Article

The Contributions of Hydrographic Data Towards the Digital Twin of the Ocean

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The ocean, encompassing 70% of the Earth's surface and 97% of its water, is absorbing carbon dioxide emissions, releasing half of the world's oxygen, regulating the climate, and supporting marine ecosystems (Keller et al., 2018). Hydrography is the science of measuring and mapping the physical features of the ocean and seas as well as their evolution over time. Its primary purpose is to produce a nautical chart of the ocean for safe navigation. However, it supports all other marine activities thus, plays a crucial role in supporting human understanding of the ocean's behavior and dynamics.

Hydrographic data is important for almost all activities that take place at sea. Hydrography provides critical data on the physical, biological and chemical properties of the ocean, including the nature of the seafloor, temperature, pressure, salinity, turbidity, sound velocity, currents, waves, and wind. These data are indispensable for the development of a Digital Twin of the Ocean (DTO). The DTO is a digital replica of the ocean that uses real-time and past data to represent the past and present, and models to imitate future scenarios.

Concept of Digital Twin of the Ocean

Digital Twin of the Ocean is a virtual imitation of Real Ocean (Figure 01). In this case, data, along with models, are used to create a digital twin that demonstrates how the real world changes. The concept is to demonstrate the ocean system by incorporating all resources related to the sea, i.e. data and models with digital technologies for the representation of real-time or nearly real-time portrayal of the ocean. A DTO allows citizens to be able to take well-informed decisions supported by

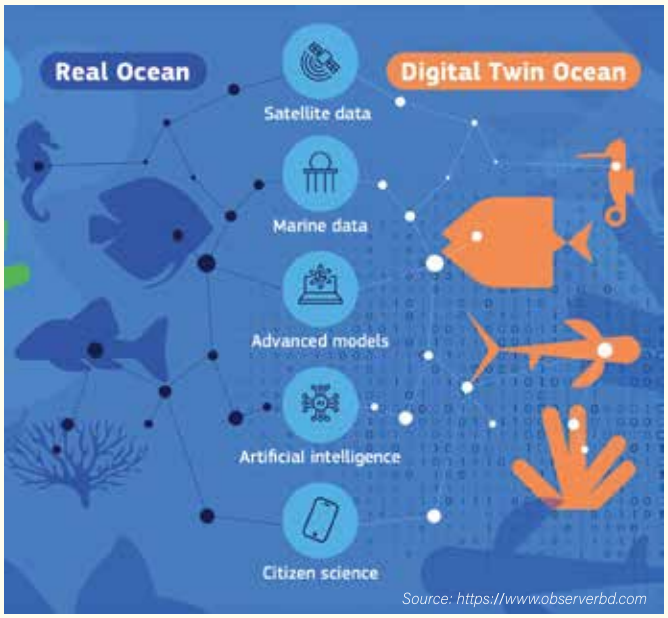


Figure 01: A Digital Twin of the Ocean

data and technology to conserve marine environments through the creation of a digital replica of the ocean.

The aim of DTO is to create knowledge available to every citizen on Earth, revolutionizing our understanding of the ocean environment and provide a true testing ground for prediction of future changes. By transforming ocean science into knowledge, the DTO will be a game-changer in decision making for the protection of ocean and sustainable resource management of it (Ossing et al., 2023).

Hydrography – An Indispensable Foundation to the Development of Digital Twin of Ocean

The relevance and contributions of hydrographic services toward the digital twin of the ocean can be visualized in the subsequent paragraphs:

Mapping the Seafloor: The bathymetry and configuration of the seafloor are fundamental for understanding the circulation patterns of the ocean that affect climate and weather patterns, tides, waves, tsunamis, fishing, morphological and environmental changes, and much more. These data are used to develop a 3D model of the ocean floor. By creating a 3D model of the seafloor, it is possible to simulate the effects of ocean currents, tides, and waves, and predict changes in the ocean environment and ecosystems.

