**
Variables	1) Core variables in existing coverage.	1) Expanded core variable coverage. 2) Moderate service variables added.	1) Further expanded variable coverage. 2) High service variables added.
Data Sources	1) Interoperability among central CIOOS RAs for data access, formats, descriptions and metadata.	1) Interoperability extended to some of the source data nodes.	1) Interoperability extended to all source data nodes.
QA/QC	1) Nodes implement localized QA/QC. 2) Data providers include relevant QA/QC information and implement systematic workflows. 3) QARTOD subset for all nodes. 4) Data providers follow common data quality flagging scheme. 5) Original datasets preserved in raw form.	1) QARTOD subset for all nodes with required/strongly recommended tests applied. 2) Quality flags contained in data files. 3) User-friendly annotation tools. 4) Annotations linked with corresponding data. 5) Raw data preserved, while allowing user format preferences. 6) Well-documented QA/QC processing steps.	1) QARTOD manuals followed across all nodes with 3 levels of tests applied. 2) Consistent quality flags representation. 3) ISO 19137 included in ISO 19115 metadata records.
Timestamps and Datums	1) ISO 8601 timestamp. 2) Locally time source documentation. 3) Datum specified where known. 4) Consistent	1) Clock sync for autonomous instruments before deployment/after recovery. 2) WGS1984	1) Common metadata framework to disseminate time source details. 2) GCGD 2013 vertical datum.

	Low service	Moderate Service	High Service
	coordinate formatting.	horizontal datum. 3) Commonly-used projection that has transformation capabilities.	
Controlled Vocabulary	1) WoRMS Taxonomy. 2) ISO 3166 Country codes. 3) The CASRAI Iridium Glossary.	1) Agreed controlled vocabularies. 2) Nodes may support additional vocabularies. 3) Nodes contribute suggestions for new terms. 4) Common substrate classification applied to new datasets.	1) Common framework for geographical place names and feature vocabularies. 2) Crosswalks for historically used substrate. 3) Historical datasets migrated.
Metadata Formats	1) ISO 19115 with local profile.	1) ISO 19115 with partial agreement of profile. 2) Darwin Core for biology.	1) ISO 19115 metadata records with common profile. 2) Appropriate Catalog harvesters.
Data Formats & File Conventions	1) Filenaming adheres to Data One best practice. 2) Raw data formats archived. 3) NetCDF for scalar data.	1) ODV for temperature and salinity. 2) AAT Telemetry. 3) WAV Audio. 4) 2016 workshop rec's for video.	1) Temperature and salinity contributed to GTS. 2) Passive acoustic data follows working group conventions.
Identifiers	1) ORCID-CA membership. 2) European Directory of Marine Organizations registration.	1) ORCIDs supported in metadata framework. 2) Funder identifiers. 3) European Directory of Marine	1) ORCIDs supported in their data management services. 2) ICES codes for platforms.

	Low service	Moderate Service	High Service
		Organizations identifiers where available. 4) OBIS contributions. 5) IGSN registration.	3) WMO IDs for GTS contributions. 4) Expedition identifiers.
Research Data Management	1) Subset of FAIR Principles.	1) Selected FAIR Principles supported by all nodes in same manner.	2) FAIR Principles fully supported
Oceanographic data Management	1) Local application of best practices. 2) Alliance for Coastal Technologies for instrument selection. 3) TEOS-10.	1) Expert recommendation of best practices. 2) Voluntary compliance.	1) Full compliance with expert-recommended best practices.
Indigenous Community and Citizen Scientists	1) Indigenous data, welcome, but not targeted. 2) Citizen scientist data is not directly supported.	1) Partial accommodation of indigenous and citizen scientist data. 2) Indigenous community engagement plan. 3) Citizen science engagement plan.	1) Indigenous and citizen scientist data is actively sought out and supported. 2) Extended Indigenous community engagement plan. 3) Best practices for indigenous and citizen scientist data for inclusion. 4) Researchers are engaged.
Data Preservation & Repository Certification	1) Nodes as preservation brokers for core variables. 2) Data One practices for raw data preservation. 3) CoreTrustSeal for	1) Nodes as preservation brokers for data rescue. 2) WDS certification for Individual nodes.	1) Nodes as preservation brokers for additional data rescue efforts. 2) WDS certification for all nodes.

	Low service	Moderate Service	High Service
	selected criteria.		
Metadata and Documentation	1) Attributions maintained in metadata. 2) Data ONE for measurement technique descriptions. 3) Metadata for infrastructure and expeditions. 4) Calibration records accessible. 5) Content management for ancillary documentation. 6) Data products documented and publicly accessible. 7) Metadata framework supports all low-service variables.	1) Comprehensive calibration information. 2) Cruise Summary Reports. 3) Metadata committee for maximizing interoperability. 4) Metadata framework supports all moderate-service variables.	1) Metadata framework supports all high-service variables.
Reproducibility, Provenance and Versioning	1) Best-effort provenance records. 2) Metadata records enable proper crediting post-redistribution. 3) Database retains provenance histories. 4) Dataset alterations tracked. 5) Software versioning.	1) GTS, OBIS and other distributors submissions tracked. 2) Data processing steps available to end-users. 3) Alterations to datasets accessible to end-users. 4) Data contribution updates supported.	1) Common framework implemented. 2) All provenance information accessible to end-users. 3) Users can obtain reproduced datasets.
Data Citation	1) DOIs for 'static' datasets. 2) Pilot dynamic data	1) Dynamic data citation training. 2) Locally determined	1) Shared approach to dynamic dataset granularity.

	Low service	Moderate Service	High Service
	citation study.	granularity for dynamic datasets. 3) DOIs for dynamic datasets. 4) Identifiers for data subsets. 5) Subset of RDA dynamic data citation recommendations.	2) Dataset DOI in metadata. 3) Dynamic data citations leverage metadata. 4) 'Resolver' tool 5) All RDA dynamic data citation recommendations supported. 6) User documentation.
Data Restrictions	1) All metadata and data provided to CIOOS are restriction-free.	1) All metadata restriction-free, but some datasets may be restricted by nodes.	1) Permissions-based access to restricted data considered.
Interoperability	1) Standards-based interfaces to query existing systems. 2) Generally accepted protocol or data exchange format. 3) Controlled vocabularies and standards for data description. 4) Restricted attributes in metadata kernel 5) Standards for data description.	1) Multiple accepted protocols or data exchange formats. 2) Protocol-based service delivery through different access points.	1) Standardized existing systems.

4.3. PILOT IMPLEMENTATION

As was well detailed in the CIT report, one possible pathway to rapidly implement CIOOS would be to establish a pilot or prototype implementation. The findings of this IE are amenable to a pilot implementation, of a few of the highly feasible variables (e.g. temperature). Amongst other benefits, this would provide a proof of concept, identify issues that need work or improvement, offer an opportunity for further outreach and consultation with the stakeholders, and improve cost estimates.

4.4. RESOURCES

Resources required to execute the recommendations in this report are largely personnel, with the following caveats:

1) In discussion with DFO, the oceanographic tools to measure the variables were understood to be out of scope – thus this report's discussion of resources only refers to those required once the data has been collected.
2) Recommendations for the resources associated with cyber infrastructure and visualization to execute CIOOS are not included in this discussion, but rather provided in the two accompanying reports in this series.

Capital Investment: Given the above caveats, there is no anticipated initial capital investment for the recommendations contained within this IE.

Skills: It is of critical importance to understand that there is not a surfeit of the skills required for CIOOS available in the labour market, in Canada or elsewhere. As a result, personnel costs are not insignificant and strong emphasis needs to be placed on training and organizational development. While much effort is constantly being expended in this field to increase automation, regular manual review and oversight is and will continue to be required. Estimates for personnel requirements are detailed in Table 13, using information on the cost of similar personnel at current observatories in Canada (SLGO, ONC, OTN) and scaling for the anticipated workload of CIOOS.

Training: Training will be required for both internal development of those engaged at the regional associations and nodes (as noted above), as well as external training for users and stakeholders. Costs can be controlled to some degree by hosting these events either via webinars or in conjunction with existing meetings, such as the Canadian Meteorological and Oceanographic Society.

Tools: In keeping with the principles of open data, collaboration with other ocean observing systems, and adoption of existing tools, most of the recommended tools should not have an explicit cost. Exceptions to this are collaboration, communication and project management tools which charge user fees ranging from $3.25 to $21 USD per user per month. However, open source tools do come with a personnel cost, as the tools must be maintained and supported internally. An additional tool cost consideration includes the purchase of standards, such as ISO 19115.

Citizen science: Citizen science, as outlined earlier in this report, is a unique and growing source of ocean observation. However, this type of data is often labour intensive to ingest, and would be improved with a designated citizen science focused position at each regional association.

Indigenous communities, Nations, and governments' data: Similarly, facilitating the integration of Indigenous Knowledge and access by Indigenous Nations to CIOOS is a time-consuming a specialized skill, which would be well served by a designated position at each Regional Association.

Travel for collaboration and outreach: Budget considerations need to be made to allow for outreach to stakeholders, collaboration amongst regional associations and nodes, and also CIOOS should be actively involved with international organizations such as QARTOD (Quality Assurance of Real Time Ocean Data), and Argo to develop and implement recommended standards and practices for oceanographic data QA/QC.

Table 13. Estimation of resources to support a data system (per RA, per year, based on information at current observatories in Canada (SLGO, ONC, OTN) and scaling for the anticipated workload of CIOOS. This estimation does not include any central resources (assumed to be covered under the governance IE)

	Low service	**Moderate service**	**High Service**
Travel for collaboration and outreach	$10,000 Minimal outreach, one collaborative meeting per year for 1 person from each RA.	$20,000 Minor outreach, one collaborative meeting per association per year. Includes First nation and Citizen Science outreach travel.	$40,000 Annual workshop for stakeholders and users, collaborative travel to coordinate internationally on development of new standards, travel to coordinate across associations.
First nations	$0 Ad-hoc First Nations engagement as resources permit	$40,000 Shared First Nations/citizen science officer	$80,000 Designated First Nations position
Citizen science	$0 Ad-hoc citizen science engagement as resources permit	$40,000 Shared first nations/citizen science officer	$80,000 Designated citizen science position
Tools	$1,000 Freeware where possible, limited users	$5,000 Limited user accounts	$10,000 Many accounts for optimized collaborative work
Data management personnel	$360,000 4 member team at each RA	$720,000 8 member team at each RA	$1,440,000 16 member team at each RA for the first year, potentially reduced team after first 3 years of implementation
Training	$10,000 Training for staff and users	$25,000 Training for staff and users	$50,000 Training for staff and users
Total	$381,000	$850,000	$1,700,000

4.5. DATA POLICIES

4.5.1. Context

Within Canada, a range of data policy approaches exist across government entities, universities, networks, consortia and observatory facilities. However, there is a strong push towards both standardized data management policies and provision of open data.

Generally speaking, the following principles underlie the development of science data management policies:

1) Recognizing the value (priceless and irreplaceable) of the time-stamped scientific data and the need to ensure they are well managed to guarantee their conservation and sustainability;
2) Making sure data are available, accessible, relevant and reliable by managing the entire life cycle; from acquisition to dissemination;
3) Implementing structured and secured data repositories to ensure long-term preservation;
4) Acknowledging that recent data are the most critical for decision making and making sure they are timely and accessible;
5) Fostering open access while respecting the confidential and/or sensitive nature of data; and
6) Promoting data exchange with the international scientific community to enhance knowledge.

The Open Data Imperative

"The fundamental role of publicly funded research is to add to the stock of knowledge and understanding that are essential to human judgements, innovation and social and personal well-being. The technologies and processes of the digital revolution provide a powerful medium through which scientific productivity and creativity can be enhanced by permitting data and ideas to flow openly, rapidly and pervasively through the networked interaction of many minds. If this social revolution in science is to be realized it is vital that we adopt a default position that publicly funded data should be made publicly accessible and reusable when a research project through which the data have been collected is completed."

– The Open Data in a Big Data World international accord

Source: Science International (2015): Open Data in a Big Data World. Paris: International Council for Science (ICSU), International Social Science Council (ISSC), The World Academy of Sciences (TWAS), InterAcademy Partnership (IAP)

4.5.2. Existing Canadian policies

4.5.2.1. Tri-Agency Statement of Principles on Digital Data Management

At the time of this report, Canada's three federal research funding agencies, the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Social Sciences and Humanities Research Council of Canada (SSHRC) are actively reviewing with a view to enhancing their data management requirements for agency-supported researchers. In the 2016 Tri-Agency Statement of Principles on Digital Data Management[103], expectations are set forth that:

1) Data management planning is necessary at all stages of the research project lifecycle, from design and inception to completion;
2) Research data must be managed in agreement with all commercial, legal and ethical obligations;
3) Data should be managed in accordance with the most appropriate and relevant standards and best practices, while recognizing that these are in a state of rapid evolution;
4) Data should be collected and stored throughout the research project using software and formats that ensure secure storage, and enable preservation of and access to the data well beyond the duration of the research project;
5) All research data should be accompanied by metadata that accord with international and disciplinary best practices to enable future users to access, understand and reuse the data;
6) Research data resulting from agency funding should normally be preserved in a publicly accessible, secure and curated repository or other platform for discovery and reuse by others;
7) Data should be shared as early as possible in the research process when they are considered to be informative and of appropriate quality;
8) Data are significant and legitimate products of research and must be recognized as such;
9) Data management should be efficient and cost effective.

4.5.2.2. Government of Canada's 3rd Biennial Plan

At both federal and international levels, the Government of Canada is strongly committed to open data and currently chairs the international Open Data Working Group as part of the Open Government Partnership[104]. Canada also championed the development of a new International Open Data Charter [105]in collaboration with governments and civil society organizations around

[103] Tri-agency statement of principles on digital data management: http://www.science.gc.ca/eic/site/063.nsf/eng/h_83F7624E.html
[104] Canadian page of the Open Government Partnership website: https://www.opengovpartnership.org/countries/canada
[105] Open data charter website: https://opendatacharter.net/

the world. Among the Government of Canada's relevant commitments in their Third Biennial Plan[106] (2016-18) are those to:

1) Ensure that data must be discoverable, accessible, and reusable without restriction;
2) Provide enhanced, centralized, one-stop access to digital content from departments and agencies across government;
3) Ensure the ongoing preservation of this information through the application of consistent standards and practices for long-term preservation;
4) Make more high-quality, authoritative, and useable geospatial data available in open formats;
5) Make the science performed in support of Government of Canada programs and decision-making open and transparent to Canadians;
6) Expand collaboration with provincial, territorial, and municipal partners on further standardizing and harmonizing the delivery of open government data across jurisdictions.

4.5.2.3. Government of Canada's Open Data Principles

The Government of Canada has also established ten Open Data Principles for released datasets, which should:

1) Be as complete as possible;
2) Come from primary sources;
3) Be made available to the public in a timely fashion;
4) Be as accessible as possible;
5) Be stored in widely-used file formats that lend themselves to machine processing;
6) Have as few barriers to use as possible;
7) Be in freely available file formats as often as possible;
8) Fall under the Open Government License -- Canada agreement;
9) Remain online, with appropriate version-tracking and archiving over time, and be provided free of charge.

4.5.2.4. Department of Fisheries and Ocean Data Policy

Fisheries and Oceans Canada's current data policy became effective on September 1st, 2013. This policy allows for some data to be embargoed or withheld from the public if approved by Regional Directors, or where third-party agreements, privacy concerns, legal restrictions or commercially beneficial intellectual property rights are involved. Regional or national Data Nodes[107] [1] will be responsible for:

[106] Third Biennial Plan to the Open Government Partnership: http://open.canada.ca/en/content/third-biennial-plan-open-government-partnership

[107] Data node definition from DFO data policy: "Data node is taken to mean an entity within DFO comprising an organization and staff dedicated to the functions of Data content management and having access to the necessary infrastructures and services to perform these functions. There may be specialized Data Nodes that address a specific domain."

Maintaining inventories and documentation for all Data holdings for which they have designated responsibility, including Metadata;

1) Providing basic data retrieval, integration and summarization;
2) Coordinate sharing arrangements with other organizations;
3) Performing data quality control, verification and removal of duplicates and other value-added processing;
4) Ensuring that Data and Metadata are protected against loss, remain accessible in the long term.

4.5.3. Existing International policies

These principles reflect the intent of the IOC Oceanographic Data Exchange Policy, which stipulates that member states "shall provide timely, free and unrestricted access to all data, associated metadata and products generated under the auspices of IOC programs."

4.5.4. Identified Issues

Data policies promoting data sharing have existed for many years now, both at the university level and in various levels of government. Despite that fact, most data management objectives, that generally advocate in favor of QA/QC, compliance with interoperability standards, description of metadata, and preservation and sharing among other attributes, have only been partially achieved, including the overarching goal of making the data accessible.

In public organizations, the problem is often linked to the lack of dedicated resources providing support for data management and developing technological services enabling access to databases. In the academic world, the same problem, while aggravated by a race to publish culture, derives in particular from the *modus operandi* of scientific journals. It is indeed recognized that the scientific community favors, often not by choice, the publication of scientific articles, to increase the chances of future funding, hence the adage "publish or perish". Scientific articles have become the main criterion for evaluating scientific achievement. Undeniably, this current hegemony does not prioritize good data management and sharing, notwithstanding the strong intent that could rest behind an official data policy (Le Temps[108]).

It is therefore not surprising that scientists dedicate more of their research funds to research and publication and less to data management. In such a context it is difficult to imagine a major change in academic institutional culture leading to systematic access to well-managed ocean science data.

[108] Le Temps Publish or Perish: https://www.letemps.ch/sciences/2017/09/19/publish-or-perish-science-met-chercheurs-pression

As early as September 2009, William Michener stated: "We need to change the culture of science to one that equally values publications and data." (Nelson, B., 2009). In 2011, Dirk Fleischer and Kai Jannaschk wrote in Nature of "Reluctance to deposit data is rife among researchers, despite broad agreement on the principle of data sharing" (Fleischer~~, D.~~ and Jannaschk~~, K~~., 2011).

4.5.5. Towards solutions

Things have changed since 2009. As mentioned above, we have entered an era of open data and progress has been made in terms of data access. More scientists are seeing the added value of sharing their data. However, the issues mentioned above concerning the ability of organizations to make their data accessible and researchers to do so remain very real. Scientists need technical support for data management as well as incentives, not just policies and statements.

Thus, actions leading to a cultural change are necessary in the context of setting up a CIOOS. To do this, actions are needed at different levels. The Responsibilities section of the tri-Agency Statement of Principles on Digital Data Management outlines appropriate responsibilities for researchers, research communities, research institutions, and research funders. CIOOS can take a leadership role in translating these into actions. It should also include responsibilities for scientific journals, for instance when reviewing articles for a journal, peers could indicate if data were shared or not, in a way that scientists are also evaluated on their data sharing history. Although this practice exists in places, it is not widespread.

In point 5 of the 1st principle of the International Open Data Charter, the authors make two recommendations that, if applied by CIOOS, could address some of the issues listed above, and could help convert the data policies desires into concrete action:

1) *Establish a culture of openness, not only through legislative and policy measures, but also with the help of training and awareness programs, tools, guidelines, and communication strategies designed to make government, civil society, and private sector representatives aware of the benefits of open data;*
2) *Develop the leadership, management, oversight, performance incentives, and internal communication policies necessary to enable this transition to a culture of openness in all government departments and agencies, including official statistics organizations;*

Only actions with the required financial support at all these levels will foster a real change of culture and will provide the scientific community with the necessary means to share and access quality data in a timely manner.

4.5.5.1. Does CIOOS require an Act?

The governance structure of CIOOS favours a model that will enable gathering data from an inter-jurisdictional network of data producers (government, academia, industry, and communities) to support sustainable ecosystem management and decision-making processes. This model has proven to be efficient at integrating multidisciplinary data and at allowing multi-institutional collaboration to share data (SLGO, created in 2005). But this model makes it difficult to provide CIOOS with a regulatory framework for data sharing, as potential partners to CIOOS may be dissuaded from joining CIOOS if brought there by force of law.

In addition, implementing the actions proposed in the previous section to bring about a culture change, and working with the community, providing the tools to support data sharing will should certainly be considered before seeking a legislative solution. On the plus side, if the Act also comes with a budgetary allocation for CIOOS, it could become a powerful tool to move the establishment of the observation network forward.

4.5.6. Recommendations

It is undeniable that we are in an open data era and that many governments and various organizations around the world are promoting open data principles and charters. CIOOS also needs to develop and abide by a data policy that extends to data provision via the CIOOS nodes and regional associations. Generally speaking, this policy should promote excellence in digital data management and data stewardship. CIOOS should build upon the three funding Tri-Agency Statement of Principles on Digital Data Management.

> **Funding agencies** should regard the costs of open data processes in a research project to be an intrinsic part of the cost of doing the research, and should provide adequate resources and policies for long-term sustainability of infrastructure and repositories. Assessment of research impact, particularly any involving citation metrics, should take due account of the contribution of data creators.
>
> Open Data in a Big World Accord[109]

It is recommended that CIOOS carry out the following actions as early as possible, since culture changes takes time:

1) Draft a data policy for CIOOS in consultation with the main partners in order to ensure maximal uniformity between partners' policies. However, it is clear that this policy would serve as a guide, listing principles that could not be unilaterally imposed upon all CIOOS potential partners;

[109] Open Data in a Big World Accord: https://twas.org/sites/default/files/open-data-in-big-data-world_short_en.pdf

2) Raise awareness in the scientific community on the importance of sharing data, not just with a policy, but with continuous communications including success stories, and conferences;
3) Promote increased data management training with the academic community and for the next generation of data managers;
4) Request the academic community to include basic training in data management in science programs so that early in their studies, future scientists acquire this culture of data sharing and the knowledge needed to ensure good data management. "A young scientist's early approach to sharing will likely become their approach for life." (The Atlantic[110]);
5) Work with the academic community to promote the implementation of a data management system (tool) (e.g. ISMER and IML_DFO Ocean Data Management System (DMS)) and to oblige researchers to deposit their data in an appropriate DMS;
6) Work with academia and government to promote establishment of qualified data management teams to support scientists in sharing data;
7) Work with Canadian funding agencies to require data dissemination as a funding requirement. Although the tri-Agency Statement of Principles on Digital Data Management includes: "where appropriate, providing peer reviewers with guidance and developing assessment material for including data management considerations in the application assessment process" it does not state that data must be accessible and that it will be funded; and
8) Work with three federal funding agencies so that funded research project data are required to be accessible. Such requirements be supported financially and planned over a few years in consort with various data producers, in order to gradually implement this with the necessary tools and support mentioned above;

These actions could be embedded in a Canadian Integrated Ocean Observing System Charter.

[110] The Atlantic - Scientists have a sharing problem: https://www.theatlantic.com/health/archive/2014/12/scientists-have-a-sharing-problem/383061/

Other considerations - 10 reasons why scientist don't share data

While providing the community (science, NGO, government…) with the technical means, resources and tools may go a long way toward enabling timely and open data access, it is largely recognized that there are other considerations causing scientists to refrain from sharing their data:

1) Lack of time and money;
2) Lack of the technical capability;
3) Contractual arrangements: either it's not legal to share or scientists aren't sure if they can;
4) Data not properly manage/curated, or there is no metadata. Doing the extra work requires sufficient time and money;
5) Small labs have even less resources than highly funded ones;
6) Fear of getting scooped: when an outside researcher publishes using open data before the researcher who collected the data can;
7) Pressure to publish positive data;
8) Pressure to publish in high impact factor journals, which are not often open;
9) Lack of centralized digital storage space;
10) Absence of uniform methods to record or describe data;

(Blumenthal et al., 2006; Back, B., 2016[111]; Leeming, J., 2016[112]; Digital Science, 2015[113]; Puniewska, M., 2014[114])

The CIOOS coordination office should have the resources to tackle these obstacles and provide recommendations to overcome them.

[111] Why do many scientific researchers not share their data?: https://www.quora.com/Why-do-many-scientific-researchers-not-share-their-data

[112] Why don't scientists always share their data?: http://blogs.nature.com/naturejobs/2016/10/21/why-dont-scientists-always-share-their-data/

[113] Why scientists should share their data: https://www.digital-science.com/blog/guest/why-scientists-should-share-their-data/

[114] Scientists have a sharing problem: https://www.theatlantic.com/health/archive/2014/12/scientists-have-a-sharing-problem/383061/

4.6. BECOMING A GOOS REGIONAL ALLIANCE

There are different GOOS Regional Association (GRA) models, but CIOOS would most likely fit as a national system. To become an approved GRA, an organization must conform to GOOS principles and guidelines, while cooperating effectively with overlapping neighboring and thematic GRAs. There are also a range of representation and reporting responsibilities.

GOOS principles include the need for a **designed**, **standardized**, **long-term, policy-driven** approach, which covers the **end-to-end** process from data capture to production of finished **products**. The GOOS focus is **global**, which means that GRAs should aim to contribute **high-quality** data that helps address questions and needs at the global scale. At the same time, the GRA must **flexibly coexist** and interoperate with other contributors, and evolve **incrementally** over periodic **review** cycles. **Individual** GRAs operate autonomously, providing **voluntary** contributions to the global scientific community, while also helping **support** organizations in less-developed countries to participate and benefit.

Specific guidelines include the need for:

1) A planned approach;
2) End-to-end data management;
3) Networked, timely, operational delivery of value-added data products for:
    3.1. Operational agencies
    3.2. Scientists
    3.3. Data managers;
4) User-relevant data processing;
5) Continuously managed databases;
6) Quality control;
7) Standards-~~conformant~~ conforming metadata;
8) Feedback and improvement loops;
9) Permanent archives.

For additional details, refer to Appendix 7.5.

