User-Centered Design for Web-Mapping Applications: A Case Study with Ocean Mapping Data for Ocean Modellers

by

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ABSTRACT

Technological innovations in the last few years offer a new digital medium for map making, opening a wide range of possible interactions between the user and the map interface. Nowadays, web-mapping applications are a common way to deliver geographic data through the internet; and within the ocean mapping community, there is a demand for visualizing and downloading data online for navigation, engineering, natural resources, ocean modelling or habitat mapping purposes. However, the existing web-mapping applications are simple data repositories for data download, and the user point of view and context of use is not usually considered. In this research, a User-Centered Design (UCD) approach was applied for the development of a web-mapping application, considering only one kind of ocean mapping users, ocean modellers. A work domain analysis was conducted as the first stage of the methodology, to determine the required application functionalities and content, followed by the development of a web mapping application prototype. The application was then evaluated by users, closing the loop of the UCD methodology. The results of the evaluation show a useful tool, high user satisfaction, and states a wide range of recommendations and a need for new functionalities. This research will enlighten the ocean mapping community with the data and the spatial functionalities that ocean modellers demand, putting together these two related fields. Moreover, it will serve as the foundations for future development and improvement of the web mapping application within the Ocean Mapping Group (OMG) at the University of New Brunswick (UNB).

DEDICATION

To my co-supervisors, Dr. Stefanakis and Dr. Church, for their constant support and dedication to this work. Thank you for putting your trust in me when I was lost.

To the people from Madrid University, to who I owe the opportunity of being where I am. Thank you for seeing my potential and for supporting me, even in the most difficult moments.

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List of Symbols, Nomenclature or Abbreviations

ADCP - Acoustic Doppler Current Profiler

API - Application Programming Interface

CGI - Common Gateway Interface

CSV - Comma Separated Value

CTD - Conductivity, Temperature and Depth

EU - European Union

GML - Geographic Markup Language

HCI - Human Computer Interaction

KML - Key Markup Language

MVP - Moving Vessel Profiler

NOAA - National Oceanic and Atmospheric Administration

OMG - Ocean Mapping Group

PNG - Portable Network Graphics

SHP - Shape File

UCD - User-centered Design

UNB - University of New Brunswick

US - United States

WFS - Web Feature Service

WMS - Web Mapping Service

WPS - Web Processing Service

1. Introduction

Ocean mapping embraces the study of the nature and configuration of the sea and the seabed, including the bathymetry, subsurface, and the sea and water masses characteristics and dynamics. Determining the nature of the sea implies the collection of a large amount of heterogeneous data, which is captured or extracted from different platforms and sources (e.g. multibeam and sub-bottom data, Conductivity, Temperature and Depth (CTD) profiles and tidal data, and Acoustic Doppler Currents Profiler (ADCP) data). There is a demand for visualizing and downloading this data online, making it available to the scientific community, which requires it for navigation, engineering, natural resources, ocean modelling or habitat mapping applications.

The way geospatial data is usually made available to the scientific community is through Web Mapping applications. Technological innovations in the last few years have influenced the way maps are designed, offering a new digital medium and increasing the possibilities for the user to interact with it. Web-mapping tools combine different types of geospatial data and map layers from different sources into a single viewing environment using the Web, where a user can interact with a map online (Tsou and Curran, 2008). The Ocean Mapping Group (OMG) at the University of New Brunswick (UNB) currently collects ocean mapping data and distributes it online, using web-mapping tools for multibeam data (Muggah, 2011). In the United States, web-based mapping services have been adopted by the federal government to deliver ocean mapping data (NOAA Bathymetry viewer, n.d.; NOAA tidal and currents viewer, n.d.; NOAA Real-time Coastal observations, n.d.).

Regarding the users that would visualize, download or interact with this data; ocean modellers use ocean mapping data to generate models of the ocean circulation. The first step for an ocean modeller is to define the model boundaries, using the bottom of the oceans (bathymetry), one of the main ocean mapping products. After the modelling process is completed, the model output allows the calculation and prediction of ocean parameters, which is a useful product for ocean mapping. Making ocean data available would benefit these two related fields which depend on each other, ocean mapping and ocean modelling.

1.1 Problem Statement and Contribution

During the process of generating an ocean model, scientists need to gather as much ocean data as is available for a region. This procedure is sometimes tedious since the ocean modeller needs to gather data from different sources and data might not be available or might not be easy to access (Figure 1). An opportunity exists in geomatics to design web-mapping applications that engage users and meet user needs (Maceachren, 2013). However, most of the web-mapping applications that deliver ocean mapping data are simple data repositories, focused on the data or the available technologies, and the user point of view and the context of use is usually forgotten (e.g. NOAA Bathymetry viewer, n.d.; Muggah, 2011). The concept of focusing on the user and the context of use is included in User Centered Design (UCD). UCD describes the approach followed for the creation of a product in which end-users influence how the design process takes shape, considering their needs and expectations (McLoone, Jacobson, Hegg & Johnson, 2010). One of the challenges related to UCD approaches is the diversity of the users (Tsou and

Curran, 2008), that leads to different needs of information services and thus, may require different types of user interfaces. There is always the question of whether to create multiple customized user interfaces for various users, or to provide one single user interface for all different users.

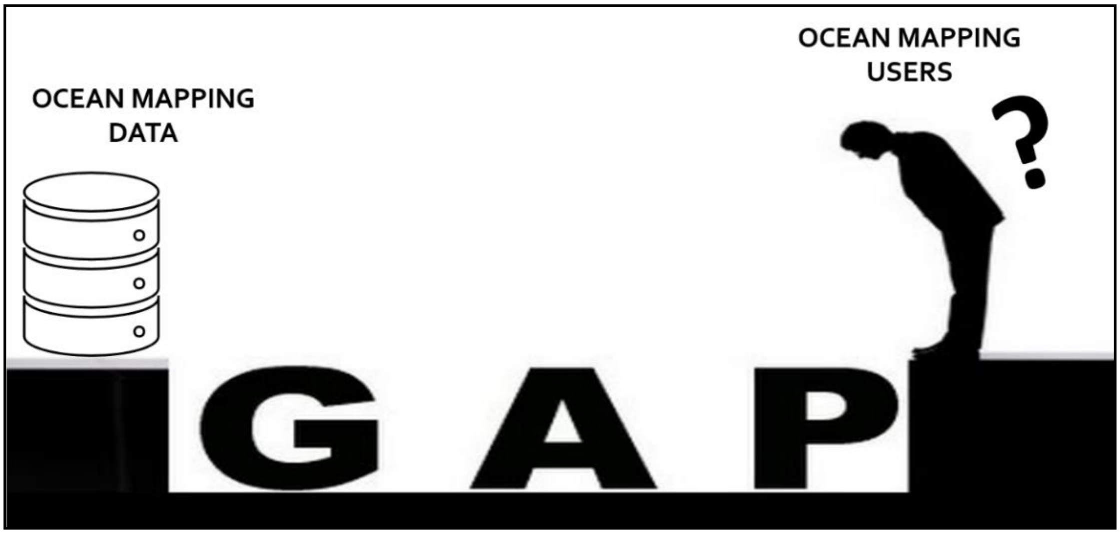


Figure 1.- Existing gap between Ocean Mapping Users and Ocean Mapping Data

The hypothesis of this thesis is that UCD can be applied to the development of web mapping applications that use ocean mapping data, bridging the gap between ocean modellers and the data (Figure 2). Therefore, this research develops an ocean web mapping application for ocean modellers combining existing UCD frameworks and methods.

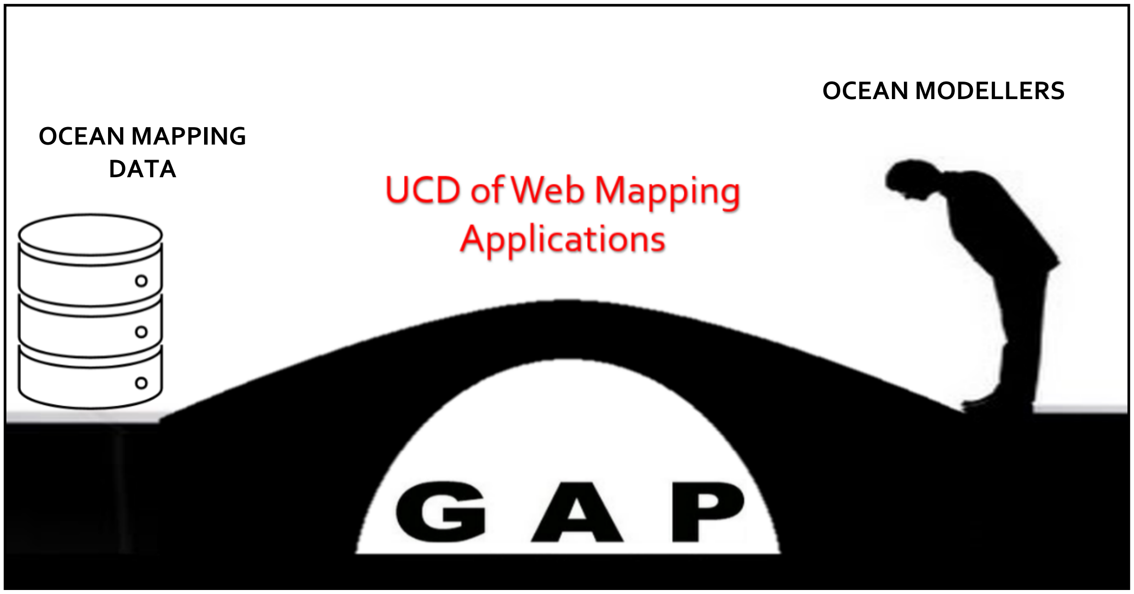


Figure 2.- User-Centered Design of Web Mapping Applications as the bridge between Ocean Modellers and Ocean Mapping Data

The main contribution of this work is the application of a UCD framework to the creation of a web mapping application for ocean modellers. An analysis of the ocean modelling field will enlighten the ocean mapping community with the data and the spatial functionalities that ocean modellers demand, putting together these two related fields. Furthermore, the prototyped application will serve as the foundations for future web mapping developments within the ocean mapping field and the OMG at the University of New Brunswick. Since the framework will be based in UCD techniques, efforts are made on creating the right product for the right people, and the same or similar frameworks could be extended and applied to other kinds of ocean mapping users (e.g. habitat mapping).

1.2 Research questions

The main question of this research is the following:

- How to bridge the gap between the users and the data that exists in the ocean mapping field?

The hypothesis of this thesis is that UCD techniques and frameworks can be applied to the development of web mapping applications that use ocean mapping data. The resulting application would meet ocean modellers' needs and facilitate the creation of ocean models, improving utility and usability. To tackle the main research question, there are several secondary research questions:

- Should the existing UCD frameworks be modified for this application? What kind of UCD methods should be applied?

- What type of data should be made available to ocean modellers to facilitate the creation of an ocean model?

- What type of functions should be made available to ocean modellers to facilitate the creation of an ocean model?

- Would a web mapping application developed using UCD techniques be useful to ocean modellers for the creation of an ocean model?

1.3 Research Objectives

The main objective of this research is to develop a web mapping application for ocean modellers using a UCD approach. In order to achieve this objective, several secondary objectives have been identified:

- To review UCD frameworks and methods and select the ones most suitable for the development of the web mapping application.

- To perform a needs assessment study and work domain analysis of ocean modellers that will determine data and functionality needs.

- To implement a web mapping application prototype based on the results from the previous study.

- To evaluate the web mapping application to test the usability and utility for ocean modellers and to identify future improvements, recommendations, and additional functionalities.

1.4 Thesis structure

This thesis is structured in six chapters. Chapter one introduces the research topic; explaining the motivation, problem, research questions, objectives and the research contribution to the scientific community. At the end of this chapter, the outline of the thesis structure is presented.

Chapter two presents the theoretical background about UCD techniques and frameworks, along with existing web mapping technologies and applications. This reviews the core concepts in this investigation and discusses a literature review on UCD applied to web mapping applications. The conclusion for this literature review is that UCD processes have not yet been applied to ocean web mapping data applications.

Chapter 3 explains the methodology followed for the UCD process: work domain analysis, conceptual development, development of the prototype, user evaluation, and revised prototype.

Chapter 4 shows the results obtained by applying the proposed methodology. Since the methodology applied is sequential, and the results from one step influence the next steps, each result is discussed and concluded at the end of each step.

Finally, conclusions, and future work and recommendations are presented in chapter 5 and 6 respectively. Five appendices provide the informal interview notes, the online survey, the user evaluation form, the administrator manual, and the user manual.

2. Background

Technological innovations in the last few years offer a new digital medium to make maps, expanding the possibilities for the user to interact with geospatial data. Map-making science has switched from traditional cartography to web-based mapping, where now the role of the map maker has been transformed into a collaboration of efforts between spatial databases, web map servers, and map browsers (Tsou and Curran, 2008).

The term interactive map embraces web maps, map-based applications, and other GIS or visualization tools that make use of a digital map as the interface to geographic information (Roth, Ross, and Maceachren, 2015). Nowadays, digital interactive maps are everywhere and in our everyday life, and they are the front-end of information systems in a variety of fields. People use maps on their phones, cars or computers to have access to spatial data, performing spatial queries and interpreting the geographical information.

Cartographic interaction is defined as the two-way dialogue between a user and a map, mediated by a computing device (Roth, 2011). Such definition implies the distinction between two components (Beaudouin-Lafon, 2004): the interaction itself, as the sequence of requests-responses between the user and the map; and the interface, as the developed tool designed to support those interactions. The traditional cartographic communication model (Kolácný, 1969) and the cartographic communication model for interactive maps (Peterson, 1995), lack the inclusion of the user as a main component in the process of interactive map design and web-mapping. Schobesberger (2012) presents an updated cartographic communication model (Figure 3) where the user takes part in the design process and provides continuous feedback in all the stages.

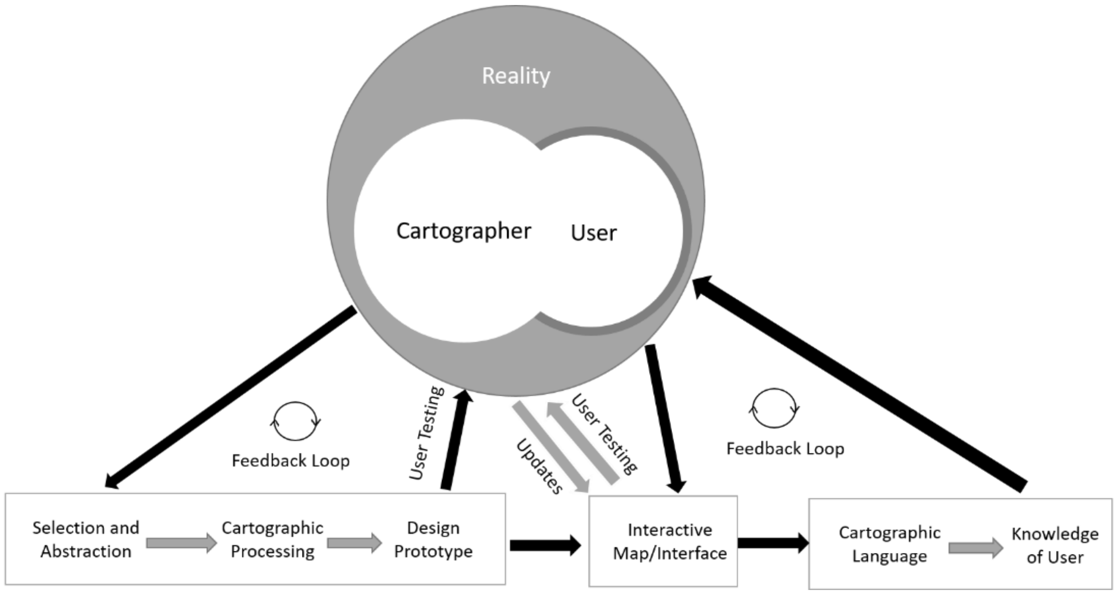


Figure 3.- Updated Cartographic Communication model. Adapted from Schobesberger (2012).

Tsou and Curran (2008) describe an interactive web-based mapping communication framework where maps are dynamic objects that can be transferred and requested between web map servers and map browsers. They highlight the distinction between the traditional cartographic communication model and their framework, where the role of the map user is considered and there is a near real-time user feedback. (Figure 4).

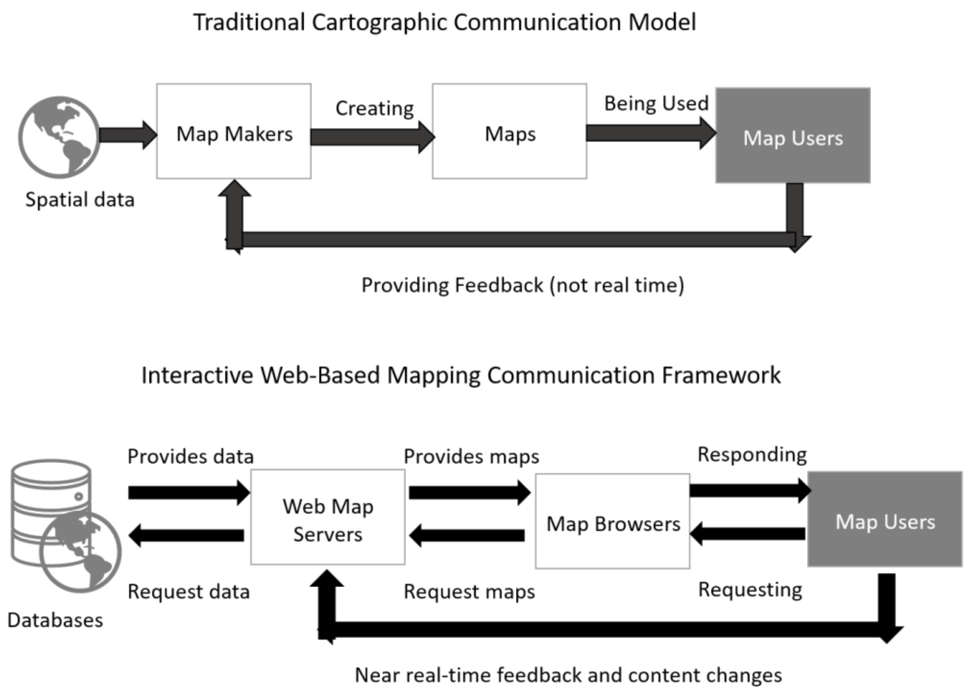


Figure 4.- The new user role in web-based mapping applications compared to traditional cartography. Adapted from Tsou and Curran (2008)

2.1 General frameworks for UCD

The term *design* has three main levels of meaning that shifts depending on the context of usage (Heskett, 2005): (a) Design as a field or concept, (b) Design as finished result, i.e. a product or an object (the concept made actual); and (c) Design as an action or activity, i.e. the approach, plan or process followed for the creation of a new object (product).

Based on the last meaning of the word design, User-Centered Design (UCD) can be described as the approach followed for the creation of a new object in which end-users influence how the design process takes shape (McLoone et al, 2010). Therefore, the aim of UCD is to support the entire product development process with user-centered activities, to create applications that are easy to use and match the needs of the intended user groups (Nivala & Sarjakoski 2007).

UCD has great potential to improve user acceptance and productivity, and considering user needs promotes suitability for purpose, as it minimizes the need of redesigning the project (Nielsen 1992). There are several situations in which the application of UCD methods is highly recommended: there are demanding user needs, the product needs to be used under difficult conditions or situations, user tasks are unknown, the situations where the product is going to be used are unknown or there are a variety of different users which will be using the product (Nivala & Sarjakoski, 2007).

User-centered design can be applied to cartography, assisting the development of interactive maps and web-based mapping tools. There are several general theoretical frameworks for UCD that have been applied to cartographic products.

The ISO standard 9241-210 (ISO, 2010) "Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems" describes a general framework for UCD. The framework sets out the major human-centred design activities that are carried out in designing an interactive system, not specifying a particular process or technique. These activities are the following (Figure 5): (a) Understand and specify context of use (analysis), (b) Specify user requirements (specification), (c) Produce design solutions to meet these requirements (design), (d) Evaluate design against requirements (evaluation). The process is not sequential and the activities must be iterated until the desired result is achieved.

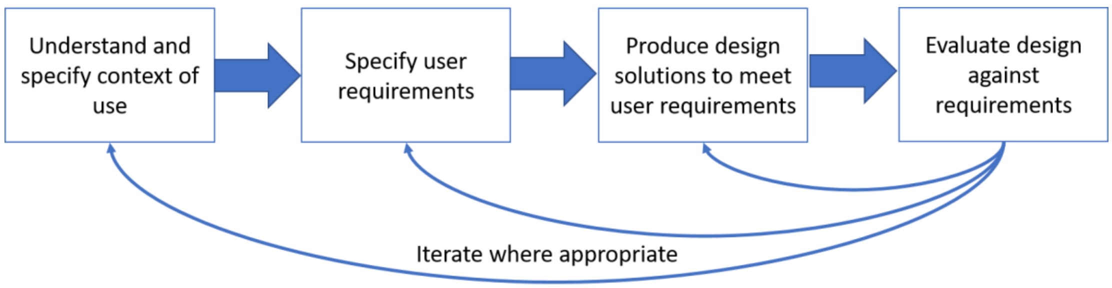


Figure 5.- ISO 9241 framework schema. Adapted from ISO 9241-210 (ISO, 2010)

This framework presents UCD as a general idea to be applied to any kind of system, and there are more specific frameworks that adapts the UCD process to web design. The origins of the Web were all about information, a medium for publishing documents and files and linking them to each other. However, as the technology advanced and new functionalities were added to Web browsers and Web servers, the Web developed more complex features that enabled the collection and manipulation of information, becoming interactive.

Regarding web interfaces design, Nielsen (1992, 1994) adapted and popularized the *eight* user interface design *golden* rules (Shneiderman, 1987), emphasizing the importance of iterative evaluation and revision during the UCD process. He developed a usability engineering model based on eleven elements:

(0) Consider the larger context. The first stage aims at understanding the target user population and user tasks placed in context.

(1) Know the User. Assess needs of target users to understand individual user characteristics and user tasks in order to build user profiles and use case scenarios.

(2) Competitive Analysis. Existing and competing products are often the best prototypes of a product. A competitive analysis critically compares existing products

supporting similar use cases to determine how the proposed product should look like to fill unmet needs. If several products are available, a comparative analysis of the different approaches to the user interface design can be done, providing ideas for new design and guidelines for good or bad approaches.

(3) Setting Goals. Formalize a requirements document of proposed functionality to guide design and development using the insight from the needs assessment and competitive analysis.

(4) Participatory Design. A set of target users are recruited to participate in the conceptual design of the interface.

(5) Coordinated Design. The design must be coordinated across every development project team to achieve a consistent product identity.

(6) Guidelines and Heuristic Analysis. The interface must be evaluated according to guidelines: generalized insights generated from the scientific investigation of digital interfaces; and heuristics (well-accepted, overarching design principles drawn from experience).

(7) Prototyping. Create static or interactive mock-ups of the interface.

(8) Empirical Testing. Recruit a representative set of target users to evaluate the utility and usability of numerous prototypes during their evolution. There are two different kinds of evaluations: (a) formative, the feedback solicited in the early to intermediate stages of the project; and (b) summative, conducted on the full release of the interface to determine if the usability and utility goals have been achieved.

(9) Iterative Design. The interface must be revised based on feedback from the analysis and empirical testing.

(10) Collect Feedback from Field Use. Acquire feedback about the interface after it is transitioned into the field to inform future product releases.

Garrett (2002), in his book "The Elements of User Experiences: User-centered Design for the Web", describes five progressive stages of website design and implementation procedures, dividing them into web as software interface (task oriented/functionality) and web as hypertext system (information oriented):

- Stage 1: Strategy plane. The first step is to consider strategic concerns: user needs and product objectives.

- Stage 2: Scope plane. The strategy is transformed into requirements: functional specifications and content requirements (information).

- Stage 3: Structure plane. The scope is given structure through interaction design (functionality), defining how the system behaves in response to the user and through information architecture (arrangement of content).

- Stage 4: Skeleton plane. The structure is made concrete, breaking down into three components: information design (presentation of information in a way that facilitates understanding, interface design (functionality) and navigation design (interface for an information resource).

- Stage 5: Surface plane. The sensory experience created by the finished product.

Figure 6 shows every plane, comparing the duality between the web as functionality (left) to the web as information (right) and emphasizing the two major components of websites: content design (information architecture) and user interface design.

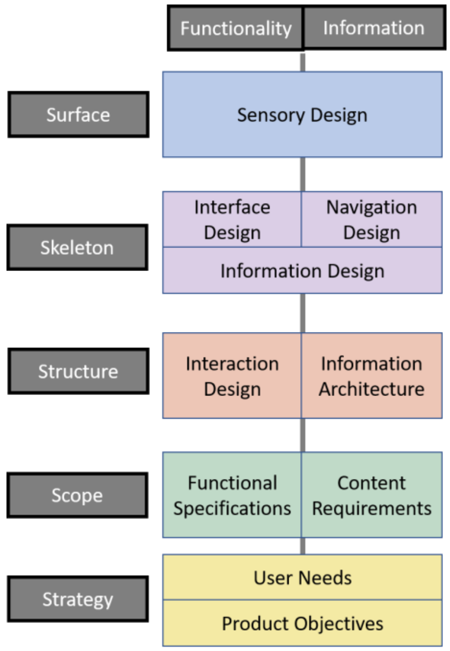


Figure 6.- Garrett's 5 stage model for web design, emphasizing the two major components of websites: content design (right) and user interface design (left). Adapted from Garret (2002)

One clear aspect of all these frameworks is that applying UCD to web interface design involves multiple interface evaluations and revisions until the interface meets user needs and support user case scenarios. However, how could this interface success be measured? Interface success addresses the issue of whether the interface can be used to achieve the desired goals, and can be measured using two concepts: utility and usability (Grudin, 1992). Usability is a quality attribute that assesses the ease of using an interface to complete the user's desired set of objectives; while utility describes the usefulness of an interface for completing the user’s desired set of objectives (Grinstein, Kobsa, Plaisant, Shneiderman, and Stasko, 2003). There is often a controversy of what should come first, usability or utility, and focusing on one or another will lead to two different kind of interfaces: (a) expert-interfaces, that provide great utility, but are difficult to learn and use; and (b) general-use interfaces, that require little or no learning to use, but support only a small set of user tasks (Robinson, Roth, and MacEachren, 2011). A geomatics example of these two-different kind of interfaces, would be ArcGIS (expert and utility oriented) against Google maps (general-use and usability oriented).

Roth, Ross and Maceachren et al. (2015) argue that to achieve interface success in web mapping applications, iterative user → utility → usability loops need to be addressed: first, user needs and characteristics are determined; second a utility threshold is set to respond to these user characteristics and needs; third, the usability of interface design is improved within the utility threshold; and finally, the users evaluate the interface, initiating a new loop in the process. These are the three u's for interface success (Figure 7).

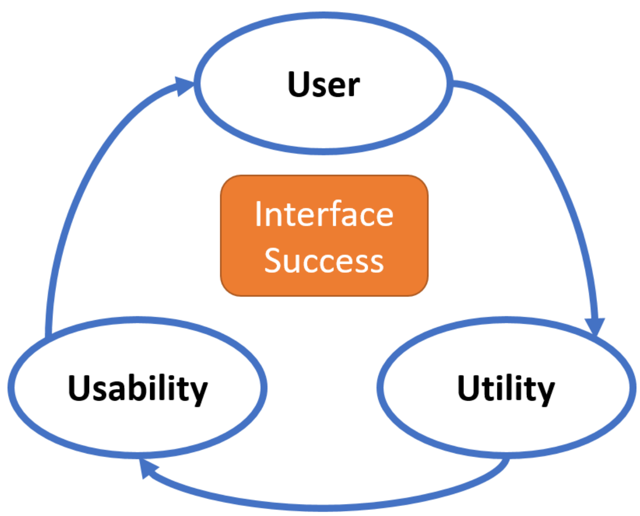


Figure 7.- The Three U's for interface success. Adapted from Roth et al. (2015)

2.2 Methods for interface evaluation

One of the challenges of applying a UCD approach, is selecting the method used to evaluate the interface. The frameworks provide guidance in the process of iterative evaluations and revisions, but they do not identify what method to use in each stage. There is a wide diversity of methods available, which combined, allow the compilation of user information and needs to evaluate the utility and usability of an interface. Bowman, Gabbard and Hix (2002) suggest that six questions need to be addressed prior to selecting an interface evaluation method: (1) What would be the goals of the interface evaluation method?; (2) When would the interface evaluation method be used?; (3) In what situations would the interface evaluation method be useful?; (4) What would be the costs of using the interface evaluation method?; (5) What would be the benefits of using the interface evaluation method?; and (6) How are the results of the interface evaluation method used to improve the interface?

Several scholars organize the interface evaluation methods according to the recommended stage in the UCD process during which the method should be applied (Marsh, S. L., 2007; McLoone et al. 2010). Marsh, S. L. (2007) in her thesis *Using and evaluating HCI techniques in geovisualization*, distinguishes between frameworks, methods, data collection and data analysis techniques (Table 1). Frameworks are structures in which different methods can be applied, data collection techniques can be used within different methods, and data analysis techniques describe some of the methods that can be applied to data recorded within certain frameworks, methods or techniques. Then, she identifies at what stage frameworks and methods can be implemented in the design process. Schobesberger (2012) presents a similar classification for study designs:

formative, summative, comparative, longitudinal, case studies, remote studies and budget usability testing; and presents different data collection methods: interview, survey, observational and product analysis methods.

Table 1.- HCI methodologies described by Marsh (2007)

Frameworks	Methods	Data Collection Techniques	Data Analysis Techniques
Formative	Usability testing	Questionnaires	Content analysis
Summative	Field Studies	Interviews/demos	ANOVA
Quick and dirty	Predictive Evaluations	Focus Groups	Severity rating
Longitudinal	Heuristics Evaluations	Verbal protocol analysis	Problem frequency
Convergence	Cognitive Walkthroughs	Onscreen Capture	Performance
Case Study	Co-Discovery	Diary/Note keeping	Subjective analysis
Remote Study	Task Analysis	Scenarios	Discourse Analysis
Participatory Design		Affinity Diagramming	
		Card Sorting	
		User Defined Tasks	
		Product Defined Tasks	
		Paper Based Prototyping	

However, Roth et al. (2015) argue that a classification of interface evaluation methods based on the stage they are applied is an oversimplification imposed for practical purposes, as there are methods that can be slightly modified to be applied at all the UCD process stages. Therefore, they propose a classification based on the evaluator that is performing the evaluation: (1) Expert-based methods: input and feedback comes from experts in the field; (2) Theory-based methods: the designers and developers evaluate the interface themselves using theoretical frameworks; (3) User-based methods: input and feedback comes from a set of target users. Table 2 presents a summary of the methods described, for which they provide a wide analysis of pros and cons, related methods, and a reference to an example when applied in geomatics. A general definition for the method and a description of the references have been added to Table 2.

Table 2.- Interface Evaluation methods presented by Roth et al. (2015). Definitions and applications have been added to the table.

	Methods	Related methods	Definition	Reference	Application
Expert-based	Guidelines & heuristic evaluation	Rules of thumb	Evaluation of an interface design by applying a set of heuristics or relevant design guidelines (Bowman et al. 2002).	Hix. et al. (1999)	Expert heuristic evaluation applied to visualization in a virtual environment, not following specific user task scenarios.
	Conformity assessment	Feature inspection, Consistency inspection, Standards inspection, Guideline checklist	Evaluation of an interface by evaluating the consistency against expert-field guidelines/standards.	Kostelnick et al. (2008)	Conformity assessment to cartographic guidelines of symbols for humanitarian demining
	Cognitive walkthroughs	Pluralistic walkthroughs, prototyping, storyboarding, wizard of oz.	Evaluation of an interface stepping through user tasks and evaluating the ability of the interface to support them (Bowman et al. 2002).	Richards & Egenhofer (1995)	Extension of cognitive walkthrough method, combining task analysis and the Keystroke-Level to compare two GIS user interfaces for map overlay.
				Roth et al. (2017)	Cognitive walkthroughs of two wireframes for a Lake water level viewer

Theory-based	Scenario-based design	Personas, use case scenarios, scenarios of use, context of use, theatre	Scenarios are characterizations of users and their tasks in a specified context, offering concrete representations of a user working with a product in order to achieve a particular goal.	MacEachren et al. (2008)	Development of a use case scenario to portray the features of a web-based GIS enabled cancer atlas.
	Secondary sources	Content analysis, competitive analysis.	A competitive analysis study is a usability engineering method administered to critically compare a suite of similar applications according to their relative merits (Nielsen 1992), I.e. a content analysis of secondary sources.	Roth et al. (2015)	Competitive analysis for evaluating water level visualization tools, comparing them across representation and cartographic interaction.
	Automated evaluation	Unmoderated user-based methods, adaptive interfaces, automated interaction logs.	Any kind of evaluation performed by a software automatically.	Stanney et al. (2003)	Development of MAUVE, Multi-criteria assessment of usability for virtual environments, an automated tool that assists designers and evaluators of VE systems

User-based	Participant observation	Ethnographies, field observation, MILCs, journal/diary sessions, screenshot captures, interaction log.	Technique for observing people by joining them in their working environment and analyze how they perform their activities, how they use the computer software…	Robinson et al. (2005)	Ethnographic case study where one of the developers worked together with an epidemiologist to uncover issues regarding the functionality and usefulness of a geovisualization tool for epidemiology
	Surveys	Questionnaires, entry/exit surveys, blind voting, cognitive workload assessment.	Written set of questions used to obtain user information (Bowman et al. 2002).	Robinson et al. (2011)	Needs assessment survey with targeted end-users for designing a web-based learning portal for geographic visualization and analysis in public health
				Roth et al. (2015)	Formative and summative Online Survey using discrete scale ratings and unstructured form fill-in free response questions, as a part of a whole UCD process for the development of a crime analysis tool
				Kostelnick et al. (2008)	Basic survey about improvement over previous symbols for humanitarian demining (yes/no answer). The participants were also encouraged to provide written comments or suggestions.

	Interviews	Structured interviews, semi-structured interviews, unstructured interviews, contextual inquiry.	Technique for gathering information about users by talking to them directly.	Slocum et al. (2003)	Combination of individual interviews and focus groups conducted for three distinct groups of participants: novices, geography students, and domain experts for the development of a Program for Exploring Spatiotemporal Point Data.
				Roth et al. (2015)	Needs assessment interviews.
				Roth & Harrower (2008)	Cognitive interview that allows participants to discuss their experience after the completion of user tasks, allowing the user to share their thoughts and comments.
	Focus groups	Supportive evaluation, workshops, Delphi, e-Delphi.	Way of gathering data through group participants' interaction (Krueger, 2014).	Kessler et al. (2000)	Using focusing groups to evaluate a data exploration system for the submarine conflict of 1939-1945
				Robinson, Chen, Lengerich, Meyer and MacEachren (2005)	Focus group to discuss a geovisualization tool, using two moderators to lead the discussion.
				Kostelnick et al. (2008)	Participants were assembled together to discuss various aspects of the prototyped symbols for humanitarian demining in a guided group discussion.

	Card sorting	Q methodology, concept mapping, affinity diagramming, brainstorming.	Technique to explore how people group items using cards. Participants are asked to group items in a way that makes sense to them, naming the resulting groups (Gaffney, 2000).	Roth et al. (2011)	Describes a framework for the experimental design settings for the card sorting method applied to structuring and refining large map symbol sets.
				Robinson et al. (2005)	Card-sorting method applied to trying and reorganizing the interface.
	Talk aloud/ think aloud studies	Verbal protocol analysis, co-discovery study.	Ascertaining the internal processing conducted by a user while carrying out a task. Users are asked to verbalize what they are thinking while interacting with the interface. (Haniff and Baber, 2003).	Roth & Harrower (2008)	Formal evaluation of an interactive map using verbal protocol analysis.
				Robinson et al. (2005)	Verbal protocol analysis combined with follow-up focus groups to capture the details inherent in the epidemiological workflow and user reflections and comments.
				Roth et al. (2015)	Expert-based think aloud study on the alpha released prototype using design experts outside of the project team.
	Interaction studies	Performance measurement, controlled experiments	Capturing users’ interaction with the interface, generating interaction logs that need to be analysed.	Edsall (2003)	Two-phase evaluation where the interaction log of the user using the interface was recorded and then analyzed for a GIS for exploration of multivariate health statistics.

2.3 UCD for geomatics applications

Web-interface principles can be applied to web-mapping applications as a set of practical guidelines for their design and implementation processes. The existing UCD general frameworks (ISO, 2010; Garrett, 2002; Nielsen, 1992; Nielsen 1994) have been adapted and modified to develop geomatics applications.

Gabbard et al. (1999) developed a UCD process for virtual environments which was modified by Slocum, Cliburn, Feddema and Miller (2003) to develop a water balance visualization tool, including six stages: (1) creation of a prototype; (2) domain expert evaluation; (3) software refinement; (4) usability expert evaluation; (5) additional software refinement; and (6) decision maker (i.e., target user) evaluation. The approach is interesting since the first step is to develop a prototype instead of gathering user information (unlike most of UCD processes). They argue that rapid prototyping might be beneficial in some cases when the designers/developers have expertise in the field, allowing to start the designing process faster.

Robinson et al. (2005) recommended an iterative six stage UCD process for interactive maps, which include end-users through-out in each stage: (1) work domain analysis; (2) conceptual development; (3) prototyping; (4) interaction and usability studies; (5) implementation; and (6) debugging (Figure 8).

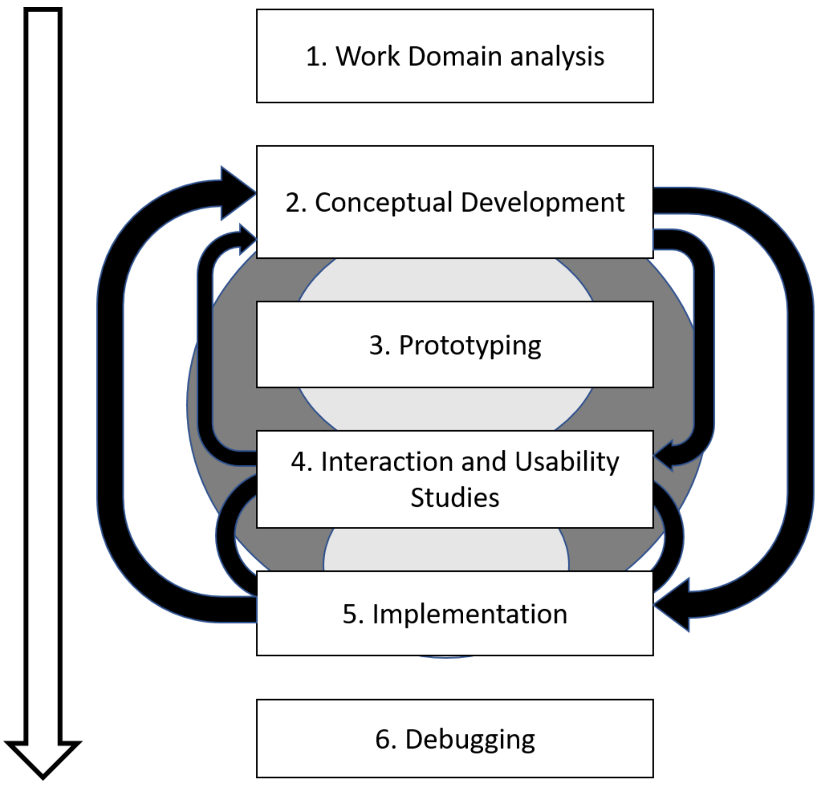


Figure 8.- Robinson et al. (2005) UCD framework. Adapted from Robinson et al. (2005)

Kramers (2008) redesigned the Web-Based Atlas of Canada following a UCD methodology based in three main stages: examination of business requirements, user requirements research and product and systems designs. He summarizes the value of UCD as the following points: reduction in the effect of poor and inaccurate assumptions, balance of business and user requirements, developers do not have to evaluate their own designs, increase user satisfaction and product effectiveness, and the right product is produced for the right reasons and for the right users.

Van Elzakker & Wealands (2008, 2007) applied a UCD approach for mobile tourism applications based in three stages: analyze requirements, produce design solutions, and evaluate designs.

Tsou and Curran (2008) adapted the five-stage UCD framework described by Garrett (2002) to develop a Web-based Geospatial Information Service for the Management of Real-time Surface Water Hydrology in the United States, including the implementation of databases, web map servers and map browsers.

Roth, Ross, Finch, Luo and Maceachren (2009) and Roth et al. (2015) modified Robinson et al. (2005) approach to develop a crime analysis visualization tool, performing the prototyping stage first as in Slocum et al. (2003).

Later, Roth et al. (2015) improved this crime analysis tool, following iterative user → utility → usability loops described in Figure 7, and iterating a total of three times, applying different methods and evaluations in each of the steps: needs assessment study, expert-based think aloud study, formative online survey and summative online survey.

Schobesberger (2012) presented an integrated framework for user-centered web-map design and evaluation based on the model developed by van Elzakker et al. (2008, 2007), but including additional elements related to web mapping applications. The four stages are: (a) application goals & requirements, (b) application/Cartographic concepts, (c) application/Map prototypes and (d) final application (Figure 9, grey). As can be seen in Figure 9, Project and Developers domain assists the establishment of application goals and requirements, the application environment domain assists the application concepts stage, and the guidelines are used to assist the design process in the application concepts and prototypes. Users (Figure 9, blue) assist all these four stages through user research and iterative evaluations.

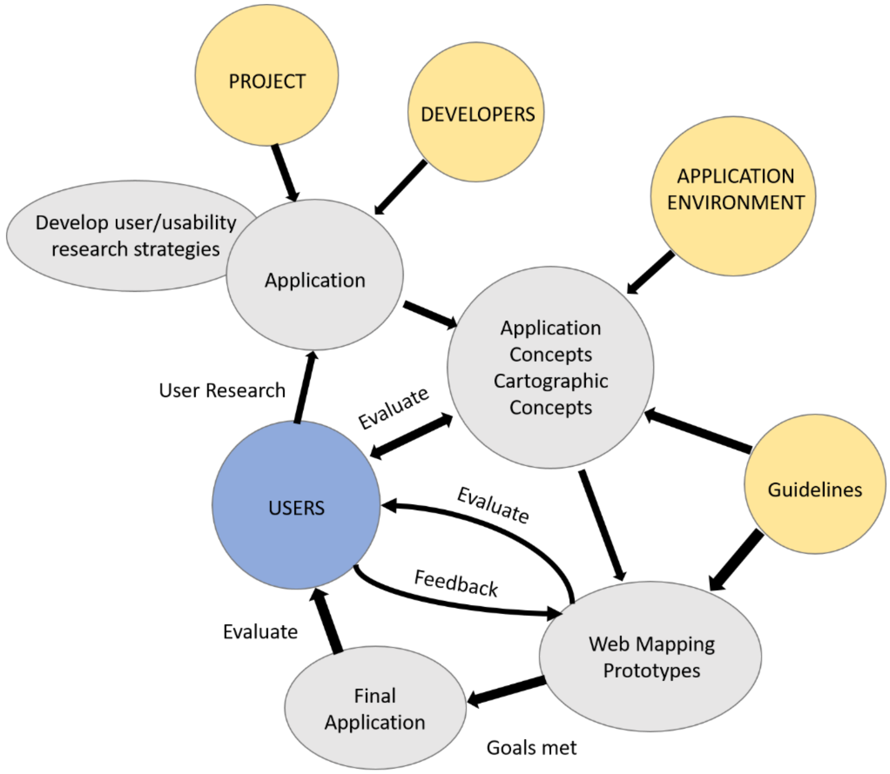


Figure 9.- Integrated framework for user-centered web-map design and evaluation. Blue ovals represent the stages, blue ovals the users and yellow ovals the necessary input. Adapted from Schobesberger (2012)

Macek (2012) also applied the Robinson et al. (2005) UCD model to develop the University of Victoria's International Connections Mapping Application, but conducted the work domain analysis in conjunction with the conceptual development stage. Elder (2013) implemented a web mapping service for the San Diego river watershed, using UCD and the sensor web. The methodology was based in four stages: user-needs survey, web map design and implementation, test group, and expert review. UCD has also being applied to interactive maps that use atmospheric data (Oakley et al., 2016).

Roth, Hart, Mead, and Quinn (2017) designed the NOAA Lake Level viewer following the UCD framework described by Robinson et al. (2005). However, their research is focused on the prototyping stage, where they developed two sets of wireframes to separately address the representation and interaction components of the user experience, which were evaluated using target users.

UCD has also been used in the development and design of digital geospatial libraries and geographic applications, such as location based services (Delikostidis, 2011; Haklay & Nivala, 2010; Roth, 2011), geovisualization tools (Fuhrmann and Pike, 2005; Lloyd, 2009; Koh, Slingsby, Dykes, and Kam, 2011) and decision support tools (Argyle et al., 2017, Roth et al., 2009).

As shown in the reviewed literature, UCD have been applied in Geomatics for more than a decade, using the general guidelines of the UCD traditional frameworks (ISO, 2010; Garrett 2002; Nielsen, 1992; Nielsen 1994), and all of them having similar stages: know the user needs, conceptualize those needs, prototyping/implementation, and iterative usability studies until the needs are met. One of the most common frameworks applied is the one developed by Robinson et al. (2005) (Roth et al., 2009; Macek, 2012; Roth et al., 2015; Roth et al., 2017); however, there are other interesting approaches more focused on the user experience design and the technical development of web mapping components (Tsou and Curran, 2008). One difference between these frameworks, is that some of them perform the prototyping stage first, instead of gathering user information (Slocum et al., 2003; Roth et al., 2010). They give several reasons for this: (1) a prototype is sometimes necessary to receive enough funding to perform user analysis, (2) sometimes a midway managed project is taken over or the design is for a new version of an existing application, (3) the community of users might be yet unknown or not accessible at the time of development, and (4) the initial prototype is meant for a specific group of users, but needs now to be improved to meet the needs of a broader user group. Therefore, rapid prototyping might be beneficial in some cases when the designers/developers have expertise in the field, allowing to start the designing process faster.

A user-centered approach throughout all stages of design might seem essential for the successful design of Web-mapping applications; and there is an increasing desire of the users to be more involved in the conceptualization, evaluation, and refinement of their interactive mapping systems (Roth, 2015). Therefore, there have been several attempts to define UCD frameworks for interactive cartographic products and web-mapping applications. However, apart from the reviewed literature, studies that involve all stages of UCD are still rare in geomatics (Flink et al., 2011). Research has not yet provided sufficient guidance for conceptualizing the overall UCD process nor the range of specific evaluation decisions needed. Other reasons for deviating from UCD approaches are the lack of access to the target users, the lack of time or money to involve the users, the potential of feature creep, and even a general belief held by designers and developers, that they know best (Roth et al. 2015).

Although there are some applications related to ocean water resources and hydrology (Roth et al., 2017; Elder, 2013; Tsou and Curran, 2008), no web-mapping application using ocean-mapping data was found in the UCD literature. An extensive analysis of the existing web-mapping applications using ocean mapping data is presented in the competitive analysis section (Chapter 4).

2.4 Web mapping Applications

Web-based mapping tools combine different types of geospatial data and map layers from different sources into a single viewing environment via the Internet. There are three major web mapping components which follow the traditional client-server architecture (Figure 10): databases, web map servers, and client-side web applications (running on a web browser). In order to develop a web-mapping application, all these components need to be considered:

- Databases: a geographical database (which can handle coordinates and geographical features) constitute the foundations of web mapping applications. The databases are connected to the web map server to provide geospatial data. A user can also access the database directly using a proper Application Programming Interface (API) or using a Common Gateway Interface (CGI) architecture (Figure 10). There are several well-known databases that offer spatial capabilities: (a) Commercial (Oracle Spatial); and (b) Open source (Postgres/PostGIS, Neo4j-Spatial, MongoDB…).

- Web Map Server. Web map servers retrieve data from the database or the file system, and provide spatial data and services to the client-side web mapping application. Considerations when choosing a web map server include the different mapping formats (drivers) and services (WMS, WFS, WPS, layer styling…) that the server must provide. There are several well-known web map server engines: (a) Commercial (ArcGIS Server, ArcIMS, AutoDesk's MapGuide) and (b) Open source (MapServer and GeoServer).

- Client-side web mapping application. The interface to the user which displays the map layers and spatial information, and it is developed using web mapping technologies. The data is retrieved, either from the map server or directly from the database (using an API or a CGI application) and presented to the user. Spatial functions and services can be supported by web map servers (WFS, WMS, WPS, WCS…) or through server-side scripts following the CGI architecture.

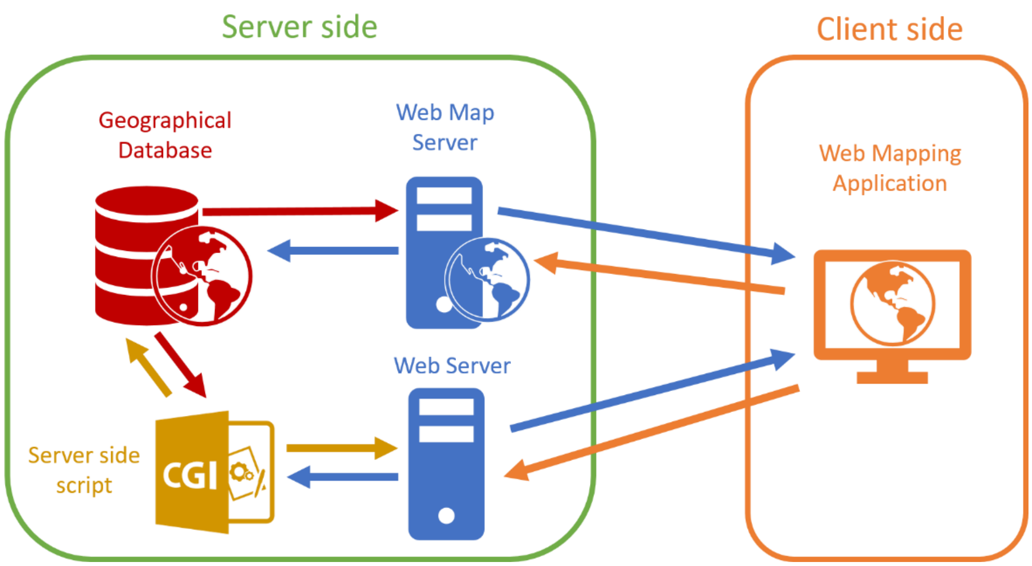


Figure 10.- Traditional Client-Service Architecture in Web Mapping Applications

Tsou and Curran (2008) described the relationship between these three web mapping components and the different UCD stages:

- Databases. Database design should be carried out at the beginning of the prototype design stage. The data required in the applications is identified and a data object list must be formalized. The database is created by combining these data objects into an integrated relational database or multiple data files.

- Web Map servers. The web Map Server component should be designed at the beginning of the prototype design stage. The spatial functions required should be identified and formalized on a list for proper implementation and election of the right map server that can provide these functions.

- Map Browsers. The design of map browsers covers several aspects of UCD processes: design of the interface and layer symbolization. In designing map browsers, the tasks cover all aspects of the Skeleton stage and Surfaces stage.

2.5 Web mapping Technologies

Web mapping applications are developed using the so-called web mapping technologies, defined as the compilation of APIs, frameworks, libraries, and services, that altogether enable the creation and dissemination of web maps (Kraak and Brown 2001; Peterson 2003). Roth et al. (2014) stated that the ever-evolving nature of web mapping technologies, and their increasing flexibility and interoperability, create new opportunities for cartographers, who now have a lot of tools within their grasp for creating interactive maps. Moreover, as the technologies evolve and change quickly, the cartographer skills and expertise needs to evolve and update along with the technologies.

