DITTO Programme Whitepaper

[Draft]

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V1	May 2022	For discussion/input through the 1st Digital Twins of the Ocean Summit

SCOPE

The paper provides an initial outline of the concept of Digital Twins of the ocean and lays out the challenge, opportunities for action and suggestion for their implementation for development.

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1. Executive Summary

Digital twins are virtual representations of objects and systems - the real twin (in this case the ocean system or a part of it). The concept of digital twins has been widely used in engineering and has more recently been adapted to earth system applications. Digital twins provide the ability to make informed operational, management, and policy decisions about the real twin.

Digital twins build on an observing system and predictive processes or data-driven models that users can interact with to support their needs. The connection between the digital twin and the real one requires a well-formulated interface between the digital twin, environmental data, and the user. User interaction is therefore an essential function that is embedded in the design of digital twins, including visualisation, user-driven data transformation and data-science tools.

Thus, Digital Twins will enable users to address 'What if' questions based on shared data, models and knowledge. They empower ocean professionals, citizen scientists, policymakers, and the general public alike to visualise and explore ocean knowledge, data, models and forecasts. The use of Digital Twins is wide and rapidly developing spanning a wide range of use cases from engineering to policy to science to operational services.

The UN Ocean Decade Program DITTO will establish a framework for Digital Twins by promoting co-design of twins, establishing and sharing good and best practice, enabling interoperability and promoting education and uptake to demonstrate and realise the value in the Digital Twins.

2. Digital Twins explained

Programatics

The Digital Twins of the Ocean (DITTO) Programme is part of the UN Decade of Ocean Science for Sustainable Development and brings together actions from around the world.

The Vision of the Digital Twins of the Ocean (DITTO) Programme is a world where digital twins are used to support ocean science, ocean protection, ocean governance and a sustainable ocean economy. The Mission of DITTO is to develop and share a common understanding of digital twins of the ocean, to establish best practice in their development, and to advance a digital framework to empower ocean professionals from all sectors around the world to effectively use digital twins.

DITTO will promote co-design of twins with targeted end users, raise awareness of their uses and applications, and demonstrate their potential for decision making across multiple sectors including ocean governance.

Characteristics of Digital Twins

Digital twins are virtual representations of physical objects and systems - the physical or real twin (in this case the ocean or a part of it) - which have been widely applied in the engineering realm for tasks such as engine optimization and port management. Digital twins include predictive and data-driven models that users can interact with to support their needs. Digital twins thus provide the ability to make informed operational, management, and policy decisions for the real twin. This connection between the digital twin and the real one requires a well-formulated interface between the digital twin, environmental data, and the user. User interaction is therefore an essential function that is embedded in the design of digital twins, including visualisation, user-driven data transformation and data-science tools.

Why Digital Twins of the ocean?

A **Digital Twin of the Ocean (DTO)** is a virtual representation of the real ocean that has a two-way connection with it. Observations from the real ocean, in combination with models, data science and artificial intelligence, are used to create a digital twin that adapts as the real world changes. Manipulating the twin to address 'what if' scenarios can provide information for decision-making and highlight regions of the real ocean in need of better or different observations. A well-constructed digital twin of the ocean will enable a wide range of users to interact with ocean data and information to improve understanding and inform decisions and can support ocean literacy and ocean understanding. They can be used to explore ways in which the ocean will respond to a changing set of conditions, providing a powerful tool for decision making. DTOs will provide ocean researchers, professionals, citizen scientists, educators, policymakers, and the general public alike with the capability to visualise and explore ocean knowledge, data, models and forecasts.

The fundamental building blocks

An adequate and increasingly accurate **Observing system** co-designed between

users and developers of the observing networks needed for digital twins of the ocean will create a positive and continual feedback loop between both where information from the digital twin can be used to inform and optimise the observing network whilst benefiting from it.

