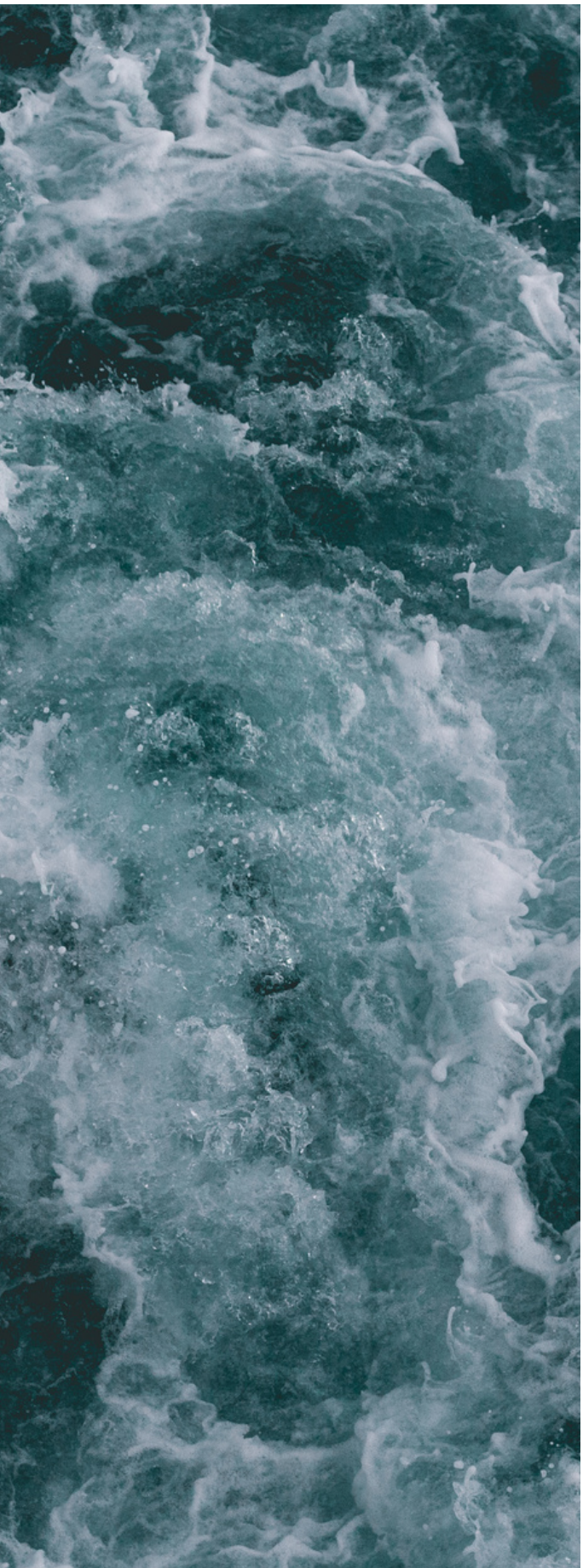
DEVELOPING DIGITAL TWINS OF THE OCEAN FOR CANADA

A webinar report by the Tula Foundation, supported by Fisheries and Oceans Canada and Environment and Climate Change Canada

April 2024. Written by Naomi Boon with contributions from Pramod Thupaki, Isabelle Gaboury, Youyu Lu, Hui Shen, Nancy Soontiens, Fraser Davidson, Patricia Pernica, Di Wan, Mike Smit, Joshua Barnes, Nabil Belacel and Alain Arnaud.



CONTENTS

TERRITORIAL ACKNOWLEDGEMENT

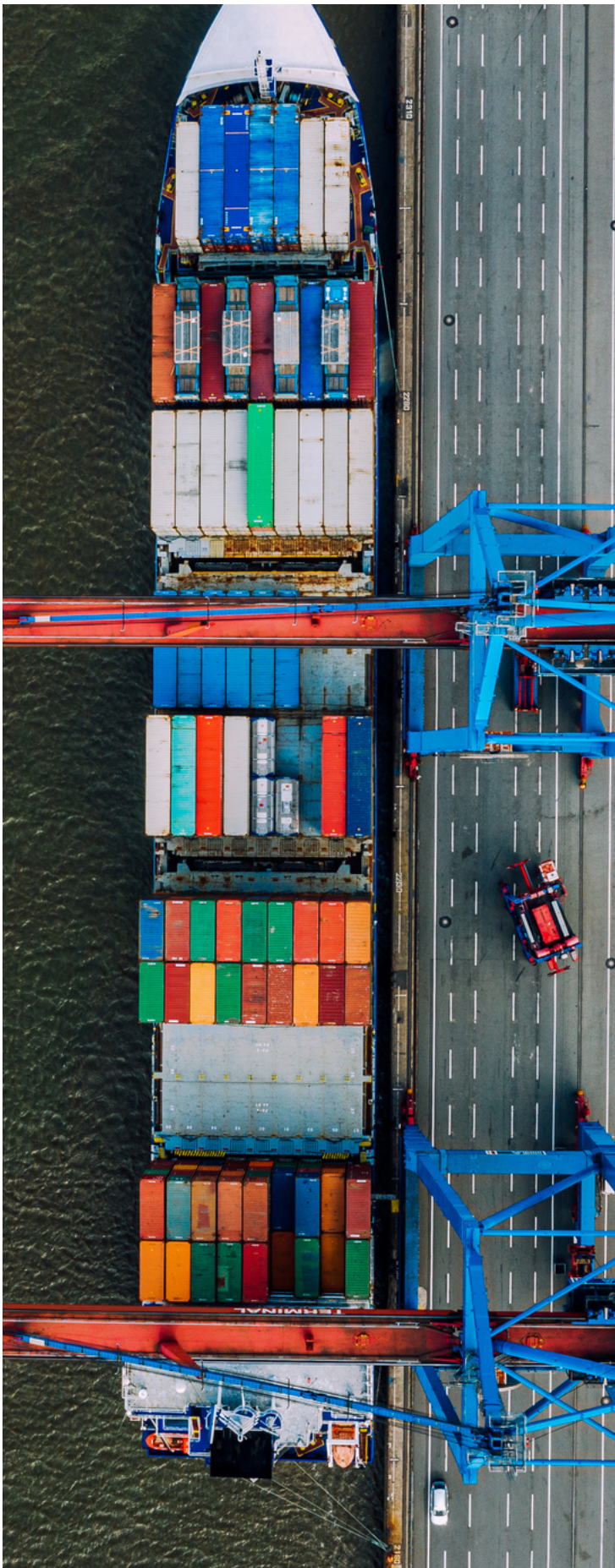
From the coast to the deep water and across boundaries and borders, we acknowledge the traditional, ancestral and unceded territories of all the Indigenous Peoples who have called this land home since time immemorial. This webinar was hosted from the traditional territory of the W̱SÁNEĆ Peoples. The organizers of this event recognized that we all live and work in different places and therefore were joining the webinar from different Indigenous traditional territories. Participants were encouraged to identify and reflect on their own land acknowledgement using Native-Land.ca or Whose.Land.

ACKNOWLEDGEMENTS

Thanks to the 85 people who participated in this webinar on November 22, 2023. We want to thank, in particular, the presenters at the webinar and the group who helped to organize and host the webinar.

LIST OF PRESENTERS

Alain Arnaud, Mercator Ocean International
Mike Smit, Dalhousie University, Ocean Frontier Institute
Isabelle Gaboury, Fisheries and Oceans Canada
Nancy Soontiens, Fisheries and Oceans Canada
Hui Shen, Fisheries and Oceans Canada
Youyu Lu, Fisheries and Oceans Canada
Joshua Barnes, National Research Council of Canada
Nabil Belacel, National Research Council of Canada
Fraser Davidson, Environment and Climate Change Canada



EXECUTIVE SUMMARY

Developing a digital twin of the ocean (DTO) is an emerging approach that has the potential to play a key role to address several of the challenges identified by the UN Decade of Ocean Science for Sustainable Development (hereafter referred to as Ocean Decade).

A digital twin is a virtual replica of a physical object or system that uses real-time data to monitor and simulate behavior (DITTO, 2023). DITTO, an endorsed global programme of the Ocean Decade established in 2021, aims to support ocean protection, governance and a sustainable blue economy through the development and use of DTOs. The programme is working to develop a common global understanding of DTOs, establish best practices, and create a digital framework to be used by ocean professionals worldwide (DITTO, 2023).

DITTO supports the development of digital twins through establishing and advancing a digital framework on which data, models and knowledge can be shared to answer “what if” questions across a range of marine sectors, from marine spatial planning to fisheries management (DITTO, 2023).

