HYDROGRAPHISCHE NACHRICHTEN

Journal of Applied Hydrography 03/2024 HN 127

UN-Ozeandekade

40 Jahre DHyG

DEUTSCHE HYDROGRAPHISCHE GESELLSCHAFT e.V. DHyG

 DOI: 10.23784/HN127-05

Building coastal digital twins in the UN Ocean Decade

An article by KNUT HARTMANN, MONA REITHMEIER and MAGNUS WETTLE

Coastal zones are among the most dynamic, valuable and vulnerable ecosystems on earth. The challenge is to highlight the importance of these coastal zones and to innovate and implement strategies for their sustainable monitoring and management. Earth observation technologies offer a powerful means of continuously mapping coastal zones. Earth observation elements also contribute to the creation of a coastal digital twin. In the long term, digital twins of coastal regions will become an increasingly indispensable tool for coastal monitoring and modelling and response planning.

coastal zone | monitoring | earth observation | Copernicus | digital twin | COASTS
Küstenzone | Monitoring | Erdbeobachtung | Copernicus | digitaler Zwilling | COASTS

Die Küstengebiete gehören zu den dynamischsten, wertvollsten und empfindlichsten Ökosystemen der Erde. Die Herausforderung besteht darin, die Bedeutung dieser Küstenzonen hervorzuheben sowie Strategien für ihre nachhaltige Überwachung und Bewirtschaftung zu entwickeln und umzusetzen. Erdbeobachtungstechnologien bieten ein leistungsfähiges Mittel zur kontinuierlichen Erfassung der Küstenzonen. Außerdem tragen Erdbeobachtungselemente zur Erstellung eines digitalen Zwillings der Küstengebiete bei. Auf Dauer werden digitale Zwillinge von Küstenregionen zu einem zunehmend unverzichtbaren Instrument für die Küstenüberwachung und -modellierung und die Reaktionsplanung.

Authors
Dr. Knut Hartmann and Mona Reithmeier work at EOMAP GmbH & Co KG. in Seefeld, Germany. Dr. Magnus Wettle works at EOMAP Australia Pty Ltd in Australia.

hartmann@eomap.de

The UN Ocean Decade: coastal challenges

In the face of escalating environmental challenges, the United Nations has declared the period from 2021 to 2030 as the Ocean Decade. This global initiative underscores the urgent need to improve our understanding and management of the oceans, which are vital to life on earth. The Ocean Decade aims to foster scientific research and technological innovation to support a more sustainable relationship between humanity and the ocean. With over 70 % of our planet covered by oceans, managing this immense resource is critical for addressing climate change, preserving biodiversity, and supporting economic growth through activities such as fishing, tourism and shipping.

One of the most pressing and complex tasks within this context is the monitoring and management of coastal zones. Coastal zones represent some of the planet's most dynamic, valuable and vulnerable ecosystems. These areas are where land meets sea, hosting diverse habitats ranging from sandy beaches and rocky shores to mangrove forests and coral reefs. They provide critical services including coastal protection, carbon sequestration and supporting livelihoods for communities through trade, fisheries and tourism. They are the frontline of climate change impacts: rising sea levels, increased storm intensity and pollution all threaten the delicate balance these ecosystems maintain. The challenge, therefore, is not only to highlight the importance of these coastal zones but also to innovate and implement strategies for their sustainable monitoring and management.

Coastal zones are subject to numerous of stressors that include coastal erosion, habitat degradation, pollution and the overexploitation of marine resources. These pressures are compounded by the effects of climate change, making coastal resilience a critical area of focus. As climate change accelerates sea-level rise and increases the frequency of extreme weather events, the risk of flooding, land loss and biodiversity. Moreover, with approximately 40 % of the world's population living within 100 kilometres of the coast, the socioeconomic implications of failing to protect these areas are immense. Losses from coastal flooding are predicted to increase, so robust and immediate action is essential to mitigate these impacts.

Monitoring coastal zones is prerequisite to understanding their complexities and vulnerabilities. This requires a comprehensive collection of data on coastal morphology, habitats and the forces that shape them, including both climate and weather patterns. Achieving such an understanding is a challenging task, demanding extensive resources, advanced technological tools and interdisciplinary collaboration. Earth observation (EO) technologies (space or airborne) offer a powerful means of continuously collecting these critical data across extensive, often remote and sometimes inaccessible areas. These technologies can track changes in coastal morphology below and above the water, changes in benthic habitats, water quality including turbidity, eutrophication, oil and other pollution, coastal algae blooms, sea state and much more.

