Coastal Crete: The Ship routing/Harbor Safety Digital Twin of the Ocean

Antonios Parasyris[1]*, Vassiliki Metheniti[1], Laura Vettorello[2], João Ribeiro[3], Miguel Delgado[3], Jonny Goddard[4], Jaan Rebane[5], Margit Egerer[5], George Alexandrakis[1], Giorgos Kozyrakis[1], Simon Keeble[4], Maria Luisa Quarta[2], Asko Ristolainen[5], Adélio Silva[3], Evangelos Agorogiannis[6], Konstantina Papachristopoulou[6], Charalambos Ipektsidis[6], Nikolaos Kampanis[1]

[1] Coastal & Marine Research Lab, FORTH-IACM, Heraklion, Greece
[2] Meteorological Environmental Earth Observation-MEEO S.r.l, Ferrara, Italy
[3] Hidromod, Porto Salvo, Portugal
[4] Blue Lobster IT, Wales, United Kingdom
[5] Centre for Biorobotics, Department Of Computer Systems,Tallinn University of Technology
[6] Netcompany-Intrasoft, Athens, Greece
* Corresponding author antoniosparasyris@iacm.forth.gr

The Coastal Crete service is offered by CMRL, FORTH, developed within the framework of the ILIAD – Digital Twins of the Ocean (DTO) Project, is a DTO tailored to the Cretan Sea, delivering advanced high-resolution marine forecasting capabilities. By integrating real-time in-situ observations, it enables the simulation of predictive scenarios, including "what-if" analysis, to support decision-making in maritime operations, environmental safety, and coastal management. This advanced system employs a multi-model approach, leveraging high-resolution data assimilation and forecasting to provide actionable insights with a forecast horizon of up to four days. Central to this system is the Weather Research and Forecasting (WRF) model, dynamically downscaled to a 3 km spatial resolution using its Data Assimilation module (WRF-DA). This ensures highly realistic atmospheric simulations, which are critical for accurately driving subsequent model components. Outputs from WRF-DA then serve as inputs for the hydrodynamic NEMO (Nucleus for European Modelling of the Ocean) model and the wave model WAVEWATCH III, both configured to operate at a 1 km spatial resolution, specifically tailored to the complex dynamics of the Cretan Sea [1].

The Ship Routing and Harbor Safety Ocean Twin builds upon this foundation by offering two key application packages to optimize maritime operations and enhance safety. The first application focuses on calculating optimal ship routes, aiming to minimize travel distance, time, and CO_2 emissions. This tool leverages VISIR-2 software [2], which employs sophisticated algorithms to determine efficient vessel paths. By integrating real-time and predictive data, the application adapts to changing marine conditions, enabling dynamic route adjustments. Results are displayed through the GeoMachine platform (www.geomachine.com), where users can interact with and customize routing outputs to suit operational needs.

The second application targets harbor safety with high-resolution wave forecasting, employing a SWAN model refined to a spatial resolution of 50 m. This model delivers accurate three-day forecasts for wave height and direction, essential for ensuring safety in port operations and coastal navigation. The forecasting outputs, which include high-resolution atmospheric, oceanic, and wave data along with the SWAN model outputs are seamlessly visualized and made freely accessible through the ADAM platform and its accompanying ADAM API. The platform provides an intuitive interface for interaction and analysis, while the Python-based ADAM API enables

automated data access and integration into user-defined workflows, supporting advanced applications such as real-time ship routing and harbor safety assessments.

By delivering precise forecasts and enabling optimal routing strategies, the Digital Twin empowers stakeholders, including harbor authorities, shipping companies, and maritime planners, to enhance safety, reduce operational risks, and adopt greener shipping practices. The system's focus on high-resolution modeling and operational voyage optimization aligns with global efforts to minimize ecological impacts and promote sustainable maritime transport.

Both applications integrate real-time measurements from Hydromast devices, developed for monitoring ocean currents and waves [3], from the Port of Heraklion to trigger the two applications based on sensor issued alerts indicating severe weather conditions, providing a robust tool for stakeholders managing harbor safety and vessel operations. This integration ensures reliable support for critical decisions, contributing to safer and more efficient maritime activities.

The technical foundation of these tools is supported by dockerized application packages, distributed through Iliad's unified catalogue. The SWAN and Ship Routing models are available via dedicated GitHub repositories, ensuring accessibility and streamlined deployment for users. Both applications are accompanied by Common Workflow Language (CWL) scripts, enabling easy configuration and execution. CWL ensures reproducibility, consistency of the results as well as flexibility for diverse operational scenarios.

These innovations cater to the global maritime industry's operational demands, emphasizing sustainability, safety, and efficiency. By combining advanced modeling, real-time data integration, and user-friendly visualization, the Ship Routing and Harbor Safety Ocean Twin delivers a comprehensive suite of tools for optimizing maritime operations and ensuring harbor safety under dynamic marine conditions. Further documentation and links to the Digital Twin components can be found in https://ocean-twin.eu/marketplace/product/ship-routing.

Acknowledgements: This research has received funding from the European Union's H2020 programme ILIAD under GA No 101037643.

References:

[1] Parasyris, A., Metheniti, V., Alexandrakis, G., Kozyrakis, G. V., and Kampanis, N. A. (2024). Data Assimilated Atmospheric Forecasts for Digital Twin of the Ocean Applications: A Case Study in the South Aegean, Greece. Algorithms, 17(12), 586. doi: 10.3390/a17120586

[2] Mannarini, G., Salinas, M. L., Carelli, L., Petacco, N., and Orović, J. (2024) VISIR-2: ship weather routing in Python, Geosci. Model Dev., 17, 4355–4382. doi:10.5194/gmd-17-4355-2024

[3] Egerer, M., Ristolainen, A., Piho, L., Vihman, L., and Kruusmaa, M. (2024). Hall Effect Sensor-Based Low-Cost Flow Monitoring Device: Design and Validation. *IEEE Sensors Journal*, vol. 24, no. 5, pp. 5986-5997. doi: 10.1109/JSEN.2024.3354194