4.7. TOOLS

4.7.1. Context

To achieve the objectives and recommendations outlined in the sections above, CIOOS will need to make use of software-based tools and functions. These tools, whether they are adopted from already-established programs or developed in-house, should integrate well with those being implemented by the CIOOS Cyber Infrastructure and Visualizations teams to ensure interoperability between the different branches of the CIOOS infrastructure. The tools should also, when possible, integrate well with the methods and software being utilized at the regional level.

The tables below outline:

1) Organizations that could act as sources of software tools for CIOOS;
2) Software available from those sources, which may be relevant to CIOOS' efforts;
3) Some details about the nature and cost of that software. (Unless otherwise stated, the software can be assumed to be open-source freeware).

4.7.2. Data Ingestion and Manipulation

The first batch of tools relate to how data are handled after they has been collected *in situ* but before storage in a data server (Table 14).

Table 14. International research groups, the relevant software and tools they have available, and some details about the nature of each piece of software.

Organization	Tool or Software ID	Comments
IOOS (Integrated Ocean Observing System)	General Resources	The general IOOS repository pages, containing the code and documentation for the other IOOS tools listed below, are located at: 1) https://github.com/ioos 2) https://ioos.github.io/ These general links should be monitored for additional tools in the future.

Organization	Tool or Software ID	Comments
IOOS (Integrated Ocean Observing System)	QARTOD QA/QC	Collection of utilities, scripts and tests to assist in automated quality assurance and quality control for oceanographic datasets and observing systems. From the website: 1) General Information Website 1.1. https://ioos.noaa.gov/project/qartod/. 2) Github Repository 2.1. https://github.com/ioos/qartod. 3) Current tests are taken from the Wind, Water Level, Currents, In-Situ Temperature and Salinity QARTOD Manuals. 4) Currently implemented tests are: Gross Range Test, Attenuated Signal Test, Flat Line Test, Rate of Change Test. 5) LIMITATION: Currently, most methods in QARTOD assume monotonically increasing, time series data with evenly spaced intervals. Where there are irregular or large time gaps between successive data points, the tests as written will not take this into account.

Organization	Tool or Software ID	Comments
IOOS (Integrated Ocean Observing System)	Compliance Checker	The IOOS Compliance Checker is a python based tool for data providers to check for completeness and community standard compliance of local or remote netCDF files against CF and ACDD file standards. The python module can be used as a command-line tool or as a library that can be integrated into other software. 1) Github Repository 1.1. https://github.com/ioos/compliance-checker 2) The compliance checker can also be run using the IOOS-provided web-based client, rather than generating an independent instance using the repository library. 2.1. https://data.ioos.us/compliance/index.html. 2.2. The web-based version of the Compliance Checker was developed to enable a broader audience and improve accessibility for the checker. With the web version, providers can simply provide a link or upload their datasets and get the full suite of capabilities that Compliance Checker offers. 3) In addition to a web-based front-end for the IOOS Compliance Checker project, an API is provided for users interested in batch processing files hosted via OPeNDAP. Details on how to use the API are available on the Compliance Checker Web wiki page. 3.1. https://github.com/ioos/compliance-checker-web/wiki/API.

<table>
<tr><th>Organization</th><th>Tool or Software ID</th><th>Comments</th></tr>
<tr><td>IOOS (Integrated Ocean Observing System)</td><td>Glider DAC (Data Assembly Center)</td><td>A service for processing ocean glider data and integrating it into a central database. Also has elements for some baseline QA/QC and data visualisation.
1) General Websites about the IOOS service
1.1. https://gliders.ioos.us/
1.2. https://gliders.ioos.us/benefits
1.3. https://gliders.ioos.us/map/
2) IOOS Glider DAC Wiki
2.1. https://github.com/ioos/ioosngdac/wiki
3) Online service for tracking the status of data submitted to the Glider DAC system
3.1. https://gliders.ioos.us/status/
The Glider DAC system also has operable, open-source code that can be used or adopted by an outside party.
1) IOOS Glider DAC Code Documentation
1.1 https://github.com/ioos/ioosngdac
2) MATLAB-based code developed by John Kerfoot at the Institute of Marine & Coastal Sciences, Rutgers University, USA. Only works for Slocum Gliders
2.1. https://github.com/kerfoot/spt
3) Python-based code, funded by SECOORA (Southeast Coastal Ocean Observing Regional Association; http://secoora.org) and developed by Axiom Data Science (https://www.axiomdatascience.com/). Only works for Slocum gliders.
3.1. https://github.com/SECOORA
3.2. https://github.com/SECOORA/GUTILS
3.3. This code is currently being incorporated into the OTN Canada glider program software infrastructure, and integrates with the Sensor Tracker software developed by Brad Covey at the Ocean Tracking Network, Halifax, Canada (see the OTN section of this Table).</td></tr>
</table>

Organization	Tool or Software ID	Comments
IOOS (Integrated Ocean Observing System)	Passive Acoustic Monitoring	A series of tools for incorporating passive acoustics data and metadata into a database. There are numerous organizations and tools serving passive acoustic data globally, all utilizing similar spectrogram visualization approaches. Acoustic data annotation (content classification-) technologies are evolving, but there are no interoperable standards yet. Documentation isn't as clear as other available tools so this item has not been investigated thoroughly. It has been included in case the CIOOS projects wants to pursue this topic in the future. 1) Github Repository 1.1. https://github.com/ioos/passive-acoustics
SOCIB (Balearic Islands Coastal Observing and Forecasting System)	Glider Toolbox	An alternative to IOOS' Glider DAC system, allowing for the management, processing, and visualisation of ocean glider data. 1) General Program Information 1.1. http://www.socib.eu/ 2) Github Repository for the SOCIB Glider Code 2.1. https://github.com/socib/glider_toolbox 2.2. The scripts are written in MATLAB/Octave. 2.3. Supports Slocum, SeaExplorer, and SeaGlider glider platforms. 2.4. This code is currently being incorporated into the DFO (Fisheries and Oceans Canada) Atlantic division's glider program, hosted at the Bedford Institute of Oceanography. Part of this decision was due to this program's use of SeaExplorer gliders rather than Slocum gliders.
OTN (Ocean Tracking Network)	Sensor Tracker	Software and web front-end for generating metadata files that are compliant with the IOOS Glider DAC system. Created in-house for OTN Canada at Dalhousie University, Halifax, Canada. 1) Gitlab Repository 1.1. https://gitlab.oceantrack.org/ocean-gliders-canada/sensor_tracker 2) Can drastically reduce the time and effort required to generate mission-specific data/metadata files for every deployment.

Organization	Tool or Software ID	Comments
OTN (Ocean Tracking Network)	Live Schemer	Software tool for parsing Slocum glider data files and generating a .KML file for data visualisation. KML files can be used in programs that visualise geographic data, such as Google Earth. Created in-house for OTN Canada at Dalhousie University, Halifax, Canada. 1) Gitlab Repository 1.1. https://gitlab.oceantrack.org/ocean-gliders-canada/live_schemer

Organization	Tool or Software ID	Comments
IMOS (Integrated Marine Observing System)	IMOS Toolbox	The IMOS MATLAB Toolbox aims to provide an automated, easy-to-use interface for converting raw instrument data into IMOS compatible Quality Controlled NetCDF files, ready for handover to AODN (Australian Ocean Data Network; https://portal.aodn.org.au/). The toolbox is designed to process data that is manually retrieved from long-term mooring sites. 1) General Website and Wiki 1.1. https://github.com/aodn/imos-toolbox/wiki 2) GitHub Repository 2.1. https://github.com/aodn/imos-toolbox The IMOS Toolbox is distributed under the GNU GPLv3 license. 1) GNU License Information 1.1 https://github.com/aodn/imos-toolbox/blob/master/license.txt Some notable features: 1) The entire toolbox should, generally, be installed as a single package. MATLAB functions within the toolbox are co-dependent and call each other. However, some functions (such as instrument parsers or specific QC functions) could be isolated and used independently. 2) Along with its source code, binaries are provided so that it can also be used without MATLAB. 3) Converts instrument raw files (proprietary file types based on instrument manufacturer software) into NetCDF format. 4) NetCDF files need to be manually uploaded to a server to be checked for compliance (using for example the IOOS compliance checker). 5) The toolbox can only handle time series data (ex/ moored temperature logger), time series profile data (ex/ moored ADCP) and profile data (ex/ CTD cast). It cannot, in its current form, handle "trajectory" type data such as ship transects, gliders, ARGO buoys, etc. 6) The toolbox can handle new instrument types, as long as a custom parser script is written for that instrument. 7) The toolbox incorporates (and in some cases requires) data/metadata from an attached database (or a set of .csv files) containing deployment information (instrument serial number, deployment/recovery times, etc.). Instructions on configuring a deployment database are available at: 7.1 https://github.com/aodn/imos-toolbox/wiki/ToolboxInstallation#configure-deployment-database 7.2. From an IMOS contact: "If you intend to use the toolbox without any deployment database, when some metadata is missing then some operations will not work".

Organization	Tool or Software ID	Comments
IMOS (Integrated Marine Observing System)	Gliderscope	GLIDERSCOPE is an IMOS Ocean glider Facility Windows platform software package designed to allow users quick and easy visualization of Ocean glider oceanographic data, via a convenient graphical user interface. 1) General Website 1.1. http://imos.org.au/facilities/oceangliders/glider-data/gliderscope/ 2) GLIDERSCOPE User's Manual 2.1. http://anfog.ecm.uwa.edu.au/software/GliderscopeV7/Users_Manual_GLIDERSCOPEv7.pdf From the website: 1) By using the freely available GLIDERSCOPE software, all users will be able to read the NetCDF files, filter out the bad data and apply a variety of useful data graphical visualisation techniques to examine the data, e.g. using three/four-dimensional plots of water properties, interpolated contour charts, vertical profile plots, water properties comparison charts, etc. Users can easily choose and extract segments of data. Additionally, users can also export their data to text or NetCDF files for easy access in other applications. Whether you use a Windows or a Macintosh computer, Gliderscope is available for use. It can either be installed as standalone software, or as an App for use in Matlab, if you already have Matlab installed.

4.7.3. Collaboration, Communication, and Project Management

In addition to software capable of ingesting and processing data, tools that allow for more efficient project management and communication between members of the CIOOS team are also beneficial. This requires programs that can provide functionality such as file hosting, document- and code version control, wiki pages, and chat services. These tools are summarized in Table 15.

Table 15. Programs and services providing project management, collaboration, and communication tools.

Organization	**Services Provided**	**Comments**
GitHub	Document and Code Storage and Version Control	A platform for hosting, managing, and collaborating on computer code and other documentation. Integrates with the Git functionality that lets you locally track changes and push or pull changes from remote resources. 1) General Website: 1.1. https://github.com/ There are apps that integrate with GitHub available on the "GitHub Marketplace" which can increase the functionality of the service. 1) https://github.com/marketplace The cost for GitHub membership, as a business, is approximately $21 USD per user per month. 1) Pricing Website: 1.1. https://github.com/pricing
GitHub	Project Management	Part of the functionality of the GitHub service is providing project management oversight. Highlighting issues, allocating tasks, tracking and merging issues, etc. 1) Project Management Website: 1.1. https://github.com/features/project-management/
GitHub	Wiki Hosting	As part of its service, GitHub provides wiki functionality to allow for the hosting of project information and supporting documentation. 1) GitHub Wiki Pages Website: 1.1. https://pages.github.com/

Organization	Services Provided	Comments
GitLab	Document and Code Storage and Version Control	GitLab can be used in place of, or in conjunction with, GitHub. It has many of the same features. 1) General Website: 1.1. https://about.gitlab.com/ There are some differences between the two services, such as improved issue tracking and user permission levels through GitLab. 1) Documentation comparing the two services: 1.1. https://about.gitlab.com/comparison/ 1.2. https://usersnap.com/blog/gitlab-github/ 1.3. https://www.upwork.com/hiring/development/gitlab-vs-github-how-are-they-different/ The cost for GitLab membership, as a business with up to 500 users, is approximately $3.25 USD per user per month. 1) Pricing Website: 1.1. https://about.gitlab.com/products/
Google	Document Collaboration and File Hosting	Google provides a suite of online services that can utilised by a group or organization. They all allow for real-time collaboration and editing by multiple contributors. These services mirror products that are part of the Microsoft Office Suite (Microsoft analog in brackets): 1) Google Docs (Microsoft Word) 1.1. https://gsuite.google.com/learning-center/products/docs/get-started/ 2) Google Sheets (Microsoft Excel) 3) Google Slides (Microsoft Powerpoint) In addition, these services integrate with other Google products, such as: 1) Google Drive (online file storage) 2) Google Photos (online photo storage) 3) Gmail (Google's email service). Storage up to 15 GB is free, with the monthly cost increasing with storage volume: 1) Google Storage Pricing Guide 1.1. https://www.google.com/drive/pricing/

Organization	Services Provided	Comments
	Wiki Hosting	An additional service offered by the Google online suite is the creation and hosting of wiki pages. However, if CIOOS is already adopting the use of GitHub with its own wiki system, then this wiki service would be redundant. 1) Google Sites Webpage: 1.1. https://gsuite.google.com/learning-center/products/sites/get-started/
Glip	Communication /Chat Service	A communication and chat service that can integrate with other popular platforms such as GitHub, Dropbox, Google Drive, etc. Provides messaging, file sharing, shared calendars, and task-allocation. 1) General Product Website: 1.1. https://glip.com/product The basic Glip service and functionality is free to use. Additional features such as video chat can be obtained for $5 per month. 1) Pricing Website: 1.1. https://glip.com/pricing
Slack	Communication /Chat Service	A communication and chat service that can integrate with other popular platforms such as GitHub, Google Drive, etc. It also allows for the archiving of messages (paid service) and a search function for those archives. 1) General Product Website: 1.1. https://slack.com/features 2) Apps can be integrated with the Slack platform: 2.1. https://slack.com/features/workflow 2.2. https://slack.com/apps The basic service is free, with an option for a paid business-class tier of product with an unknown pricing scheme. 1) Basic Service Website: 1.1. https://slack.com/pricing 2) Enterprise Service Website: 2.1. https://slack.com/pricing/enterprise-grid 2.2. https://slack.com/enterprise

4.7.4. Additional Software Tools

In addition to the tools listed in the sections above which fulfill facets of a larger, overarching goal such as "data ingestion", there are pieces of software that could provide functionality for smaller, miscellaneous tasks (Table 16).

Table 16. Additional software and tools that can potentially provide additional functionality for CIOOS.

Function	Comments
FTP (File Transfer Protocol)/File Upload	Software for transferring files over the internet. Can be used, for example, for uploading files from users to a server to check for format/compliance. 1) FileZilla: 1.1. https://filezilla-project.org/ 1.2. https://www.siteground.com/tutorials/filezilla/
NetCDF Reader	Software for viewing and visualising NetCDF files without requiring MATLAB or other programming platforms. 1) General list of NetCDF readers: 1.1. https://www.unidata.ucar.edu/software/netcdf/software.html 2) Panoply 2.1. https://www.giss.nasa.gov/tools/panoply/ 2.2. https://www.giss.nasa.gov/tools/panoply/downloa/ 3) ncBrowse 3.1. ftp://ftp.epic.noaa.gov/java/ncBrowse/install.htm#windows 4) Ocean Data View (ODV) 4.1. Listed here for its use in exploring and visualising NetCDF files, however this program has a wide range of functionality that could be explored. However a lot of that functionality falls under the "Visualisation" branch and is not directly relevant to the Data IE branch. 4.2. https://odv.awi.de/

4.7.5. Potential Consulting Companies for Future Tool Development

It is worth including that the following companies, while they do not appear to have any software tools currently relevant to the Data IE branch of CIOOS, do provide software development services for a fee. If CIOOS decides that a tool needs to be created in the future and does not have the capacity to build it in-house, these companies could be approached to determine whether they could assist.

1) 52 North (http://52north.org/about/52north)
   - 1.1. Contact email: info@52north.org
   - 1.2. Available products: http://52north.org/resources
   - 1.3. Approximate fee for services is in the range of 100 EUR per hour (excl. VAT).

2) Axiom Data Science (https://www.axiomdatascience.com/)
    2.1. Contact email: rob@axiomdatascience.com
    2.2. Fee for service is unknown.
3) Portage (https://portagenetwork.ca/)
    3.1. Contact information: https://portagenetwork.ca/contact-us/
    3.2. Available products (focused on data management): https://assistant.portagenetwork.ca/en/help#ToolHelp
    3.3. Fee for service is unknown.
4) SeaDataNet (https://www.seadatanet.org/)
    4.1. Software infrastructure for ocean and marine data management
    4.2. Contact information: https://www.seadatanet.org/sendform/contact
    4.3. Available products: https://www.seadatanet.org/Software
    4.4. Fee for service is unknown.

5. CONCLUSION

Canada derives profound social, economic, cultural and environmental benefits from its relationship with the ocean. As an ocean nation, Canada stands to significantly grow these benefits in the future as it embraces new technology and the emerging opportunities of "Blue Growth". We will have to carefully manage this growth if it is to be done sustainably. This in turn will require that we coordinate and expand current ocean monitoring, and initiate new ocean science activities, to provide the knowledge needed for a future guided by thoughtful, visionary, science-based policy development and decision-making.

This report on the collection and management of ocean data and observations is one of a suite of three interconnected studies commissioned by the Government of Canada. Their purpose is to evaluate the current status of Canada's ocean monitoring and reporting, to determine how it fits within international ocean science efforts, to identify areas in which Canada can provide ocean leadership, and to make recommendations on how to organize a Canadian Integrated Ocean Observing System for the future. In examining current ocean monitoring activities within the Canadian governmental, academic, not-for-profit and other sectors, it is clear that Canada has a solid base in ocean science, especially in the Federal government and academic sectors, and is generating highly relevant information of value nationally and internationally. Its ocean scientists are high caliber, well trained by national and international institutions, internationally engaged, and provide global scientific and technological leadership in a number of ocean science areas including electronic animal telemetry, cabled observatories, cold ocean science and the use of moored profiling systems. These activities incorporate Canadian ocean technology companies who develop and manufacture the equipment needed, and sell into international markets to the benefit of the Canadian economy. This creates a promising nexus for Canada's future in ocean observation.

With regards to ocean data and observations, Canadian scientists already collect a great deal of data about a wide variety of ocean variables. These are used to provide new knowledge about the ocean, and to meet immediate needs for information by decision and policy makers. Certain classes of information are of broad utility to a wide variety of sectors. For example, information about ocean temperatures is essential for weather forecasting, predicting fishery yields, and understanding future climate changes. Other data address particular needs for local or regional applications, or are on the cusp of developing issues that will require substantial monitoring efforts into the future (e.g. CO2, ocean noise, etc.).

This report, in identifying a suite of Core Ocean Variables of primary importance to Canadian ocean observation, as well as useful ancillary variables that could be added to the observation core as needs arise and resources become available, will assist Canada in directing efforts to meet its immediate information needs, and in planning future ocean observation activities. It will also assist with coordinating observing efforts across the government/university/other sectors that are currently collecting ocean data, allowing Canada's observing efforts to extract maximum value and efficiencies from the resources that are being invested. This will be critical because our information needs are large, the areas we have to cover are vast, and our resources to do so are limited. A key component of this efficiency will be providing data systems that will make this information discoverable and available in a timely fashion, and that will serve it up in the form of knowledge products of use to decision makers, policy makers, ocean stakeholders, and the general public. To this end, the authors of this report have worked closely with the teams that are crafting the two additional reports in the series, covering the necessary cyber-infrastructure hardware/software and data analysis, access and visualization tools that will need to be mated to data and observations to create a Canadian Ocean Observing System.

While we currently have gaps, Canada's ocean science enterprise is vigorous, world class, internationally connected and strong. Canada has the human and technological capability to develop and maintain an integrated national ocean observing system. Most importantly, it needs one.

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7. APPENDICES

7.1. SPECIFICATION SHEETS

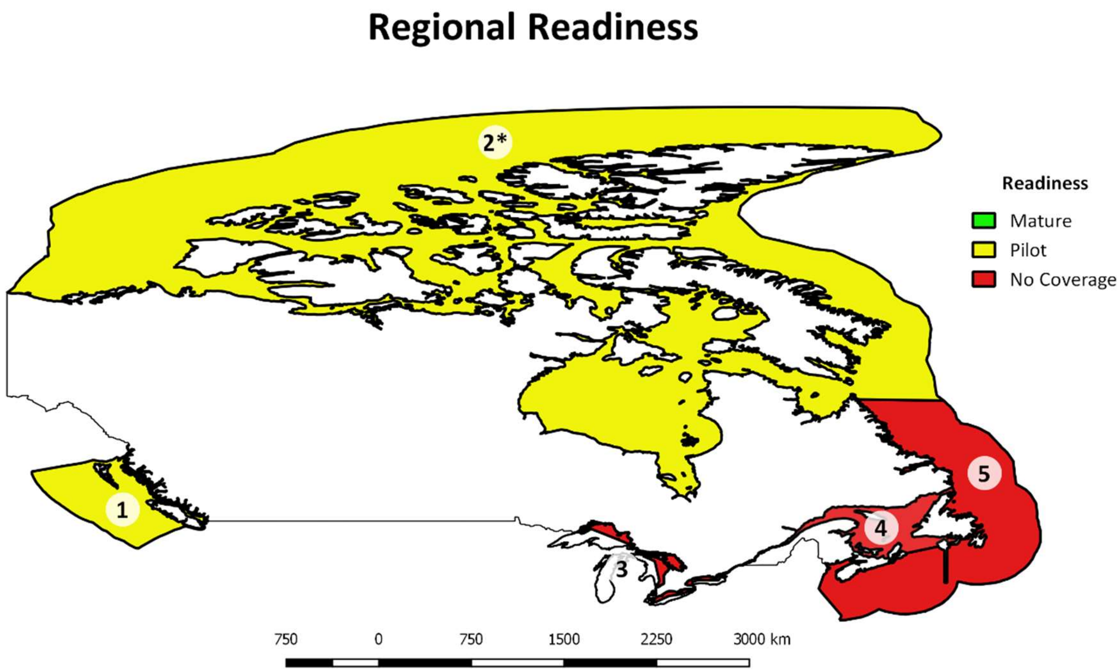
Ambient Sound

Variable Information	
Name of Variable	Ambient Sound
Sub-Variables	Sound Pressure Level (dB re μPa)
Derived Variables	Sound pressure level in octave bands, spectral density distribution (spectrogram), classification of content (ship or marine mammal), direction and/or range to source, source levels
Phenomena to Capture	All acoustic sources (e.g. ships, mammals, wind, waves, Earthquakes)

GOOS Requirements by Phenomena
There are none

CIOOS Current Observing Elements	
Observing Elements	Hydrophone
Regions Present	Pacific, Atlantic, Arctic
Organizations Displaying Data	ONC
Phenomena Addressed	*Not defined*

CIOOS Current Observing Elements	
Horizontal Resolution	Varies
Vertical Resolution	N/A
Temporal Scale	Constant while hydrophone deployed



Regional readiness for Ambient Sound in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5). *Pilot (in that is does not have national/uniform coverage), but low coverage.

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https://www.sciencebase.gov/catalog/item/530f8a0ee4b0e7e46bd300dd
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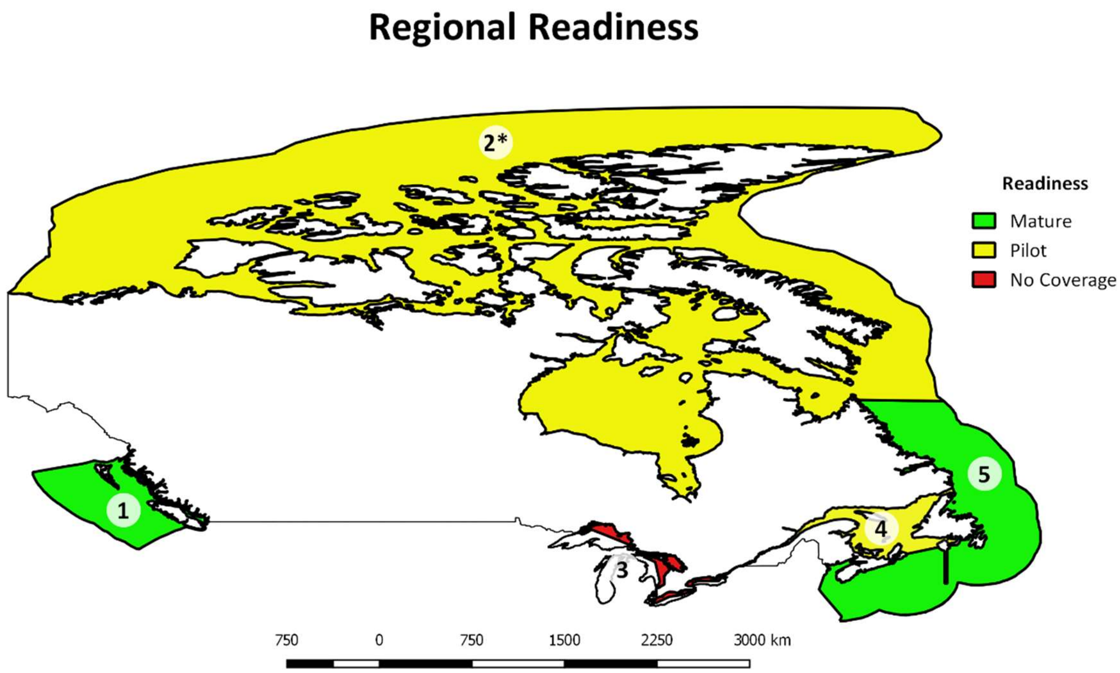
Currents (surface and subsurface)

Variable Information	
Name of Variable	Currents (surface and subsurface)
Sub-Variables	Water velocity (speed and direction) at stated depth, geostrophic velocity (from hydrography), near-surface Ekman currents, tidal currents, wind driven currents, buoyancy driven currents, residual currents, mean currents, Stokes drift
Derived Variables	Mass transport, horizontal heat and freshwater fluxes, surface stress, kinetic energy and kinetic energy flux, upper-ocean turbulent mixing, surface turbulent heat and freshwater/salt fluxes, air-sea fluxes, advection of oceanic properties (biogeochemical tracers, pollutants, debris, etc.), particle dispersion, larval drift, wave forecasts, Ekman velocities, Stokes drift
Phenomena to Capture	Air-sea flux, tides, circulation, fronts and eddies, coastal shelf exchange processes

GOOS Requirements by Phenomena					
Phenomena to Capture	Air-sea Fluxes	Fronts and Eddies	Coastal Shelf Exchange Processes	Circulation	Tides
Temporal Scales of the Phenomena	hourly	weekly	hourly	weekly	hourly
Horizontal Resolution	100km	10km	1km	50km	100km
Vertical Resolution	*Not defined*				

CIOOS Current Observing Elements					
Observing Elements	High Frequency Radar	Fixed Stations (e.g. ADCP)	Satellite	Drift Bottles	Argo Floats
Regions Present	Pacific	Pacific, Atlantic, St. Lawrence, Arctic	Atlantic	Pacific, Arctic	Pacific, Atlantic
Organizations Displaying Data	ONC	SLGO, ONC, DFO (AZOMP, OpenGov, Pacific Region Science and Research, Polar Data Catalogue)	DFO (AZMP)	DFO (The Drift Bottle Project)	Argo Canada
Phenomena Addressed	Circulation, Surface waves	Tides, Air-sea fluxes, Coastal shelf exchange processes	Circulation, Coastal shelf exchange processes, Tides, Air-Sea Fluxes	Gyre-scale circulation	Gyre-scale circulation
Horizontal Resolution	Hundreds of meters to kilometers	Point measurements	75-250km	Global to basin scale	0.5 degrees - global
Vertical Resolution	Surface	Specific depths (not all surface)	Surface (top 200m)	N/A	m (upper 2000m)
Temporal Scale	hourly to daily	minutes to hours, some annually	seasonally	days to years	10 days



Regional readiness for Currents (surface and subsurface) in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5). *Mature technology, but low coverage.