There are several mapping libraries and APIs available for web mapping applications. In the recent years, there has been a shift in web-mapping technologies from standalone and proprietary technologies to open technologies following web standards (e.g. HTML, CSS, SVG, XML). This shift is due to three main reasons: the development of Google Maps in 2005 based in AJAX; the improvement of telecommunications bandwidth and hardware, along with the widespread use of mobile devices; and the formation of open source interest groups across the web mapping community, such as the Open Geospatial Consortium (OGC; www.opengeospatial.org) and Open Source Geospatial Foundation (OSGeo; www.osgeo.org/ home) (Roth 2015). A comparison between the four most used web mapping technologies are shown in Table 3 (Data from Datanyze, 2018).

Table 3.- Comparison between Web-Mapping Libraries (Data from Datanyze, 2018).

Feature	ArcGIS	Google Maps	MapBox	Leaflet
Current Websites	9,966	3,867,659	170,360	61,159
Market Share	0.24%	91.5%	4.03%	1.45%
Rank in Datanyze (2018)	8	1	2	3
License	Proprietary	Proprietary	Open source	Open source
Features	Easy integration with other ArcGIS products like ArcGIS Server's.	Most popular Map library. Good support.	Best mapping service outside of Google Maps. It uses leaflet API. Beautiful maps.	JavaScript library for interactive maps with basic developing functionalities. Big community and easily expandable using plugins

Google maps still takes the lead in web mapping technologies, with a huge difference against their competitors (91.5% versus 4.03%). However, even though it provides a good support and a wide range of APIs and tools, it uses a proprietary license, and their code is not open source. If deployed in a big scale, there are limits of mapping loads and requests that can be made per day, and additional premiums plans needs to be activated to increase this limit (Google documentation, 2018).

Regarding the second most used web mapping technology, Mapbox, there is an important distinction to make. Mapbox offer two different kinds of products: Mapbox GL js and Mapbox js. Mapbox GL js is a JavaScript library that uses WebGL to render interactive maps from vector tiles and Mapbox styles. The library is part of the Mapbox

GL ecosystem, and needs to be used inside Mapbox Studio accounts connected to their service. Same as Google Maps, there are limits of mapping loads and requests that can be made per day, and there are several options for premium plans to increase these limits. On the other hand, Mapbox.js is a web mapping library that extends Leaflet.js, another open source web mapping library, to integrate it with the Mapbox stack (i.e. an API to Mapbox Studio) (Mapbox documentation, 2018).

Leaflet is an open source web mapping library for interactive maps with basic developing functionalities, allowing tiles and spatial data from different servers to be requested, and using different tools for displaying, styling and animating them. With regards to the development of an open source based project, there is not much difference between using Leaflet.js or Mapbox.js, as both are based on the same core library. It would only make sense to use Mapbox if the application will be using data stored in their servers. Mapbox and Leaflet are the biggest libraries after Google Maps and their popularity is increasing during recent years as they offer an open source alternative to Google Maps.

Roth et al. (2014) performed a competitive analysis study based on representation and interaction capabilities of 35 current web mapping technologies. After this study, they selected four technologies, Google maps, Open Layers, Leaflet and D3, and performed a diary study among a small number of participants. The insights from this study can be summarized as follow:

- The large majority of web mapping technologies leveraged JavaScript as the base programming language, and thus integrated with the Open Web Platform broadly.

- Most of the technologies support raster tiles in a cylindrical projection, as well as panning, zooming, retrieval of details, and overlay of context information.
- There is a gap between contemporary web mapping practice and traditional cartographic methods, including thematic mapping beyond choropleth and proportional symbol representation techniques and the calculate, filter, reexpress, and reproject interaction operators.
- Participants accomplished slightly more scenario requirements with the closed Google Maps API, but they had a slightly more positive emotional experience using the open Leaflet library.
- Good web map design is more important than using novel tools.
- University programs, government agencies, and cartography firms actively should combat path dependencies on one technology that lead to its use beyond its functional utility.
- Emphasis on support for (user-driven) interactivity when choosing a technology, and placed less importance on (system-driven) animation and real-time updates.
- Nuanced differences in supported functionality across the four candidate technologies, suggesting their relative affordances and limitations.
- All this variety of solutions and functionalities derive the recommendation of pairing web map requirements with potentially viable technology solutions,

allowing for design to precede development (rather than allowing technology to constrain design).

All these insights should be considered when choosing a web mapping technology for the development of a web mapping application.

3. Methodology

For the development of the ocean web-mapping application, a UCD process was applied. As reviewed in the literature, the most common UCD framework in geomatics applications is the one developed by Robinson et al. (2005), having two variants: performing the prototyping stage before or after a work domain analysis. The completion of a work domain analysis prior to prototyping was chosen, as the designer did not have any expertise in the field to be able to come up with a prototype, and the target user-group was accessible and well-known. In addition to the Robinson et al. (2005) framework, the technical development of the different web mapping components and the user experience must be considered, as presented by Tsou and Curran (2008), who applied Garret's (2002) five planes. Therefore, a mixed approach between the two frameworks was followed as the methodology for the UCD of the ocean web-mapping application (Table 4): (1) work domain analysis, (2) conceptual development, (3) prototyping stage, (4) evaluation stage and (5) revised prototype. Each of these five stages, include one or more Garret's (2002) planes. The methodology includes one and a half User → Utility → Usability loops, corresponding to one and a half loops of the User experience design planes (Garret 2002).

As per UCD evaluations methods, an interview, a competitive analysis, an online survey, a cognitive walkthrough and a formative survey were applied. The selection of these methods was influenced by the limited accessibility of the users and the time constraint for the project.

Table 4.- Methodology Applied for the Development of the Ocean Web Mapping Application

Success aspect	Robinson et al. (2005) Process	Garret (2002) plane	Ocean web mapping application: Methodology	Interface	Content
User	Work domain analysis	Strategy	(1) Work Domain Analysis	Web mapping application objective. Target user profiles/Use cases Assessment interview. Competitive analysis. Online survey	
Utility	Conceptual development	Scope	(2) Conceptual development	Functional requirements	Data requirements
Usability	Prototyping	Structure	(3) Prototyping stage	System architecture	
				Formalized function list	Data objects.
		Skeleton		Determining what type of service will offer each functionality and how	Format conversion scripts and database uploading scripts
		Surface		Window arrangement/implementation	Organizing and styling layers
User	Interaction/Usability study	Evaluation	(4) Evaluation stage	Cognitive walkthrough/Formative survey	
Utility	Revised Conceptual development	Scope	(5) Revised prototype	Revised functional specification	Revised map content requirement
Usability	Implementation	Structure		Revised prototype	
		Skeleton			
		Surface			

3.1 Work domain analysis

The Work domain analysis encompass the strategy plane, where the web mapping application objective, target user profiles, and use case scenarios were defined, and the needs assessment, competitive analysis and online survey were conducted.

3.1.1 Application objective, user profiles and use case scenarios

The UCD process began with the definition of the web-mapping application objective, to establish the strategy that will be followed during the development. The next step was to formalize target user profiles and use case scenarios for the ocean web mapping application. Ocean modellers are the target user group, therefore some user profiles related to ocean modelling and associated use case scenarios were identified.

3.1.2 Ocean modellers assessment interview

An interview is a technique for gathering information about users by talking to them directly. This procedure can be formal, with a predefined set of questions and structure; or informal, without a predefined structure and just following general guidelines.

This UCD data collection method was chosen to get a general overview about ocean modelling, due to the lack of ocean modelling knowledge of the designer. Talking to an ocean modeller directly was a good way to get a first insight about the ocean modeller community.

An ocean modeller from the Department of Fisheries and Oceans Canada participated in an informal 60-minute interview. The interview was chosen to be informal, as there was no prior knowledge about the subject to establish a good set of predefined questions. The results extracted from the interview served to establish the basics to start the UCD process and have guidance to prepare the online survey for target users.

The questions asked during the interview were the following: (1) What do ocean modellers do? (2) What process do they follow to produce an ocean model? (3) What datasets do they need to use in this process? and (4) From what sources do they get the data?

The notes taken from the interview can be consulted in Appendix A. Using these notes, a potential list of data and functionalities for ocean modellers was prepared.

3.1.3 Competitive analysis

A competitive analysis study is a usability engineering method administered to critically analyze and compare a set of similar applications according to their relative merits (Nielsen 1992); i.e. a content analysis of secondary sources.

This UCD method was chosen because it will provide an extensive literature review about the existing web mapping applications related to ocean mapping data, being able to identify trends and gaps in these applications.

A competitive analysis study of twenty-four existing ocean web mapping applications found online was conducted. The requirements for the inclusion in the analysis were: (1) it is a web-map based application, and (2) it provides potentially useful data for ocean modellers such as bathymetry, temperature, salinity, weather data or other information. These requirements forced the addition of sensor visualization tools, although these tools do not use ocean mapping data and products per se.

The applications evaluated are shown in Table 5, including name, country or continent that developed or supports the application, geographical coverage, the data focus of the application, a brief description of it, and the link to the web portal.

Bathymetry and ocean mapping data collection are usually part of government or research organizations, as every country needs to map their territory and marine jurisdiction with political and environmental purposes. The government usually offers this kind of data to the public, either freely (e.g. the United States), or by limited licensing agreements (e.g. Canada). Along the following description, numbers are referenced to the first column (#) of Table 5. In the United States, ten applications were developed, supported or funded by U.S. federal agencies [1, 2, 3, 5, 6, 7, 8, 20, 24], one by an alliance of U.S. state agencies [5], a university research project [6], an alliance between several organizations and non-profit agencies [2], and two of them are owned by private companies or industries [4, 9]. In Europe, there are four applications developed by national institutions [10, 11, 12, 14] and one common for the European Commission [13]. Within Canada, several applications were included in the analysis: the government of Canada web portal for data products and surveys [15], a federal and provincial government organization application [22], one application owned by a private company [21], a project from the University of Victoria [23], and two research projects from the University of New Brunswick [18, 19]. The government of Australia also provides a web portal for bathymetry and backscatter data [16]. Finally, one of the tools analyzed [15] is an alliance between EU, Canada and US for Atlantic Ocean Research Cooperation.

Regarding geographic coverage, seven applications have a geographic coverage of the entire globe [1, 2, 3, 4, 7, 9, 21]; seven by a single country [8, 9, 12, 15, 16, 20, 23];

three by several US states [5, 6, 24]; three are regional [18, 19, 22]; and five include several countries and jurisdictions [10, 11, 13, 14, 17].

The methodology to perform the competitive analysis followed Roth's (2013) distinction within cartography, differentiating the analysis between: (1) representation, i.e. the way the information in the map is encoded, and (2) interaction, i.e. the ways a user can manipulate the map. The topics covered were based on the ones analyzed by Roth (2015), but with modifications and several additional topics which considered the potential needs of ocean modellers. Related to representation, a total of four topics were analyzed: (1a) data offered/represented, (1b) inclusion of uncertainty as a variable of the information, (1c) inclusion of time as a variable of the information, and (1d) variation in the basemap provided. Related to interaction, a total of four topics were analyzed: (2a) variation across supported interaction operators that will include data download functionalities and analysis tools; supported formats, distinguishing between (2b) bathymetry and (2c) other kinds of data; and (2d) variation in the web mapping technology used to implement the web application.

The results from the competitive analysis depicted the state of the art regarding web mapping applications related to ocean mapping data, and helped to identify potential required functionalities and data for ocean modellers. This potential data and functionalities were included in the subsequent online survey.

Table 5.- Description of the Web Mapping Applications included in the Competitive Analysis

#	Name	Agency	Country/ Continent	Coverage	Focus	Description	Link
1	NOAA Bathymetry Data Viewer	NOAA	US	Entire globe/US	Bathymetry	Bathymetry downloading service by NOAA (multibeam, single beam, BAG surfaces, DEMs…). Multibeam and single beam available for the entire globe. BAG surfaces/Lidar and DEM mostly limited to the US.	https://maps.ngdc.noaa.gov/viewers/bathymetry/
2	IEDA Data Browser / GMRT MAP TOOL	MGDS (Marine Geoscience Data System). Part of the Interdisciplinary Earth Data Alliance (IEDA).	US	Entire globe	Bathymetry	Allows to download bathymetry grid files of any part of the world using the GMRT dataset.	http://www.marine-geo.org/tools/GMRTMapTool/ http://app.iedadata.org/databrowser/
3	Crowdsourced Bathymetry (prototype)	NOAA, IHO	US	Entire globe/US	Bathymetry	Web-application to download crowdsourced bathymetry products. Bathymetry available for the entire globe. BAG surfaces/Lidar mostly limited to the US.	https://maps.ngdc.noaa.gov/viewers/csb/index.html
4	Bathymetrics Data Portal	Partnership between DHI, TCARTA MARINE, DIGITAL GLOBE	US	Entire globe	Bathymetry	Simple web-mapping application that allows to purchase bathymetry (2m or 90m resolution).	https://bathymetrics.shop/#/mappage/
5	MID-ATLANTIC OCEAN DATA PORTAL	MARCO (Mid-Atlantic Regional Council on the Ocean). Supported by NOAA	US	New York, New Jersey, Delaware, Maryland, and Virginia	Ocean Data, including bathymetry	Data portal that allows to build ocean stories using storytelling techniques.	http://portal.midatlanticocean.org/ocean-stories/every-map-tells-a-story/

6	Pacific Islands Ocean Observing System Voyager	Research project funded by NOAA	US	Globally/ US. Most data only Hawaii and other Pacific Islands	Ocean data, including bathymetry	An interactive map interface for visualizing and downloading oceanographic observations, forecasts, and other ocean related data.	http://www.pacioos.hawaii.edu/voyager/
7	NOAA Grid Extract	NOAA	US	Entire globe	Elevation/ Bathymetry	Simple downloading service for the global bathymetry models	https://maps.ngdc.noaa.gov/viewers/wcs-client/
8	Data Access Viewer	NOAA	US	US	Elevation/ Bathymetry	NOAA downloading portal for elevation, imagery and land cover. It includes coastal bathymetry lidar.	https://coast.noaa.gov/dataviewer/#/
9	Planet OS	Private company (Intertrust, Innogy, Philips)	US	Entire globe	Ocean data including bathymetry	Data hub from different providers. Access to weather, climate and environmental datasets.	http://data.planetos.com/datasets?state=eyJwcm9kdWN0X3R5cGUiOltdLCJwYWdlIjowfQ==
10	CCLME ECO-GIS Viewer	IOC, IEO, UNESCO COoperacion Espanola	Spain / Europe	West African regional scale, Canary Islands	Ocean data, including bathymetry	Dynamic GIS analytic tool aimed to create meaningful data products of the ocean.	http://www.ideo-cclme.ieo.es/
11	Mareano	Institute of Marine Research, Geological Survey and Norwegian Mapping Authority	Norway / Europe	Norwegian offshore areas, including Iceland and coast UK	Ocean Data, including bathymetry	Data portal for bathymetry, sediment composition, biodiversity, habitats, biotopes and other kinds of biological and ocean data for the Norwegian offshore areas.	http://mareano.no/en/maps/mareano_en.html?language=en

12	INFOMAR Data Viewer	Geological Survey and Marine Institute of Ireland	Ireland	Ireland	Bathymetry and other ocean mapping data	The INtegrated Mapping FOr the Sustainable Development of Ireland's MArine Resource integrates mapping products of the physical, chemical and biological features of the seabed.	https://jetstream.gsi.ie/iwdds/delivery/INFOMAR_VIEWER/index.html
13	EMODnet portal for Bathymetry	European Marine Observation and Data Network.	Europe	Europe	Bathymetry	Web-application to download bathymetry products for the European Union region. Gaps with no data coverage are completed by integrating the GEBCO Digital Bathymetry.	http://portal.emodnet-bathymetry.eu/
14	Baltic Sea Bathymetry Database	Baltic Sea Hydrographic Commission. European Union	Baltic sea Countries/ Europe	Baltic Sea	Bathymetry	The Baltic Sea Bathymetry Database (BSBD) distribute bathymetry data for the areas of all Baltic Sea countries.	http://data.bshc.pro/#2/58.6/16.2
15	North Atlantic Data Viewer	AORA (Atlantic Ocean Research Alliance).	Canada, European Union and US	Entire globe	Bathymetry	Bathymetry from different sources: NOAA, EMODNet, NRCan and MAREANO	https://maps.ngdc.noaa.gov/viewers/north_atlantic/index.html
16	Data products and surveys	Fisheries and Oceans Canada Government of Canada	Canada	Canada	Bathymetry / Nautical Charts	Bathymetry data products from the government of Canada.	http://www.charts.gc.ca/data-gestion/500map-eng.asp
17	Bathymetry and Backscatter Data Access	Government of Australia	Australia/ Oceania	Australia and New Zealand	Bathymetry	Different resolution bathymetry and backscatter data for the Australian coast. Maintained by Geoscience Australia	http://marine.ga.gov.au/#/
18	Lower Saint John River Data Overview	Ocean Mapping Group (UNB)	Canada	Lower Saint John River	Bathymetry and MVP data	Web portal for the bathymetric surveys performed by the OMG at the UNB. It also includes MVP data.	http://omg.unb.ca/Projects/lowerSJRiver/

19	ArticNet Amundsen Multibeam Data	Ocean Mapping Group (UNB)	Canada	Artic	Bathymetry	Bathymetry and Backscatter data web application that includes the multibeam data collected for the ArticNet Amundsen project.	http://www.omg.unb.ca/Projects/Arctic/google/
20	Tide data viewer	NOAA	US	US	Tidal and current data	Tidal and currents sensors viewer	https://tidesandcurrents.noaa.gov/map/
21	Ocean Viewer	Marine Environmental Observation, Prediction and Response Network (MEOPAR)	Canada	Entire globe/Atlantic Canada	Ocean data	Data hub that links to the different providers for real time ocean and weather variables. Data is retrieved as animated grids.	http://oceanviewer.org/atlantic-canada/water-temperature/global-rtofs/test554
22	Marine Conditions	St. Lawrence Global Observatory. Fisheries and Oceans (DFO), Environment and Climate Change Canada (ECCC) and the Institut des sciences de la mer (ISMER)	Canada	Canada	Ocean data	The application displays a wide range of recent and near real-time data collected by various monitoring systems installed in a vast territory from the Great Lakes to the St. Lawrence Gulf. They recently included data for the Canadian west coast.	https://ogsl.ca/conditions/?lg=en
23	Ocean Networks Canada	University of Victoria (British Columbia)	Canada	Canada	Ocean data	The organization operates ocean observatories around Canada, collecting data on physical, chemical, biological, and geological aspects of the ocean to support the scientific and research community.	http://dmas.uvic.ca/DataSearch

24	SECOORA	Southeast Coastal Ocean Observing Regional Association	US	US South Coast	Ocean data	Real-time sensors data visualization and downloading.	http://portal.secoora.org/#map?lg=50c39f3c-c75d-11e4-a389-00265529168c&z=7&ll=31.35010%2C-79.17731

3.1.4 Ocean modellers needs assessment online survey

Using the results from the informal interview and the conclusions drawn from the competitive analysis, an online survey was prepared to be conducted by ocean modellers.

This UCD data collection method was chosen due to the inaccessibility of the users, and it allows user input from different user groups and organizations, which will support the development of the web mapping application.

The questions were a series of discrete scale ratings (on a scale of 1–5) and unstructured form fill-in free response questions, divided in five different sections:

- Section 1.- General information: organization, position, and GIS and ocean modeling knowledge.

- Section 2.- Ocean modelling information: what kind of software do they use to work with ocean models, what kind of coordinates (projected/geographical…) do they work with, their interest in Free and Open Software, and the resampling methods they use when dealing with bathymetric data.

- Section 3.– Open source Software and formats: how much ocean modellers value open source software and open formats.

- Section 4.- Data sources: where do ocean modellers get the information from, what kind of online sources do they use.

- Section 5.- Ocean Web Mapping Application Data Layers: what kind of data would ocean modellers like to have access to? What kind of basemap would they like to see the data overlaid on? What additional information (metadata, resolution, uncertainty…) would they like to have access to? This section will determine the data requirements for the application, and consequently, the data that needs to be stored in the database.

- Section 6.- Ocean Web Mapping Application Functionalities: based on the competitive analysis, a list of functionalities is presented to be rated by the users.
- Section 7,– Data Formats: questions related to what formats will the users prefer for downloading data.

The online survey can be consulted in Appendix B. The results from the survey were plotted and analyzed using Tableau Software. Sections 4 and 5 were represented using a Likert Scale Visualization based on a Gantt chart. Only functionalities and data with a positive average more than 4 points (rated very useful) were considered for the consequent stages of the development.

3.2 Conceptual development

The conceptual development includes the scope plane, where the strategy is transformed into requirements. Using the combination of results from the work domain analysis, a list of data and functional requirements was prepared.

3.3 Prototyping stage

The prototyping stage includes the structure, skeleton and surface plane. The structure was defined by the system architecture, taking into consideration the results from the survey and giving shape to the requirements, showing how the elements of the application integrate with each other. Within this architecture, the data objects that the prototype use were defined, along with a formalized function list. The skeleton makes the structure concrete, determining what type of service each functionality will offer (and how) and creating format conversion scripts and uploading scripts to populate the database. Finally, the surface plane brings all these components together in the graphical interface, arranging the prototype interface window and organizing and symbolizing the map layers.

3.4 Evaluation stage

The prototype was evaluated using the cognitive walkthrough method and a formative online survey, closing the first loop of user-utility-usability.

A cognitive walkthrough evaluates an interface by stepping through user tasks and checking the ability of the interface to support them (Bowman et al. 2002). This evaluation was applied as an initial testing, and helped to identify any programing or usability issues (misleading or confusing functionalities) and to get additional feedback from the users for future development of the application. Seven target users participated in the cognitive walkthrough and the formative survey, purposefully selected from DFO, NRCan and the University of New Brunswick. They were users who also participated in the work domain survey, therefore already familiar with the project and with several years of expertise in ocean modelling and ocean mapping data.

The whole procedure was conducted online due to the inaccessibility of the users and the limited time they had to provide feedback. It consisted of a series of user tasks that represent main user case scenarios and interaction with the prototype. The users were given the prototype in advance, being able to explore it individually. After the exploration, they were asked to perform each of the tasks described in an online form. The tasks were divided in sections according with the topic (general, bathymetry, weather, salinity, temperature data, etc.). After the completion of every task, and after every section, they were asked to brainstorm and answer the following questions:

- What do you think of this functionality?
- Do you think it would be useful for an ocean modeller?
- Please describe any problems encountered during the task.
- Any recommendations for improvement or additional functionality?

The formative survey was included at the end of the evaluation as a set of discrete scale ratings 1-5, following the utility and usability question framework from Roth et al. (2015). This UCD data collection method was chosen to analyze the overall results and satisfaction of the users with the application, centering the attention into utility and usability issues. The complete evaluation form can be consulted in Appendix C.

The qualitative data extracted from the task evaluation was categorized depending if they mention (1a) positive comments, (1b) negative comments, (2a) problems related to utility, (2b) problems related to usability, (3a) recommendations related to utility and (3b) recommendations related to usability. After the categorization, the data was analyzed and the most important comments, problems and recommendations were highlighted. The results from the formative survey were plotted and analyzed in Tableau Software, using the same visualization technique as the work domain analysis survey.

3.5 Revised prototype

Considering the comments, problems and recommendations extracted from the evaluation stage, a revised prototype was developed. Some problems were fixed, while others are suggested for future work on the next versions of the application.

4. Results and discussion

4.1 Work domain analysis

Objective: Bridging the gap between ocean modellers and ocean mapping data, providing a useful and usable web-mapping application that meets ocean modellers' needs.

Target user profiles: Table 6 shows examples of target user profiles, including hypothetical organizations, sector and use case scenarios.

Table 6.- Target User Profiles and Hypothetical Use Case Scenarios for the Ocean Web Mapping Application

Target user profile	Hypothetical organization	Hypothetical sector	Hypothetical use case scenario
Ocean mapping researcher	University of New Brunswick	University/Research	I need data for the development of an ocean model in Lower Saint John River (New Brunswick) to study the dynamics of the reversing falls.
Ocean modeller	Department of Fisheries and Oceans	Government organization	I need data to validate an existing ocean model for the Bay of Fundy area to apply it to the improvement of ship routing.
Marine Infrastructure Research Engineer	National Research Council Canada	Government organization	I need data of the Squamish river area to model the seabed and support waste disposal and resource extraction planning activities.

4.1.1 Ocean modellers assessment interview

Analyzing the notes taken from the interview, the expected data inputs' needs for an ocean modeller were identified: (1) coast lines, (2) bathymetry, (3) tidal data, (4) temperature data, (5) salinity data, (6) currents data and (7) weather data, for example wind, heating flux and precipitation. Ocean mapping data is usually extracted from existing web resources or from surveys particularly designed to run the ocean model. Observations can be extracted from particular surveys (e.g. CTD or ACDP profiles) or installed sensors and stations; and weather data is usually extracted from weather models or weather stations.

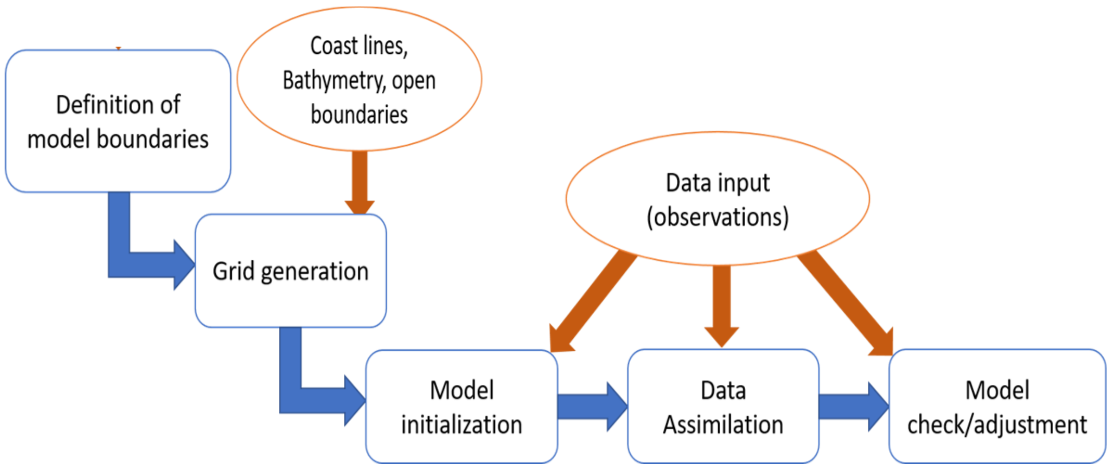


Figure 11.- Ocean modelling general task workflow. Data inputs are coloured in dark orange and the main process is coloured in blue

Extracted from the formalized notes, Figure 11 presents the task workflow that an ocean modeller performs when developing an ocean model, showing the data inputs required in dark orange and the main workflow in blue. Other remarks from the interview were the importance given to bathymetry resolution (as the size of the ocean model grid might be variant, and excessive bathymetry resolution will slow down the grid generation); the importance of time, as the models are usually time dependent; and the importance given to the source where the data came from (metadata).

4.1.2 Competitive analysis

Analyzing the set of similar existing applications, there exist several patterns worth mentioning. In the following analysis, numbers refer to the number in the first column (#) of Table 5. First, some applications are only focused on bathymetry data, while others include bathymetry as well as other ocean data observations. In the first group, most of the applications are intended for data distribution and download; some for free [1, 2, 3, 7, 9, 15, 18, 19], free under request [1, 3, 15] or by purchase [1, 3, 4, 8, 9, 15, 16]. This kind of applications limit their functionality to show only what data is available for a given organization, providing a link for download, and serving as data repositories. Planet OS [9] is a special case of website, being a Datahub linking to ocean, weather and climate data from the main government organizations and companies. In contrast to the first group, other applications support data exploration, enabling more user interaction through querying, filtering and basic analysis or calculations, such as depth profiles, measuring tools [10, 13, 14, 17], area statistics [6], or even storytelling techniques to support marine planning [5]. Across the whole analysis, n represents the number of applications that implement that feature or provides that data.

4.1.2.1 Representation

Related to representation, four themes were analyzed: (1a) Data included, (1b) inclusion of uncertainty as a variable and the way uncertainty is portrayed (1c) inclusion of time as a variable and the way the time is portrayed, (1d) variation in the basemap provided.

(1a) Data included

The results from the informal survey showed the kind of data that might be useful for an ocean modeller. The web applications were analyzed to determine if they include all different kinds of data: bathymetry, MVP/CTD, weather, tidal, coast lines, water level, river discharge and currents.

Table 7.- Kind of data included in the web mapping applications analyzed

#	Name	Bathymetry	MVP Profiles	Weather	Tidal	Coast lines	Water level	River discharge	Currents	TOTAL	Other kinds of data
1	NOAA Bathymetry Data Viewer	✓								1	Lidar Bathymetry. DEM
2	GMRT MAP TOOL	✓								1	Cruise tracks, geochemistry data, geo/thermochronology data, seismic data
3	Crowdsourced Bathymetry	✓								1	DEM
4	Bathymetrics Data Portal	✓								1	
5	MID-ATLANTIC PORTAL	✓		✓						2	Oceanographic data, seabed forms, marine life, Fishing security… and other themes
6	Voyager	✓	✓	✓	✓	✓	✓	✓		7	Benthic habitats,
7	NOAA Grid Extract	✓								1	
8	Data Access Viewer	✓								1	Imaginery, Land Cover, Elevation
9	Planet OS	✓		✓					✓	3	Climate and environmental data
10	CCLME ECO-GIS Viewer	✓	✓	✓			✓	✓		5	Upwelling index, floating devices profiles, biological data
11	Mareano	✓				✓			✓	3	Sediments, habitats, Geochemistry,

12	INFOMAR Data Viewer	✓	✓							2	Seabed classification, survey track lines…
13	EMODnet	✓				✓				2	
14	Baltic Sea Bathymetry Database	✓								1	
15	North Atlantic Data Viewer	✓								1	
16	Data products and surveys	✓								1	Nautical charts, Natural Resources maps
17	Bathymetry and Backscatter Data Access	✓								1	Backscatter data
18	Lower Saint John River Data Overview	✓	✓							2	Survey footprints
19	ArticNet Amundsen Multibeam Data	✓								1	Backscatter
20	Tide data viewer			✓	✓		✓		✓	4	
21	Ocean Viewer			✓	✓				✓	3	Salinity, temperature, Chlorophyll…
22	St. Lawrence Global Observatory			✓			✓		✓	3	
23	Ocean Networks Canada		✓	✓					✓	3	
24	SECOORA			✓			✓	✓	✓	4	Stream Height
TOTAL		19	5	9	3	3	5	3	7		

The results from the analysis showed that there are nineteen applications that provides bathymetry (n=19), nine applications that provides weather data (n=9), seven provide current data (n=7), five provide water level data and CTD or MVP data (n=5), and three of them provide tidal, coast lines or river discharge data (n=3). None of the applications provide all the data expected to be useful by an ocean modeller. Several conclusions can be extracted from the analysis:

- The web pages can be subdivided in three main categories: (a) bathymetry data portals, which exclusively deliver bathymetry data and they do not include additional data [1, 2, 3, 4, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19]; (b) sensors and observations data portals, as the opposite of bathymetry data portals, they deliver all kinds of data but bathymetry, only focusing on observations (either real time or historical) [20, 21, 22, 23, 24]; (c) data portals that combine both bathymetry and other kinds of data [5, 6, 9, 10, 11].

- CTD profiles data and MVP, although a main product of ocean mapping surveys, it is not data usually delivered, with only five web portals offering it [6, 10, 12, 18, 23]. The Pacific Islands Ocean Observing System Voyager [6] offers ocean glider data, which could be considered as similar to MVP data. However, ocean gliders collect data along an undulating underwater track and they do not perform vertical profiles.

- CCLME ECO-GIS Viewer [10] and Pacific Islands Ocean Observing System Voyager [6] are the web portals which offer almost all the different datasets, being the most complete.

(1b) Inclusion of uncertainty

Uncertainty is a measure that describes any mismatch between reality and the user's understanding of reality (Roth 2009), and it can appear at any part of the process of converting the reality into knowledge: reality → variable-definition → data-collection → information- assembly → knowledge-construction (Longley et al. 2005). Information uncertainty in Geomatics is described using (at least) three components: (1)

accuracy/error, or the correctness of a measurement or estimate, (2) precision/resolution, or the exactness of a measurement or estimate, and (3) trustworthiness, or the confidence that the user has in the information (MacEachren et al. 2012).

The results from the analysis show that uncertainty is not represented on the map as a cartographic variable in any of the web applications. Moreover, weather data and other observations are not accompanied by the uncertainty of the measurement. However, some of the bathymetric tools include uncertainty information related to two themes: (a) bathymetry uncertainty (the uncertainty associated to the depth measurement) and (b) bathymetry resolution (the pixel size in the real world of the grid). Table 8 provides an overview of the inclusion of these two kinds of uncertainty across the web applications. As an exceptional case, INFOMAR Data Viewer [12] includes data quality as one of the attributes for the MVP surveys (Figure 12). However, this information is limited to good/fair/unknown/DNP, without any explanation about the meaning of these values.

Table 8.- Inclusion of uncertainty in the web mapping applications analyzed. A blue square indicates that the tool considers uncertainty data.

#	Name	Bathymetry uncertainty	Bathymetry resolution
1	NOAA Bathymetry Data Viewer	Uncertainty included in the BAG surfaces	
3	Crowdsourced Bathymetry	Uncertainty included in the BAG surfaces	
4	Bathymetrics Data Portal	Not possible to determine as the data cannot be downloaded without payment	Two options: 2m or 90m
6	Pacific Islands Ocean Observing System Voyager		Different options depending on the area
8	Data Access Viewer		Just as metadata
9	Planet OS	Depends on the data source	
12	INFOMAR Data Viewer		Three different options. There is a resampling option when downloading.
14	Baltic Sea Bathymetry Database		Only as low/high resolution
15	North Atlantic Data Viewer	Uncertainty included in the BAG surfaces	
17	Bathymetry and Backscatter Data Access		Just as metadata
18	Lower Saint John River Data Overview	Uncertainty included in the BAG surfaces	
TOTAL		4	6

SVP Name	Date	Depth m	Data Quality
030511_01_01	May 10, 2003	109	Good
030511_01_02	May 10, 2003	70	Fair
030511_01_03	May 10, 2003	129	Unknown
030511_01_04	May 10, 2003	180	Good
030511_01_06	May 10, 2003	267	Good

Figure 12.- INFOMAR Data Viewer data quality for MVP surveys

Several conclusions can be extracted from Table 8:

- Bathymetry uncertainty is only included in four tools [1, 3, 15, 18]. Uncertainty is a component of the BAG bathymetry format and it is not represented on the map.

- Bathymetry resolution is included in six tools [4, 6, 8, 12, 14, 17]. However, the resolution is only included as metadata (name of the layer) in two of them [8, 17], and no different options are given. When there are several resolutions for the same area, it is usually due to different surveys that were performed at different scales. The idea would be to provide the user with different resolutions under request, even if the survey was performed in another resolution (resampling the data).

(1c) Inclusion of time

Analyzing the web mapping applications, time is not represented or usually considered in bathymetric tools. The only way to know the date and time a survey was performed is by querying the layer or searching through the metadata. Both UNB tools [19, 20] include the year of the survey as the name of the layer; therefore, a user would be able to select the bathymetry depending on the year. NOAA applications provides a time search (by year) for the surveys.

Regarding CTD profiles and MVP data, Pacific Islands Ocean Observing System Voyager [6] provides an animation tool for visualizing the movement of ocean gliders. However, it does not provide a search or query tool to retrieve data based on date or time (the only filter is by vessel). CCLME ECO-GIS Viewer [10] provides a spatio-temporal data viewer that allows the user to find CTD data for a specific month or year.

As opposed to bathymetry, time is considered in all the web applications that contain sensor observations, either as a search tool that applies a filter, or as a time slider that allows the user to change the date/time of the visible measurements. Ocean viewer [21] includes a sophisticated animation tool that allows the user to visualize on the map the different gridded data provided as a time series. Table 9 summarize the inclusion of time across the web mapping applications.

Table 9.- Inclusion of time across the web mapping applications included in the analysis. A blue square indicates that the tool includes time as a variable.

#	Name	Time filter	Time slider	Time search	File name	TOTAL
1	NOAA Bathymetry Data Viewer			✓		1
3	Crowdsourced Bathymetry			✓		1
6	Pacific Islands Ocean Observing System Voyager		Animation for ocean gliders data			1
10	CCLME ECO-GIS Viewer	✓		✓		2
18	Lower Saint John River Data Overview				✓	1
19	ArticNet Amundsen Multibeam Data				✓	1
20	Tide data viewer	✓		✓		2
21	Ocean Viewer		Animated			1
22	St. Lawrence Global Observatory	✓		✓		2
23	Ocean Networks Canada	✓		✓		2
24	SECOORA		✓			1
TOTAL		4	3	6	2	

(1d) Basemap context information

Web mapping applications are usually organized into basemaps and overlays. Basemaps layers are usually rasterized, serving as a set of tiles to provide context information to the user, who will retrieve information about overlay layers. Table 10 provides an overview about the most important basemap options available across the web mapping applications. Some of the applications offer other kinds of basemaps not included in the table.

Table 10.- Kinds of basemaps used across the web mapping applications. A blue square indicates that that kind of basemap is included in the application. A darker blue shaded square indicates the default basemap when the application is launched. If more than one option is given for a type of basemap, it is indicated with the number of options in white.

#	Name	Street Map	Satellite Image	Hybrid map	Topographic/Terrain	Ocean basemap	Nautical Charts	Global Bathymetry	Simple	TOTAL
1	NOAA Bathymetry Data Viewer		✓	✓		✓	✓	✓	2	7
2	IEDA Data Browser / GMRT MAP TOOL							✓		1
3	Crowdsourced Bathymetry		✓	✓		✓	✓	✓	2	7
4	Bathymetrics Data Portal							✓		1
5	MID-ATLANTIC OCEAN DATA PORTAL	✓	✓	✓		✓	✓			5
6	Pacific Islands Ocean Observing System Voyager	✓	✓	✓	✓	✓			✓	6
7	NOAA Grid Extract							✓		1
8	Data Access Viewer	✓	✓						✓	3

9	Planet OS								✓	1
10	CCLME ECO-GIS Viewer					✓		✓		2
11	Mareano							✓		1
12	INFOMAR Data Viewer	✓	✓	✓	✓	✓			✓	6
13	EMODnet portal for Bathymetry					✓				1
14	Baltic Sea Bathymetry Database							✓		1
15	North Atlantic Data Viewer		✓	✓		✓		✓	2	6
16	Data products and surveys					✓				1
17	Bathymetry and Backscatter Data Access		✓			✓				2
18	Lower Saint John River Data Overview	✓								1
19	Artic Net Amundsen Multibeam Data	✓	✓		✓					3
20	Tide data viewer	✓	✓	✓	✓	✓		✓	✓	7
21	Ocean Viewer	✓	✓						2	4
22	St. Lawrence Global Observatory	✓	✓							2
23	Ocean Networks Canada		✓							1
24	SECOORA		✓							1
TOTAL MAIN		2	6	1	0	7	0	5	4 (3)	
TOTAL		9	14	7	4	11	3	10	13 (9)	

The analysis identified eight different basemap types: satellite image (n=14), simple basemap (as a grey/black/white map) (n=13), ocean basemap (ocean basemap from Esri) (n=11), global bathymetry (as any layer portraying the global bathymetry of the oceans) (n=10), street map (n=9), hybrid map (n=7), topographic/terrain (n=4) and nautical charts (n=3). None of the applications provides all the basemaps options, and ten of them provide only one option. Several conclusions can be extracted from the analysis:

- There are many tools that only provide one basemap (n=10). This fact might be explained because they only support downloading operations and the user interaction is limited (and not necessary).

- There is a large number of tools providing simple basemaps, being the second most used basemap (n=13) and the starting basemap in four tools (n=4). This could show a tendency of ocean web mapping applications to be simplistic, either because the main purpose is just downloading data or because of designed purposes.

- There are only three tools which provides a nautical chart basemap. This option might seem one of the best regarding ocean web mapping applications, however, this kind of information is usually owned by government organizations and not open to the public, therefore it may be hard to access.

- Pacific Islands Ocean Observing System Voyager [6] provides more than 20 additional different options for basemaps, apart from the one mentioned on Table 10. The provision of more number of basemap options might seem useful as it could support a wider range of user tasks, allowing the map to be personalized (Roth, 2015). However, a huge number of options might overwhelm the user and be unnecessary for the purpose of the map.

- A lot of web mapping applications simply use the basemap tool from Esri, which provides a set of standard basemaps options. However, it is argued that it should be studied what would be the context information required by the user to provide them with the right one, instead of providing all the options. Also, there are more alternatives to Esri basemaps that could enrich an ocean web mapping application (i.e. bathymetry and nautical charts).

- The statement above might be the reason why the number of web applications that provides street maps as a basemap is high (n=9). A street map might be viewed as of little use for ocean web mapping applications.

4.1.2.2 Interaction

Related to interaction, four themes were analyzed: (2a) variation across supported interaction functionalities; (2b) bathymetry supported formats; (2c) other data supported formats; and (2d) variation in the web mapping technology used to implement the web application.

(2a) Supported interaction functionalities

Interaction functionalities describe any kind of functionality which allows the user to interact with the map or tool (Roth 2012; Roth 2013a). Table 11 provides an overview of the supported interaction functionalities across the web mapping applications. The most commonly implemented functionality is metadata retrieval (n=19), which allows users to retrieve metadata of a set of data, either as a link or as information shown in the same map view. The second most implemented functionality is requesting help or tutorials about the tools (n=17). The applications provide a page or help button explaining how the application must be used, including the different types of uses. The third most common functionality implemented was information retrieval (n=15), or the ability to request specific details about a feature on the map, which is a common functionality in web mapping applications. Data download, which is one of the main purposes in ocean web mapping applications, was subdivided in two functionalities: bulk download (n=12), downloading whole datasets; and data download by area (n=13), allowing the user to draw an area on the map to download only a specific set of data. Most of the applications include one or both options [6, 8, 13, 17, 23]; and there are only four applications [5, 10, 11, 19] which do not provide any of them.

The filter and the search functionality are implemented in twelve applications (n=12), and somewhat related to each other. Filtering is the ability to adjust the map to only show map features that match one or more user-defined conditions; searching is the ability to identify map features of interest. Most of the applications provide a search tool that applies a filter on the map when a specific kind of feature is selected.

The results from the analysis reveals several opportunities for the development of the web mapping application prototype. Several functionalities are under represented in existing applications: Area of interest (n=1), area statistics (n=1), map annotation (n=2), and vertical profiles (n=2). These functionalities are more analytical and task specific, instead of general purpose functionalities as data download. The idea would be to combine all these tools to improve analytical work and support the ocean modellers workflow.

(2b) Bathymetry Supported formats

Table 12 provides the results from the analysis of bathymetry supported formats. The most supported formats are GeoTIFF (n=6) and BAG, LAS/LAZ and ArcGIS ASCII formats (n=5). Most of the tools make available more than one format for the download of bathymetry data. There are only three applications [8, 16, 18] which only provide one format.

(2c) Other data Supported formats

Other kinds of data would include alphanumerical data (time series observations or profiles) and vector data. The most common format for delivering this kind of data is CSV format, a simple standardized format to provide tabular data (numbers and text) in plain text (Table 13).

Table 11.- Supported interaction functionalities across the web mapping applications analyzed. A blue square indicates that the functionality is implemented in the application.

#	Bulk Data download	Data download by area	Filtering	Searching	Area of interest	Info retrieval	Change projections	Measuring tools	Export/save/print map	Own data	Map annotation	Metadata retrieval	Longitudinal profiles	Vertical profiles	Export profiles	Area statistics	User profiles	Help/tutorials	TOTAL
1	✓		✓	✓			✓					✓						✓	6
2		✓					✓						✓		✓				4
3	✓		✓	✓			✓					✓						✓	6
4		■								✓							✓		3
5				✓		✓			✓	✓	✓	✓					✓		7
6	✓	✓	✓	✓		✓		✓	✓			✓		✓	✓	✓		✓	12
7		✓																	1
8	✓	✓	✓	✓	✓	✓						✓						✓	8
9	✓		✓	✓		✓						✓					✓		6
10			✓	✓		✓				✓			✓	✓	✓			✓	8
11				✓		✓	✓	✓	✓			✓						✓	7
12		✓	✓	✓		✓		✓	✓	✓	✓	✓	✓					✓	11
13	✓	✓				✓		✓		✓		✓	✓		✓			✓	9
14		✓										✓	✓					✓	4
15	✓											✓						✓	3
16	✓		✓															✓	3

17	✓	✓				✓		✓				✓	✓						6
18	✓					✓						✓						✓	4
19						✓						✓							2
20		✓	✓	✓		✓						✓						✓	6
21	✓					✓						✓						✓	4
22		✓	✓									✓					✓	✓	5
23	✓	✓	✓	✓		✓						✓					✓	✓	8
24		✓	✓	✓	✓	✓						✓						✓	6
Total	12	13	12	12	1	15	4	5	4	5	2	19	6	2	4	1	5	17	

Table 12.- Kind of bathymetry formats offered to the user across the web mapping applications. A blue square indicates that the application provides that kind of format.

#	BAG	Raw data	LAS/LAZ	GeoTIFF Float 32	GeoTIFF RGB	GMT	Coards	ArcGIS ASCII	NetCDF	XYZ	ArcGIS Grid	Fledermaus Scene	PNG Image	NGrid	TOTAL
1	✓	✓	✓												3
2				✓		✓	✓	✓							4
3	✓	✓	✓												3
4	Data Available only under purchase (format unknown)														
6				✓					✓						2
7				✓		✓		✓	✓	✓					5
8			✓												1
9	Need for an account														
12			✓								✓	✓			3
13				✓	✓			✓							3
14				✓	✓			✓		✓			✓		5
15	✓	✓	✓												3
16	✓														1
17				✓				✓						✓	3
18	✓														1
Total	5	3	5	6	2	2	1	5	2	2	1	1	1	1	

Table 13.- Kind of formats for other data supported across the web mapping applications analyzed. A blue square indicates that the application provides that kind of format.

#	Name	Excel	XML	JSON	CSV	KML	PNG/JPEG/SVG	ASCII	NetCDF	SHP	TOTAL	Type of data
6	Pacific System Voyager	✓	✓	✓							3	Ocean gliders profiles
11	CCLME ECO-GIS Viewer				✓		✓	✓	✓		4	Vertical profiles and charts
13	INFOMAR Data Viewer					✓				✓	2	N/A
21	Tide data viewer				✓		✓				2	Charts
22	Ocean Viewer	Links to different providers									-	N/A
23	St. Lawrence Global Observatory				✓						1	N/A
24	Ocean Networks Canada			✓	✓		✓	✓	✓		5	Time series
25	SECOORA				✓						1	N/A
TOTAL		1	1	2	6	1	3	2	2	1		

(2d) Web Mapping Technologies and Mobile Support

Web mapping technologies support the implementation of maps and specific functionalities in web mapping applications. Table 14 provides an overview of the client-side web mapping technologies used to implement the set of web mapping applications analyzed. Esri products take the lead on web mapping technologies used to develop ocean web mapping applications (n=10), followed by google maps (n=5) and leaflet (n=4). The widespread use of Esri products might be explained as it provides a wide range of services (for example, ArcGIS Server, ArcGIS Online, and ArcGIS API for JavaScript) to develop and support web mapping applications. Bathymetry datasets are usually large, and need a powerful server development which is already built into the ArcGIS suite. However, ArcGIS is a commercial software and is not open source, which means high pricing for licensing, storage and development, and less possibilities for plugins and personalization. For this reason, many of the applications have the exact same look, as they are developed using basic Esri templates. Google Maps is also widely used, however, having the same problem as Esri Products plus not providing web map servers. Regarding open source web mapping technologies, leaflet is the most used technology, followed by Mapbox (same API). The rest of web mapping technologies (Open Layers, Geoexplorer) have decreased in popularity during recent years and their APIs are not well-maintained, resulting in maps which are inferior in appearance.

These results align with the ones obtained by Roth 2015, indicating a broad transition in web mapping technologies from proprietary plugins to modern web standards, and an increase in popularity of open source solutions. There is an emerging and active community of open source web map developers; and although open source solutions might suffer from poorer stability, updates and innovations can be incorporated into the code more easily and they are free to use (Roth 2015). Moreover, as concluded by Roth et al. (2013) Leaflet is able to produce web maps of comparable functionality to Google Maps, but resulting in a more satisfying development experience (more beautiful maps) given the openness and extensibility of the code repository.

With respect to mobile support, 16 of the 24 applications provide support for mobile devices, adapting the interface for smaller screens and maintaining all the functionalities available.

Table 14.- Web Mapping technologies and mobile support across the web mapping applications. A blue square indicates that the application is built using that technology. A green square is used for mobile support.

#	Name	Google Maps	Mapbox	Leaflet	Esri Products	Geo explorer	Open Layers	Bing Maps	Mobile support
1	NOAA Bathymetry Data Viewer				✓				✓
2	IEDA Data Browser / GMRT MAP TOOL	✓							✓
3	Crowdsourced Bathymetry				✓				✓
4	Bathymetrics Data Portal		✓						
5	MID-ATLANTIC OCEAN DATA PORTAL				✓				
6	Pacific Islands Ocean Observing System Voyager	✓							
7	NOAA Grid Extract				✓				✓
8	Data Access Viewer				✓				
9	Planet OS			✓					✓
10	CCLME ECO-GIS Viewer				✓				

11	Mareano					✓			✓
12	INFOMAR Data Viewer				✓				✓
13	EMODnet portal for Bathymetry						✓		✓
14	Baltic Sea Bathymetry Database			✓					✓
15	North Atlantic Data Viewer				✓				✓
16	Data products and surveys				✓				
17	Bathymetry and Backscatter Data Access				✓				✓
18	Lower Saint John River Data Overview			✓					✓
19	Artic Net Amundsen Multibeam Data	✓							✓
20	Tide data viewer			✓					✓
21	Ocean Viewer	✓							
22	St. Lawrence Global Observatory							✓	✓
23	Ocean Networks Canada	✓							
24	SECOORA		✓						✓
TOTAL		5	2	4	10	1	1	1	16

4.1.3 Online survey

4.1.3.1 Section 1 – General information

This section asked question related to information about the participants of the survey. Of a total of eighteen participants, fourteen were from Departments of Fisheries and Oceans of the Government of Canada. The rest were from each of the following organizations: Golder Associates, Haikai Institute, National Research Council Canada, and the University of Southern Mississippi (one participant per each group). This provided a wide range of participants, having representatives from university, industry, government and scientific research organizations. Regarding the position within their organization

(Figure 13), most of the participants were scientists (14 representatives) and the rest were a graduate student, a post doctorate fellow, a research council officer, a water resources engineer and a global computer fluid dynamics' lead. With respect to the frequency of use of geographic information, 72% of the participants claimed to use it daily, while 28% claimed to use it weekly. Results are similar about the use of ocean models, varying from 67% daily use, 28% weekly use and 6% variable (ranging from daily to monthly, depending on the occupation) (Figure 14). Therefore, the participants were ocean modelling experts quite familiar with geographic information, using ocean models mainly for research purposes.