Currently, different countries or regions in the world have different degrees of preparedness for DTO development and implementation. The identified common barriers to overcome include the data availability and quality, data compatibility and cost (Tzachor et al. 2023), and the quality and functions of numerical ocean models. Ocean models are similarly limited in their inclusion of specific ocean processes and spatial resolution, particularly for biological processes and nearshore regions. Functionality to allow users to run models themselves to simulate "what-if" scenarios is also not typically available. The computational resources required to model and simulate “what-if” scenarios pertaining to a large array of applications would likely be impractical. Data sharing and dissemination is also a barrier for end users, as often data is not openly available or accessible to end users. Such barriers are very evident in Canada’s ocean sector. Overcoming these barriers to allow for successful DTO development in Canada and beyond will require strong cross-disciplinary collaboration, funding, further incentivization of data sharing, and strategic prioritization of the approach to digital twin development, all of which were discussed in this webinar.

This webinar was a satellite event of the International Digital Twins of the Ocean Summit 2023 hosted in Xiamen, China. It was hosted with the intention of engaging experts across Canada to share information on the current state of Canada's digital twin of the ocean, identify gaps and to work collaboratively on a shared vision for the future of DTOs in Canada.

The webinar aimed to:

- Inform, educate and coordinate activities relevant to DTOs across Canada and beyond.
- Understand the opportunities and challenges facing the development of DTOs in Canada so that resources can be mobilized and utilized more effectively.
- Better understand the international context of digital twin development and understand where Canadian efforts can fit into this landscape and effectively collaborate on a global scale.
- Create a more engaged and connected community that brings together government departments, universities, industry and non-profit organizations within Canada.
- Link various activities relevant to DTOs around Canada, thereby understanding user needs that can be addressed by creating these applications.
- Stimulate an effort towards an active and innovative digital ocean ecosystem for applications that would bring together observations, models, and end-user focussed applications.

The webinar recording is available on vimeo and this report is intended to be a supplementary written record of the event, which we hope will stimulate further discussion and collaboration in developing DTOs for Canada.

INTRODUCTION TO EUROPEAN DIGITAL TWINS OF THE OCEAN

By Alain Arnaud, Mercator Ocean International

Alain Arnaud is the Head of Digital Ocean Department at Mercator Ocean international. He graduated from Ecole Polytechnique (X89) and received his PhD in computer science in 1997. He worked at the French Space Agency (CNES), at the European Space Agency (ESA) and in the private sector. He joined Mercator Ocean International in 2017 and is now the manager of the Digital Twin of the Ocean program.

Mercator Ocean International (MOi) is a non-profit organization, in the process of transforming into an intergovernmental organization, providing ocean science-based services of general interest focused on the conservation and the sustainable use of the oceans, seas and marine resources. Since 2014, Mercator Ocean has been entrusted by the European commission to implement the European ocean-monitoring service, the Copernicus Marine Service.

In the EU, digital twins technology has been rapidly evolving since 2021. The work is being led by four main groups, representing political, technical, science and international collaboration: EU Mission Restore our Ocean and Waters, Destination Earth and ESA, the UN Decade of Ocean Science for Sustainable Development, and various member states initiatives. The UN Decade work on digital twins in the EU is particularly connected to the Decade Collaborative Centre for Ocean Prediction (hosted by MOi) and the DITTO program.

Figure 1. The infrastructure required to develop a European Digital Twin of the Ocean.

The European Digital Twin of the Ocean, EDITO, has received core funding from the EU for its development. High quality science and data is supporting the development of an innovative set of user-driven, interactive decision-making tools. There are two sister projects within EDITO which will drive the operational infrastructure:

- EDITOinfra
  - This is the public infrastructure backbone of the digital twin, which uses existing data infrastructures from the EU including Copernicus Marine Service, Copernicus Data and Information access services, and European Marine Observation and Data Network (EMODnet).
  - This project integrates key data services and shares cloud processing capabilities and software into a single digital framework.
- EDITOModelLab
  - This project is focused on developing the next generation of ocean models from digital twins, combining AI and HPC, and provides access to focus application and simulations of different 'what-if' scenarios.

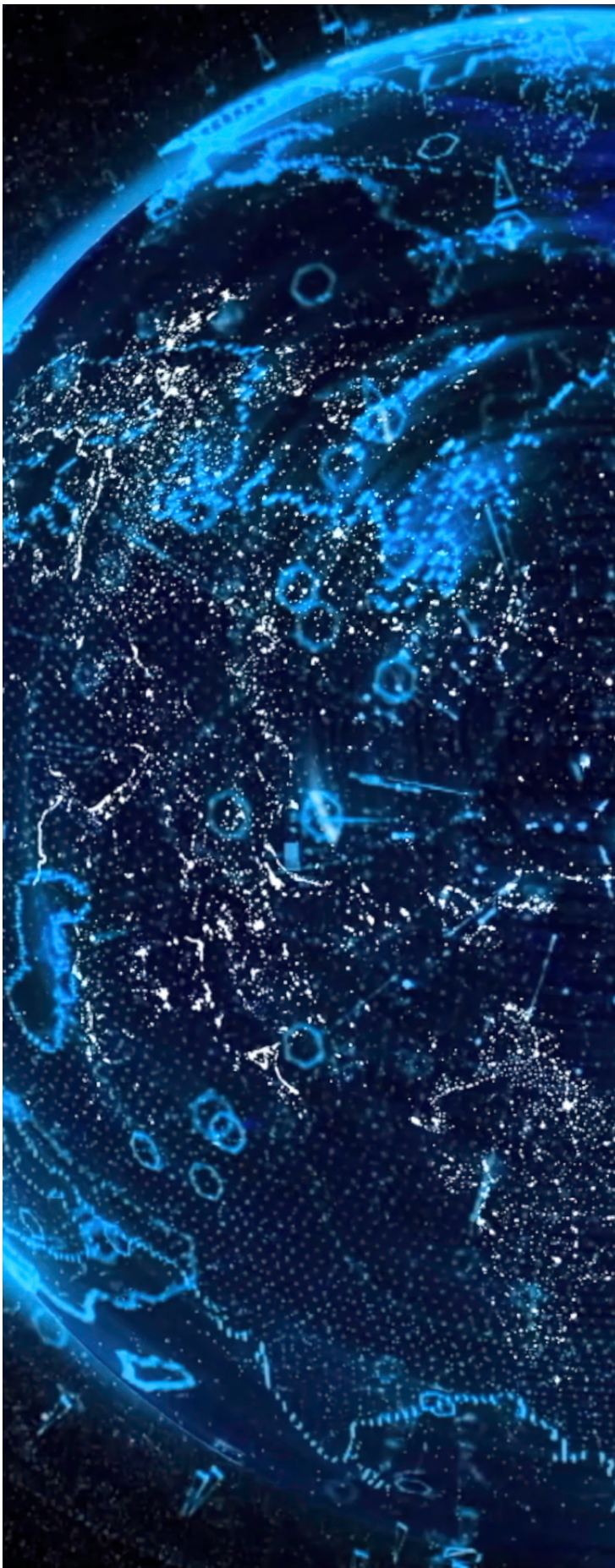
EDITO is providing an architectural basis for the interconnections of assets, creating a data lake which will enable seamless access to all of the marine data within EMODnet and Copernicus. The processing engine will allow for the launch of models, AI machine learning, hybrid models and applications. This makes it possible to construct different layers of the ocean (e.g. physics, biochemistry or socioecology) within a single framework so that all of the data can be accessed together.

However, it is difficult, operationally, to connect all of these assets. In order to develop a common vision for European DTOs, multiple Digital Ocean Forums were hosted in 2022 and 2023. In June 2023, the European Digital Ocean Forum brought together 55 projects, to promote data and tool interoperability and sharing between projects to provide continuity to users and increase the impact of the data. This highlights one of the greatest strengths of digital twins of the ocean, which is to combine efforts that are usually dispersed or siloed. Within this forum, four technical working groups were created (data, model, ocean intelligence, digital component), as well as four sectoral working groups (blue economy, blue ocean, decision making, biodiversity and marine environment), which are focused on how to include science-policy-society considerations in the development of DTOs.

Through the EDITO project, users are being offered three different ways to access digital twin technology: firstly, to explore through using the digital twin of the ocean platform; secondly, to contribute, through adding data and services to the digital twin platform; and thirdly, to create, by building external third-party services.