Figure 02: Mapping the Seafloor

Maritime Transport: Sea-borne trade contributes more than 80% of international trade (Liang & Liu, 2020). The shipping industry needs a safe, smooth, and speedy operation. As such, uncharted or poorly charted areas or lacking navigational information can cause the ship to take more time than usual, and may not allow optimum loading of ships, thus increasing the costs. The accurate depth information and correct routing can save time and money. Besides, the International Convention for the Safety of Life at Sea (SOLAS) Convention Chapter V identifies a ship as unseaworthy if it does not comply with up-to-date charts. In such a case, hydrographic services provide a solution to these problems by supplying quality maps and charts.

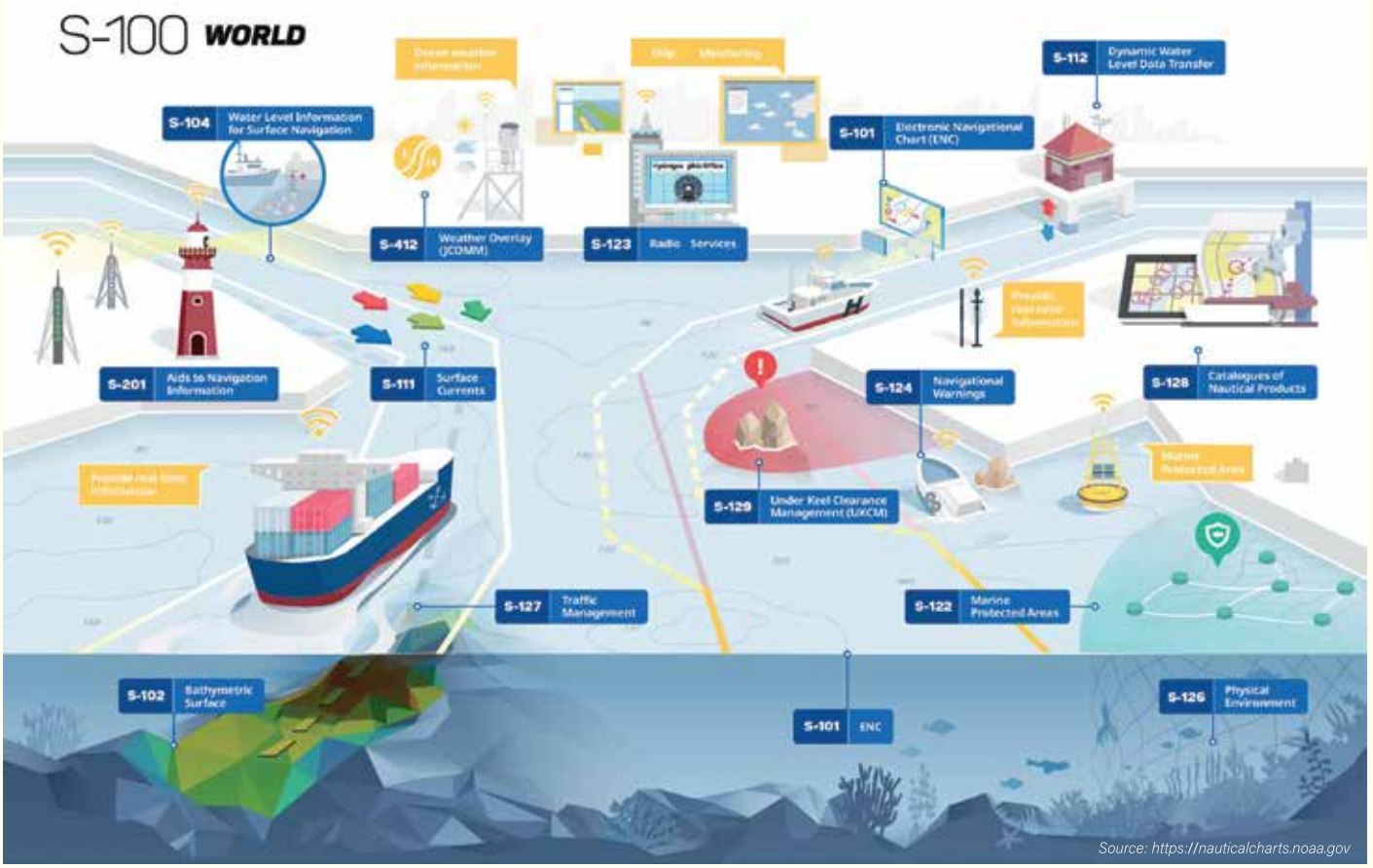
Developing Models and Simulations: One of the most significant contributions of hydrography to the digital twin of the ocean is the use of hydrographic data in developing models and simulations. These models allow us to predict changes in ocean currents, tides, and sea levels, which are essential for understanding the ocean's complex systems.