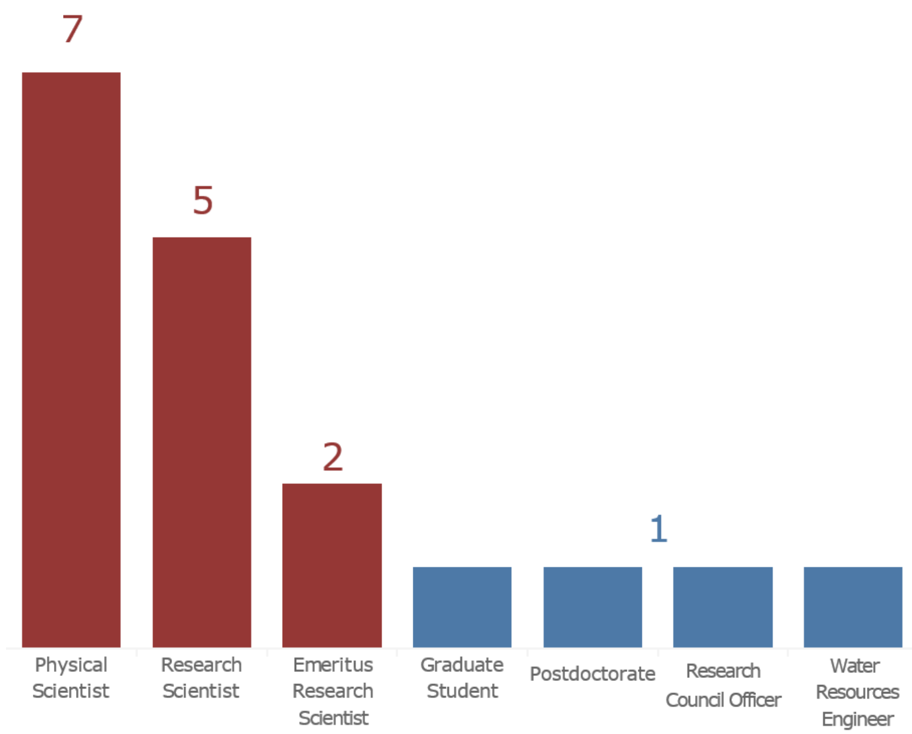


Figure 13.- Participant's positions within their organizations

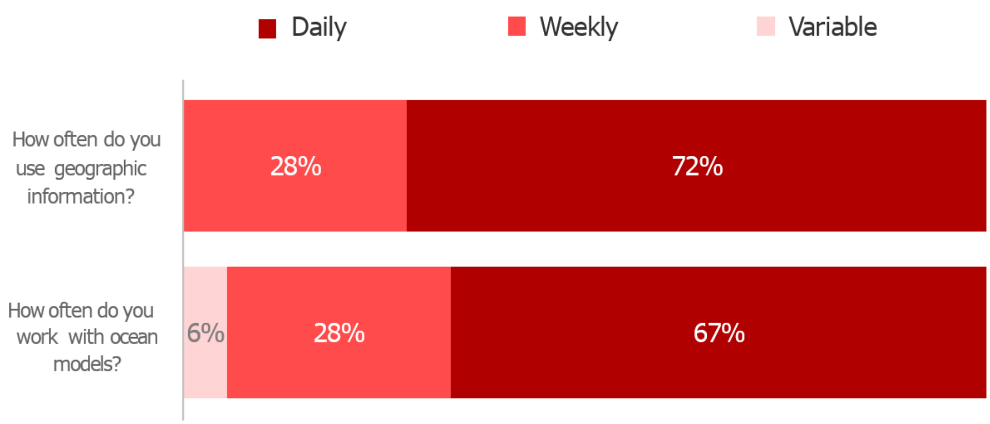


Figure 14.- Familiarity with geographic information and ocean models within participants

4.1.3.2 Section 2 – Ocean modelling information

In this section, more specific questions about ocean modelling were asked. Ocean modelling simulation and grid generation software usage is depicted in Figure 15 and Figure 16, showing the number of times a software was mentioned in participant's responses (n). FVCOM was the most mentioned ocean modelling simulation software, with fourteen mentions. The other three software packages worth of mention were NEMO (n=5), ROMS (n=3) and POM (n=2). The rest of the software packages were only mentioned once in the responses. Regarding grid generation software, Matlab and SMS were the packages mentioned the most times (n=5), followed by Resolute and custom scripts (usually Python scripts) (n=3) and GMSH and Genesis [2]. The rest of the software packages were only mentioned one time by one participant.

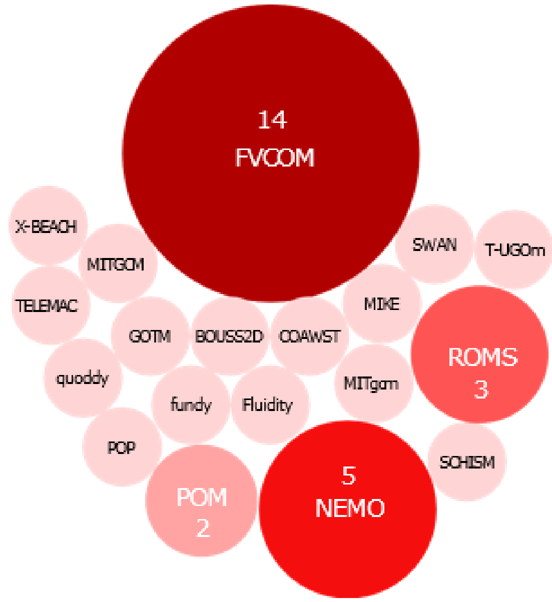


Figure 15.- Ocean modelling simulation software packages mentioned in the survey. The size of the bubbles is proportional to the number of mentions

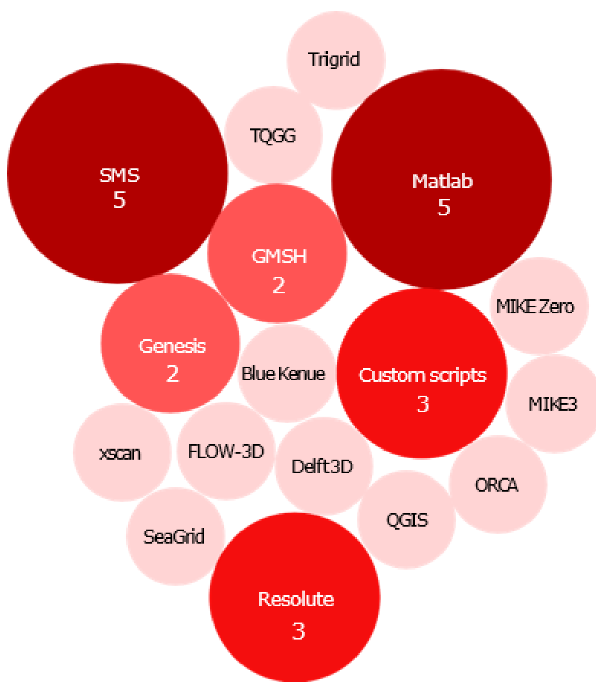


Figure 16.- Grid generation software packages mentioned in the survey. The size of the bubbles is proportional to the number of mentions

Regarding the kind of coordinates the participants usually work with (Figure 17), geographic coordinates (latitude and longitude) was the most selected option, with 83.33% of the participants, followed by projected coordinates on a plane (44.44%) and Geocentric coordinates (X, Y, Z) (33.33%). The next question asked participants to mark the kind of projected coordinates they work with (in case they do). Figure 18 shows the three projections mentioned: Universal Transverse Mercator (UTM), mentioned six times; Lambert Conformal Conic (Lambert), mentioned four times; and Mercator, mentioned once.

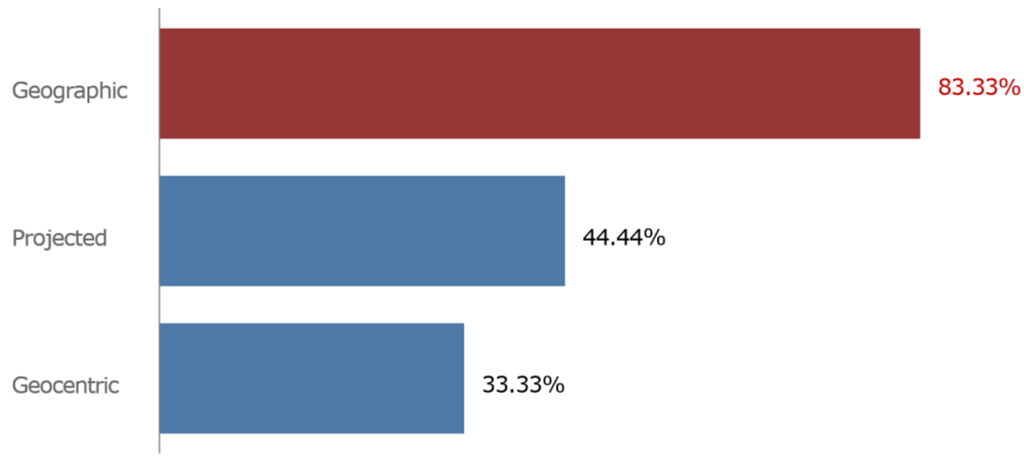


Figure 17.- Kind of coordinates the participants work with. The number shows the percentage of participants who checked that option.

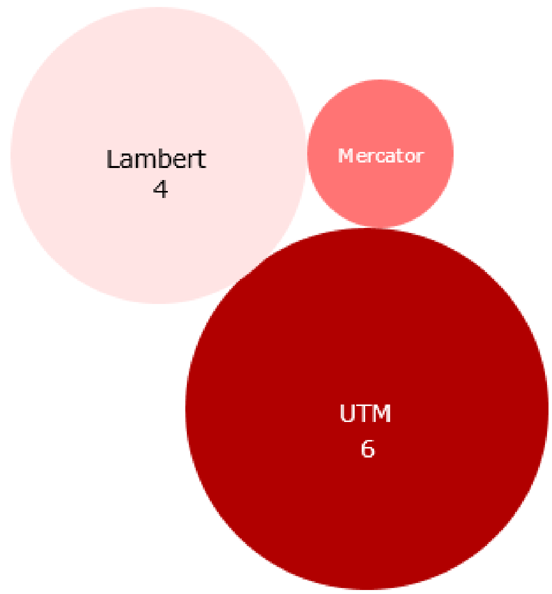


Figure 18.- Kind of projected coordinates the participants work with. The size of the bubbles is proportional to the number of mentions.

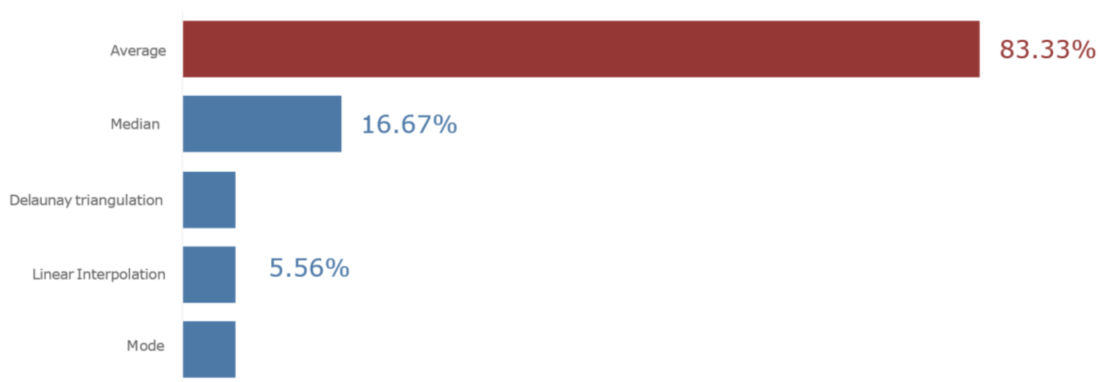


Figure 19.- Resampling Method used when bathymetry resolution is greater than the model resolution. The number shows the percentage of participants who checked that option

Figure 19 shows the answers to the question about the method used to resample bathymetry data, when the resolution is greater than the model resolution. 83.33% of the participants checked simple average of the area as the method to determine the new depths, 16.67% checked the median, and 5.56% (only one person) checked either Delaunay triangulation, Linear interpolation or the mode.

4.1.3.3 Section 3 – Open source software and formats

The results from the survey show that free and open software and open formats are highly valued by participants, with an average of 4.9 and 4.7 out of 5, respectively (Figure 20).

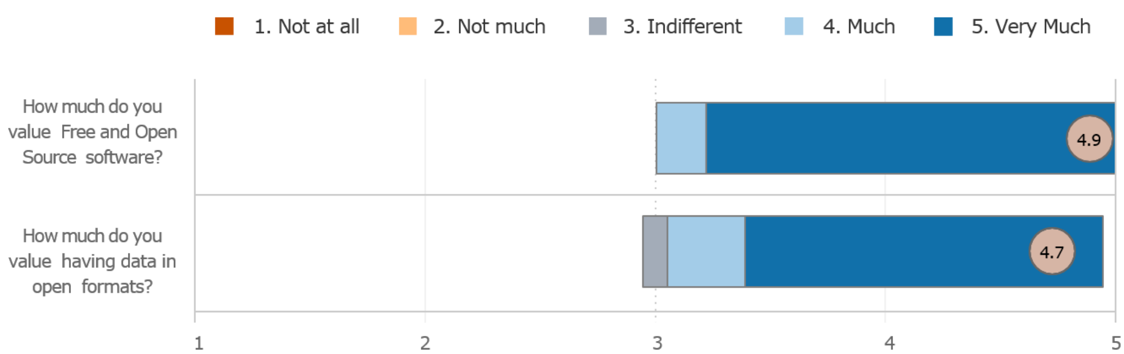


Figure 20.- Free and Open Source software and Open formats Likert scale. The average value from all the responses is shown in the bubbles.

4.1.3.4 Section 4 – Data Sources

This section analyzed common data sources among ocean modellers. Figure 21 shows what kind of sources the participants extract their data from. Open data from government web portals is the option that was checked the most (with 88.89% of the participants), followed by public weather models (77.78%) and Open data from university research web portals (38.89%). Overall, open data is used more frequently than private data, as 68.33% of the answers were referred to open data and only 31.67% of the answers referred to private data (pie chart Figure 23). NOTE: the number of answers is not the same as the number of participants since it was a multi-choice question and the participants could choose more than one option.

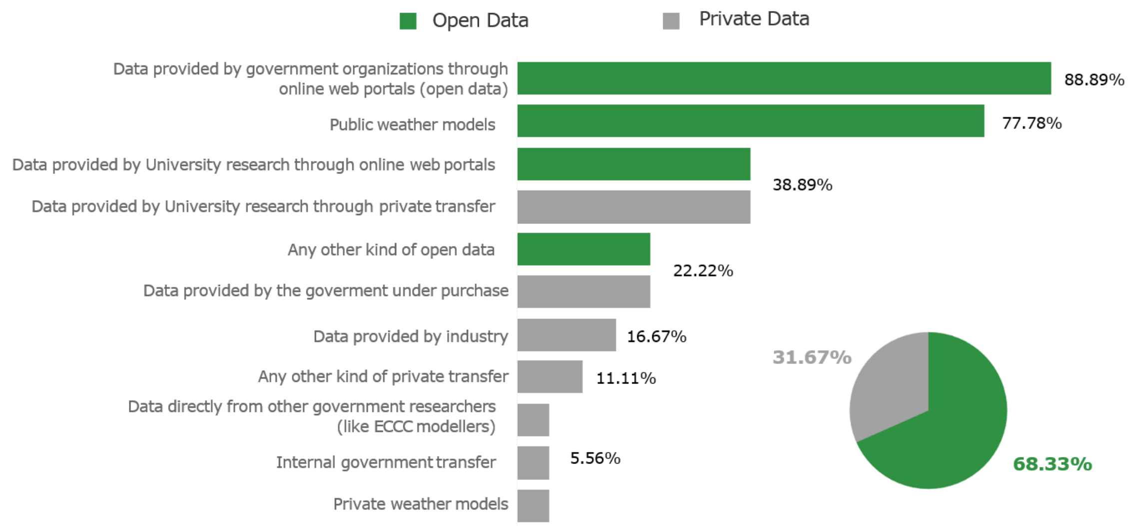


Figure 21.- Data Sources participants extract their data from

4.1.3.5 Section 5– Ocean Web Mapping Application Data Layers

The data included in the survey was extracted from the individual interview performed with an ocean modeller, adding sensors that collects this kind of data (CTD, ADCP and buoys): tidal data, weather data, coast lines, bathymetry, river discharge, water level data, sea temperature, sea salinity data, currents data, CTD data, ADCP data, and buoy data. Figure 22 show the results of rating the usefulness of each kind of data. All the data layers are rated with an average of more than 4 points (very useful), therefore all this data should be included in an ocean modeller web mapping application. The questionnaire had a section where participants could add any kind of data they thought was missing. Figure 23 shows the additional types of data mentioned in this question, categorized by sediments related data, topographic data, moored data, weather data, and bio-chemistry related data. It was surprising that weather related data was mentioned nine times, even though it was included in the list. Some of the comments were “if not included in weather data”, showing a special interest in this kind of data. The participant who mentioned moored oceanographic data, included the following comment: “in-situ timeseries in general are especially valuable to validate a model but very scarce and/or very hard to get”. Bio-chemistry related data (i.e. oxygen, nutrients, pH…) were mentioned four times, same as sediment related data. These results show a necessity of a web mapping application for ocean modellers to be interdisciplinary, covering not only ocean mapping data but other oceanographic data needed to validate ocean models.

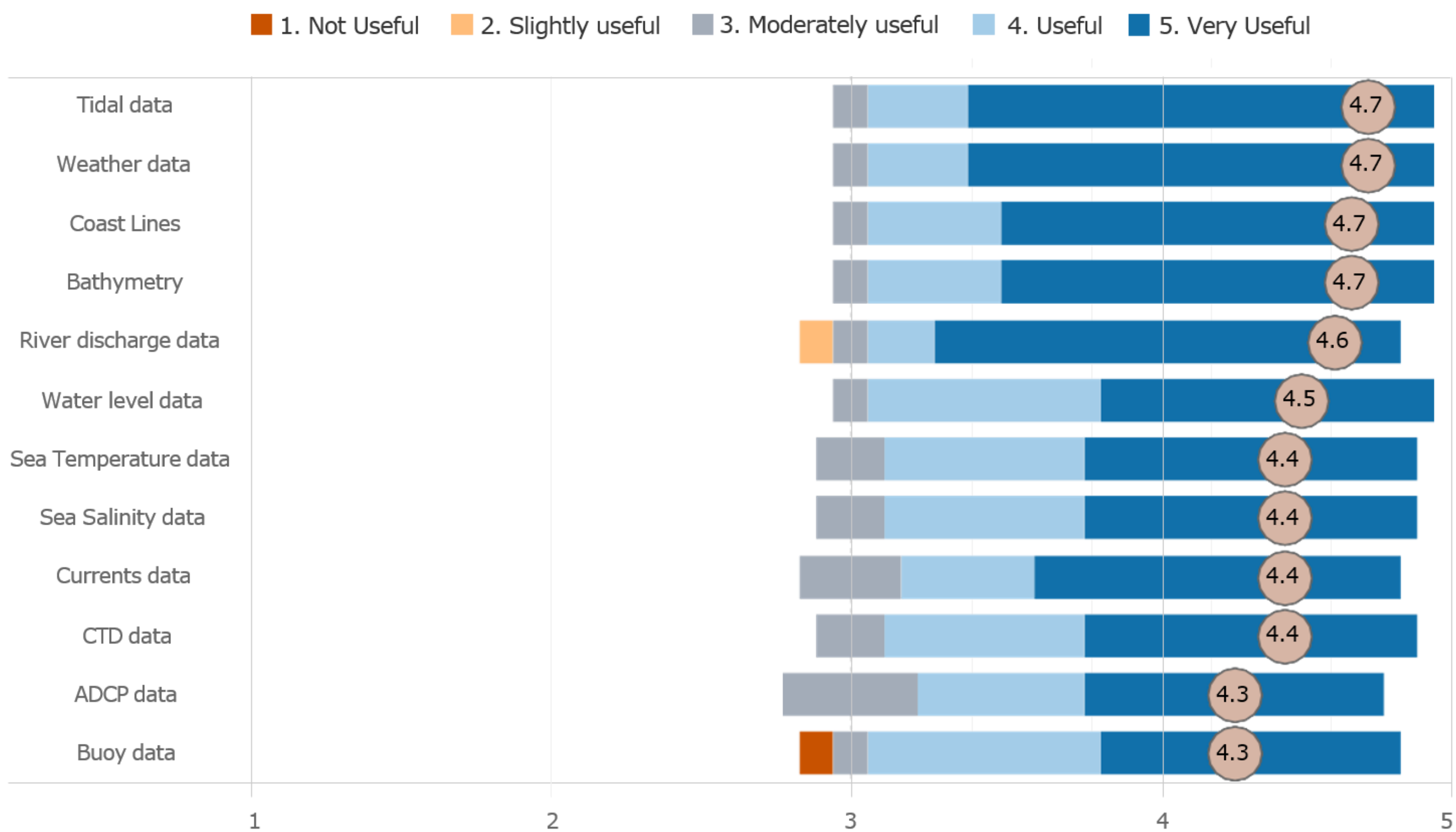


Figure 22.- Data Layers Likert Scale. Average response values are shown in the bubbles

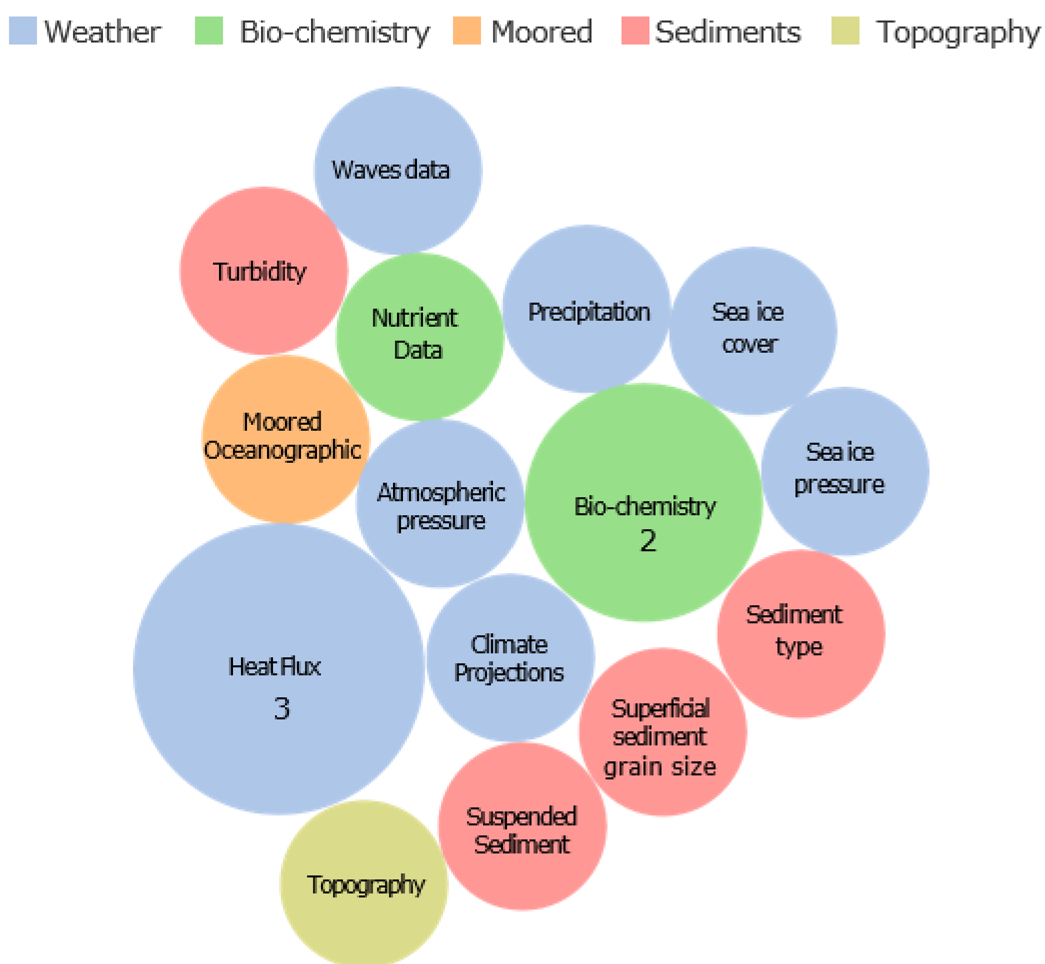


Figure 23.- Additional useful data mentioned by participants. Size of the bubbles is proportional to the number of mentions.

Regarding the basemap types, the results show that the most useful basemap for ocean modellers would be a satellite image, rated with an average of 4.4 out of 5. The second most useful basemap would be topographic/terrain, with an average of 4.1 out of 5 and the third would be an ocean map (4/5) (Figure 24). Satellite images are realistic representations of the earth surface and can be used to extract coast lines. Surprisingly, nautical charts average is lower than 4 (3.9) and were not rated as one of the most useful basemaps. As expected, street maps would not be useful for an ocean modeller, with an average of 1.8 and 6 participants marking the option “Not useful”. As in the data layers question, the question was opened to suggestions. The only additional basemap that was mentioned was a latitude/longitude grid over a satellite image.

With respect to additional information an ocean modeller would find useful in an ocean mapping application, the four kinds of information: metadata, bathymetry resolution, time and uncertainty; were found very useful, all of them with an average more than 4.4 out of 5 (Figure 25).

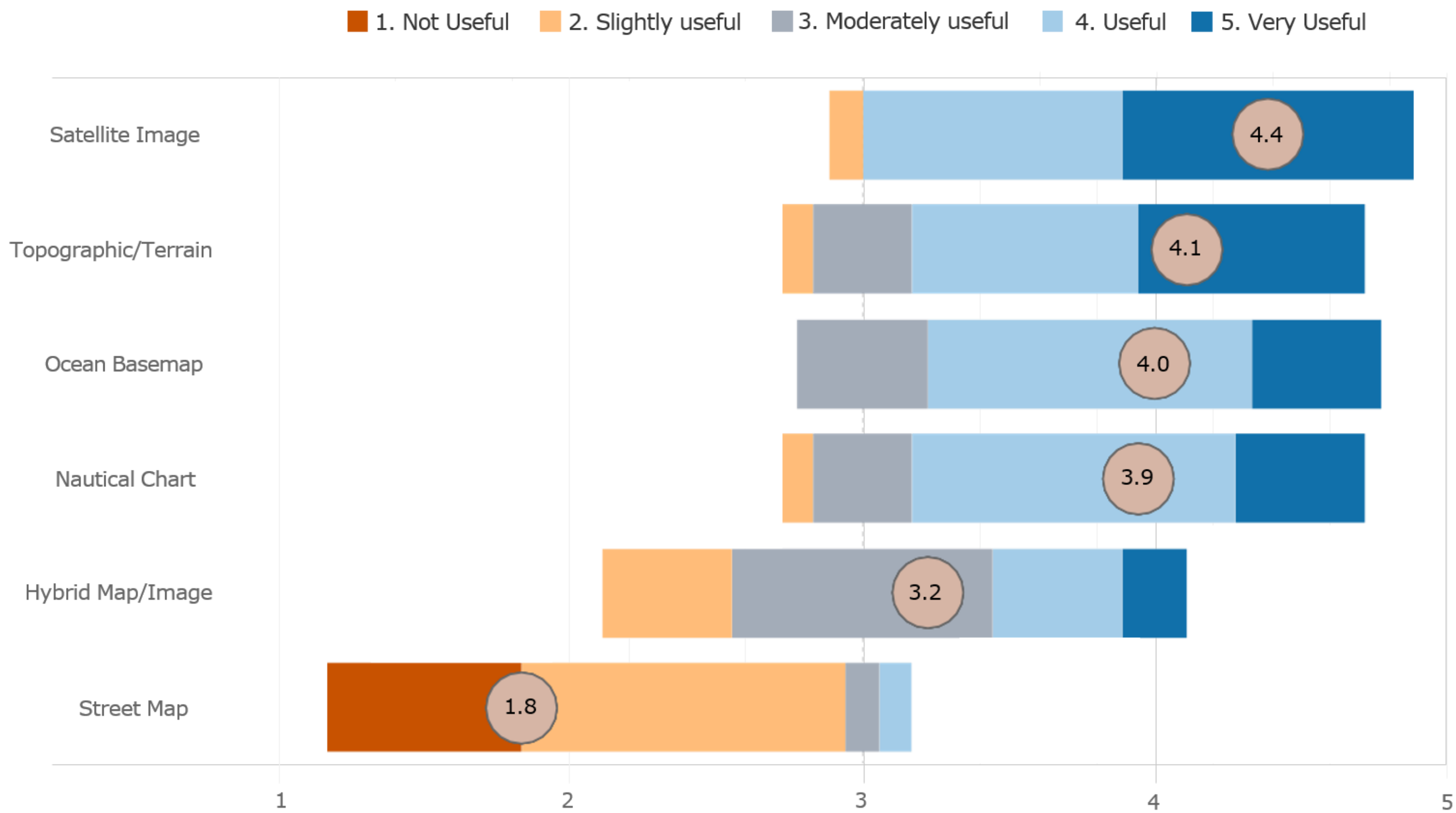


Figure 24.- Basemaps Likert Scale. Average response values are shown in the bubbles

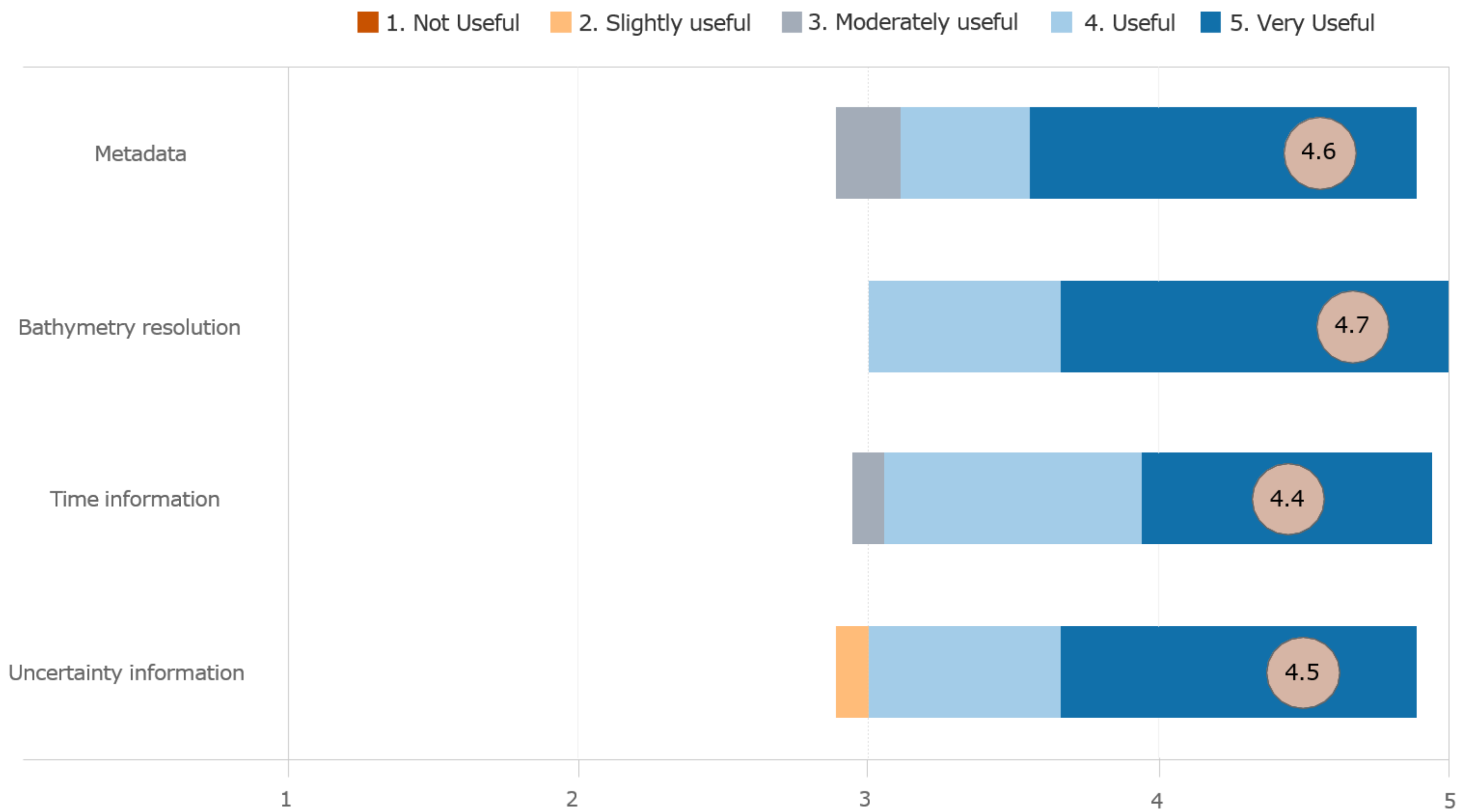


Figure 25.- Additional information Likert Scale. Average response values are shown in the bubbles

4.1.3.6 Section 6– Ocean Web Mapping Application Functionalities

The results from the participants rating about application functionalities are shown in Figure 26 and Figure 27. Figure 26 shows functionalities rated with an average more than 4 out of 5, considered very useful. Figure 27 shows functionalities rated with an average lower than 4 out of 5. Most of the usual web mapping application functionalities found in the competitive analysis were rated with high usefulness. However, others like changing the map projection, storing own drawings, using user profiles and adding additional data to the map through web map services were rating low (3.3 – 3.89). However, none of the functionalities were rated less than 3 points, being all of them considered at least moderately useful. There were three comments related to additional functionality not mentioned on the list: "Averaging over a cross section, area, or volume"; "for in-situ data, users are generally interested in where (lat-lon-depth), what (variables), when (time) and how (instrument & other metadata if available) and tools to retrieve the data based on those same parameters"; and "it would be good to have python scripting availability".

4.1.3.7 Section 7 – Data Formats

Results related to bathymetry data formats show that NetCDF (72.2%) and XYZ ascii (61.1%) would be the preferred formats when downloading bathymetry data (Figure 28a). GeoTIFF is the third most selected format, with 16.7% participants selecting it; and BAG format is the last one, with no participants (0%) checking these options. This means that although the current efforts made from the IHO and other ocean organizations to promote this standardized format to deliver bathymetry data, it does not seem to be popularized around the ocean modelling community who answered the survey. A BAG format, however, has a NetCDF structure (NetCDF 4) and it would not be hard for the ocean modelling community to adapt to this format (as any program that can read NetCDF files should be able to read a BAG file).

Regarding vector data formats (Figure 28b), the most selected format was CSV, with 82.35% of the participants marking this option, followed by SHP and KML formats with 41.18%. The rest of the formats (GeoJSON and GML) where only marked by two participants (11.76%). One participant wrote the mat format (Matlab) as the one they would prefer; however, mat is not a vector format.

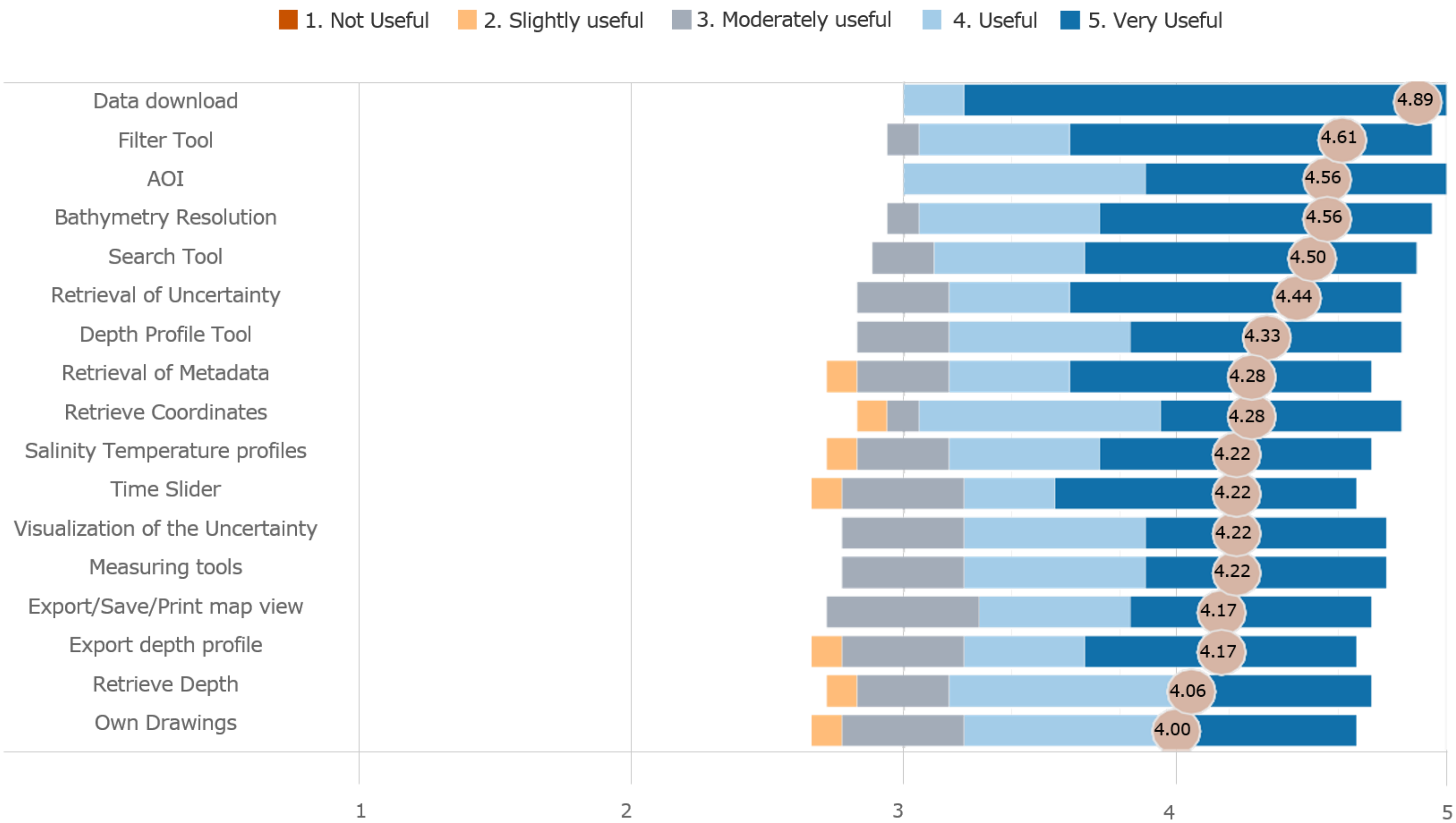


Figure 26.- Application functionality Likert Scale (part 1). Average response values are shown in the bubbles

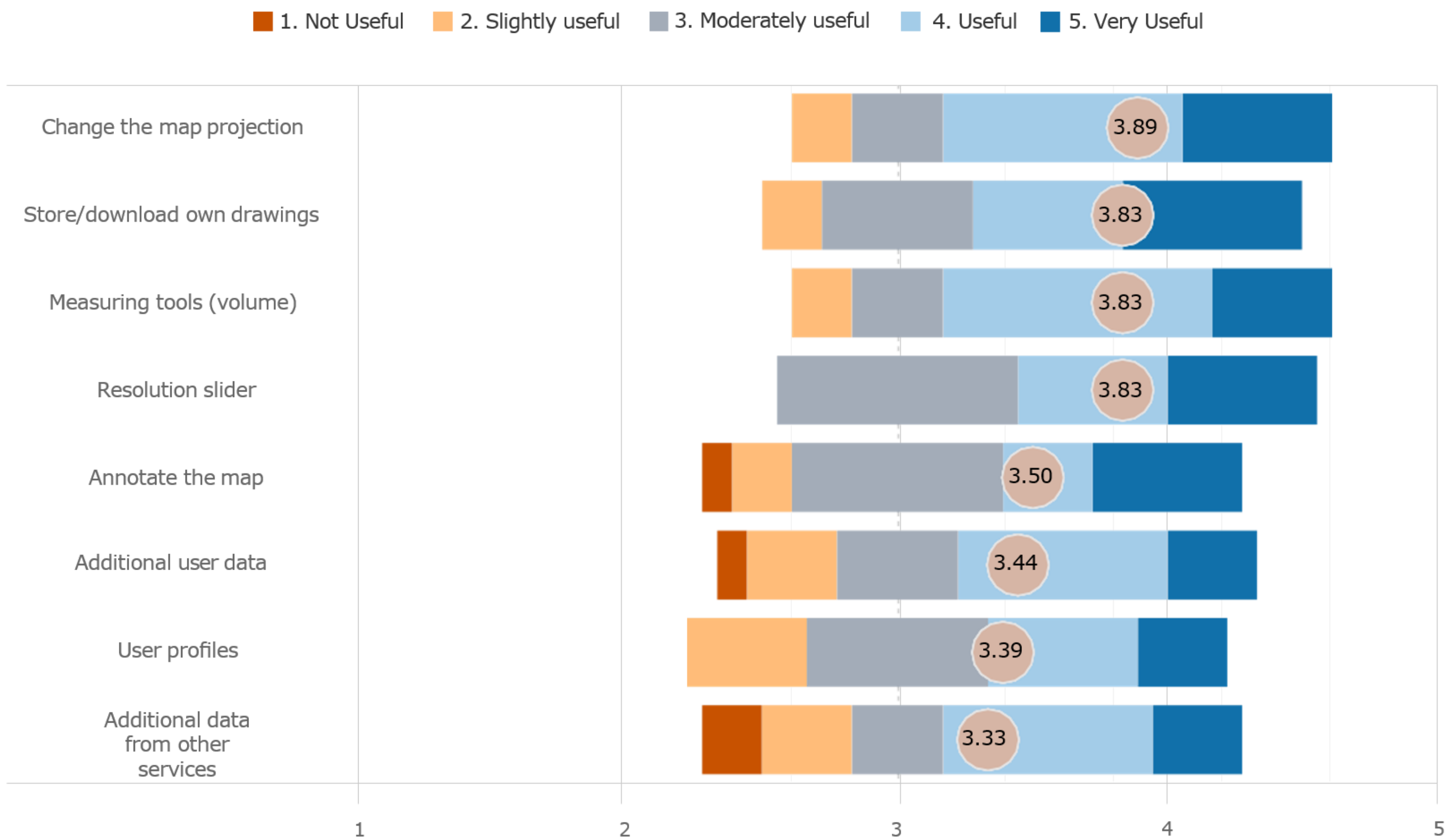


Figure 27.- Application functionality Likert Scale (continuation). Average response values are shown in the bubbles

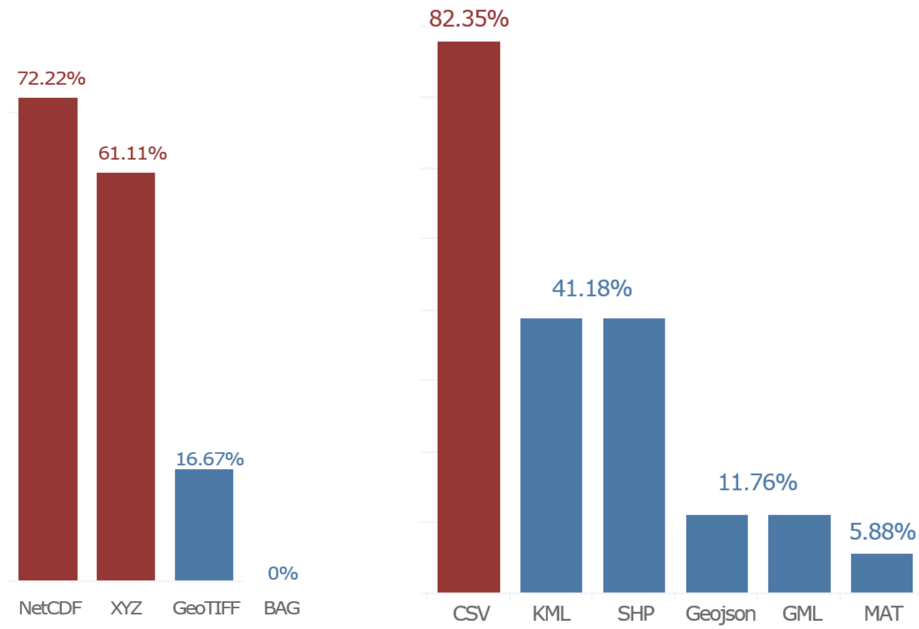


Figure 28.- (a) Percentage of participants who selected each bathymetry format as their preference. (b) Percentage of participants who selected each vector format as their preference

4.2 Conceptual development

Insights from the online survey and from the competitive analysis enabled the formalization of data, services and functional requirements. Several considerations were taken into account and influenced the development of the first prototype of the ocean web mapping application:

- Due to the results obtained from the survey, the decision was made to base the whole development of the application on open software, putting efforts on providing data in open formats that would be readable by any system or software.

- Results from the data source section of the survey, show an extensive use of open data by ocean modellers. The application will deliver both kind of data: data from university research (OMG at UNB) and data from open portals and web sites (external sources). Efforts are made to leverage open data and to provide ocean modellers with open resources.

- Geographic coordinates were the most selected type of coordinates (83.33%) in the survey. Therefore, the initial prototype will use WGS84 as coordinate system, with latitude and longitude coordinates.

- Projected coordinates were also ranked high in the survey (44.44%). However, the functionality of changing map projection only had an average of 3.89 out of 5. Most web mapping technologies use EPSG:3857 (Web Mercator) as the projection to display the map on the screen. However, the way the APIs usually input and return coordinates is using geographic coordinates (latitude and longitude). The calculation of projected coordinates would imply the use of a coordinate transformation engine. Therefore, projected coordinates are not considered for the development of the first prototype and geographic coordinates would be used instead. Projected coordinates would be worth considering in future improvements of the application, for example implementing UTM projection, and other local projections (Lambert or New Brunswick stereographic), depending of the area.

- Regarding the resampling method, data averaging was the most selected method (83.33%) in the survey. The decision was made to provide the user with several resampling methods (including averaging), so that the user can select the one that best fits their work or purposes.

- As mentioned before, all the data layers and additional information were rated with an average more than 4 points out of 5 and therefore considered very useful. All data of this type are included in the application (Table 15).

- Regarding additional data mentioned by participants, most of the weather data was already included in the application (atmospheric, heat flux, precipitation…), along with oceanographic data (MVP and ADCP). However, data regarding other topics that expand the limits of ocean mapping data (bio-chemistry and sediments) are left for future development.

- The decision was made to implement any functionality with a rating more than 4 points (very useful) in the online survey (Table 16). An additional functionality for visualizing ADCP and CTD data over river levels was also included.

- With respect to bathymetry data formats and leveraging open formats, the user will be given two different options for bathymetric data download: NetCDF (NetCDF-3) and XYZ ASCII. The BAG format, although a type of NetCDF file, is not considered for the following reasons: (a) it is not a popular format among ocean modellers, (b) among the FOSS community, there are not yet drivers available to read and write this format. GeoTIFF, the next most ranked format (16.67%), could be considered for future development.

- With respect to vector data formats, CSV was implemented, being the most valued format by participants (82.35%) and readable by almost any kind of software. Other formats like KML and SHP were also considered. Open source community promotes the use of GML as vector format, but it does not seem to be popular yet among the ocean modeller community, therefore it was not considered.

- Four different basemaps were included in the application: satellite image, topographic/terrain, ocean and simple basemaps (Table 17). The first three are the most valued basemaps in the survey, and a simple basemap (grey/white) was also included to follow the tendencies of the reviewed existing web mapping applications.

- To support the application, the three web mapping components, web map server, database and web browser, must be implemented as well as a web server to host the map server and database and make the web page accessible from anywhere. To support downloading, visualizing and processing of data, OGC services were used (WFS, WMS, WCS, WPS) and implemented by the map server. To support additional functionality, server scripts were developed and enabled on the web server (Table 17).

Table 15.- Data requirements for the Ocean Web Mapping Application

#	Data Requirement
1	Weather
2	Tidal
3	Currents
4	Buoy
5	Bathymetry
6	Coast lines
7	Sea temperature
8	Sea salinity
9	CTD
10	ADTC
11	Water level
12	River discharge
13	Metadata
14	Bathymetry resolution
15	Time information
16	Bathymetric Uncertainty
17	Orthophotographs
18	River levels

Table 16.- Functionality requirements of the Ocean Web Mapping Application.

#	Functionality Requirement
1	Bathymetry, CTD and ADCP data download
2	Filtering bathymetry and other data by time
3	Being able to select an area of interest, showing only the data available for that region
4	Being able to choose the resolution of the bathymetry data
5	Being able to choose the resampling method
6	Being able to look for bathymetry and other data for a particular time frame
7	Retrieval of bathymetric uncertainty data
8	Being able to draw a longitudinal profile
9	Retrieval of metadata information
10	Retrieve coordinates
11	Being able to draw vertical profiles at a point
12	Measuring areas
13	Export/save/print the map view
14	Export Depth profile
15	Retrieve depth
16	Own Drawings
17	Calculate statistics of an area
18	Visualization of ACDP and CTD data recording dates over River levels for a year

Table 17.- Services Requirements for the Ocean Web Mapping.

#	Services Requirement	Service type
1	Satellite image basemap	Basemaps
2	Topographic/terrain basemap	
3	Ocean basemap	
4	Simple basemap	
5	WFS	Web Map Server-side
6	WMS	
7	WCS	
8	WPS	
9	Server-side scripts	Server side
10	Geospatial Database Management System	
11	Web Server	

4.3 Prototyping stage

4.3.1 System architecture

The proposed system architecture to support the requirements presented in the previous section is portrayed in Figure 29, and follows the general architecture for web mapping applications presented in Chapter 2. The architecture follows the Free and Open Source Software concepts for Geospatial applications (FOSS4G). Six different components can be distinguished within the application:

- Data sources: data collected by the OMG in different formats (bathymetry, CTD, ADCP profiles, etc.), and other existing open data sources provided by open standards by governments or organizations (external sources).

- Format conversion scripts: programming scripts that automatically convert the different files/formats to the one supported by the database/map-server.

- Database Management System (DBMS): implemented in PostgreSQL with the PostGIS spatial plugin. A database open source solution that allows the storage of vector and raster data, creates spatial indexes and provides spatial capabilities.

- Web Map Server: implemented in GeoServer software, allowing the publication of datasets using Open Geospatial Consortium (OGC) standards. The capabilities of GeoServer are expanded by developing specific geospatial processes, using a scripting language (python) and the GeoScript library (scripting for GeoTools). These processes are served using the Web Processing Service (WPS).

- Web Server: implemented in Microsoft Internet Services Provider. It hosts the web map server, database and web page, making them accessible from anywhere. It also allows the execution of the server-side scripts.

- Web Mapping application: the actual interface to the user. Implemented using Leaflet, the open source solution web mapping technology for interactive maps.

Within this system architecture, data storage could be provided by three means:

- Data could be stored in the database within tables.

- Data could be stored in GeoServer, using the file system.

- Data could be stored in the web page, as HTML variables.

The functionalities of the web mapping application are provided using three different kind of approaches:

- OGC Services: Web Feature Service (WFS), Web Map server (WMS), Web Coverage Service (WCS) and Web Processing Service (WPS); provided by GeoServer.

- Other Services: implemented using server-side scripts under the CGI application architecture, using Python as scripting language.

- Browser functionality: some functionalities are implemented within the client-side, using the leaflet API, leaflet plugins and browser capabilities.