EDITO and the EU's Digital Twin of the Ocean is intended to be a platform for global cooperation, and while it is technically challenging to implement, the framework is revitalizing the way research projects are done. The intention is that this collaborative initiative will make ocean knowledge open-access and therefore available to citizens, scientists and policy makers around the world.

DIGITAL REPRESENTATIONS OF THE OCEAN IN CANADIAN UNIVERSITIES AND THE OCEAN DECADE



By Mike Smit, Ocean Frontier Institute

Mike Smit is one of the foundational leads of the Atlantic Regional Association of the Canadian Integrated Ocean Observing System (CIOOS), and the Deputy Scientific Director for the Ocean Frontier Institute. He is one of the co-leads of the Transforming Climate Action: Addressing the Missing Ocean CFREF project. He is a Professor and Acting Dean in the Faculty of Management at Dalhousie University, where he studies how new technology can benefit people, organizations and society.
Mike's presentation outlined the current efforts within the UN Ocean Decade and across Canadian universities to create a digital representation of the ocean, which involves developing digital twins of the ocean.

The UN Ocean Decade is currently undertaking a strategic initiative called the "Vision 2030" process, which aims to review all of the identified Decade challenges, and from a big picture perspective, define what success will look like at the end of the Decade for each challenge, and what milestones are needed to achieve such success. Each challenge has a dedicated working group that is collaboratively writing a white paper on the strategic ambition. For Challenge 8, "create a digital representation of the ocean", the overall goal identified is to, "develop a comprehensive digital representation of the ocean, including a dynamic ocean map which provides free and open access for exploring, discovering, and visualizing past, current and future ocean conditions in a manner relevant to diverse stakeholders". This dynamic ocean map includes, but is not limited to, digital twins. It also encompasses data systems, and the importance of making data known and available to the people who need it.

The Transforming Climate Action (TCA): Addressing the Missing Ocean project, a Canada First Research Excellence Project, focused on the northwest Atlantic and led by Dalhousie University, Université du Québec à Rimouski, Memorial University and Université Laval. The project offers an integrated approach, necessary to reduce the uncertainty of the ocean, particularly with regards to climate, which must be done through improved observation and modeling. TCA aims to identify just and equitable climate adaptation methods, and to improve the infrastructure of data availability and the data being used to help understand and transform climate action, through transformation accelerators. Transformation accelerators (data management, policy, education and decolonization, and innovation and commercialization) have been designed to get research out of the lab and into the world for real application.

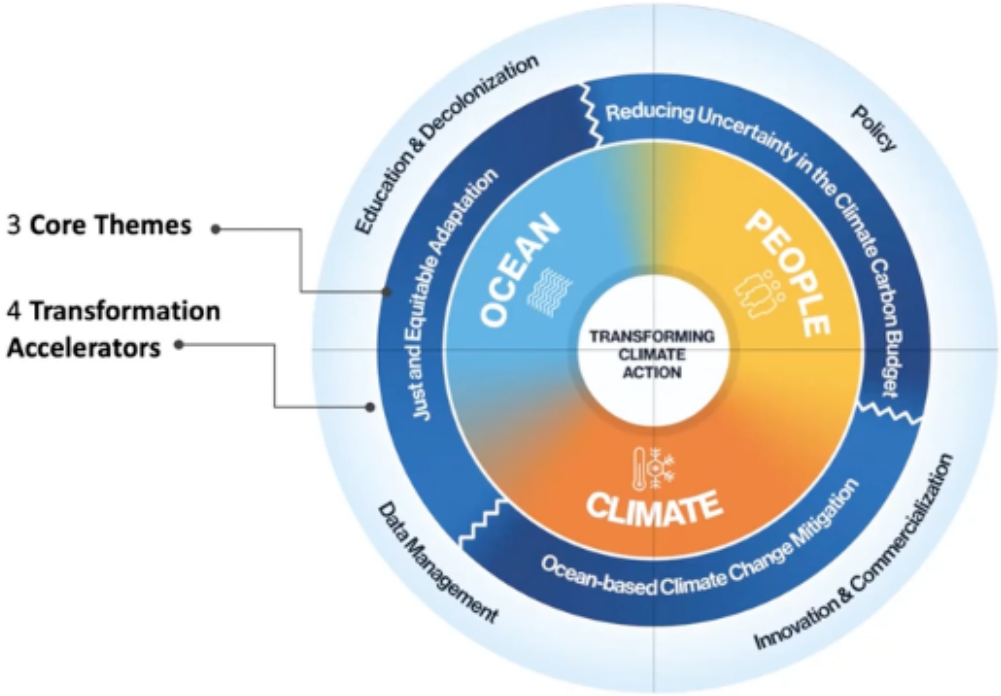


Figure 2. Structure of the Transforming Climate Action program.

Another important project being led by organizations in Atlantic Canada is the North Atlantic Carbon Observatory (NACO), which aims to turn intelligent observations and data into information outputs which can influence marine Carbon Dioxide Removal (mCDR) and climate forecasting to enable effective response to climate change. It is hoped that this effort will influence strategy and policy and increase public confidence in climate change mitigation efforts by getting reliable ocean information into the hands of those who need it.

DIGITAL TWINS OF THE OCEAN IN CANADA: BUILDING BLOCKS

By Isabelle Gaboury, Fisheries and Oceans Canada

Isabelle Gaboury is the National Manager for Modelling and Prediction within Fisheries and Oceans Canada's Ocean Science Program. She is located in Ottawa and works with scientists nationally on ocean research, modelling, analysis, advice, and services.

Isabelle's presentation focused on activities and data that exist in Canada and that could be utilized as building blocks for creating digital twins of the ocean, including research, ocean observation and monitoring, data management, ocean modelling and analysis, and services. The presentation also included a selection of case studies from Canadian ocean science.

Canada has the longest coastline in the world and has been monitoring the ocean for decades. This data and information are essential for assessing ocean health and productivity but also form a strong foundation for the development of digital twins of the ocean. The key building blocks for DTO are:

- Observing systems
- Data space
- Analytics and prediction engine
- Interactive provisioning layer (the means by which users and tools interact with the data)

There are many observing systems already in place that can contribute to DTOs, with platforms including ships, moorings, autonomous platforms, and satellites. Observing systems include long-term monitoring programs as well as targeted observations from platforms. Evolving technologies are making real-time and near real-time data increasingly available. The collection and sharing of ocean data is a collaborative effort from governments, academic, industry, citizen science and the nonprofit sector, both nationally and internationally. Examples of such activities are the Argo program for profiling of ocean conditions and hourly sea surface current maps derived from coastal radar stations.

Data spaces bring together diverse data streams to make them accessible and usable. This provides an opportunity to combine observational, derived, and model data for development of digital twins, but requires stewardship to ensure the data are accurate and reliable. Furthermore, data spaces must be supported by standards and frameworks to support the interoperability of datasets and systems. Applying internationally recognized data principles such as the FAIR (Findability, Accessibility, Interoperability, and Reusability) principles and the CARE (Collective Benefit, Authority to Control, Responsibility, Ethics) principles for Indigenous data ensures that data spaces and observing systems are managing data appropriately and ethically (Carroll et al., 2021). Examples of Canadian data space initiatives include the Canadian National Oceanographic Data Centre (CNODC) operated by DFO and the Canadian Integrated Ocean Observing System (CIOOS).