The role of earth observation

The European Copernicus programme is the European Union's earth observation and monitoring programme. It aims to provide easily accessible data to enable stakeholders and downstream services to improve environmental management, to understand and to mitigate the effects of climate change and ensure civil security. The Copernicus Marine Project and the newly launched Coastal Hub is a Copernicus service offering marine environmental monitoring services. The Copernicus Sentinel fleet are satellites and instruments which were developed for the specific needs of the Copernicus programme and to foster the uptake of earth observation information. In addition to Copernicus data, there are many other earth observation satellites that observe the globe with high frequency and in great detail, namely Planet's and Maxar's fleet who stand out for their recording frequency and quality.

Satellite EO provides uniform coverage of the earth's surface. The EO data and the created services and data products – so called downstream services – make high-quality data available for coastal zones around the globe, regardless of a country's capacity to conduct local monitoring efforts. This global availability democratises access to critical information, enabling resource-poor or remote regions to benefit from advanced monitoring technologies without the need for substantial local investment in data collection infrastructure. It ensures that stakeholders, regardless of location, have access to the insights needed for evidence-based decision making. The global coverage of satellite data is particularly important for oceans, which are transboundary water bodies of shared ecosystems, where coordinated action based on common data sets can lead to more effective regional management strategies and foster international collaboration on coastal conservation and resilience building.

One of the core strengths of satellite EO is its extensive archive of historical data, which allows for the establishment of comprehensive baselines of coastal regions. This historical data is crucial for understanding long-term trends in coastal geomorphology, pollution, sediment deposition and alterations in coastal vegetation. These baselines serve as benchmarks against which current and future status can be measured.

The temporal frequency and rapid availability of satellite EO data enable timely insights into coastal dynamics, offering near-real-time monitoring capabilities that are essential for both long-term management and emergency response. Advancements in satellite technology and data processing have significantly reduced the latency between data collection and availability, allowing for the detection of sudden changes in coastal environments, such as storm damage, oil spills or algal blooms, only a few hours after they have been recorded in space. This capability supports quick decision-making and action, which is crucial for minimising damage and mobilising effective responses to environmental crises.

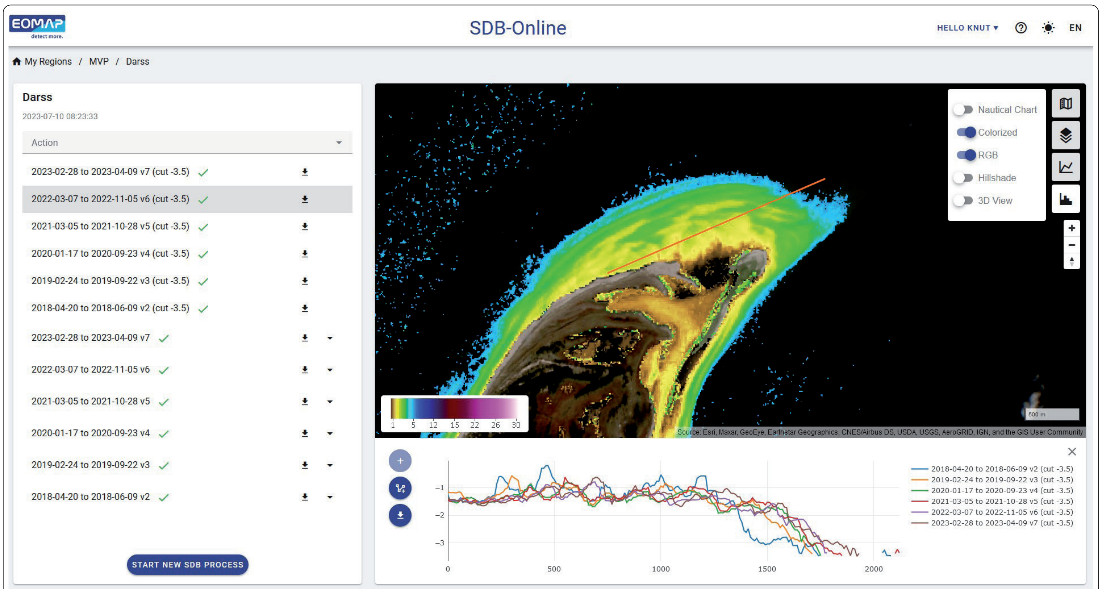

Fig. 1: Bathymetric data for the Darß area in the German Baltic, derived from the cloud-based earth observation service SDB-Online. The transects show the depth profiles for various years in a specific transect

Currently 34 petabytes of data have been recorded by the Sentinel missions alone. Progress in cloud computing and big data analytics has further transformed our ability to process and interpret the vast amounts of information collected from these observations. This enables us to feed those data into sophisticated models that can predict future changes and inform strategies for coastal protection, habitat restoration and climate adaptation. However, the effective deployment of these technologies requires a concerted effort from governments, research institutions and communities. It demands investments in scientific research, the development of infrastructure and the fostering of international collaboration to share data and best practices. The European EMODnet projects, the GEBCO project or Seabed 2030 – all of which EOMAP contributes to as data provider – or international innovation projects in the frame of the Horizon programmes are great examples to strengthen international cooperations and achieve advances beyond the current state.