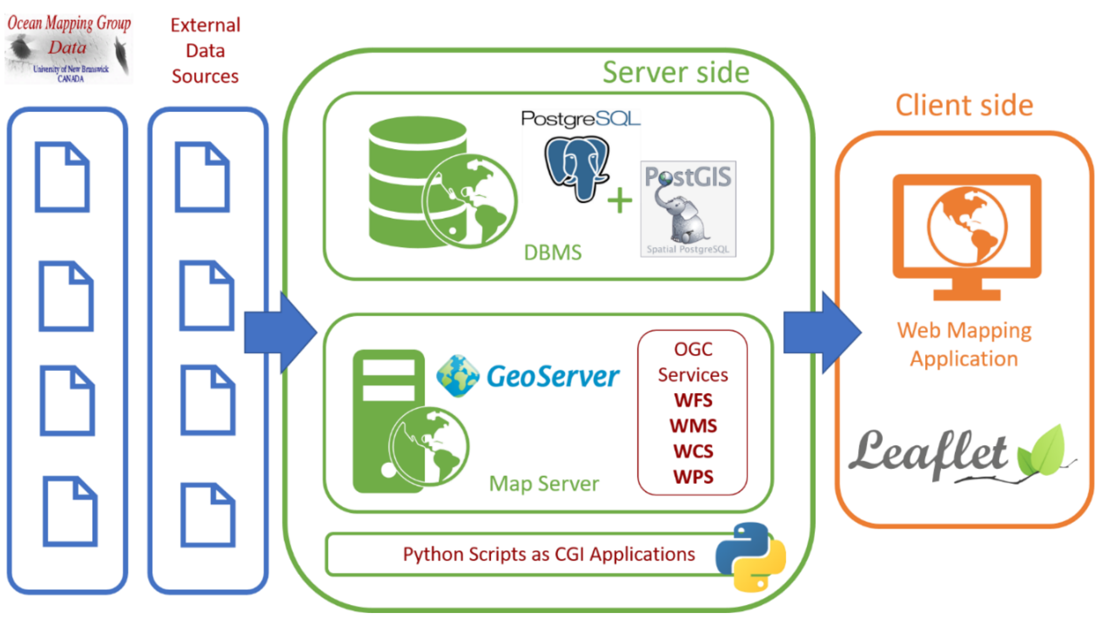


Figure 29.- Proposed system architecture

4.3.2 Formalized data objects

Table 18 shows the formalized data objects that were included in the web page and lists the data sources and the method used to store the data. The following considerations were made:

- Any kind of vector data is stored in the database as tables.

- CTD and ADCP data are stored in the database as points, including the date and time each point was collected.

- Weather data was downloaded from the Environment and Climate Change (Government of Canada) website for the Saint John Airport Station and was stored in the database. If expanding the web page, more data should be downloaded for each station.

- Stations for which there are observations (e.g. buoy data, tidal data, water level data, and river discharge data) are stored in the database as points. Data for each station is linked to it, either using a link to the downloading page or to the data stored in the database (weather data).

- River levels are added to represent the ADCP and CTD data recording dates on a plot, to visualize what data is available in every year. This data was stored in the web page as an HTML/JavaScript array variable and consist of a set of daily river level values. The decision to store the data directly in the webpage was made due to the need to quickly access the data in order to draw plots on the web page. If the data were stored in the database, an application interface would be required in order to access the data from the web page. For future development, this kind of storage could be improved, storing the data in the database and access it at any granularity (year/month/day).

- Metadata is not stored, but it is provided as links to the source information. The development of a metadata repository might be considered for future development, perhaps using metadata catalogs (CSW, OGC).

- Raster data (i.e. bathymetry and orthophotos) is stored in GeoServer using the file system. For the purpose of the prototype, the file storage could cover the end users' needs in an easier way than database storage. For future development of the prototype, this decision might want to be reconsidered, perhaps developing database storage, image pyramids or a web tiled management system (Kotsollaris, 2017).

Table 18.- Formalized data objects of the Ocean Web Mapping Application

#	Data Requirement	Source	Storage
1	Weather	Environment and Climate Change Canada stations (Government of Canada)	Database
2	Tidal	Environment and Climate Change Canada stations Government of Canada	Database
3	Buoy	Smart Atlantic Alliance Canada	Database
4	Bathymetry	Bathymetric OMG surveys	File System in GeoServer
5	Coast lines	Geogratis (Government of Canada)	File System in GeoServer
6	CTD (will include temperature and salinity data)	CTD profiles OMG surveys	Database
7	ADCP (will include current data)	ADCP profiles OMG surveys	Database
8	Water level	Hydrometric Stations Government of Canada	Database
9	River discharge	Hydrometric Stations Government of Canada	Database
10	River levels	OMG collected data	Web Page
11	Metadata	Different sources	Not stored (just links)
13	Raster Time information	Date of the surveys	Footprints (Database)
	Vector time information		Timestamp field in the database
14	Bathymetric Uncertainty	Bathymetric OMG surveys	File System in GeoServer
15	Bathymetric resolution	Created from Bathymetric OMG surveys	Different Image Mosaics in GeoServer
16	Bathymetric resampling method	Created from Bathymetric OMG surveys	Additional dimension for image Mosaic
15	Orthophotographs	New Brunswick Open data (MrSID)	File System in GeoServer

Regarding bathymetry, the data is stored using GeoTIFF image mosaics in GeoServer, which were extracted from the BAG surfaces available from OMG surveys. An image mosaic assembles a set of (overlapping or not) geospatially referenced images of the same resolution into a contiguous image. This data storage method in GeoServer allows the addition of different dimensions to a raster dataset. The built-in dimensions are elevation and time, but additional personalized dimensions can be added. Therefore, the single mosaic is held in a queryable structure to allow access to a specific dataset with a dimensional filter. Also, an index for each image of the image mosaic is stored in the database for quicker access to them. There are four main dimensions considered when dealing with bathymetry: time, resolution, uncertainty and resampling method. The way each of them is handled is explained below:

- The bathymetry time is stored using the survey footprints of the whole bathymetric dataset, each of them having a specific date and time. The footprints were extracted from the BAG data and stored in the database, with a timestamp column containing the date when the survey was made.

- Bathymetric uncertainty is stored as a second band in the bathymetry GeoTIFF file. Therefore, each GeoTIFF bathymetry file contains two bands: band 1 for depths and band 2 for uncertainty.

- Bathymetric resolution is handled using different image mosaics stores in GeoServer. Therefore, there will be one store for each resolution that is served to the user (i.e. 1m store, 5m store, 10m store, 50m store…). This approach was taken in order to make the data accessible faster.

- Bathymetric resampling method is handling as an additional dimension in the image mosaic store. Therefore, for each resolution, for the same given area, there will be as many images as different resampling methods are served (Figure 30).

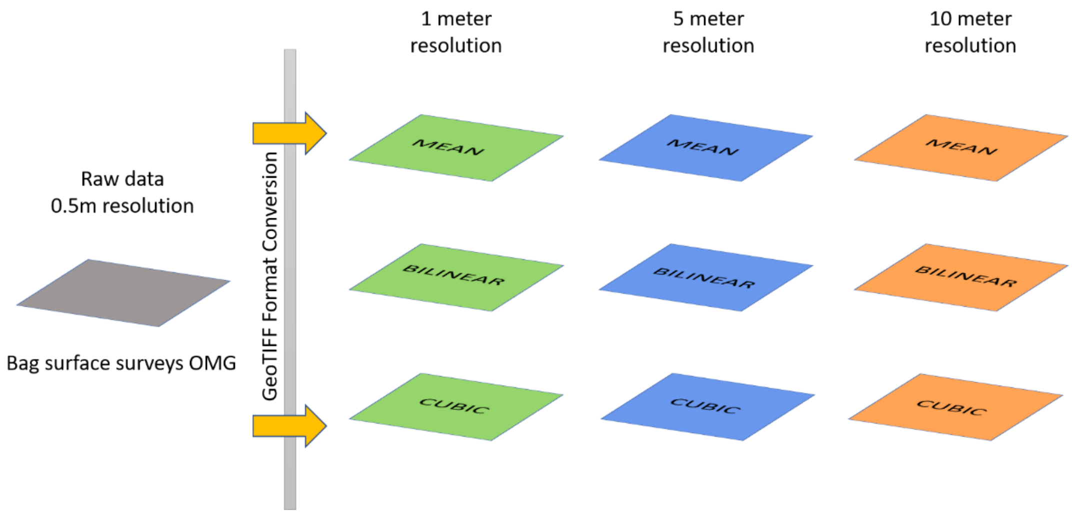


Figure 30.- Approach taken for the storage and management of the bathymetry data

The bathymetric formats available are NetCDF and XYZ ASCII. The variables stored in the NetCDF files are Method (resampling method), Latitude, Longitude and Bathymetry (Depth).

Discussion on other alternatives

To justify the approaches taken for the bathymetry storage, and in order to present ideas for future development, other alternatives to serve and store the different bathymetry variables are described below:

- Time could be served creating an image mosaic as a composition of each survey, allowing a user to request depths for a specific time. For the purpose of this prototype, footprints served as a first approach to test the time component for bathymetry.

- Bathymetric uncertainty could be stored directly if BAG format drivers were available in GeoServer. Using this approach, the BAG file would contain depths, uncertainty and metadata. However, BAG format drivers are not yet available in

GeoServer and, as shown in the survey results, ocean modellers did not request this format (0%). A two bands GeoTIFF file follows the same idea, providing similar functionality.

- Bathymetric resolution could be handled storing only one GeoTIFF at the maximum resolution, and using WCS capabilities to resample the data every time a request is made to the server. Using this approach, resolution and resampling method would be the parameters for the WCS request, outputting any area at any resolution (Figure 31). However, this approach would require more computing time and server resources, as every time a request is made, the server needs to resample the data to serve it to the user. The approach taken in this prototype provides a faster method to access bathymetry data, however, the resolution and resampling methods are constrained to the ones stored in the server.

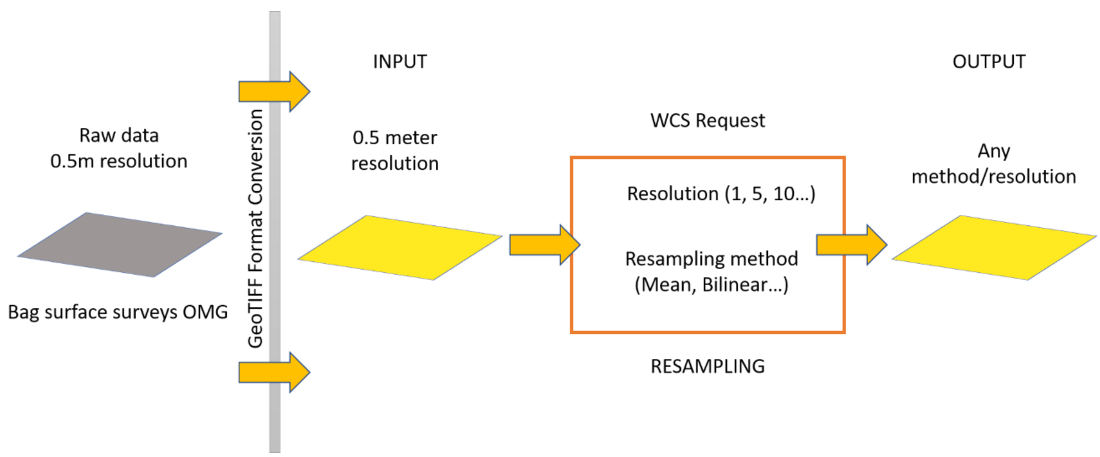


Figure 31.- Alternative approach to store and manage bathymetry data

4.3.3 Database Schemas

For each of the data types that needed to be stored in the database, it was necessary to create a database table. Regarding bathymetry data, one table per image mosaic was created to be used as an image index by GeoServer: Bahymetry_1m, Bathymetry_5m, Bathymetry_10m, Bathymetry_50m. The columns for these tables are described below:

- Fid [Integer]: unique identifier and primary key.
- The_geom [Polygon]: minimum bound rectangle enclosing the image.
- Location [String]: name of the file where the image is stored (relative to the mosaic configuration files GeoServer directory).
- Method [Integer]: resampling method used to create the image at that resolution. Bilinear: 1, Mean: 2, Cubic: 3.

Regarding vector data, seven tables were created and are described below:

Bagfootprints: table to store the footprints for each OMG BAG survey, handling the time for the bathymetry data. The columns are described below:

- Gid [Integer]: unique identifier and primary key.
- Campaign [String]: name of the survey campaign.
- Datestring [String]: string representing the date of the survey.
- Shape_leng and shape_area [Float]: perimeter length and enclosed area of the footprint polygon.
- Dates [Date]: date the survey was performed.

- Geom [Polygon]: geometry defining the survey footprint.
- Vessel [String]: name of the Vessel the survey was done with.
- Sensor [String]: name of the sensor to collect the data for the survey.
- Metadata [String]: link to the metadata page for each survey.

Buoys: each row of this table represents a buoy. Data are linked to the buoy station by using a link to the data provider. The columns are described below:

- id [Integer]: unique identifier and primary key.
- Buoyname [String]: given name for the buoy.
- Geom [Point]: geometry representing the buoy's location.
- Provider [String]: name of the agency or organization that maintains the buoy and collects the data.
- Waterdepth [Float]: depth measurement under the buoy in meters.
- Sensors [String array]: array containing the name of the sensors the buoy provides with.
- Link [String]: link to the buoy data to access the data.

Waterlevelstations: each row of this table represents a station that measures water levels and river discharge data. The columns are described below:

- id [Integer]: unique identifier and primary key.

- Stationnumber [String]: identification number of the water level station.
- Stationname [String]: name of the water level station.
- Province [String]: province of the location of the water level station.
- Status [String]: status of the water level station (A for active).
- Geom [point]: geometry representing the location of the water level station.
- Startyear [String]: first year of data timeseries.
- Finishyear [String]: last year of data timeseries.
- Drainagearea [Float]: area of the drainage area of the water level station.
- Real time [String Y/N]: if the water level station performs real time measurements or not.
- Datum [String]: name of the datum the measurements are referred to.

Weatherstations: each row of this table represents a station that measures weather information. The columns are described below:

- id [Integer]: unique identifier and primary key.
- Stationname [String]: name of the weather station.
- Province [String]: name of the province the station is in.
- Geom [Point]: geometry representing the location of the weather station.

- Stationed, climateid, wmoid, tcid [String]: different identifiers for the station.
- Startdate [Date]: date and time of first data record.
- Finishdate [Date]: date and time of last data record.
- Interval [String]: granularity of the data (for example, monthly, daily, or hourly).
- Available data [String array]: array containing all the weather available data for that station.

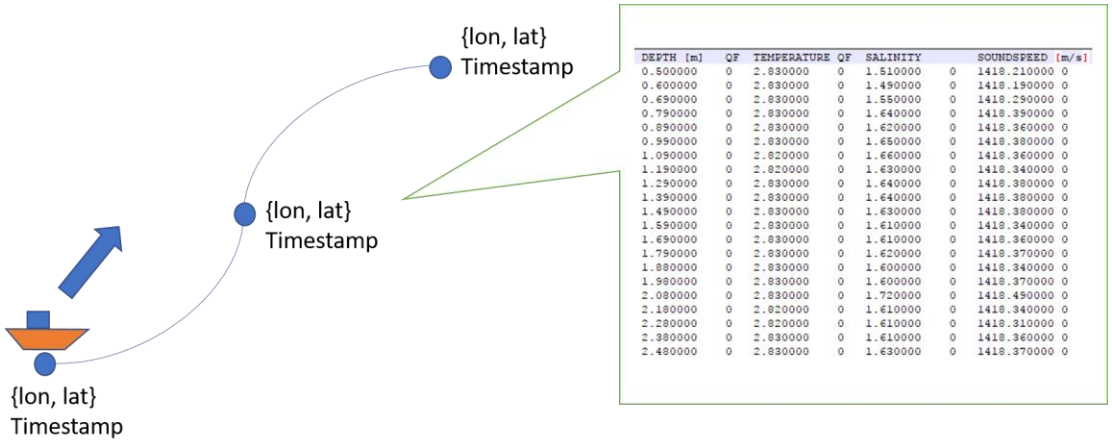
Weather: each row of this table is a weather data measurement for an specific timestamp at a station. The columns are described below.

- id [Integer]: unique identifier and primary key.
- Timestamp [Timestamp]: timestamp of the weather measurement.
- Year, Month, Day, time [String]: string representations of the timestamp
- Dataquality [String]: quality of the weather data.
- Temperature, Dewtemperature, Relhumidity, Winddirection, Windspeed, Visibility, Stnpressure, Hmdx, Windchill [Float]: weather variables (one column per each variable).
- Weather [String]: string that summarizes the weather conditions (e.g. cloudy or windy with clouds).

Mvp_points: MVP data from OMG surveys were provided in csv files, where each row represented a point measurement at a certain depth at a particular time (Figure 32). These files are structured as follows: Cruise, Station, month/day/yr, hh:mm, Longitude, Latitude, Bot. Depth [m], DEPTH [m], QF, TEMPERATURE [°C], QF, SALINITY [PSS-78], QF, SOUNDSPEED [m/s], QF. Therefore, the data structure is duplicated and not optimized to be stored in the database as the first six values are repeated for each measurement along the vertical profile until the measuring point changes, (Figure 32). There are several alternatives for storing this kind of data structure:

- Create two tables, one storing the points (geometry) and another one storing the data for each point. The link between this two tables would be the point id, being an attribute of the second table.

- Create only one table to store the points (geometry) along with the data, storing the data as arrays. This way each row will contain the first six fields and same dimension arrays containing the depth, temperature, salinity and sound speed (there is a measurement for each variable for each depth).



DEPTH [m]	QF	TEMPERATURE	QF	SALINITY		SOUNDSPEED [m/s]	
0.500000	0	2.830000	0	1.510000	0	1418.210000	0
0.600000	0	2.830000	0	1.490000	0	1418.190000	0
0.690000	0	2.830000	0	1.550000	0	1418.290000	0
0.790000	0	2.830000	0	1.640000	0	1418.390000	0
0.890000	0	2.830000	0	1.620000	0	1418.360000	0
0.990000	0	2.830000	0	1.650000	0	1418.380000	0
1.090000	0	2.820000	0	1.660000	0	1418.360000	0
1.190000	0	2.820000	0	1.630000	0	1418.340000	0
1.290000	0	2.830000	0	1.640000	0	1418.380000	0
1.390000	0	2.830000	0	1.640000	0	1418.380000	0
1.490000	0	2.830000	0	1.630000	0	1418.380000	0
1.590000	0	2.830000	0	1.610000	0	1418.340000	0
1.690000	0	2.830000	0	1.610000	0	1418.360000	0
1.790000	0	2.830000	0	1.620000	0	1418.370000	0
1.880000	0	2.830000	0	1.600000	0	1418.340000	0
1.980000	0	2.830000	0	1.600000	0	1418.370000	0
2.080000	0	2.830000	0	1.720000	0	1418.490000	0
2.180000	0	2.820000	0	1.610000	0	1418.340000	0
2.280000	0	2.820000	0	1.610000	0	1418.310000	0
2.380000	0	2.830000	0	1.610000	0	1418.360000	0
2.480000	0	2.830000	0	1.630000	0	1418.370000	0

Figure 32.- Recording diagram and file structure of MVP data from OMG

The second alternative was adopted, as the data is going to be accessed in bulk and the variables would not usually be queried for a specific depth. Also, this structure is considered to be more efficient, as everything is kept in one table, making data access easier. Therefore, each row represents an observation point for the moving vessel in a specific timestamp. Columns are described below:

– id [Integer]: unique identifier and primary key.

– Cruisename [String]: name of the cruise that performed the survey.

– Instrumentation [String]: name of the instrumentation that allowed to collect the MVP data.

– Timestamp [Timestamp]: date and time associated to the measurement.

– Geom [Point]: geometry representing the location of the point measurement.

– Bottomdepth [Float]: depth measurement at the bottom of the observation point.

- Depth [Float array]: array containing the depths at which the measurements were taken.
- Temperature, salinity, soundspeed [Float array]: array containing the temperature, salinity and soundspeed measurements at each depth point.
- Timegeoserver [Date]: for handling the time, only the date is considered, not the time. Therefore, this would be the field associated to the time dimension in GeoServer.

ADCP: each row represents an observation point for the moving vessel in a specific timestamp. Currents were not stored for the purpose of this prototype, only the recording points. The columns are described below:

- gid [Integer]: unique identifier and primary key.
- Pointname [String]: point identifier.
- Time [String]: string representing the timestamp for the measurement.
- Timezone [String]: string representing the time zone.
- Campaign [String]: name of the campaign the data was collected in.
- Timestamp [Timestamp]: timestamp for the measurement.
- Time_geose [Timestamp]: modified timestamp to be able to be read by GeoServer (considering time zone differences).

– Geom [Point]: geometry representing the location of the point where the measurements were taken.

– Date [Date]: date for the measurement, not considering time.

4.3.4 Database Relationships

The only relationship in the proposed schema is the one between weatherstations and weather tables. Each weather station contains a set of data in the weather table, but each row of data in the weather table belongs to only one station. The way these tables are related is using the stationid field as a foreign key, storing the id for the station that the data is from (Figure 33).

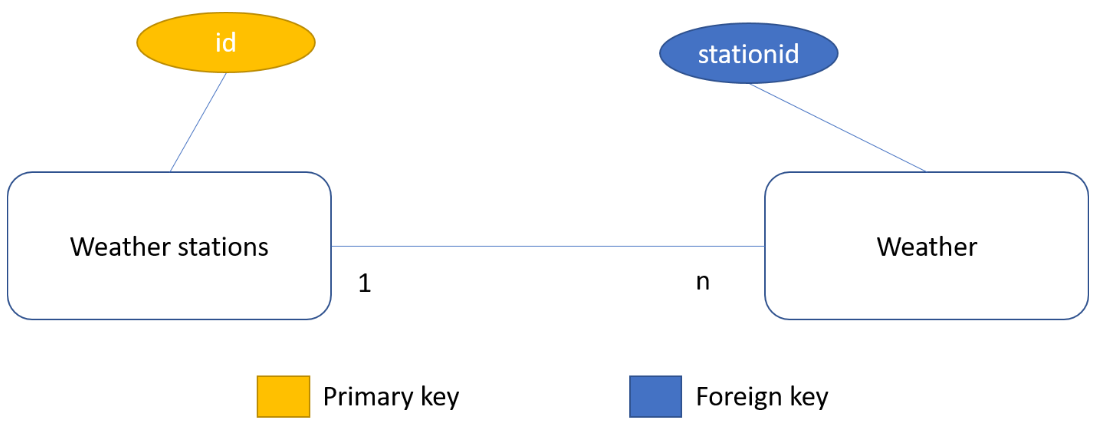


Figure 33.- Database relationship between weather stations and weather data tables

Another alternative to store the weather data would be to create one table per each station, accessing different tables depending on what station is requested. This might be an option as every station might have different kind of data and the amount of data per each station is huge (only for one station, there are 157665 rows of data). For the purpose of the prototype, only the data for one station was downloaded and this kind of storage might be reconsidered in future developments.

4.3.5 Formalized service objects

Table 19 shows the formalized service list, showing how each service is provided. Regarding basemaps, Esri and Stamen basemaps services are used. Esri provides a high-resolution imagery for the whole world, along with an ocean map (at small scales). Stamen provides different and simple basemaps, using the grey and the terrain maps. GeoServer provides with the standardized web map services: WFS for vector data download, WCS for raster data download, WMS for web map visualization, and WPS for performing geo-processes on the fly. The Geospatial Database Management Service is provided by Postgres database and PostGIS extension, as explained above. The web server was developed using Internet Services Provider in Windows, and configured to host the database, the GeoServer and the web page. The web server is able to run server-side scripts using the CGI protocol and running applications coded on python language.

Table 19.- Formalized service objects for the Ocean Web Mapping application

#	Services Requirement	Provider
1	Satellite image basemap	Esri imagery
2	Topographic/terrain basemap	Stamen terrain/Esri topographic
3	Ocean basemap	Esri Ocean map
4	Simple basemap	Grey Map from stamen
5	WFS	GeoServer
6	WMS	
7	WCS	
8	WPS	
9	Server-side scripts	Python CGI applications
10	Geospatial Database Management System	Postgres + PostGIS
11	Web Server	Internet Services Provider (Microsoft)

4.3.6 Formalized function list

Table 20 shows the function list, after formalizing the functionality requirement list.

Table 20.- Formalized function list for the Ocean Web Mapping Application

#	Functionality Requirement	Formalized function
1	Bathymetry, moored data and observations data download	Data download functions
2	Filtering bathymetry and other data by time	Time Filter tool
3	Being able to select an area of interest, showing the data available only for that region	AOI selection tool
4	Being able to choose the resolution of the bathymetry data	Resolution selector
5	Being able to choose the resampling method	Resampling method selector
6	Being able to look for bathymetry and other data for a particular time frame	Time Search tool – Charts for data available
7	Retrieval of bathymetric uncertainty data	Uncertainty download functions
8	Being able to draw a longitudinal profile	Depth profile tool
9	Retrieval of metadata information	Metadata links
10	Retrieve coordinates	Coordinates identify function
11	Being able to draw vertical profiles along a point	Salinity/temperature profile tools
12	Measuring areas	Measuring tools
13	Export/save/print the map view	Exporting tools
14	Export Depth profile	Export Depth profile option
15	Retrieve depth	Coordinates identify function
16	Own Drawings	Drawing tool
17	Calculate statistics of an area	Area statistics tool
18	Visualization of ADCP and CTD recording dates over River levels for a year	River level Plots

4.3.7 Format conversions and database data upload

To automate the process of getting data into the platform, a set of four Python scripts were developed to perform necessary format conversions and upload the data into the database automatically.

4.3.7.1 Weather data

Weather data are obtained through an URL based procedure offered by Environment and Climate Change data, which allows downloading data in bulk for a weather station. For the purpose of this prototype, only one station's data was downloaded for the period of 1953 to 2017 (Station 6250 [1953-2012] and Station 50310 [2012-2017] - Saint John Airport) The following commands were executed in Linux:

```
for year in `seq 1953 2012`;do for month in `seq 1 12`;do wget --content-disposition "http://climate.weather.gc.ca/climate_data/bulk_data_e.html?format=csv&stationID=6250&Year=${year}&Month=${month}&Day=14&timeframe=1&submit= Download+Data" ;done;done
```

```
for year in `seq 2012 2017`;do for month in `seq 1 12`;do wget --content-disposition "http://climate.weather.gc.ca/climate_data/bulk_data_e.html?format=csv&stationID=50310&Year=${year}&Month=${month}&Day=14&timeframe=2&submit= Download+Data" ;done;done
```

The execution of these commands resulted in a directory with a weather data file for each month of the period requested. To upload this data to the database, a Python script was developed (Script#1), which reads every file in the directory and formats the data for insertion into the created weather table. The process is described in Figure 34.

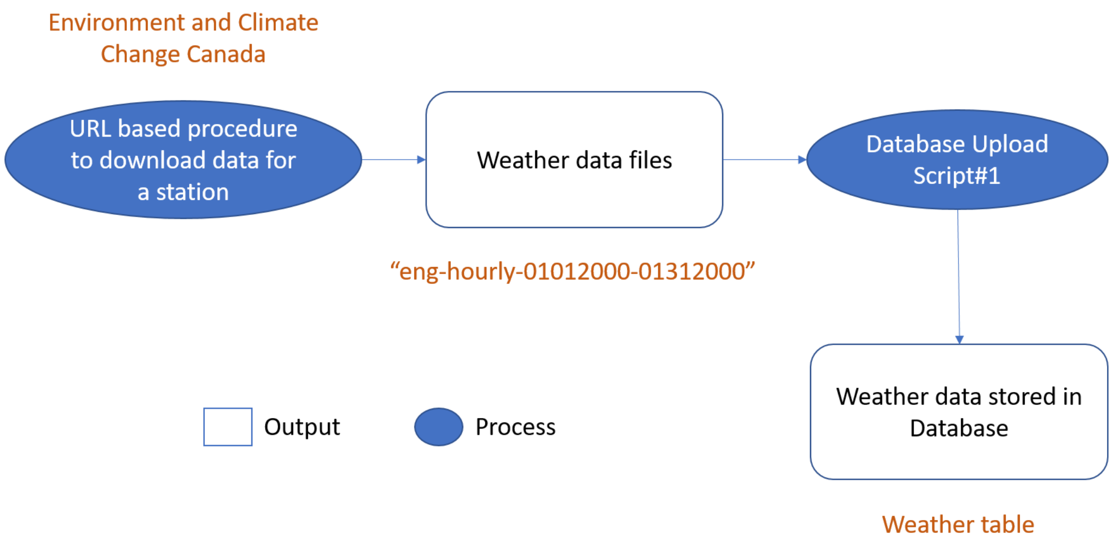


Figure 34.- Process followed to create the weather data table from weather files of Environment and Climate Change Canada

4.3.7.2 MVP data

As described in the database schema, the measurements are stored as data arrays attached to each measuring point. Therefore, a format conversion is needed for the CSV files prior to inserting the data into the database (Script#2). After the format conversion, the new CSV structured file can be uploaded (Script#3). The process is described in Figure 35.

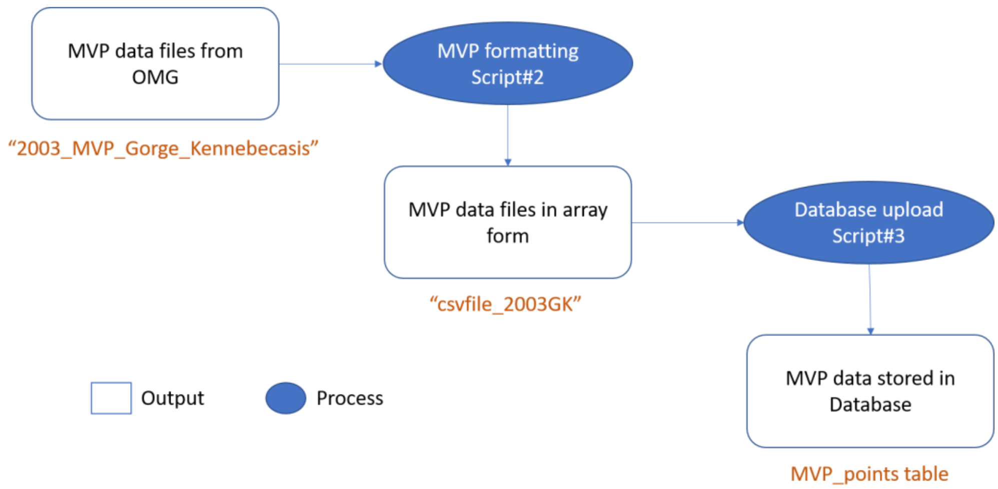


Figure 35.- Process followed to store the MVP data in the database

Hydrometric Stations

The data for the hydrometric stations coordinates and information were downloaded from Environment and Climate Change Canada as a csv file. The data contained in this file need to be formatted prior to inserting the point geometries into the database. This procedure of formatting and uploading is done by Script#4, and the whole process is shown in Figure 36.

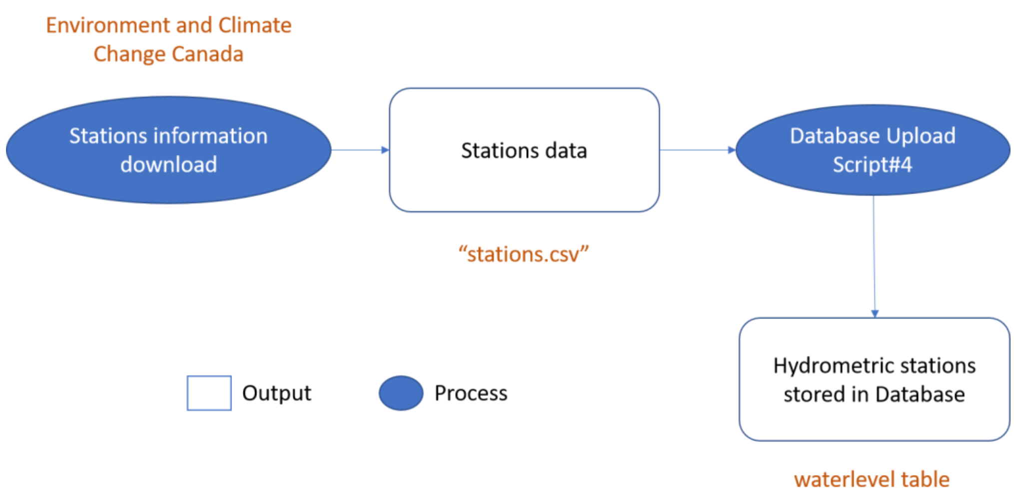


Figure 36.- Process followed to upload the hydrometric stations data to the database

4.3.7.3 Weather Stations

Weather stations data was added manually since, for the purpose of this prototype, only two stations are added and only one will contain data.

4.3.7.4 Buoy Stations

Buoys stations data was also added manually as the data source (SmartAtlantic, 2018) did not provide with any means of linking the stations or downloading the stations coordinates. Therefore, each buoy was accessed and the data was inserted in the database.

4.3.7.5 ADCP data

ADCP data was added from an SHP file from the OMG data collection. The data were uploaded to the database using shp2pgsql tool from PostGIS. The steps followed were:

- Load OMG ADCP SHP files to ArcGIS software.
- Export SHP files to a new layer to be able to edit the attribute table.
- Add Campaign and year fields.
- Merge all the shapefiles in one using the merge tool from the ArcGIS toolbox.
- Insert the merged SHP file into PostGIS using shp2pgsql:

```
shp2pgsql -I -s 4326 merge_adcp.shp public.adcp | psql -U postgres -d oceanMapping
```

4.3.7.6 Multibeam Survey Area footprints

The footprints were extracted from the OMG survey's BAG surfaces and then inserted to the database. The following steps were used:

- Load each BAG survey into ArcGIS software.
- Extract the footprint for each survey using the raster domain toolbox from ArcGIS software.
- Create two additional fields in the polygons generated: date and campaign.
- Merge all the polygons in one layer using the merge toolbox from ArcGIS software.
- Insert the merged SHP file into PostGIS using shp2pgsql:

```
shp2pgsql -I -s 3395 footprints.shp public.bagfootprints | psql -U postgres -d oceanMapping
```

4.3.8 Functionality implementation

Table 21 shows the way each functionality requirement was implemented and the script or plugin associated to the functionality (Reference).

Table 21.- Functionality implementation for the Ocean Web Mapping Application

#	Functionality Requirement	Implementation	Reference
1	Data download	WCS for raster data, WFS for vector data	Script#10 for WCS
2	Filter tool	Time filter as WMS parameter (TIME)	Leaflet-WMS plugin
3	AOI	Browser capability	Leaflet Draw plugin
4	Being able to choose the resolution of the bathymetry data	Different files for each of the available resolutions stored in GeoServer	Script#10
5	Search tool	Browser capability	-
6	Retrieval of bathymetric uncertainty data	WCS for raster data (Band 2)	Script#10
7	Depth profile tool	Custom WPS process	Script#5 and Script#8
8	Retrieval of metadata information	Including links to the data source/metadata	-
9	Retrieve coordinates	WMS get feature info	Leaflet-WMS plugin
10	Salinity/temperature profile tools	Python CGI script	Script#7
15	Export Vertical profile tool	Python CGI script	Script#14
11	Being able to select the time of the data layers	Time filter as WMS parameter (TIME) or time query to the database	Script#12 for weather data, Script#11 for MVP
12	Visualization of the uncertainty	Second band of the bathymetry data stored in GeoServer	Leaflet-WMS plugin
13	Measuring tools	Browser capability	Leaflet Measure plugin
14	Export/save/print the map view	Browser capability	Leaflet easy print plugin
15	Export Depth profile tool	Python CGI script	Script#13
16	Retrieve depth	WMS get feature info	Leaflet-WMS plugin
17	Own Drawings	Browser capability	Leaflet Draw plugin
18	Depth statistics of an area	Custom WPS process	Script#6 and Script#9
19	ADCP and CTD recording dates over River levels for a year	Interactive Plot	Blue line chart (red vertical lines for ADCP or CTD data)

4.3.8.1 Server-side implementation

Regarding server-side implementation, a set of ten Python scripts were developed to implement the necessary functionality of the application. The scripts are described below.

Script#5: WPS for generating a Longitudinal Profile

This Python script is a custom WPS to generate a longitudinal profile and was created to be run by GeoServer under a user request. Script inputs are the raster file for the bathymetry data and the geometry of the user defined line to calculate the profile. Figure 37 illustrates the entire process: the coordinates are projected to EPSG:2036-New Brunswick Stereographic planar projection (in order to calculate distances); the line is subdivided in points every 5 meters (to extract the depths in those points); the total distance of the profile is calculated; and the coordinates are reprojected back to the geographic coordinates to be able to get the depth values from the raster. In each of the steps, a predefined geometric/geographic process was used (marked in blue in the figure) and all of them were chained together to obtain the desired result. Outputs include an array of coordinates (x, y) of the points along the profile, their corresponding depths (z array) and the total distance along the profile (from the first to the ending point).

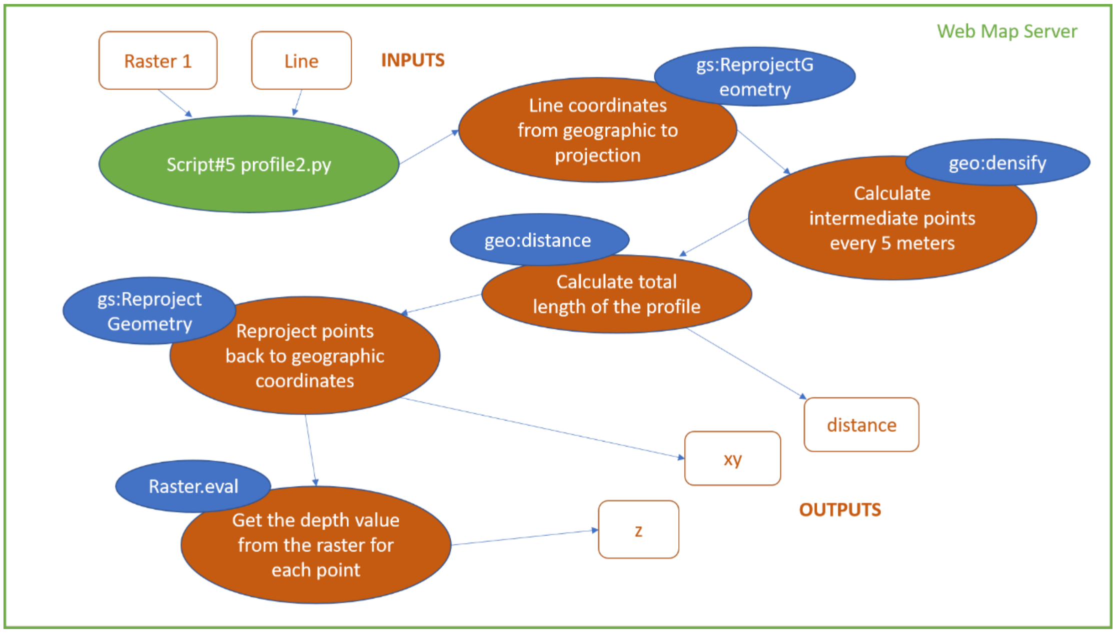


Figure 37.- Process description followed by Script#5 to generate a longitudinal profile. White rectangles represent input/output data, green ovals represent WPS scripts, orange ovals represent the steps of the process and blue ovals represent predefined geographic processes executed by GeoServer.

Script#6: Bathymetry area Statistics

This Python script is a custom WPS created to be executed by GeoServer under a user request to calculate the statistics of a Bathymetry area. It‘s inputs are the raster file for the bathymetry data that is used to calculate the area statistic, and the geometry of the area (polygon) in which the statistics are calculated. Figure 38 illustrates the process: first, the polygon is transformed from WKT (the format of the input) to a Feature collection (in order to match the input for the second process) and then the raster statistics are calculated. The outputs when executing the process are basic statistics for an area: maximum, minimum and average value, sum of the values, total number of depths in the calculation (count) and the standard deviation of the depths.

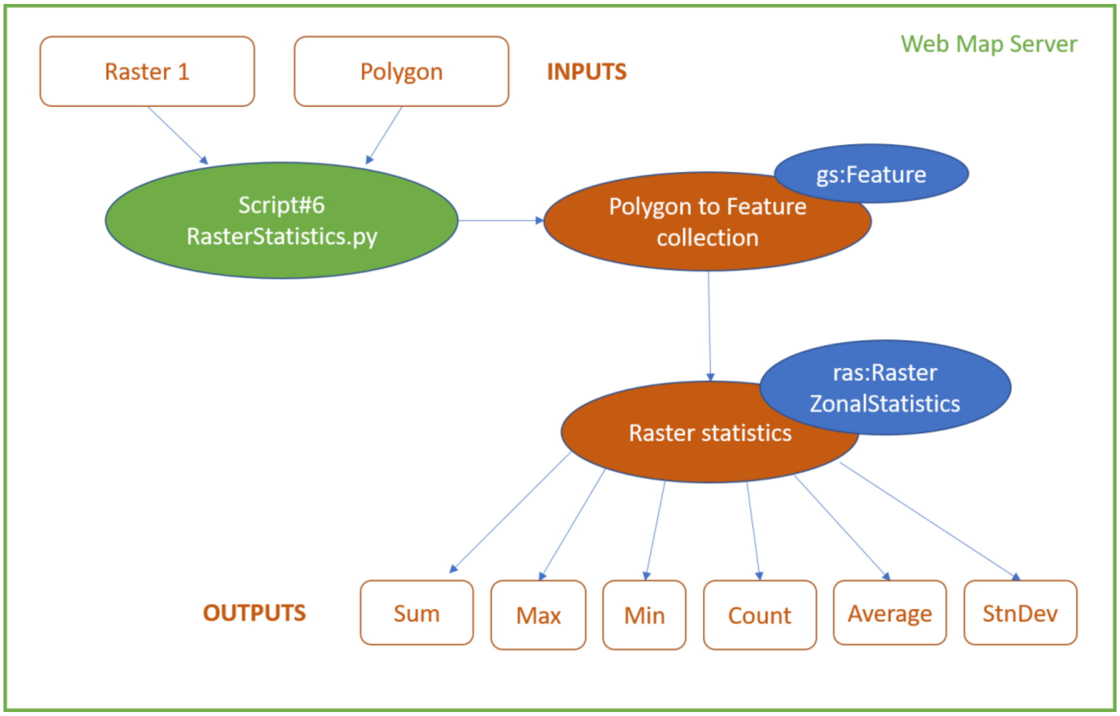


Figure 38.- Process description followed by Script#6 to calculate statistic of a bathymetry area. White rectangles represent input/output data, green ovals represent WPS scripts, orange ovals represent the steps of the process and blue ovals represent predefined geographic processes executed by GeoServer.

Script#7: CGI application to generate vertical Profiles

This script is a Python script that is executed in the web server as a CGI application to calculate vertical profiles for a given point. After the user requests the vertical profiling tool, the script takes the point id from the user point selection, builds the appropriate query, and queries the database to obtain the data for the selected MVP point (Figure 39). As the data for depth, temperature, salinity and sound speed were stored as arrays for the point, the data can be easily processed. The outputs for the operation are the plots for the profiles, which the user can visualize and download.

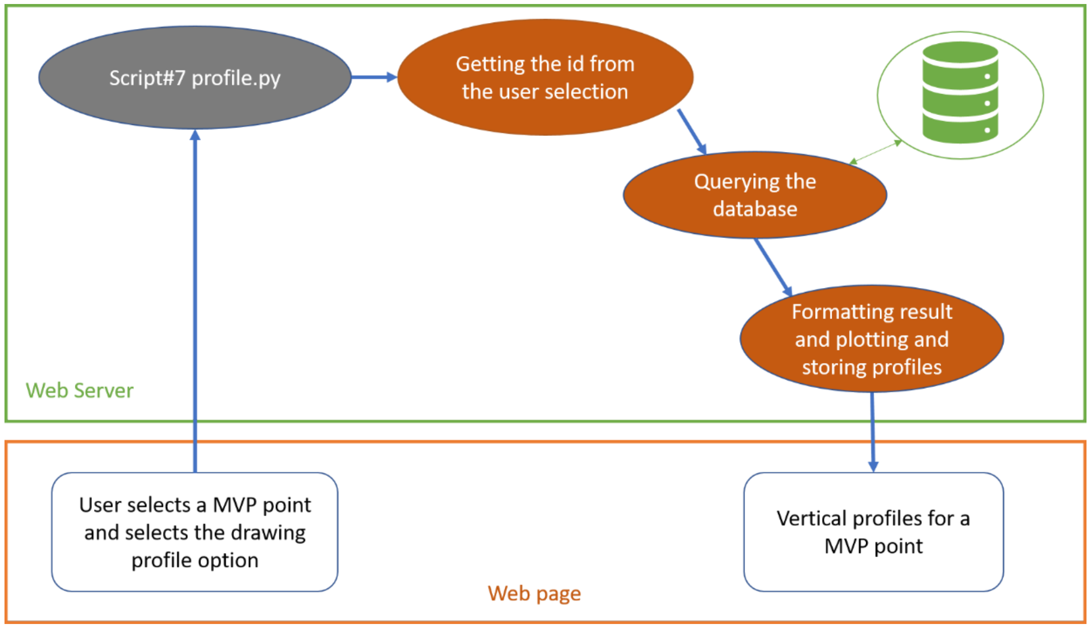


Figure 39.- Process description of generating a vertical profile. White rectangles represent user input/output, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#8: CGI application that creates a WPS request to calculate a longitudinal profile

This script is a Python script that is executed in the web server as a CGI application to construct a WPS XML POST request to calculate a longitudinal profile (using Script#5) and plot the results. After the user draws a line and select the longitudinal profile option, the script takes the coordinates of the line drawn, builds the appropriate WPS request (including the bathymetry and the geometry for the line), sends this request to the map server, and waits for the request to be completed (Figure 40). The results are formatted and the profile is plotted (outputs), which the user can visualize and download.

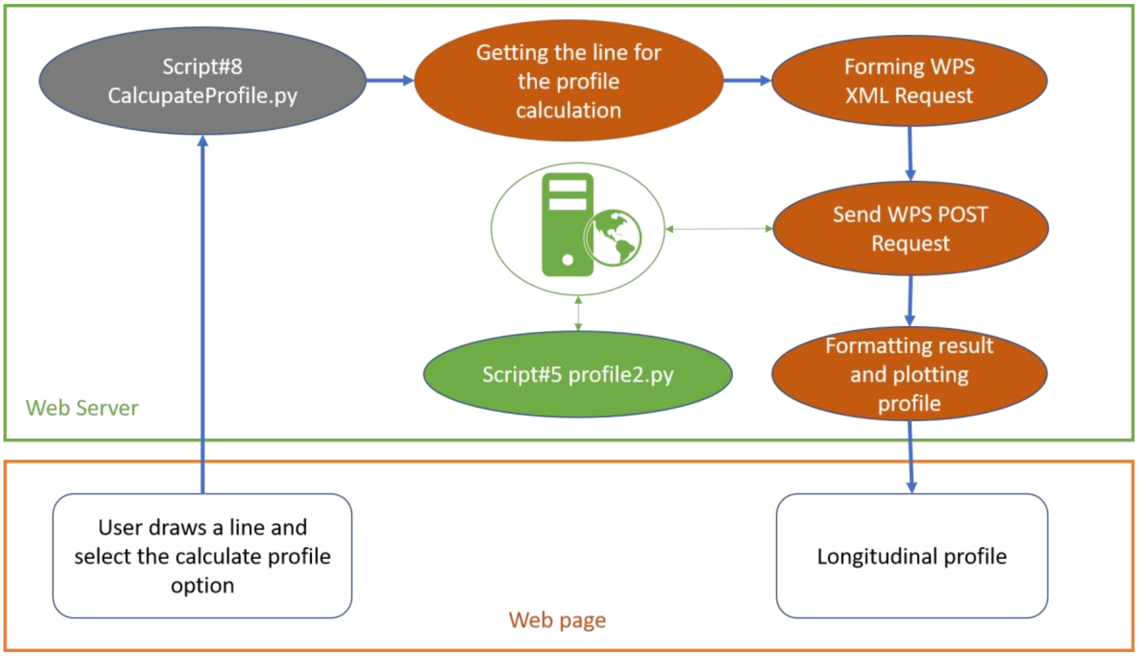


Figure 40.- Process description of creating a WPS request to calculate a longitudinal profile. White rectangles represent user input/output, green ovals represent WPS scripts, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#9: CGI application that creates a WPS request to calculate area statistics

This script is a Python script that is executed in the web server as a CGI application to construct a WPS XML POST request to calculate bathymetric statistics (using Script#6). After the user draws an area rectangle and select the calculate statistics option, the script takes the coordinates of the area drawn, builds the appropriate WPS request (including the bathymetry and the geometry for the area), sends this request to the map server, and waits for the execution to be completed (Figure 41). The results are formatted as an HTML page.

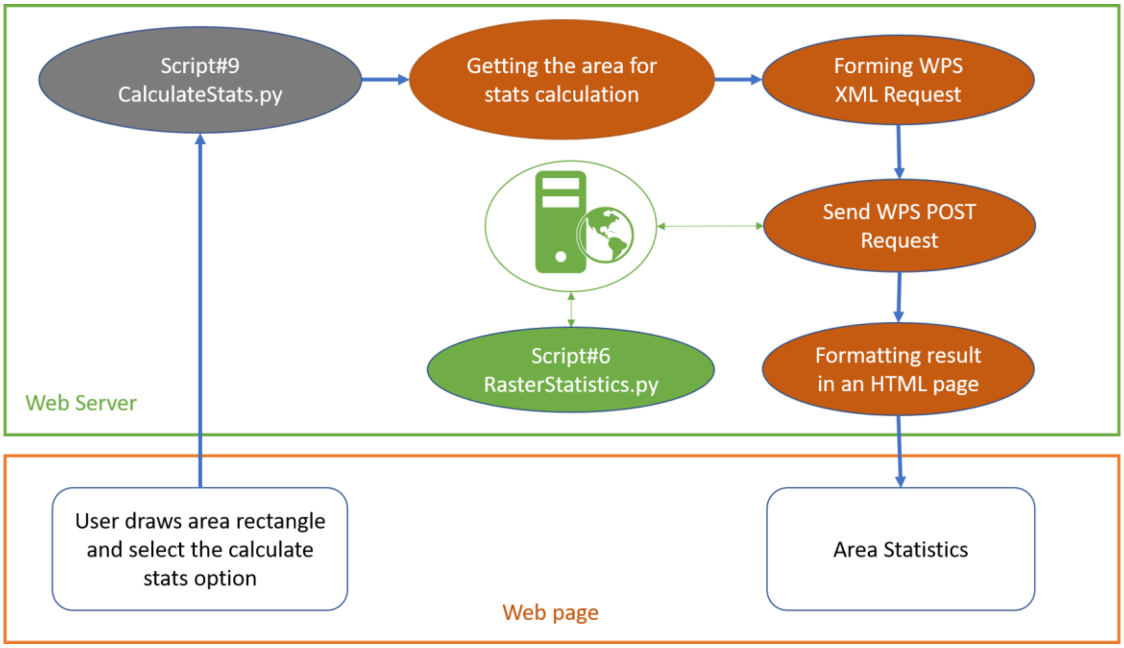


Figure 41.- Process description of creating a WPS request to calculate statistics of a bathymetric area. White rectangles represent user input/output, green ovals represent WPS scripts, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#10: CGI application that creates a WCS request to download bathymetry and uncertainty data

This script is a Python script that is executed in the web server as a CGI application to construct a WCS GET request to obtain bathymetry (or uncertainty) data for a particular area. The user inputs are the resolution, resampling method, type of data (uncertainty or bathymetry) and the desired output format. All these parameters are extracted from the form and used to build the WCS URL. The page is redirected to the constructed URL, which accesses the map server and returns the desired coverage as the output for the process (Figure 42).