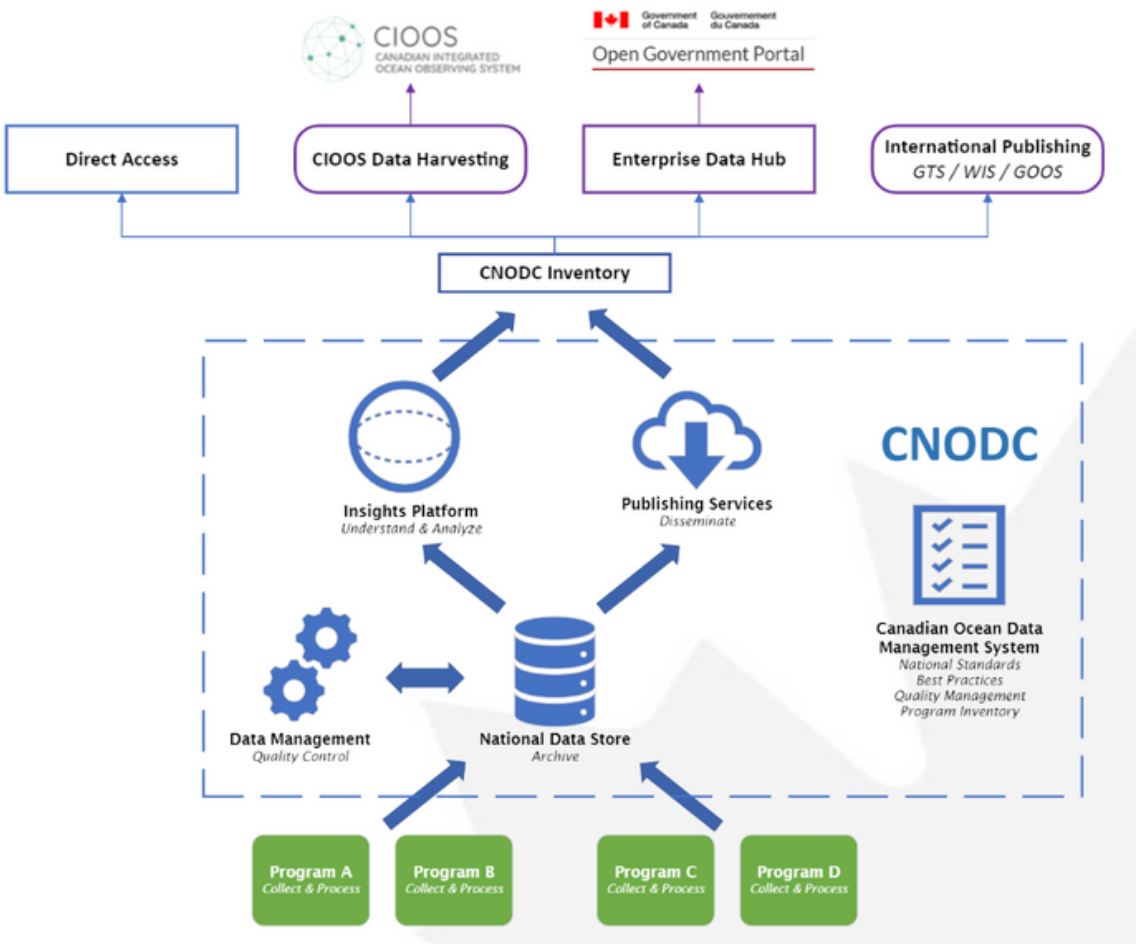


Figure 3: Framework for how the CNODC and its partners make data available to the public.

Data analytics and prediction systems build upon observing systems and data spaces to provide targeted, fit-for-purpose products and tools that provide information on past, present, and possible future ocean conditions, processes, and impacts. For example, collaborations such as the Canadian Operational Network of Coupled Environmental Prediction Systems and the Canadian Centre for Climate Modelling and Analysis advance science and applications relating to analysis and prediction of atmospheric, ocean, and ice conditions on scales from hours to centuries and from individual ports up to the entire globe. In addition to existing analytical and modelling approaches, this component of DTOs is an active area of exploration for emerging tools such as Machine Learning and Artificial Intelligence.

Finally, an interactive provisioning layer allows users to visualize and interact with data to meet their specific needs, either directly with DTO platforms or through machine-to-machine connections across multiple platforms. For example, the Ocean Navigator web interface allows users to access ocean information from both ocean observations and ocean models, and Dynamic Electronic Navigation systems are increasingly making it possible for mariners to access hydrographic products and live navigation services directly from the bridge of a vessel.

Despite the progress to date, additional development is needed to achieve full digital twins of the ocean for Canada. Areas of improvement needed to achieve this include expansion and increased interoperability of data repositories to create data lakes; greater capacity for on-demand and interactive numerical analysis and modelling; expanded platforms for data interaction, analysis and visualization; and improved DTO literacy among current and potential users and stakeholders. The UN Decade activities around digital twins of the ocean provide an exciting opportunity for Canada and other countries to collaborate and move toward successful national and international DTOs.

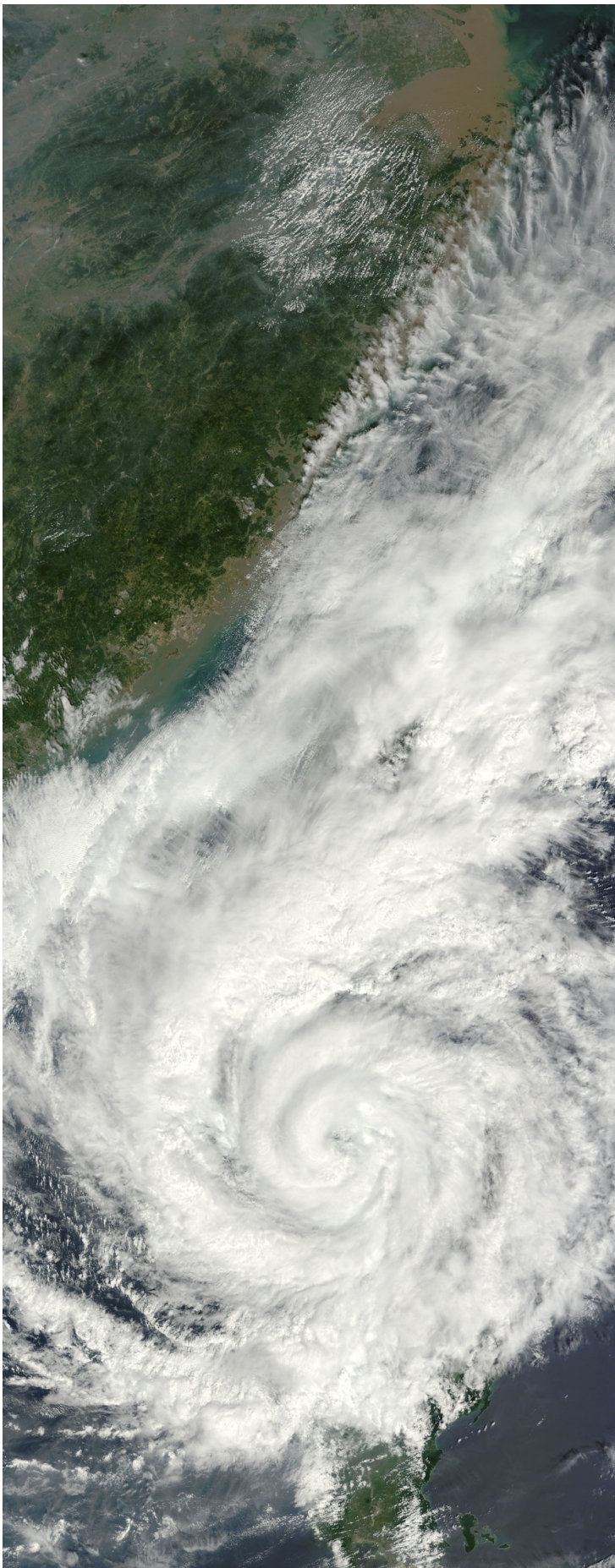
REVIEW OF THE 2023 CMOS CONFERENCE SESSION ON DIGITAL TWINS OF THE OCEAN

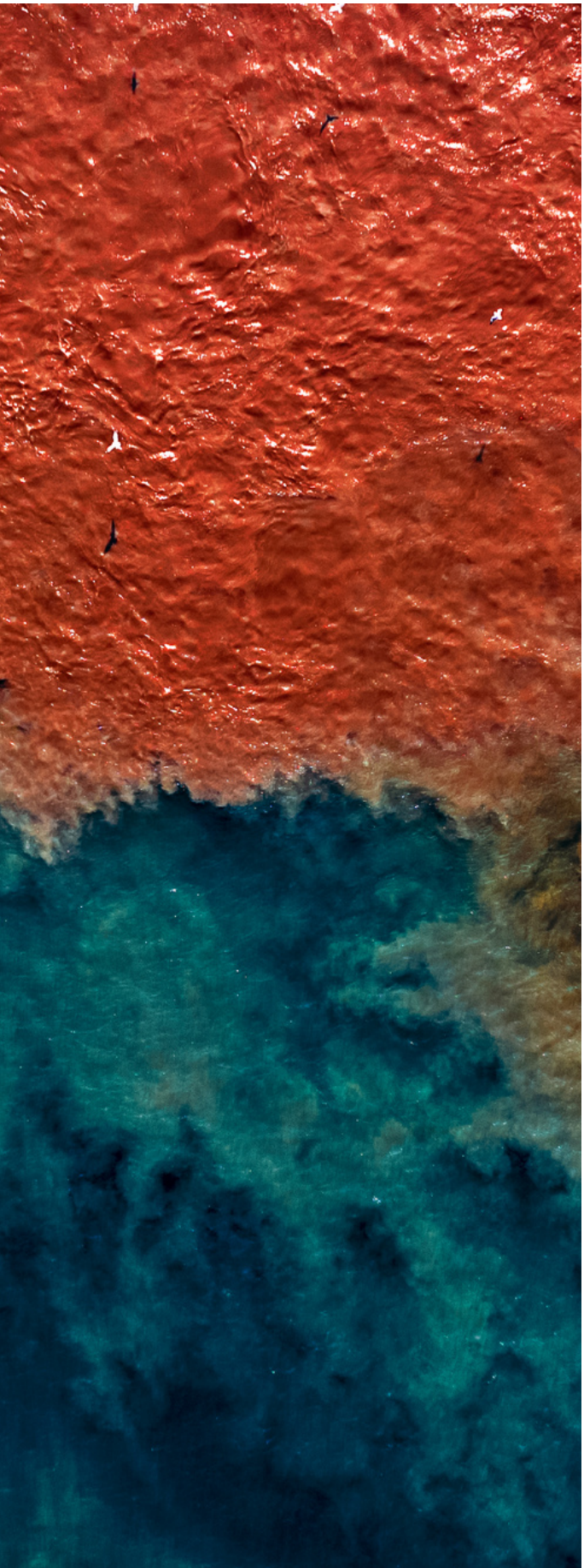
By Nancy Sootniens and Hui Shen, Fisheries and Oceans Canada

