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SUMMARY REPORT FOR OGC FEDERATED MARINE SDI 2024 PILOT - BRIDGING LAND AND SEA

ENGINEERING REPORT

PUBLISHED

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I OVERVIEW

The *OGC Federated Marine SDI 2024 Pilot – Bridging Land and Sea* addresses the integration of terrestrial and marine geospatial datasets across the intertidal zone, a highly dynamic and operationally critical area. Sponsored by the UK Hydrographic Office (UKHO), NOAA, and the National Geospatial-Intelligence Agency (NGA), and supported by Ordnance Survey, the US Geological Survey (USGS), and the Canadian Hydrographic Service (CHS), the pilot showcases innovative, standards-based solutions developed by Compusult, Pangaea Innovations, and TCarta. Using technologies such as OGC APIs, Discrete Global Grid Systems (DGGS), and satellite-derived hydrospatial data, the pilot demonstrates scalable approaches for erosion monitoring, port operations, and shoreline awareness. The Engineering Report highlights the importance of vertical datum reconciliation, semantic uplift, and dynamic 4D integration methods.

In parallel, a Draft Guide and Best Practices Report (D002) is being developed to consolidate implementation guidance, international standards alignment, and lessons learned. It introduces five actionable best practices for sustainable and interoperable coastal data infrastructures: (1) **Unified Geospatial Reference** through modern vertical datums and separation surfaces; (2) **FAIR Data Principles** using rich metadata and recognized catalog standards; (3) **Mind the Gap** by addressing spatial and temporal voids in the intertidal zone; (4) **Coordinated Governance** via multi-agency data frameworks like IGIF-Hydro; and (5) **Scalable Resolution Management** for integrating multi-scale elevation data with techniques like TINs and DGGS. These practices aim to improve cross-domain geospatial coordination and support climate resilience, safety of navigation, and integrated coastal zone management.

II EXECUTIVE SUMMARY

The Federated Marine Spatial Data Infrastructure (FMSDI) 5 Pilot addresses the growing challenge of integrating terrestrial and marine datasets across the dynamic and operationally critical intertidal zone. Intertidal areas, where land meets sea, present complex environmental and data management challenges, especially as coastal dynamics intensify under climate change.

The FMSDI 5 Pilot was designed to respond directly to the needs and objectives articulated by the project sponsors, including the **UK Hydrographic Office (UKHO)**, the **US National Oceanic and Atmospheric Administration (NOAA)**, and the **National Geospatial-Intelligence Agency (NGA)**. Supporting organizations such as **Ordnance Survey**, the **US Geological Survey (USGS)**, and the **Canadian Hydrographic Service (CHS)** contributed valuable expertise and alignment with national geospatial strategies. Sponsors prioritized improving interoperability between land and sea datasets, accelerating the adoption of open standards, and promoting sustainable, scalable approaches to coastal data integration, monitoring, and management.

The pilot brought together Compusult, Pangaea Innovations, and TCarta to explore innovative, standards-based solutions that enable seamless land-sea data integration. Each organization contributed a complementary approach:

- **Compusult** demonstrated a web-based platform that combines land and sea data into unified visualizations and supports navigational decision-making through dynamic tidal modeling.
- **Pangaea Innovations** showcased the use of Discrete Global Grid Systems (DGGS) to link diverse terrestrial and marine datasets using a simple, scalable indexing system that eliminates the need for complex data harmonization.
- **TCarta** applied satellite technologies to generate dynamic, real-time shoreline and bathymetric data, offering a cost-effective solution for continuous coastal monitoring.

Additionally, a separate **Draft Guide and Best Practices Engineering Report** developed by **OceanWise** and **Pelagis** captures key lessons and provides practical recommendations for integrating terrestrial and marine data across the coastal zone.

Key findings from the pilot include:

- The adoption of a **Unified Geospatial Reference** using modern vertical datums and separation surfaces enables precise integration of land and marine elevation data, eliminating discontinuities at the coastline.
- Applying **FAIR Data Principles** through rich metadata and international catalog standards improves data discoverability, automation, and reuse across federated systems.
- Addressing intertidal data voids—through the **Mind the Gap** approach—ensures that spatial and temporal gaps between land and sea datasets are filled using remote sensing, targeted surveys, or documented interpolation.
- Implementing **Coordinated Governance** frameworks such as IGIF-Hydro clarifies institutional responsibilities, reduces duplication, and accelerates policy alignment across sectors.
- **Scalable Resolution Management** allows the fusion of multi-scale elevation datasets using techniques like TINs and DGGS, balancing local detail with regional context for resilient coastal planning.