A fit for purpose **Data Repository** (i.e., as central or distributed data space or data lake) that provides access to ocean observations through data communication and management in a timely way following common data principles. These principles include tailored computing capacity (often cloud based), an information management framework, a forum for setting data standards and protocols, and a system for data mapping architectures and data lineage to track data transformations. The aspect of (data) interoperability also is an important topic to be considered when creating Digital Twins of the Ocean.

A **Data Analytics and Prediction Engine** to maximise the understanding and value from these data, that provides tools to add value to ocean observation through predictive modelling, emulation, and artificial intelligence / machine learning to create, manipulate and analyse marine information. Digital twins incorporate the additional capacity for the user to modify the prediction engine to explore options, scenarios, and consequences.

An **Interactive and Provisioning** layer allows users to visualise, interact with and tailor the data, scenarios and models to meet their needs as a powerful interface to the information and tools in the data engine that is easy to adapt and use, and represents one of the characteristic features of digital twinning. These provisioning layers are tailored towards human users and are often visually pleasing front-end interfaces with easy, intuitive access. Machine-to-machine provisioning is also common, in which case the provisioning layer is tailored to enable federating with other twins or systems.

Systems perspectives and needs

Comparisons of existing and planned Twin architectures, interoperability standards, sharing of good and best practices and community-based learning. We must secure investments in long-term sustainable observations and promote development of capacities, which will raise the accuracy of our models and predictions.

An Outreach and Training capability to enable full participation of developers, experts and users in digital twins' environments respecting the capabilities and realities of the diverse international communities. In some areas the uptake of the concept of DTs is still incipient, possibly due to limited regional technical capacities combined with deficient sustainable access to marine technologies and research platforms. The success of the adoption of DT in these areas depends strongly on local reality which may be dictated by the social vulnerability, low growth, as well as high contrasts and inequalities.

Digital twins are not new. However, their application to the earth system and ocean domains is relatively recent. Support to develop international capacity and capabilities is needed to ensure that observations and other data are accessible through appropriate Data Spaces, that models and analytics systems are available and usable to all and that DTO information can be developed and applied to serve diverse international communities' user needs.

3. Supportive ocean observations and data systems

SUMMARY

An adequate and increasingly accurate ocean observing system co-designed between users and developers of the observing networks needed for digital twins of the ocean will create a positive and continual feedback loop between both where information from the digital twin can be used to inform and optimise the observing network whilst benefiting from it.

Possible actions include:

- Partner with nations to identify gaps in ocean observing data sharing, and establish strategies on how to address them.
- Establish links with actors from the maritime sector including offshore energy, shipping, mariculture and tourism to explore the provision of additional data.
- Identify additional information needed other than EOVs; ocean use, topography, traffic, marine spatial planning, human impact and pressure, etc.
- Strong link to the data lake and interoperability, and data analytics WGs.

CHALLENGE

Digital Twins have the ambition to provide an accurate representation of the ocean system. Thus they require an ocean observing system that can describe with an adequate accuracy the current state of the ocean system. Clearly, today the ocean is under-observed and the establishment of digital twins will put increasing demands on accuracy and coverage of ocean observing systems. While many digital twins will operate regionally, they often require input to their open boundaries from a more global system. Thus, we expect a productive co-design process to advance ocean observing systems.

A key challenge is to secure the needed resources for infrastructure, personel (capacity development) and observation networks and ensure they are sustainably grow and maintain an inclusive and fit for purpose observing system framework for digital twins to operate properly.

An equally key challenge is ensuring inclusivity and the need to engage local communities, society and scientists in ocean observing activities that support DITTO. Part of this challenge is the limited access to marine technologies and research platforms in a sustainable way, lack of know-how and easy to operate instrumentation and platforms. Local actors (scientists, the public and stakeholders) are better equipped to act as knowledge brokers within their local social-political contexts thus helping co-design and fit-for-purpose scenarios and solution generation.