Hui Shen is a manager on ocean data and information, within Fisheries and Oceans Canada's Maritimes Science group. His background includes physical oceanography, satellite remote sensing, and operational oceanography. Nancy Soontiens is a Fisheries and Oceans Canada Research Scientist working out of the Northwest Atlantic Fisheries Centre in St. John's, NL. She specializes in ocean modeling and drift prediction. Recently, Nancy helped co-organize the scientific program of the 57th Congress of the Canadian Meteorological and Oceanographic Society (CMOS).

At this year's Congress of the Canadian Meteorological and Oceanographic Society, there were two dedicated sessions on digital twins of the ocean: (1) *Enhancing the Analyses and Applications of Ocean Observation and Modeling Data: Towards Development of Made-in-Canada Digital Twins of the Ocean* and (2) *Operational Applications Using Canadian Operation Ocean Forecasting Systems.*

Session one reviewed the status of available and future development of ocean observation and modeling data, introduced classical and novel methodologies of ocean data analysis, presented recent achievements in developing applications for ocean data, and discussed national and international collaboration opportunities in this space. There were nine presentations in this session, including presentations focused on Europe and the Great Lakes, with the final session focusing on "ideas and collaborations toward development of Canada's digital twins of the ocean". The foundational discussion from this session helped to guide the learnings of this webinar.





The DTO work in Europe is well centralized, coordinated and funded, building on over 20 years of operational oceanography (as outlined in this webinar by Alain Arnaud). In Canada, the foundation is in place for strong DTO development, including successful monitoring programs and climate modeling work (as outlined in this webinar by Isabelle Gaboury).

Session two highlighted that operational ocean forecasting in Canada has improved over the last many years due to the development of government-academic partnerships, international collaborations and the leadership of intergovernmental programs such as the Canadian Operational Network for Coupled Environmental Prediction Systems (CONCEPTS) and the Ocean Protection Plan (OPP). In Canada, ocean forecasts are being used in increasingly more applications, for various services including marine search and rescue, oil spill response and marine ecosystem monitoring, to name a few. The success of these applications is dependent on reliable service delivery mechanisms as well as strong engagement with the end-user. In this conference session, a variety of applications which use ocean forecasting systems to enable and support various operations were highlighted.

During the session, six talks and one poster were presented on various existing and developing applications, including CIOOS' new visualization tool for recreational ocean users (now called OceanConnect) and an operational drift monitoring tool developed by Environment and Climate Change Canada (ECCC) to support oil spill response. One common theme that emerged was that the availability and accessibility of ocean forecasts lead to value-added products and services.

Overall, this session demonstrated that the Canadian oceanographic community is interested in the development of digital twins of the ocean, and that multiple groups and platforms are investigating ways to disseminate and share oceanographic data and information. It is clear that an integrated Canadian approach would make digital twin development more efficient, but more resources, funding and intentional collaboration is needed to connect the dots and make tangible progress. Current DTO efforts in Canada are piecemeal, and while government, academic and nonprofit organizations are involved, more high level coordination is needed. A robust DTO solution for Canada with interdisciplinary collaborations and end-user engagement could allow for "specific-purpose DTOs" to be fully integrated within a national DTO.

ENHANCING OCEAN DYNAMIC ANALYSIS TOWARDS DEVELOPING DIGITAL TWINS OF THE OCEAN IN CANADA

By Youyu Lu, Fisheries and Oceans Canada

Youyu Lu is a Research Scientist with DFO, at Bedford Institute of Oceanography. He has over 30 years of experience in research in physical oceanography, ocean modeling, analysis of ocean variations, and applications for marine ecosystems and environment.

Youyu presented a case study of ongoing work in Atlantic Canada which will ultimately be useful for the development of a digital twin of the ocean. Canada's oceanographic research over the past few decades means there is a lot of ocean observational data, both in situ, for example, tide gauge, moorings, ship based, argo, gliders, and satellite remote sensing that can be utilized to develop DTOs. The models are quite realistic in terms of their setting and forcing, and have good spatial and temporal resolutions. The data and models can be used in complex dynamic and statistical (including AI) analysis, but to develop applications, the scientists developing them need to better understand user needs. Therefore, effective collaborations with many different disciplines is crucial. DTOs will improve the applications of ocean data and models for search and rescue, military operation marine transportation, marine conservation, fisheries management and aquaculture, etc.

In Youyu's example of working towards a digital twin for marine conservation in Atlantic Canada, historical observations and ice-ocean model data are being used, with the model data being tailored into indices operable for marine conservation applications.

The project is also studying ocean temperature variability and what drives this variability, by looking at rapid cooling in coastal water during cold-air outbreaks and interannual variations along the coast of Nova Scotia. Particle tracking modeling is being used to assess radiological risk from the nuclear generating station in the Bay of Fundy using a high resolution model. This assesses the radiological risk of planned and unplanned releases of tritium and cesium from a nuclear generating station including modeling hypothetical “what if'' scenarios.

While this work is still relatively new and exploratory, the development of DTOs in Atlantic Canada for multiple applications, including oil spill response, sea ice variations, ocean temperature variations and risk assessment is rapidly evolving and would be immensely valuable.

MARITIME MASTERY AND ANOMALY DETECTION: A DIGITAL TWIN SHOWCASE

By Joshua Barnes and Nabil Belacel, National Research Council of Canada

Joshua Barnes is a Data Scientist and Naval Architect working in the Data Science and Artificial Intelligence team of the National Research Council’s Ocean, Coastal, and River Engineering Research Centre. He has worked in research across several industries including environmental forecasting for marine operations, satellite remote sensing, and genomic data analysis in life sciences. He is currently focusing on the development of high fidelity simulation models for the maritime sector. Dr. Nabil Belacel is a Senior Research Officer at the National Research Council of Canada. His recent focus has been on the development of cutting-edge online machine learning algorithms tailored for streaming data that addresses a pivotal need in the era of rapidly evolving information streams, with a specific emphasis on Digital Twin technologies.

The National Research Council of Canada (NRC) has many diverse research centers. The two focused on digital twin development are ‘digital technologies’ and ‘ocean, coastal and river engineering’, represented by Joshua and Nabil, who presented on the DTO ambition at NRC.

Digital twins are high fidelity simulations, consisting of comprehensive layers of physical, numerical and machine learning models, which are validated using measured data, and data interoperability, with sensors modeled in silico and the ability to interface with real sensors. The layers need to be able to understand each other's environments and connect with each other's sensors. This is known as data interoperability - the key differentiator between conventional computer simulations and digital twins.

At NRC, the current focus is on ships and their ability to sense their environment, but there are also future plans to extend to coastal applications. NRC operates large scale test facilities, and the digital twins that are being developed can be used for informing energy and fuel consumption, resistance and propulsion, maneuvering performance, seakeeping and stability, amongst other applications.

NRC has formed a consortium with Memorial University and Virtual Marine to build a physical facility where numerical simulation and digital twin assets can be developed, remote operations can be piloted and data and models can be stored. This public-private-academic partnership will help to achieve the ambitious vision for digital twins of the ocean in a shorter period of time, with Memorial University leading on the testing of the effectiveness of new digital technologies aboard the bridges of ships, and Virtual Marine developing the marine simulators.

