Data, Observation & Modelling

Fri. Nov 13, 2026 9:00 AM - 10:30 AM JST | Fri. Nov 13, 2026 12:00 AM - 1:30 AM UTC | Room C (201) (2F)

Oral C4 Marine Biodiversity & Ecosystem Modelling

Chair: Cheng-Hao Lu, Qiang Deng

9:00 AM - 9:15 AM JST | 12:00 AM - 12:15 AM UTC

[uRAGwoU2-01] Advancing Marine Ecological Monitoring through a Digital Twin of the Ocean Framework

*Morane Clavel-Henry[1] (1. GEOMAR (Germany))

9:15 AM - 9:30 AM JST | 12:15 AM - 12:30 AM UTC

[uRAGwoU2-02] Turning biodiversity data into dynamic digital ecosystems

*Klaas Deneudt[1] (1. VLIZ (Belgium))

9:30 AM - 9:45 AM JST | 12:30 AM - 12:45 AM UTC

[uRAGwoU2-03] Toward a Digital Twin of Rocky Intertidal Ecosystems: From Long-Term Monitoring to Social Implementation

*Ken ISHIDA[1] (1. JAMSTEC (Japan))

9:45 AM - 10:00 AM JST | 12:45 AM - 1:00 AM UTC

[uRAGwoU2-04] A Coastal Ecosystem Digital Twin: Integrating Numerical Modeling and Interactive Visualization

*Takashi Nakamura[1] (1. Institute of Science Tokyo (Japan))

10:00 AM - 10:15 AM JST | 1:00 AM - 1:15 AM UTC

[uRAGwoU2-05] Impact of land mass effect on trace metal distribution: Insights from the Gough Island, South Atlantic

*Miranda Sitofile[1] (1. Southern Ocean Carbon-Climate Observatory (SOCCO) & Stellenbosch University (South Africa))

10:15 AM - 10:30 AM JST | 1:15 AM - 1:30 AM UTC

[uRAGwoU2-06] A Cloud-Native Subsea Digital Twin Architecture for Multi-Sensor Telemetry Fusion and Deterministic Robotic Execution

*Satish Ramachandran[1] (1. Mr (India))

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[uRAGwoU2-01] Advancing Marine Ecological Monitoring through a Digital Twin of the Ocean Framework

*Morane Clavel-Henry[1] (1. GEOMAR (Germany))

Long-term ecological monitoring provides essential information on patterns, trends, and variability in biodiversity of marine ecosystems, including highly pressured coastal environments. The Digital Twin of the Ocean (DTO) framework offers new opportunities to combine biological and environmental observations with modelling methodologies, enabling the generation of near-real-time, spatially upscaled ecological indicators. Within the EU-funded DIGI4ECO project, a digital platform is being developed to expand marine information across four dimensions (space and time). Here, the objective is to demonstrate how a DTO framework can enhance the value of marine observatories and their platform networks by connecting in-situ observations, modelling tools, and decision-support interfaces within a coherent digital framework. The presentation will showcase project activities structured around three core themes: (i) observed and predicted data; (ii) Big Data infrastructure and pipeline; and (iii) machine-learning approaches.

The first theme develops on acquisition, integration, and harmonisation of multi-source datasets, including imagery, computationally assisted environmental DNA (eDNA), historical archives, and sleeping data. These observations are complemented by models that support the spatial upscaling of species distributions and socio-ecological analyses, helping to fill data gaps and strengthen decision-support capabilities. The second theme focuses on the integration of cross-site, cross-sectoral data streams while ensuring compliance with FAIR data principles within the DTO framework. We will also highlight advances in autonomous data collection and transmission between observing assets, including interactions between fixed platforms and mobile robotic systems through docking technologies. The third theme presents developments in automated organism classification using image analysis and machine-learning techniques, as well as their integration with remote mission supervision and adaptive control of multi-parameter sensor systems.

Ultimately, the DTO services developed within DIGI4ECO are designed to support the expansion of datasets, the deployment of new marine observatories, and evolving monitoring requirements driven by international policies and directives.