There are large observational gaps for many essential ocean variables (EOVs) and their spatial and temporal coverage. For many twin challenges there is simply not enough data to adequately initiate or verify the digital twin. We might find a place to have integrated ocean observations to make a testbed / pilot for the digital twin. We need to identify the most mature / observed EOVs as good candidates for an early digital twin pilot.

We can also identify the least observed EOVs and thus identify priorities for further development.

We have extended the global coverage of ocean observations at coarse resolution. However, there are still gaps and in particular in the very dynamic coastal ocean. In the same context, we put efforts to build operational observing systems capturing most of oceanic variability with limitations of instruments and budget. However, we still have temporal gaps and need to increase sampling rates.

Not all observations are easily or fully available for the DT. By implementing FAIR and CARE principles, we can promote and ensure open access to more data and thus narrow down observational gaps. Another challenge here is to share best practices to handle observations and to conduct data quality assurance and control appropriately, and to supply meta data of sufficient granularity following accepted standards. We need to grow and foster a culture of data sharing in ocean observing. We also need to create incentives to make data available, for instance data-papers in peer-reviewed journals like ESSD, and create structures that make it easy and desirable to share data - technically and also politically. This can be a barrier in many nations, since some data are considered sensitive or withheld from private actors to secure exclusive economic benefits.

AREAS FOR ACTION AND PARTNERSHIPS

Thus, there is an opportunity to network with identifying priority / focus areas based on gap analysis in a view of the digital twin, the data assimilation technique can connect observations and numerical models at a reasonable level. Sustainability of observations needs to be ensured. Today the majority of in-situ ocean observations are made on short-term science funding. Moreover, latency of data delivery is sometimes an issue for different delivery areas.

A number of key partners for activities and connections have been identified. First and fore most national agencies with an ocean observing mandate will be very important partners to grow and sustain the ocean observing systems in particular within national exclusive economic zones and their coastal regimes.

The international ocean observing supporting frameworks and networks of the Global Ocean Observing System (GOOS) and their projects and regional substructures will be a key partner as well as remote sensing capabilities coordinated by the Committee on Earth Observation Satellites (CEOS) and the national and regional space agencies.

Work with private sector maritime actors and civil society to explore new streams of observational data from their respective platforms and activities.

The UN Ocean Decade and its Decade Collaboration centres (DCC ocean prediction, DCO on data, a possible DCO on ocean observing) as well as other UN decade endorsed programmes: Observing Co-Design, CoastPredict, etc. (e.g., https://www.oceandecade.org/decade-actions/)

IMPLEMENTATION

In the next 12 months there is an opportunity to.

Partner with nations to identify gaps in ocean observing data sharing, and establish strategies on how to address them. During those discussions one should: Make a case for the utility of data to serve many users (measure once, use many times). Make a case to national and regional governments to observe EOVs, and share data. Make it mandatory to share data in order to get funding. Certain kinds of data (non-sensitive) to be shared.

Establish links with actors from the maritime sector including offshore energy, shipping, mariculture and tourism to explore the provision of additional data.

Identify additional information needed other than EOVs; ocean use, topography, traffic, marine spatial planning, human impact and pressure, etc.

Strongly link to the data lake and interoperability, and data analytics WGs, if there is overlap and need to communicate and link (cross-reference).

Can local archives be checked and digitised to support a DT historic aspect, targeted to a specific audience.

4. Data analytics and prediction engines

SUMMARY

A Data Analytics and Prediction Engine to maximise the understanding and value from these data, that provides tools to add value to ocean observation through predictive modelling, emulation, and artificial intelligence / machine learning to create, manipulate and analyse marine information. Digital twins incorporate the additional capacity for the user to modify the prediction engine to explore options, scenarios, and consequences.

Possible actions include:

- Develop high-resolution model setups for the coastal regions that aid in decision making for climate-change related changes that affect coastal infrastructures and islands.
- Pre-defined quality controlled what-if scenarios that explore different outcomes with applications in climate change, marine spatial planning and ecosystem-based decision making.
- Develop tailored data analytics and predictive capabilities based on machine learning and artificial intelligence that provide the Digital twin with its necessary functionality (monitoring vs. alerts vs. decision making).