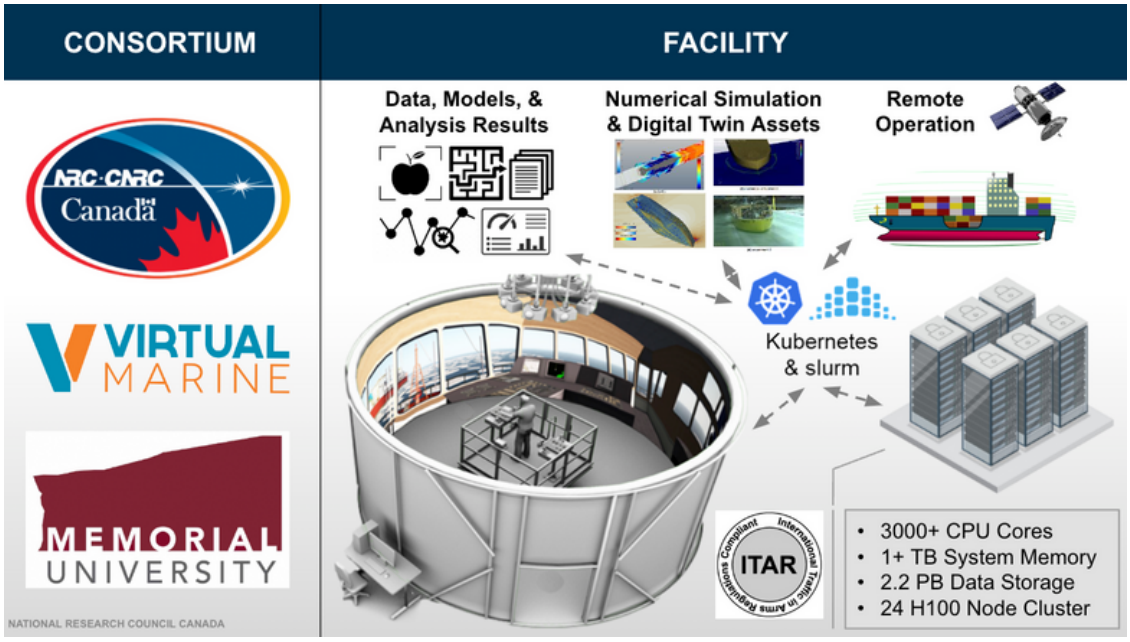


Figure 4: NRC's physical facility for developing digital twins assets, partnering with Virtual Marine and Memorial University.

NRC-OCRE aims to organize and lead Canadian efforts towards novel maritime digital technologies through partnerships with academic institutions, SMEs and other governmental departments. Ultimately, technology aboard ships will use digital twins as their brains, allowing for autonomous ships and remote operation of vessels.

Further applications of digital twins will allow for decision support technology which will increase vessel efficiency, optimize operations and increase safety at sea, as well as *in silico* testing of ship design, the development of desktop tools which can study the effects of climate change on maritime operations, and human-in-the-loop experiments to measure the efficacy of technology.

NRC is uniquely qualified to lead these efforts since it is a trusted partner across all economic sectors - routinely supporting SMEs and academics alike. Furthermore, their world-class physical testing facilities allow them to generate large datasets of controlled experiments, giving them the data necessary to train and validate the simulation models needed.

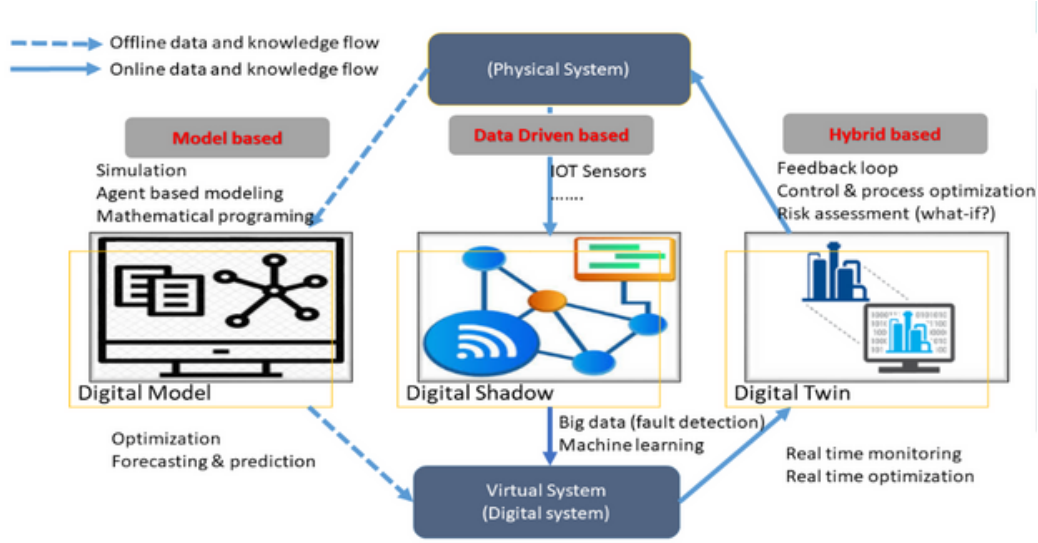
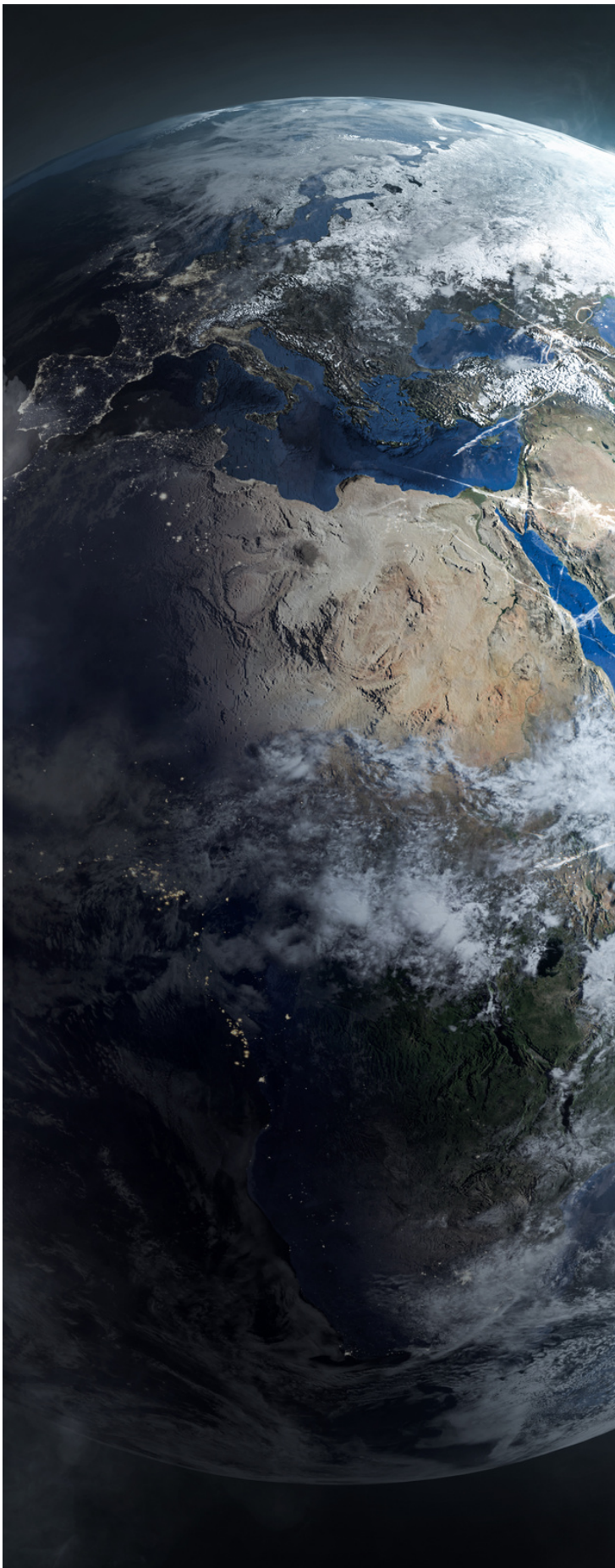


Figure 5: NRC's digital twin concept for real time monitoring.

Dr. Nabil Belacel outlined the concept of a digital twin for real-time ocean monitoring. Digital twins developed for controlled systems can be coupled with a digital shadow, which can go between the physical and virtual (digital) system. Data flows into the system and the digital shadow can take information from the physical to digital system automatically, allowing for anomaly detection, meaning that it can identify deviation from expected data. When there is a high volume, variety and velocity of data coming into a system, it is important to be able to process and analyze this data quickly, which requires smarter and faster algorithms; this is where anomaly detection becomes very useful.