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Fish Abundance and Distribution

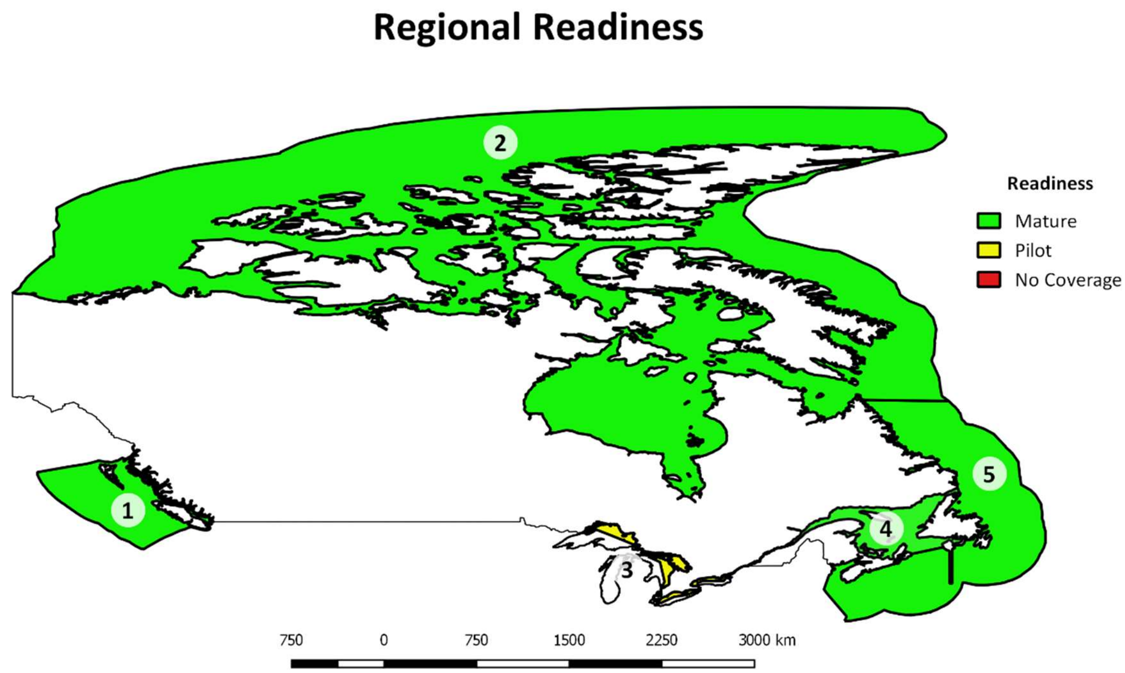
Variable Information	
Name of Variable	Fish Abundance and Distribution
Sub-Variables	Number, biomass or abundance index of fish of different taxa per unit volume or area of water in a specific region, stock or population, and measured by a standard or known protocol; Numbers or biomass of fish by size/age/stage
Derived Variables	Fish abundance indices; Fish diversity indices; Size-based indicators of fish assemblages, including mean fish size, size spectra, and large fish indicators; Food web indicators, including proportion of predatory fish; Fish production; Fish habitat
Phenomena to Capture	Change in sizes of individuals, species populations, taxonomic; Changes in fish distribution; Functional role of a (group of) species in the ecosystem; Species invasions; Fish recruitment; Phenology

GOOS Requirements by Phenomena						
Phenomena to Capture	Change in sizes of individuals, Species populations, taxonomic	Changes in fish distribution	Functional role of a (group of) species in the ecosystem	Species invasions	Fish recruitment	Phenology
Temporal Scales of the Phenomena	Annual to decadal	Seasonal to decadal	Decadal or longer	Decadal or longer	Annual	Seasonal to decadal or longer
Horizontal Resolution	100 - 1000km	100 - 1000+km	1000+km	100 - 1000km	1000+km	1000+km
Vertical Resolution	*Not defined*					

CIOOS Current Observing Elements				
Observing Elements	Trawl Surveys	Commercial Fisheries	Shore Seine Nets	Acoustic tags
Regions Present	Pacific, Atlantic, Arctic, St. Lawrence	Pacific, Atlantic, Arctic, St. Lawrence	St. Lawrence	Atlantic, Arctic, Pacific
Organizations Displaying Data	SLGO, OBIS Canada, BCMCA	WCPFC, NAFO, OBIS Canada, SLGO, IPHC, BCMCA	SLGO	OBIS Canada, OTN
Phenomena Addressed	Single or multiple species abundance and distribution	Single or multiple species commercial landings	Single or multiple target species abundance and distribution	Single or multiple target species abundance and distribution
Horizontal Resolution	10-1000km	1-5 degrees, NAFO regions (10-1000km)	1km	1-100km
Vertical Resolution	Varies: some stratified by depth, some bottom	N/A	Surface to 10m	N/A
Temporal Scale	seasonally to annually	daily to annually	seasonally	hours to months

CIOOS Current Observing Elements				
Observing Elements	Fixed Traps	Tag-recapture studies	Museum Collections	Acoustic Sonar
Regions Present	St. Lawrence	Arctic, Atlantic, St. Lawrence, Pacific	Pacific, Atlantic, Arctic, St. Lawrence, Great Lakes	Arctic

CIOOS Current Observing Elements				
Organizations Displaying Data	SLGO	OBIS Canada	OBIS Canada	Polar Data Catalogue
Phenomena Addressed	Single or multiple species abundance and distribution	Changes in fish distributions	Single or multiple species abundance and distribution	Single or multiple species abundance and distribution
Horizontal Resolution	Point measurements	1-1000+ km	Point observations, regional to global coverage	m to <2km
Vertical Resolution	10m to surface	N/A	1-10,000km	m
Temporal Scale	2-3 times a day seasonally	days to years	point observations	Constant while deployed, hundreds of hours of recordings



Fish Abundance and Distribution readiness in the, Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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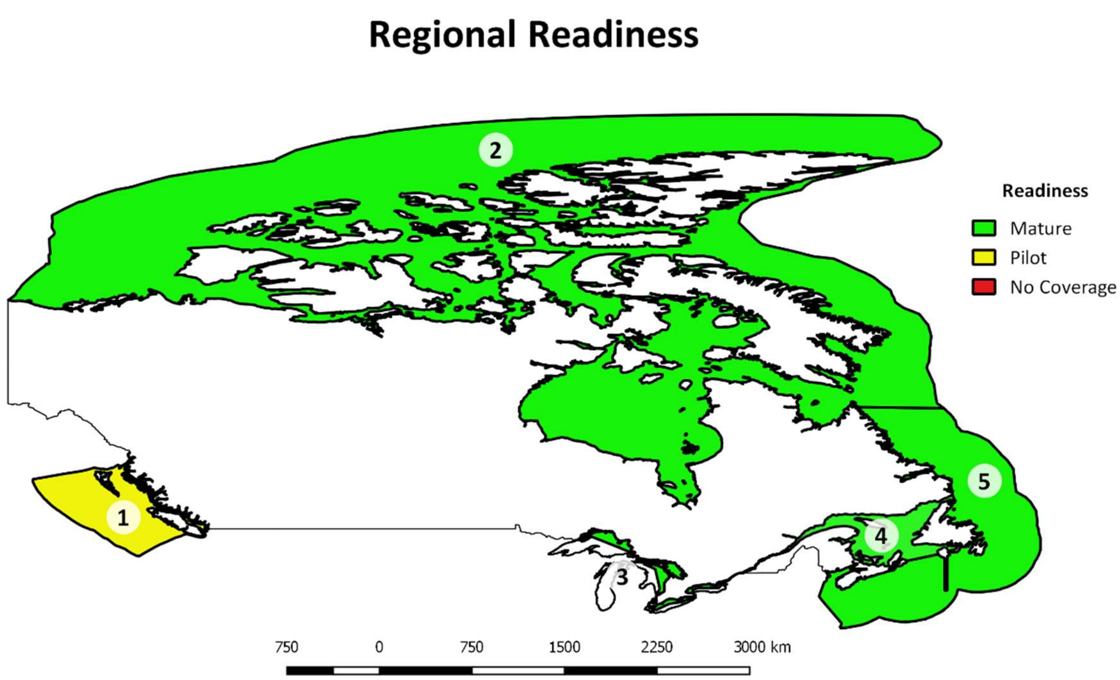
Ice (cover and concentration)

Variable Information	
Name of Variable	Ice (cover, concentration, or thickness)
Sub-Variables	Ice extent and area, Ice concentration, Ice thickness, Ice motion, Fast ice, Ice type (first year, multi-year), Ice salinity, Snow cover thickness, Surface freeze-up and melt time, Melt pond coverage
Derived Variables	Freshwater fluxes, Ice dynamics and kinematics, Seasonal ice extent, Sea ice formation in polynyas
Phenomena to Capture	Water masses, Air-sea fluxes, Sea-ice extent, Surface waves

GOOS Requirements by Phenomena				
Phenomena to Capture	Water masses	Air-sea fluxes	Sea-ice extent	Surface waves
Temporal Scales of the Phenomena	monthly	monthly	weekly	weekly
Horizontal Resolution	100km	100km	50km	10km
Vertical Resolution	*Not defined*			

CIOOS Current Observing Elements			
Observing Elements	Satellite	Buoy/Fixed Position	ArcGIS Map Layer
Regions Present	Atlantic, St. Lawrence, Great Lakes, Arctic	Arctic, Pacific	Atlantic, St. Lawrence, Great Lakes

CIOOS Current Observing Elements			
Organizations Displaying Data	CIS, DFO (AZMP), EC	ONC	DFO
Phenomena Addressed	Air-sea fluxes, Sea ice extent, Surface waves	Sea ice extent, growth rates, water masses, Air-sea fluxes	Sea Ice Extent
Horizontal Resolution	5km (CIS), regional (DFO-AZMP)	Point measurements	1km
Vertical Resolution	Surface	Surface	Surface
Temporal Scale	daily to weekly (CIS), monthly (DFO-AZMP)	minutes to daily	average 1981-2010



Regional readiness for Ice in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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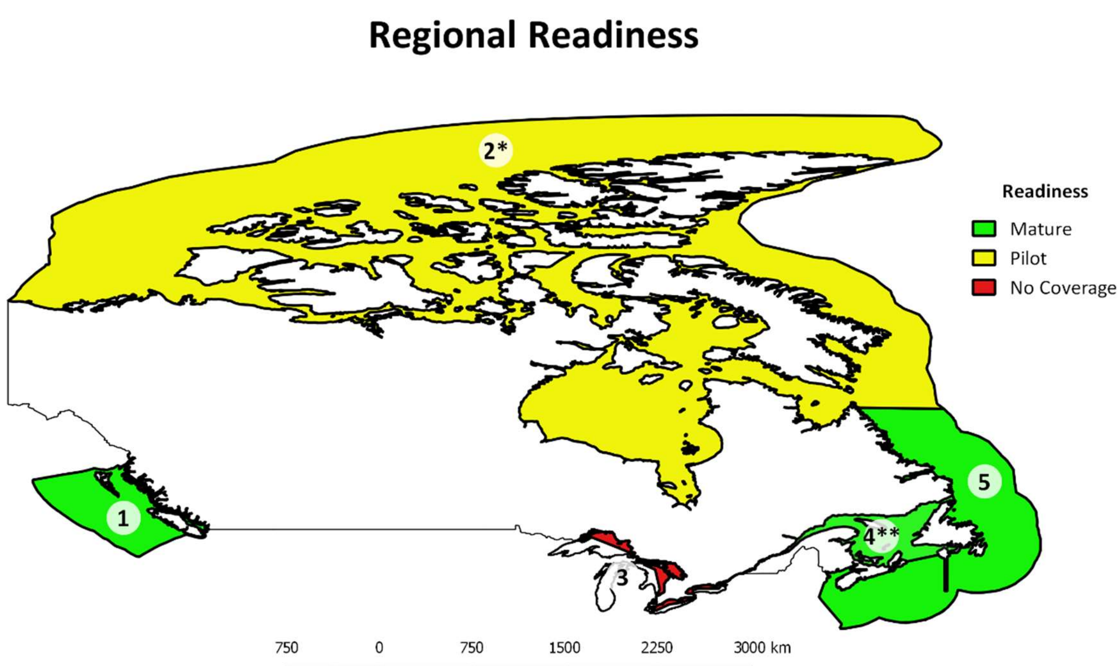
Inorganic Carbon

Variable Information	
Name of Variable	Inorganic Carbon
Sub-Variables	Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial pressure of carbon dioxide (pCO2) and pH
Derived Variables	Saturation state (aragonite, calcite), Dissolved carbonate ion concentration, Air-sea flux of CO2, Anthropogenic carbon, Change in total carbon
Phenomena to Capture	Air-sea fluxes, Storage/inventory, Ocean acidification, Primary production, Export fluxs

GOOS Requirements by Phenomena					
Phenomena to capture	Air-sea Fluxes	Storage/Inventory	Ocean acidification	Primary production	Export fluxes
Temporal Scales of the Phenomena	Monthly	Annual	Coastal: daily Open Ocean: Seasonally	Seasonal to decadal	Seasonal to decadal
Horizontal Resolution	1-250km	100-1000km	Coastal: 0.1-100km Open Ocean: 100-1000km	Coastal: 1-100km Open Ocean: 100-1000km	Coastal: 1-100km Open Ocean: 100-1000km
Vertical Resolution	*Not defined*				

CIOOS Current Observing Elements		
Observing Elements	Buoy/Fixed Station	Ships/CTD
Regions Present	Pacific, Arctic, Atlantic	Pacific, Atlantic, St. Lawrence

CIOOS Current Observing Elements		
Organizations Displaying Data	NANOOS, ONC, DFO (BBMP)	ONC, SLGO, MEOPAR, DFO (Pacific Region Science and Research, AZOMP)
Phenomena Addressed	Air-sea fluxes, Ocean acidification, Primary production	Air-sea fluxes, Ocean acidification, Primary production, Export fluxes
Horizontal Resolution	Point measurements	<1km-100km, Point measurements (SLGO)
Vertical Resolution	Surface/Specific depths	Specific depths, m to 300m (SLGO)
Temporal Scale	minutes to hours	minutes, singular observations (SLGO)



Regional readiness for Inorganic Carbon in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5). *Mature technology, but low coverage. **Mature technology, but inconsistent measuring.

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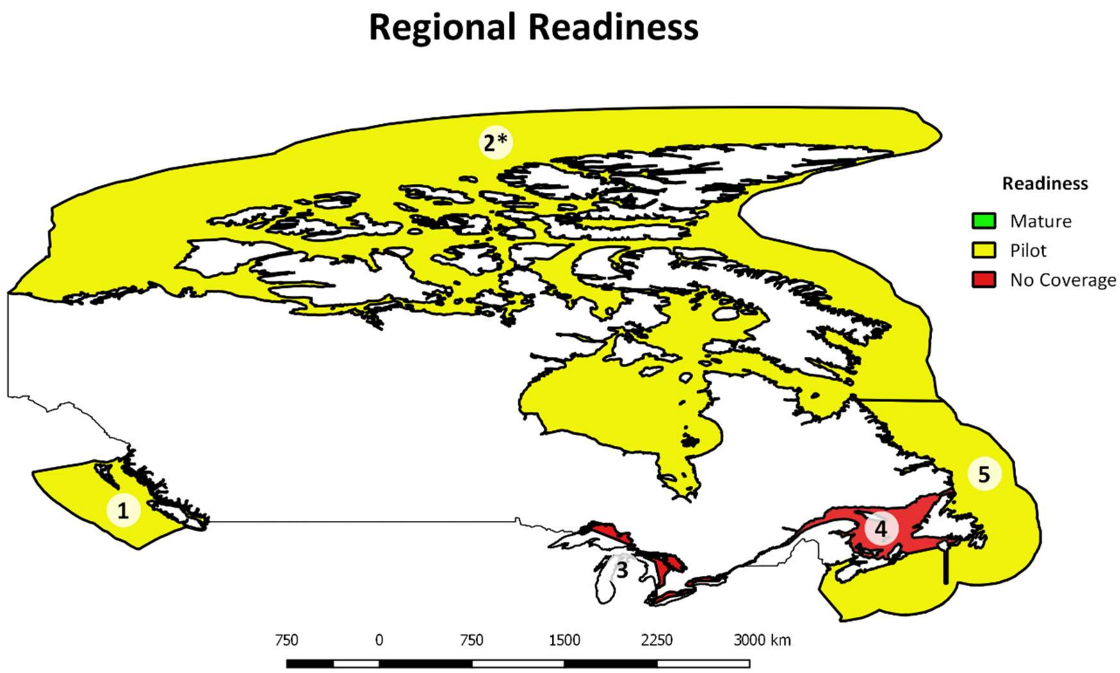
Live Coral

Variable Information	
Name of Variable	Live Coral
Sub-Variables	Live coral cover and areal extent; Coral diversity (species, genera and functional type, and alpha, beta or gamma); Coral condition (diseases, bleaching, mortality (partial and full), predated, silted, other conditions/syndromes); Total habitable substrate (less sand/silt substrates, structural complexity); Coral size classes (recruits/small corals, size class distribution)
Derived Variables	Maps of coral and areal extent; Inventories of coral diversity; Coral condition; Coral recruitment and size class distributions; Coral reef habitat classifications, mapped layers; Coral reef system health (with key fish, urchins, macroalgae variables); Convention indicators - Aichi Target 10, SDG 14.2/5 IPBES
Phenomena to Capture	Status and trends (all sub-variables); Severe decline (all sub-variables, from coral bleaching, cyclones, COTs, other); Recovery processes (recruitment, size, transitions)

GOOS Requirements by Phenomena			
Phenomena to Capture	Status and trends (all sub-variables)	Severe decline (all sub-variables, from coral bleaching, cyclones, COTs, other)	Recovery processes (recruitment, size transitions)
Temporal Scales of the Phenomena	Years to decades	Weeks to 2-3 years	Weeks to years to decades
Horizontal Resolution	Local, regional, global	Local, regional	Local, regional
Vertical Resolution	*Not defined*		

CIOOS Current Observing Elements		
Observing Elements	Trawl Sample	ROV Video
Regions Present	Atlantic, St. Lawrence, Arctic	Pacific
Organizations Displaying Data	DFO (OpenGov)	ONC
Phenomena Addressed	Status and trends, Severe declines, Recovery processes	Status and trends, Severe declines, Recovery processes
Horizontal Resolution	Varies, <100km	<1m along ROV route
Vertical Resolution	N/A	<1m
Temporal Scale	Singular observation	Seconds (during video capture)



Regional readiness for Live Coral in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5). *Pilot, but low coverage.

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Oceans 2.0: Video of corals

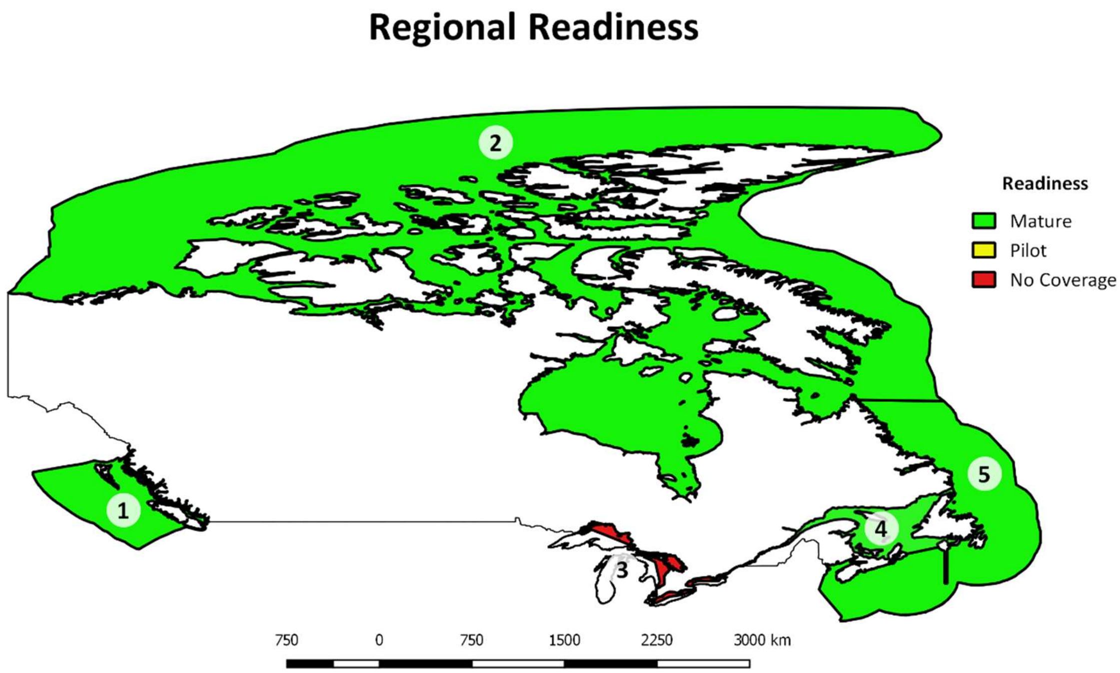
Marine Mammals Abundance and Distribution

Variable Information	
Name of Variable	Marine Mammals: Species, Abundance, and Distribution
Sub-Variables	Species presence/absence, Age, Sex, Count data, Repeated individual presence (tracking/resights)
Derived Variables	Density, Hotspots, Home range, Utilization distribution (relative occupation of home range), Movement patterns, Migration pathways, Habitat maps, Population status (increasing, decreasing, stable)
Phenomena to Capture	Population status and trends, Distribution shifts, Species diversity, Mass mortalities

GOOS Requirements by Phenomena				
Phenomena to Capture	Population status and trends	Distribution shifts	Species diversity	Mass mortalities
Temporal Scales of the Phenomena	Months to decades	Seasonal to years	Annual (seasonal) to decadal	Seasonal to annual
Horizontal Resolution	1km to 1000s km	1km to 1000s km	10km to 1000s km	1km to 1000s km
Vertical Resolution	*Not defined*			

CIOOS Current Observing Elements						
Observing Elements	Observer Sighting	Acoustic Detection	Acoustic Tags	Brand Re-sightings	Acoustic Sonar	Aerial surveys

CIOOS Current Observing Elements						
Regions Present	Pacific, Atlantic, St. Lawrence, Arctic	Pacific Atlantic	Atlantic, St. Lawrence	Atlantic, St. Lawrence	Arctic	Pacific, Arctic
Organizations Displaying Data	SLGO (ROMM), OBIS Canada	MEOPAR, ONC	OBIS Canada, OTN	OBIS Canada	Polar Data Catalogue	OBIS Canada, BCMCA
Phenomena Addressed	Population status and trends, Distribution shifts, Species diversity	Population status and trends, Distribution shifts, Species diversity	Population status and trends, Distribution shifts	Population status and trends, Distribution shifts	Single or multiple species abundance and distribution	Population status and trends, Distribution shifts, Species diversity
Horizontal Resolution	Meters to 10,000km	5 nautical miles (9.26km)	Varies	Varies	m to <2km	1-100km
Vertical Resolution	Surface	N/A	Varies	N/A	m	Surface
Temporal Scale	point observation	constant (cabled) or while glider is deployed	hours to years	months to years	constant while deployed, hundreds of hours of recordings	annual



