

Change – The transformative power of citizen science

## The Iliad digital twins of the ocean: opportunities for citizen science

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### Abstract

In recent years, there has been growing interest in digital twins (or virtual representations) of the environment. Programs in the European Union and the UN are investing in digital twins, particularly those of the ocean (DTOs). While citizen science has been mentioned as a potential data source for digital twins, the full potential of citizen science in this context has yet to be fully realised. The Iliad project (<https://ocean-twin.eu>), funded by the European Commission, is developing a comprehensive set of digital twins of the oceans which are interoperable, data-intensive, and cost-effective. The project (2022–2025) brings together over 50 partners to demonstrate the technologies and methodologies required to develop DTOs. Citizen science and engagement play a pivotal role in the project, with the following goals: (a) exploring the potential for citizen science to contribute to digital twins of the oceans; (b) demonstrating how citizen scientists (and society more broadly) can benefit from digital twins. The Iliad team is currently working on over 20 separate digital twins of the oceans that fall into two primary categories: (i) environmental and ecological digital twins; (ii) engineering and industrial digital twins. Using the Iliad DTOs as case studies, lessons learned for citizen science are presented from the development of each digital twin.

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Within the field of environmental modelling, the concept of digital twins is gaining traction, with programmes in place to develop a digital twin of the Earth (Bauer et al. 2021). The term “digital twin” originally emerged within industry and described a system consisting of “a physical entity, a virtual counterpart and the data connections in between” (Jones et al. 2020, p.36). Whilst the concept is at an early stage of maturity within environmental science, initial examples are emerging. For example, a digital twin of the terrestrial water cycle has been developed for the Mediterranean region (Brocca et al. 2024). As with more traditional modelling, citizen science has been proposed as a solution to fill data gaps within digital twins (Bye et al. 2023). However, the potential of citizen science in this context may be limited by current data practices which can be lacking in terms of data licensing, documentation, interoperability and infrastructure (Bowser et al. 2020).

The Iliad project (<https://ocean-twin.eu>) is developing a comprehensive set of over 20 separate digital twins of the ocean (DTO), providing tools to explore, simulate, analyse and predict environmental processes and inform marine management (Bye et al. 2022). The project, which was funded by the European Commission through its Horizon 2020 research programme (grant agreement number: 101037643), runs from 2022 until 2025 and brings together over 50 partner organisations to demonstrate the technologies and methodologies required to develop DTOs. Citizen science and engagement play a pivotal role in the project with the following goals: (a) exploring the potential for citizen science to contribute to digital twins of the oceans; (b) demonstrating how citizen scientists (and society more broadly) can benefit from digital twins. Importantly, the value of citizen science is recognised to extend beyond just the provision of data. Incorporating citizen science into the development of digital twins has the potential to: increase public engagement and involvement in the topic of the digital twin; increase public awareness and education (including enhancing ocean and water literacy); increase public participation in decision making; and increase the societal relevance of the digital twins developed.

To illustrate the project activities, a short description of the citizen science elements of four of the Iliad DTOs are given below.

- 1. Jellyfish swarm forecast, Israel.** Citizen science observations from the Meduzot project (Edelist et al. 2022) are combined with metocean parameters to develop an interactive forecasting tool for jellyfish swarms.
- 2. Harbour safety, Varna Bay, Bulgaria.** A new citizen science app “I SEE SEA” has been developed to enable citizens to report coastal pollution, jellyfish swarms, weather changes and other unusual phenomena. Sightings are incorporated into a digital twin of Varna Bay which is used by vessels within Varna Port to minimise risk during adverse weather conditions or other risks to harbour safety.
- 3. Oil spill monitoring, Thracian Sea, Greece.** Citizen observations (extracted from social media) are used to provide early warnings of potential oil pollution and are used to trigger and validate oil spill models.
- 4. Cultural heritage monitoring, Israel.** An ongoing citizen science project engages interested parties and actors, including students, to report archaeological finds along the Israeli coast. Reports are validated, catalogued, and then included within an interactive digital record of cultural heritage sites.

The pilot digital twins developed within Iliad can provide a number of lessons learned for the integration of citizen science in digital twins across a range of marine topics and for environmental digital twins more broadly. Of particular importance is the availability and interoperability of citizen science data. To support this, the Iliad project is developing an Ocean Information Model (OIM) as a tool to provide full semantic interoperability within digital twins of the ocean (Zaborowski et al. 2023). A core principle of the OIM is to adopt common ontologies and establish alignment with other existing models in a modular approach rather than developing a new ontology from scratch. This modular approach also helps overcome challenges of creating a single model to cover several heterogeneous domains. A core, cross-domain layer defines terms relevant across all domains such as temporal concepts (adopting W3C OWL Time) and geographical/spatial concepts (adopting OGC GeoSPARQL). Domain-specific modules are then adopted. For example, the Iliad Jellyfish swarm forecast DTO connects to Darwin Core standards for biodiversity informatics and PPSR Core for citizen science. The OIM is available via a GitHub repository (Palma and Atkinson 2023) and in the future will be accessible on the OGC Rainbow server. To support further capacity strengthening around citizen science within the marine sector, the Iliad project has established a citizen science community within the UNESCO IOC Ocean Best Practices Repository (OBPS, Pearlman et al. 2019) The aim of the community is to provide a collection of marine-specific citizen-science best practices, manuals, guides, handbooks and other documents which ultimately can be adopted across Europe and beyond and are readily available for adoption by marine researchers (including those interested in developing a DTO).

To gain further insight into the opportunities and barriers for citizen science in the context of digital twins, the Iliad consortium is carrying out a series of semi-structured interviews with project leaders from each of the Iliad DTOs. So far, 15 interviews have been held including five DTOs where citizen science is

already integrated, six with some potential for citizen science, and four where the project leader believes citizen science is not applicable. Each interview lasted around one hour and included questions covering: (i) the project leader's experience with citizen science; (ii) details about their DTO including data gaps and plans for validation; (iii) the social relevance of the DTO; and (iv) how citizen science could bring value to their DTO. Initial results indicate opportunities for citizen science through: promoting existing (or establishing new) citizen science standards to enable data to be more easily integrated into models; including citizens in discussions around contentious marine management decisions such as pollution or wind-energy; and engaging professionals such as fishers or energy technicians as citizen scientists, not just members of the public. Commonly cited barriers to citizen science include: issues of accessibility, particularly for sites far from the coast; lack of capacity within the DTO team to engage with citizens; lack of added-value over abundant sensor data; and issues of trust or lack of transparency, especially for more industry-based DTOs. Further outputs from the Iliad project, including the full results from this review, will be shared via the Iliad Marketplace (<https://ocean-twin.eu/marketplace>).

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