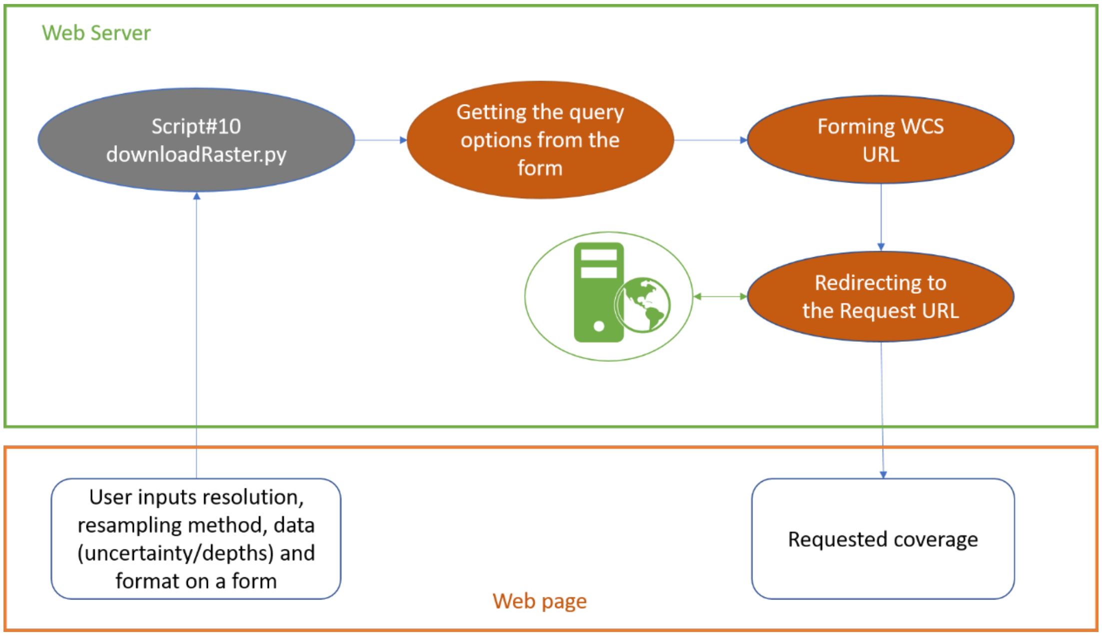


Figure 42.- Process description of creating a WCS request to download bathymetry data. White rectangles represent user input/output, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#11: CGI application that performs a Spatial/time query to download MVP points

This script is a Python script that is executed in the web server as a CGI application to construct a database query to obtain all the MVP points for a particular area. After the user draws an area and selects the download data option, the script takes the polygon and the time frame from the user point selection, builds the appropriate query, and queries the database to obtain the data for the MVP points selected (Figure 43). When querying the database, a geometry operation needs to be included in the request, to match all the points that falls into the inputted polygon (ST_WITHIN). The results from the query are written in a csv file and returned to the user.

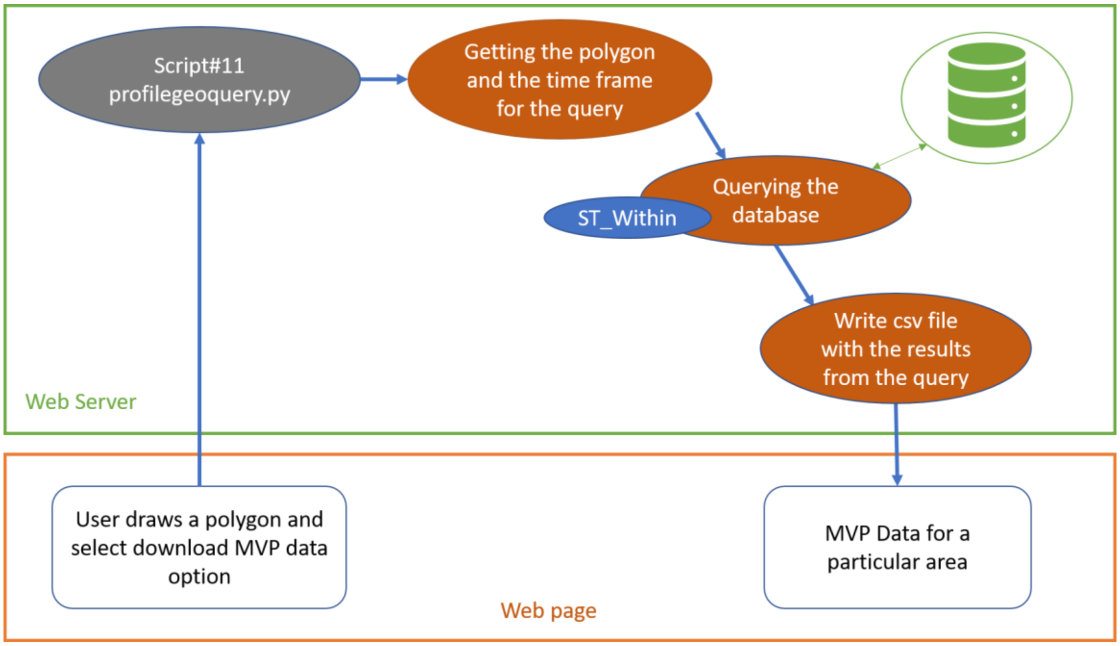


Figure 43.- Process description of downloading a set of MVP points. White rectangles represent user input/output, blue ovals represent predefined geographic processes executed by GeoServer, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#12: CGI application that performs a time query to download weather data

This script is a Python script that is executed in the web server as a CGI application to construct a database query to obtain weather data from a particular station. After the user selects a station, the weather variables and the time frame, the script takes these options from the form, builds the appropriate query, and queries the database to obtain the weather data. The results from the query are written to a csv file and returned to the user (Figure 44).

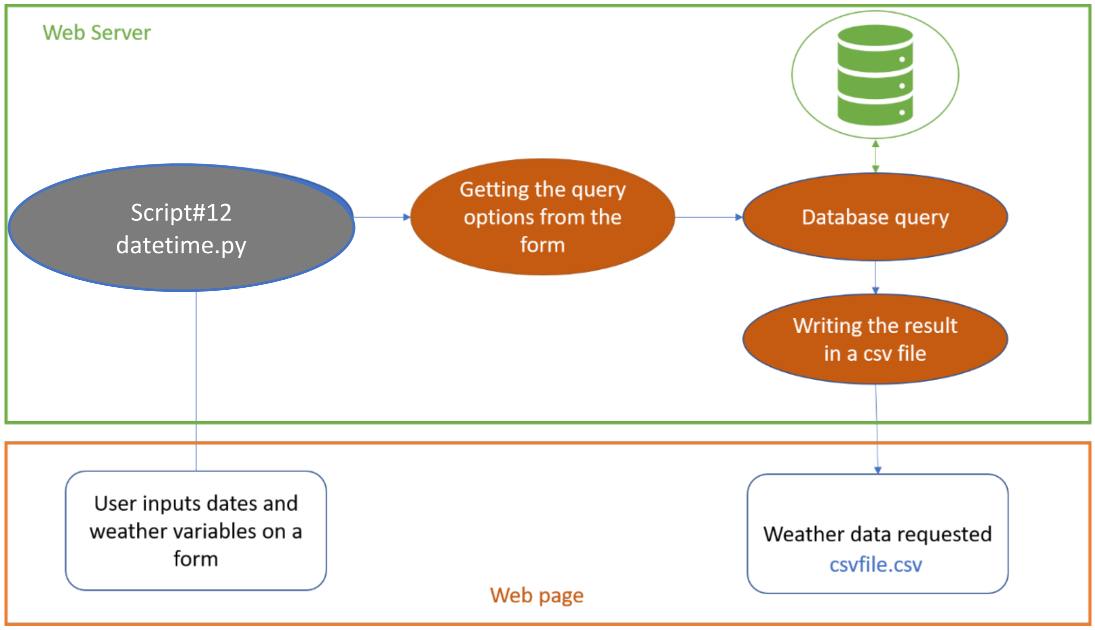


Figure 44.- Process description of downloading weather data. White rectangles represent user input/output, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#13: CGI application to export a longitudinal profile to csv

This script is a Python script that is executed in the web server as a CGI application to export the longitudinal profile data. After the user has generated a longitudinal profile (Script#8 and Script#5), they can select the option to download the data. The script takes the coordinates list from the profile and writes a formatted csv file with the data for the profile (list of coordinates and depths) (Figure 45).

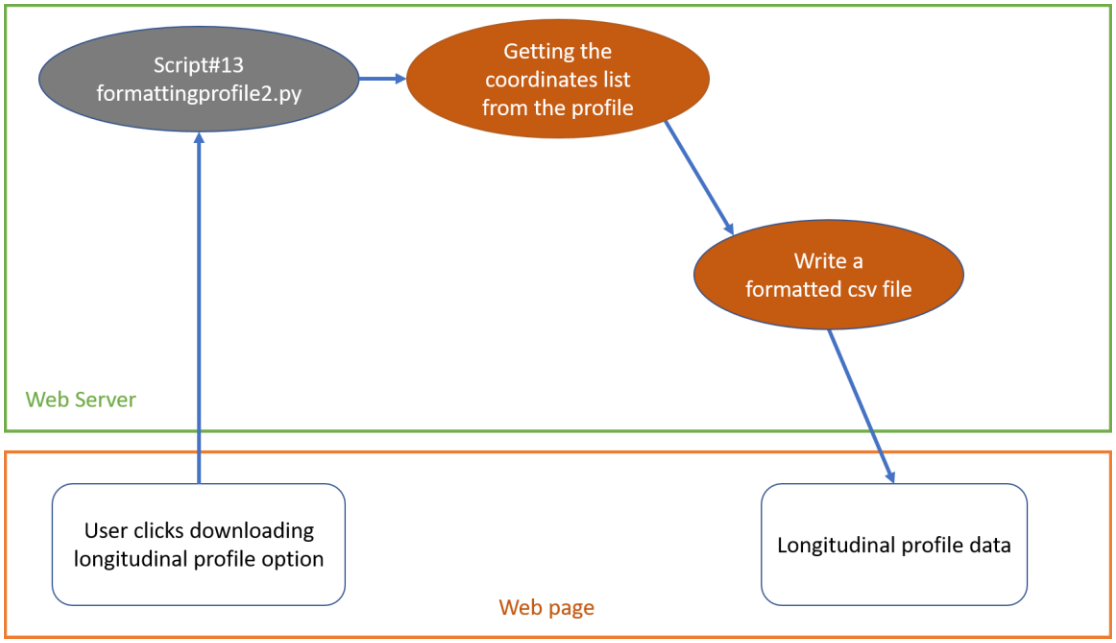


Figure 45.- Process description of downloading a longitudinal profile in CSV format. White rectangles represent user input/output, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

Script#14: CGI application to export MVP data

This script is a Python script that is executed in the web server as a CGI application to export the data of a vertical profile. After the user has generated vertical profiles (Script#7), they can select the option to download the data. The script takes the id from the selected point, queries the database to get the data and writes a formatted csv file with the data for a point (Figure 46).

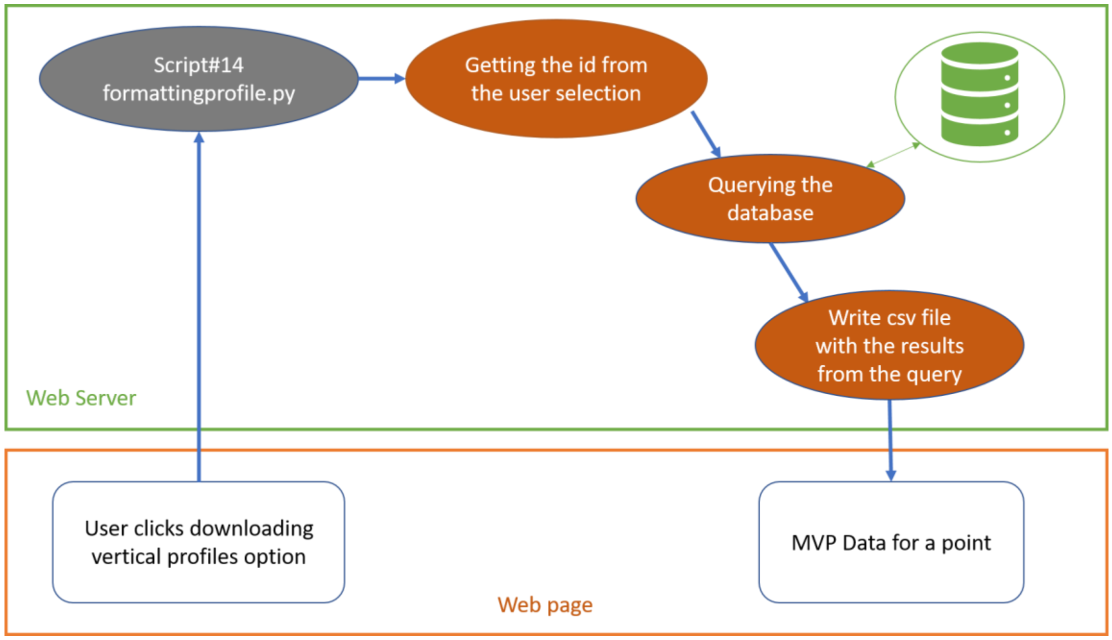


Figure 46.- Process description of downloading a vertical profile in CSV format. White rectangles represent user input/output, grey ovals represent CGI scripts and orange ovals represent the steps of the process.

4.3.8.2 Client-side implementation

Leaflet is a simple map library which provides basic functionality to interact with maps online. Additional functionality is added through Leaflet plugins, which are maintained by the development community. There are several plugins which were used to provide the functionality the web application prototype required.

Leaflet-WMS plugins. OGC WMS clients for leaflet, which allow the user to interact with the Layers in GeoServer. These plugins are an interface to perform all the WMS operations: getCapabilities, getMap and getFeatureInfo. They were used to handle the following functionalities.

- Visualize the raster layers on the map. Since the WMS plugin inherits from Leaflet Tile Class, the tiling is done automatically by the API. After the bathymetry and Orthophotographs are loaded on the map, the navigation through the different zoom levels is fast.

- To retrieve dates and times for which data are available from GeoServer. Data and Time is stored as a GeoServer layer dimension and so the dates and times available for a particular layer can be accessed through the get Capabilities document. This functionality provides the time range of the available data and it is automatically updated if more data is uploaded to the server.

- Time management. Time is handled as a WMS parameter (TIME) when requesting the tiled layers from GeoServer. This parameter can be set to change the visualization on the map depending on the time frame requested. The time parameter is updated whenever the user enters a value in the time search box or moves the time slider. This is the way the filter tool and the search tool are implemented.

- Showing attributes for tiled layers. GetFeatureInfo request returns the attributes of a selected feature. This is the method by which the user can retrieve the coordinates and depth for a point, accessing the getFeatureInfo for the Bathymetry layer.

Leaflet Draw plugin. The leaflet draw plugin enables drawing, editing and deleting of vector features such as polylines, polygons, rectangles, circles and markers. The plugin is used to handle the following functionalities.

- Area of interest. The user is able to draw the area of interest using the rectangle drawing tool.

- Select area to download. The user is able to draw the area to download, either using the polygon or the rectangle drawing tool.

- Draw a line to calculate a profile. The user is able to draw a longitudinal profile using the polyline drawing tool.

- Own Drawings. The user is able to add their own markers and comments to the map.

Leaflet Measure plugin. The Leaflet measure plugin is used to include coordinate linear and area measure control for Leaflet maps which implement the measuring tool functionality.

Leaflet easy print plugin. The Leaflet easy print plugin adds an icon to print or export a map, implementing the export/save/print map view functionality.

Other implementations

- The search tool was implemented for the current and CTD data, and provides the user with the ability to select a year and visualize the data available in that year on a plot. The plot shows the recording date of every point, to be able to select them and load them on the map.

- The filter tool is implemented in bathymetry, currents, temperature, salinity and sound speed data.

4.3.9 Interface design and implementation

The surface plane describes the final visual look of the product, i.e. the design of the web mapping application user interface. This user interface will be divided in three different pages: the welcome page where the application is presented and the user is invited to access the site (Figure 47); the area selection page which presents the available data and lets the user to select their area of interest (Figure 48); and the web application main page where the data are presented along with all the functionalities (Figure 49). When a user enters the application, they navigate through the first two pages until reaching the main page were all the functionality is provided.

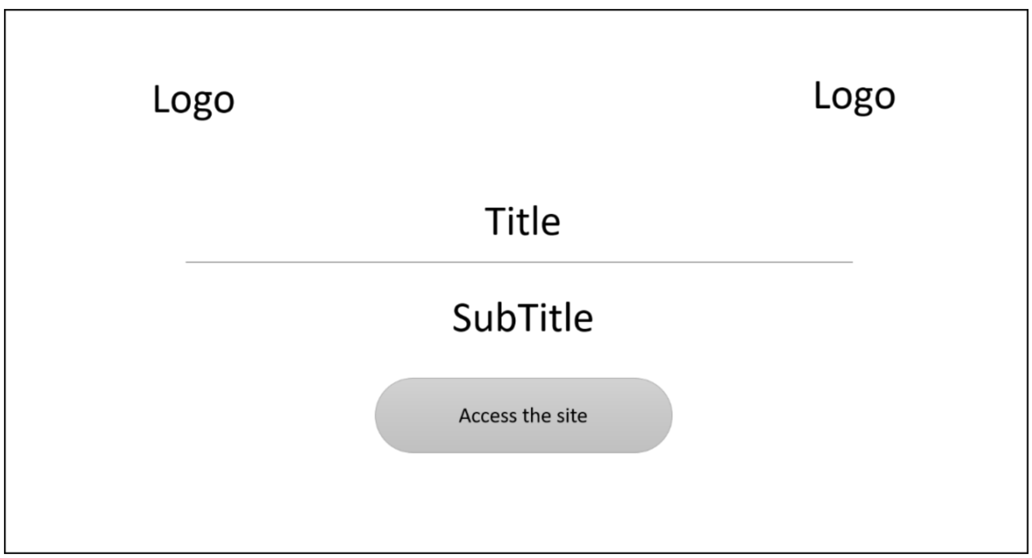


Figure 47.- Interface design for the welcome page

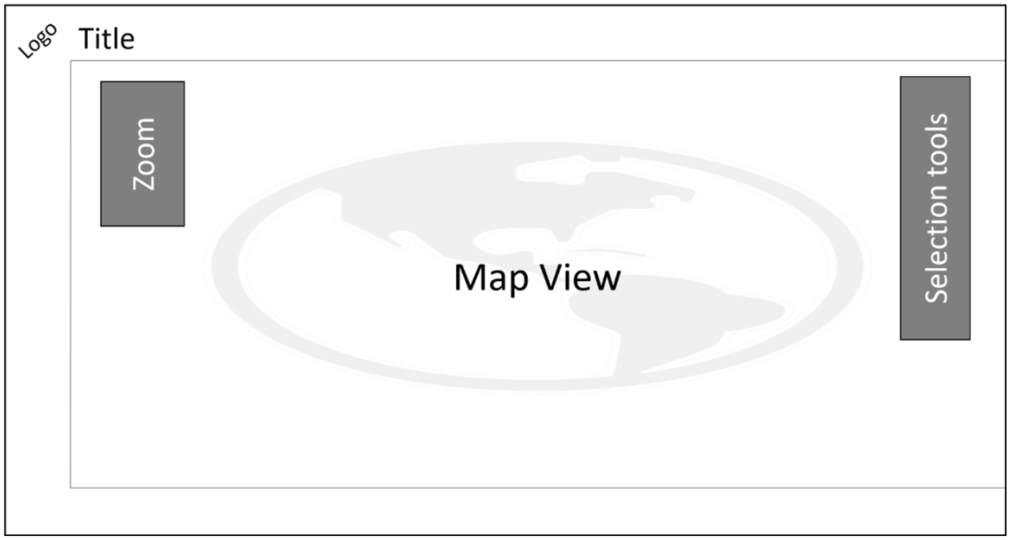


Figure 48.- Interface design for the Area Selection page

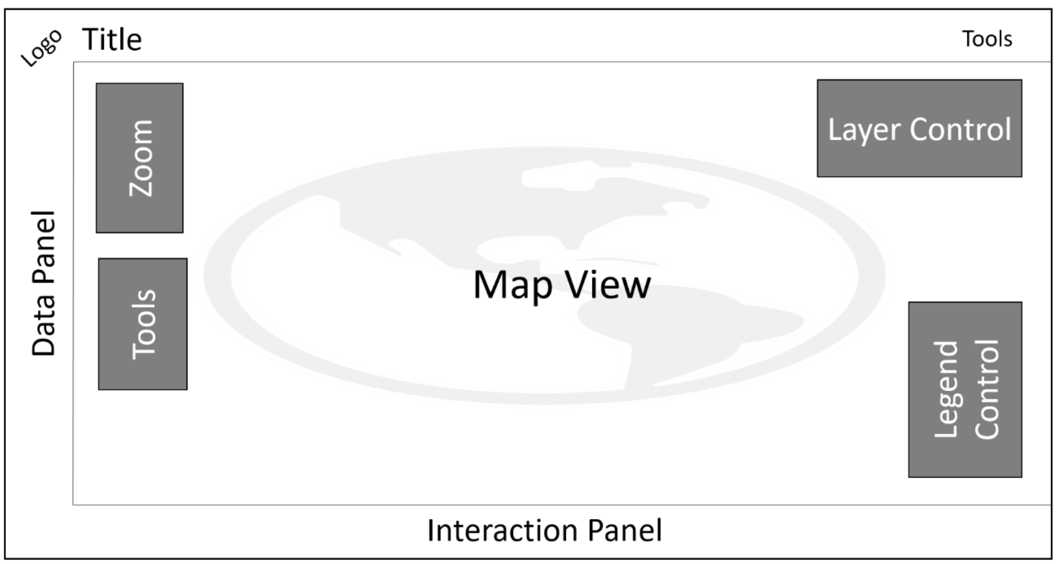


Figure 49.- Interface design for the web application main page

The main page is subdivided in three different panels: Map panel, Data panel and Interaction panel; which are described below:

- Map Panel. The central map view provides basic web mapping interaction controls (zoom in, zoom out, panning…) along with a layer control (to change between basemaps and turn on/off overlay layers), tools control and legend control. The tools control includes the following: measuring tools, adding markers, editing and deleting tools, and printing tools. The Legend control will change depending on which data is loaded onto the map. When selecting an item on the map (marker/point) or clicking on a raster layer, a popup window is activated containing the related information.

- Data Panel. The Data Panel provides the controls to turn on the different datasets on the map: Bathymetry, Temperature, Salinity and Sound Speed, Water Velocity (currents), Weather, Hydrometric data, Buoys and Coast lines. The interface is programmed in a way that only one data set can be loaded at a time. Each data is represented by a characteristic icon.

- Interaction Panel. The interaction panel will be opened every time a dataset is loaded on the map with options changing to correspond with the loaded dataset. Therefore, it provides the specific tools for each layer (for example, download data, plots, profiles, time filter/search etc.).

Table 22 provides a summary of the interfaces used to implement each of the functionality, which are described below:

- The data download interface for bathymetry, orthophotographs, coast lines, currents, and temperature, salinity and sound speed data consists of a button to activate the drawing tool to select the area to download data (select area to download). A popup window appears after the area is drawn so that the download can be started. In the case of bathymetry, a popup form will appear so that the user can select the download parameters (resolution, resampling method, kind of data and format). After clicking the popup button, the user receives the data in the desired format.

- The data download interface for weather data appears in the interaction panel after clicking a weather station. It includes the following items: inputs for date and time (start and end), check boxes to select the desired data for download, and a button to initiate data retrieval after the parameters are selected.

- The data download interface for hydrometric, tidal, and buoys stations includes links to the data providers. The data download must be done through the providers' websites.

- The depth statistics for a bathymetry area was implemented as a popup button after selecting an area on the map. After clicking the button, the user is redirected to a new page were the statistics are calculated.

- The bathymetry time filter interface consists of a time slider that will change the time parameter for the WMS footprints layer request.

- Regarding currents and CTD data, the time filter is implemented as several inputs for year, month and day; and a button to load the data for the specific selected date on the map.

- The selection of the Area of interest interface consist of a button to start drawing a rectangle. After the user has finished the operation, a button appears to select that area.

- The search tool interface consists of time inputs (year, month, day). ADCP and CTD recording dates over River levels for a year functionality is supported by an interactive plot with a blue line chart showing the river levels, and red vertical lines for ADCP or CTD data.

- The depth tool interface consists of a button to activate the drawing line tool, and a popup button after the line is drawn, that will generate the profile plot in a new window.

- The vertical profile tool interface consist of a popup button after a point is selected, which will generate the plots for the temperature, salinity and sound speed in a new window.

- Retrieve coordinates and depth are shown in a popup window interface after clicking a point on the map.

- Measuring, export map and own drawings tools interface are image buttons representing a characteristic icon for the tool (ruler, printer and marker).

– Exporting profiles as images or csv files functionalities are supported by a button interface.

Regarding the data representation, Table 23 provides a description of how each data layer is represented and symbolized on the map, and Figure 50 shows some legends and symbols used. For point data, stations are represented with blue markers, while ADCP and CTD data are represented as points coloured by season. For raster data, bathymetry and uncertainty are represented as tiled overlay layers colored by the depth and uncertainty values (color ramps). Each survey polygon is coloured with a different color and the coast lines are coloured blue.

Table 22.- Interface implementation for each functionality requirement

Functionality Requirement	Interface
Data download (bathymetry, orthophotographs, coast lines, currents and temperature, salinity and sound speed data)	Button to activate, drawing tool, button to start downloading
Data download (weather)	Form with inputs for parameters
Data download (hydrometric, tidal and buoys stations)	Link to the external data provider
Time filter (bathymetry data)	Time slider
Time filter (currents and temperature, salinity and sound speed data)	Year, Month and Day inputs and load on map button
AOI	Drawing tool, select this area popup button
Being able to choose the resolution of the bathymetry data	Popup form
Search tool	Time selector/Plots
Retrieval of bathymetric uncertainty data	Popup form
Depth profile tool	Button to draw line/Plots
Retrieve coordinates	Popup window
Salinity/temperature profile tools	Popup button/Plots
Measuring tools	Ruler image button
Export/save/print the map view	Printer image button
Export Depth profile tool	Export button
Retrieve depth	Popup window
Own Drawings	Marker button
Depth statistics of an area	Button/new window
ADCP and CTD recording dates over River levels for a year	Blue line chart (red vertical lines for ADCP or CTD data)

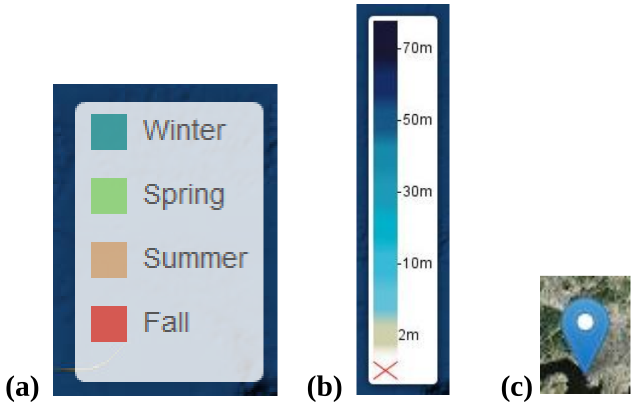


Figure 50.- Data legends for (a) ACDP/CDT data and (b) Bathymetry. (c) Blue marker representation for stations

Table 23.- Representation and symbolization of each data layer

#	Data Requirement	Representation	Symbolization
1	Weather	Markers representing weather stations	Blue markers (Figure 50)
2	Tidal	Markers representing tidal stations	Blue markers (Figure 50)
3	Currents	Tiled layer of Points representing ADCP observations	Points coloured by season of the observation time (Figure 50)
4	Buoy	Markers representing each buoy	Blue markers (Figure 50)
5	Bathymetry	Tiled layer	Blue colour ramp depending on depth (Figure 50)
6	Coast lines	Tiled layer of Lines	Blue lines
7	Sea temperature, salinity and sound Speed	Tiled layer of Points representing CTD observations	Points coloured by season of the observation time (Figure 50)
11	Hydrometric data	Markers representing hydrometric stations	Blue markers (Figure 50)
15	Survey footprints	Tiled layer of polygons representing each survey	A different colour per survey
16	Bathymetric Uncertainty	Tiled layer	Colour ramp

Combining all these components together, the end user interface for the three main pages of the web mapping application are shown in Figure 51, Figure 52 and Figure 53.

Figure 54 to Figure 60 show the interfaces for the interaction panels depending on what dataset is selected,

Figure 61 shows the plot representation of ADCP and CTD recording dates over river levels and Figure 62 shows the different popup windows for data download and coordinate/metadata retrieval.

Figure 51.- Implemented interface for the welcome page

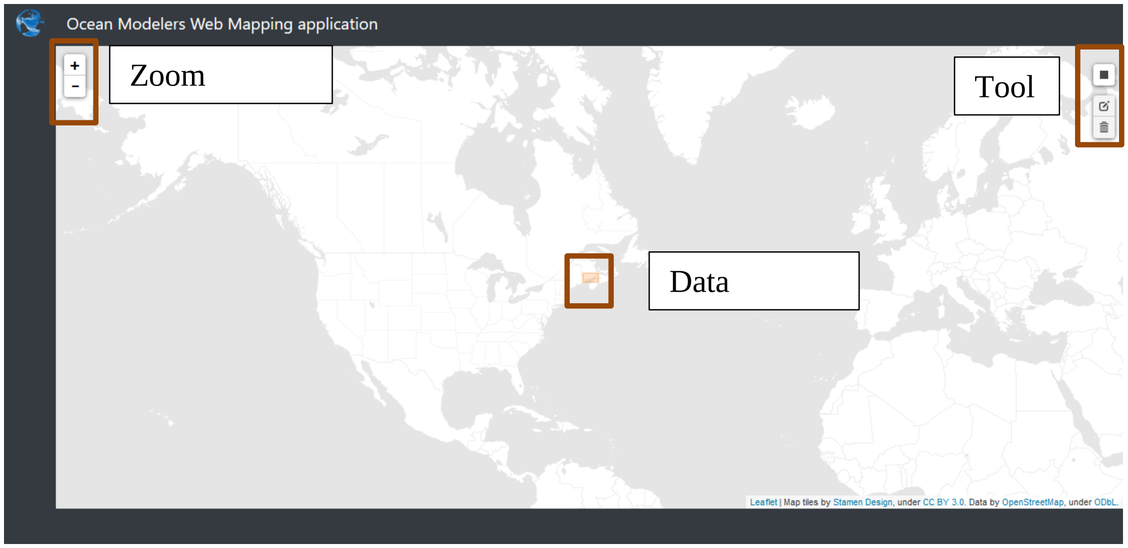


Figure 52.- Implemented interface for the area selection page

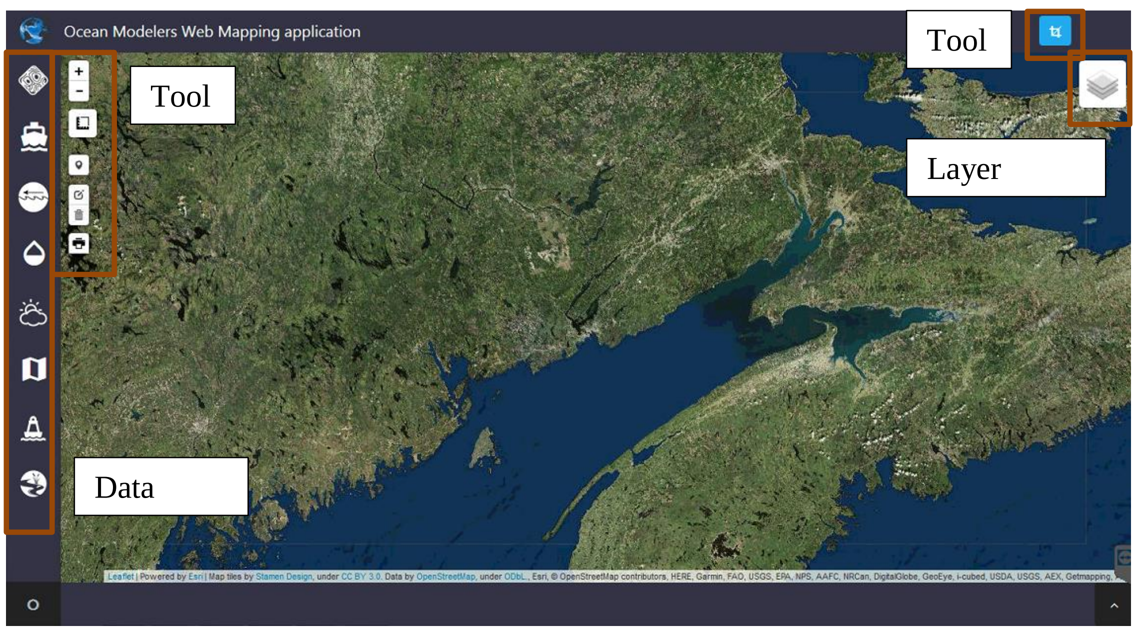


Figure 53.- Implemented interface for the web application main page

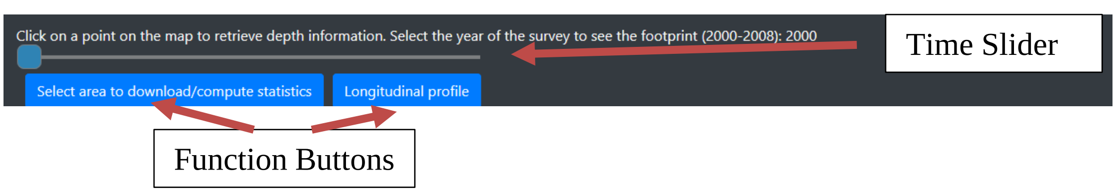


Figure 54.- Final interface for the Bathymetry data interaction panel

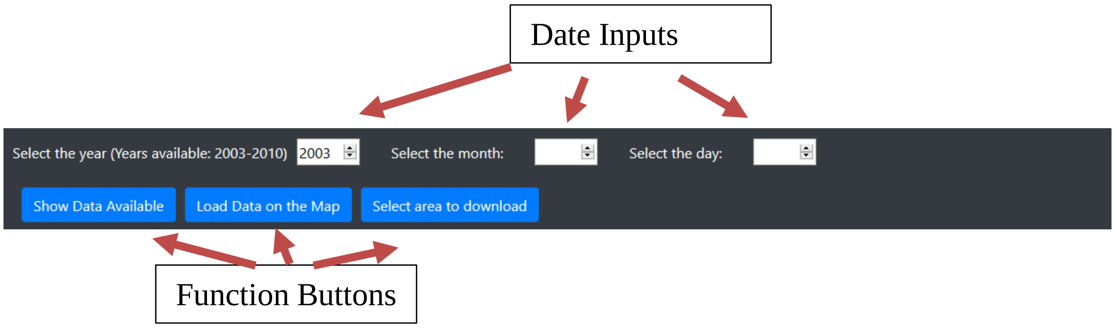


Figure 55.- Final interface for the CTD and ADCP data interaction panel

Figure 56.- Final interface for the Hydrometric Stations data interaction panel

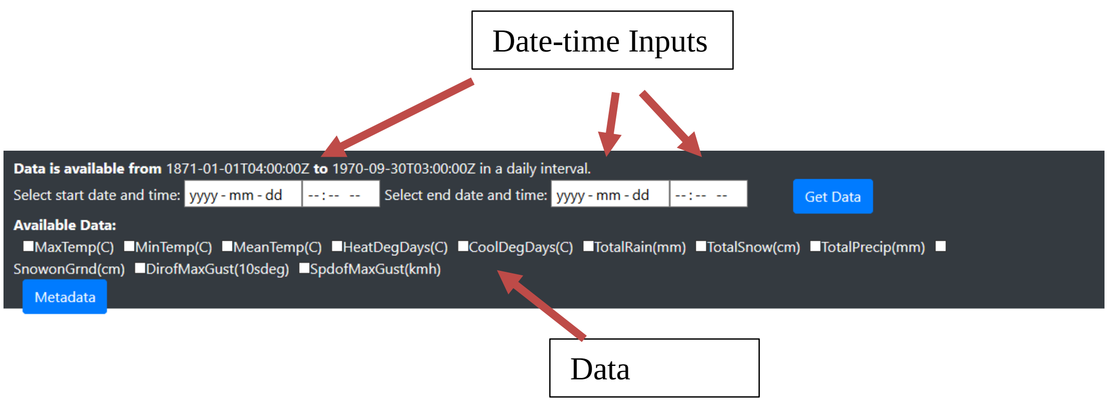


Figure 57.- Final interface for the weather data interaction panel

Figure 58.- Final interface for the Orthophotographs interaction panel

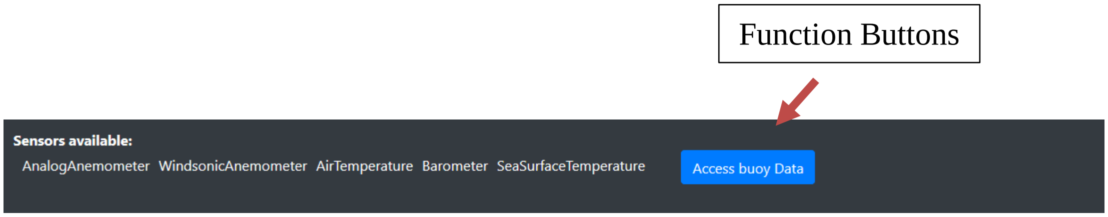


Figure 59.- Final interface for the Buoy data interaction panel

Figure 60.- Final interface for coast lines data interaction panel

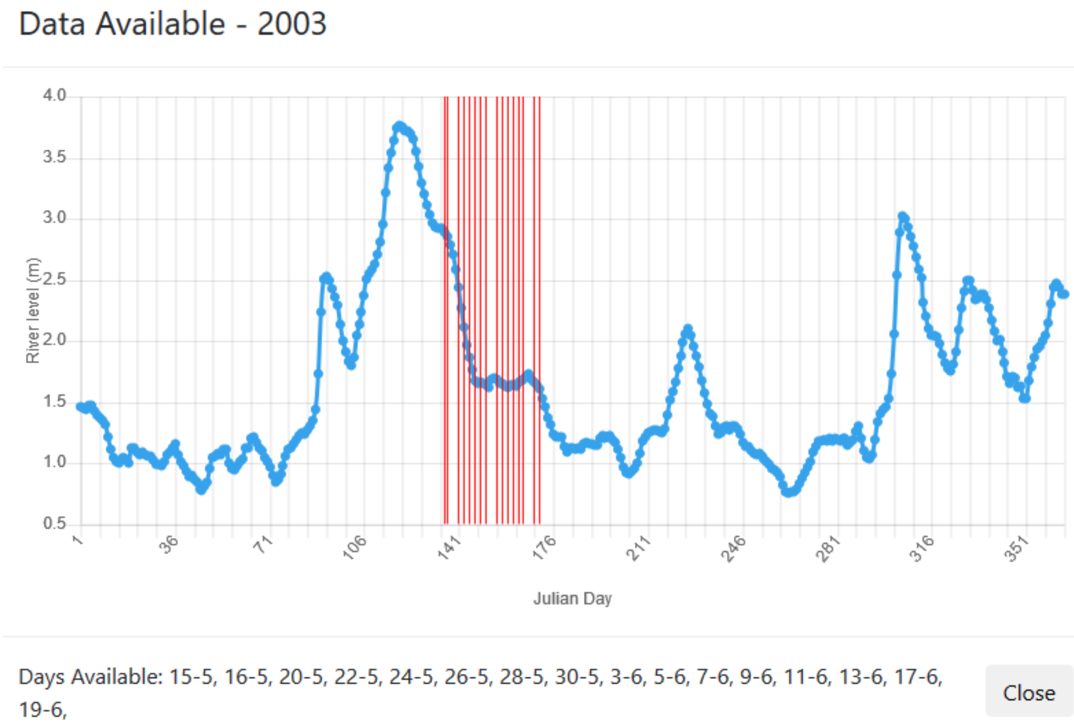


Figure 61.- Plot representation of ADCP and CTD recording dates over river levels

(a) (b) (c)

Figure 62.- Popup's final interfaces for (a) Bathymetry download, (b) Coordinates retrieval and (c) CTD/ADCP data

4.4 Evaluation Stage

A total of 7 participants participated in the evaluation stage, providing written responses for each task and question of the cognitive walkthrough and the formative online survey.

4.4.1 Cognitive walkthrough

The written responses from the cognitive walkthrough were categorized and analyzed. Figure 63 shows the total number of comments made by the participants during the evaluation, distinguishing between positive and negative comments for each of the sections.

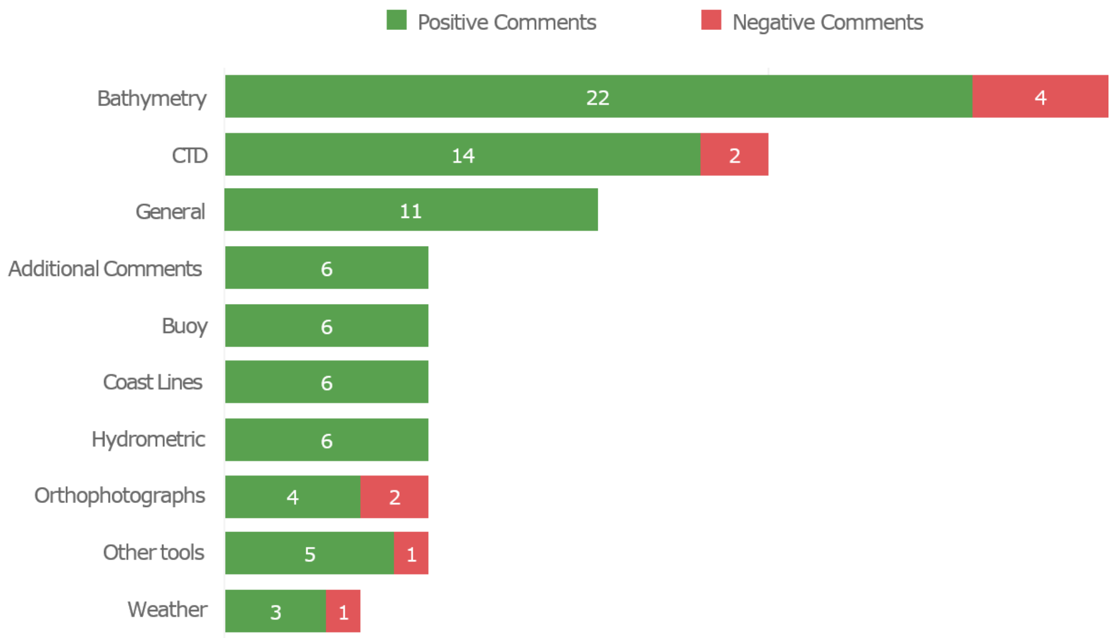


Figure 63.- Comments made by participants during the cognitive walkthrough evaluation

The bathymetry section received the most comments in the cognitive walkthrough evaluation with a total of 26 comments, 22 positive and 4 negative. This was probably due to the fact that there were more tasks and interactions using bathymetry data. This section was also the one that received the most negative comments. Five of the sections (General, Additional Comments, Buoy data, Coast Lines and Hydrometric) did not get any negative comments. The orthophotographs section received the most negative comments in relation with the total number of comments for the section; 33.33% of the comments for orthophotographs were negative. Within a UCD process, negative comments are considered the most important kind of comments, since they provide user feedback to improve consequent versions of the application. Table 24 presents all the negative comments for the cognitive walkthrough evaluation and if they are related to a usability or utility concept. There is a total of ten negative comments, eight of them regarding to the application utility, two regarding usability, and one that refers to both concepts. The usability comments refer to long loading times for statistics calculations, that it was not clear how to access the statistics area selection, and a comment about the inconsistency of selecting tools (for bathymetry is a rectangle, while for moored data is a polygon). Regarding utility, the longitudinal profile tool was mentioned not to be useful. However, as one of the participants mentioned, “gradient affects advection, upwelling...” and could be useful as a support for the ocean model calculation. The orthophotographs data downloaded was not considered useful for two participants, as well as other tools and the CTD data. The weather data download did not work for one of the participants. These negative comments might be addressed in following development of the application.

Table 24.- Negative comments made by participants during the evaluation

Section	Task	Response	Utility/Usability
Bathymetry	Longitudinal Profile	Not very useful for me.	Utility
	Download Bathymetry	One meter may not be very useful because it is close to your raw data.	Utility
	Statistics	The statistics results were taking too long to load	Usability
		It wasn't obvious where to go to select the area. Not sure how useful this functionality is.	Utility/Usability
CTD	Download area	Have you changed the format on how to choose the area? Before it was a box now it is a polygon. This is confusing.	Usability
	Search/Load Data	Not very useful since this is a mapping tool mainly for bathymetry data, not a statistical tool for data analysis	Utility
Orthophotographs	Data Download	I do not need orthographic data for my research of interest. This is not a feature I will use in my research.	Utility
		Not sure about usefulness. this is not something that I use.	Utility
Other tools	All	I tried them. But I don't think they are useful for ocean modelers.	Utility
Weather	Data Download	I could not get this to work. The latest end date was 1970.	Utility

4.4.1.1 Problems and recommendations

Problems and recommendations were extracted and categorized from participants responses and classified into usability or utility concepts. Table 25 shows a summary of the number of problems and recommendations mentioned by participants, presented by section and divided into usability and utility.

Table 25.- Number of problems and recommendations mentioned by participants, depending if they refer to utility or usability concepts

Section	Problems			Recommendations		
	Usability	Utility	Total	Usability	Utility	Total
Additional Comments	0	0	0	3	5	8
Bathymetry	2	5	7	7	14	21
Buoy	0	0	0	0	2	2
Coast Lines	0	1	1	1	4	5
CTD	5	1	6	9	2	11
General	2	1	3	4	7	11
Hydrometric	0	1	1	1	2	3
Orthophotographs	1	0	1	0	2	2
Other tools	0	0	0	1	7	8
Weather	2	4	6	4	4	8
TOTAL	12	13	25	29	50	79

A total of 25 problems and 79 recommendations were identified during the cognitive walkthrough evaluation. Bathymetry is the section that received both the most problems (7) and recommendations (21). However, CTD data section is the one with the most usability recommendations (9) and usability problems (5). Worth mentioning is the number of utility problems regarding weather data (4).

Table 26 summarizes all the problems encountered during the evaluation with the section, the number of mentions, and if it refers to utility or to usability concepts. Results show that there is probably a programming issue regarding weather data, as data download problems were mentioned four times by participants. Another clear issue was that the page is slow to load data, which was also mentioned four times.

Table 27 summarizes all the recommendations encountered during the evaluation, indicating the section, the number of mentions and if refers to utility or to usability concepts. The recommendation of adding more for Canada was mentioned six times, which shows a desire of the users to see the development of the application to their working areas. Adding additional data was also mentioned six times. The data mentioned was backscatter, soil classification of the seabed, tidal harmonic constants, sediment data, dates of photos and incorporation of historical imagery, mean wind speeds and directions, atmospheric pressure and global model atmospheric fields from ERA. Other recommendations worth mentioning were the addition of more output format options (GeoTIFF, ESRI grid, csv, THREDDS, NetCDF) and the need of changing the date input format for the weather data download, as it was claimed to be confusing.

Table 26.- Problems mentioned by participants during the evaluation. The most mentioned problems are highlighted in red.

Section	Problem	# Times mentioned	Util/Usa
Bathymetry	Generate Profile is showing the same profile.	1	UT
	Mapped figure was not shown.	1	UT
	Slow to load	4	US
	Having options at the bottom is not a standardized format.	1	US
	It wasn't obvious where to go to select the area to calculate statistics	1	US
Coast Lines, Bathymetry	There seems to be a mismatch between basemap and data	2	UT
CTD	Area selection method is a polygon instead a rectangle	1	US
	It is tricky how to determine the order of points in the CSV file.	1	US
	The data showed are the runoff.	1	UT
	It is difficult to click on the CTD point on the map.	1	US
	Area selection by polygon is not allowed to be discarded in the mid-way.	1	US
	The plot for data available lacks information and has a confusing format	1	US
General	Browser compatibility	1	UT
	Once an area is selected the map recenters on it automatically	1	US
Hydrometric	When clicking on historical data, it takes to a real-time data page	1	UT
Orthophotos	When you select an area without any data it gets you to download a file containing the error.	1	US
Weather	Could not access weather data	4	UT
	The input format is hard to figure out.	2	US

Table 27.- Recommendations made by participants during the evaluation, colored in red by number of times mentioned.

Section	Recommendation	# Times mentioned	Util/Usa
General	Extend coverage to more parts of Canada	6	UT
	Always use polygon area selection	2	US
	Add additional data	6	UT
	Change selection tool hovers to 'select region' when selecting AOI	1	US
	Be able to click on the orange rectangle to access the data	1	US
	Be able to download the basemap as a GeoTIFF/GeoTIFF screenshot tool	2	UT
	Overlap the variables on the map	1	US
	Eliminate the AOI re-center function	1	US
	Add a spatial scale	1	UT
	Get data processed automatically by server (weather data computations)	1	UT
	Pop-up mentioning types of data available when selecting an area	1	UT
Bathymetry	Let the user specify the resolution when downloading bathymetry	1	US
	Add standard deviation	2	UT
	Add information on projections/datums (horizontal and vertical)	2	UT
	Limit the after decimal digits when outputting calculations/profile	2	US
	Allow multi-segment longitudinal profile	3	UT
	Improve downloading function	1	UT
	Have the time below (or above) the time bar for ease of use	1	US
	Be able to select multi-year periods	2	UT
Bathymetry, CTD	More output format options (GeoTIFF, ESRI grid, csv, THREDDS, NetCDF)	4	UT

	Plot and computations in a pop-up window	3	US
Bathymetry, Other tools	Be able to import coordinates (for profiles or markers)	2	UT
CTD	Selection of points in order by multiple clicks	1	US
	Use icons for selection tools, rather than "Select area to download" button	1	US
	Need to include heathers in files when downloading vertical profiles	1	US
	Show what data is available not having to check each year	1	US
	Make it same style as bathymetry and be able to select a time range as well	1	US
	Be able to click on the graph to bring up the data on the map	1	US
	Plot units and labels for the vertical profiles	2	US
	Vertical profiles bulk download (more than one)	1	UT
Hydrometric	Station name when the mouse hovers over the marker	1	US
Weather	Change date input format/Include format example	4	US
	Automatically updated to include current data without manual intervention.	1	UT
Coast Lines	Separate the coastline from lakes, ponds, streams…	1	UT
Orthophotographs, Other tools	Spend less time on improving this function	1	UT
Other tools	Separate distance and area	1	US
	Keep markers when exiting and returning to the map	1	UT
Additional Comments	Add a tutorial	2	US
	Improve the consistory of the interface	2	US
	An effort should be made to integrate as much data from as many different sources	3	UT
	Always include the source of the data	2	UT
	Additional GIS functions are of secondary importance	1	UT
	Focus mainly in data download	1	UT

4.4.2 Formative Survey

Results for the formative survey are shown in Figure 64, with respect to utility; and Figure 65, with respect to usability.