Regional readiness for Marine Mammals in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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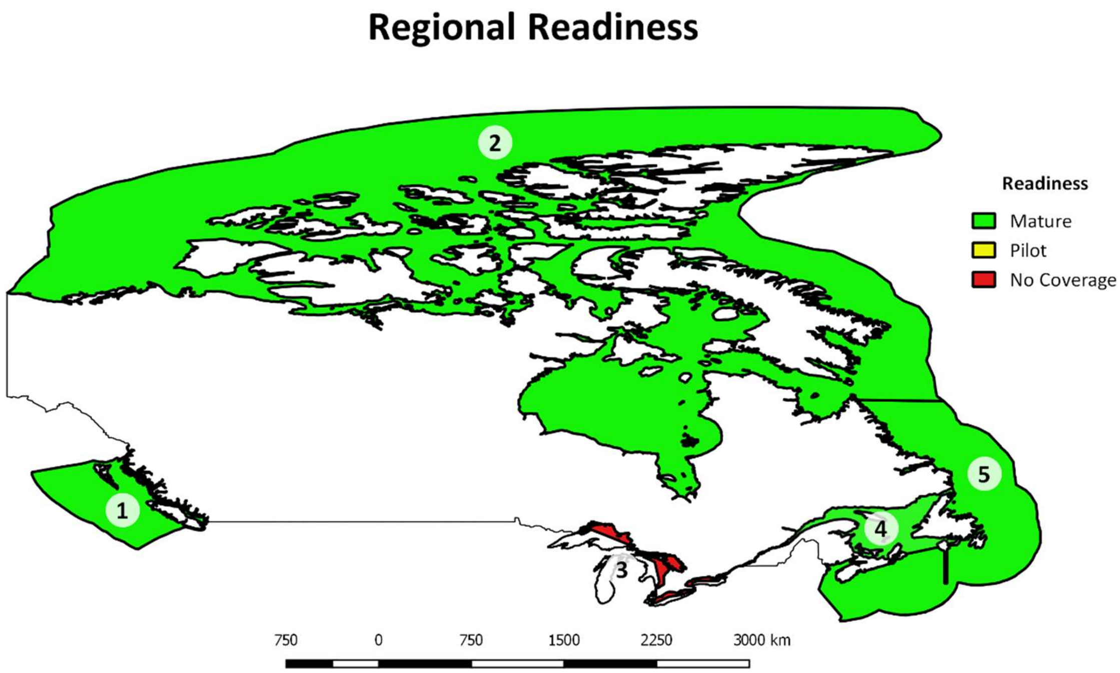
Nutrients

Variable Information	
Name of Variable	Nutrients
Sub-Variables	Nitrate (NO_3^-), Nitrite (NO_2^-), Ammonium (NH_4), Phosphate (PO_4), Silic acid ($Si(OH)_4$)
Derived Variables	Quasi-conservative tracers such as nitrate (N*) and nitric oxide (NO) etc.
Phenomena to Capture	Ventilation, Remineralization, Primary production, Eutrophication

GOOS Requirements by Phenomena				
Phenomena to Capture	Ventilation	Remineralization	Primary production	Eutrophication
Temporal Scales of the Phenomena	Annual to decadal	*Not defined*	Seasonal to decadal	Sub-weekly to decadal
Horizontal Resolution	1000-3000km	*Not defined*	Coastal: 0.1-100km Open Ocean: 100-1000km	Coastal: 0.1-100km
Vertical Resolution	*Not defined*			

CIOOS Current Observing Elements		
Observing Elements	Fixed Station	Ship/CTD
Regions present	Pacific, Atlantic, St. Lawrence, Arctic	Pacific, Atlantic, St. Lawrence, Arctic

CIOOS Current Observing Elements		
Organizations Displaying Data	SLGO, DFO (OpenGov, Pacific Region Science and Research, AZOMP), ONC, BBMP	SLGO, DFO (AZMP, Pacific Region Science and Research), Polar Data Catalogue
Phenomena Addressed	Ventilation, Remineralization, Primary production, Eutrophication, Deoxygenation	Ventilation, Remineralization, Primary production, Eutrophication, Deoxygenation
Horizontal Resolution	Point measurements	Point measurements
Vertical Resolution	Depth specific. Most are at the surface, but not all.	m to 300m (SLGO), Specific depths <10-100m apart
Temporal Scale	minutes to hours, some seasonally-annually	singular observations (SLGO), some hours to daily, some seasonally - annually



Regional readiness for Nutrients in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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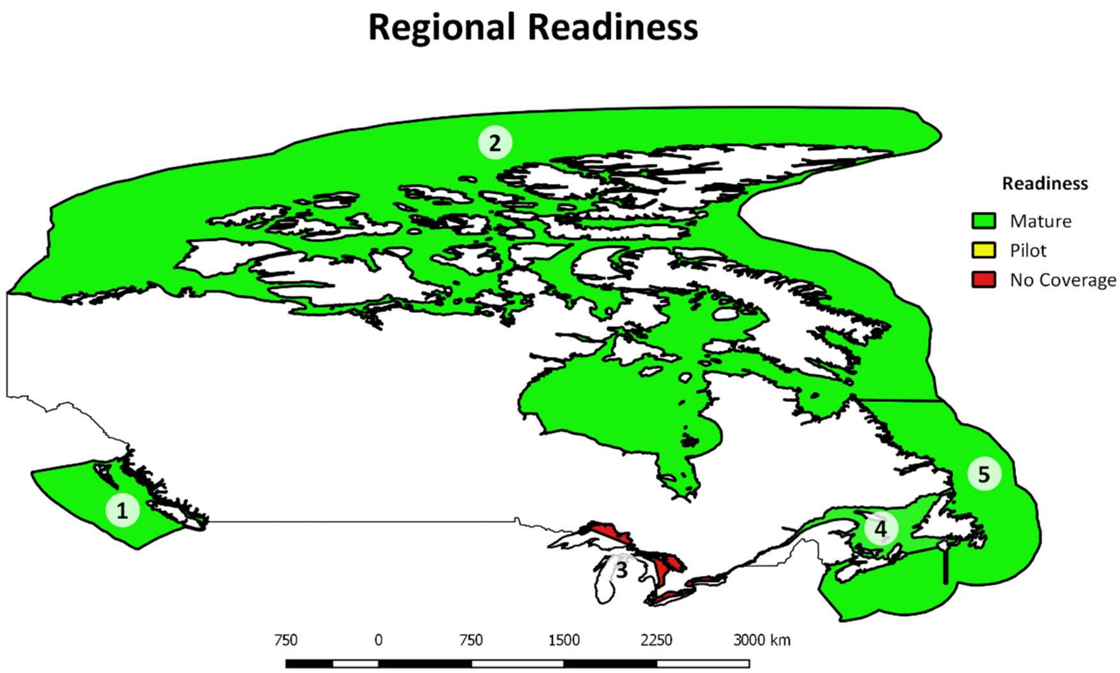
Oxygen

Variable Information	
Name of Variable	Oxygen
Sub-Variables	Dissolved Oxygen (O2) Concentration
Derived Variables	Apparent oxygen utilization, Air-sea O2 fluxes, Net community production (NCP), Net carbon export flux, Ocean oxygen inventories, relative to saturation
Phenomena to Capture	Air-sea fluxes, Deoxygenation, Primary production

GOOS Requirements by Phenomena			
Phenomena to Capture	Air-sea Fluxes	Deoxygenation	Primary Production
Temporal Scales of the Phenomena	Monthly	Coastal: Seasonal Open Ocean: annual to decadal	Weekly to monthly
Horizontal Resolution	1-250km	Coastal: 0.1-100km Open Ocean: 100-1000km	Coastal: 1-100km Open Ocean: 100-1000km
Vertical Resolution	*Not defined*		

CIOOS Current Observing Elements			
Observing Elements	Buoy/Fixed Station	Ship (CTD/Bottles)	Argo Float
Regions Present	Pacific, Atlantic, Arctic, St. Lawrence	St. Lawrence, Atlantic, Pacific, Arctic	Pacific, Atlantic
Organizations Displaying Data	NANOOS, ONC, DFO (AZOMP, OpenGov, Pacific Region Science and Research), SLGO, BBMP, Polar Data Catalogue	SLGO,ONC, DFO (AZOMP, AZMP, Pacific Region Science and Research), Polar Data Catalogue	Argo Canada
Phenomena Addressed	Air-sea fluxes, Primary Production	Deoxygenation, Air-sea fluxes, Primary production	Air-sea fluxes, Deoxygenation, Primary Production
Horizontal Resolution	Point measurements	<1km-100km	Point measurements, global coverage up to every 3 degrees
Vertical Resolution	Surface/Specific depths	Specific depths; m to 300m (SLGO)	meters
Temporal Scale	minutes to daily, some seasonally and others annually	minutes to monthly; singular observations (SLGO)	10 days



Regional readiness for Nutrients in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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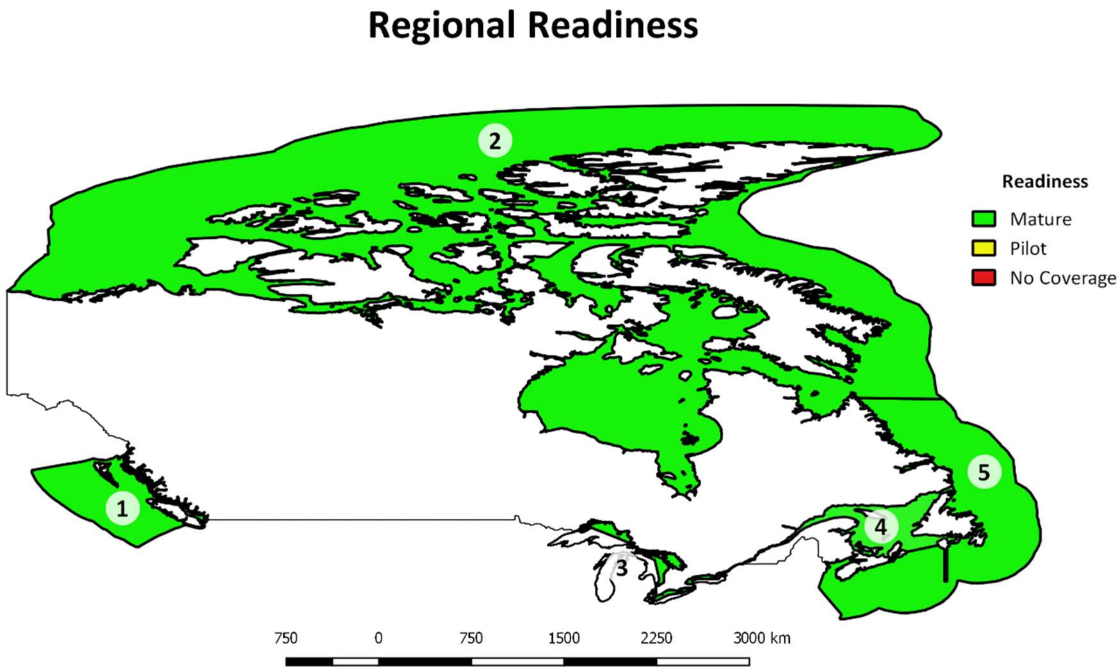
http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

Phytoplankton Biomass and Diversity

Variable Information	
Name of Variable	Phytoplankton Biomass and Diversity
Sub-Variables	Presence/absence/relative abundance, Diversity/taxonomy, Genomic information, In viro/in vivo pigment fluorescence, Pigment concentration by spectrophotometry (chlorophyll a, b, HPLC pigments), Spectral reflectance (ocean color/remote sensing methods), Primary productivity (different methods)
Derived Variables	Phytoplankton functional types; Diversity indices, species richness, species evenness, other; Harmful or beneficial algal bloom indices, including Harmful Algal Events; Global biogeography/spatial distribution; Primary production and carbon and nutrient cycling, storage, and export
Phenomena to Capture	Status and trends, Phenology, Role in transport/cycling of elements, Occurrence of HABs

GOOS Requirements by Phenomena				
Phenomena to Capture	Status and trends	Phenology	Role in transport/cycling of elements	Occurrence of HABs
Temporal Scales of the Phenomena	Weekly to seasonal over decades	Anomalies in time relative to climatology, Events	Anomalies in time relative to climatology, Events	Hours-years (~week-scale changes are common)
Horizontal Resolution	Meters to regional and basin-scale (~10m-1000km)	Anomalies in location, region, latitudinal range	~10m-1000km Connection to land fluxes, upwelling sites, large-scale oceanographic anomalies.	~10m-1000km
Vertical Resolution	*Not defined*			

CIOOS Current Observing Elements			
Observing Elements	Fixed Station	Ship Cruise	Satellite
Regions Present	Pacific, Atlantic, St. Lawrence, Arctic	Pacific, Atlantic, St. Lawrence, Arctic	Global, Pacific Atlantic
Organizations Displaying Data	ONC, SLGO, DFO (OpenGov), OBIS Canada, BBMP	ONC, DFO (AZMP, AZOMP, and Pacific Region Science and Research), Polar Data Catalogue, OBIS Canada	DFO (Ocean Color Database, AZMP) BCMCA
Phenomena Addressed	Status and trends, Phenology, Role in transport/cycling of elements, Occurrence of HABs	Status and trends, Phenology, Role in transport/cycling of elements, Occurrence of HABs	Status and trends, Phenology, Role in transport/cycling of elements, Occurrence of HABs
Horizontal Resolution	Point measurements	Varies	4km (global), 1.5km (Atlantic)
Vertical Resolution	Specific depths	Specific depths	Surface
Temporal Scale	minutes to days	minutes to days, monthly to annually	weekly (global), semi-monthly (Atlantic)



Regional readiness for Phytoplankton in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

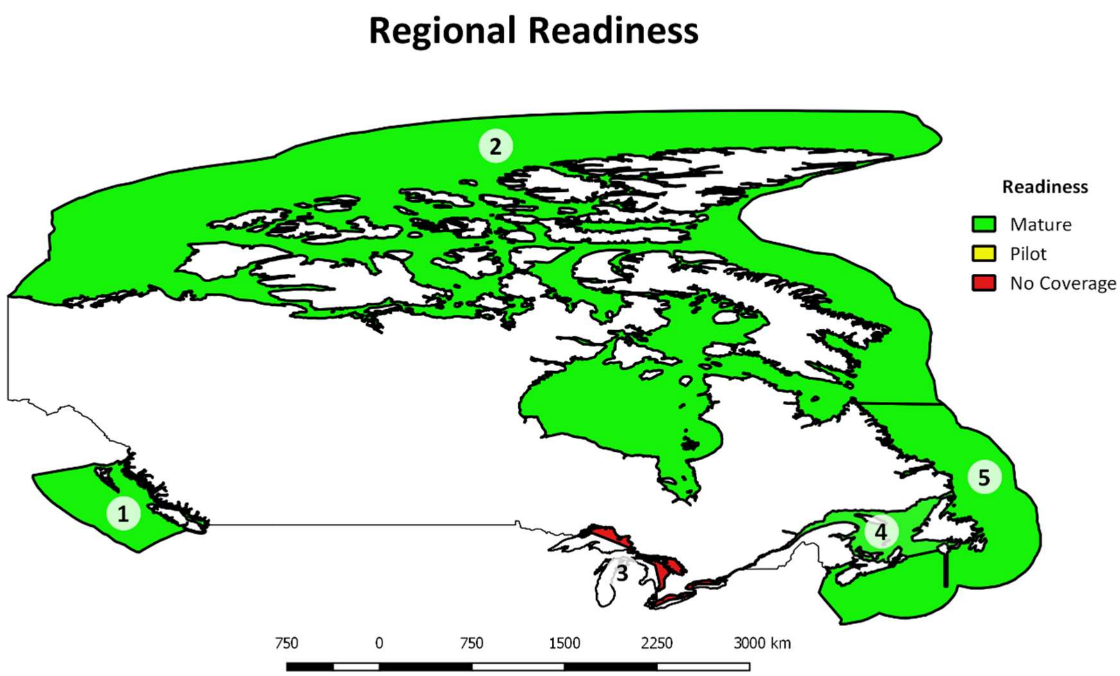
Salinity (surface and subsurface)

Variable Information	
Name of Variable	Salinity (surface and subsurface)
Sub-Variables	Absolute and practical salinity, Bulk surface salinity, Skin surface salinity, Near surface salinity at stated depth, Foundation and bulk subsurface salinity
Derived Variables	Surface - Evaporation and precipitation estimate for the global ocean; River runoff and glacial and land ice melting rates; Sea surface density, alkalinity and pCO2 Subsurface - Ocean freshwater content; ocean freshwater transport; Subsurface density; Mixed layer depth; Geostrophic currents/velocities; Water mass identities; Steric and halosteric sea level
Phenomena to Capture	Air-sea Flux (including ice-sea flux); Coastal shelf exchange process; Front and eddies; Riverine

GOOS Requirements by Phenomena				
Phenomena to Capture	Air-sea Flux (including ice-sea flux)	Coastal shelf exchange process	Front and eddies	Riverine
Temporal Scales of the Phenomena	daily	daily	weekly	monthly
Horizontal Resolution	100km	1km	10km	50km
Vertical Resolution	*Not defined*			

CIOOS Current Observing Elements					
Observing Elements	Fixed Buoy/Station	Submerged Fixed Station and Seabed Cabled Platforms	Glider	Ship/Moving Platform	Argo Float
Regions Present	Pacific, Atlantic, St. Lawrence, Arctic	Pacific	Atlantic, St. Lawrence	Pacific, Atlantic, St. Lawrence, Arctic	Pacific, Atlantic
Organizations Displaying Data	ONC, NANOOS, SLGO, DFO (OpenGov, Pacific Region Science and Research), BBMP, Polar Data Catalogue	NANOOS, ONC	OTN, MEOPAR	DFO (Pacific Region Science and Research, AZOMP, AZMP),Polar Data Catalogue	Argo Canada
Phenomena Addressed	Circulation, stratification, upwelling, mixed layer	Circulation, stratification, upwelling, mixed layer	Circulation, Upwelling, Stratification, Mixed layer, Coastal shelf exchange processes	Freshwater storage, Water masses, Sea level circulation	Air-sea fluxes, Fronts and eddies, Freshwater storage, Water masses, Sea level, circulation
Horizontal Resolution	Point measurements	Point measurements	<1km	Point measurements along a course - distance apart varies	Point measurements, global coverage up to every 3 degrees

CIOOS Current Observing Elements					
Vertical Resolution	Surface, a few measurements at -6m	Specific depth (varies)	1-10 meters	Specific depths 1-10s of meters apart	meters
Temporal Scale	minutes to daily, some seasonally	minutes to hours, some seasonally to annually	minutes to hours	hourly to daily	10 days



Regional readiness for Salinity in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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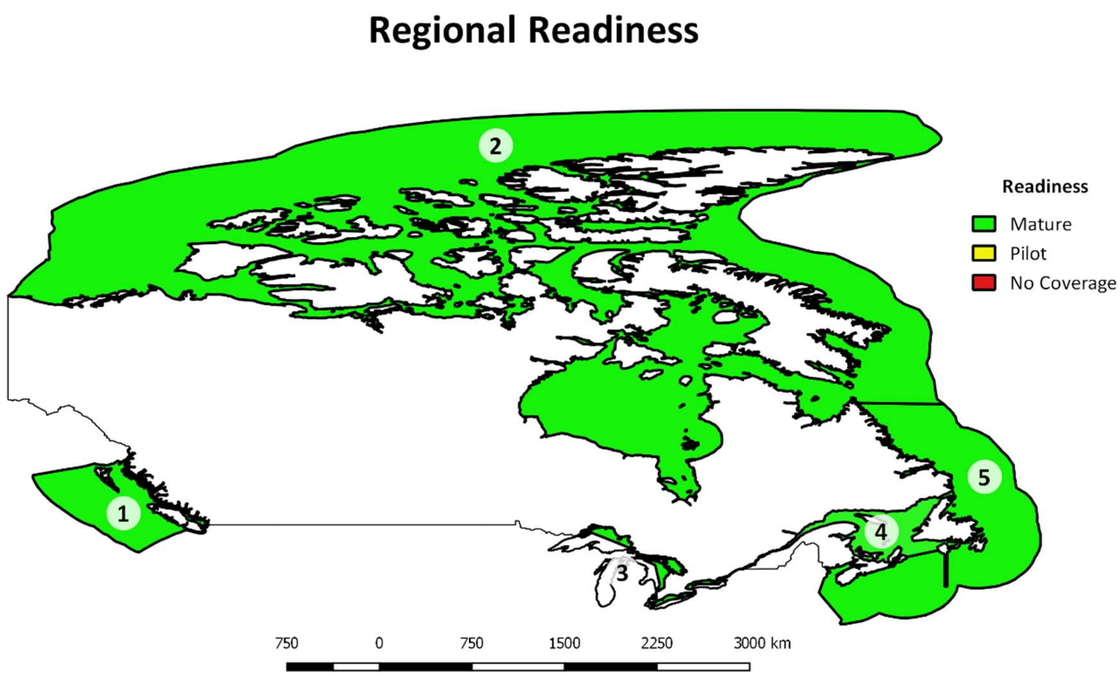
Sea State

Variable Information	
Name of Variable	Sea State (wave conditions)
Sub-Variables	Significant wave height, Wave period, Wave direction, Maximum wave height, Swell, Directional spectrum, Whitecap fraction
Derived Variables	Wavelength, Whitecap fraction, Rogue waves, Stokes drift, and Ocean albedo, Beaufort Scale
Phenomena to Capture	Air-sea flux, Surface waves, Extreme events

GOOS Requirements by Phenomena			
Phenomena to Capture	Air-sea flux	Surface waves	Extreme events
Temporal Scales of the Phenomena	hourly	hourly	hourly
Horizontal Resolution	100km	10km	10km
Vertical Resolution	*Not defined*		

CIOOS Current Observing Elements	
Observing Elements	Buoy/Fixed Station
Regions present	Pacific, Atlantic, St. Lawrence, Great Lakes, Arctic
Organizations displaying data	SLGO, NANOOS, DFO (CWD) , NOAA/EC, ENR, ONC, GLOS

CIOOS Current Observing Elements	
Phenomena addressed	Surface waves, Air-sea fluxes, Extreme events
Horizontal Resolution	Point measurements
Vertical Resolution	Surface
Temporal Scale	minutes to daily



Regional readiness for Sea State in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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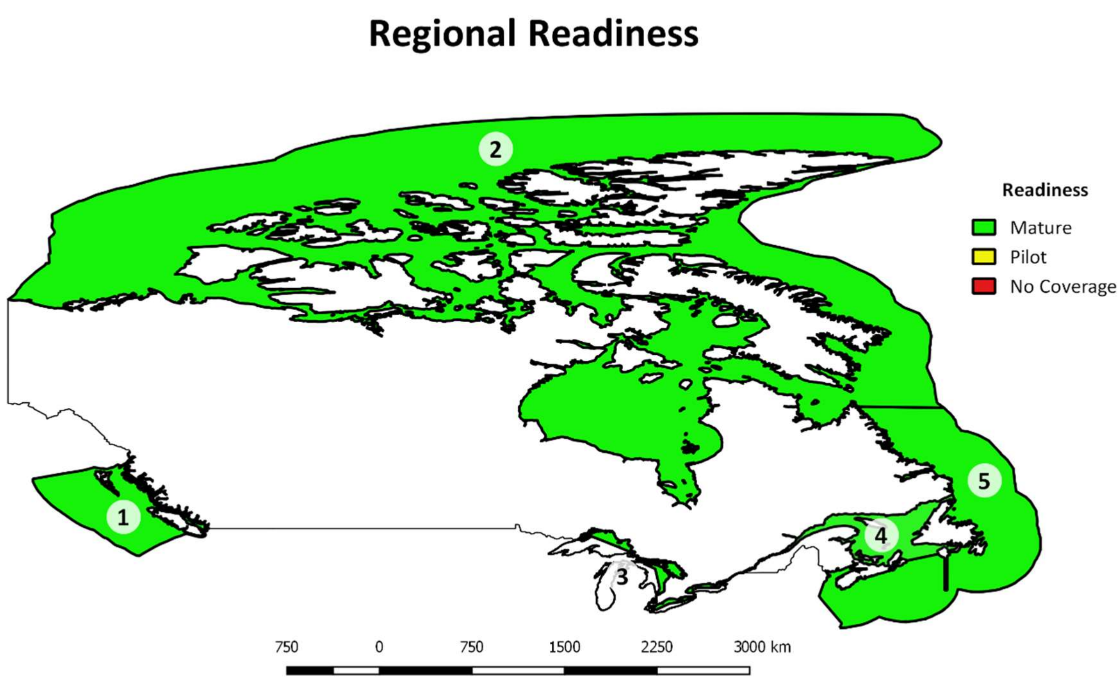
Sea Surface Height

Variable Information	
Name of Variable	Sea Surface Height
Sub-Variables	Sea level anomaly, Sea surface height gradients, Sea level extremes, Tidal range, storm surge
Derived Variables	Upper ocean heat content, Tropical cyclone heat potential, Ocean volume variability, Sea level rise trends, Surface geostrophic currents, Data assimilative operational mesoscale ocean forecasts (e.g. Mercator-Ocean; HYCOM; ENSO), Tsunami warning
Phenomena to Capture	Sea level, Coastal shelf exchange processes, Circulation, Fronts and eddies, Extreme events, Tsunami, Storm Surge

GOOS Requirements by Phenomena					
Phenomena to Capture	Sea level	Coastal shelf exchange processes	Circulation	Fronts and eddies	Extreme events
Temporal Scales of the Phenomena	monthly	hourly	weekly	monthly	hourly
Horizontal Resolution	100km	10km	100km	10km	10km
Vertical Resolution	*Not defined*				

CIOOS Current Observing Elements	
Observing Elements	Tide and Pressure Gauges
Regions Present	Pacific, Atlantic, St. Lawrence, Great Lakes, Arctic

CIOOS Current Observing Elements	
Organizations Displaying Data	SLGO; ONC, DFO (TWCL, AZMP)
Phenomena Addressed	Sea level, Extreme events, Circulation
Horizontal Resolution	Point measurements
Vertical Resolution	Surface
Temporal Scale	minutes to months