CHALLENGE

The challenge with hydrodynamic and biological ocean modelling is the time needed (performance) and requirement to data storage when run operationally and in high resolution (time and space). Depending on the purpose of the Digital Twin this will require high-performance computational infrastructure (HPC) and performant storage units as well as performant access to ocean observations for reanalyses. However, developments in the field of machine learning (ML) and artificial intelligence (AI) in recent years deliver promising means to address these challenges.

Digital Twins for coastal areas will have different requirements to spatial and time resolution than Digital Twins for the open ocean, Digital Twins for disaster response will have other requirements to time resolution and prediction accuracy than climate change scenarios. This will challenge the development of data analytics and prediction engines also to include interoperability aspects to leverage developments from other Digital Ocean Twins and other ocean areas. This aspect will also include the separation of data and data analytics with the opportunity to bring data processing to the data, and to leverage newest technology.

AREAS FOR ACTION AND PARTNERSHIPS

Thus, there is an opportunity to network with ocean modellers and data scientists from all over the world to gather the best available technology and opportunities in the field of data analytics and predictions. Key elements to be developed during the Decade to support the worldwide implementation of the architectures include:

- Data sources, with the objective of linking/facilitate access to the existing entry points.
- Software Tools: Understood as a software component adopted by the community to be a part of the value chain, including AI elements.

- Best practices: methodologies that repeatedly produced superior results relative to other methodologies with the same objective
- Standards: standards have the same objectives as best practices, but the difference is that they may serve as benchmarks for evaluation in addition to being processes.
- Establish operational readiness levels (ORL): An ORL index to establish the milestones for service evolution and describe its degree of maturity. It considers all aspects of an operational system.
- Identification of required improvements in the value chain to improve the application of models and data sciences in the decision making process.
- Partnerships are critical to achieve the Data Analytics and Prediction Engine objectives. Such collaboration include:
  - Other Ditto WG, to ensure consistency and coordination. More specifically, a special close dialog is needed with:
  - Data lakes and interoperability, to understand the findings of this team and include it on the architecture considerations.
  - Architecture, design, and implementation, to understand the flow of data and information in Digital Twins
- Expert Team on Operational Ocean Forecast Systems (ETOOFS): To understand its role on the final architecture and how this body will contribute to the certification processes.
- Other Decade programmes, especially with:
  - BestPractices, to ensure coordination on the definition of Standards and Best Practices
  - Foresea, to exploit complementary visions and align properly the work
  - CoastPredict, to ensure the link with the coastal activities
  - OceanPredict and its Task Teams, specially Intercomparison and Validation TT and Coastal TT, to incorporate the proper scientific background
- Decade DCC and DCU different from DCC-OP, to ensure alignment towards decade objectives.
- User experience and communication experts, to identify how models and data sciences can be applied for decision-making and explore the limits existing in doing so
- Private sector, to understand their needs and expectations.

IMPLEMENTATION

In the next 12 months there is an opportunity to establish close collaboration between the different UN Decade programs that have similar requirements to data analytics and predictions.

5. Data lakes and interoperability

SUMMARY

A Data Repository (centralised or distributed) will provide access to ocean observations and the output from predictive systems through data communication and management in a timely way following common data principles. These principles include an information management framework, a forum for setting data standards and protocols, and a system for data mapping architectures and data lineage to track data transformations. The data repository will be connected to the data analytics and prediction engine.

Possible actions include:

- Definition and guidelines to describe the required data repository for each Digital Twin.
- Define and describe interoperability aspects for different data from a variety of sources.
- Close collaboration with different data strategies and groups that address these strategies (Dataspaces, distributed data repositories, edge computing)

CHALLENGE

The challenge with ocean data is its spatial and time dimension which might differ between observations, modelled data and other (unstructured) data like video or images or indigenous / citizen data. This variety affects interoperability of different data and requires specific pre-processing of data before they might be used within a Digital Twin. The amount of available data is increasing at a significantly higher pace than capacity for data transfer which means that data needs to be handled, accessed and processed close to its source and data repositories move from being centralised to be distributed. There are several well-established data curation activities across the globe that have started addressing these challenges.