FMSDI 5 confirms that a next-generation Marine Spatial Data Infrastructure must be dynamic, federated, and standards-driven to support coastal resilience, environmental stewardship, and operational effectiveness. The pilot's results lay the groundwork for future implementations that will empower coastal communities and maritime stakeholders to make better, faster, and more informed decisions.

III KEYWORDS

The following are keywords to be used by search engines and document catalogues.

fmsdi, intertidal, vertical datum, coastal, land, hydrospatial

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V FUTURE OUTLOOK

Looking ahead, the FMSDI 5 Pilot sets the stage for broader adoption of federated, standards-based marine spatial data infrastructures that can dynamically integrate land and sea datasets. Future initiatives will focus on operationalizing demonstrated approaches such as DGGS-based indexing, semantic uplift, and real-time EO-derived shoreline updates, enabling seamless interoperability across agencies and jurisdictions. Emphasis will also be placed on aligning with global initiatives like the UN-GGIM IGIF-H and the IHO S-100 framework, supporting climate resilience, coastal planning, and maritime safety.

The Draft Best Practice Report developed during the pilot will be expanded and refined in future collaborative work to produce a final version. This will consolidate implementation guidance and promote consistent, standards-aligned approaches to coastal data integration. Continued adoption of open frameworks and modular architectures will support the evolution of a Marine SDI that is adaptable, coordinated, and designed for long-term interoperability.

VI VALUE PROPOSITION

The FMSDI 5 Pilot demonstrates the practical and strategic value of a federated, standards-based approach to integrating land and marine geospatial data across the intertidal zone. By enabling seamless interoperability through open APIs, semantic uplift, and dynamic indexing systems like DGGS, the pilot empowers agencies to make faster, data-driven decisions in navigation safety, coastal planning, and environmental management. It reduces redundancy, enhances data usability across jurisdictions, and lays the groundwork for more resilient and efficient marine spatial data infrastructures that can support both public and private sector needs.

1

INTRODUCTION

1 INTRODUCTION

The fifth version of the Federated Marine Spatial Data Infrastructure (FMSDI5) Pilots addresses one of the most complex challenges in geospatial data management—**data integration at the land-sea interface**. This interface represents the transitional zone where land-based and marine-based data systems meet. Differences in data standards, methodologies, scaling, and spatial-temporal coverage across agencies create significant interoperability barriers. Dynamic natural processes, such as tidal shifts, erosion, sedimentation, and human activities, further reshape the intertidal zone, adding to the complexity.

1.1. Aims

The initiative explores innovative methods to unify disparate datasets and models into consistent workflows. It highlights practical solutions through demonstrators and prototypes that align with international geospatial standards. These efforts are grounded in real-world scenarios that emphasize interoperability across agencies and domains.

This report (D001) compiles the outcomes, lessons learned, and experiences from the Pilot. The content emphasizes:

1. Key challenges and practical solutions for integrating terrestrial and marine geospatial data across the intertidal zone.
2. Technical and organizational contributions of participating stakeholders and solution providers.
3. Technology demonstrator platforms that showcase cross-domain data interoperability through open standards and APIs.
4. Recommendations to support global alignment of land-sea data integration efforts with evolving standards and frameworks.
5. A Draft Guide and Best Practices Report (D002) to aid organizations in addressing the complexities of merging data at the land/sea interface.

1.2. Objectives

The **FMSDI Pilot** focuses on two primary objectives:

1. **Defining best practices** for achieving seamless data interoperability across land-sea boundaries.

2. **Developing dynamic data integration approaches** that enable near real-time, lossless conflation of terrestrial and marine datasets.

2

BACKGROUND

2 BACKGROUND

2.1. The Land/Sea Interface: Definition and Importance

The inter-tidal and nearshore region, also referred to as the **“white ribbon”**, is the area of the shoreline that alternates between being exposed to air during low tide and submerged underwater during high tide. This dynamic region serves as the boundary between terrestrial and marine ecosystems and undergoes constant changes due to tidal cycles.