Regional readiness for Sea Surface Height in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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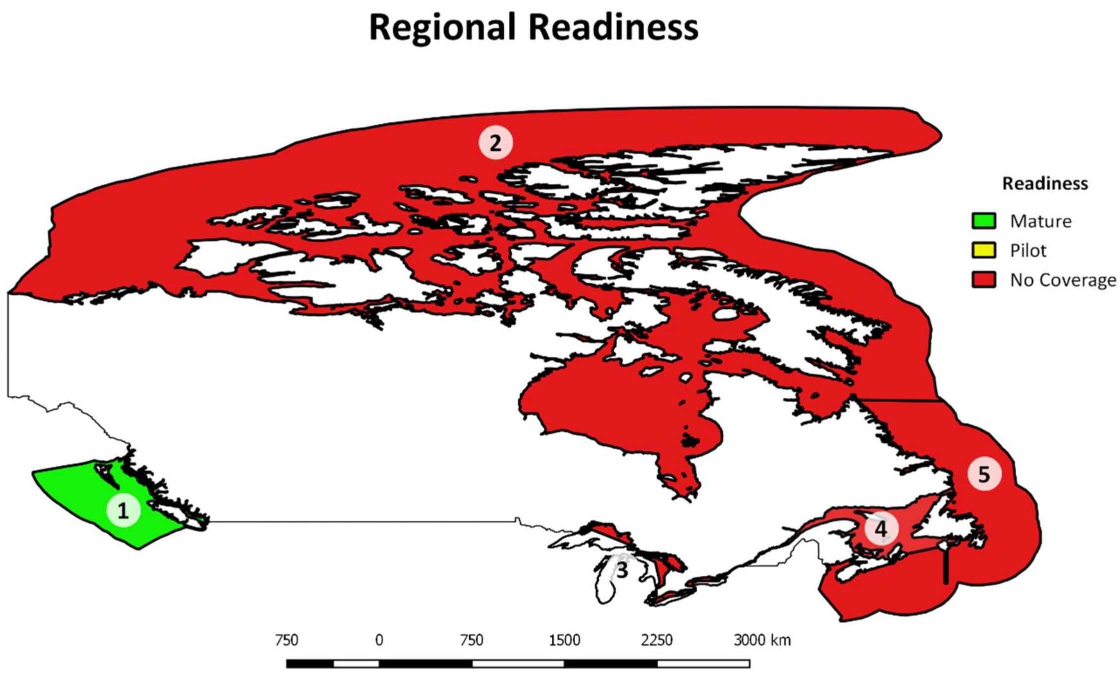
http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

Seagrass Cover

Variable Information	
Name of Variable	Seagrass Cover
Sub-Variables	Shoot density/cover, Canopy height, Seagrass diversity (species), Areal extent of seagrass meadows, Photosynthetic efficiency (measured with PAM)
Derived Variables	Primary and secondary production, Global and regional seagrass distribution, Contributions to "blue" carbon storage, Essential fish habitat extent, Seagrass habitat fragmentation
Phenomena to Capture	Status and trends (Seagrass cover and areal extent, species composition); Severe events (mass mortality due to disease, heat stress, erosion or destruction, etc.); Recovery processes

GOOS Requirements by Phenomena			
Phenomena to Capture	Status and trends (Seagrass cover and areal extent, species composition)	Severe events (mass mortality due to disease, heat stress, erosion or destruction, etc.)	Recovery processes
Temporal Scales of the Phenomena	Seasonal to decadal	Weeks to year	Annual to decadal
Horizontal Resolution	10m - 1000km	100m - 1000km	10m - 1km
Vertical Resolution	*Not defined*		

CIOOS Current Observing Elements			
Observing Elements	Distribution Map (compilation of multiple datasets and datatypes)	Occurrence Database (compilation of multiple datasets)	Citizen Science
Regions Present	Pacific	Pacific	Pacific
Organizations Displaying Data	BCMCA	OBIS Canada	OBIS Canada
Phenomena Addressed	Status and trends, Severe events, Recovery processes	Status and trends, Severe events, Recovery processes	Status and trends, Severe events, Recovery processes
Horizontal Resolution	m-km	Point observations	Point observations
Vertical Resolution	N/A	N/A	N/A
Temporal Scale	Once - compilation of multiple data sets	Varies	Annual



Regional readiness for Seagrass Cover in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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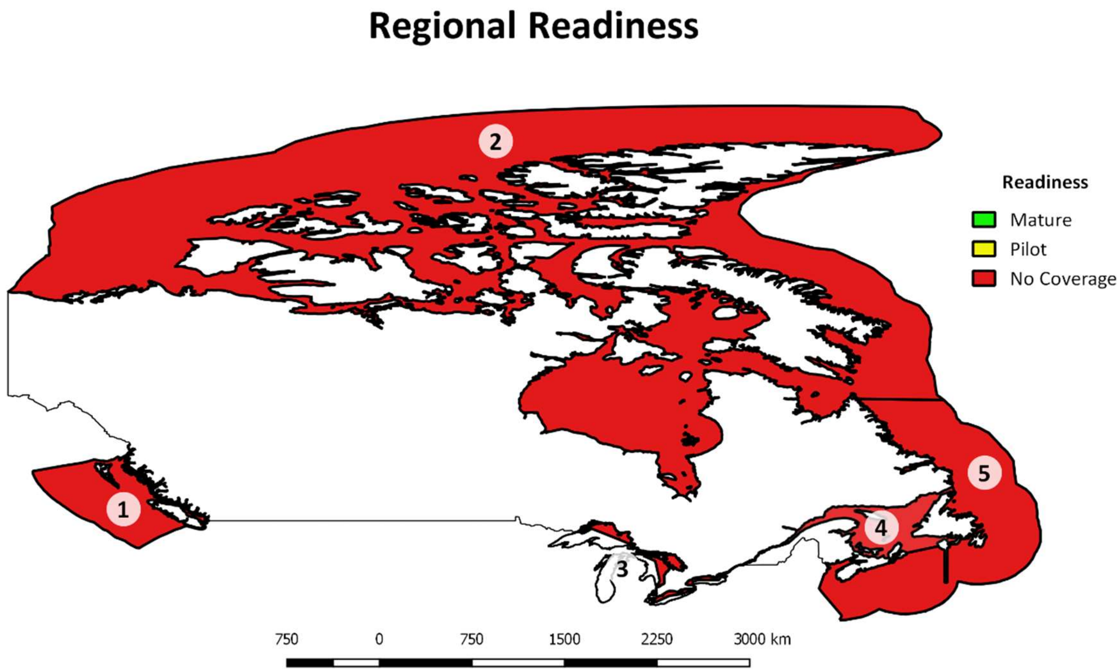
http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

Surface Heat Flux

Variable Information	
Name of Variable	Surface Heat Flux
Sub-Variables	Latent heat flux, Sensible heat flux, Net shortwave radiation, Downward shortwave radiation, Upward shortwave radiation, Albedo, Net longwave radiation, Downward longwave radiation, Upward longwave radiation, Photosynthetically available radiation
Derived Variables	Net heat flux, Moisture flux, Diurnal temperature variability, Heat storage, Sea ice extent, Penetrating radiation absorption in the mixed layer, Mixed layer depth, Atmospheric boundary layer stability
Phenomena to Capture	Mixed layer and extreme events, Stratification, Freshwater cycle, Sea ice extent, Sea level and heat storage, Water masses and circulation

GOOS Requirements by Phenomena						
Phenomena to Capture	Mixed layer and Extreme events	Stratification	Fresh water cycle	Sea ice Extent	Sea level and heat storage	Water masses and circulation
Temporal Scales of the Phenomena	hourly to interseasonal	hourly to synoptically	hours to decades	daily to seasonal	seasonally to decades	3 hours to seasonally
Horizontal Resolution	10km to 10,000km	<1-600km	3km to global	5km to global	3km to global	100km to 10000km
Vertical Resolution	*Not defined*					

CIOOS Current Observing Elements
There is not currently any data on Surface Heat Flux publicly available in Canada



Regional readiness for Surface Heat Flux in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

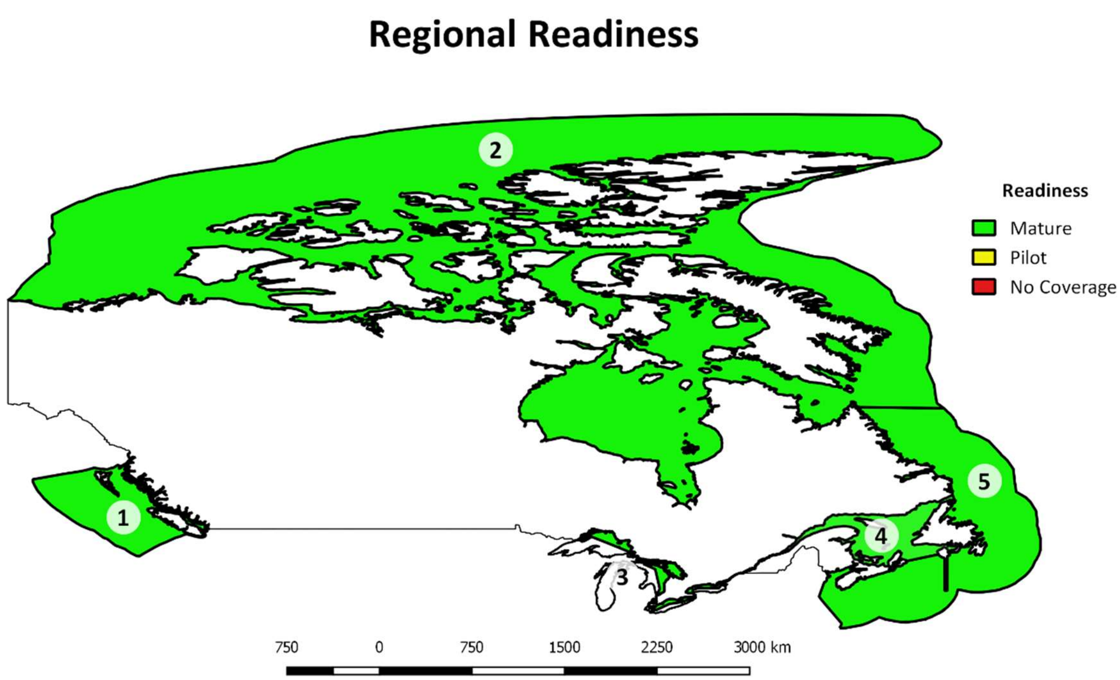
Surface Stress

Variable Information	
Name of Variable	Surface (Wind) Stress
Sub-Variables	Equivalent neutral winds, Stress equivalent neutral winds, Scalar stress
Derived Variables	Ocean upwelling indices, Sea state, Upper ocean mixing, Ekman transport and Ekman pumping, Air-sea fluxes of heat, Water and gases, Height-adjustment of near surface oceanic and atmospheric variables
Phenomena to Capture	Water masses, Circulation, Upwelling, Sea level, Fronts and eddies, Air-sea Fluxes, Mixed layer, Extreme events, Surface waves

GOOS Requirements by Phenomena									
Phenomena to Capture	Water masses	Circulation	Upwelling	Sea Level	Fronts and Eddies	Air-sea fluxes	Mixed layer	Extreme events	Surface waves
Temporal Scales of the Phenomena	monthly	monthly	weekly	daily	weekly	daily	hourly	hourly	hourly
Horizontal Resolution	100km	100km	10km	10km	10km	100km	10km	10km	10km
Vertical Resolution	*Not defined*								

CIOOS Current Observing Elements	
Observing Elements	Buoy/Fixed Station
Regions Present	Pacific, Atlantic, St. Lawrence, Great Lakes, Arctic

Organizations Displaying Data	SLGO, NANOOS, ENR, GLOS, NOAA/EC, DFO (CWD, Pacific Region Science and Research)
Phenomena Addressed	Air-sea fluxes, Stratification, Mixed layer, Extreme events
Horizontal Resolution	Point measurements
Vertical Resolution	Surface
Temporal Scale	minutes to daily



Regional readiness for Surface Stress in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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Temperature (surface and subsurface)

Variable Information	
Name of Variable	Temperature (surface and subsurface)
Sub-Variables	Surface: Skin SST, Sub-skin SST, Near surface Temperature at stated depth, Bulk SST, Foundation SST Subsurface: Temperature, Potential temperature (theta)
Derived Variables	Surface: Foundation SST; Bulk SST; Latent, sensible and long-wave air-sea heat flux; Evaporation Subsurface: Ocean heat content; Ocean heat transport; Air-sea fluxes; Subsurface density; Mixed layer depth; Geostrophic currents; Water mass identities; Steric and thermosteric sea level
Phenomena to Capture	Air-Sea fluxes, Fronts and eddies, Coastal shelf exchange processes, Upwelling

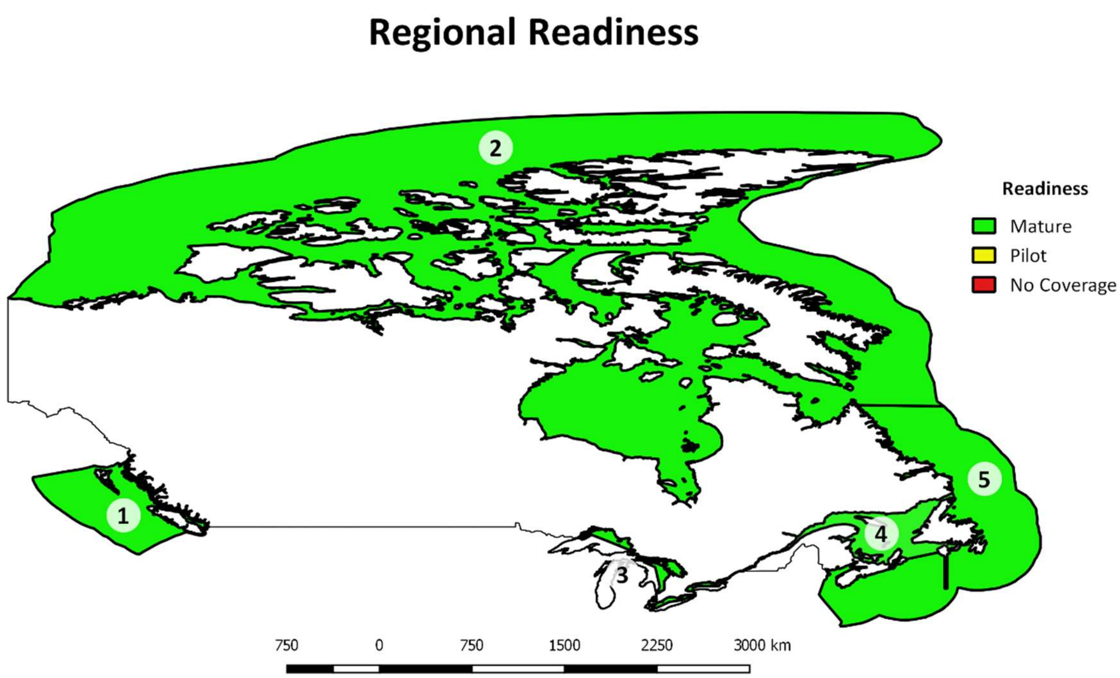
GOOS Requirements by Phenomena				
Sea Surface Temperature				
Phenomena to Capture	Air-sea Fluxes	Fronts and Eddies	Coastal Shelf Exchange Processes	Upwelling
Temporal Scales of the Phenomena	daily	weekly	> hourly	weekly
Horizontal Resolution	100km	10km	1km	10km
Vertical Resolution	*Not defined*			

GOOS Requirements by Phenomena								
Subsurface Temperature								
Phenomena to Capture	Heat storage as a function of depth	Water mass	Sea level	Circulation	Stratification	Upwelling	Mixed layer	Coastal shelf exchange process
Temporal Scales of the Phenomena	Monthly	Monthly	Monthly	Weekly	Weekly	Weekly	Hourly	Hourly
Horizontal Resolution	300km	100km	100km	50km	10km	10km	10km	1km
Vertical Resolution	Full depth	10m	Integrated quantity	10m	10m	1m	1m	1m

CIOOS Current Observing Elements					
Observing Elements	Buoys, Research Stations, Tide Gauges, Seabed Cabled Platforms	Ocean Glider	Ships	Argo Float	Satellite
Regions Present	Pacific, Atlantic, St. Lawrence, Great Lakes, Arctic	Atlantic, St. Lawrence	Pacific, Atlantic, Great Lakes, Arctic	Pacific, Atlantic	Global, Atlantic and St. Lawrence (AZMP)

CIOOS Current Observing Elements					
Organizations Displaying Data	NANOOS, SLGO, MEOPAR, GLOS, DFO (OpenGov, Pacific Region Science and Research, BBMP, AZMP), NOAA/EC, ONC, Polar Data Catalogue	MEOPAR, DFO-AZMP, OTN	ONC, DFO (Pacific Region, AZOMP, AZMP), Polar Data Catalogue	Argo Canada	DFO (AZMP, SST Database)
Phenomena Addressed	Fronts and Eddies, Upwelling, Air- Sea Fluxes, Coastal Shelf Exchange Processes, Circulation, Stratification, Mixed layer, Upwelling	Fronts and Eddies Upwelling Air Sea Fluxes Coastal Shelf Exchange Processes, Circulation, Stratification , Upwelling, Mixed layer	Fronts and Eddies, Upwelling Air Sea Fluxes, Heat storage, Watermasses, Sea level, Sea level, Circulation	Air-sea fluxes, Fronts and eddies, Heat storage, Watermasses, Sea level, Sea level, Circulation	Fronts and Eddies, Upwelling, Air- Sea Fluxes, Coastal Shelf Exchange Processes
Horizontal Resolution	Point Measurements	<1km along specific routes	<1km - 10km along specific routes	Point measurements, global coverage up to every 3 degrees	4-18km
Vertical Resolution	Specific depths. Most, but not all, are at the surface	Meters	Specific depth	Meters	Surface

CIOOS Current Observing Elements					
Temporal Scale	minutes to hours, some daily, a few monthly	minutes to hours	minutes to hours	10 days	weekly



Regional readiness for Temperature (surface and subsurface) in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct

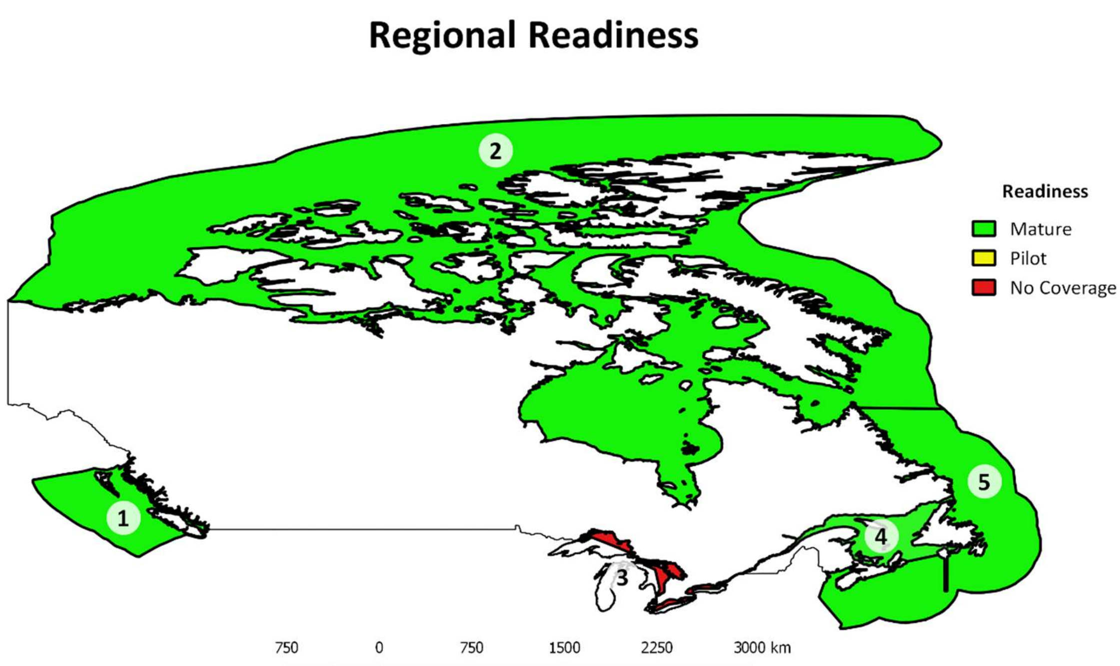
Zooplankton Biomass and Diversity

Variable Information	
Name of Variable	Zooplankton biomass and diversity
Sub-Variables	Biomass overall; biomass or abundance (or presence/absence) by taxon, functional group or size class
Derived Variables	Geographical distributions by taxon or functional group, Life history timing, community size structure
Phenomena to Capture	Phenology, Biogeographical shift, Ecological regime shift (species to assemblage scale), Ocean productivity, Carbon sequestration

GOOS Requirements by Phenomena					
Phenomena to Capture	Phenology	Biogeography shift	Ecological regime shift	Ocean productivity	Carbon sequestration
Temporal Scales of the Phenomena	Daily to seasonal over annual to decadal scales	Seasonal, annual to decadal	Decadal	Annual to decadal	Annual
Horizontal Resolution	Local to basin scale	200km - basin scale	Regional to basin scale	Local to global	Basin scale to global
Vertical Resolution	*Not defined*				

CIOOS Current Observing Elements		
Observing Elements	Buoy/Fixed station	Ship Cruise
Regions Present	Pacific, Atlantic, Arctic	Pacific, Atlantic, St. Lawrence, Arctic

CIOOS Current Observing Elements		
Organizations Displaying Data	DFO (OpenGov, AZOMP), ONC, OBIS Canada	OBIS Canada
Phenomena Addressed	Phenology, Biogeographical shift, Ecological regime shift (species to assemblage scale), Ocean productivity, Carbon sequestration	Phenology, Biogeographical shift, Ecological regime shift (species to assemblage scale), Ocean productivity, Carbon sequestration
Horizontal Resolution	Point measurement	1km-1000km
Vertical Resolution	Integrated over 100m (OpenGov), Specific depths 10-100m apart (AZOMP), Echo-sounder (<1m)	Varies
Temporal Scale	seconds to hours, annually	seasonally to annually



Regional readiness for Zooplankton in the Pacific (1), Arctic (2), Great Lakes (3), St. Lawrence (4), and Atlantic (5).

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http://obiscanada.marinebiod
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http://www.marineregions.org/gazetteer.php?p=browser&id=1900&expand=true#ct
Oceans 2.0 Zooplankton Acoustic Profiler

7.2. EXPERT ADVICE FROM Z. WILLIS (verbatim)

Assessment of state of Core Ocean Variables

Background

The Global Ocean Observing System (GOOS), open ocean module, is guided by the Global Climate Observing System (GCOS) implementation plan[115]. This focused on Essential Climate Variables; however, the GOOS program often referred to the program elements e.g ARGO, Drifters etc rather than focusing on the collection of ECV. The GOOS coastal module has from the beginning focused on core variables. The coastal GOOS is guided by An Implementation Strategy for the Coastal Module of the Global Ocean Observing System, GOOS Report No. 148[116]; IOC Information Documents Series N°1217; UNESCO 2005. See page 65 for core variables.

The United States Integrated Ocean Observing System (IOOS®)[117] took its guidance from the GOOS Report No. 148 and the A Coastal Theme for the IGOS Partnership[118] — For the Monitoring of our Environment from Space and from Earth. Paris, UNESCO 2006. 60 pp. (IOC Information document No. 1220) - p 15 and developed 20 core variables which are found in The First IOOS Developmental Plan Ocean.US publication #9[119]. IOOS updated its core variables to account for ocean acidification and published these in the U.S. Integrated Ocean Observing System: A Blueprint for Full Capability[120], Version 1.0, November 2010. IOOS, through an interagency task team, updated IOOS biological variables resulting in 10 additional variables being proposed. Information on this process can be found here: Biological and Ecosystem Observations within the United States Waters 1: A Survey of Federal Agencies[121] and the Biological and Ecosystems Observations within the United States II: A Workshop Report to inform Priorities for the United States Integrated Ocean Observing System[122].

The Australia Integrated Marine Observing System[123] has also adopted core variables.

[115] The Global Observing System for Climate Implementation Needs: https://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/gcos_ip_10oct2016.pdf
[116] GOOS report no. 148: https://www.ioos.noaa.gov/wp-content/uploads/2016/05/GOOS-148-COOP-lowres.pdf
[117] US IOOS: https://ioos.noaa.gov/
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[120] IOOS Blueprint for full capability: https://ioos.noaa.gov/wp-content/uploads/2015/09/us_ioos_blueprint_ver1.pdf
[121] NOC Survey of federal agencies for biological and ecosystem observations: biological_and_ecosystem_observations_within_united_states_waters1
[122] Workshop report to inform priorities for IOOS: http://www.iooc.us/wp-content/uploads/biological_and_ecosystem_observations_within_united_states_waters2.pdf
[123] Australia's IMOS website: http://imos.org.au/home/

GOOS moved to the concept of Essential Ocean Variables post the Ocean OBS 2009 and the publishing of the Framework for Ocean Observing (FOO). GOOS reorganized in the same timeframe. The GOOS governance model is divided in three tiers: a multinational Steering Committee to provide oversight, scientific Expert Panels to guide system requirements, and Observation Coordination Groups that implement global unified network execution. The GOOS Project Office facilitates the collaboration between these different governance bodies.

GOOS Expert Panels

1) Physics[124]: Ocean Observations Panel for Climate (OOPC)
2) Biogeochemistry[125]: The International Ocean Carbon Coordination Project (IOCCP)
3) Biological and Ecosystems[126]: new panel
    1.1. Note the GOOS Panel for Integrated Coastal Observation Panel (PICO) was disbanded. The OOPC picked up additional coastal responsibilities.

The GOOS Expert Panels have developed 28 core variables. IOOS has 26 core variables and 10 proposed. IMOS has identified 29 core variables. Table 1 is a comparison of GOOS core variables, IMOS and IOOS

Implementation

GOOS expert panels have developed specification sheets for all variables except ocean color and are linked in Table 1. Neither IOOS nor IMOS developed specifications sheets for the core variables. IOOS uses the attributes within the IGOS coastal theme report as the *de facto* specification sheets, which have been submitted internally within the National Oceanic and Atmospheric Administration (NOAA) observing portfolio management system which requirements variables to be defined according to horizontal, vertical resolution, latency, etc.