AREAS FOR ACTION AND PARTNERSHIPS

Thus, there is an opportunity to establish a dedicated network with partners that contribute to developing a Digital Twin of an ocean area as part of Digital Twins of the Ocean and discuss opportunities and guidelines for data observation, data repositories and best practices. Together with the UN Decade Data Coordination Group and similar collaboration activities with the private sector partnerships for tailored Ocean Twins can be developed accordingly. National governments can join forces with neighbouring states to develop Digital Twins of their seas and oceans. Initiatives like this might build on Interreg activities or the EU Mission which bring together partners from the different ocean basins.

IMPLEMENTATION

In the next 12 months there is an opportunity to establish a global collaboration framework on ocean data to discuss and address requirements to data acquisition, storage and handling that result from different policies and sources or data.

The development of this framework needs to include participants from science, governments and the private sector to account for the different perspectives on data from these stakeholders.

6. Interactive layers and visualizations

SUMMARY

The Interactive and Provisioning layer, a characteristic feature of digital twinning, is a powerful, adaptable and easy to use interface that allows users to visualise, interact with and tailor the data, scenarios and models to meet their needs e. Provisioning layers are catered to human users and are often visually pleasing front-end interfaces with easy, intuitive access. Machine-to-machine provisioning is also common, in which case the provisioning layer is tailored to enable federating with other twins or systems.

Possible actions include:

- Make inventory of existing visualization strategies in sciences, serious gaming, infographics, and the Internet.
- Make inventory of existing DTOs and how specific audiences are defined and integrated.
- Dynamically fine-tune provisioning layers to cater to the needs of specific audiences.
- Seek close collaboration with groups that develop these strategies.

CHALLENGE

A Digital Twin must visualize data and provision access to analytical tools that cater to the needs of wide-ranging audiences, with wide ranges of objectives and interests. The challenge here is to provision access to data and analyses with just enough detail to be useful. This equally applies to visualization strategies, where visualized data and data patterns must meet the often implicit expectations of audiences. Whereas the ability to discover and disseminate data has seen great advanced through the establishment of metadata standards, such advances have not yet been made to commonly describe the abilities of analytical tools and visualisations, which inherently complicates the ability of automated systems to cater to even less easily quantified policy objectives and user expectations. As such, the major challenge to interactions and visualizations of a DTO will be to serve up relevant data, using relevant visualizations, from relevant models and /or prediction engines, to provide users and machines with a meaningful connection to the DTO.

AREAS FOR ACTION AND PARTNERSHIPS

Thus, there is an opportunity to establish a dedicated network with partners in science, the (gaming) industry and policy makers to discuss visualization and data provisioning strategies with the aim to establish case-specific best practice guidelines. In separation, scientific visualizations and serious gaming approaches can be unified to develop generic feature rich and flexible provisioning layers for the construction of specific Digital Twins of the Oceans. Especially here is an opportunity to seek collaboration between DTO implementing networks, UN Ocean Decade projects, serious game developers, and the global Marine Spatial Planning community.

IMPLEMENTATION

As a first step, collaborations should be sought with existing activities that are in the process of conceptualizing and constructing DTOs, and to seek dialogue to establish standards and best practices to allow homogenization and standardization of visualization engines, data provisioning, and interaction with analytical models. Here, in particular, DITTO can play a key role.