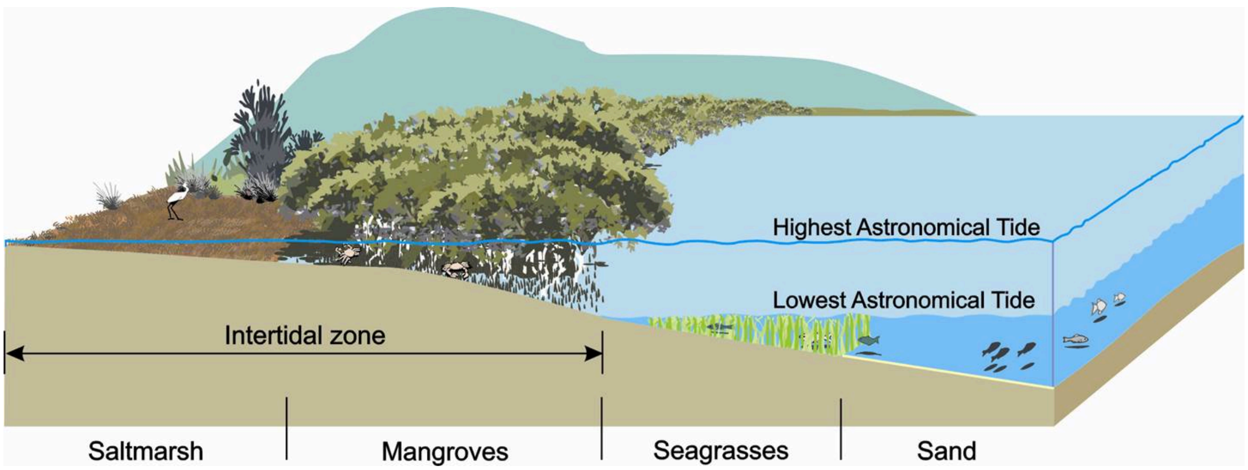

Figure 1 — Natural shoreline gradation illustrating the land-sea interface.
Source: NSW Department of Primary Industries – Fish Habitat Network.

The intertidal zone holds significant ecological importance as a habitat for a diverse array of species, including plants, animals, and microorganisms that are uniquely adapted to survive in both aquatic and terrestrial conditions. It supports intricate food webs, provides breeding grounds for marine species, and functions as a natural filter by trapping sediments and processing nutrients, thereby enhancing water quality.

Economically, the intertidal zone contributes through resources such as fisheries, aquaculture, and tourism. It also plays a crucial role in coastal protection by absorbing wave energy and mitigating the impacts of storm surges. Environmentally, this zone offers valuable insights into changes such as sea-level rise, erosion, and the effects of climate change. It serves as a natural laboratory for studying sediment dynamics, coastal morphology, and the interaction of biological and physical processes.

The intertidal zone also holds cultural and recreational value, being a space for traditional practices, heritage activities, and leisure pursuits like fishing and tide pooling. Furthermore, it is pivotal for sustainable coastal zone management and urban planning, influencing policies related to conservation, development, and disaster mitigation.

2.2. Tides Geography

Tides, as well known, are the periodic rise and fall of sea levels caused primarily by the gravitational forces exerted by the Moon and the Sun on Earth. The interaction of these forces with Earth's rotation generates tidal bulges in the oceans. As Earth rotates, these bulges shift, creating the high and low tides experienced along coastlines. The Moon's gravitational pull has the most significant influence, with the Sun's gravity acting as a secondary force, modifying the intensity of tides depending on their alignment with Earth.

Tidal patterns vary globally due to factors such as the Earth's tilt, ocean basin shapes, and coastal configurations. There are three main tidal patterns: diurnal, semidiurnal, and mixed. Diurnal tides consist of one high and one low tide each day, common in locations like the Gulf of Mexico. Semidiurnal tides, observed in areas like the Atlantic coast, feature two high and two low tides of approximately equal height within a day. Mixed tides, prevalent in the Pacific, display two high and two low tides of unequal height daily.

Spring and neap tides further illustrate tidal variability. Spring tides occur during full and new moons when the Sun, Moon, and Earth align, amplifying tidal forces and resulting in higher high tides and lower low tides. Conversely, neap tides occur during the first and third quarters of the lunar cycle when the Sun and Moon are at right angles to Earth, diminishing tidal effects and producing lower high tides and higher low tides.

Local geography plays a significant role in shaping tidal behavior. Coastal and underwater topography can amplify tidal ranges in narrow inlets, bays, or estuaries, leading to phenomena like tidal bores. In contrast, open ocean regions may experience minimal tidal changes due to the lack of such constraining features.