Models need to be developed which can detect every anomaly in unlabeled data, quickly or in real time, without triggering a false alarm or requiring parameter tuning. It needs to be able to automatically adapt to changing statistics to be the perfect detector. This work is currently in proof of concept to be applied in ocean monitoring, using sensor data with tools that can analyze the data in real-time, but could have application for oceanographic monitoring, environmental sensing, aquaculture management and natural disaster early warning.

MOVING THE CANADIAN DIGITAL TWIN APPROACH FORWARD TOGETHER: OPPORTUNITIES, GOALS AND DESIRED OUTCOMES



By Fraser Davidson

This concluding presentation by Fraser highlighted the outcomes and next steps for this work in Canada.

Digital twins of the ocean will enable the full value chain and can ensure full information value from prediction and observing systems, in enabling the blue economy, safety at sea and information ocean management decisions effectively. The value chain requires big data content, in that large quantities of data are instantly accessible to the user, value added operations and models, and an interface (as outlined in Isabelle's presentation). Enabling the full DTO value chain will connect the world around and within ocean forecasting, and allow for effective decision making and management.

Digital twins will improve the transformation of advanced environmental information into relevant decision support information for a variety of applications including marine safety, reduction of property loss and damage due to climate change, and improved early warning systems for marine events.

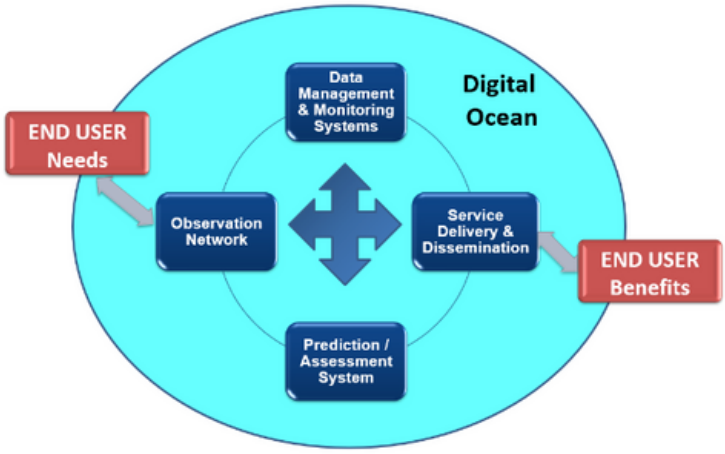


Figure 6: Value chain of digital twins of the ocean.

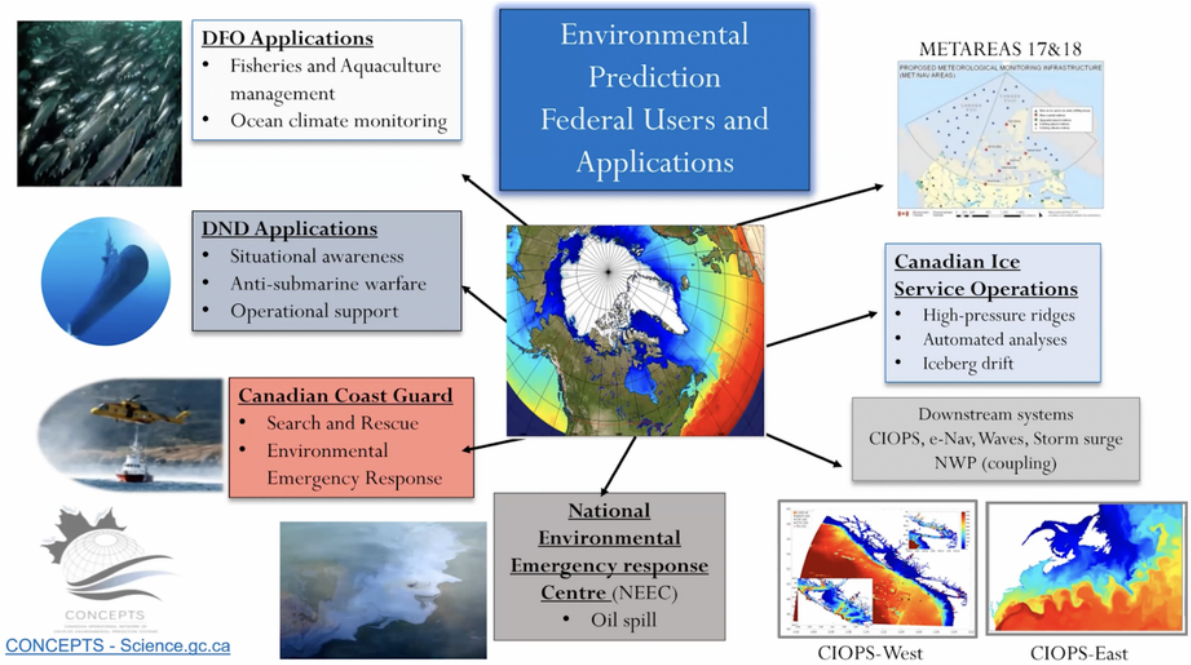


Figure 7: Federal users and applications of environmental prediction applications.

While digital twins of the ocean have an abundance of applications, there is more need for such applications in the coastal environment. The framework for ocean prediction is currently being developed under the UN Decade, and the operational oceanography value chain is maturing as a result. It is crucial that Canada connects to, and leverages, this international approach by working collaboratively with UN Decade endorsed programs and Decade Collaborative Centres (DCC) such as DITTO, Ocean Predict and DCC Predicted Ocean.

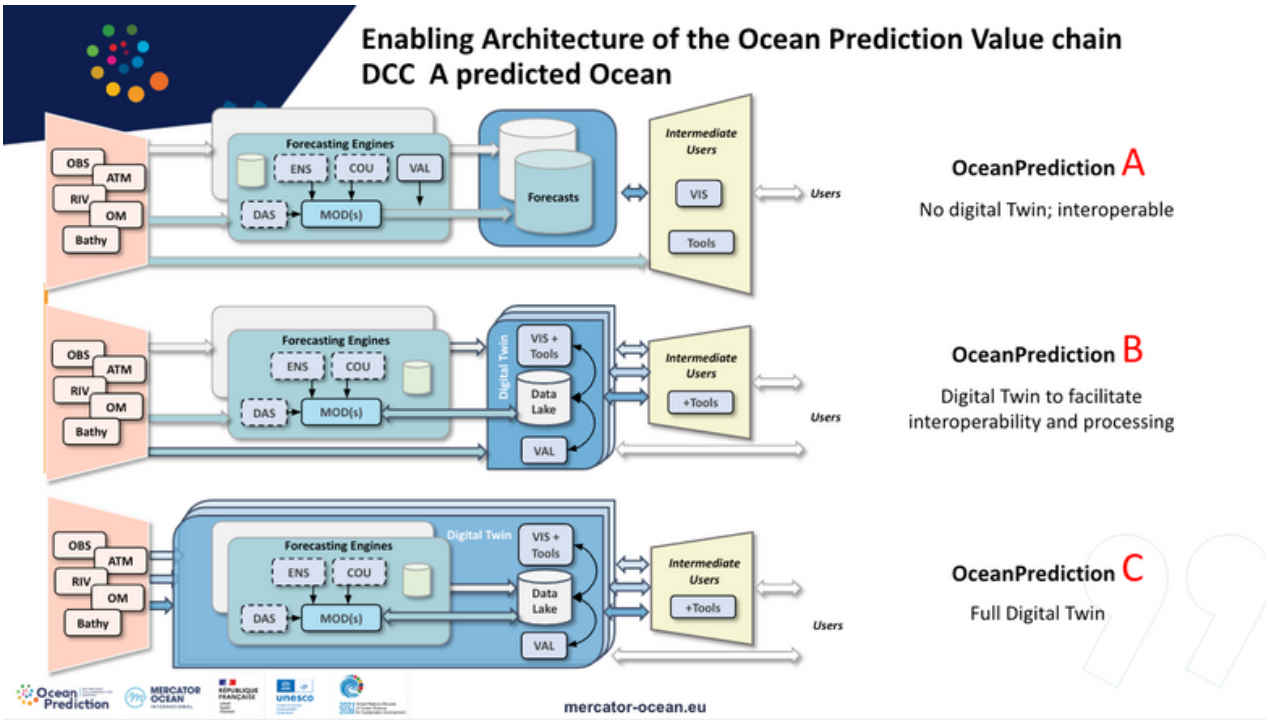


Figure 8. Enabling architecture of the ocean prediction value chain in different scenarios of DTO development.