7. Framework - architecture, design and implementation

SUMMARY

The true impact of Digital Ocean Twins will depend on their **complementarity**, i.e. complementarity between oceans, models and data which in turn depends on **interoperability** between these aspects. Interoperability can be achieved through defining the meaningful **building blocks of Digital Twins of the Ocean** as well as a functional and flexible **architecture** that accounts for existing systems, recognised architecture models and **technology** developments that are relevant for Digital Twins. Such an architecture needs to acknowledge related strategies on data sharing and twinning, like e.g. the Destination Earth (DestinE) that aims at creating a digital replica of our planet where Digital Twins of the Ocean will play a crucial role.

Digital Twins of the Ocean will emerge for different areas, in different qualities and for different purposes. A co-created architecture framework for these twins will ensure interoperability and thus complementarity,

Possible actions include:

- Establish an operational working group and contact point for Digital Twins of the Ocean developers.
- Conduct a series of workshops to establish definitions and cornerstones for Digital Twin architectures with a focus on interoperability and federation.
- Participate in relevant fora on Ocean data and Digital (Ocean) Twins to promote the working group and its results.

CHALLENGES

Interoperability: Digital Twins of the Ocean will be systems of Digital Ocean Twins that have been developed a) for a specific ocean area and b) for a specific purpose. These purposes may range from monitoring of environmental parameters or habitats to climate change assessments for a wider area of the global ocean. That means that there will be a variety of Digital Ocean Twins that should be capable of interoperating.

Dissimilarity: Digital Twins or similar systems have already emerged or are about to be developed. The approaches and technology stacks of these twins can be very different with respect to quality, resolution in time and space and sophistication and ease for access to the twin.

Definition: There is a common understanding in the scientific community that there are 3-5 specific building blocks that comprise Digital Twins of the Ocean:

1) (near) real-time data from observations (in-situ sensors, satellite) feed into the twin and ensure that the twin changes together with its twin environment

2) Data repositories contain Digital Twin relevant data and are updated frequently with data from 1) or 3). They are accompanied by metadata repositories for machine-to machine interaction.

3) Data processing capabilities include (but are not limited to) ocean models (hydrodynamic, coastal dynamics, ecosystem dynamics) for the physical, chemical and biological representation of

the ocean, often referred to as the blue, green and white ocean, AI analysation and processing capabilities fuse model data with data from observations, and AI predictive models extend environmental predictions beyond their current limitations.

4) Computing infrastructure to host data processing and re-runs of models (reanalyses, what-if scenarios). These may range from edge computing (on the sensor carrier) to cloud or include HPC clusters.

5) A user interaction layer which might be as simple as a dashboard, as sophisticated as AR/VR immersive visualisation or anything between those two including feedback into the twin to run what-if scenarios or trigger actuators and alerts.

In some architecture approaches, 3) and 4) are considered as one block, while others even consider 2), 3), and 4) as one block.

Rapid technology development in the field of sensor technology, edge computing and software for user interaction with data offer unprecedented possibilities and opportunities for Digital Ocean Twins but come with the challenge to define a robust and accepted Digital Twins of the Ocean architecture framework that secures interoperability of different twins on one hand while allowing to account for future innovations and variety at the same time.

AREAS FOR ACTION AND PARTNERSHIPS

Currently there are a number of initiatives that work toward or in support of a Digital Twin of the Ocean, e.g. the EU strategy for the Digital Twin Ocean, NOAA's National Centre for Environmental Information, the IOC Ocean Data and Information System ODIS, the IOC Ocean Best Practice System OBPS, the Ocean Data Action Coalition and the UN Data Coordination Group, only to name few.

Thus, there is an opportunity to network towards one of DITTO's priority activities to '*articulate and advance a common understanding of Digital Twins of the Ocean architecture*'.

IMPLEMENTATION

Partners from the above-mentioned and other initiatives have joined forces to discuss different architectures that support interoperable Digital Twins of the Ocean. In the next 12 months and beyond there is opportunity and motivation to to coordinate ongoing initiatives and to interlink ocean-oriented digital twins to one another, as well as to existing and emerging data systems, cloud capacities, and other digital resources.