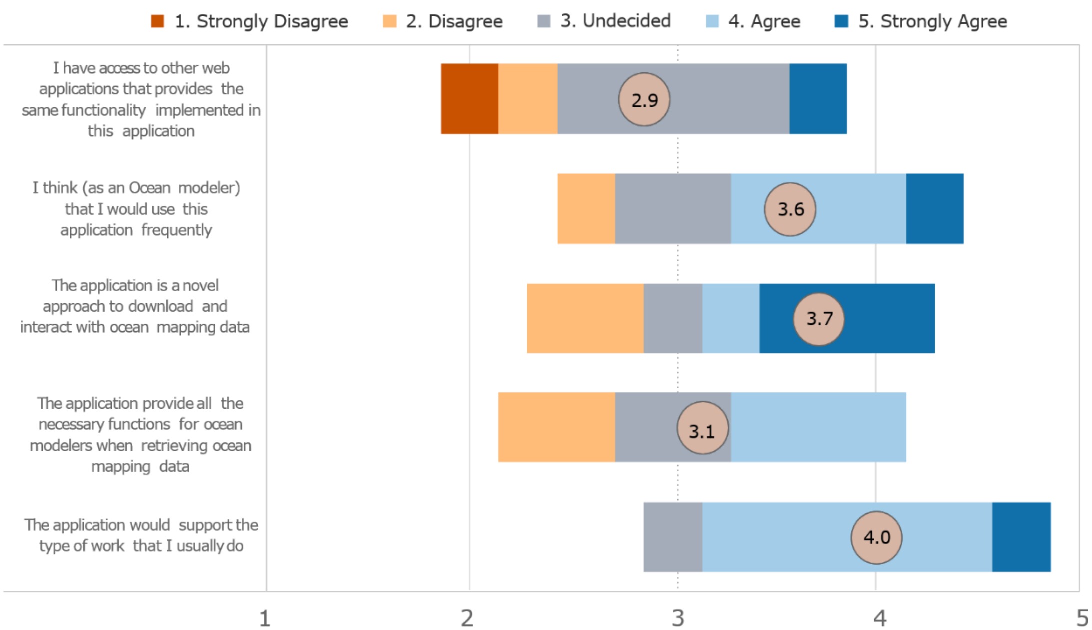


Figure 64.- Results for the formative survey with respect to utility

Utility scores are high (between 3.1 and 4 points) for positive questions, and low for negative questions (2.9). The highest score (4) is given to "the application would support the type of work that I usually do", while the lowest score is given to both, inclusion of all the necessary functions and access to other applications with same functionality (3.1). The overall score considering the inverse of the negative question, gives a total of 3.5 points out of 5.

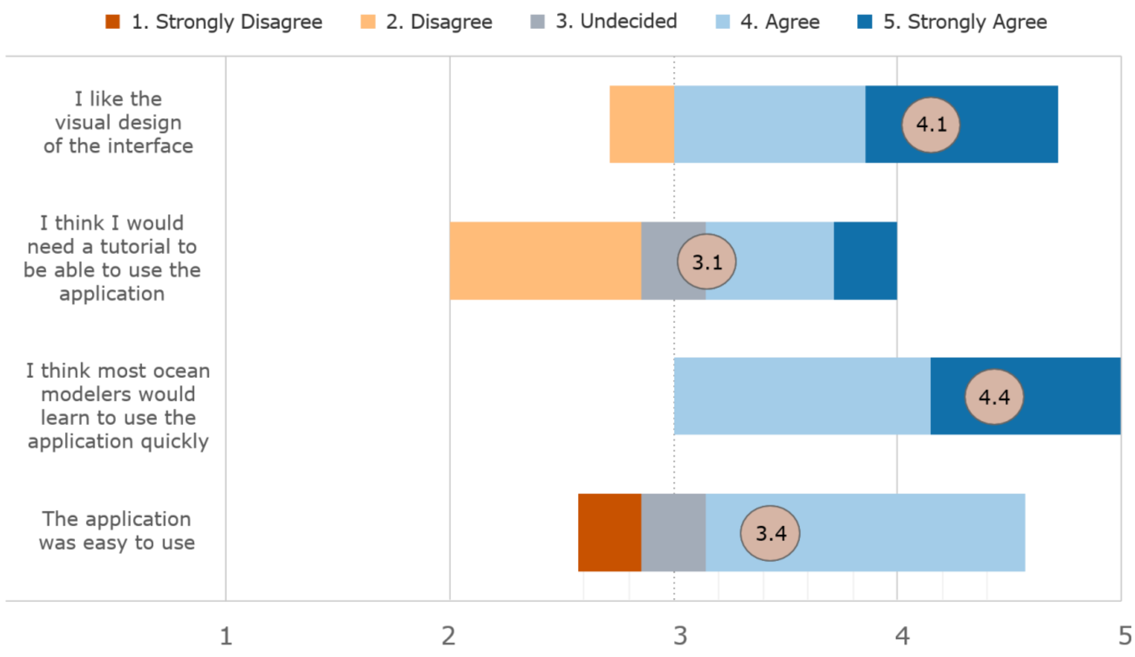


Figure 65.- Results for the formative survey with respect to usability

Regarding usability, results are also high, between 3.1 and 4.4 points. The maximum score is given to "most ocean modellers would learn how to use the application quickly", while the lowest is given to the need of using a tutorial (3.1). The overall score for this section is 3.75 points out of 5.

4.5 Revised prototype

Taking into consideration the problems and recommendations, several solutions were suggested and implemented, presented in Table 28 and Table 29. A total of eight problems were solved and thirteen recommendations implemented. Some of the recommendations were considered for future work. This way the prototype was revised and improved, finalizing the first loop of the UCD approach.

Table 28.- Proposed solutions to the problems encountered during the evaluation stage

Section	Problem	Proposed Solution	Fixed
Bathymetry	Generate Profile is showing the same profile.	Programming issue	Yes
	Mapped figure was not shown.	Not considered as It is not the purpose	N/A
	Slow to load	Server Improvement	No
	Having options at the bottom is not a standardized format.	Not considered	N/A
	It wasn't obvious where to go to select the area to calculate statistics	Icons/Tutorial	Partially
Coast Lines, Bathymetry	There seems to be a mismatch between basemap and data	Not considered	N/A
CTD	Area selection method is a polygon instead a rectangle (as in Bathymetry data)	Bathymetry selection by Polygon	No
	It is tricky how to determine the order of points in the CSV file.	Points have coordinates	Yes
	The data showed are the runoff.	Not considered	N/A
	It is difficult to click on the CTD point on the map.	If the features are not loaded as map features, it cannot be solved	No
	Area selection by polygon is not allowed to be discarded in the mid-way.	Polygon can be deleted once created	Yes
	The plot for data available lacks information and has a confusing format	Plot interface improvement	Yes
General	Browser compatibility	Browser aware programming	No

	Once an area is selected the map recenters on it automatically	Removal of the map re-center feature	Yes
Hydrometric	When clicking on historical data, it takes to a real-time data page	Change links to direct to real time data	Yes
Orthophotos	When you select an area without any data it gets you to download a file containing the error.	Not to return file if there is an error	No
Weather	Could not access weather data	Programming issue	Yes
	The input format is hard to figure out.	Specify format and add a default value for the inputs	Yes

Table 29.- State of the recommendations mentioned during the evaluation stage

Section	Recommendation	Developed
General	Extend coverage to more parts of Canada	Future work
	Always use polygon area selection	Yes
	Add additional data	Future work
	Change selection tool hovers to 'select region' when selecting AOI	Yes
	Be able to click on the orange rectangle to access the data	Yes
	Be able to download the basemap as a GeoTIFF/GeoTIFF screenshot tool	Not possible
	Overlap the variables on the map	No
	Eliminate the AOI re-center function	Yes
	Add a spatial scale	Future work
	Get data processed automatically by sever (weather data computations)	Future work
	Pop-up mentioning types of data available when selecting an area	Future work
Bathymetry	Let the user specify the resolution when downloading bathymetry	Future work
	Add standard deviation	Yes
	Add information on projections/datums (horizontal and vertical)	Future work
	Limit the after decimal digits when outputting calculations/profile	Yes
	Allow multi-segment longitudinal profile	Yes
	Improve downloading function	Future work
	Have the time below (or above) the time bar for ease of use	Yes
	Be able to select multi-year periods	Future work
Bathymetry, CTD	More output options (GeoTIFF, ESRI grid, csv, THREDDS, NetCDF)	Yes
	Plot and computations in a pop-up window	Yes

Bathymetry, Other tools	Be able to import coordinates (for profiles or markers)	Future work
CTD	Selection of points in order by multiple clicks	Not possible
	Use icons for selection tools, rather than "Select area to download" button	Future work
	Heather in columns when downloading profiles	Future work
	Show what data is available not having to check each year	Future work
	Make it same style as bathymetry and be able to select a time range as well	Future work
	Be able to click on the graph to bring up the data on the map	Future work
	Plot units and labels for the vertical profiles	Yes
	Vertical profiles bulk download (more than one)	Future work
Hydrometric	Station name when the mouse hovers over the marker	Future work
Weather	Change date input format/Include format example	Future work
	Automatically updated to include current data without manual intervention.	Future work
Coast Lines	Separate the coastline from lakes, ponds, streams…	Future work
Orthophotographs, Other tools	Spend less time on improving this function	N/A
Other tools	Separate distance and area	Future work
	Keep markers when exiting and returning to the map	Future work
Additional Comments	Add a tutorial	Yes
	Improve the consistory of the interface	Future work
	An effort should be made to integrate as much data from as many different sources	Future work
	Always include the source of the data	Yes
	Additional GIS functions are of secondary importance	N/A
	Focus mainly in data download	N/A

5. Conclusions

The main objective of this research was to develop a web mapping application for ocean modellers using a UCD approach, to bridge the gap between the users and the data that exist in the ocean modelling field.

After an extensive literature review about UCD frameworks and methods, a combined approach between two existing frameworks (Robinson et al. 2005; Garret, 2002) was applied for the development of the web mapping application, performing the first loop of the iterative process. With respect to the UCD methods, the ones which fit the needs for this project to analyze the ocean modelling field, as well as the limitations of user accessibility and time constraint, were applied: an interview, a competitive analysis, surveys and a cognitive walkthrough.

The data and functionality needs of ocean modellers when using ocean mapping data were determined during the work analysis stage of the UCD framework. The study also helped to understand the kind of spatial data they work with (coordinates, projections, etc.), the software they use, and the data formats they would like to have.

The evaluation stage served as a confirmation that a UCD methodology will result in a useful application. The cognitive walkthrough approach allowed the identification of problems and programming bugs, and gave the users the opportunity to give recommendations regarding product development. There was a higher number of positive comments (83) compared to the number of negative comments (10); and the number of recommendations (79) was high in comparison with the number of participants (7), showing a desire of the users to be involved in the designing process. Moreover, the application was claimed to be useful and easy to use in the results of the formative survey. A high score (3.7 out of 5) was given to the novelty of the application, which shows a user realization about the potential of an UCD approach in the development of these kind of tools. Also, all the participants included a comment at the end of the survey, showing a willingness to participate in the subsequent development of the web mapping application, which supports the statement of the desire to get involved in this kind of project.

Overall, the Web mapping application for ocean modellers case study, demonstrates the benefit of following a UCD approach in designing Geomatics applications. The contribution of this work is a web mapping application developed for ocean modellers using UCD techniques. The results from the study and evaluations helped to better understand the ocean modeller community in order to provide them with a product that better fits their needs.

However, as mentioned before, UCD frameworks are iterative approaches that need to be conducted recursively, to keep improving the application using constant user feedback. Therefore, the resulting application is only considered the first step on bridging the existing user-data gap, serving as the foundation for future web mapping developments within the ocean mapping field and the OMG at the University of New Brunswick. Additional loops in this iterative process should be performed in order to achieve a consistent final product.

6. Future work

UCD processes are iterative, and usability/utility evaluations should be conducted until the user needs and expectations are met. For the purpose of this project, only one iteration was completed; however, consequent iterations are proposed and should be conducted to develop final release of the ocean web mapping application. Two additional User → Utility → Usability loops are proposed for the continuation of this work, making a total of three loops (Table 30).

6.1 Second Loop

The results from the evaluation stage, helped to develop a revised prototype addressing problems and recommendations extracted from the evaluation. After solving all the problems and addressing all the recommendations, a second evaluation should be conducted to confirm the improvement against the first prototype, completing a second User → Utility → Usability loop.

A think aloud study ascertains the internal processing conducted by a user while carrying out a task using the user interface. Users are asked to verbalize what they are thinking while interacting with the interface (Haniff and Baber, 2003). There are two different kinds of think aloud studies depending when the method is applied: (a) concurrent: the protocol is performed during the user testing activity; (b) retrospective, the protocol is performed after the user testing session. After a first revised prototype, the application of this method would be beneficial in order to assess usability and utility issues of the application, analyzing user input and talking to them directly. This implies a step forward compared to the first evaluation (cognitive walkthrough), which was conducted online due to the limited accessibility of the users.

6.2 Third Loop

After the second evaluation, another set of revised conceptual functionality and needs could be extracted. Based on this revised conceptual development, a third prototype release could be developed. After the third prototype, a summative survey similar to the formative one performed in this study could be sent out to the users. The differences between the formative and the summative survey would help to analyze the improvement and identify any existing usability or utility gap.

Table 30.- Proposed future work for the Ocean Web Mapping application, showing the subsequent UCD loops.

Web-mapping app success aspect	Robinson et al. (2005) Process	Tsou and Curran (2008) plane	Ocean web mapping application: Interface	Ocean web mapping application: Content
User	Work domain analysis	Strategy	Web mapping application objective. Target user profiles/Use cases Ocean modeller's assessment interview. Competitive analysis. Online survey	
Utility	Conceptual development	Scope	Functional requirements	Data requirements
			System architecture	
Usability	Prototyping	Structure/Skeleton/Surface	Ocean web mapping first prototype	
User	Interaction/Usability study	Evaluation	Cognitive walkthrough/Formative survey	
Utility	Revised Conceptual development	Scope	Revised functional specification	Revised map content requirement
Usability	Implementation	Structure/Skeleton/Surface	Revised prototype	
User	Interaction/Usability study	Evaluation	Think aloud study	
Utility	Revised Conceptual development	Scope	Revised functional specification	Revised map content requirement
Usability	Implementation	Structure/Skeleton/Surface	Revised prototype (alpha release)	
User	Interaction/Usability study	Evaluation	Summative survey	

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Appendix A: Informal Interview Notes

(1) What do ocean modellers do?

Ocean modellers run hydrodynamic numerical models, which solve conservation equations (conservation of momentum, mass, kinetic energy, salinity and temperature) for a particular area of the ocean. Having a model set for a region allows the prediction of the ocean circulation for any point in the model.

(2) What process do they follow to produce an ocean model? (3) What datasets do they need to use in this process?

The first step in running an ocean model implies the definition of what is called **model boundaries**. The basic datasets necessary to set up the model boundaries are the following:

- **Coast lines**: model boundary where the water meets the land.
- **Bathymetry**: bottom model boundary. Coastal topography might also be needed, depending on intertidal surfaces.
- **Open boundaries**: if not modelling the entire globe, the model domain will have an open boundary onto water.

Using these boundaries, a **grid** is generated as the base for the model calculation (for example, a regular grid or an unstructured triangular grid, depending on the ocean model used). In every cell of this grid, the model equations are solved independently. Several processes are needed to solve the equations:

- **Initialize** the model.

- **Force the model boundaries.** For the open boundaries, the sea surface height, temperature, salinity and current data are needed. For the sea surface, weather and atmospheric data are needed.

- Also, additional data is needed for **model validation and calibration**.

(4) From what sources do they get the data?

Ocean mapping data is usually extracted from **existing web resources** or from **surveys** particularly designed to run the ocean model. Weather data is usually extracted from a **weather model**, for example the one provided by environmental Canada.

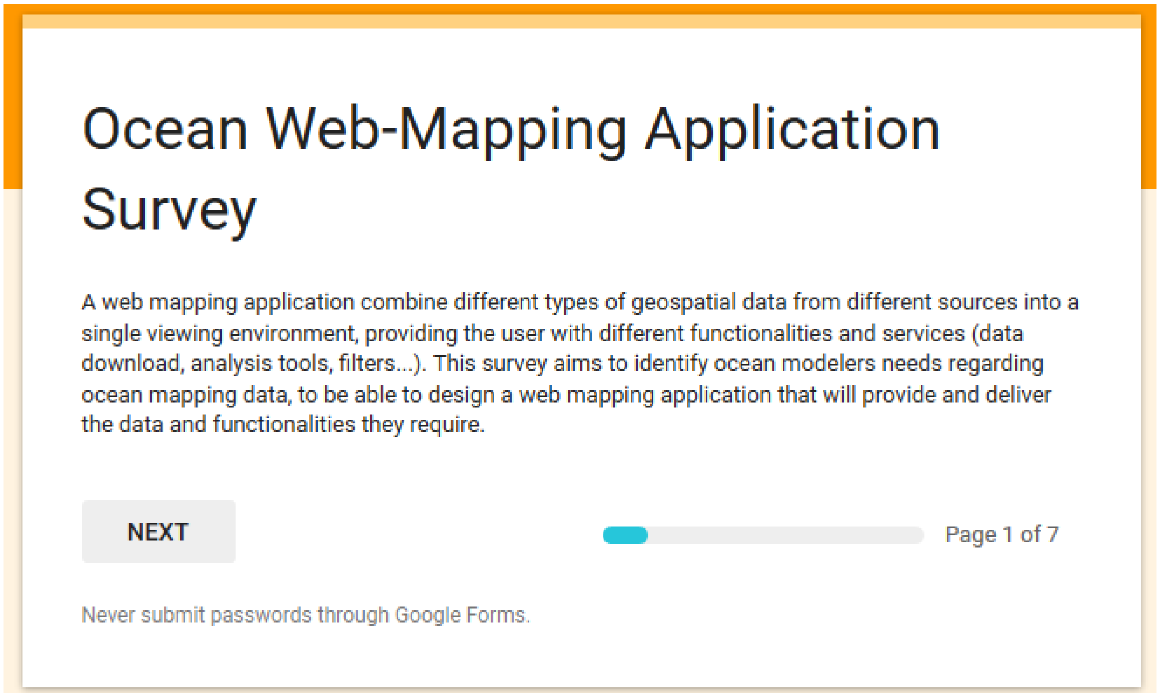
(5) Other important remarks taken from the interview

- The **bathymetry resolution** needed will depend on the size of the grid. If the length of the grid is 23 km, it does not make sense to have a resolution of 1 meter, which will slow down the development of the grid.

- Ocean models are **time dependent**; therefore, the dates/time of the measurements/data are an important variable to consider.

- It might be interesting for an ocean modeller to know the source/lineage from where the data came from (**metadata**).

Appendix B: Online Survey Questions



Ocean Web-Mapping Application Survey

A web mapping application combine different types of geospatial data from different sources into a single viewing environment, providing the user with different functionalities and services (data download, analysis tools, filters...). This survey aims to identify ocean modelers needs regarding ocean mapping data, to be able to design a web mapping application that will provide and deliver the data and functionalities they require.

NEXT

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Never submit passwords through Google Forms.

General information

This section asks for general background information in order to contextualize the users of the survey. No other personal information will be collected during the survey.

What organization or department do you work for?

Your answer

What is your position within your organization?

Your answer

How often do you work with ocean models?

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Yearly
- ◯ Rarely
- ◯ Other:

How often do you use geographic information (maps, spatial data, GIS, web mapping...)

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Yearly
- ◯ Rarely
- ◯ Other: ____________

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Ocean Modelling information

This section asks more specific question about ocean modelling tasks and how the user works with ocean models.

What ocean modelling simulation software do you use?

Your answer

What kind of coordinates does your model work with?

- ☐ Geographic coordinates (latitude/longitude)
- ☐ Geocentric coordinates (X, Y, Z)
- ☐ Projected coordinates (x, y on a plane)

If you work with projected coordinates, what projection/s do you use?

Your answer

How much do you value Free and Open Source software?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very much

What software package/s do you use to generate and modify the model grid?

Your answer

Regarding bathymetry data, when the resolution is greater than the model resolution, what method do you use to resample the data?

- ☐ Average
- ☐ Median
- ☐ Mode
- ☐ Other: ____________

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Data sources

This section is focused on the different data sources an ocean modeler could gather data from to run an ocean model.

How much do you value having data in open formats?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very much

What data sources do you usually get the data from to run an ocean model?

- ☐ Data provided by government organizations through online web portals (open data)
- ☐ Data provided by the goverment under purchase
- ☐ Data provided by University research through online web portals
- ☐ Data provided by University research through private transfer
- ☐ Data provided by industry
- ☐ Public weather models
- ☐ Private weather models
- ☐ Any other kind of private transfer
- ☐ Any other kind of open data
- ☐ Other:

Could you provide an example of a website that you use to obtain data

Your answer

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Ocean Web Mapping Application Data Layers

This section is focused on the actual web mapping application. It will help to determine what kind of data ocean modelers seek for when running an ocean model.

On a scale of 1 to 5, 1 being not useful and 5 being very useful, please rate the usefulness of the following overlay layers for an Ocean Web Mapping Application for Ocean Modelers

	1	2	3	4	5
Weather data	○	○	○	○	○
Tidal data	○	○	○	○	○
Currents data	○	○	○	○	○
Buoy data	○	○	○	○	○
Bathymetry	○	○	○	○	○
Coast Lines	○	○	○	○	○
Sea Temperature data	○	○	○	○	○
Sea Salinity data	○	○	○	○	○
CTD data	○	○	○	○	○
ADCP data	○	○	○	○	○
Water level data	○	○	○	○	○
River discharge data	○	○	○	○	○

Could you think of any other useful overlay data?

Your answer

On a scale of 1 to 5, 1 being not useful and 5 being very useful, please rate the usefulness of the following basemaps for an Ocean Web Mapping Application for Ocean Modelers

	1	2	3	4	5
Satellite Image	○	○	○	○	○
Street Map	○	○	○	○	○
Nautical Chart	○	○	○	○	○
Ocean Basemap	○	○	○	○	○
Hybrid Map/Image	○	○	○	○	○
Topographic/Terrain	○	○	○	○	○

Could you think of any other useful basemap?

Your answer

On a scale of 1 to 5, 1 being not useful and 5 being very useful, please rate the usefulness of the following information for an Ocean Web Mapping Application for Ocean Modelers

	1	2	3	4	5
Uncertainty information	○	○	○	○	○
Bathymetry resolution	○	○	○	○	○
Time information (surveys/data)	○	○	○	○	○
Metadata	○	○	○	○	○

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Ocean Web Mapping Application Functionalities

This section is focused on the actual web mapping application. It will help to determine what kind of services and functionalities an ocean modeler could benefit from when using the web mapping application.

On a scale of 1 to 5, 1 being not useful and 5 being very useful, please rate the usefulness of the following functionalities for an Ocean Web Mapping Application for Ocean Modelers

	1	2	3	4	5
Search tool (survey year, survey name, places...)	○	○	○	○	○
Filter tool (survey year/time/resolution /uncertainty)	○	○	○	○	○
User profiles (being able to be identified and store preferences in the web application)	○	○	○	○	○
Retrieve coordinates of a point after click	○	○	○	○	○
Retrieve depth of a point after click	○	○	○	○	○
Create an Area of Interest to work on (available data will be only displayed in the AOI)	○	○	○	○	○
Data download	○	○	○	○	○
Visualization of the resolution of the bathymetry data	○	○	○	○	○
Visualization of the uncertainty of the data	○	○	○	○	○
Retrieval of uncertainty data	○	○	○	○	○
Time slider to dynamically filter data by date/time/year	○	○	○	○	○

Being able to select the bathymetry resolution using a slider	○	○	○	○	○
See/retrieve metadata information	○	○	○	○	○
Measuring tools (distance, area)	○	○	○	○	○
Measuring tools (volume)	○	○	○	○	○
Depth profile tool	○	○	○	○	○
Export Depth profile tool	○	○	○	○	○
Salinity/temperature profile tools	○	○	○	○	○
Annotate the map (georeferenced notes)	○	○	○	○	○
Export/save/print the map view	○	○	○	○	○
Draw own points/lines /polygons on the map	○	○	○	○	○
Store/download own drawings as vector files	○	○	○	○	○
Change the map projection (artic/mercator /antartic)	○	○	○	○	○
Adding additional user data to the map (through web services)	○	○	○	○	○
Adding additional user data to the map (through own data files)	○	○	○	○	○

Could you think of any other useful functionality that you would like to have on a web mapping application?

Your answer

Which formats would you prefer when downloading bathymetry data?

- [ ] BAG Surface
- [ ] NetCDF
- [ ] GeoTIFF
- [ ] XYZ ASCII (point coordinates and depth)
- [ ] Other:

Which formats would you prefer when downloading vector data?

- [ ] GML
- [ ] KML
- [ ] Shapefile (shp)
- [ ] Geojson
- [ ] csv (comma separated values)
- [ ] Other:

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Ocean Web-Mapping Application Survey

Thank you very much for taking the time to fill up the survey, we really appreciate your participation. You made research possible!

Any other comments/suggestions for a Web Mapping Application for Ocean Modelers?

Your answer

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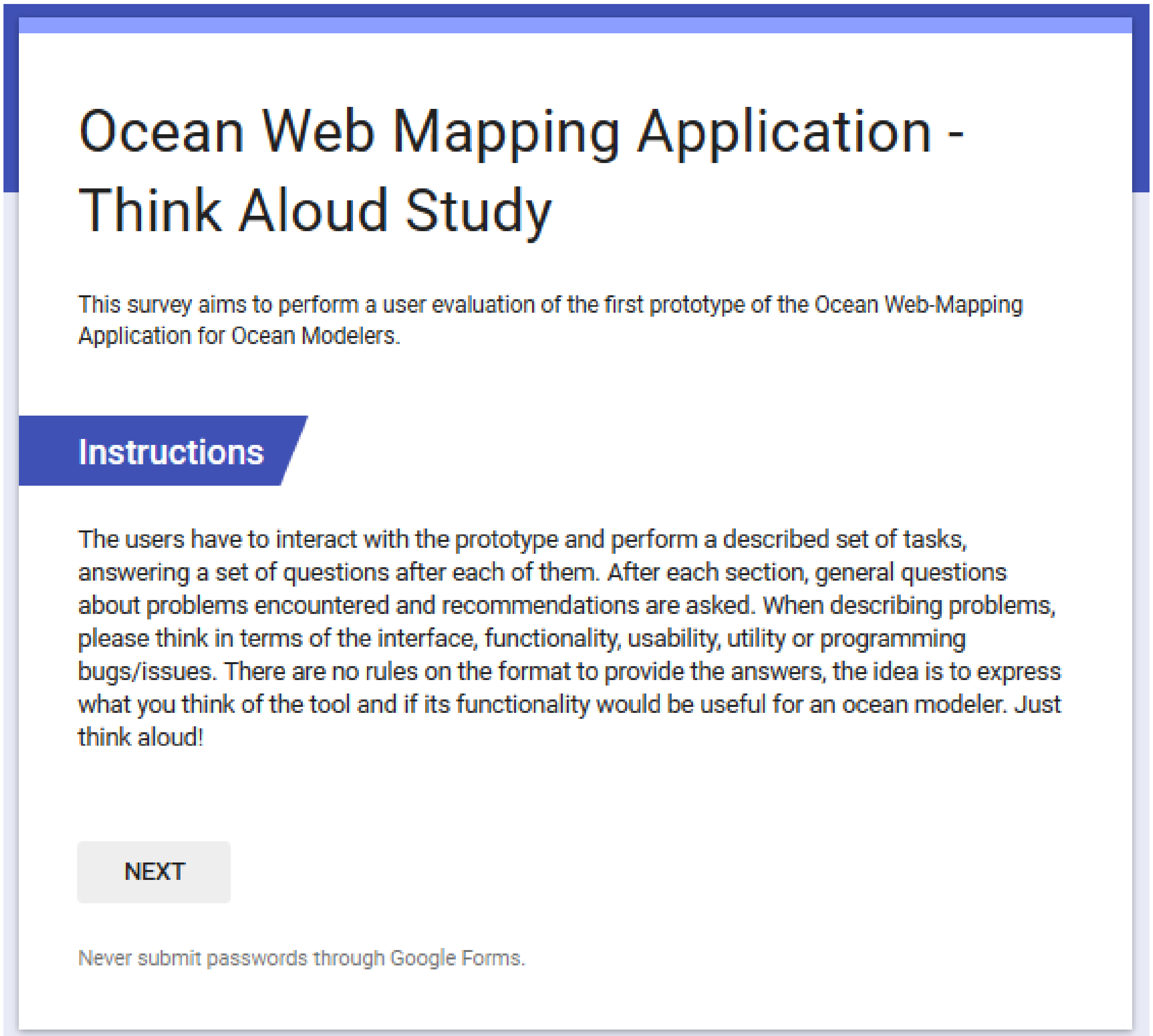
Appendix C: Evaluation Survey Questions



Ocean Web Mapping Application - Think Aloud Study

This survey aims to perform a user evaluation of the first prototype of the Ocean Web-Mapping Application for Ocean Modelers.

Instructions

The users have to interact with the prototype and perform a described set of tasks, answering a set of questions after each of them. After each section, general questions about problems encountered and recommendations are asked. When describing problems, please think in terms of the interface, functionality, usability, utility or programming bugs/issues. There are no rules on the format to provide the answers, the idea is to express what you think of the tool and if its functionality would be useful for an ocean modeler. Just think aloud!

NEXT

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General tasks

Task#1

Open the application and select the area of interest of the Lower Saint John River, marked on the map with an orange rectangle.

What do you think of this functionality? Do you think it would be useful for an ocean modeler?

Your answer

Task#2

Once the map is loaded, interact with it and change the basemap to the different ones provided

What do you think of this functionality? Do you think the basemaps are useful for an ocean modeler?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Bathymetry Data

Task#3

Access the bathymetry data and retrieve the information of any survey made in 2008.

What do you think of the time filter functionality for the surveys?

Your answer

Task#4

Select a small bathymetry area and compute the statistics for that area.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Task#5

Select a small bathymetry area (it could be the same) and retrieve the bathymetry at 5m resolution, bilinear interpolation method, in ascii format.

Task#6

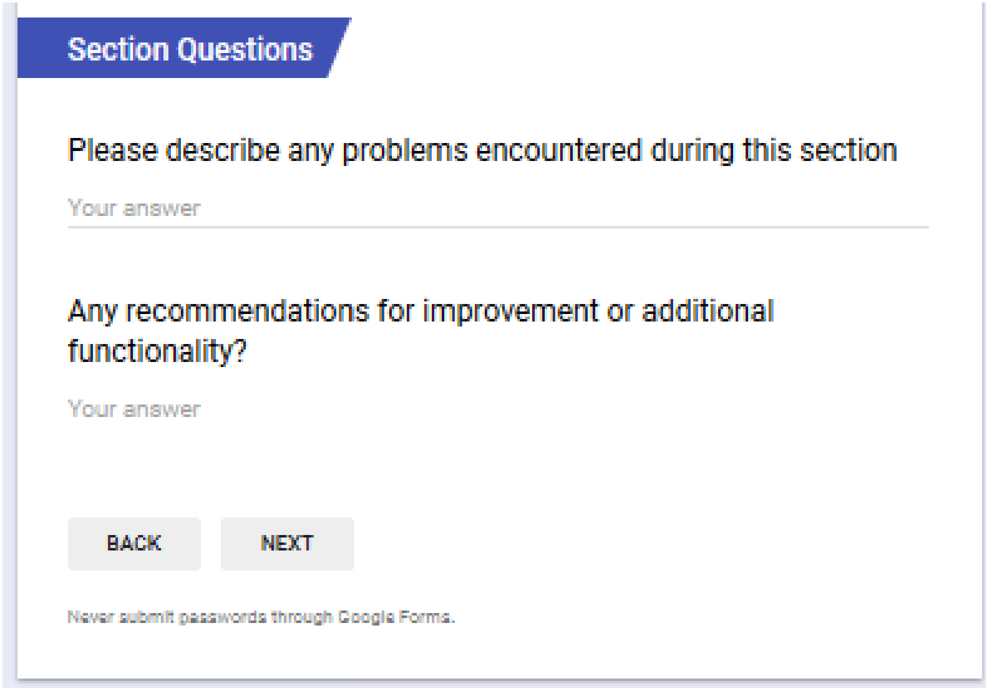
Do the same for the uncertainty at 1m resolution, cubic interpolation method, in netcdf format.

What do you think of the options given for downloading bathymetry data? Can you think of any other variable you would like to include when downloading bathymetry data?

Your answer

Do you think the inclusion of uncertainty would be useful for ocean modelers?

Your answer



Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Temperature, Salinity and Sound Speed Data

Task#8

Access the temperature and salinity data and look at the data available for 2008.

Task#9

Load the data for April 30th 2008 on the map.

What do you think of the time filter functionality?

Your answer

Task#10

Select a point and generate the vertical profile. Download the temperature profile in png.

What do you think of this functionality? Would it be useful for ocean modelers?

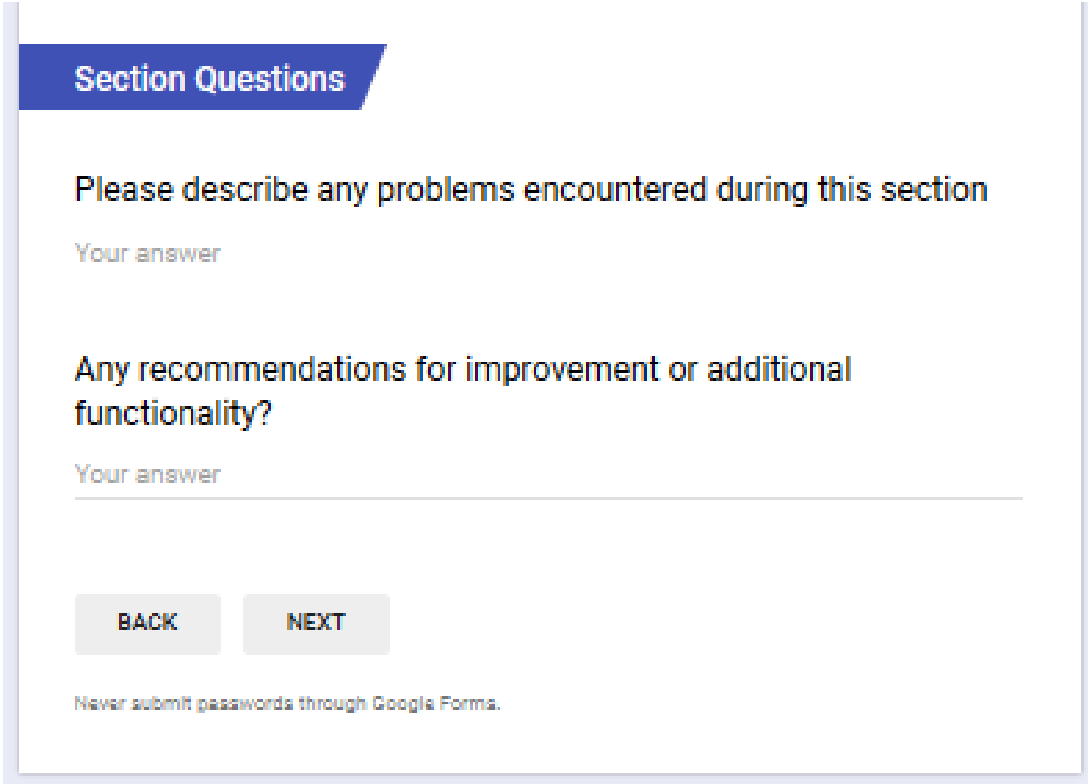
Your answer

Task#11

Select an area on the map to download (it should include more than one point) and download the csv file.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer


Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Hydrometric Data

Task#12

Select the SAINT JOHN RIVER Station (next to the reversing falls) and explore the real time and historical data functionalities.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Weather Data

Task#13

Select the weather Station at the Saint John Airport (Saint John A) and retrieve the temperature, wind speed and wind direction for the period of November 7th 2017 at 5:45PM to November 21st at 8:15PM at 2017.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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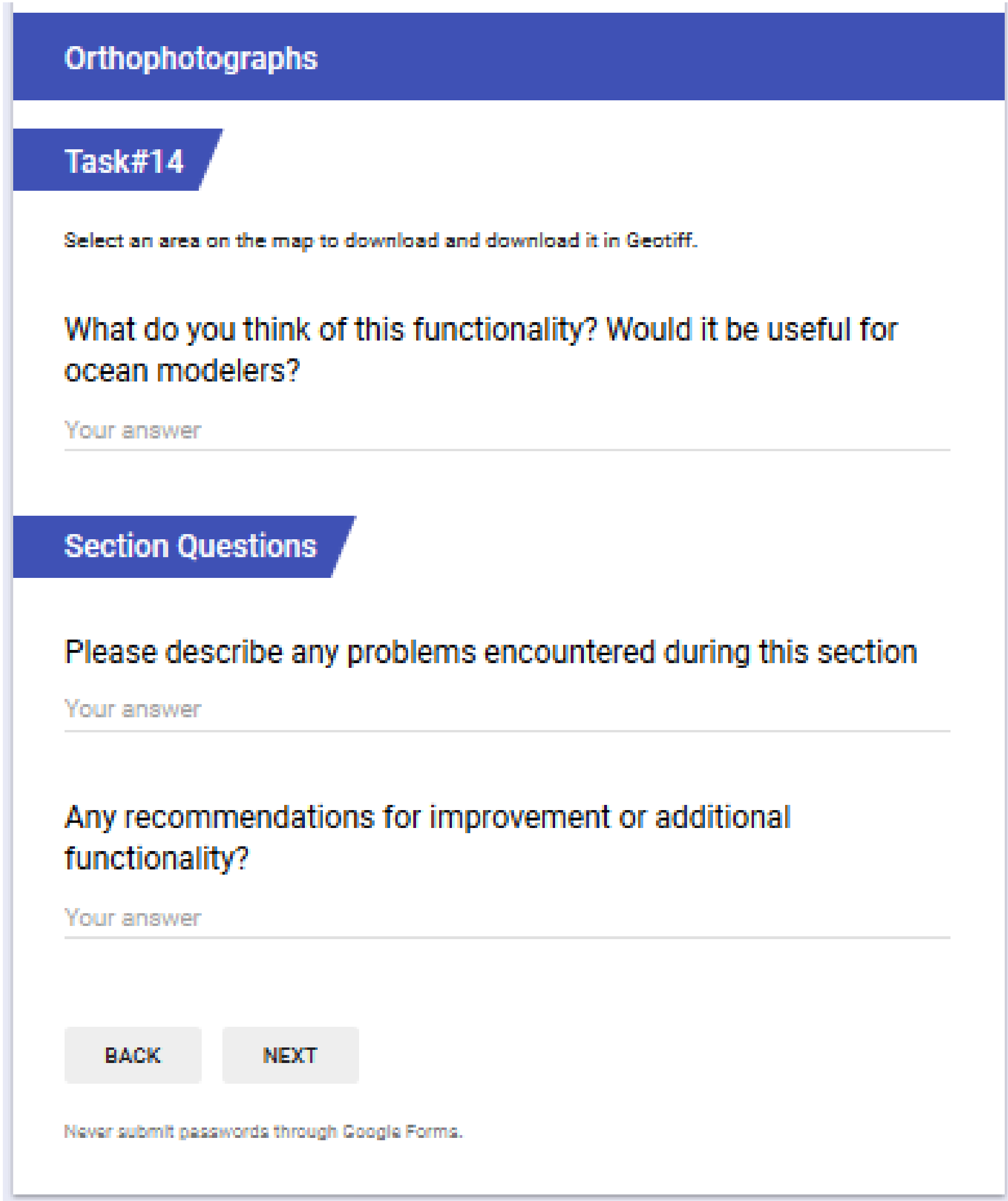

Orthophotographs

Task#14

Select an area on the map to download and download it in Geotiff.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Buoy Data

Task#15

Access the data for the buoy next to the Saint John river.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Coast Lines

Task#16

Download the coast lines data in KML.

What do you think of this functionality? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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Other tools

Task#17

Create a new measurement for a particular area.

Task#18

Print a map on portrait mode showing the Saint John harbor.

Task#19

Create a marker and add a note on a point on the map.

Task#20

Change the area of interest

What do you think of these functionalities? Would it be useful for ocean modelers?

Your answer

Section Questions

Please describe any problems encountered during this section

Your answer

Any recommendations for improvement or additional functionality?

Your answer

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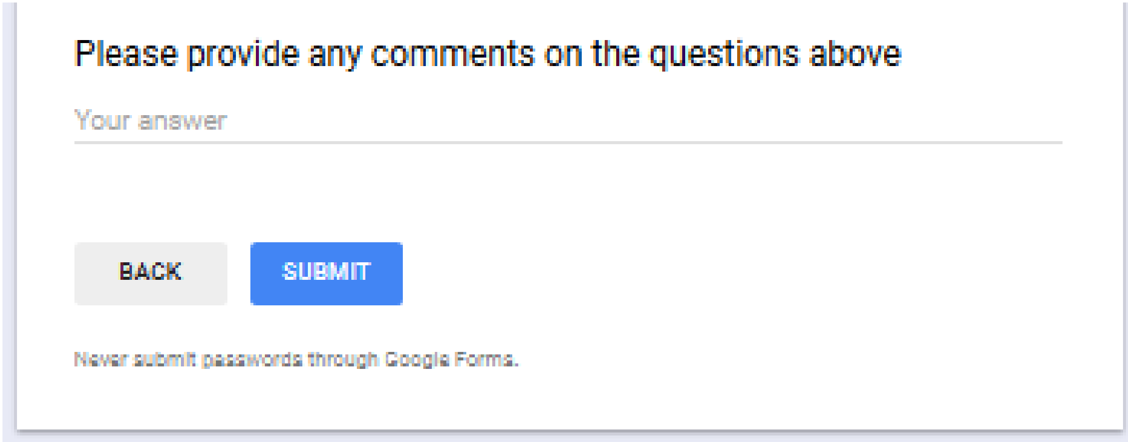
Overall questions

On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, please rate the following statements

	1	2	3	4	5
I think (as an Ocean modeler) that I would use this application frequently	○	○	○	○	○
The application would support the type of work that I usually do	○	○	○	○	○
The application is a novel approach to download and interact with ocean mapping data	○	○	○	○	○
I have access to other web applications that provides the same functionality implemented in this application	○	○	○	○	○
The application provide all the necessary functions for ocean modelers when retrieving ocean mapping data	○	○	○	○	○
The application was easy to use	○	○	○	○	○
I think I would need a tutorial to be able to use the application	○	○	○	○	○
I think most ocean modelers would learn to use the application quickly	○	○	○	○	○
I like the visual design of the interface	○	○	○	○	○


Please provide any comments on the questions above

Your answer

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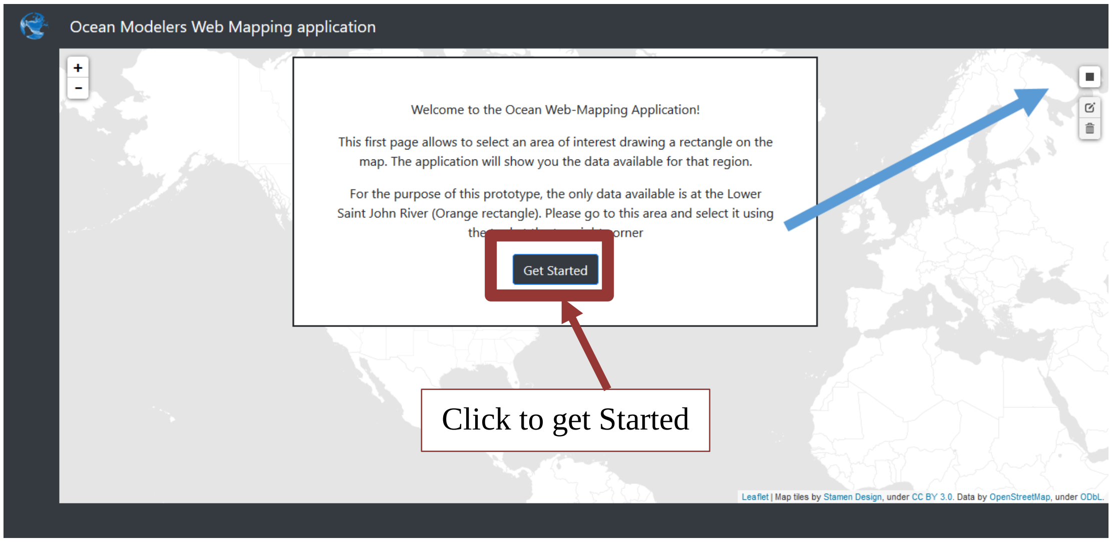
Appendix D: User Manual

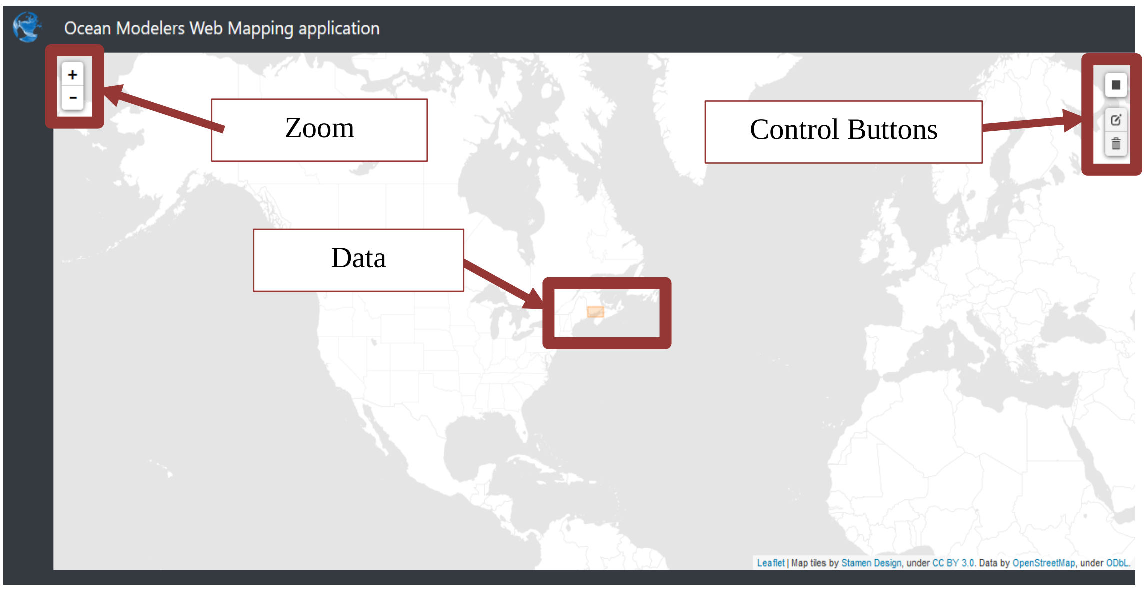
Accessing the site

Once the web page is loaded, a welcome page is presented to the user. To access the site, please click the access site button.

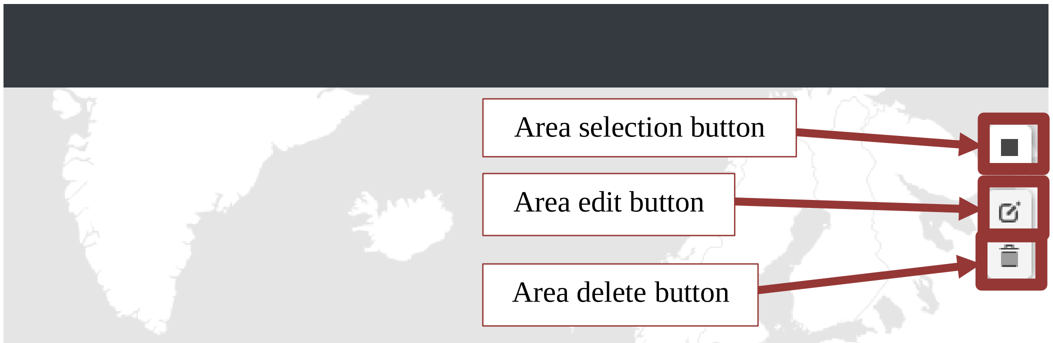
After clicking this button, a new page will appear, showing a map and a welcome message to the user, indicating the instructions to get started and select the area of interest.



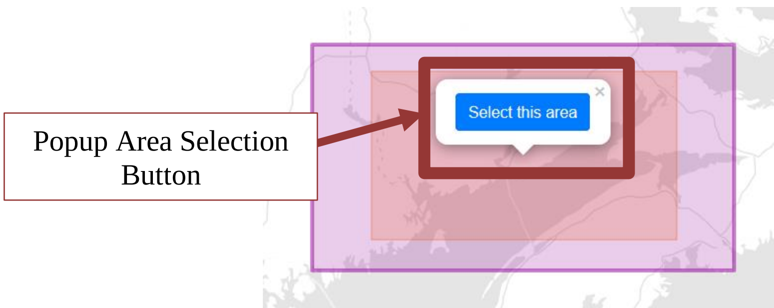
Clicking on the Get Started button, the popup window disappears, and the user can explore the data available on the site (shown by orange rectangles). In this map view, the basic zoom controls for the map are situated at the upper left corner, and the tool control buttons situated at the upper right corner. Hovering over the orange rectangles, the name of the area will be shown.



There are three map control buttons: Area selection button, Area edit button and Area delete button. To select the area of interest, the user needs to click Area selection button, represented on the map by a rectangle image button. The drawing mode is activated (mouse changes to a cross), and the user can click on the map to start drawing (inserting upper left corner) and click again to finish the drawing (inserting bottom right corner). After creating an area to select, the user can edit it or delete it using the other two buttons.



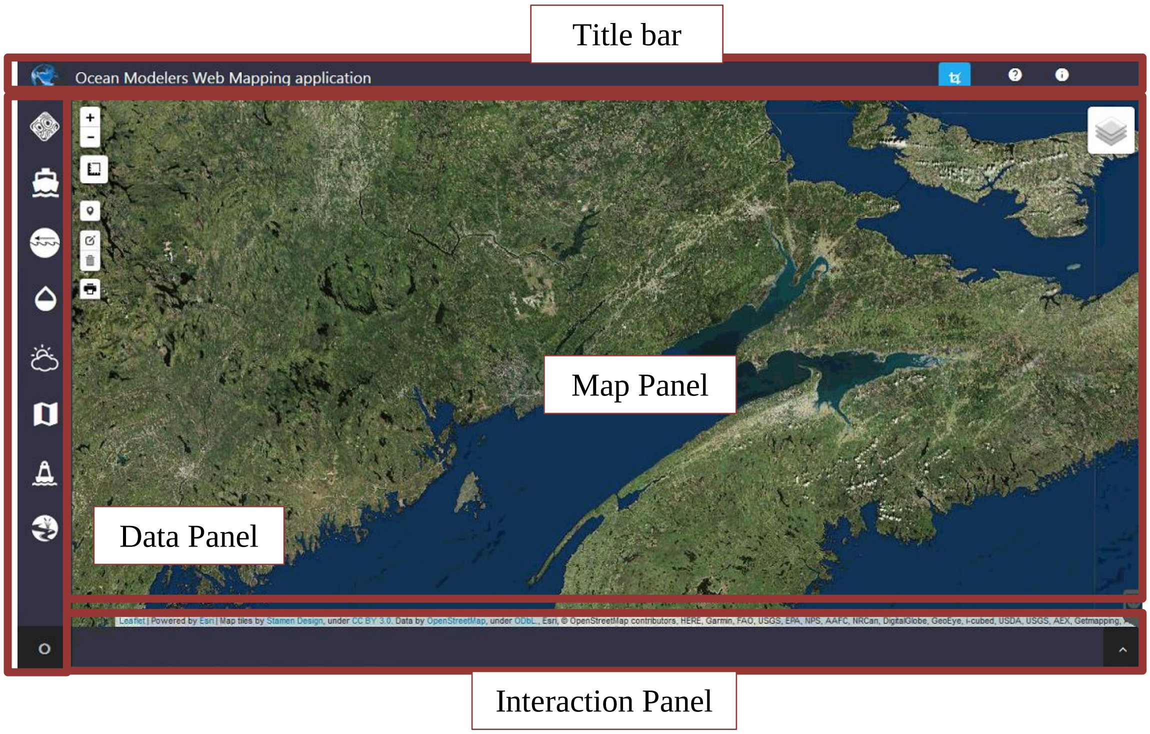
After drawing the rectangle for the desired area, a pop up window will be shown with a button to select this area. This allows the user to modify their selection if desired.



After clicking the popup area selection button, the application will show the web application main page, centered in the area of interest selected by the user.