In Figure 8, various options for the ocean prediction value chain are presented by the DCC Predicted Ocean. Canada is currently in scenario A, working on increasing interoperability of data and models, and moving towards scenario B. Scenario C would have forecasting engines as part of the digital twin, which would allow for "what if" scenarios. The ambition must be to work towards a full digital twin where different kinds of mitigation measures against climate change can be implemented as a result.

Digital twin technology enables cohesion between ocean observing and ocean prediction groups in Canada and internationally, and a co-designed, collaborative approach to developing the observing networks needed for digital twin development is crucial, to help identify key gaps. As outlined by the presentations in this webinar, Canada has great ambition for digital twins of the ocean but is currently in its DTO infancy, with a need for an overall vision and holistic approach, including viewing the digital ocean as part of the digital earth. Nonetheless, successful DTO development will enable better knowledge sharing across disciplines, create a decrease in time from idea to information product, and enable effective use of exascale computational environmental prediction output.

To maximize the potential of digital twins of the ocean technology, experts in Canada should collaboratively agree on a definition of success, and identify a strong vision for the digital twins to help create a digital representation of the ocean in the Ocean Decade. Over the next five years, success will see big datasets made accessible and hosted on supported servers, a development environment created for interfaces and AI work, multiple developed value added applications, as well as international leveraging of Canada's digital twin and leveraging of international digital twins by Canadians. Success will be achieved by moving from creating and pushing fixed products to clients to enabling the client to create the information they need from a comprehensive full ocean dataset.

By nature of a digital twin, this work cannot be done in silos. The community of digital twins experts and enthusiasts must work collaboratively, to develop best practices and standards, improve communication and awareness of existing efforts and ambitions, and think about the global framework and Canada's role in the big picture of digital twins of the ocean.

AUDIENCE PARTICIPATION POLLS

Acknowledging that this webinar was mainly one-way information sharing from DTO experts, we introduced a series of interactive polls throughout the webinar to better understand participants' level of expertise about digital twins of the ocean. Before the presentations began, participants were asked to submit up to five words that they would use to describe digital twins of the ocean.

Figure 9. Words used by participants to describe digital twins of the ocean at the beginning of the webinar.

Some of the most commonly submitted words appearing in the first word cloud included 'data', 'innovation' 'models' and 'collaboration', but also 'confused', 'overwhelming', 'curious' and 'difficult', perhaps indicating that most of the webinar attendees were relatively unfamiliar with DTOs and wanted to learn more.

We also polled participants about their level of expertise with DTOs, asking participants to self identify as having 'none at all', 'some familiarity' or 'expert' level of familiarity.

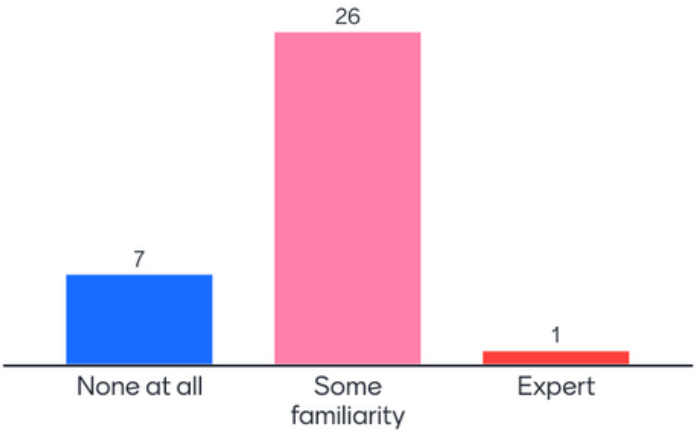


Figure 10. The graph shows that most participants (76%) indicated that they only had some familiarity with DTOs, 21% had no familiarity and only 1% claimed to be an expert.

Participants were asked if they were a user or developer of digital twins, to give an indication of how many participants are actively working with DTOs.

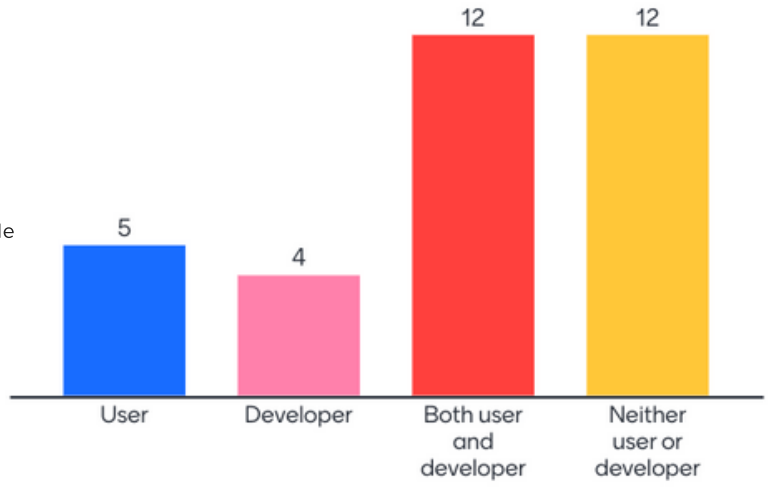


Figure 11. The graph shows that 36% of participants indicated they were neither users or developers, while another 36% indicated they were both users and developers. An additional 12% indicated they were DTO developers, and an additional 15% were users.

After the presentations were complete, participants were once again asked to submit up to five words that they would use to describe digital twins of the ocean. Our intention with the word clouds was to demonstrate any difference in participant perception between the beginning and the end of the webinar. We hoped that the presentations would be informative enough to result in an increase in words reflective of a positive view of digital twins of the ocean, or more informed response than at the beginning of the webinar. Overall, this trend was seen to some degree, and we hope that the participants took new information and knowledge from the presentations.

Figure 12. Words used by participants to describe digital twins of the ocean at the end of the webinar. While there were less responses to this poll (due to timing constraints), some of the most commonly used words in the second word cloud included ‘integration’, ‘interoperability’, ‘what if’ and ‘anomaly detection’.

Finally, we asked participants to indicate what kind of follow-up they would like to see from this webinar. The key word that emerged from this free text poll was ‘collaboration’, with the audience in agreement with the presenters that more collaboration is needed across Canada on DTO development. Some suggestions for further collaboration included workshops, development of a national DTO strategy, connecting with end users for input and feedback, and sharing best practices.

CONCLUSIONS AND NEXT STEPS

This webinar was a starting point to bring together the various groups in Canada actively working on digital twins of the ocean, and the organizing group hopes to stimulate more collaboration across Canada in 2024. For example, a DTO-themed session during CMOS 2024 is intended to bring collaborators together to create a shared vision for DTOs in Canada.

Ocean Decade activities in 2024 include the Ocean Decade conference in Barcelona, which saw the ten working groups for the Decade challenges present their white papers as the culmination of the Vision 2030 process. New Decade actions will continue to be endorsed through regular calls for actions, which provides an opportunity for new collaborations around DTOs in Canada.

Additional webinars, workshops or simple information sharing around DTOs and any relevant activities under the Ocean Decade will also help to improve coordination and reduce duplication of effort.

If you are interested in being a part of ongoing DTO activities in Canada, please contact the authors of this report.

ACRONYMS / TECHNICAL LANGUAGE

AI: Artificial Intelligence
CARE: Collective benefit, Authority to control, Responsibility, Ethics
CIOOS: Canadian Integrated Ocean Observing System
CMOS: Canadian Meteorological and Oceanographic Society
CNODC: Canadian National Oceanographic Data Centre
CONCEPTS: Canadian Operational Network of Coupled Environmental Prediction Systems
DCC: Decade Collaborative Centre
DFO: Fisheries and Oceans Canada
DITTO: Digital Twins of the Ocean global programme under the UN Ocean Decade of Ocean Science for Sustainable Development
DTOs: Digital Twins of the Ocean
ECCC: Environment and Climate Change Canada
EDITO: European Digital Twin of the Ocean
EMODnet: European marine observation and data network
ESA: European Space Agency
EU: European Union
FAIR: Finable, Accessible, Interoperable, Reusable
HPC: High Performance Computing
OPP: Ocean Protection Plan
MOi: Mercator Ocean International
NRC: National Research Council of Canada
OCRE: Ocean, Coastal and River Engineering Research Centre
SMEs: small and medium-sized enterprises
TCA: Transforming Climate Action

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