In addition to the vertical rise and fall of water, tides generate tidal currents, which are horizontal water movements associated with changing tides. Flood currents carry water inland as the tide rises, while ebb currents move seawards as the tide falls. These currents influence sediment transport, nutrient cycling, and coastal erosion, making them essential to both natural processes and human activities.

Tidal patterns are also subject to long-term variations due to factors such as Earth's axial tilt, orbital eccentricity, and the reshaping of ocean basins. Over decades or centuries, these changes can alter tidal ranges and frequencies, impacting coastal ecosystems and infrastructure.

The effects of climate change are expected to amplify tidal impacts. Rising sea levels will increase the baseline water level, intensifying high tides and making low-lying areas more vulnerable to flooding. These shifts highlight the importance of understanding and predicting tidal behavior to mitigate risks and protect coastal environments.

2.3. Challenges in Harmonizing Land and Marine Data

Harmonizing land and marine data presents numerous challenges stemming from the distinct approaches, priorities, and methodologies of the respective communities. One significant challenge lies in differing scaling practices. Land data often focuses on localized, high-resolution features, while marine data typically emphasizes broader, regional scales to accommodate vast oceanic expanses. This disparity complicates efforts to create consistent models that accurately represent both environments.

Temporal aggregation poses another obstacle. Terrestrial data may prioritize long-term trends and static features, whereas marine data often requires high-frequency updates to account for dynamic conditions such as tides, currents, and seasonal variations. Aligning these temporal frameworks is essential but requires sophisticated integration techniques to avoid information loss or misrepresentation.

Data density further complicates harmonization efforts. Land data is frequently collected at a high density in urban or economically significant areas, while marine data often suffers from uneven coverage, especially in remote or deep-sea regions. This uneven distribution results in gaps that hinder the creation of comprehensive, interoperable datasets.