Specific topics that will be addressed include:

- to apply and extend existing interoperability architectures to support coordinated development and operations of digital twins in the ocean domain,
- to ensure that digital twins are able to interoperate with diverse ocean data systems, to both acquire and deliver data and information products, models, and other digital assets,
- to combine data, models and information across different Seas, domains and stakeholders through a system of systems to accommodate different existing assets and digital ocean twins,
- to accompany and support the development with an interoperability dataspace and best practises for ocean data acquisition and sharing,

- to identify where cross domain digital twin interoperability is required

8. Education, training and capacity development

SUMMARY

Digital Twins of the Ocean take advantage of the increasing number of ocean observations from a wide range of sources, the ability to curate and share those data in public data repositories, to fuse the data with ocean predictions systems and the ability to build decision support systems, that we call digital twins of the ocean. The design, operation and deriving benefits from those systems require a digital literate ocean community of practice around the globe and across sectors and disciplines. Take advantage of existing and implement new opportunities by working with appropriate networks, programs and projects to facilitate education and training in the area of digital ocean technology and in that sense builds the needed capacity globally.

Possible actions include:

- Establish a pilot program for a professional master degree program in “Digital Ocean Data Science and Engineering” that would be offered by a combination of digital lecture modules and on-site practical at a network of universities
- Liaise with other Ocean Decade efforts and promote summer schools, lab rotations and other international opportunities
- Consult with the ECOP community and discuss opportunities of global mutual learning and exchange of expertise using peer-to-peer networks

CHALLENGE

The challenge is that there is a rapidly increasing number of digital platforms and structures that provide access to meta-data and data holding in the marine domain. Depending on the type of data those holdings are well organized, easy to access or at times more poorly documented and harder to access. At the same time potential users of this information often lack the training and knowledge to search for those holdings and access the information within. This lack of capacity is true globally but has different gaps in different regions. In the global north there tend to be more people who in principle have the background and means to access the information, but often lack the knowledge where to find it. In the global south often some of the basic digital literacy is lacking. And most regions and application sectors are somewhere in the middle.

AREAS FOR ACTION AND PARTNERSHIPS

Thus, there is an opportunity to network with other actors in this space who are in the process to develop training opportunities and provide capabilities. For example, there are a set of actors promoting the advancement, operation and delivery of the ocean observing system associated with programs such as GOOS, GEO Blue Planet and POGO. There are others in the ocean prediction sector that advance the design, operation and use of ocean prediction systems in association with Ocean Predict and related efforts. Finally, oceanographic data systems are advanced by global programs such as IODE and ODIS but also data holding from NGO and the private sector.

Translation of scientific knowledge to local languages/realities is certainly essential for a more equitable extraction of the information in a more palatable way to the public in general, which do not require information as provided in peer-reviewed journals (using evidence, agreement and uncertainty/confidence language).

IMPLEMENTATION

In the next 12 months there is an opportunity to establish a network of universities and training facilities with the ambition to establish an international master program in "Digital Ocean Data Science and Engineering". Early discussions are underway and there is a need to find a funding mechanism for such a program. The cornerstones could be a repository of digital lectures that would be available globally. Those lectures would be supplemented by practical assignments offered at a local university with in-presence attendance. Finally, one could imagine that master projects could be done in a different location in order to promote mobility and cross sectorial and cultural experiences.

A second opportunity is to link amongst different programs to share existing opportunities for summer schools and related advance training opportunities. One could also imagine that some of the more advanced Digital Twin of the Ocean projects could be encouraged to develop such offerings.

Finally, one could explore informal peer-to-peer learning and engagement opportunities using existing networks such as the Ocean Decade ECOPs to encourage bi-later interactions and exchange.

9. Summary

Digital twins are virtual representations of objects and systems - the real twin (in this case the ocean system or a part of it). The concept of digital twins has been widely used in engineering and has more recently been adapted to earth system applications. Digital twins provide the ability to make informed operational, management, and policy decisions about the real twin. Digital twins build on an observing system and predictive processes or data-driven models that users can interact with to support their needs.