As an example, the authors would like to highlight one component of how earth observation elements contribute to a coastal digital twin, developed by a recent international Horizon 2020 project, »4S«. Specifically, we wish to spotlight the SDB-Online web app (and API). This cloud-based solution can generate shallow water bathymetric grids for both monitoring and historical analysis. Fig. 1 displays results for the Darß area in the German Baltic Sea. Annual bathymetric composites from 2018 to 2023 were derived from satellite imagery. This data, along with the transect shown in the figure, enables monitoring of seabed changes, including deposition and erosion processes. In this example, the deposition of sediments to the northeast of the area could be identified and quantified. It serves as one of the required components of a digital twin.

Digital twins

The European definition is as follows: »A digital twin is a digital representation of real-world entities or processes. Digital twins use real-time and historical data to represent the past and present and numerical models to simulate future scenarios.« It is not a visualisation of a 3D model, nor is it a type of geographical information. It might include those components, but the concept of digital twins goes beyond that. In the arsenal of strategies to address the diverse challenges faced by coastal zones, the concept of a digital twin stands out as a transformative tool. When applied to coastal regions, a digital twin enables for understanding, managing and preserving these critical ecosystems.

The creation of a digital twin for coastal areas embodies the convergence of advanced earth observation technologies, sophisticated data analytics and scenario modelling.

It harnesses the power of multiple sources, including the Copernicus satellites and missions, in-situ monitoring, sampling and surveying to feed a continuously updated digital model that mirrors the real-time status of coastal environments. This model is not just a passive reflection of the current state; it's a dynamic platform that can simulate future scenarios based on various input parameters, including climate change projections, urban development plans and conservation strategies.

Digital twin in practice: »COASTS«

Coastal digital twins are still under development and different aspects are already published or commercialised, although the term ›digital twin‹ is

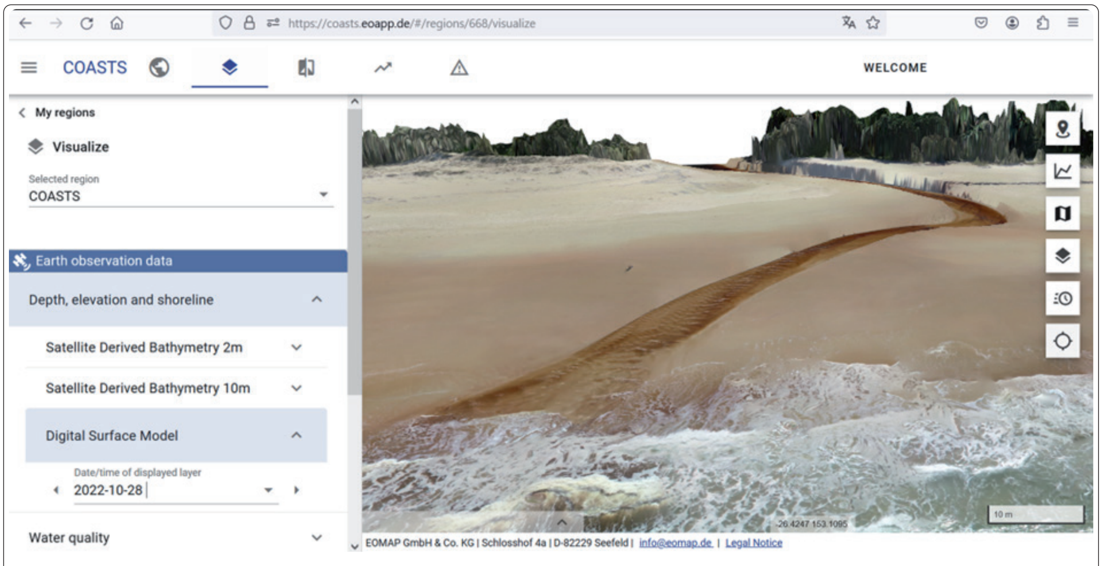

Fig. 2: Screenshot of the COASTS digital twin. The image shows a 2.5 D visualisation of a drone survey and the derived coastal surface model