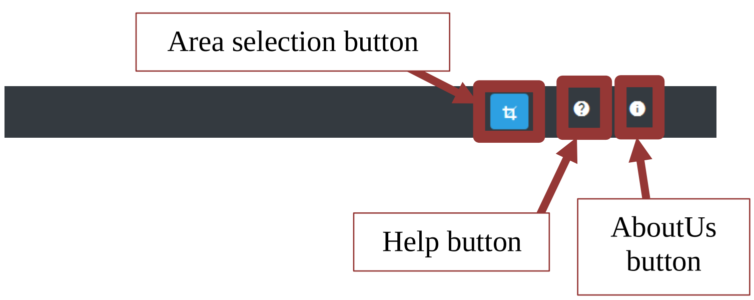
Main Page description

The main page allows to access the data that is available in the platform, and it is divided in a title bar and three main Panels: Map Panel, Data panel and Interaction Panel.



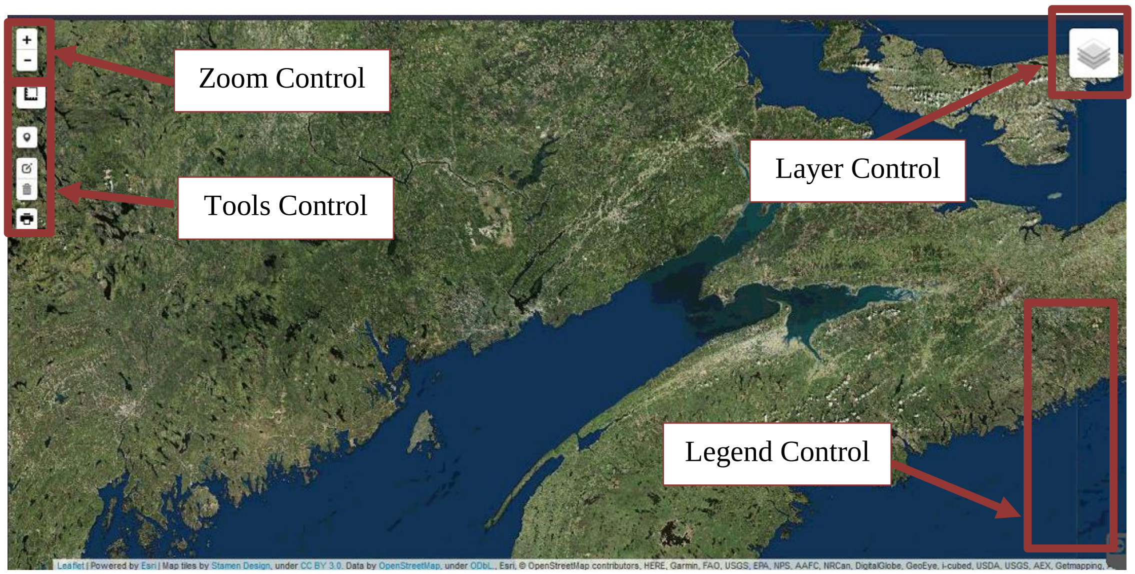
Title bar

The title bar includes the logo and title of the app, and three simple functions: select the map area again, help (tutorial) and about. To select the area again, click on the button and it will take the user to the previous select area page. The help and about button redirect to the tutorial and the Ocean Mapping Group page respectively.



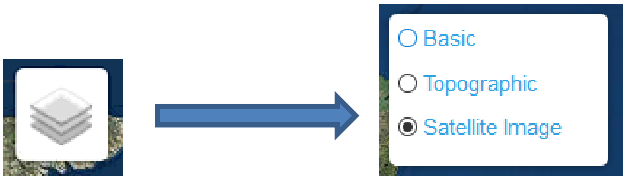
Map view

The map view is the interface where all the data will be loaded. It includes the following controls:

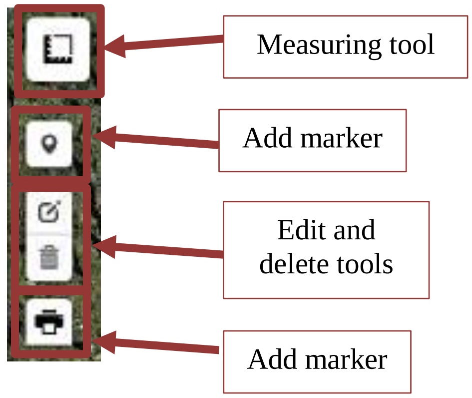


– Basic zoom controls: it allows to zoom in and zoom out the map.

– Layer control: to change between basemaps and turn on/off overlay layers.



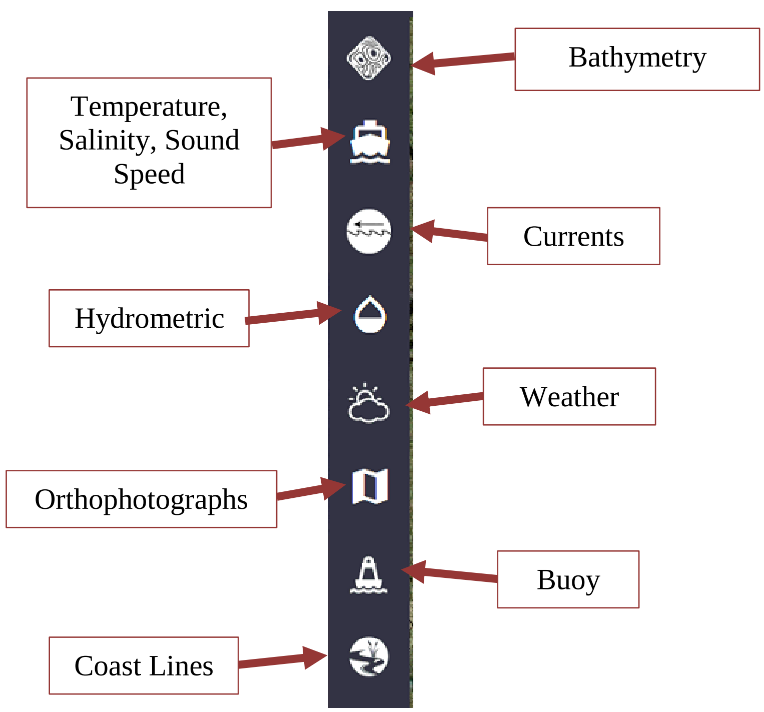
– Tools control: it includes the following: measuring tools, adding markers, editing and deleting tools, and printing tools.



– Legend control: it will change depending on which data is load on the map.

Data Panel

The Data Panel provides the controls to load the different datasets on the map: Bathymetry, Temperature, Salinity and Sound Speed, Water Velocity (currents), Weather, Hydrometric data, Buoys and Coast lines. Only one data set can be loaded at a time. Each data is represented by a characteristic icon.

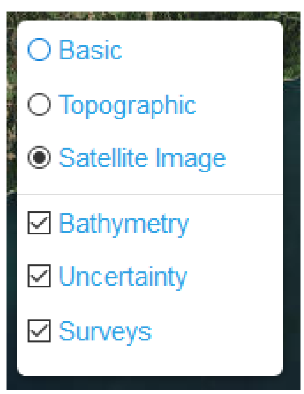


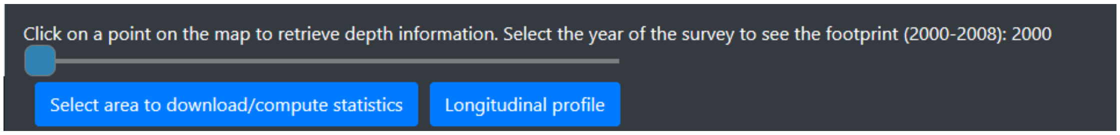
Interaction Panel

The interaction panel will be opened every time a dataset is loaded on the map, changing the options depending on the data layer. Therefore, it will provide with the specific tools for each layer (download data, plots, profiles, time filter/search…).

Bathymetry data

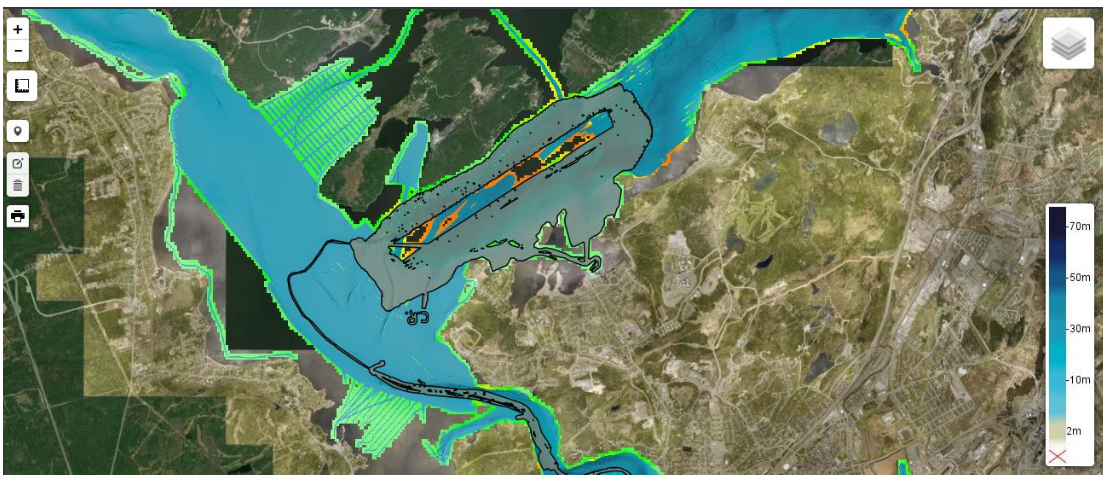
Bathymetry is loaded on the map clicking on the correspondent icon in the Data panel. This action will open the interaction panel, which will show the function controls for the Bathymetry data: time filter, select area to download or compute statistics, calculate a longitudinal profile. Bathymetry data consists of three kinds of data: Bathymetry (depths), Uncertainty (uncertainty associated to each depth measurement) and surveys (survey footprints for each year). These layers can be turned on and off in the layer control. Also, when bathymetry is activated, the legend will be shown in the legend control.

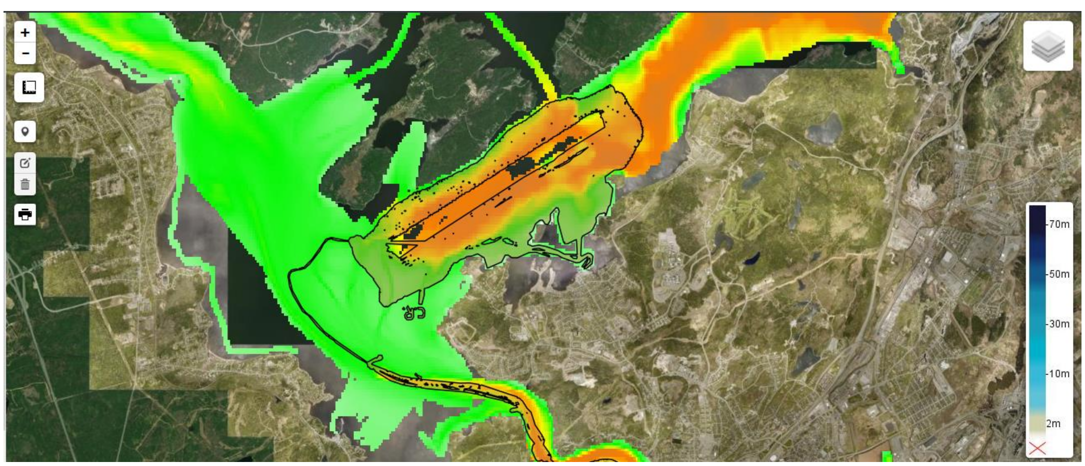




Visualize bathymetry data

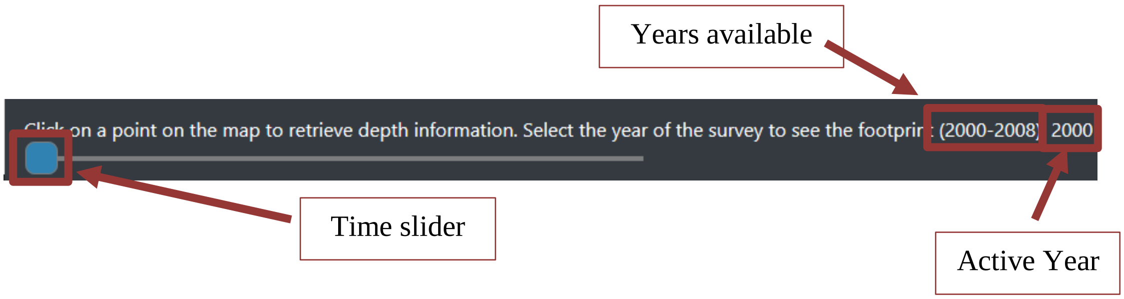
Once activated, the user can navigate the map to visualize the bathymetry, uncertainty and survey data. The bathymetry is represented as a blue color ramp colored by depth, the uncertainty is a color ramp by uncertainty values and each survey polygon is colored by a different color in order to distinguish them.

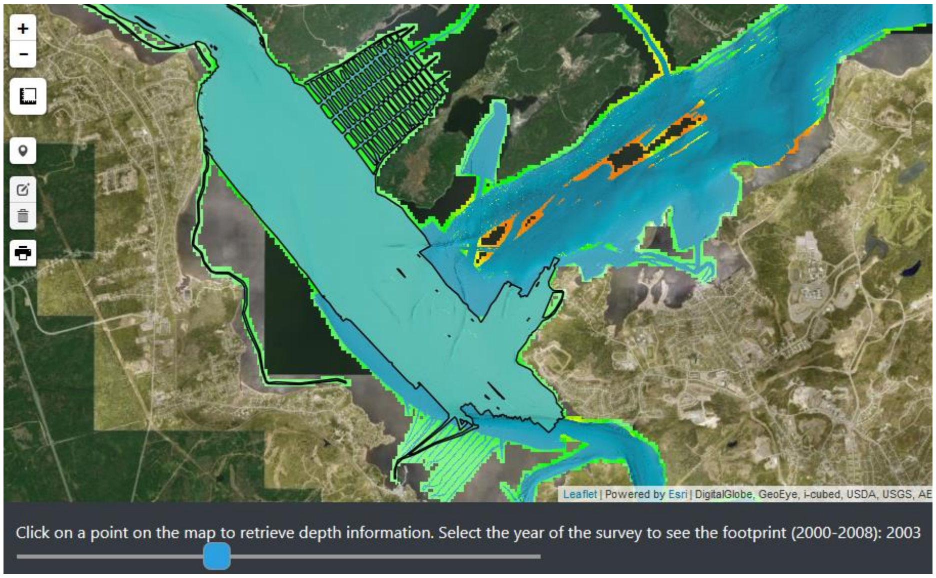


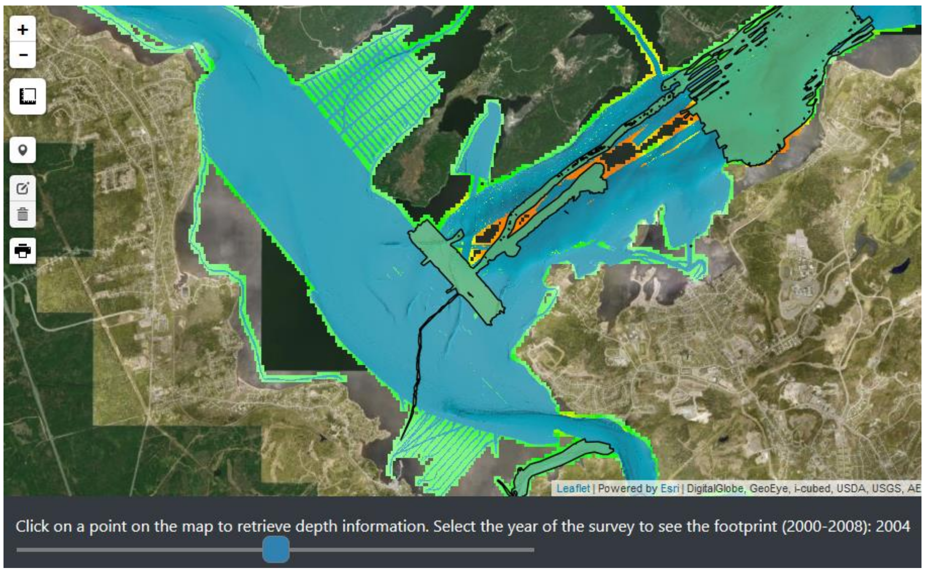


Time Filter

The time filter functionality for the bathymetry data allows to change the year of the surveys displayed on the map. It consists of a time slider which the user can interact with. Sliding left and right will change the year on the map display.





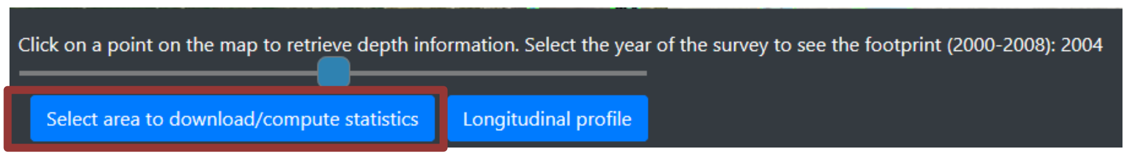


Query coordinates and metadata

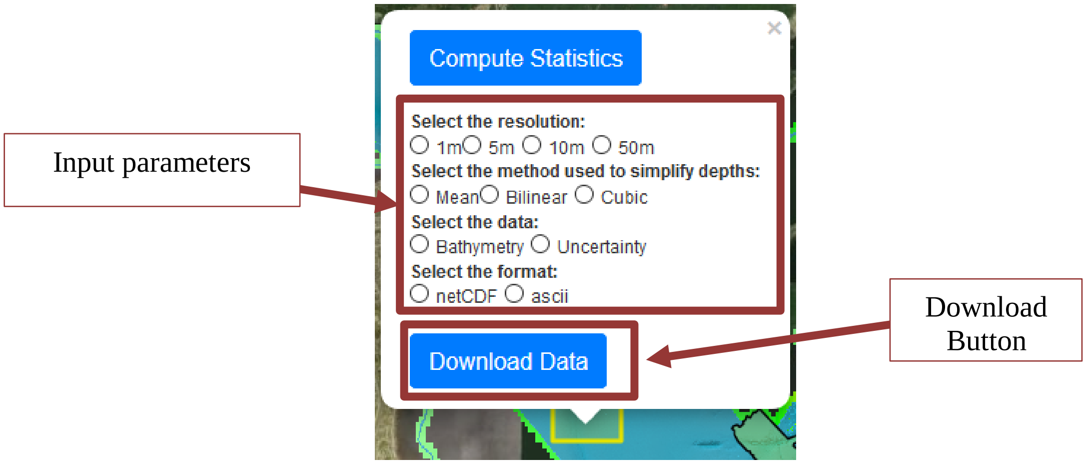
In order to query coordinates on the map (latitude, longitude and depth) and access the metadata of each survey, the user needs to click on the bathymetry layer. Once clicked, a pop up window will be shown, including the coordinates, information about the survey and a link to the metadata.

Download data

To download data, the "Select area to download/compute statistics" button needs to be clicked.

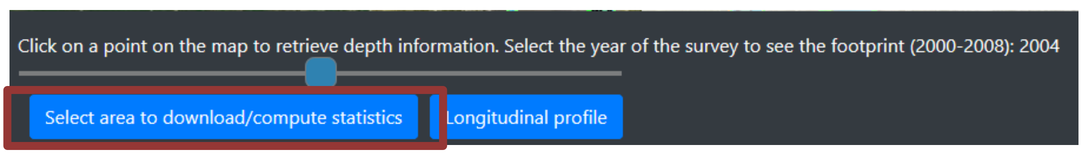


After clicking the button, the drawing tool is activated and the user can draw a rectangle on the map (first click for the upper left corner and last click for bottom right corner). After the area is drawn, a popup window appears, showing all the different parameters that the user can select regarding bathymetry data: resolution, resampling method, data (bathymetry or uncertainty) and format (NetCDF or ASCII). After selecting the parameters, the user needs to click on the download button, which will retrieve the data in the desired format.

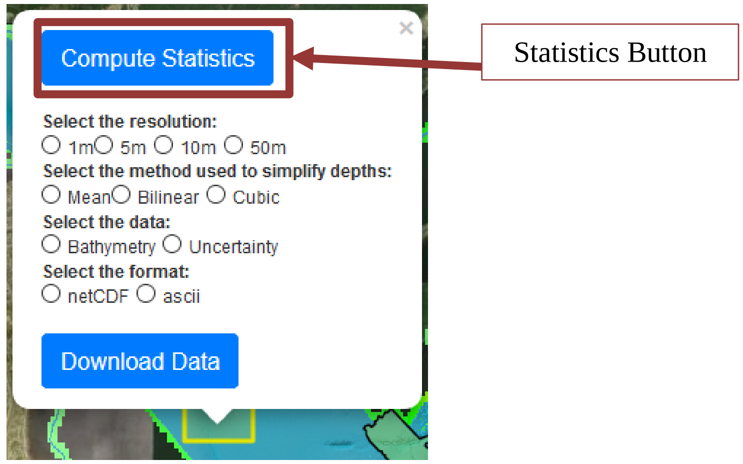


Compute Statistics

To compute the statistics for a bathymetry area, the "Select area to download/compute statistics" button needs to be clicked.



After clicking the button, the drawing tool is activated and the user can draw a rectangle on the map (first click for the upper left corner and last click for bottom right corner). After the area is drawn, a popup window appears, showing a button to compute the statistics. After clicking this button, the statistics are computed and showed in a new window.



Area covered:

POLYGON((-66.17322921752931 45.308337942
45.30833794299046))

Total number of Depths: 410262

Maximum depth: -5.89499998093

Minimum depth: -12.3109540939

Average depth: -9.0193332067

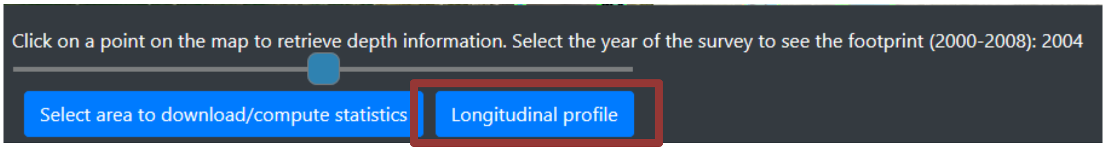
Standard deviation: 0.977552735684

The results show the following outputs:

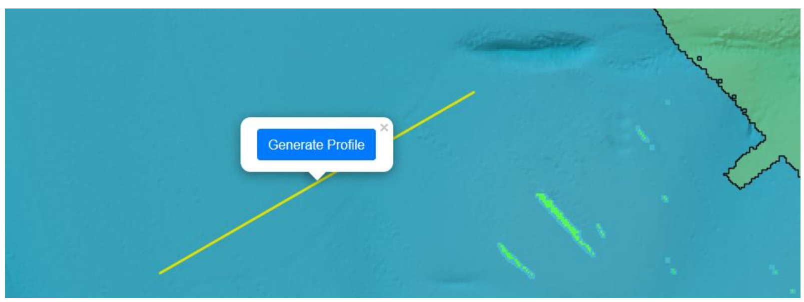
- Area covered: the coordinates for the area that the user selected (in WKT format).
- Total number of Depths: total number of depths in the area, which were used to compute the statistics.
- Maximum depth: the shallowest depth on the area.
- Minimum depth: the deepest depth on the area.
- Average depth: the average depth of the area.
- Standard deviation: the standard deviation of the area.

Calculate Longitudinal Profile

To calculate a longitudinal profile for an input line, the "Longitudinal Profile" button needs to be clicked.



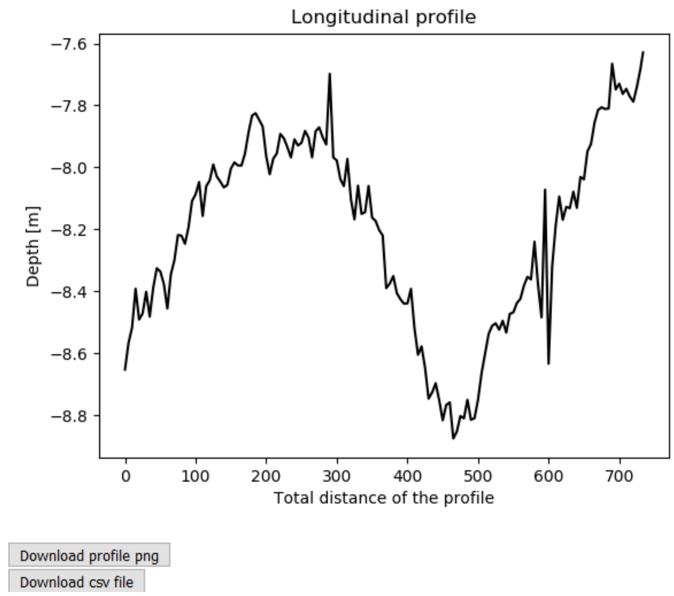
After clicking the button, the drawing tool is activated and the user can draw a two points line on the map (first click for the first point and last click for second point that will close the drawing tool). After the line is drawn, a popup window appears, showing a button to Generate the profile. After clicking this button, the profile is calculated and showed in a new window.



Total length of the profile: 733.734913011

Starting point: [-66.1644744873047, 45.303961469764886]

Ending point: [-66.15636348724367, 45.307251464813774]

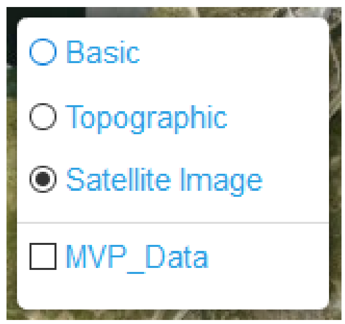


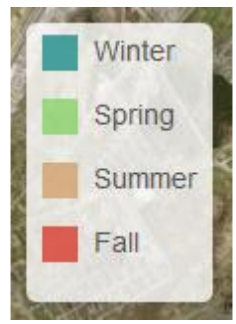
The results show the following outputs:

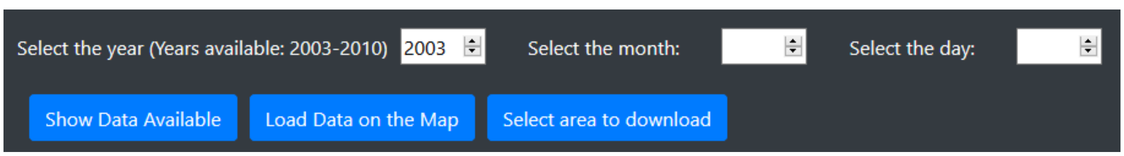
- Total length of the profile: the total length of the inputted line in meters.
- Starting point: the coordinates for the first point of the profile.
- Ending point: the coordinates for the last point of the profile.
- Longitudinal profile plot: an image showing the profile calculated.
- Button to download profile in PNG format: clicking this button the profile will be downloaded as an image.
- Button to download profile in csv format: clicking this button the profile will be downloaded as a csv file, including the point number, latitude, longitude and depth.

Temperature, Salinity and Sound Speed data

Temperature (T), Salinity (S) and Sound Speed (SS) data is loaded on the map clicking on the correspondent icon in the Data panel. This action will open the interaction panel, which will show the function controls for this data: time filter/Search, show data available, Load data on the map and select an area to download. The T/S/SS layer can be turned on and off in the layer control. Also, when the layer is activated, the legend will be shown in the legend control.

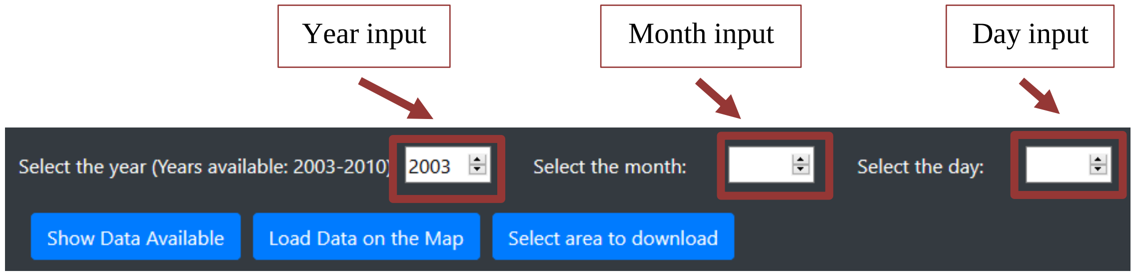






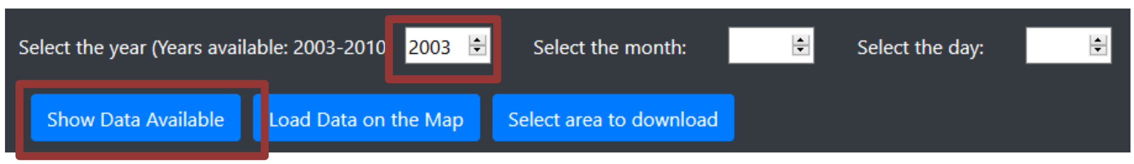
Time Filter/Search

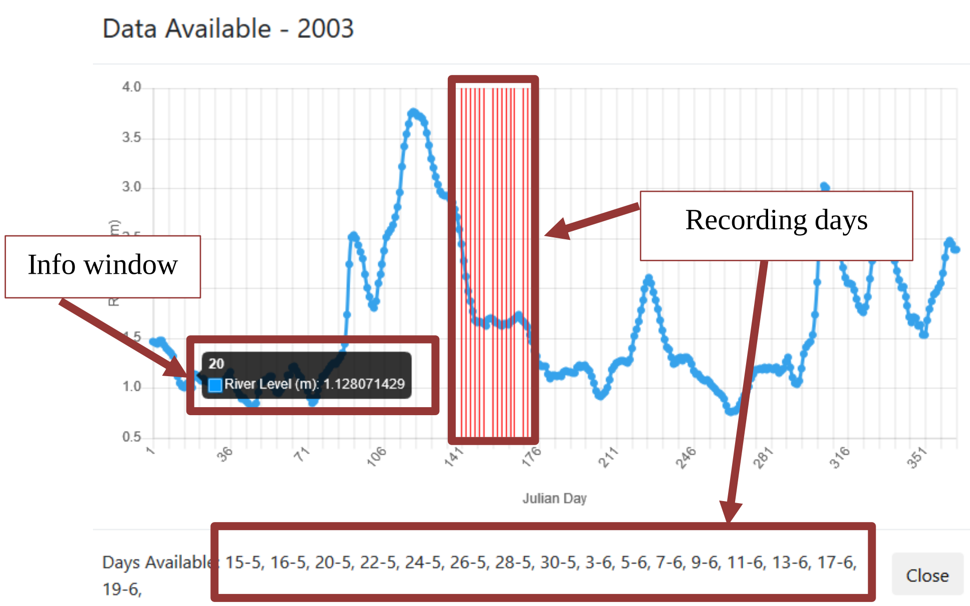
The time filter functionality for the T/S/SS data allows to show the data available for a particular year, and to load data on the map for a particular time period (year, month and day). It consists of three inputs: year input, month and day input.



Show data Available

This functionality allows to show the T/S/SS data available for a year. After the year is inputted in the year input box, clicking on the data available button will popup a graph showing all the data recorded that year.

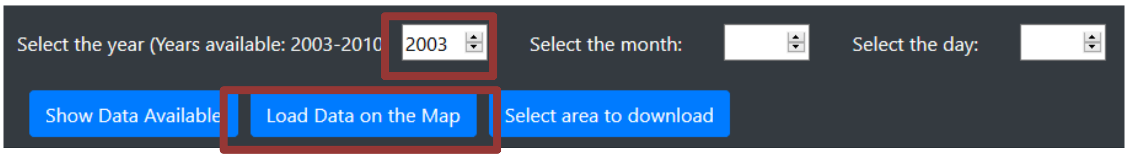




The graph shows river levels for each day of the year, represented as a blue line; as well as recording days plotted as vertical red lines. At the bottom of the graph, the days available are presented as a Day-Month format (so the user can take the day and month and show the data on the map). Hovering over the river levels, an info window will show the river level and day of the year.

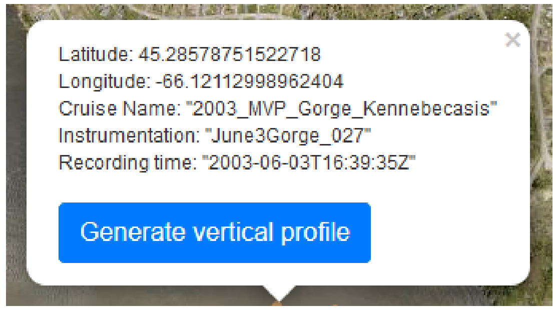
Visualize data on the map

To visualize the data on the map, a time period needs to be selected. The data can be loaded for a whole year (only filling the year input box), for a month (filling year and month box) and for a specific day (filling the three input boxes).



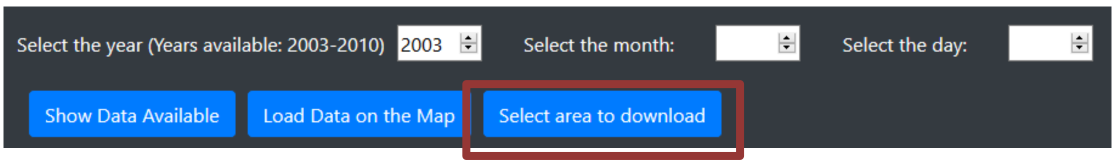
Once the Load Data on Map button is clicked, the data can be visualized on the map. The data is represented as points colored by the season they were recorded in.

Clicking on a point on the map, information about point coordinates, time, and the survey the data was recorded.

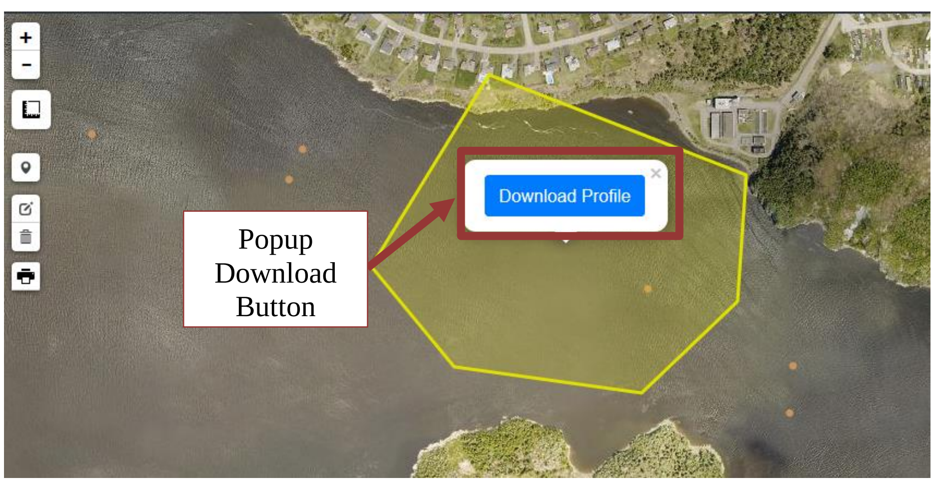


Select an area to download

To download data, the "Select area to download" button needs to be clicked.



After clicking the button, the drawing tool is activated and the user can draw a polygon on the map (clicking consecutive points and clicking on the first point to finish the drawing). After the area is drawn, a popup window appears showing a download profiles button. After clicking on the button, the user receives the data in a csv format, showing the coordinates for each selected point (as a header) and the Temperature, Salinity, Sound Speed values for each Depth.

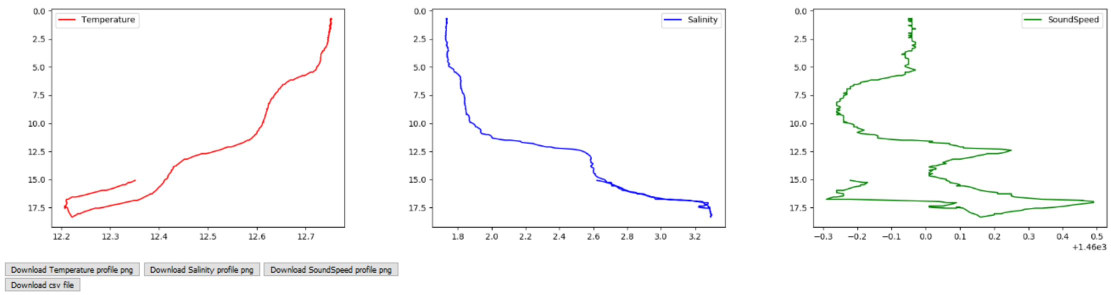


Calculate Vertical profile

To calculate a vertical profile, the T/S/SS data must be loaded to the map first and then a point must be selected. In the popup window that appears after selecting a point, there will be a Generate Vertical Profile button.

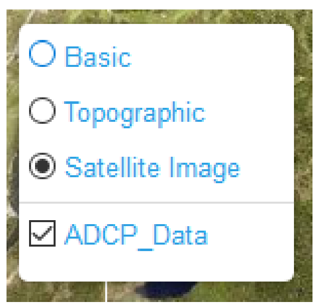
Clicking on this button opens a new window where the vertical profiles for the selected points are generated. The results show the following outputs:

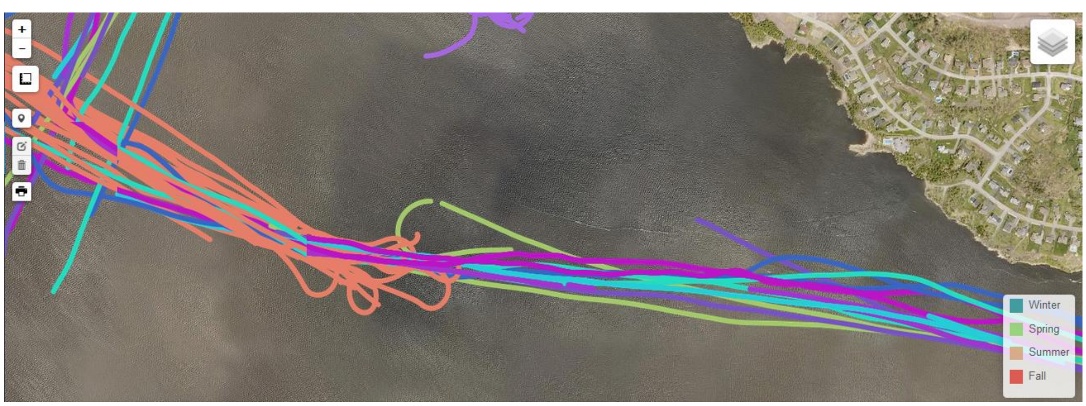
- Vertical profile red plot representing temperature over Depth.
- Vertical profile blue plot representing salinity over Depth.
- Vertical profile green plot representing sound speed over Depth.
- One Button to download each profile in PNG format: clicking this button each profile will be downloaded as an image.
- Button to download profile in csv format: clicking this button the profile will be downloaded as a csv file, including a header (cruise, station, lon, lat, timestamp, bottomDepth) and the data as Depth, Temperature, Salinity, Sound Speed.



Current data

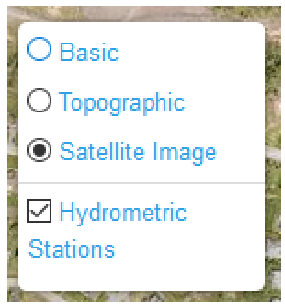
Current data has the same format and functionalities than Temperature, Salinity and Sound Speed data. Please refer to this section for further details. At the moment of writing this tutorial, the data download functionality is not available yet, neither profiles generation.

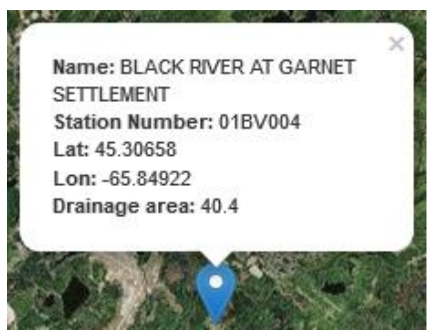


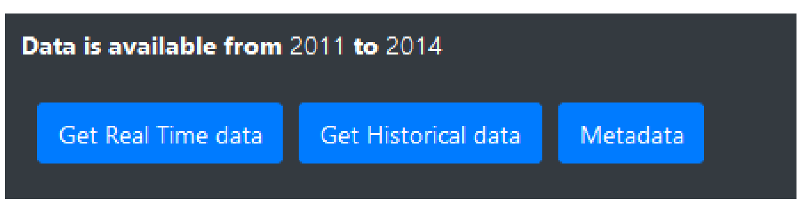


Hydrometric Data

Hydrometric data is loaded on the map clicking on the correspondent icon in the Data panel. The data are hydrometric stations represented as blue markers on the map. Clicking on a station will open a popup window with the station information, as well as the interaction panel, showing the year range the data is available, and the function controls for the station: Get real time data, Get historical data and access the metadata.



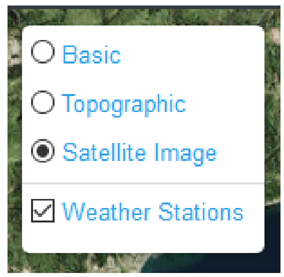


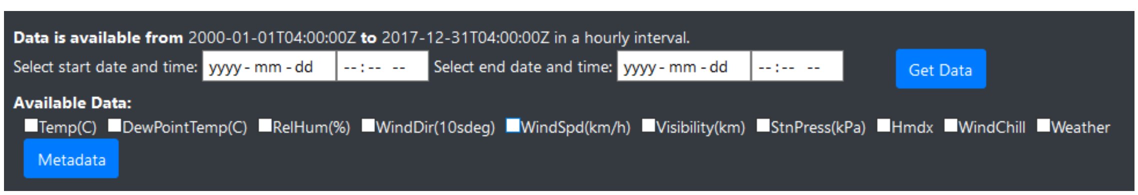


Get Real Time and Historical data buttons will open a new window with the station data from the Government of Canada web page. Following the instruction in that page will allow the user to download data for a particular station.

Weather data

Weather data is loaded on the map clicking on the correspondent icon in the Data panel. The data are weather stations represented as blue markers on the map. Clicking on a station will open a popup window with the station information, as well as the interaction panel, showing a form for data download and the link to the metadata.

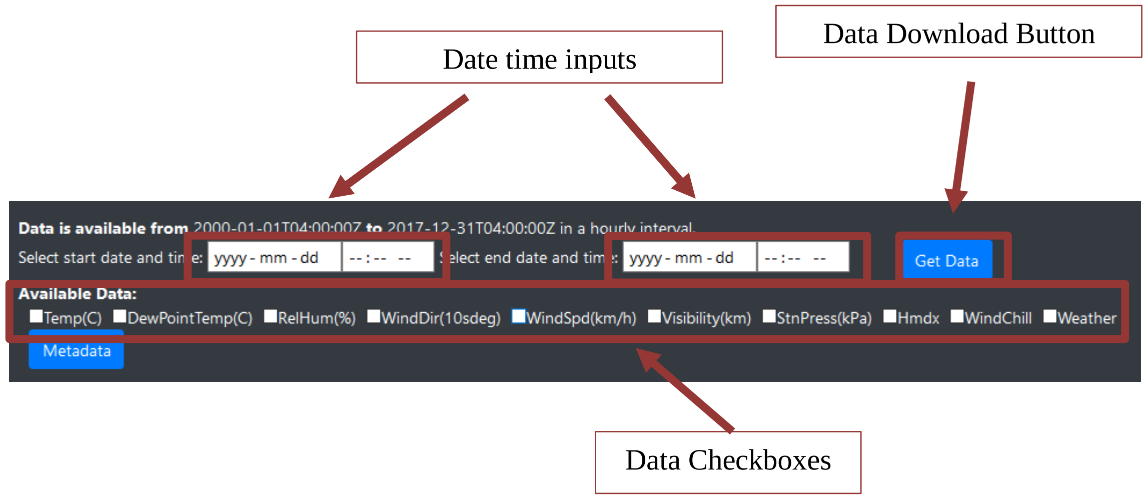




Download weather data

Weather data is downloaded through the form showed in the interaction panel after clicking on a station. The parameters that needs to be imputed are: starting date and time, end date and time and the kind of data that wants to be downloaded (check boxes). The format for the date and time is the following:

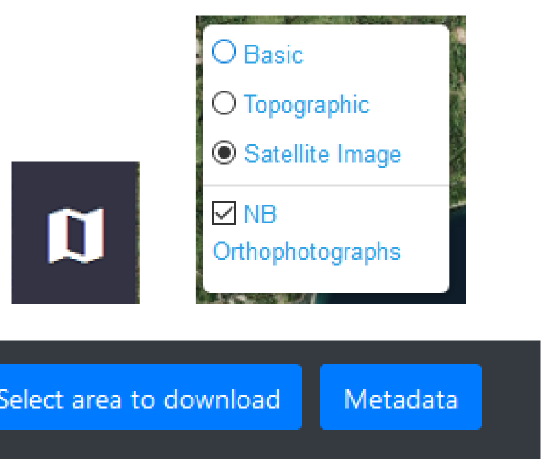
yyyy-mm-dd hh:mm AM/PM



After entering the input data on the form, the Get Data button must be clicked to download the data. The data is downloaded in a csv file containing all the variables selected on the checkboxes.

Orthophotographs

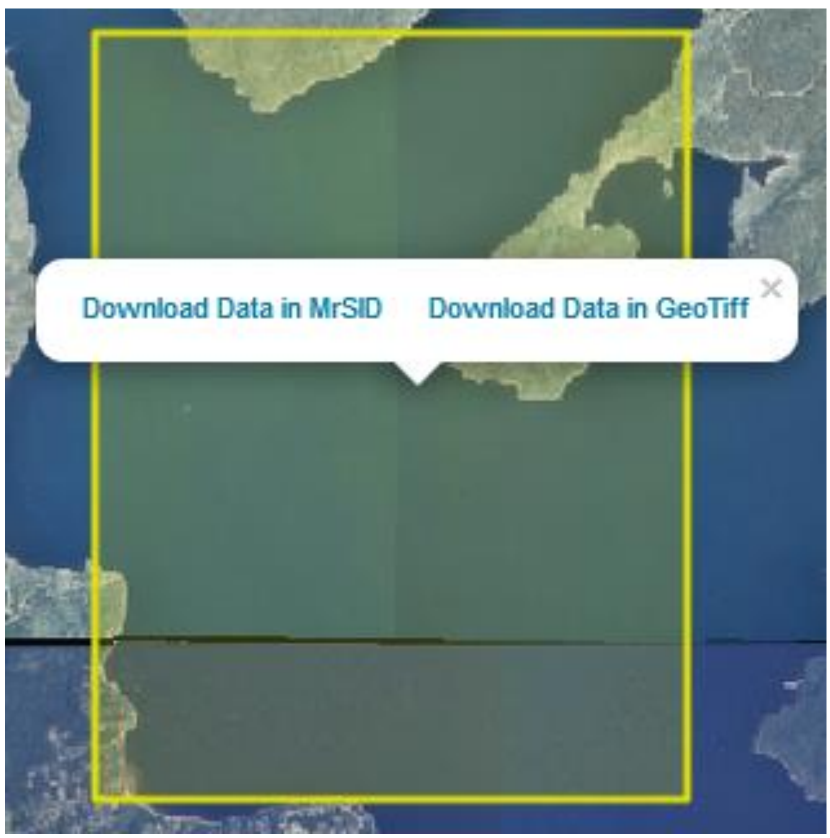
Orthophotographs are loaded on the map clicking on the correspondent icon in the Data panel. This action will open the interaction panel, that will show the function controls for the Orthophotographs data: Select area to download and access the metadata. The layer can be turned on and off in the layer control.



Download an orthophoto area

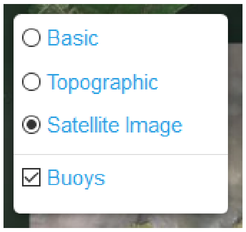
To download data, the "Select area to download" button needs to be clicked.

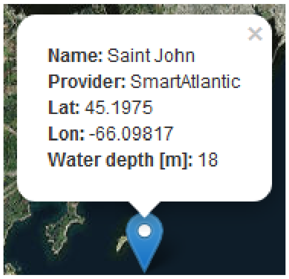
After clicking the button, the drawing tool is activated and the user can draw a rectangle on the map (first click for the upper left corner and last click for bottom right corner). After the area is drawn, a popup window appears, showing the formats available (MrSID or GeoTIFF). After clicking on any of the links, the data will be retrieved in the desired format.

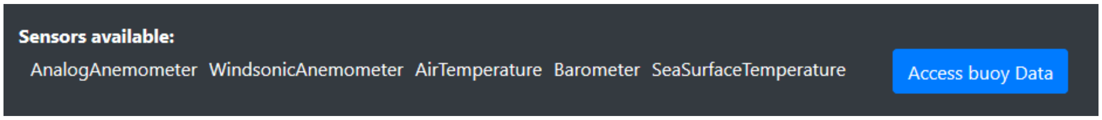


Buoy Data

Buoy data is loaded on the map clicking on the correspondent icon in the Data panel. The data are Buoy stations represented as blue markers on the map. Clicking on a station will open a popup window with the station information, as well as the interaction panel, showing all the sensors available for that buoy, and a button to access that buoy data.



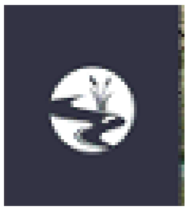


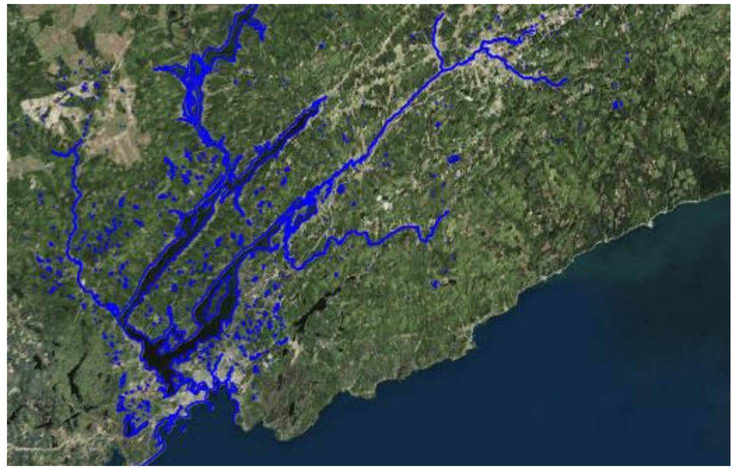


The access buoy data button will open a new window with the station data from the smart Atlantic Canada provider. Following the instruction in that page will allow the user to download data for a particular buoy.

Coast Lines Data

Coast Lines data is loaded on the map clicking on the correspondent icon in the Data panel. The coast lines data is represented as blue lines on the map. This action will open the interaction panel, that will show the function controls for the Coast Line data





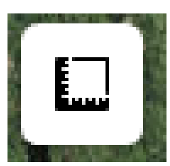
The only options available for coast lines data is to download in two different formats: CSV and KML. Clicking in any of the links will retrieve the data and send it to the user in the clicked format.

Other tools

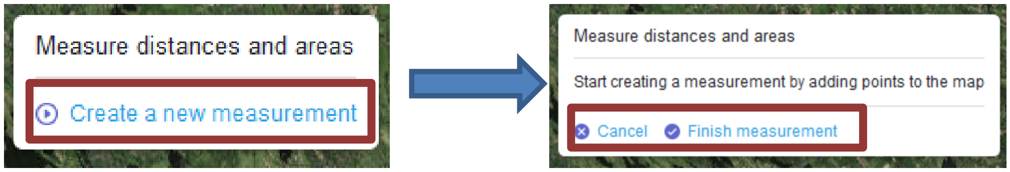
The Tools control on the map page includes additional basic functionality.