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[uRAGwoU2-02] Turning biodiversity data into dynamic digital ecosystems

*Klaas Deneudt[1] (1. VLIZ (Belgium))

Marine habitats present specific and one-of-a-kind issues when it comes to observing, mapping, and monitoring biodiversity in marine ecosystems. In spite of the fact that significant advancement has been made in Europe to collect, harmonise, and make available data on marine biodiversity, a large portion of the data that is currently being collected is unavailable and inaccessible.
The core mission of the DTO-BioFlow Project is to unlock those “sleeping” biodiversity data, enabling the sustained flow of these and new data via primary integrators and EMODnet into the EU Digital Twin Ocean. It is working to create a digital replica of marine biological processes, transforming new and existing data flows into evidence-based knowledge.
The project aligns with the EU's Biodiversity Strategy and Nature Restoration Law and with the mission "Restore our oceans and waters by 2030", both of which advocate for the protection and restoration of land and sea regions.
Over the four years, the DTO-Bioflow consortium has been working on consolidating standards, quality control, communication protocols, harmonisation pipelines, data products, data models, ingestion procedures and incentives for sustainable connection to improve the interoperability and digitisation of biodiversity data. The project will also test out various technologies that are both affordable and adaptable to carry out species monitoring on a massive scale. The end-to-end approach will be demonstrated via a number of science-based use cases and via mechanisms to monitor, measure progress and drive community action towards increasing biodiversity data flows.

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[uRAGwoU2-03] Toward a Digital Twin of Rocky Intertidal Ecosystems: From Long-Term Monitoring to Social Implementation

*Ken ISHIDA[1] (1. JAMSTEC (Japan))

With global climate change, the frequency and intensity of disturbances such as marine heatwaves and typhoons are increasing, severely impacting marine ecosystems and their services. There is, therefore, an urgent need to evaluate the impacts of these disturbances on ecosystems and predict their future states.

While constructing a "digital twin" is highly anticipated as a promising approach to this challenge, actual examples targeting coastal ecosystems remain virtually non-existent worldwide due to a severe lack of both environmental and ecological data.

In this presentation, we overcome this bottleneck by focusing on the rocky intertidal zone in Japan, where an exceptionally long-term dataset spanning over two decades across more than a hundred sites has been accumulated. Based on this rich data, we present a vision for building a rocky intertidal digital twin.

We also discuss the scalability of this model to wider geographical regions. To expand environmental data, we propose a correction model for nearshore-offshore data discrepancies. For ecological data, we plan to develop a method to extract biological information from publicly available photographs across the nation.

Furthermore, we outline the prospects for this concept to evolve beyond a purely academic proposal into a practical tool supporting socioeconomic benefits. In fisheries, it can ensure stable business management through future predictions for oysters and key seaweeds (such as Gloiopeltis and Analipus), while assisting decisions on shifting target species from declining to thriving ones. In coastal zone management, predicting biofouling organisms like barnacles can reduce port maintenance costs and enhance safety. Finally, in environmental impact assessments, this tool can contribute to corporate TNFD disclosures, future risk assessments of Marine Protected Areas (MPAs), and the selection of new candidate conservation sites.

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[uRAGwoU2-04] A Coastal Ecosystem Digital Twin: Integrating Numerical Modeling and Interactive Visualization

*Takashi Nakamura[1] (1. Institute of Science Tokyo (Japan))

Conserving coastal ecosystems is essential for the sustainable use of the ecosystem services they provide. One serious barrier to coastal ecosystem conservation is that many people are unaware of the degraded state of these ecosystems, as underwater environments are not easily visible. Coastal ecosystem digital twins offer a means of visualizing these underwater conditions. They therefore have the potential to raise awareness of the state of coastal ecosystems and to promote conservation actions. In this context, we developed a coastal ecosystem digital twin that employs an integrated land–ocean–ecosystem model as its core engine and Cesium JS as its visualization platform.

For the integrated land–ocean–ecosystem model, we used the Soil & Water Assessment Tool Plus (SWAT+; Bieger et al., 2017) as the land model component to estimate nutrient discharge from rivers adjacent to the coastal waters. Both the Regional Ocean Modeling System (ROMS; Haidvogel et al., 2008) and Simulating WAves Nearshore (SWAN; Booij et al., 1999), embedded in the Coupled Ocean–Atmosphere–Wave–Sediment Transport (COAWST) modeling system (Warner et al., 2010), were used as the ocean model components. For the ecosystem component, we employed the Marine Coupled Pelagic–Benthic Ecosystem Model with Element Tracers (Marine CoMET; Nakamura et al., in prep.). To generate the initial and boundary conditions for biogeochemical parameters, we developed a machine learning model based on GLODAP, BGC-Argo, and satellite-derived chlorophyll-a products (Nakamura, in prep.).