Process

Core variables do not sell a program, output and products do; therefore, IOOS has not assessed how as a system they are meeting the core variables. IMOS did assess their system against the variables and the FOO, within the IMOS – National Science and Implementation Plan 2015-25[127] – pages 116-119. This is a format that Canada IOOS can adopt. It suggested that Canada IOOS

[124] GOOS Physics and climate panel:
http://www.goosocean.org/index.php?option=com_content&view=article&id=124&Itemid=281
[125] GOOS Biogeochemistry panel:
http://www.goosocean.org/index.php?option=com_content&view=article&id=80&Itemid=275
[126] GOOS Biology and ecosystem panel:
http://www.goosocean.org/index.php?option=com_content&view=article&id=79&Itemid=273
[127] IMOS National Science and Implementation Plan 2015-25:
http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/documents/IMOS/Plans___Reports/Science_Implementation_Plans/IMOS_National_Science_and_Implementation_Plan_Very_FINAL_V2.pdf

identify what it will accomplish and then determine the variables that will support those requirements and not begin with variables.

Table 1: Core Ocean Variables – comparison of candidate variables being developed by GOOS Physics, Biogeochemistry, and Biology & Ecosystems Panels with variables being observed by IMOS and IOOS

GOOS Panel variables (11+9+8 = 28)	IMOS variables (29)	IOOS variables (26 + 11 proposed)
Physics Panel/OOPC		
1) Sea-surface temperature (SST)	1) Temperature- surface	1) Temperature*
2) Sea-surface salinity (SSS)	*(gap just starting to be addressed)*	2) Salinity*
3) Sea-surface height	2) Sea Surface Height	3) Sea Level**
	(tide gauge network sits outside IMOS)	
4) Sea state	3) Surface waves – amplitude	4) Surface Waves**
	4) Surface waves – spectrum	
5) Sea ice	*(identified gap)*	5) Ice Distribution
6) Surface Current	5) Velocity	6) Surface Currents*
7) Ocean Surface Stress	6) Wind velocity (stress)	7) Wind Speed and Direction*
8) Ocean Surface Heat Flux	7) Air-sea fluxes	8) Heat Flux
9) Sub surface Temperature	8) Temperature- Subsurface	(Temperature – no surface/sub distinction)
10) Sub surface Salinity	9) Salinity	(Salinity – no surface/sub distinction)
11) Sub surface currents	(Velocity – see above)	Not identified
	10) Waves – internal	

GOOS Panel variables (11+9+8 = 28)	IMOS variables (29)	IOOS variables (26 + 10 proposed)
Biogeochemistry Panel/IOCCP		
1) Oxygen	11) Oxygen	9) Dissolved Oxygen*
2) Nutrients	12) Macronutrient concentration	10). Dissolved Nutrients*
3) Inorganic carbon	13) pCO2	11) Partial Pressure of CO2
	14) pH	12) Acidity
	15) Total. Inorg. Carbon	
	16) Alkalinity	
4) Transient Tracers		
5) Suspended Particulates		13) Total Suspended Matter
6) Nitrous Oxide		
7) Stable Carbon Isotope		
8) Dissolved Organic Matter	17) CDOM and Backscatter	14) Colored Dissolved Organic Matter
9) Ocean Colour	18) Chlorophyll a concentration	15) Ocean Color

GOOS Panel variables (11+9+9 = 28)	**IMOS variables (29)**	**IOOS variables (26 + 10 proposed)**
Biology & Ecosystems Panel		
1) Phytoplankton biomass and diversity	19) Phytoplankton species	16) Phytoplankton Species*
	20) Phytoplankton Biomass	Abundance (proposed)
2) Zooplankton (biomass/abundance)	21) Zooplankton Species	17) Zooplankton Species
	22) Zooplankton Biomass	18) Zooplankton Abundance
3) Mangrove/seagrass area	*(not currently in scope for IMOS)*	Submerged Aquatic Vegetation Species/Abundance (proposed)
4) Live Coral	*(AIMS Long Term Monitoring Program)*	Coral Species/Abundance (proposed)
5) Seagrass cover	*(not currently in scope for IMOS)*	
6) Marine turtles, birds, mammals abundance and distribution	23) Top Predators species 24) Top Predators - population	Marine Mammal Species/Abundance (proposed) Sea Bird Species/Abundance (proposed) Sea Turtle Species/Abundance (proposed)
7) Fish abundance and distribution		19) Fish Species 20) Fish Abundance

8) Macroalgal canopy		
	25) Nekton Species	Invertebrate species/abundance (proposed)
	26) Nekton Biomass	
	27) Benthos (% coverage of species)	Micorbial Species/Abundance/Activity (proposed)
	28) Detritus (flux)	Biological Vital rates (proposed)
	29) Primary Productivity	Nekton Diet (proposed)
		Sound (proposed)*

GOOS Panel variables (11+9+7 = 27)	**IMOS variables (29)**	**IOOS variables (26 + 10 proposed)**
Other		
		21) Bathymetry
		22) Bottom Character
		23) Contaminants
		24) Optical Properties*
		25) Pathogens
		26) Stream Flow

Preliminary list of Core Ocean Variables

Background

Before diving into defining core ocean variables, I suggest Canada IOOS discuss the focus of the system, where integration can really make a difference and if collected which variables will advance the goals of Canada IOOS. Variables should be derived based on what services one wants the system to deliver.

The classic questions for these networks are: (1) Will the system be "operational" or "research" focused, and (2) Will the system deliver operational products or be defined by scientific questions? The U.S. Integrated Ocean Observing System (IOOS®) is defined as an operational system but is underpinned by research and development. Australia's Integrated Marine Ocean Observing System (IMOS) is a research infrastructure program that is based on science themes and questions. However, as IOOS and IMOS developed we came to realize that while the initiation of the efforts had a different focus the fundamental issue is how to provide sustained ocean observing. There is not a bright demarcation between "operational" and "research." For example, the IOOS High Frequency Radar Network provides operational support to the United States Coast Guard for search and rescue operations and to the National Oceanic Atmospheric Administration (NOAA) for oil spills, but it also serves as an infrastructure for ecosystem studies. Similarly, the observations collected by IMOS are used to answer science questions AND are used by the Australia Bureau of Meteorological for daily forecasts. A classic example is the Argo program. Argo, an international coalition, is often resourced from research programs (including within the United States), began as an ocean climate variability program but is also an important contribution to operational weather forecasting.

The United States addressed this this issue its National Plan for Civil Earth Observations[128] written under the auspice of the United States – Group on Earth Observations (USGEO). The National plan defines two categories of observations based not on intention but on the duration of the Federal commitment to the period of observations: either sustained over time or experimental and therefore time-limited. Sustained observations may be used to support BOTH public services and research for public interest. Experimental observations may be used to support a variety of purposes, including: advancing human knowledge through basic and applied research, exploring technical innovations, or improving public services. The plan further stated that all civil Earth observations collected by the public sector are considered public good, and that data from systems in any one category maybe reused for purposes other than those for which the observation was originally taken.

[128] National plan for civil earth observatories: https://remotesensing.usgs.gov/2014_national_plan_for_civil_earth_observations.pdf

Recommendation: Canada IOOS take the approach of characterizing the system as focused on sustained observations to support public services and research for public interest. A relationship to those that focus on experimental observations can be defined and as those efforts mature can be targeted for transition to Canada IOOS.
Secondly, like IOOS, Canada IOOS is not starting a new system but integrating already existing systems that are funded through a variety to mechanisms including both national "operational" organizations such as Department of Fish and Oceans (DFO) and research infrastructure projects such as Ocean Tracking Network (OTN). Further Canada IOOS is looking to expand to provincial or territorial, and municipal governments and First Nations. Therefore, it is important as Canada IOOS determine up front who is part of Canada IOOS, those external to Canada IOOS and what is the relationship between those external to Canada IOOS. For example, Fish and Oceans Canada (DFO) is responsible for tides, currents, navigation etc, however the Canadian Coast Guard, a special operating agency within DFO is responsible for oil spill response but they receive their oil spill trajectory forecasts from Environment Canada[129]. Therefore what is the relationship of Canada IOOS and Environment Canada.

It is important to understand where Canada IOOS can a value add. For example, the delivery of nautical charts. Nautical charts carry liability issues and therefore the charting agencies are legally charted in each country. Within the United States, NOAA is named as the national charting agency. While IOOS recognizes bathymetry as a core variable and considers all of NOAA's activities as a contribution to IOOS but the reality is that the nautical charting efforts, by necessity, is a closed community. Therefore, while there is a close relationship between the US IOOS Office in NOAA and the NOAA Office of Coast Survey the production of nautical charting is not dependent on the IOOS enterprise for its data. Will the production of nautical charts be a service of Canada IOOS?

Recommendation: Canada IOOS determines where an integrated observing system can improve services, further scientific knowledge and advance technologies. There are plenty of areas where a Canada IOOS can create efficiencies and will be more successful if the hard decisions of identifying where Canada IOOS does not make sense are made early in the start of the program.

Defining initial list of variables

Hypothesis: Canada IOOS provides sustained observing to support public services and research for public interest

[129] Canadian Coast Guard internal and external support agencies: http://www.ccg-gcc.gc.ca/eng/Ccg/er_National_Response_Plan/app_b

To determine a starting point for the discussion of Canada IOOS variables, I looked at the missions of the various organizations that have been identified as being the foundation of Canada IOOS: DFO, Ocean Tracking Network(OTN); MEOPAR; St. Lawrence Global Observatory (SLGO) and Ocean Networks Canada(ONC). I evaluated the scientific themes of IMOS and appropriateness to Canada IOOS. U.S. IOOS has not defined a specific list of services but broadly supports seven societal benefit areas.

Recommendation: Canada IOOS determine which service and questions will be addressed. Derive the variables that are associated with those services and questions.

Organization Mandates:
Fisheries and Oceans Canada (DFO): Lead federal role in managing Canada's fisheries and safeguarding its waters. Three strategic outcomes: Economically Prosperous Maritime Sectors and Fisheries; Sustainable Aquatic Ecosystems; Safe and Secure Waters.
Services most closely tied to variables across DFO includes:

- Tides, Currents and Water Levels
- Wave forecasting
- Marine Forecasting* (daily forecasts, hazards, hurricane, sea ice**)
- Oil Spill Response*
- Nautical Charting***
- Search and Rescue
- Fishery openings and closures
- Integrated Fisheries Management Plans
- Ocean Sciences and Climate Change Adaptation
    - Climate Change Adaptation Services
    - Impacts of Climate issues – ocean acidification and hypoxia
    - Climate models for risk management and fisheries resources
- Circumpolar Biodiversity Monitoring Programs
- Aquatic Species at Risk
- Aquatic Invasive species
- Environmental management and reporting in regard to aquaculture
- Harmful Algal Bloom Forecasting

* daily forecast, hazard warnings, oil trajectory forecasts are provided from Environment Canada
**sea ice forecasts are provided by the Canadian Ice Service
***provided by the Canadian Hydrographic Service within DFO

Ocean Tracking Network (OTN): Enabling international sustainable management of valued aquatic species by providing knowledge of animal movements, survival, and habitats and of how all are linked to environmental conditions. Fostering technological and operational innovation that will revolutionize our management of the ocean.

Overarching Research Questions

1. What are the physical, chemical, and biological oceanographic linkages that determine the population structure, dynamics, movement, and critical habitat of marine organisms?
2. How will climate variability, change, and anthropogenic activities affect the distribution and abundance of marine organisms?
3. What are the ocean governance implications, including social, economic, and legal dimensions, of OTN findings?

OTN's Frameworks:
Framework 1: How do oceanographic and environmental features (both physical, and biological) affect animal habitat uses, movement and migration
Framework 2: How do aquatic species interactions and areas of ecological significant relate to habitat use, movement patterns and biotic/abiotic features.
Framework 3: How does anthropogenic activities and development influence aquatic animal behavior and ecology?
Marine Environmental Observation, Prediction and Response (MEOPAR): MEOPAR supports interdisciplinary research activities that lead to advances in ocean observation, prediction and/or response which address the interaction between human activity and the marine environment. Research is focused in Two Themes"
Theme 1: Hours to Seasons (Weather) - prediction and rapid response to marine emergencies (e.g. storm surge, hurricanes, oil spills, accidents)
Theme 2: Seasons to Decades (Climate) - longer-term predictions and impacts (e.g. sea level rise, ocean acidification)
St Lawrence Global Observatory (SLGO): SLGO facilitates accessibility, dissemination and exchange of official and quality data as well as electronic information regarding the St. Lawrence ecosystem through the 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. Organized under the following Societal Benefit Areas: Security, Safety; Human Health; Environment; Resource Management; Development; Exploration and Conservation
SLGO has three applications – that I used as a proxy for public services

1. Marine Conditions – Access to Realtime data and forecast data
2. Ocean Forecasts – Water levels, currents, sea ice conditions
3. Biodiversity – Presence, Abundance and distribution of living species

Ocean Networks Canada (ONC): ONC operates world-leading ocean observatories for the advancement of science and the benefit of Canada. The observatories collect data on physical, chemical, biological, and geological aspects of the ocean over long time periods, supporting research on complex Earth processes in ways not previously possible.
Scientific Themes/Questions

- Understanding Human-Induced Change in the Northeast Pacific Ocean

Question 1: What are the magnitudes and rates of changes occurring in the Northeast Pacific Ocean?
Question 2: How will Northeast Pacific Ocean marine ecosystems respond to increasing ocean acidification?
Question 3: How does the depletion of oxygen in coastal waters affect ecosystem services?

- Life in the Environments of the Northeast Pacific Ocean and Salish Sea[130]

Question 4. How are changes in the Northeast Pacific affecting fish and marine mammals?
Question 5: How do benthic marine populations and communities respond to and recover from physical and biological disturbance?
Question 6: What are the functions and rates of seafloor and subseafloor biogeochemical processes?
Question 7: What limits life in the subseafloor?
Question 8: How do the microbial communities regulate and respond to times when oxygen is low and how do these changes affect animal communities?
Question 9: How do ocean transport processes impact primary productivity in the Northeast Pacific?

- Interconnections Among the Seafloor, Ocean, and Atmosphere[131]

Question 10: What are the mechanisms and magnitude of chemical and heat exchanges between the oceanic crust and seawater?
Question 11: In what ways do upper ocean processes influence the formation of aerosols?
Question 12: How large is the flux of methane from the seafloor to the atmosphere?
Question 13: What are the advantages and risks of ocean geoengineering to mitigate climate change?

- Seafloor and Sediment in Motion[132]

Question 14: How is the physical state of the subseafloor in the Northeast Pacific related to earthquake generation?
Question 15: How can we improve prediction of the speed and size of tsunamis?
Question 16: What mechanisms regulate underwater landslides on the Fraser River Delta?

Description of the Spreadsheet

Based on the mandates and questions above, a set of services and research questions were defined. The GOOS core variables are then represented to each of the services, with additional variables taken from IOOS. **Note:** GOOS, US IOOS, IMOS do not characterize variables

[130] ONC Life in the environments of the Northwest Pacific Ocean and Salish Sea: http://www.oceannetworks.ca/science/science-plan/science-themes/life
[131] ONC Interconnections: http://www.oceannetworks.ca/science/science-plan/science-themes/interconnections
[132] ONC Seafloor and sediment in motion: http://www.oceannetworks.ca/science/science-plan/science-themes/seafloor-motion

associated with cabled observatories – while these questions are included in the spreadsheet; the defined variables do not sufficiently address the measurements taken. Additional variables would need to be developed.

Those that are **bolded** can be considered a first list of variables. A quick scan of easily available data across parts of the US IOOS enterprise is included in Table 1. Not unexpectedly most of the physical oceanographic variables are collected. The biogeochemistry variables is focused on hypoxia (oxygen) and ocean acidification. There are pockets of the IOOS system to focuses on nutrients. Not surprising the biological/ecosystem variables are least representative. This does not mean that they are not collected but are often resident in niche data holdings that are not well represented by the US IOOS DMAC or IOOS Regional Portals. This is an area that Canada IOOS could take a leadership role.

Table 1: Quick scan of IOOS variables there could easily be seen through the main data portals.

IOOS Sensor Map	NANOOS	CARICOOS	GCOOS	IOOS ATN	PacIOOS
SST	SST	SST	SST		SST
Temp – depth	Temp -depth		Water Temp		Water Temp
Salinity	Salinity	Salinity	Salinity		Salinity
Waves	Waves	Waves	Waves		Waves
Wind	Wind	Wind	Wind		Winds
Dissolved Oxygen	Dissolved Oxygen		Dissolved Oxygen		Dissolved Oxygen
pH	pH	pH			pH
CO2	CO2	CO2			CO2

Currents	Surface Currents	Currents	Currents		Currents
Chlorophyll (Ocean Color)	Chlorophyll (Ocean Color)	Chlorophyll (Ocean Color)	Chlorophyll (Ocean Color)		Chlorophyll (Ocean Color)
Blue Green Algal		Sargasso	Algae (Red Tide)		
Conductivity					
Water Level	Water Level	Water Level	Water Level		Water Level
Sea Floor Depth (fm buoys, estuary gauges)					
Turbidity	Turbidity		Turbidity		Turbidity
	Nitrate				Nitrate
	Optical Properties				CDOM
	Pathogens				
	Zooplankton				
		Coral Reef Bleaching			

				Marine Turtles, birds, mammal tracks	
				Fish tracks	Fish tracking and distribution
					Bathymetry
					Benthic habitats

Suggested Next Steps:

1. Gather a strategic group to discuss the definition of Canada IOOS system in terms of operational, research or sustained.
2. Debate the public services and scientific themes; determine what Canada IOOS will deliver
3. After determining what Canada IOOS will deliver; complete the variable matrix
4. Determine what variables Canada IOOS is already collecting – do that via data catalogs and not surveys – if it is not visible in a data portal it does not exist (can be done in parallel with #1-3 as an independent check)
5. Compare the matrix based on discussion with what is being collected and finalize a list of those variables that are being collected and those that should be collected.

7.3. PUBLIC AVAILABILITY OF CORE VARIABLES

Format:

The following table includes a list of all Canadian organizations and partners publicly offering variable data in Canada, organized by variable and region. References for each organization are listed below (web url and any additional notes), also organized by variable, subdivided by region. No models or forecasts were included.

From the SOW

This includes identifying who has the capability to monitor the proposed baseline variables

	Region				
Variable	**Pacific**	**St. Lawrence**	**Atlantic**	**Great Lakes**	**Arctic (E-East/W-West)**
Ambient Sound	ONC				ONC (E)
Bathymetry	CHS, DFO, BCMCA	CHS, DFO	CHS, OpenGov, DFO	CHS, DFO	CHS, DFO
Bottom Type	BCMCA				
Currents	ONC (surface, profile), ARGO Canada, Pacific Region Science and Research, The Drift Bottle Project	SLGO (surface, 6m),OTN (surface),	SLGO (surface, 6m), ONC (surface, profile), OTN (surface gliders), , AZMP (surface), AZOMP, Argo Canada		OpenGov, The Drift Bottle Project, Polar Data Catalogue
Fish Abundance and Distribution	OTN, OBIS Canada, IPHC, WCPFC, BCMCA	SLGO, OTN, NAFO, OBIS Canada	SLGO, OTN, NAFO, OBIS Canada	OTN, OBIS Canada	OTN, NAFO, OBIS Canada, Polar Data Catalogue
Ice	ONC	EC, CIS, DFO, AZMP	EC, CIS, DFO, AZMP	EC, CIS, DFO	ONC (E), EC (E/W), CIS, DFO
Inorganic Carbon	NANOOS, ONC, Pacific Region Science and Research	SLGO	MEOPAR, AZOMP, BBMP		ONC(E)
Live Coral	ONC	OpenGov	OpenGov		OpenGov
Marine Mammals	Jasco*, OBIS Canada, BCMCA	SLGO, OTN, OBIS Canada	SLGO, MEOPAR, Jasco*, OTN, OBIS Canada		SLGO(E), (E/W), Jasco (W)*, OBIS Canada, Polar Data Catalogue
Nutrients	ONC, Pacific Region Science and Research	SLGO, AZMP	OpenGov, AZMP, AZOMP, BBMP		ONC (E), Polar Data Catalogue

	Region				
Variable	**Pacific**	**St. Lawrence**	**Atlantic**	**Great Lakes**	**Arctic (E-East/W-West)**
Oxygen	NANOOS,ONC, Pacific Region Science and Research, Argo Canada	SLGO, OTN (surface and profiling gliders; bioprobes), AZMP	ONC, OTN (surface and profiling gliders; bioprobes), AZMP, AZOMP, Argo Canada, BBMP		ONC(E), OpenGov, Polar Data Catalogue
Phytoplankton	Chloro: ONC, OBIS Canada, OpenGov, Pacific Region Science and Research, Ocean Color Database, BCMCA	Fluo: SLGO, AZMP, OTN (profiling glider) Chloro: SLGO, MEOPAR, OTN (surface and profiling gliders), OBIS Canada, Ocean Color Database, AZMP	Biomass/Abundance: OpenGov, AZOMP Fluoro: AZMP, SLGO, OTN (profiling glider) Chloro: SLGO, OpenGov, MEOPAR, OTN (surface and profiling gliders), OBIS Canada, Ocean Color Database, AZMP, AZOMP, OpenGov, BBMP	Chloro: GLOS, Ocean Color Database	Fluoro: Polar Data Catalogue Chloro: ONC (E), Polar Data Catalogue, OBIS Canada, Ocean Color Database
Salinity	NANOOS (surface, 6m), ONC (surface, profile), Argo Canda (profile), OpenGov (surface), Pacific Region Science and Research (surface and profile)	SLGO (surface, profile), MEOPAR (surface, profile), AZMP (surface, profile), OTN (surface,profile),	SLGO (surface), ONC (surface, profile), MEOPAR (surface, profile), AZMP (surface, profile), OTN (surface,profile), Argo Canada (profile), AZOMP (profile), BBMP		ONC (E: surface & profile), OpenGov (surface), Polar Data Catalogue
Sea State	SLGO, NANOOS, CWD, NOAA/EC, ENR	SLGO, CWD, OTN (Wave Glider), ENR, NOAA/EC	SLGO, ONC, CWD, NOAA/EC, OTN (Wave Glider), ENR,	SLGO, GLOS, CWD, NOAA/EC, ENR	CWD (W), ENR (E/W), NOAA/EC
Sea Surface Height	SLGO, TCWL	SLGO, TCWL, AZMP	SLGO, TCWL, AZMP	SLGO, TCWL	TCWL (E/W)
Seagrass Cover	BCMCA				
Surface Heat Flux					
Surface Stress	SLGO, NANOOS, NOAA/EC, ENR, CWD, Pacific Region Science and Research	SLGO, OTN (Wave Glider), ENR, NOAA/EC, CWD	SLGO, OTN (Wave Glider), ENR, NOAA/EC, CWD	SLGO, GLOS, NOAA/EC, ENR, CWD	ENR (E/W), NOAA/EC (W), CWD

	Region				
Variable	**Pacific**	**St. Lawrence**	**Atlantic**	**Great Lakes**	**Arctic (E-East/W-West)**
Temperature	NANOOS (surface & 6m), SLGO (surface & 6m), ONC (profile), MEOPAR (surface), NOAA/EC (surface), Argo Canada (profile), OpenGov (surface and profile), SST Database (surface), Pacific Region Science and Research (surface and profile), ENR (surface)	SLGO (surface, profile), MEOPAR (surface, profile), AZMP (surface, profile), OTN (surface and proflling gliders, bioprobes), ONC, NOAA/EC (surface) ENR (surface), STT Database (surface)	SLGO (surface, profile), ONC (surface, profile), MEOPAR (surface, profile), OTN (surface and profiling gliders, bioprobes), AZMP (surface, profile), NOAA/EC (surface), ENR (surface), Argo Canada (profile), AZOMP (surface and profile), SST Database (surface), BBMP	SLGO (surface, 6m), GLOS (surface), NOAA/EC (surface), SST Database (surface), ENR (surface)	ONC (E: surface, profile, W: surface), OpenGov (surface), SST Database (surface), ENR (surface), NOAA/EC (surface), Polar Data Catalogue (surface and profile)
Zooplankton	OBIS Canada	OTN (profiling glider mounted sonar), OBIS Canada	OpenGov, OTN (profiling glider mounted sonar), OBIS Canada, AZOMP, BBMP		OBIS Canada

References for publicly available variable data:

Variable	Region	References
Ambient Sound	Pacific	● ONC: http://dmas.uvic.ca/DataSearch, data for several locations along BC
	Arctic	● ONC: http://dmas.uvic.ca/DataSearch, hydrophone data for Cambridge Bay
Bathymetry	Pacific	● CHS: http://www.charts.gc.ca/data-gestion/resourcemaps-cartesressources-eng.asp, can select quadrat to see depth lines of that area ● DFO: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer ● BCMCA: http://bcmca.ca/datafeatures/eco_physical_bathymetry/
	St. Lawrence	● CHS: http://www.charts.gc.ca/data-gestion/resourcemaps-cartesressources-eng.asp, can select quadrat to see depth lines of that area ● DFO: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer
	Atlantic	● CHS: http://www.charts.gc.ca/data-gestion/resourcemaps-cartesressources-eng.asp, can select quadrat to see depth lines of that area ● OpenGov: http://open.canada.ca/data/en/dataset/3f78ae16-d59f-494e-bb1f-ffbabb8eff9bhttp://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer ● DFO: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer

Variable	Region	References
	Great Lakes	● CHS: http://www.charts.gc.ca/data-gestion/resourcemaps-cartesressources-eng.asp, can select quadrat to see depth lines of that area ● DFO: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer
	Arctic	● CHS: http://www.charts.gc.ca/data-gestion/resourcemaps-cartesressources-eng.asp, can select quadrat to see depth lines of that area ● DFO: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Bathymetry_500m_ENG/MapServer
Bottom Type	Pacific	● BCMCA: http://bcmca.ca/maps-data/browse-or-search/?cat=12&submit=generate+feature+list, http://bcmca.ca/datafeatures/eco_physical_benthicclasses/, http://bcmca.ca/datafeatures/eco_physical_highrugosity/, http://bcmca.ca/datafeatures/eco_physical_seamounts/
Currents	Pacific	● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=BACWL&deviceCategory=CURRENTMETER. Profile: http://dmas.uvic.ca/DataSearch?location=BACWL&deviceCategory=CURRENTMETER ● Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp ● Pacific Region Science and Research: http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/search-recherche/currentmeter-courantometre-eng.asp ● The Drift Bottle Project: http://www.dfo-mpo.gc.ca/science/data-donnees/driftbottles-bouteillesflottantes/index-eng.html
	St. Lawrence	● SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current>Surface current to show locations of data, then can download data. Profile: (6m) https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current>Current6m current to show locations of data, then can download data
	Atlantic	● SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current>Surface current to show locations of data, then can download data. Profile: (6m) https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current>Current 6m current to show locations of data, then can download data ● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=BFBR&deviceCategory=ADCP400KHZ, current data under ADCP. Profile: http://dmas.uvic.ca/DataSearch?location=BFBR&deviceCategory=ADCP400KHZ, current info under ADCP ● Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp ● AZMP: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/climat/labrador/transport-eng.htm ● AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php
	Arctic	● OpenGov: http://open.canada.ca/data/en/dataset/dc13ea13-657e-4fdd-af45-5c4d29db2060 ● The Drift Bottle Project: http://www.dfo-mpo.gc.ca/science/data-donnees/driftbottles-bouteillesflottantes/index-eng.html ● Polar Data Catalogue: https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=10992, https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11793 can download data or view in Map Viewer
Fish Abundance and Distribution	Pacific	● OBIS Canada: http://www.iobis.org/explore/#/node/9, many data sets available ● IPHC: http://www.iphc.int/research/surveys/survey-data.html/ ● WCPFC: https://www.wcpfc.int/node/4648 ● BCMCA: http://bcmca.ca/maps-data/browse-or-search/?cat=22&submit=generate+feature+list (Commercial fiseries), http://bcmca.ca/maps-data/browse-or-search/?cat=6&submit=generate+feature+list (Fishery observers), http://bcmca.ca/maps-data/browse-or-search/?cat=22&submit=generate+feature+list (trawl)

Variable	Region	References
	St. Lawrence	● SLGO: https://ogsl.ca/bio/?lg=en, select Species group>Fish ● NAFO: https://www.nafo.int/Data/Catch-Statistics ● OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available
	Atlantic	● SLGO: https://ogsl.ca/bio/?lg=en, select Species group>Fish ● NAFO: https://www.nafo.int/Data/Catch-Statistics ● OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available
	Arctic	● NAFO: https://www.nafo.int/Data/Catch-Statistics ● OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available ● Polar Data Catalogue: https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=12841, https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11992, https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11375
Ice	Pacific	● ONC: http://dmas.uvic.ca/DataSearch Search Instrument by category, Ice buoy and Shallow Water Ice profiler
	St. Lawrence	● OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/climat/ice-glace/coverage-couverture-eng.htm, monthly ice coverage for Gulf ● EC: http://www.ec.gc.ca/glaces-ice/?lang=En, select region from map, also http://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?grp=Guest&lang=en ● ”CIS: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html, https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html ● DFO ArcGIS: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Arctic_Voyage_Planning_Guide_ENG/MapServer
	Atlantic	● OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/climat/ice-glace/coverage-couverture-eng.htm, monthly ice coverage for Scotian Shelf and Newfoundland ● EC: http://www.ec.gc.ca/glaces-ice/?lang=En, select region from map, also http://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?grp=Guest&lang=en ● ”CIS: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html, https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html ● DFO ArcGIS: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Arctic_Voyage_Planning_Guide_ENG/MapServer
	Great Lakes	● EC: http://www.ec.gc.ca/glaces-ice/?lang=En, select region from map, also http://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?grp=Guest&lang=en ● CIS: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html, https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html ● DFO ArcGIS: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Arctic_Voyage_Planning_Guide_ENG/MapServer
	Arctic	● EC: http://www.ec.gc.ca/glaces-ice/?lang=En (E/W), select region from map, also http://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml?grp=Guest&lang=en ● CIS: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html, https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html ● ONC: http://dmas.uvic.ca/DataSearch Search Instrument by category, Ice buoy and Shallow Water Ice profiler ● DFO ArcGIS: http://geoportal-geoportail.gc.ca/arcgis/rest/services/Arctic_Voyage_Planning_Guide_ENG/MapServer

Variable	Region	References
Inorganic Carbon	Pacific	• NANOOS: (Vancouver) http://nvs.nanoos.org/Explorer, select pH/CO2 under Filters • ONC: http://dmas.uvic.ca/DataSearch?location=BACVP&deviceCategory=CO2SENSOR#, CO2 Sensor • Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html
	St. Lawrence	• SLGO: https://ogsl.ca/archive/?lg=en, select pH under the Variable section. Can then email request data. Also CO2 (https://ogsl.ca/archive/?lg=en)
	Atlantic	• Meopar: http://oceanviewer.org/atlantic-canada/animals/whale/test1935 • BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php • AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php
	Arctic	• ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=PHSENSOR (E), select pH Sensor under dropdown menu of Arctic
Live Coral	Pacific	• ONC: https://data.oceannetworks.ca/SeaTube?resourceTypeId=1000&resourceId=23543&diveId=1361&time=2016-05-23T07:19:03.000Z multiple videos with annotations of cnidarian, mollus, etc presence
	St. Lawrence	• OpenGov: http://open.canada.ca/data/en/dataset?q=coral&organization=dfo-mpo&sort=
	Atlantic	• OpenGov: http://open.canada.ca/data/en/dataset?q=coral&organization=dfo-mpo&sort=
	Arctic	• OpenGov: http://open.canada.ca/data/en/dataset?q=coral&organization=dfo-mpo&sort=
Marine Mammals	Pacific	• OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available • Jasco: http://www.jasco.com/publications/, various acoustic species tracking, but only papers* • BCMCA: http://bcmca.ca/maps-data/browse-or-search/?cat=10&submit=generate+feature+list (multiple datasets)
	St. Lawrence	• SLGO: https://ogsl.ca/bio/?lg=en, under Survey count you can click each cell and see each survey, species and count • OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available
	Atlantic	• SLGO: https://ogsl.ca/bio/?lg=en, under Survey count you can click each cell and see each survey, species and count • MEOPAR: http://oceanviewer.org/atlantic-canada/animals/whale/test1935, can select whales that have been detected by the gliders • OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available • Jasco: http://www.jasco.com/publications/, various acoustic species tracking, but only papers*
	Arctic	• SLGO: https://ogsl.ca/bio/?lg=en, under Survey count you can click each cell and see each survey, species and count • OBIS Canada: http://www.iobis.org/explore/#/area/259 many data sets available • Jasco: http://www.jasco.com/publications/ (W), various acoustic species tracking, but only papers* • Polar Data Catalogue: https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11992, https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11375

Variable	Region	References
Nutrients	Pacific	• ONC: http://dmas.uvic.ca/DataSearch?location=BACVP&deviceCategory=NITRATESENSOR#, Nitrate sensor • Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/cotesud-southcoast/index-eng.html, http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html
	St. Lawrence	• SLGO: https://ogsl.ca/archive/?lg=en, Select Nitrate from Data Types, or https://ogsl.ca/en/scientist-portal/azmp-shediac • OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables (phosphate, silicate)
	Atlantic	• OpenGov: http://open.canada.ca/data/en/dataset/f8c4efc1-ca70-486c-8ee0-32471f49e9a9, nutrients dataset to be downloaded • OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables (phosphate, silicate) • BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php • AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php • OpenGov: http://open.canada.ca/data/en/dataset/66aa542f-ec6a-4b12-a354-c1f93d20b596
	Arctic	• ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=NITRATESENSOR, Nitrate sensor • Polar Data Catalogue: https://www.polardata.ca/pdcsearch/PDCSearch.jsp?doi_id=11645, https://www.polardata.ca/pdcsearch/ (search for Nutrients and you get CTD data that you can download or view in map viewer with nitrate data at a multitude of stations)
Oxygen	Pacific	• NANOOS: http://nvs.nanoos.org/Explorer, select Oxygen from filters, can download specific data from Vancouver Island buoys • ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=WETLABS_WQM (East), select Oxygen under the "Filter on:" and select instruments per region • Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/cotesud-southcoast/index-eng.html, http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html • Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp
	St. Lawrence	• SLGO: (dissolved) https://ogsl.ca/archive/?lg=en, select Dissolved oxygen under the Variable section. Can then email request data • OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm
	Atlantic	• ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=WETLABS_WQM (East), select Oxygen under the "Filter on:" and select instruments per region • OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm • BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php • AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php • Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp

Variable	Region	References
	Arctic	● ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=WETLABS_WQM (East), select Oxygen under the “Filter on:” and select instruments per region ● OpenGov: http://open.canada.ca/data/en/dataset/dc13ea13-657e-4fdd-af45-5c4d29db2060 ● https://www.polardata.ca/pdcsearch/ (search for oxygen and you get CTD data that you can download or view in map viewer with oxygen data at a multitude of stations)
Phytoplankton	Pacific	● Chlorophyll ○ ONC: http://dmas.uvic.ca/DataSearch?location=KVIP&deviceCategory=WETLABS_WQM, select Water Quality Monitor ○ OpenGov: http://open.canada.ca/data/en/dataset/df70ea18-b5b4-4dd2-8ef7-51b288885389 ○ Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html ○ OBIS Canada: , http://www.iobis.org/explore/#/node/9 ○ Ocean Color Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/ocdb-en.php ○ BCMCA: http://bcmca.ca/datafeatures/eco_mammals_chlorophyll/
	St. Lawrence	● Chlorophyll ○ SLGO: https://ogsl.ca/conditions/?lg=en, Data Catalog: Water>Physico-Chemistry>Chlorophyll, then can download data, or https://ogsl.ca/en/scientist-portal/azmp-shediac ○ OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables ○ OBIS Canada: http://www.iobis.org/explore/#/node/9 ○ Ocean Color Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/ocdb-en.php ● Fluorescence: ○ SLGO:https://ogsl.ca/archive/?lg=en, select Fluorescence under Variable ○ OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables
	Atlantic	● Biomass ○ OpenGov: http://open.canada.ca/data/en/dataset/f8c4efc1-ca70-486c-8ee0-32471f49e9a9, phytoplankton dataset for the Scotian shelf ○ AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php ● Chlorophyll ○ SLGO: https://ogsl.ca/conditions/?lg=en: Water>Physico-Chemistry>Chlorophyll, then can download data ○ MEOPAR: http://oceanviewer.org/cospatial/OTN200/, chlorophyll a transect from glider ○ OpenGov: http://open.canada.ca/data/en/dataset/f8c4efc1-ca70-486c-8ee0-32471f49e9a9, chlorophyll data to be downloaded ○ OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables ○ OpenGov: http://open.canada.ca/data/en/dataset/66aa542f-ec6a-4b12-a354-c1f93d20b596 ○ BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php ○ Ocean Color Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/ocdb-en.php, 5km resolution globally and 1.5km resolution in the Atlantic ○ OBIS Canada: http://www.iobis.org/explore/#/node/9 ● Fluorescence ○ OSD (DFO-AZMP): http://www.isdm.gc.ca/isdm-gdsi/azmp-

Variable	Region	References
		pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables ○ SLGO:https://ogsl.ca/archive/?lg=en, select Fluorescence under Variable
	Great Lakes	● Chlorophyll ○ Ocean Color Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/ocdb-en.php ○ GLOS: http://portal.glos.us/#
	Arctic	● Chlorophyll ○ ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=WETLABS_WQM (E), select Water Quality Monitor ○ Ocean Color Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/ocdb-en.php ○ Polar Data Catalogue: https://www.polardata.ca/pdcsearch/ search for chlorophyll - many data sets ○ OBIS Canada: http://www.iobis.org/explore/#/node/9 there are many data sets available ● Fluorescence: ○ Polar Data Catalogue: https://www.polardata.ca/pdcsearch/ (search for fluorescence and you get CTD data that you can download or view in map viewer with fluorescence data at a multitude of stations)
Salinity	Pacific	● NANOOS: Surface: (Vancouver) http://nvs.nanoos.org/Explorer, select Salinity from filters, can download data from individual buoy. Profile: (Vancouver) http://nvs.nanoos.org/Explorer, Select Salinity from FIlter, one station along Vancouver area at -20ft ● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=KVIP.C2&deviceCategory=CTD, select CTD. Profile: http://dmas.uvic.ca/DataSearch?location=KVIP.C2&deviceCategory=CTD, select CTD ● Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp ● OpenGov: http://open.canada.ca/data/en/dataset/dc13ea13-657e-4fdd-af45-5c4d29db2060, http://open.canada.ca/data/en/dataset/719955f2-bf8e-44f7-bc26-6bd623e82884 ● Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html, http://www.dfo-mpo.gc.ca/science/data-donnees/cotesud-southcoast/index-eng.html

Variable	Region	References
	St. Lawrence	● Surface:SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Salinity to show locations of data, then can download data. Profile: https://ogsl.ca/archive/?lg=en, select Salinity ● MEOPAR:Surface:http://oceanviewer.org/atlantic-canada/salinity/global-rtofs/test600, select Salinity from Variables. Profile: http://oceanviewer.org/atlantic-canada/salinity/global-rtofs/test600, salinity transect from glider (click glider in Saint Lawrence) ● OSD (DFO-AZMP): Surface: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm. http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of the Gulf with year to view profiles of various variables
	Atlantic	● SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Salinity to show locations of data, then can download data ● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=BFIP&deviceCategory=CTD, select CTD under Minas Passage. Profile: http://dmas.uvic.ca/DataSearch?location=BFIP&deviceCategory=CTD, select CTD under Minas Passage ● MEOPAR:Surface: http://oceanviewer.org/atlantic-canada/salinity/global-rtofs/test600, select Salinity from Variables. Profile: http://oceanviewer.org/cospatial/OTN200/, salinity transect from glider ● OSD (DFO-AZMP): Surface: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm. Profile: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables ● BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php ● Argo Canada: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php ● AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php
	Arctic	● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=CTD (E), select CTD under dropdown menu. Profile: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=CTD (E), select CTD ● OpenGov: http://open.canada.ca/data/en/dataset/dc13ea13-657e-4fdd-af45-5c4d29db2060 ● Polar Data Catalogue: https://www.polardata.ca/pdcsearch/ (search for oxygen and you get CTD data that you can download or view on the map viewer for multiple stations), https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11793
Sea State	Pacific	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Wave>Maximum Height, Mean Height and Period to show locations of data, then can download data ● NANOOS: (Vancouver Island) http://nvs.nanoos.org/Explorer, select Surface Waves ● CWD: http://www.isdm.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp, select regions like Central Dixon Entran, Halibut Bank, South Moresby, etc...no search engine for specific regions ● NOAA/EC: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of two Pacific regions, area and buoy for wave height data

Variable	Region	References
	St. Lawrence	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Wave>Maximum Height, Mean Height and Period to show locations of data, then can download data ● ● CWD: http://www.isdm.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp. Select data for Magdalen Shallows, Anticosti, Iles de la Madeleine, Point Escuminac, etc...no search engine for specific regions ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select Gulf of St-Lawrence region, area and the one buoy for wave height data ● NOAA/EC: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data
	Atlantic	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Wave>Maximum Height, Mean Height and Period to show locations of data, then can download data ● ONC: http://dmas.uvic.ca/DataSearch?location=BFBR&deviceCategory=ADCP400KHZ, select ADCP under Minas Passage ● CWD: http://www.isdm.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp, select any Atlantic region areas for data. Gannet Rock, Halifax, etc...no search engine for specific regions ● NOAA/EC: http://www.ndbc.noaa.gov/, select Nova Scotia in right sidebar, then can click on EC buys for data ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of three Atlantic regions, area and buoy for wave height data
	Great Lakes	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Wave>Maximum Height, Mean Height and Period to show locations of data, then can download data ● GLOS: http://glbuoys.glos.us/, column for wave height ● CWD: http://www.isdm.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp. Select data for Gros Cap region, Port Stanley, Georgian Bay, West Lake Ontario, etc.. ● NOAA/ECCC: http://www.ndbc.noaa.gov/, select US-Great Lakes (East) region, then click on buoys ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of three Great Lakes regions, area and buoy for wave height data
	Arctic	● CWD: http://www.isdm.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp, select Tuktoyaktuk for (E) ● NOAA/EC: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data ● ENR: http://weather.gc.ca/marine/index_e.html
Sea Surface Height	Pacific	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current Level to show locations of data, then can download data ● TCWL: http://www.isdm.gc.ca/isdm-gdsi/twl-mne/maps-cartes/inventory-inventaire-eng.asp, select region and buoy, then can download sea level height file, also by locations with available observations: http://www.waterlevels.gc.ca/eng/data#s2
	St. Lawrence	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current Level to show locations of data, then can download data ● TCWL: http://www.isdm.gc.ca/isdm-gdsi/twl-mne/maps-cartes/inventory-inventaire-eng.asp, select region and buoy, then can download sea level height file, also by locations with available observations: http://www.waterlevels.gc.ca/eng/data#s2 ● AZMP: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/climat/msl-nem-eng.asp
	Atlantic	● SLGO: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Current Level to show locations of data, then can download data ● TCWL: http://www.isdm.gc.ca/isdm-gdsi/twl-mne/maps-cartes/inventory-inventaire-eng.asp, select region and buoy, then can download sea level height file, also by locations with available observations: http://www.waterlevels.gc.ca/eng/data#s2 ● AZMP: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/climat/msl-nem-eng.asp

Variable	Region	References
	Great Lakes	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Current Level to show locations of data, then can download data ● DFO (TCWL): Tides, Currents, and Water Levels, http://www.waterlevels.gc.ca/eng/find/region/6, select each lake for detailed water height records, also by locations with available observations: http://www.waterlevels.gc.ca/eng/data#s2
	Arctic	● TCWL: http://www.isdm.gc.ca/isdm-gdsi/twl-mne/maps-cartes/inventory-inventaire-eng.asp (E/W), select region and buoy, then can download sea level height file
Seagrass Cover	Pacific	● OBIS Canada: http://www.iobis.org/explore/#/dataset/31, http://www.iobis.org/explore/#/dataset/2815 ● BCMCA: http://bcmca.ca/maps-data/browse-or-search/?cat=18&submit=generate+feature+list
Surface Heat Flux	No Data	
Surface Stress	Pacific	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Air>Direction/Vitesse to show locations of data, then can download data ● NANOOS: http://nvs.nanoos.org/Explorer, select "Wind" from filters, download specific buoys around Vancouver Island ● NOAA/EC: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of two Pacific regions, area and weather station for wind data ● CWD: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm ● Pacific Region Science and Research: http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/buoydata-donneebouee/index-eng.html
	St. Lawrence	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Air>Direction/Vitesse to show locations of data, then can download data ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select Gulf of St Lawrence region, area and weather station for wind data ● NOAA/EC: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data ● CWD: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm
	Atlantic	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Air>Direction/Vitesse to show locations of data, then can download data ● ● NOAA/EC: http://www.ndbc.noaa.gov/, select Nova Scotia in right sidebar, then can click on EC buys for data ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of three Atlantic regions, area and weather station for wind data ● CWD: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm
	Great Lakes	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Air>Direction/Vitesse to show locations of data, then can download data ● GLOS: http://glbuoys.glos.us/, column for wind strength ● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select one of three Great Lakes regions, area and weather station for wind data ● NOAA/EC: http://www.ndbc.noaa.gov/, select Nova Scotia in right sidebar, then can click on EC buys for data ● CWD: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm
	Arctic	● Environment & Natural Resources (ENR): http://weather.gc.ca/marine/index_e.html (E/W), select E or W region, area then weather station for wind data ● NOAA/EC: http://www.ndbc.noaa.gov/, select Nova Scotia in right sidebar, then can click on EC buys for data ● CWD: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm

Variable	Region	References
Temperature	Pacific	• NANOOS: Surface: http://nvs.nanoos.org/Explorer, buoy from Hakai Institute. Profile: http://nvs.nanoos.org/Explorer, select Water Temperature from FIlters, one station along Vancouver Island at 6m depth • SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Temperature to show locations of data, then can download data.Profile: data for 6m depth in app • ONC:Surface: http://dmas.uvic.ca/DataSearch?location=KVIP.C2&deviceCategory=CTD, select CTD. Profile: http://dmas.uvic.ca/DataSearch?location=KVIP.C2&deviceCategory=CTD, select CTD • MEOPAR: Surface: http://oceanviewer.org/pacific-canada/water-temperature/global-rtofs/test557, Select Water Temperature under Variables and change region to Pacific Canada • NOAA/EC: Surface: http://www.ndbc.noaa.gov/, select North Pacific in right sidebar, then can click on EC buys for data • Environment & Natural Resources (ENR): Surface: http://weather.gc.ca/marine/index_e.html (E/W), select one of two Pacific regions, area and buoy for temperature data • Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp • OpenGov: http://open.canada.ca/data/en/dataset?organization=dfo-mpo&page=2, http://open.canada.ca/data/en/dataset/719955f2-bf8e-44f7-bc26-6bd623e82884 • Pacific Region Science and Research: http://www.dfo-mpo.gc.ca/science/data-donnees/cotesud-southcoast/index-eng.html, http://www.dfo-mpo.gc.ca/science/data-donnees/line-p/index-eng.html • STT Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/sst-en.php
	St. Lawrence	• SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select “Data catalog” and choose Temperature to show locations of data, then can download data. Profile: also 6m depth in app • MEOPAR: Surface: http://oceanviewer.org/atlantic-canada/water-temperature/global-rtofs/test554, select Water Temperature from Variables. Profile: http://oceanviewer.org/atlantic-canada/water-temperature/global-rtofs/test554, temperature profile from glider (click glider in Saint Lawrence) • Environment & Natural Resources (ENR): Surface: http://weather.gc.ca/marine/index_e.html (E/W), select Gulf of St Lawrence region, area and the buoy for temperature data • NOAA/EC: http://www.ndbc.noaa.gov/ • ONC: http://dmas.uvic.ca/DataSearch • OTN: http://gliders.oceantrack.org/ • AZMP: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/hydro/index-eng.html • STT Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/sst-en.php

Variable	Region	References
	Atlantic	● SLGO: Surface: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Temperature to show locations of data, then can download data. Profile: also 6m depth data? ● ONC: Surface: http://dmas.uvic.ca/DataSearch?location=BFIP&deviceCategory=CTD, select CTD under Minas Passage. Profile: http://dmas.uvic.ca/DataSearch?location=BFIP&deviceCategory=DEPTH_TEMP, select Temperature and Depth Logger ● MEOPAR:Surface: http://oceanviewer.org/atlantic-canada/water-temperature/global-rtofs/test554, select Water Temperature from Variables. Profile: http://oceanviewer.org/cospatial/OTN200/, temperature transect from glider ● OSD (DFO-AZMP): Surface: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables, also: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/climat/sst-tsm/sst-tsm-eng.asp, http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/climat/stations/hydrographi-eng.htm, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm. Profile: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/hydro/section/yearly-annuelle-eng.html?a=7&y=2014, Select region of Atlantic Canada with year to view profiles of various variables, also: http://www.isdm.gc.ca/isdm-gdsi/azmp-pmza/climat/stations/hydrographi-eng.htm, http://www.isdm.gc.ca/isdm-gdsi/ocean/index-eng.htm ● NOAA/EC: Surface: http://www.ndbc.noaa.gov/, select Nova Scotia in right sidebar, then can click on EC buys for data ● OTN (Ocean Tracking Network) Surface: gliders.oceantrack.org. Profile: gliders.oceantrack.org ● Environment & Natural Resources (ENR): Surface: http://weather.gc.ca/marine/index_e.html (E/W), select one of three Atlantic regions, area and buoy for temperature data ● BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php ● Argo Canada: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canada/cd-dc-eng.asp ● AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php ● STT Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/sst-en.php
	Great Lakes	● SLGO: https://ogsl.ca/conditions/?lg=en, select "Data catalog" and choose Temperature to show locations of data, then can download data ● GLOS: http://glbuoys.glos.us/, column for water temp ● Environment & Natural Resources (ENR): Surface: http://weather.gc.ca/marine/index_e.html (E/W), select one of three Great Lakes regions, area and buoy for temperature data ● NOAA/EC: Surface: http://www.ndbc.noaa.gov/ ● STT Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/sst-en.php
	Arctic	● ONC: http://dmas.uvic.ca/DataSearch?location=CBYIP&deviceCategory=CTD (E), select CTD in Arctic dropdown menu ● NOAA/EC: Surface: http://www.ndbc.noaa.gov/ ● Environment & Natural Resources (ENR): Surface: http://weather.gc.ca/marine/index_e.html (E/W), select one of three Great Lakes regions, area and buoy for temperature data ● OpenGov: http://open.canada.ca/data/en/dataset/dc13ea13-657e-4fdd-af45-5c4d29db2060 ● SST Database: http://www.bio.gc.ca/science/data-donnees/base/data-donnees/sst-en.php ● Polar Data Catalogue: https://www.polardata.ca/pdcsearch/PDCSearchDOI.jsp?doi_id=11793, https://www.polardata.ca/pdcsearch/ (search for temperature and you'll get CTD data that you can download or view on the map viewer for multiple stations)
Zooplankton	Pacific	● OBIS Canada: http://www.iobis.org/explore/#/node/9, many data sets available
	St. Lawrence	● OBIS Canada: http://www.iobis.org/explore/#/node/9, many data sets available

Variable	Region	References
	Atlantic	• OBIS Canada: http://www.iobis.org/explore/#/node/9, many data sets available • OpenGov: http://open.canada.ca/data/en/dataset?q=zooplankton, http://open.canada.ca/data/en/dataset/66aa542f-ec6a-4b12-a354-c1f93d20b596 • BBMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/bbmp-pobb/measurements-mesures-en.php • AZOMP: http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/labrador/labrador-en.php, http://www.bio-iob.gc.ca/science/monitoring-monitorage/azomp-pmzao/slope-pente/slope-pente-en.php
	Arctic	• OBIS Canada: http://www.iobis.org/explore/#/node/9

7.4. VARIABLE READINESS

This document combines variable readiness and availability by region (research by Dr. Willis in white, by K. Ransier and J. Hurtubise in blue). Level of readiness (based on GOOS's standards) is listed for each organization's recorded variables. Note: some redundancy due to difference in level of assessment (i.e. organization-level vs. project-level).