Relevance to Sustainable Development Goal (SDG) 2030 and UN Decade of Ocean Science: The relevance and contribution of hydrographic information to SDG 2030, and in particular "SDG 14: Life Below Water," is greatly acknowledged. The vision of SDG-14 is: "Conserve and sustainably use the oceans, seas, and marine resources for sustainable Development." The "UN Decade of Ocean Science for Sustainable Development" gives a unique opportunity to enhance the capacity to observe and understand the ocean. On the other hand, the Digital Twin offers for integration of research innovations and ocean science of the decade straightway into the decision-making process to allow people to sustainable development and protection of the ocean. All these activities are supported by hydrography.

Incorporating Electronic Navigational Chart (ENC) Data Into the Digital Twin: Electronic Navigational Chart (ENC) are digital representations of navigational paper charts for use with "Electronic Chart Display and Information System (ECDIS)." They provide accurate and up-to-date information about the ocean environment, such as water depth, hazards to navigation, and the location of navigational aids.

In the DTO, ENC data is used as a key component of the virtual model, providing information on the physical characteristics of the ocean environment. By incorporating ENC data into the Digital Twin, maritime industry stakeholders can visualize and better understand the ocean environment, and make more informed decisions. For example, vessel operators can use the Digital Twin to optimize route planning, improve safety, and reduce fuel consumption. It also helps for optimization of fleet, terminal, and container flows in the chain for optimum and smooth port operations such as vessel traffic and cargo handling.

The S-100 Universal Hydrographic Data Model: A Way to Enable Autonomous Navigation and Create Comprehensive Digital Twin of the Ocean



International Maritime Organization (IMO) has recognized S-100 (Kim et al., 2017). S-100 is a revolution in software. Its data format has been internationally accepted as the baseline standard for building a universal data structure. This data will facilitate e-navigation and related services. "International Association of Lighthouse Authorities" (IALA) and "World Meteorological Organization" (WMO) are the two main stakeholders who brought the idea of S-100 into reality. Moreover, multiple data formats like bathymetry aids to navigation, marine meteorology, etc., will always be exchangeable with each other. The S-100 data has the potential to bridge hydrography and oceanography in order to build a fully digital marine data ecosystem- the DTO.

Legal Obligation for Mariners to Use the S-100 Universal Hydrographic Data Model: In 2022, IMO adopted a resolution on ECDIS for the compliance of S-100 and its interconnected digital products. This resolution thus augmented for enhancing the safety of navigation. S-100 ECDIS will be obligatory for mariners to comply from January 2026. The changeover stage for compliance of IMO resolution on ECDIS will be until 1 January 2029. This obligation for using S-100, thus, will make way for e-navigation and a comprehensive DTO. Autonomous navigation, as well as operations, requires digital data exchange, which is a core feature of digital twins.

Challenges in Developing the DTO

Despite many opportunities and benefits of the DTO, there are still several challenges that include the collection and integration of data, development of accurate models, interoperability of data, implementation of the seabed 2030 initiative, and the S-100 Universal hydrographic data model, etc.

Hydrography, by contributing critical data on ocean properties, serves as a building block for developing a DTO. It develops a reliable and near real-time virtual depiction of the ocean, combining ocean science and data, modeling and technology. It empowers citizens, and provides an accessible platform to all for global cooperation.

The ambitious global initiative of Seabed 2030, which strives to chart the entire ocean floor by 2030 and the S-100 Universal Hydrographic Data Model, which serves as the framework for organizing and sharing hydrographic data, drive advancements

in autonomous navigation and sustainable ocean management. The benefits of the S-100 are enormous and the foundation for the digital twin. Thus, it is evident that these all are possible with the use of hydrographic data.

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