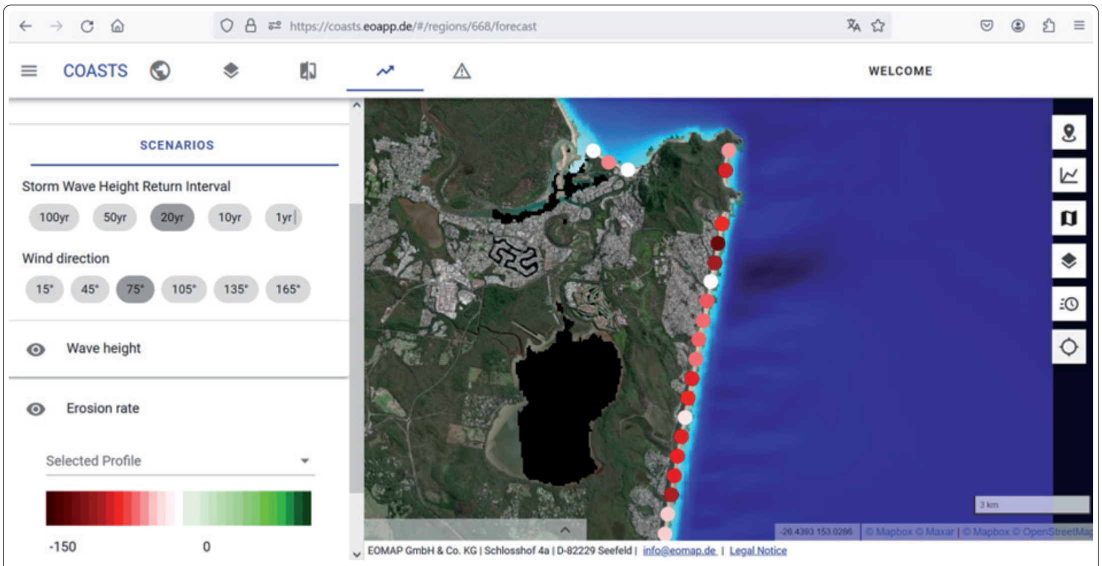

Fig. 3: Screenshot of the COASTS digital twin. The image shows the long-term prediction of coastal erosion

often used in different ways. EOMAP, the University of the Sunshine Coast and the University of Queensland have teamed up to investigate a specific coastal region in Queensland, Australia. To this end, the Coastal Observation and Analytics (multi-) Source, (multi-)Technology System (COASTS) project was conceptualised and developed as a web-based platform for managing coastal change. It leverages the use of satellite analytics, drones and SfM, numerical modelling and cloud-based portal technology to derive and deliver information about coastal processes, coastal hazards and beach safety. The satellite and airborne drone data provide hindcasts of coastal morphology, bathymetry, sediment loads and shoreline whereas live buoys record current metocean conditions and models predict coastal erosion and future metocean conditions for different scenarios. Fig. 2 and Fig. 3 illustrate screenshots of this coastal digital twins user interface.

Through the web app, stakeholders can visualise the impact of sea-level rise, storm surges, coastal erosion and other climate-induced changes on coastal infrastructure, ecosystems and communities. This visualisation not only aids in raising awareness among policymakers and the public but also provides a basis for informed decision-making. It supports adaptive management practices. As new data becomes available (e.g. a change in nearshore bathymetry) or as conditions change, the model can be updated to reflect these new realities (e.g. a different coastal erosion pattern), ensuring that management strategies remain relevant and effective. This flexibility is particularly important in the context of climate change, where uncertainty about future conditions requires dynamic and responsive planning mechanisms. COASTS was partially funded by the SMARTSat EO HUB.

In future the digital twin of coastal regions will become an increasingly indispensable tool for emergency preparedness and response planning. By providing up-to-date simulations of the paths and impacts of potential extreme weather events, such as hurricanes or tsunamis, emergency response and long-term coastal resilience strategies will arguably be more effective.

Concluding remarks

The rapid access to satellite data enhances the ability of coastal zone managers to engage in proactive rather than reactive management. This aligns with the core assumption of a coastal digital twin, that a forward-looking approach can lead to significant cost savings by preventing damage rather than having to invest in more expensive restoration efforts. This synthesis of technology, engineering and environmental science heralds a new era in coastal management, where the precision and foresight offered by digital twins can lead stakeholders to more effective coastal management, including robust defences against natural disasters, more effective conservation of biodiversity and more sustainable use of coastal resources.

Ultimately, coastal digital twin technologies, coupled with earth observation downstream information, respond to several of the seven goals of the UN Ocean Decade and are fully in line with the mission statement of »Transformative ocean science solutions for sustainable development, connecting people and our ocean.« //