Readiness Legend
C = Concept
P = Pilot
M = Mature
MT LC = Mature technology, but low coverage
M SG = Mature, but some gaps in coverage

	Variables																							
Observing Organizations and Elements	Ambient sound	Bathymetry	Bottom Type	Current-surface	Current subsurface	Fish Abundance and Distribution	Ice	Inorganic Carbon	Live Coral	Marine Mammals	Nutrients	Oxygen	Phytoplankton	Salinity - surface	Salinity - subsurface	Sea State	Sea Surface Height	Seagrass Cover	Surface Heat Flux	Surface Stress	Temperature - Surface	Temperature - Subsurface	Zooplankton	**Remarks**
ONC - HF Radar				M												P								Regional capacity
ONC- ADCP					M																			Regional capacity
ONC - Profiling gliders	M											M			M							M		Regional capacity
ONC - Ferry boat routes												M	M	M							M			
ONC - Observatories	M			M	M		M	M	M	M		M	M	M	M	P	M		M	M	M	M	M	
OTN - Acoustic Tracking						P/M				P/M				M	M						M	M		M - sustained funding and close gaps
OTN - Wave glider										P											P			Not a national capability

Observing Organizations and Elements	Variables																							Remarks
	Ambient sound	Bathymetry	Bottom Type	Current-surface	Current subsurface	Fish Abundance and Distribution	Ice	Inorganic Carbon	Live Coral	Marine Mammals	Nutrients	Oxygen	Phytoplankton	Salinity - surface	Salinity - subsurface	Sea State	Sea Surface Height	Seagrass Cover	Surface Heat Flux	Surface Stress	Temperature - Surface	Temperature - Subsurface	Zooplankton	
OTN/MEOPAR - Profiling glider program					P					P				P	P						P	P		Not a national capability
DFO - Argo														M	M						M	M		
DFO - Tide gauges (national network)																	M							
DFO - current meter - not available to external users				M	M																			
MEOPAR - HF Radar				M																				
MEOPAR - Project based								P		P			P	P	P	P					P	P		Research projects sustained ?
Polar data catalogue																								Contacted Julie Friddell for more info
ECCC - Buoy network																M				M	M			
Canadian Ice Service							M																	
Canadian Hydrographic Services		M																						
OceanColor													M								M			
NANOOS				M				M				M		M	M	M				M	M	M		Buoy and weather from Hakai Institute

Observing Organizations and Elements	Variables																							Remarks
	Ambient sound	Bathymetry	Bottom Type	Current-surface	Current subsurface	Fish Abundance and Distribution	Ice	Inorganic Carbon	Live Coral	Marine Mammals	Nutrients	Oxygen	Phytoplankton	Salinity - surface	Salinity - subsurface	Sea State	Sea Surface Height	Seagrass Cover	Surface Heat Flux	Surface Stress	Temperature - Surface	Temperature - Subsurface	Zooplankton	
AOOS																					M			
SLGO				M	M	M	M	M		M	M	M	M	M	M	M	M			M	M	M		Regional Capacity
ONC	M			M	M	M	M	M			M	M	M	M	M	M	M				M	M	M	
MEOPAR				M				M		M			M	M	M	M				M	M	M		
OTN				M	M	M				M		M	M	M	M	M				M	M	M	P	
GLOS													M			M				M	M	M		Regional capacity
Polar data catalog				P	P	P				P	M	M	M	M	M						M	M		
UN-WCMC									M	M								M						Large datasets, but no ongoing research
OBIS						M				M			M					M					M	
BCMCA		M	M			M				P			M					M						Regional capacity
NAFO						M																		Regional capacity
IPHC						M																		Regional capacity
WCPFC						M																		Regional capacity
DFO - Tides, currents and water levels				M													M			M				National capacity
DFO - Canadian wave data																M				M				National capacity

Observing Organizations and Elements	Variables																							Remarks
	Ambient sound	Bathymetry	Bottom Type	Current-surface	Current subsurface	Fish Abundance and Distribution	Ice	Inorganic Carbon	Live Coral	Marine Mammals	Nutrients	Oxygen	Phytoplankton	Salinity - surface	Salinity - subsurface	Sea State	Sea Surface Height	Seagrass Cover	Surface Heat Flux	Surface Stress	Temperature - Surface	Temperature - Subsurface	Zooplankton	
DFO - Ocean Color Database													M											
DFO - OpenGov		M		M	M				M		M	M	M	M	M						M	M	M	Regional coverage varies
DFO - AZMP				M			M				M	M	M	M	M		M				M	M		Regional capacity
DFO - AZOMP				M				M			M	M	M	M	M						M	M	M	Regional capacity
DFO - BBMP								M			M	M	M	M	M						M	M	M	Regional capacity
DFO - SST Database																					T			
DFO - The Drift Bottle Project				M																				
DFO - Pacific Region				M	M			M			M	M	M	M	M					M	M	M		Regional capacity
ECCC							M									M				M				
NOAA/EC																M				M	M			
Environment and Natural Resources				M			M									M				M	M	M		National capability
Overall	**M T L C**	**M**	**C**	**M T L C**	**M T L C**	**M**	**M**	**M**	**P**	**M**	**M S G**	**M**	**M**	**M**	**M T L C**	**M**	**M**	**P**	**N C**	**M**	**M**	**M L C**	**M**	

7.5. BECOMING A GOOS REGIONAL ALLIANCE

Draft: 28 Sept 2017
Compiled by: Dwight Owens

Executive Summary

This document summarizes principles and guidelines for becoming a GOOS Regional Alliance (GRA). There are different GRA varieties, but CIOOS would most likely fit as a national system. To become an approved GRA, an organization must conform to GOOS principles and guidelines, while cooperating effectively with overlapping neighboring and thematic GRAs. There are also a range of representation and reporting responsibilities.

GOOS principles include the need for a **designed**, **standardized**, **long-term, policy-driven** approach, which covers the **end-to-end** process from data capture to production of finished **products**. The GOOS focus is **global**, which means that GRAs should aim to contribute **high-quality** data that helps address questions and needs at the global scale. At the same time, the GRA must **flexibly coexist** and interoperate with other contributors, and evolve **incrementally** over periodic **review** cycles. **Individual** GRAs operate autonomously, providing **voluntary** contributions to the global scientific community, while also helping **support** organizations in less-developed countries to participate and benefit.

Specific guidelines include the need for:

- A planned approach
- End-to-end data management
- Networked, timely, operational delivery of value-added data products for:
    - Operational agencies
    - Scientists
    - Data managers
- User-relevant data processing
- Continuously managed databases
- Quality control
- Standards-conformant metadata
- Feedback and improvement loops
- Permanent archives

What is a GOOS Regional Alliance (GRA?)

GRAs are coalitions of nations and/or institutions which share GOOS principles and goals, but are mostly concerned with local priorities and organized around regional seas or coastal environments. There are 13 so far. Although many ocean observing systems are established to serve national purposes, many now contribute, through GRAs, to the global system. GRAs:

- Integrate national needs into regional systems
- Deliver benefits of GOOS strategies/structures/programmes, at
- National and regional levels, and
- At the global level.

GRA Types and where CIOOS would fit

GRA types include:

- Political consortia: (GRASP -- Pacific S. America, EuroGoos, GOOS Africa, SEAGOOS -- S.E. Asia)
- Basins and regions: Black Sea, Indian Ocean, Mediterranean
- Small Island Developing States: Pacific Islands, Caribbean
- Thematic: N.E. Asia, Upper SW and Tropical Atlantic
- National systems: US IOOS, IMOS

The Canadian Integrated Ocean Observing System would most likely fit as a **National system**, although a consortium with NANOOS, AOOS, GLOS, MARACOOS and NERACOOS might be considered.

Global Regional Policy 2013

GRAs were introduced to integrate national needs into a regional system to deliver benefits of GOOS at various levels. They facilitate the advancement of GOOS to enhance scientific and societal benefits and provide mutual support. GRAs facilitate:

- Sustained ocean observing
- Data management
- Modelling & other services

GRA Roles

1. Uphold GOOS Principles (see below)
2. Implement a Framework for Ocean Observing
3. Serve as platforms for:
    1. Identifying requirements for societal benefit areas
    2. Transboundary observing networks
    3. Delivering real-time / archived data streams
    4. Provided unrestricted access to data
    5. Provide data products and model output for societal benefit
    6. Assessment of readiness, capacity and performance
4. Develop regional capacity through:
    1. Sharing experiences, success stories, best practices
    2. Seeking funding
    3. Developing partnerships
    4. Working with GOOS, JCOMM, IODE capacity-building programmes
    5. Scholarships, exchanges, workshops
5. Encourage development of GRAs and OOSs by:
    1. Promoting OOS services

2. Advancing Science & Tech
3. Addressing gaps at regional/national levels
4. Participating at international level.

Qualifications

1. Formed via recommendation from applicable bodies
2. Must conform to GOOS principles and guidelines
3. Cooperate with overlapping GRAs to ensure effective use of resources to benefit all

GRA Responsibilities

1. Interface with GOOS
    1. Representative on GOOS Regional Council
    2. Bi-annual GOOS Regional Forum
    3. Annual report
    4. Respond to GOOS implementation plans
    5. Participate in activities agreed by Regional Council
    6. Public management information
2. Reports to GOOS Steering Committee
    1. Extent of implementation of GOOS principles
    2. Status of regional observing and forecasting systems
    3. Data quality and availability reporting
    4. Downstream services for users

GOOS Principles

There are 2 sets of principles, those pertaining to design and those describing participation.

Design Principles

D1. Planned

"GOOS is based on a plan designed to meet defined objectives on the basis of user needs."

- Based on a designed strategy, not an opportunistic assembly of whatever is available
- States observations required for each objective.
- Define how objectives address user needs ("public good")
- Systematically designed, with careful attention to spatial/temporal sampling, precision, accuracy, calibration and appropriateness for user needs (from GOOS-103 Data/Info Management Plan)

D2. Long term

"The design assumes that contributions to GOOS are long term."

- Sustained, ongoing or of indefinite lifetime.
- If limited-term observations are included, they contribute to the long-term dataset.

D3. Reviewed

"The design will be reviewed regularly."

- GOOS will evolve.
- Essential element is continual evaluation of system design through analysis of its products.
- Frequent review and adaptation required.

D4. Flexible

"The design allows for flexibility of technique."

- Observation methods can differ,...
- … as long as standard is adequate for purpose.

D5. Global

"GOOS is directed towards global problems and/or those ubiquitous problems benefiting from global observing systems."

- Subset of needs addressed most effectively through GOOS.
- May be a large-scale scheme of common observations.
- May only be possible through a globally coordinated/facilitated system of observations.
- Even local needs may benefit from globally coordinated context.
- Globally focused needs should not prejudice existing local systems.

D6. End-to-end

"The design covers the range from data capture to end products and services."

- Known pathway or workflow from observation to finished product.
- Process design with end user and uses in mind.

D7. Data Policy Driven

"The management, processing and distribution of data will follow a specified data policy."

- Commitment to establish, maintain, validate, make accessible, and distribute high-quality long-term data following internationally agreed standards.
- Adequate procedures for acquisition and retention.
- Includes metadata.
- Processed to a suitable level for operational data products.
- Described in internationally accessible online directories.
- Full, open, timely sharing of data and products for non-commercial purposes.

D8. Co-existent

"The design takes into account the existence of systems outside of GOOS that can contribute to and/or benefit from GOOS."

- Built upon existing regional/national/global systems of data management systems.
- Designed to co-exist with and interact cooperatively to mutual benefit with other systems.
- Some external systems may serve as central points for collection and management of certain types of data, subsets of which may be suitable for contribution to GOOS.

D9. Quality Assured

"The design takes into account quality assurance procedures."

- QA procedures are integral to GOOS.
- QA built into the design and acceptance strategy.
- Strong oversight is needed, to ensure continual review, assessment, and improvement.
- Continuous examination, including QAQC practices, quality of data and products (from GOOS-103 Data/Info Management Plan)

Participation Principles

P1. Plan-based

"Contribution to GOOS will be compliant with plans developed and agreed on the basis of the above design principles."

- Planned implementation based on design principles.

P2. Data Policy Compliant

"Contributions will be compliant with a defined GOOS data policy."

- GOOS data policy compliance is prerequisite for participation.

P3. Sustained

"Contributions should reflect an intent for sustained observations."

- Must be the intent to make sustained commitment.

P4. Quality Assured

"Standards of quality will apply to GOOS contributions."

- Quality testing of GOOS data.
- Agreed-upon QA procedures.

P5. Leverages Existing Systems

"Implementation will be effected using existing national and international systems and organizations where appropriate."

- Proliferation of new systems to serve GOOS alone is discouraged.
- Existing systems can be expanded or adapted to meet GOOS requirements.

P6. Incremental

"Implementation will be incremental and progressive, whilst bearing in mind the long term goals."

- Gradual and evolutionary approach.
- Incremental contributions are still effective.

P7. Supportive

"Participation in GOOS implies an undertaking to help less-developed countries to participate and benefit."

- GOOS meant to serve all humankind.
- Participants should assist less able countries where possible.

P8. Independent

"Participants will have full autonomy in the management of their contributions to GOOS."

- Different practices used by different countries and agencies.
- GOOS not involved with internal processes.
- Instead, GOOS encourages adherence to QA protocols, data exchange policy and GOOS principles.

P9. Voluntary

"Contributing nations and organizations will reserve the right to determine and limit their contribution to GOOS."

- Nations retain full control of resources and contributions to GOOS.

P10. GOOS Conformant

"Use of the GOOS 'label' implies conformity with the relevant principles of GOOS."

- GOOS acronym suggests quality and dependability.
- Anything with GOOS label should conform with GOOS Principles.

GOOS DATA & INFO MANAGEMENT REQUIREMENTS & GUIDELINES

The following drawn from the GOOS-103 Data/Info Management Plan (2001).

General guidelines

- Programmes must be sustained and long-term.
- Programmes should be systematically designed with careful attention to spatial/temporal sampling, precision, accuracy, calibration and attunement with user needs.
- Continuous examination of the observation programme, QAQC practices, quality of data & products.
- Cost-effective.
- Timely.
- Conform to established standards when possible.
- Provide access to metadata of acceptable standard.

Specific guidelines

Planned Process

- Pre-planning for: observing network, observation frequencies, data management system capabilities, products produced, delivery schedule, distribution methods.
- Ongoing updates of plans as knowledge and applications develop.
- Must not depend on opportunistic datasets.
- Must meet predefined standards and specifications.
- GOOS data comprise a subset of data collected globally.
- GOOS data should be distinct, separable from other data sets.
- GOOS data must be scientifically approved as meeting GOOS standards.

Operational Components

- Most GOOS systems will have operational data flows, which means they will be:
    - Timely
    - Mostly free of large gaps or periods of bad data.
- Delivery timeframe should meet user needs and expectations, including users involved in forecasting and numerical weather prediction.

Networked

- All GOOS system data centres will operate websites for electronic provision of data to users.
- Two preferred delivery networks will be the GTS (for weather/forecasting-related data) and Internet (for other data types). High-speed research networks may not be usable for operational purposes.

Processing

- Emphasis on delivering complex predictions and useful scientific products.
- Results from end-to-end approach that involves modeling and assimilation.
- Value-added processing must be timely.

Products for Data Managers

- Assist managers in monitoring data flow and identifying problems with quality, completeness and timeliness.

Continuously Managed Databases

- Always contain the “best”, highest resolution copy, which replaces earlier versions. Metadata identify the current active version and processing history.

Scientific Participation

- Scientific community involved in assuring that data products delivered are of high quality, of use to the community, and are informative.

Quality Control/Assembly Requirements

- GOOS encourages increased QC, which occurs closer to the observations, through automated procedures where possible. QC flagging is recommended.
- Data assembly is a growing need, with more sources assembled/integrated in more combinations, and early low-resolution versions of data replaced with processed higher-resolution versions.

Metadata Standards

- Metadata must be stored with the data, according to agreed standards.

Feedback

- Two types of feedback: data collection issues and data accuracy/usefulness
- Feedback will help correct:
    - Problems in data collection
    - Timeliness issues
    - Data/metadata errors, gaps
    - Model deficiencies
- Feedback will also help improve:
    - Data product design (to meet user needs)
    - Value of services being provided.

Permanent Archives

- Physical in-situ data archives are mostly adequate, but improvements in timeliness/completeness/metadata standardization needed.

- Biological and chemical data archival not at same levels, so further improvements are needed.
- Satellite data and in-situ data products not always well organized or documented, so improvements here are needed as well.
- Active data rescue programme recommended for historical archives that are of sufficient quality and applicability to the applications being served by GOOS.

End-to-end Data Management

- Responsibilities of centres providing data and information on behalf of GOOS will include:
    - Acquisition
    - Analysis and QC
    - Product generation
    - Scheduled delivery
    - Long-term archival
    - Web-based/online access to data and metadata
    - Analyses of data flow and temporal/spatial coverage

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7.6. ACRONYMS AND SPECIAL VOCABULARY

ACDD	Attribute Con~~e~~vention for Data Discovery
ADCP	Acoustic Doppler Current Profiler
AODN	Australian Ocean Data Network
AOOS	Alaska Ocean Observing System
API	Acrobat Plug-In
AZMP	Atlantic Zone Monitoring Program
AZOMP	Atlantic Zone Off-Shore Monitoring Program
BBMP	Bedford Basin Monitoring Program
BCMCA	British Columbia Marine Conservation Analysis
BODC	British Oceanographic Data Centre
CARICOOS	Caribbean Coastal Ocean Observing System
CASRAI	Consortia Advancing Standards in Research Administration Information
CDOM	Colored Dissolved Organic Matter
CF	Climate and Forecast metadata conventions
CGVD	Canadian Geodetic Vertical Datum
Chl	Chlorophyll
CHS	Canadian Hydrographic Service
CIHR	Canadian Institutes of Health Research
CIOOS	Canadian Integrated Ocean Observing System
CIS	Canadian Ice Service
CKAN	CKAN Open-source data management platform
CMECS	Coastal and Marine Ecological Classification Standard
CMOC	Centre for Marine-Meteorological and Oceanographic Climate Data
CODAR	Coastal Ocean Dynamics Applications Radar
COTS	Crown Of Thorns Starfish
CSR	Cruise Summary Report
CSV	Comma-separated Values
CSW	Catalogue Service for the Web
CTD	Conductivity, Temperature, and Depth instrument
CWD	Canadian Wave Data
DAC	Data Acquisition Centre
DataONE	Data Observation Network for Earth
Dataverse	An open-source research data repository software package
DCAT	Data Catalog Vocabulary
DFO	Department of Fisheries and Oceans Canada
DIC	Dissolved Inorganic Carbon
DMP	Data Management Platform
DOI	Digital Object Identifier
DSA	Data Seal of Approval
EBV	Essential Biodiversity Variables
EC	Environment Canada
ECCC	Environment and Climate Change Canada
ECV	Essential Climate Variable
ENR	Environment and Natural Resources Canada
ENSO	El Niño Southern Oscillation

EOV	Essential Ocean Variables
EUR	Euro
FAIR	Findable, Accessible, Interoperable and Re-usable
FGDC	Federal Geographic Data Committee (USA)
FFT	Fast Fourier Transform
Fluoro	Fluorescence
FOO	Framework for Ocean Observing
FTP	File Transfer Protocol
GB	Gigabyte
GCMD	Global Change Master Directory
GCNC	Global Compact Network Canada
GCOOS	Gulf of MexiCoastal Ocean Observing System
GEBCO	General Bathymetric Chart of the Oceans
Geonetwork	An open-source catalogue application to manage spatially referenced resources
GFCS	Global Framework for Climate Services
GLIDERSCOPE	an IMOS Ocean glider Facility Wi~~I~~ndows platform software package
GLOS	Great Lakes Observing System
GML	Geography Markup Language
GOOS	IOC-WMO-UNEP-ICSU Global Ocean Observing System
GRA	GOOS Regional Association
GRIDS	Global Research Identifier Database
GTS	Global Telecommunication System
GUI	Graphical User Interface
HABS	Harmful Algae Blooms
HF Radar	High Frequency Radar
HPLC	High-performance Liquid Chromotography
HYCOM	HYbrid Coordinates Ocean Model
HTTP	Hypertext Transfer Protocol
IAP	InterAcademy Partnership
IASC	International Arctic Science Commission
ICES	International Council for Exploration of the Seas
ICSU	International Council for Science
IE	Investigative Evaluation
IGOS	Integrated Global Observing Strategy
IHO	International Hydrographic Organization
IMOS	~~International~~ Integrated Marine Observing System (Australia)
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOCCP	International Ocean Carbon Coordination Project
IODE	International Oceanographic Data and Information Exchange (IOC)
IOOS	US Integrated Ocean Observing System
IOOS DMAC	IOOS Data Management and Communications
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPHC	International Pacific Halibut Commission
IRIS	Incorporated Research Institution for Seismology
ISO	International Organization for Standardization

ISO 16363	ISO standard for audit and certification of trustworthy digital repositories
ISO 19115	ISO standard for geographic information metadata
ISSC	International Social Science Council
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
MCDS	Marine Climate Data System
MCSS	Marine Climatological Summaries Scheme
MEDS	Marine Environmental Data Section
MP	Maya PLE Project
MEOPAR	Marine Environmental Observation, Prediction and Response
NAD	North American Datum
NAD 83/27	Geodetic reference systems of 1983 and 1927
NAFO	Northwest Atlantic Fisheries Organization
NANOOS	Northwest Association of Networked Ocean Observing Systems
NAP	North American Profile
NCP	Net Community Production
NERC NVS 2.0	UK National Environment Research Council Vocabulary Server 2.0
NetCDF	Network Common Data Form
NGO	Non-governmental Organization
NOAA	US National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Centre (IODE)
NSERC	Natural Sciences and Engineering Research Council of Canada
NREN	National Research and Education Network
NTP	Network Time Protocol
OAI-PMH	Open Archives Initiative Protocol for Metadata Harvesting
OBIS	Ocean Biogeographic Information System
OBP	Ocean Bottom Pressure
OceanObs'09	Ocean Observing Conference of 2009
OceanSITES	Ocean Sustained Interdisciplinary Timeseries Environment Observation System
ODP	Ocean Data Portal
ODIP	Ocean Data Interoperatibility Platform
ODV	Ocean Data View
OGC	Open Geospatial Consortium
ONC	Ocean Networks Canada
OOPC	Ocean Observations Panel for Climate
OOS	Ocean Observing System
OPeNDAP	Open-source Project for a Network Data Access Protocol
OpenGov	Canadian Open Government Portal
ORCID	Open Researcher and Contributor ID
OS	Operating System
OSTP	Ocean Science Technology Partnership
OTN	Ocean Tracking Network
PacIOOS	Pacific Islands Ocean Observing System (an IOOS Regional Association)
PANGAEA	Data Publisher for Earth & Environmental Science

PAR	Photosynthetically Active Radiation
PICO	Integrated Coastal Observation Panel
PIDs	Persistent Identifiers
PNG	Portable Network Graphics
Prov IG	Provenance Interest Group
Prov WG	Provenance Working Group
QA/QC	Quality Assurance and Qua~~au~~lity Control
QARTOD	Quality Assurance of Real-Time Oceanographic Data
RAiD	Research Activity Identifier
RDA	Research Data Alliance
RDMS	Relational Database Management Systems
RESTful	Representational State Transfer Web Services
ROMM	Marine Mammal Observation Network
ROV	Remotely Operated Underwater Vehicle
SCCOOS	Southern California Coastal Ocean Observing System
SDG	Sustainable Development Goal
SeaVoX	SeaDataNet and MarineXML Vocabulary Content Governance Group (BODC)
SECOORA	Southeast Coastal Ocean Observing Regional Association
SensorML	Sensor Model Language
SLA	Sensor Model Language
SLGO	St. Lawrence Global Observatory
SOCIB	Balearic Islands Coastal Observing and Forecasting System
SOS	Sensor Observation Service
SOW	Statement of Work
SSHRC	Social Sciences and Humanities Research Council of Canada
SST	Sea Surface Temperature
SWE-SOS	Sensor Web Enablement Sensor Observation Service
TA	Total Alkalinity
TEOS-10	Thermodynamic Equation of Seawater - 2010
THREDDS	Unidata's Thematic Real-time Environmental Distributed Data Services
TWAS	The World Academy of Sciences
TWCL	Tides, Currents, and Water Levels
UN-WCMC	United Nations World Conservation Monitoring Center
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USD	United States Dollar
USGEO	United States Group on Earth Observations
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VOL	Volume
W3C	World Wide Web Consortium
W3C PROV	W3C Provenance
Water Temp	Water Temperature
WAV	Waveform Audio File Format
WCPFC	Western and Central Pacific Fisheries ~~Commision~~Commission
WDS	World Data System
WGS 1984	World Geodetic System 1984 (WGS84)

WMO	World Meteorological Organization
WoRMS	World Register of Marine Species
WWW	World Weather Watch
XML	eXtensible Markup Language