The connection between the digital twin and the real one requires a well-formulated interface between the digital twin, environmental data, and the user. User interaction is therefore an essential function that is embedded in the design of digital twins, including visualisation, user-driven data transformation and data-science tools. Working groups within the DITTO programme developing actions needed for developing observation, a data analytics and prediction engine, data respiratory, visualisation, building architecture, improving education and capacity building:

An adequate and increasingly accurate ocean observing system co-designed between users and developers of the observing networks needed for digital twins of the ocean will create a positive and continual feedback loop between both where information from the digital twin can be used to inform and optimise the observing network whilst benefiting from it.

A Data Analytics and Prediction Engine to maximise the understanding and value from these data, that provides tools to add value to ocean observation through predictive modelling, emulation, and artificial intelligence / machine learning to create, manipulate and analyse marine information. Digital twins incorporate the additional capacity for the user to modify the prediction engine to explore options, scenarios, and consequences.A Data Analytics and Prediction Engine to maximise the understanding and value from these data, that provides tools to add value to ocean observation through predictive modelling, emulation, and artificial intelligence / machine learning to create, manipulate and analyse marine information. Digital twins incorporate the additional capacity for the user to modify the prediction engine to explore options, scenarios, and consequences.

A Data Repository (centralised or distributed) will provide access to ocean observations and the output from predictive systems through data communication and management in a timely way following common data principles. These principles include an information management framework, a forum for setting data standards and protocols, and a system for data mapping architectures and data lineage to track data transformations. The data repository will be connected to the data analytics and prediction engine.

To set the capabilities of Digital Twins in value an Interactive and Provisioning layer allows users to visualise, interact with and tailor the data, scenarios and models to meet their needs as a powerful interface to the information and tools in the data engine that is easy to adapt and use, and represents one of the characteristic features of digital twinning. These provisioning layers are tailored towards human users and are often visually pleasing front-end interfaces with easy, intuitive access. Machine-to-machine provisioning is also common, in which case the provisioning layer is tailored to enable federating with other twins or systems.

The true impact of Digital Ocean Twins will depend on their complementarity, i.e. complementarity between oceans, models and data which in turn depends on interoperability between these aspects. Interoperability can be achieved through defining the meaningful building blocks of Digital Twins of the Ocean as well as a functional and flexible architecture that accounts for existing systems, recognised architecture models and technology developments that are relevant for Digital Twins. Such an architecture needs to acknowledge related strategies on data sharing and twinning, like e.g. the Destination Earth (DestinE) that aims at creating a digital replica of our planet where Digital Twins of the Ocean will play a crucial role.

Digital Twins of the Ocean will emerge for different areas, in different qualities and for different purposes. A co-created architecture framework for these twins will ensure interoperability and thus complementarity,

Digital Twins of the Ocean take advantage of the increasing number of ocean observations from a wide range of sources, the ability to curate and share those data in public data repositories, to fuse the data with ocean predictions systems and the ability to build decision support systems, that we call digital twins of the ocean. The design, operation and deriving benefits from those systems require a digital literate ocean community of practice around the globe and across sectors and disciplines. Take advantage of existing and implement new opportunities by working with appropriate networks, programs and projects to facilitate education and training in the area of digital ocean technology and in that sense builds the needed capacity globally.

Through all this, Digital Twins will enable users to address 'What if' questions based on shared data, models and knowledge. They empower ocean professionals, citizen scientists, policymakers, and the general public alike to visualise and explore ocean knowledge, data, models and forecasts. The use of Digital Twins is wide and rapidly developing spanning a wide range of use cases from engineering to policy to science to operational services. The UN Ocean Decade Program DITTO will establish a framework for Digital Twins by promoting co-design of twins, establishing and sharing good and best practice, enabling interoperability and promoting education and uptake to demonstrate and realise the value in the Digital Twins.