Three sites—Shizugawa Bay, Tokyo Bay, and Sekisei Lagoon—were selected for developing the coastal ecosystem digital twin. We also developed a web application for interactively visualizing the coastal ecosystems at these three sites, built on Cesium JS and hosted on the academic cloud platform mdx I.

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[uRAGwoU2-05] Impact of land mass effect on trace metal distribution: Insights from the Gough Island, South Atlantic

*Miranda Sitofile[1] (1. Southern Ocean Carbon-Climate Observatory (SOCCO) & Stellenbosch University (South Africa))

The Southern Ocean plays a significant role in absorbing around one-third of global carbon dioxide through the biological carbon pump and the solubility pump. The biological carbon pump system is regulated by the presence of the essential micronutrient iron, with some evidence of potential iron-manganese co-limitation. Iron and manganese are essential trace metals that have a crucial effect on the functioning of photosynthetic proteins in metabolic processes and the study of their biogeochemical cycles is of great interest. Within the Southern Ocean are regions such as island wakes, which are recognized for their high productivity, usually depicted by phytoplankton blooms, a phenomenon known as the “land mass effect”, where the presence of land might contribute to increased availability of trace metals. However, the majority of observations are mostly focused on islands such as South Georgia, Crozet Island, and Kerguelen Island, whereas no observations have been made on the islands situated in the Atlantic sector of the Southern Ocean (Gough Island). This hampers our understanding of the land mass effect on significant micronutrients, as the islands differ from one another in terms of topography and the currents surrounding them, thus resulting in different distribution patterns of trace metals.
To address this gap, trace metal samples were collected during the 2023 and 2024 Gough Island cruises. These samples were collected upstream and downstream of Gough Island and were analyzed at Stellenbosch University. The data collected from these islands was utilized to examine the interplay between dissolved and particulate forms of trace metals and their distribution patterns. The chlorophyll-a distribution showed low concentrations, and furthermore, the climatology of geostrophic current velocity around the island indicated that water movement strongly influences the surrounding waters, with relatively high flow leading to continuous transport and dispersal of trace elements, weakening the chlorophyll signal typically associated with the Island Mass Effect.

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[uRAGwoU2-06] A Cloud-Native Subsea Digital Twin Architecture for Multi-Sensor Telemetry Fusion and Deterministic Robotic Execution

*Satish Ramachandran[1] (1. Mr (India))

As offshore energy operations transition toward deepwater environments and high-density ocean compute infrastructure, managing subsea structural health requires moving beyond fragmented, passive data streams. Traditional monitoring approaches suffer from siloed vendor telemetry, processing latency, and theoretical spec failures during complex 3D dynamic loads. This paper presents an API-first, cloud-native digital twin framework designed to structure multi-axis subsea telemetry into actionable operational intelligence and deterministic robotic execution.

The proposed architecture acts as a master digital integrator, unifying continuous real-time sensor streams—including Distributed Temperature Sensing (DTS), Distributed Acoustic Sensing (DAS), Depth of Burial (DoB), and Distributed Strain Sensing (DSS)—into a standardized data schema. By cross-referencing independent telemetries within an industrial data memory, the framework eliminates operational blind spots and distinguishes true structural threats from localized environmental shifts prior to vessel mobilization.
Crucially, this digital twin environment closes the loop between software insight and physical intervention. The platform enforces automated pre-mobilization fit-checks and hard-coded metocean safety interlocks, mathematically verifying vehicle capabilities against real-world 3D hydrodynamic loads (including crosscurrent drag, tether tension, and pitch torque). Validated campaign briefs automatically drive the targeted deployment of autonomous surface vessels (USVs), inspection-class ROVs, and subsea crawlers.
Commercial deployment of this digital twin integration layer—notably across complex deepwater offshore blocks—demonstrates significant reductions in vessel day rates, complete eradication of offshore scope discovery, and maximized subsea asset uptime. By establishing a seamless neural loop between physical ocean realities and cloud-native intelligence, this framework provides the operational certainty required to scale future offshore clean-energy networks.

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