Measuring tool

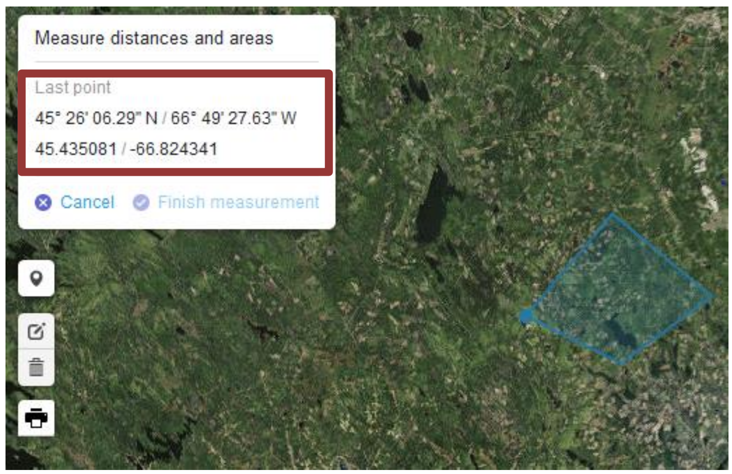
The measuring tool allows to measure distances and areas, and it is represented as a ruler icon situated at the upper left corner of the map.



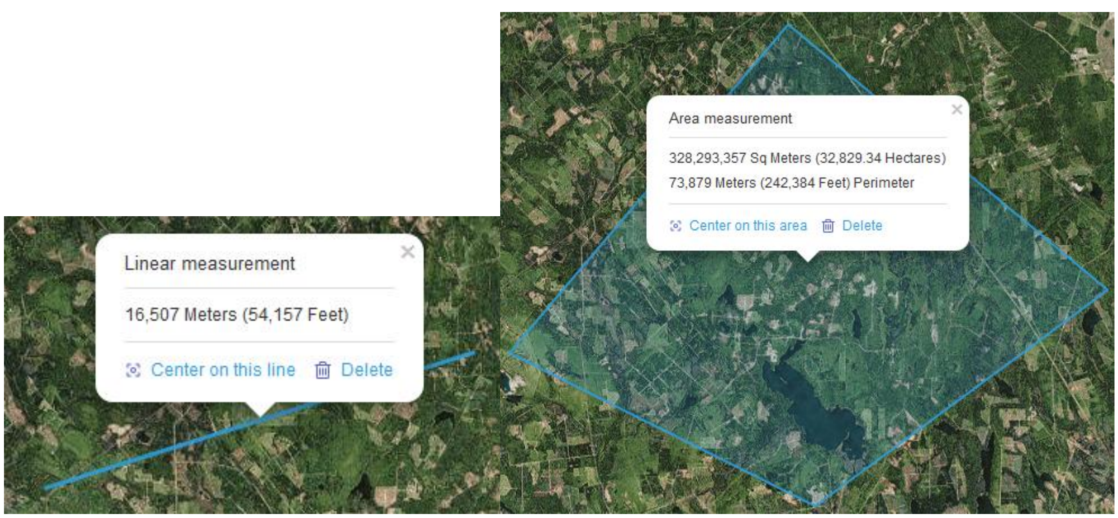
To start a new measurement, hover over the tool and select create a new measurement. After clicking on the link, the dialog changes and the user can start adding points to the map for the measurement. To cancel the measurement, click on cancel. To finish the measurement, click on Finish measurement.



After inserting each point, the dialog changes to show the coordinates of the last point added.



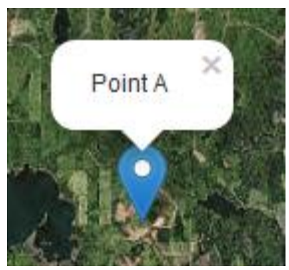
After finishing the measurement (linear or area) a popup window will be attached to the entered points, showing the linear/area measurement results.



Add a Marker

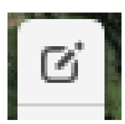
The add marker tool allows to add a marker on the map and insert a comment on the popup window. To activate this tool, click on the marker symbol at the upper left corner of the map.

After clicking on the icon, a marker is attached to the pointer and can be dropped anywhere on the map. After dropping the marker, a dialog will popup to enter the information for the market. Click enter to attach the information to the marker.

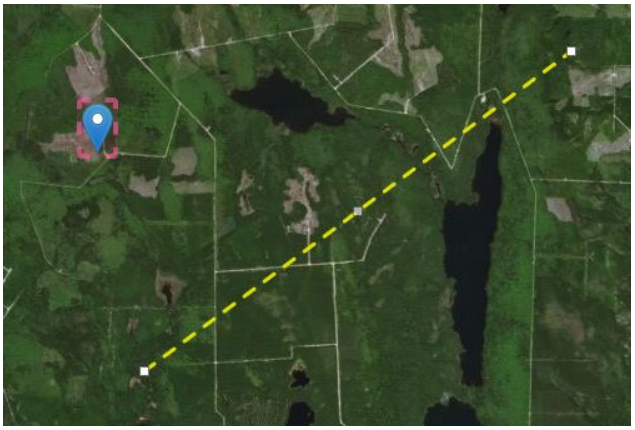


Edit Features

The editing feature tool allows to edit any vector feature on the map. To activate this tool, click on the editing icon at the upper left corner of the map.



This tool allows to drag and drop existing markers and to change vertex of existing lines and polygons.



After editing any feature, the save button that appeared at the right of the icon needs to be clicked to save the changes. Clicking the cancelling button, all the edits will be cancelled.

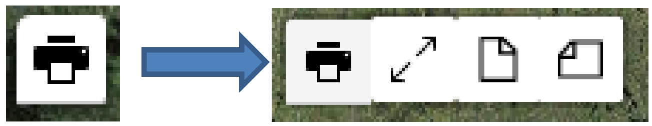
Delete Features

The delete feature tool allows to delete any vector feature on the map. To activate this tool, click on the delete icon (garbage can) at the upper left corner of the map.

After activating the tool, clicking in any added feature will delete it from the map. There are three buttons attached to the tool after activating, Save (it will save the changes), Cancel (it will cancel the changes), Clear All (it will delete all the features from the map at once).

Print Map

The print map tool allows to print the current view of the map (included any feature added to it). To activate this tool, hover over the printer icon at the upper left corner of the map.



Hovering over the printer icon, shows three available options: printing the current size of the map (two arrows icon), printing an A4 portrait of the map (portrait sheet icon) and printing an A4 landscape of the map (landscape sheet icon).

Appendix E: Administrator Manual

System architecture

The system architecture is portrayed in Figure 29. Six different components can be distinguished within the application:

- Data sources: data collected by the OMG in different formats (bathymetry, CTD, ADCP profiles…), and other existing open data sources provided by open standards by the government or organizations.

- Format conversion scripts: programming scripts that automatically convert the different files/formats to the one supported by the database/map-server.

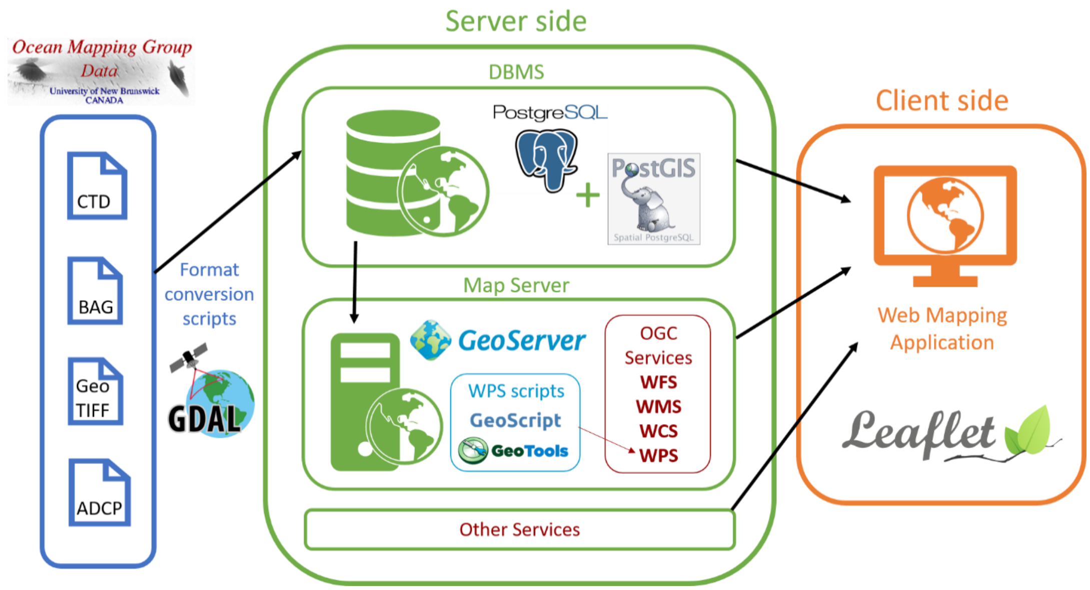
- Database Management System (DBMS): implemented in PostgreSQL with the PostGIS spatial plugin.

- Web Map Server: implemented in GeoServer software, allowing to publish datasets using Open Geospatial Consortium (OGC) standards.

- Main Server: implemented in Windows and using Microsoft Internet Services Provider for the management. It hosts the web map server, database and web page, making them accessible from anywhere. It also allows the execution of the server-side scripts.

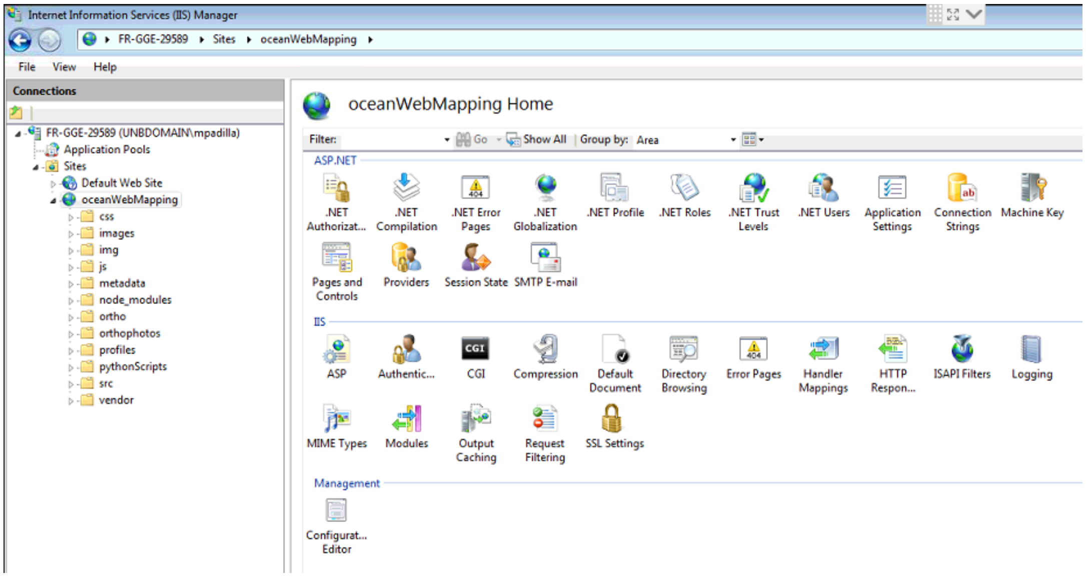
- Web Mapping application: the actual interface to the user. Implemented using Leaflet, the open source solution web mapping technology for interactive maps.

The role of the administrator would be to maintain the application and add further functionality and data to it.



Main server

It is in this server where all the components of the system architecture will be installed and developed: database, map server and web page. It was managed using Internet Information Services for Windows. To access it, open the IIS Manager in the server. Using this interface, CGI applications in other languages can be enabled, other type of files to server (MIME Types), handler Mappings, and other security settings.



Database

The database was implemented in the Server using PostgreSQL 10 Server and the following parameters:

Host: localhost port: 5432

The access to the database can be managed easily using pgAdmin 4, already installed in the Server, which allows you to view, query, delete and edit the stored data. There are three databases in the Server:

- Postgres: maintenance database (no data).
- oceanMapping: database containing all the data for the application.
- Geo_index: database containing all the tables related to indexes in GeoServer (bathymetry data)

Geo_index

There is one table per each Bathymetry Image Mosaic created in GeoServer (one per each resolution). Each table serves as an image index to be used by GeoServer to have access to the data: Bahymetry_1m, Bathymetry_5m, Bathymetry_10m, Bathymetry_50m. The columns for these tables are described below:

- Fid [Integer]: unique identifier and primary key.
- The_geom [Polygon] minimum bound rectangle enclosing the image.
- Location [String]: name of the file where the image is stored (relative to the mosaic configuration files GeoServer directory).
- Method [Integer]: resampling method used to create the image at that resolution. Bilinear: 1, Mean: 2, Cubic: 3.

OceanMapping

The main database of the application, which stores all the data available. There is a total of eight tables, one per each kind of data:

Bagfootprints: table to store the footprints for each OMG BAG survey, handling the time for the bathymetry data. The columns are described below:

- Gid [integer]: unique identifier and primary key.
- Campaign [String]: name of the survey campaign.
- Datestring [String]: string representing the date of the survey.

- Shape_leng and shape_area [float]: perimeter length and enclosed area of the footprint polygon.
- Dates [Date]: date the survey was performed.
- Geom [polygon]: geometry defining the survey footprint.
- Vessel [String]: name of the Vessel the survey was done with.
- Sensor [String]: name of the sensor to collect the data for the survey.
- Metadata [String]: link to the metadata page for each survey.

Buoys: each row of this table represents a buoy. The way data is linked to the buoy station is using a link to the data provider. The columns are described below:

- id [integer]: unique identifier and primary key.
- Buoyname [String]: given name for the buoy.
- Geom [Point]: geometry representing the buoy's location.
- Provider [String]: name of the agency or organization that maintains the buoy and collects the data.
- Waterdepth [float]: depth measurement under the buoy in meters.
- Sensors [String array]: array containing the name of the sensors the buoy provides with.
- Link [String]: link to the buoy data to access the data.

Waterlevelstations: each row of this table represents a station that measures water levels and river discharge data. The columns are described below:

- id [integer]: unique identifier and primary key.
- Stationnumber [String]: identification number of the water level station.
- Stationname [String]: name of the water level station.
- Province [String]: province the water level station is in.
- Status [String]: status of the water level station (A for active).
- Geom [point]: geometry representing the location of the water level station.
- Startyear [String]: first year that the data is available from.
- Finishyear [String]: last year the data is available to.
- Drainagearea [float]: area of the drainage area of the water level station.
- Sediment [string Y/N]: if there is sedimentation in the area.
- Real time [String Y/N]: if the water level station performs real time measurements or not.
- Datum [String]: name of the datum the measurements are referred to.

Weatherstations: each row of this table represents a station that measures weather information. The columns are described below:

- id [integer]: unique identifier and primary key.

- Stationname [String]: name of the weather station.
- Province [String]: name of the province the station is in.
- Geom [Point]: geometry representing the location of the weather station.
- Stationed, climateid, wmoid, tcid: different identifiers for the station.
- Startdate [date]: date and time the data is available from.
- Finishdate [date]: date and time the data is available to.
- Interval [String]: granularity of the data (monthly, hourly, daily…).
- Available data [String array]: array containing all the weather available data for that station.

Weather: each row of this table is a weather data measurement for an specific timestamp in a station. The columns are described below:

- id [integer]: unique identifier and primary key.
- Timestamp [timestamp]: timestamp for the weather measurement.
- Year, Month, Day, time [String]: string representations of the timestamp
- Dataquality [String]: quality of the weather data.
- Temperature, Dewtemperature, Relhumidity, Winddirection, Windspeed, Visibility, Stnpressure, Hmdx, Windchill [float]: weather variables.
- Weather [String]: string defining the weather.

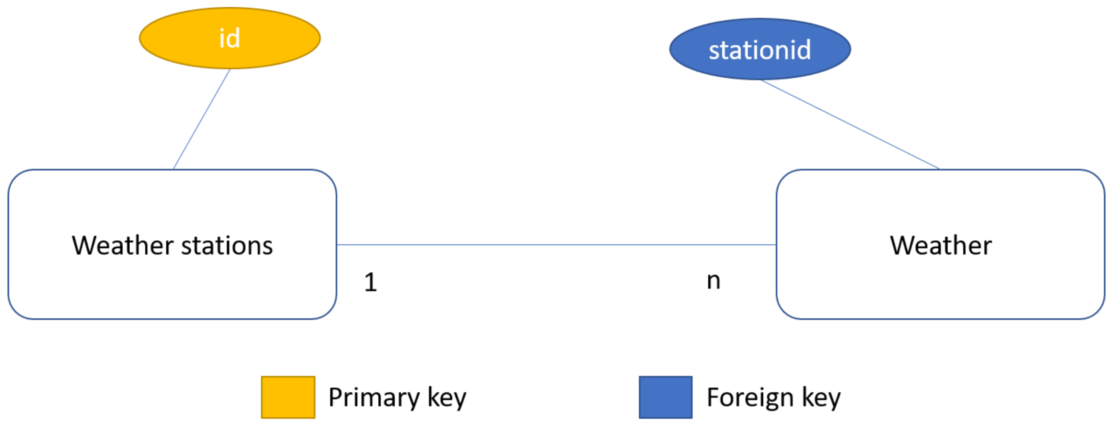
Mvp_points: one table containing the points (geometry), along with data arrays of the same dimension for the depth, temperature, salinity and sound speed variables (there is a measurement for each variable for each depth). Therefore, each row represents a MVP observation point for the moving vessel in a specific timestamp. Columns are described below:

- id [integer]: unique identifier and primary key.
- Cruisename [String]: name of the cruise that performed the survey.
- Instrumentation [String]: name of the instrumentation that allowed to collect the MVP data.
- Timestamp [timestamp]: date and time associated to the measurement.
- Geom [Point]: geometry representing the location of the point measurement.
- Bottomdepth [float]: depth measurement at the bottom of the observation point.
- Depth [float array]: array containing the depths at which the measurements were taken.
- Temperature, salinity, soundspeed [float array]: array containing the temperature, salinity and soundspeed measurements at each depth point.
- Timegeoserver [date]: for handling the time, only the date is considered, not the time. Therefore, this would be the field associated to the time dimension in GeoServer.

ADCP: each row represents an observation point for the moving vessel in a specific timestamp. The columns are described below:

- gid [integer]: unique identifier and primary key.
- Pointname [String]: point identifier.
- Time [String]: string representing the timestamp for the measurement.
- Timezone [String]: string representing the time zone.
- Campaign [String]: name of the campaign the data was collected in.
- Timestamp [timestamp]: timestamp for the measurement.
- Time_geose [timestamp]: modified timestamp to be able to be read by GeoServer (considering time zone differences).
- Geom [point]: geometry representing the location of the point where the measurements were taken.
- Date [Date]: date for the measurement, not considering time.

Database Relationships.- The only relationship contained in the model is the one between weatherstations and weather tables. Each weather station contains a set of data in the weather table, but each row of data belongs to only one station. The way these tables are related is using the stationid field as a foreign key, storing the id for the station that the data is from.

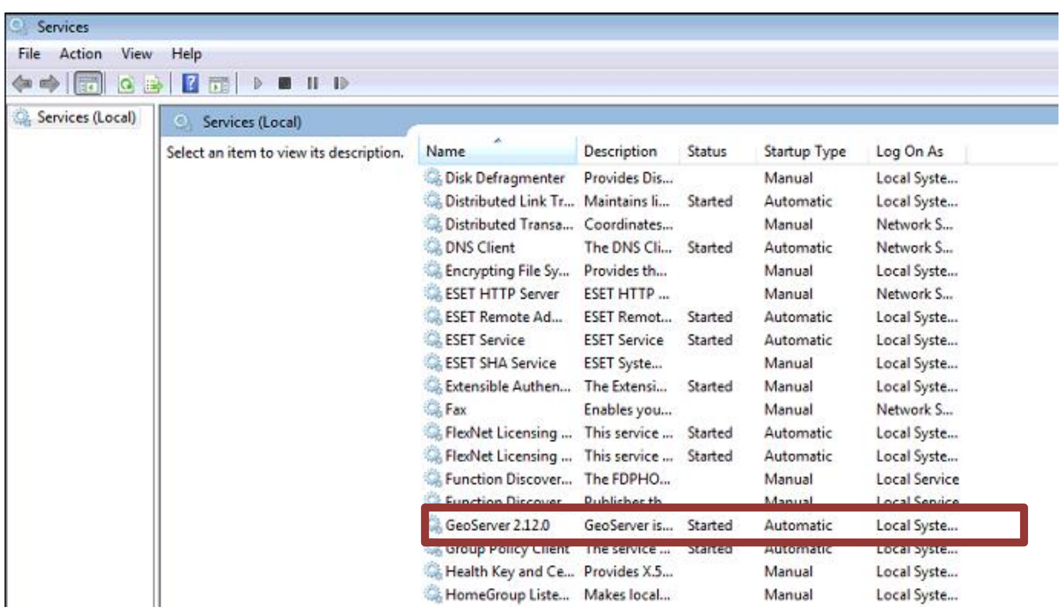


GeoServer

The web map server was implemented in the Server using GeoServer 2.12.0 software and the following parameters:

Host: localhost port: 8080

GeoServer was installed as a service, therefore, it would run every time the Server is started. The service can be manage using "services" tool from Windows. This allows to stop, start or reset the service.

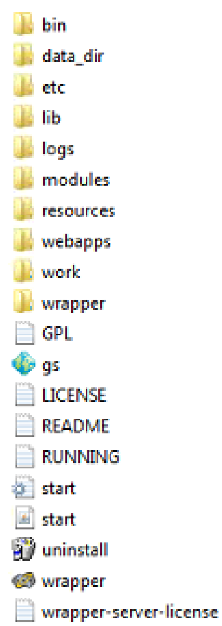


To access the GeoServer administrator page, the following URL need to be entered on a web browser: http://boqueron.gge.unb.ca:8080/geoserver/web/ or http://localhost:8080/geoserver/web/ (if accessing from the server).

GeoServer file system

The GeoServer platform is installed in the Server as a set of files under the following path:

C:\Program Files (x86)\GeoServer 2.12.0



There are a few important folders and files that can be edited in the file system when adding additional functionality or data.

- GeoServer data directory: where all the data added to GeoServer needs to be placed before adding it to the platform.

C:\Program Files (x86)\GeoServer 2.12.0\data_dir

- Log files (logs): there are two log folders (one general, wrapper.log and one for GeoServer, geoserver.log). If any error occurs in the platform, the log files can be checked in any of this folders for debugging.

C:\Program Files (x86)\GeoServer 2.12.0\logs\wrapper.log
C:\Program Files (x86)\GeoServer 2.12.0\data_dir\logs\geoserver.log

- Configuration files: two configuration files (marvin.conf and wrapper.conf) are included in this folder, and can be modified to set any service setting for GeoServer.

C:\Program Files (x86)\GeoServer 2.12.0\wrapper

- GeoServer plugins folder: when adding additional functionality to GeoServer, jar files for plugins should be added to this folder.

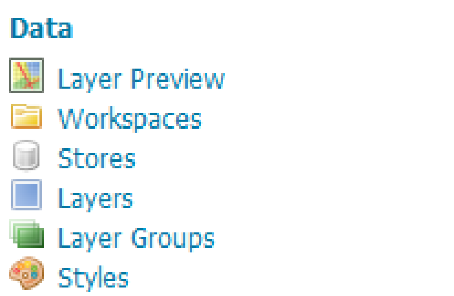
C:\Program Files (x86)\GeoServer 2.12.0\webapps\geoserver\WEB-INF\lib

- Scripts folder: custom scripts can be added to this folder, in order to add additional functionality to GeoServer by means of WPS scripts, filter functions, WFS transactions, applications…

C:\Program Files (x86)\GeoServer 2.12.0\data_dir\scripts

GeoServer platform

On the right panel of the platform, there is a Data section that allows to interact and add data to Geoserver (Figure x).



Therefore, there are four important concepts to add data and functionality in the GeoServer platform:

– WorkSpaces: container that organizes items (analogous to a namespace). A workspace is often used to group similar layers together.

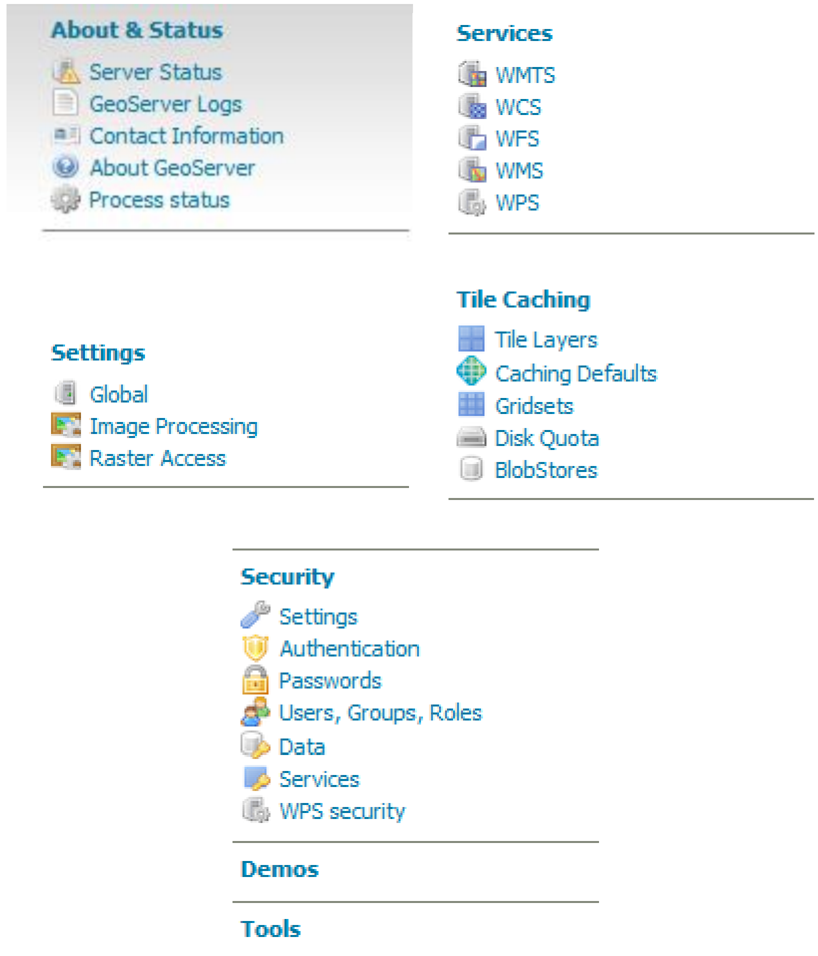
– Stores: a store connects to a data source that contains raster or vector data. There are only four kinds of stores: (a) raster file (or group of files), (b) vector file (or group of files), (c) vector database connection or (d) vector server connection.

Type Icon	Description
	raster data in a file
	vector data in a file
	vector data in a database
	vector server (web feature server)

– Layers: it refers to a raster or vector dataset that represents a collection of geographic features. Each layer has a source of data (i.e. a Store). The layer is associated with the Workspace in which the Store is defined. In the Layers section of the web interface, you can view and edit existing layers, add (register) a new layer, or remove (unregister) a layer. The Layers View page displays the list of layers, and the Store and Workspace in which each layer is contained. The View page also displays the layer's status and native SRS.

- Styles: it controls the appearance of the layers. It can be written in different formats: Styled Layer Descriptor (SLD), Cascading Style Sheets (CSS), YSLD and MBStyle.

The right panel contains other additional functionalities, related to status of the service, enabled services, tile caching, settings, security, demos and tools. The demo section contains helpful tools to generate GeoServer requests and test the enabled services.



GeoServer Demos

Collection of GeoServer demo applications

- Mapfish Printing Printing application using the Mapfish printing module embedded in GeoServer.
- Demo requests Example requests for GeoServer (using the TestServlet).
- SRS List List of all SRS known to GeoServer
- Reprojection console Simple coordinate reprojection tool
- WCS request builder Step by step WCS GetCoverage request builder
- WPS request builder Step by step WPS request builder

GeoServer implementation

For the purpose of the system implementation, there is one workspace created in GeoServer (oceanMapping) that will contain all the stores (data sources) and layers to be used by the web mapping application.

Regarding datastores, there are eight datastores created in GeoServer, seven related to raster data (bathymetry and orthophotographs) and one related to vector data:

- Bathymetry Raster data:

  - Bathymetry_1m_2: image mosaic store containing bathymetry at 1m resolution and having as an additional dimension the resampling method (cubic, mean, bilinear).

  - Bathymetry_5m_2: image mosaic store containing bathymetry at 5m resolution and having as an additional dimension the resampling method (cubic, mean, bilinear).

  - Bathymetry_10m_2: image mosaic store containing bathymetry at 10m resolution and having as an additional dimension the resampling method (cubic, mean, bilinear).

  - Bathymetry_50m_2: image mosaic store containing bathymetry at 50m resolution and having as an additional dimension the resampling method (cubic, mean, bilinear).

- Bathymetry_1m_nomosaic: GeoTIFF store containing all the bathymetry data at the lowest resolution (1m resolution).

- Sjriver_hs: GeoTIFF data source for a hill shading layer for the bathymetry area.

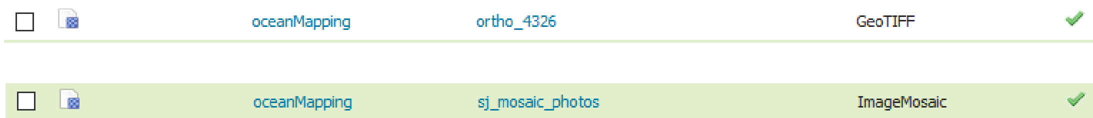
oceanMapping	bathymetry_10m_2	ImageMosaic
oceanMapping	bathymetry_1m_2	ImageMosaic
oceanMapping	bathymetry_1m_nomosaic	GeoTIFF
oceanMapping	bathymetry_50m_2	ImageMosaic
oceanMapping	bathymetry_5m_2	ImageMosaic

Store	Layer name
Sjriver_hs	LowerSJRIVER_5m_Biliner_20091001_hs3
Bathymetry_1m_nomosaic	BILI_Lowersj_1m0001_
Bathymetry_1m_2	Bathymetry_1m_2
Bathymetry_5m_2	Bathymetry_5m_2
Bathymetry_10m_2	Bathymetry_10m_2
Bathymetry_50m_2	Bathymetry_50m_2

– Orthophotographs raster data:

- sj_mosaic_photos: image mosaic store containing a mosaic of the New Brunswick

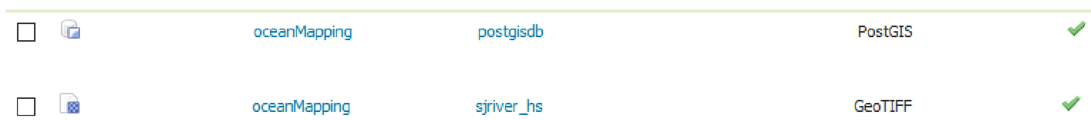
- Ortho_4326: GeoTIFF store containing all the orthophotographs joined as one file.



Store	Layer name
sj_mosaic_photos	Sj_ortho2
Ortho_4326	Orthocombined4326

– Vector data:

  - PostGISdb: data source to connect to the Postgres database, therefore being able to access all the data tables in the database. Table x show a summary of the created layers for that store.



Layer name	**Description**
bagfootprints	Layer to connect to the bagfootprint table
buoy	Layer to connect to the buoy table
mvp_points	Layer to connect to the mvp_points table
adcp	Layer to connect to the adcp table
waterlevelstations	Layer to connect to the waterlevelstations table
weatherstations	Layer to connect to the weatherstations table

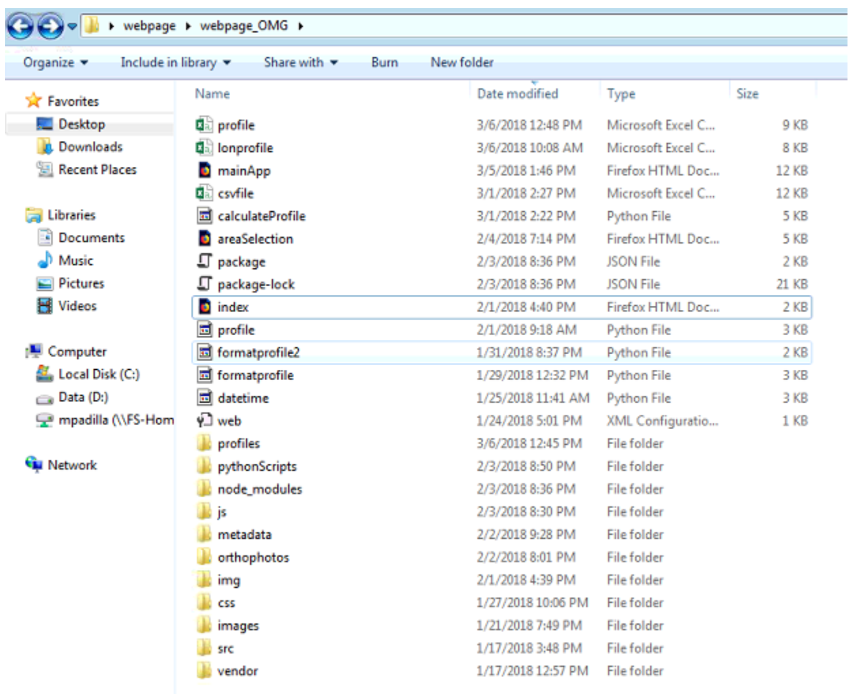
Web application

To access the web application, the following URL need to be entered on a web browser:

http://boqueron.gge.unb.ca or http://localhost (if accessing from the server).

When opening Internet Information Services for Windows manager, there is a web site created called oceanWebMapping, which host the web page. It was assigned to port :80 and linked to the folder in which the web page files are stored:

C:\Users\mpadilla\Desktop\webpage\webpage_OMG



HTML files

– Index.html: code for the first page presented to the user when loading the web page.

- areaSelection: code for the second page presented to the user, where they can select an area of interest for looking for data.

- mainApp.html: code for the main page of the web application.

Folders

- Js: folder containing JavaScript files for the web application. App (main page), app_areaSelection and app_index are the main javascript files for the web application.

- pythonScripts: folder containing python CGI scripts.

- Metadata: folder containing some of the metadata files that links to the web application.

- profiles: folder that stores calculated vertical profiles.

- Orthophotos: folder containing orthophotographs in MrSID format to be downloaded by the user.

- images and img: folder containing the images for the web application.

- Css: folder containing the style sheets for the web application.

- src, vendor and node modules: other folders for supporting files.

Other files

- Temporal csv files generated when calculating profiles and downloading data.

- Other python scripts that needs to run in the main folder.

- Configuration files for the web page.

Adding data to the application

Within the system architecture, storage was provided by storing data in the database within tables (Vector data) or storing data in GeoServer using the file system (Raster data). A description of how to add additional data is given below.

Adding Bathymetry

Data preprocessing

For adding bathymetry data, data need to be preprocessed. For this purpose, GDAL library tools provide with the functionalities for format and geographic coordinates conversions and resampling methods. The way the system is set up, a set of GeoTIFF files are needed with the following characteristics:

- One set per each resolution (bathymetry_5m, bathymetry_1m…).

- Each GeoTIFF must have two bands (bathymetry/uncertainty).

- One GeoTIFF file for each resampling method.

- The coordinate system must be 4326 (to avoid the need of coordinate transformations on the web page).

A set of examples for this kind of transformations are given, which should be applied for preprocessing the data before adding it to the platform:

- GeoTIFF format conversion (both bands and one band).

gdal_translate -of GTiff -co "TILED=YES" Archer_GGE3353_2017.bag bag.tif

gdal_translate -of GTiff -a_srs "EPSG:3395" -co "COMPRESS=LZW" -b 1 2008_Pipit.bag gtiff/2008_Pipit.tif

- Coordinate system transformation from EPSG:3857 to EPSG:4326 from a GeoTIFF file.

gdalwarp -s_srs EPSG:3857 -t_srs EPSG:4326 1mm/LowerSJRIVER_ALL.tif 1mm/LowerSJRIVER_1m43262.tif

- Change the nodata value and associating a transparent band.

gdalwarp -srcnodata "-3.4028234663852886e+038" -dstnodata "1000000" -overwrite LowerSJRIVER_5m_Mean.tif LowerSJRIVER_5m_Mean_nodata.tif

gdalwarp -co TILED=YES -co COMPRESS=LZW -srcnondata -9999 -dstnodata -9999 -dstalpha <input image> <output image>

- Forcing coordinate systems (to add a coordinate definition in case it is missing).

gdalwarp -t_srs "EPSG:3395" -overwrite 2008_STJohn.bag 2008_STJohn_srs.bag

- Coping only one band from a GeoTIFF

gdal_translate -of GTiff -a_srs "EPSG:3857" -co "COMPRESS=LZW" -b 1 5m/LowerSJRIVER_5m_Bilinear.tif 5m/tif/LowerSJRIVER_5m_Bilinear.tif

- Extract a GeoTIFF file from a BAG file and resample it to 5-meter resolution. Options: LZW compression method, tiled, only one band (bathymetry). If the one band parameter is omitted, the two bands of the BAG file will be copied to the GeoTIFF.

gdal_translate -of GTiff -a_srs "EPSG:3395" -tr 5 5 -r bilinear -co "COMPRESS=LZW" -co "TILED=YES" -b 1 2009_Plover.bag gtiff/2009_Plover.tif

Placing files

After the data is preprocessed, it needs to be published in GeoServer. The folder that contains the bathymetry data is the following: C:\Program Files (x86)\GeoServer 2.12.0\data_dir\MOSAIC_DIR. There are two case scenarios:

- Data is being added for a new resolution: a new data store (image mosaic) in GeoServer needs to be created (e.g. bathymetry_20m). Therefore, a new folder should be placed in this directory including all the bathymetry and configuration files (one for the database, one for the indexer and another one for the method property). The configuration files can be copied from an existing bathymetry directory.

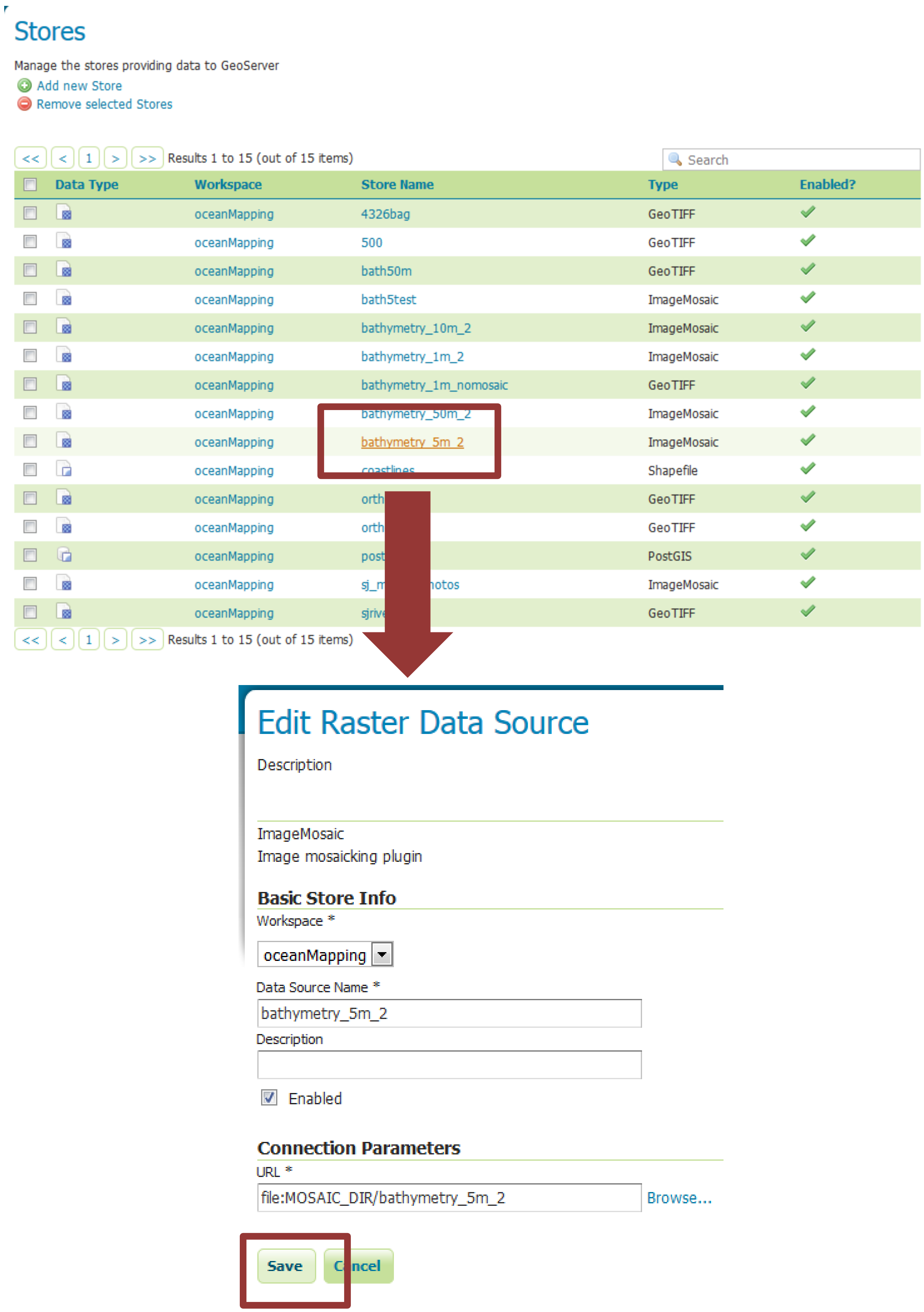
- Data needs to be added to an existing data store (same resolution but different area). Several steps need to be performed:

    - Delete the index table from the database (it will have the same name as the folder).

    - Add the new files to the bathymetry folder.

    - Delete the sample image and the layer property file from the directory.

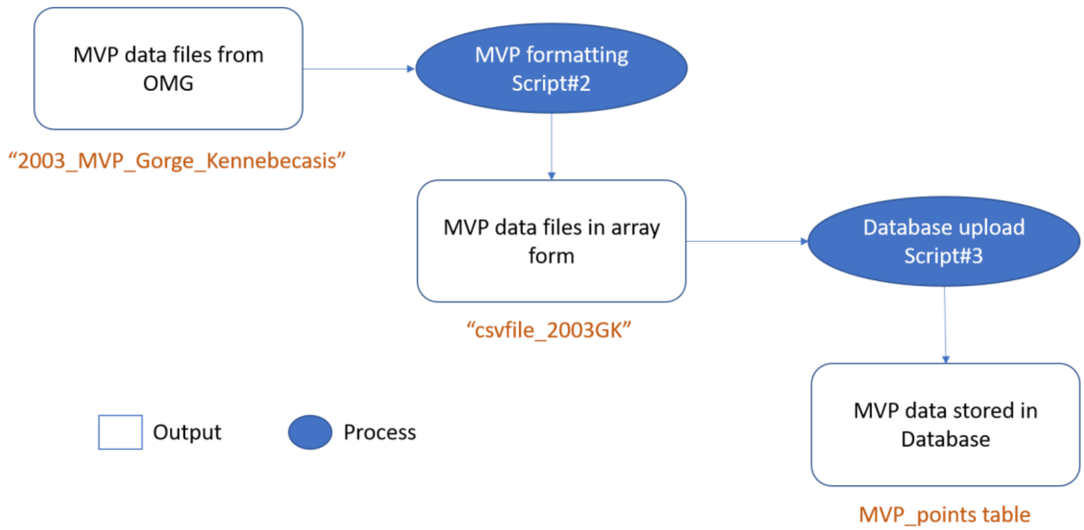
    - Publish the datastore again in GeoServer.



After following these steps, the image mosaic will be updated.

Adding Temperature, Salinity, Sound Speed data

The way this data is updated to the database is using Scripts#2 (array formatting) and #3 (database upload).



To add more files, the data needs to be in the following format:

Cruise, Station, mon/day/yr, hh:mm, Longitude, Latitude, Bot. Depth [m], DEPTH [m], QF, TEMPERATURE [°C], QF, SALINITY [PSS-78], QF, SOUNDSPEED [m/s], QF.

Using this format and running the scripts, the data will be automatically uploaded to the database. The only consideration to be taken is to update the unique id in the script#2 to the number of rows already in the database.

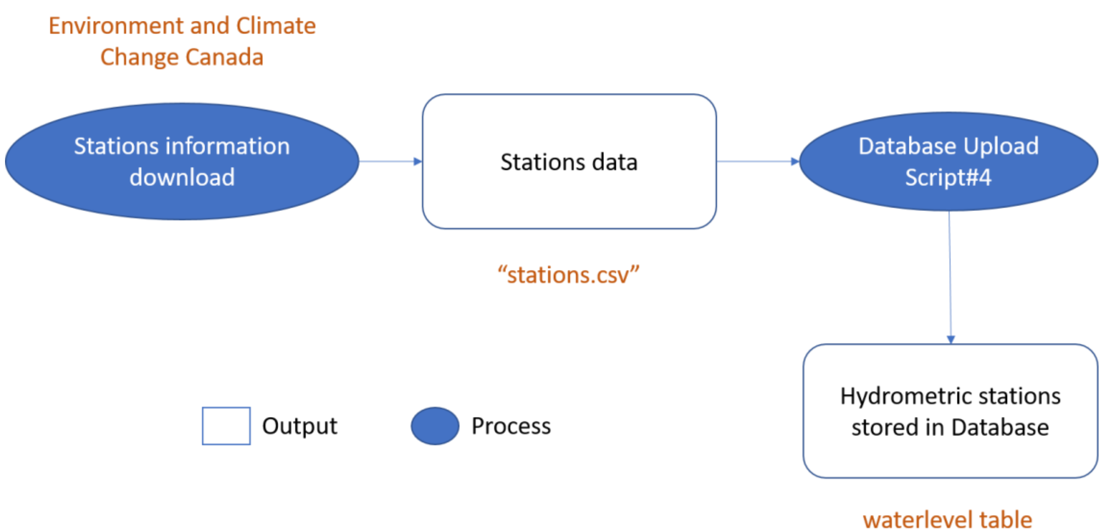
```
with open('2010_MVP_PSJ_Harbour.csv', 'r') as f:
    with open('csvfile_2010PSJH.csv', "wb") as csv_file:
        writer = csv.writer(csv_file, delimiter=',')
        reader = csv.reader(f, delimiter=',')

        next(reader)
        writer.writerow(["id","CruiseName","Instrumentation","T

        arrayDepth=[]
        arrayTemperature=[]
        arraySalinity=[]
        arraySoundSpeed=[]
        prevLine = ""
        i = 8132
```

Adding Currents data

This data was not available at the time of writing this thesis. However, as the data has a similar format, similar scripts (Scripts#2 and #3) could be used to upload this data to the database.

Adding Hydrometric station

The way this data is updated to the database is using Scripts#4 (database upload).



To add more files, the data needs to be in the following format:

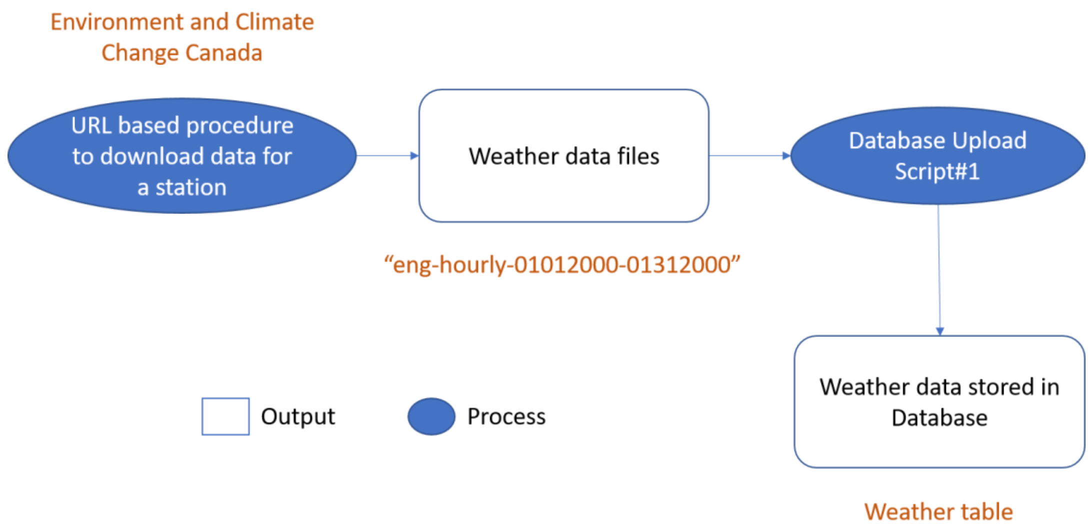
Station Number,Station Name,Province,Status,Latitude,Longitude,Year From,Year To,Drainage Area,Sediment,RHBN,Real-Time,Datum Name

Therefore, more data could be easily added following the same format and using this script, only having to update the unique id in the script#4 to the number of rows already in the database.

```
import psycopg2
import csv

conn = psycopg2.connect("host=localhost dbname=oceanMapping user=postgres password=admin")
cur = conn.cursor()

with open('stations.csv', 'r') as f:
    reader = csv.reader(f)
    next(reader)  # Skip the header row.

    i=1
```

Adding weather data

Weather stations were added manually. However, having Script#4 as a template and formatting the input, it would be easy to develop a script to upload weather stations to the existing data table, as it is the same kind of data. Regarding weather data, several scripts could be developed to automatize the process of downloading data from the Government services. To upload this new data into the database, Script#1 can be used, which reads every downloaded file and formats the data to insert it into the weather table.



Adding Orthophotographs

For adding new orthophotographs, new images can be added to an existing data store in Geoserver. Same procedure than bathymetry can be followed for this purpose.

Adding buoy stations

Buoy stations were added manually. However, having Script#4 as a template and formatting the input, it would be easy to develop a script to upload buoy stations to the existing data table, as it is the same kind of data.

Adding Coast Lines data

To add additional coast lines data, more data should be download as SHP files and using shp2pgsql tool from PostGIS, the data can be uploaded to the database. After any new data upload, the layer should be published again in GeoServer to save the changes.

Adding footprints data

To add additional survey footprints SHP files to the database, shp2pgsql tool from PostGIS can be used. After any new data upload, the layer should be published again in GeoServer to save the changes.

Adding additional functionality to the application

Within the system architecture, there are three different ways of providing additional functionalities of the application.

- Custom Web Processing Service (WPS) scripts, provided by GeoServer. Any new WPS script generated should be placed in the following folder:

  C:\Program Files (x86)\GeoServer 2.12.0\data_dir\scripts\wps

- Server-side scripts under the CGI application architecture, using Python as scripting language. Any new Python script should be placed in the following folder and be called by the web application.

  C:\Users\mpadilla\Desktop\webpage\webpage_OMG\pythonScripts

- Additional browser functionality, using the leaflet API, leaflet plugins and browser capabilities. The files should be placed in the javascript folder.

  C:\Users\mpadilla\Desktop\webpage\webpage_OMG\js

Curriculum Vitae

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Publications:

Padilla-Ruiz, M., López-Vazquez, C. (2018). Measuring conflation success. Revista Cartográfica núm. 94, enero-junio 2017, pp. 41-64.

Cha, S., Padilla-Ruiz, M., Wachowicz, M., Tran, L. H., Cao, H., & Maduako, I. (2016). The role of an IoT platform in the design of real-time recommender systems. In 2016 IEEE 3rd World Forum on Internet of Things (WF-IoT), pp. 448-453.

Conference Presentations:

Padilla-Ruiz, M., Wachowicz, M., Cha, S. (2017). Exploring Bluetooth Low Energy Beacons for Building Proactive Location Aware Services. Long Abstract for the International Symposium on Location-based Social Media Data and Tracking Data. ICC 2017, Jul. 1-2, Washington DC, USA.

Padilla-Ruiz M., Ghanbari, G. (2016). Are cyclists and pedestrians safe in Fredericton? Presented at GOVMAKER 2016 - Open Data Visualization Challenge, Nov. 21-22, Fredericton, NB, Canada.