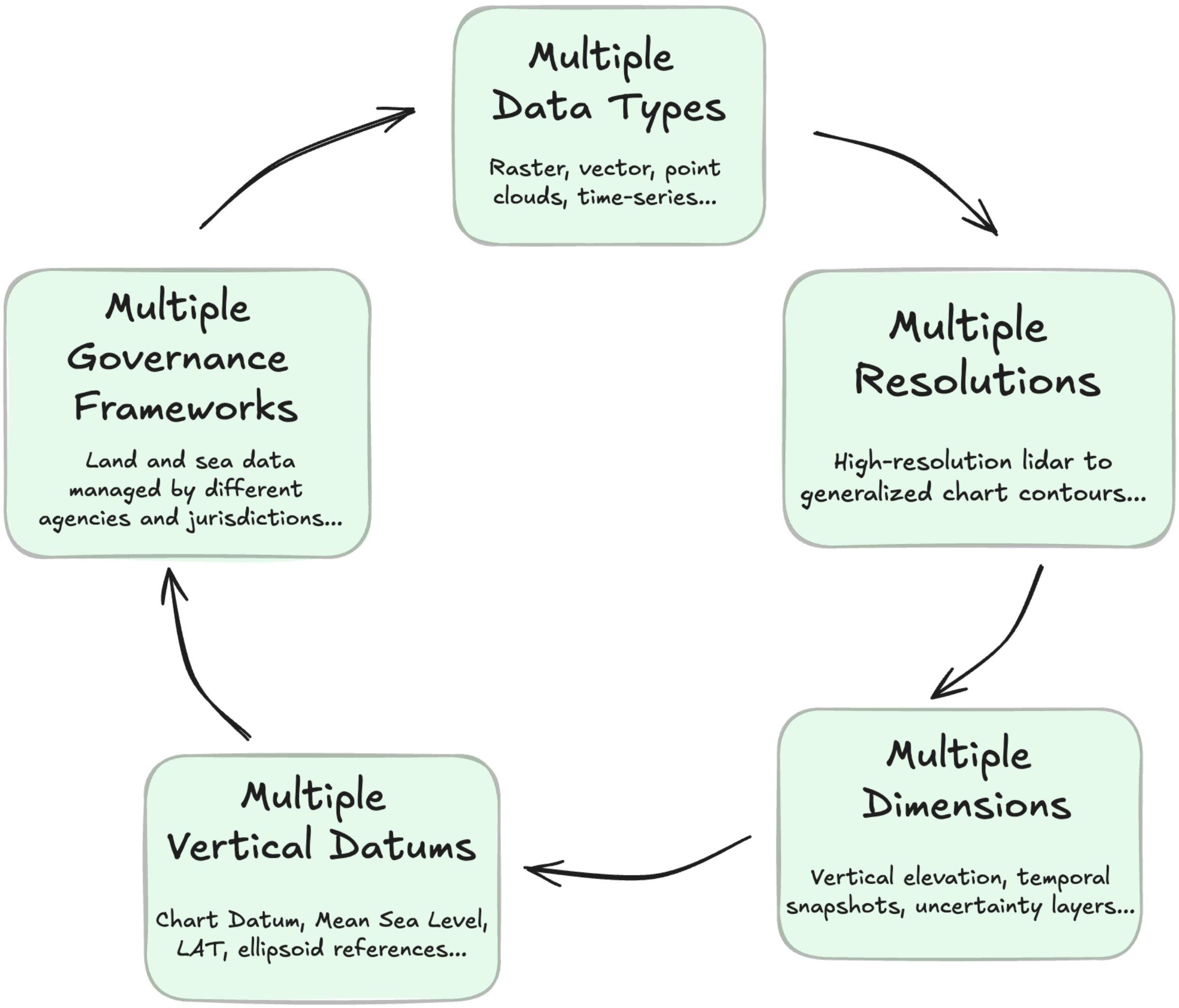

Figure 2 — Land/Sea Data Integration Challenges

This diagram summarizes key technical challenges in the integration of intertidal data—an area that inherently lies at the boundary between land and sea. It highlights five interrelated categories of complexity:

- **Multiple Data Types:** The integration of raster (e.g., satellite imagery), vector (e.g., coastline polygons), point cloud (e.g., lidar), and time-series (e.g., tide gauges) data requires harmonization at both structural and semantic levels.
- **Multiple Resolutions:** Land datasets often feature high-resolution detail for infrastructure or cadastral purposes, while marine datasets may generalize features for navigational safety. This leads to scale mismatches and spatial discontinuities when aligning features across the shoreline.
- **Multiple Vertical Datums:** Differences in reference surfaces—such as Chart Datum, Mean Sea Level (MSL), and ellipsoidal heights—must be reconciled to merge terrestrial and bathymetric data. This is especially important in intertidal zones where elevation differences define feature visibility and interpretation.

- **Multiple Dimensions:** Intertidal data is not static. Elevation, time, and uncertainty are critical dimensions in feature representation, requiring support for 4D spatio-temporal models in analysis and display.
- **Multiple Governance Frameworks:** Land and marine environments are managed by different organizations and jurisdictions, often operating under separate legal mandates. Issues include mixed or split accountabilities, differing legal frameworks, inconsistent standards and tools, lack of coordination, and mismatched funding or prioritization.

These challenges are inherently interdependent. Solving one often exacerbates or reveals others. For instance, transforming data to a common vertical datum may expose inconsistencies in resolution or sampling frequency. The cyclic nature of these challenges reinforces the need for integrated strategies and holistic data models.

In addition semantic differences in terminology, data quality standards, and methodologies across agencies exacerbate the challenge.

3

DATA INTEGRATION STRATEGIES

3 DATA INTEGRATION STRATEGIES

3.1. Semantic Uplift and Mapping for Cross-Domain Transformation

Harmonizing data between the land and marine domains involves addressing several intricate challenges to achieve seamless interoperability. One of the key aspects is the need for **semantic uplift** and the application of **mapping rules** for cross-domain data transformation. The complexity is heightened by the need to address differences in scaling, temporal aggregation, and data density between land and marine datasets. These challenges require innovative approaches and tools to ensure that data integration occurs with minimal loss of information and maximum fidelity to the original datasets.

Semantic uplift is an essential process in cross-domain data transformation, where data from one domain is enriched to align with the conceptual models and semantics of another domain. This ensures that data originally designed for land or marine applications can be accurately interpreted and utilized in the other domain with minimal information loss.

Semantic uplift involves adding context, metadata, and attributes to the source data to enhance its expressiveness and compatibility. For example, a marine dataset describing bathymetric features might require additional annotations to align with terrestrial elevation models, such as vertical datum transformations or feature type classifications.

Mapping rules form the foundation of the transformation process, defining how features, attributes, and relationships in the source data correspond to those in the target domain. These rules ensure consistent and predictable data conversion and typically include:

- **Feature Type Mapping**: Identifying equivalent or analogous feature types between land and marine datasets (e.g., mapping “seafloor elevation” to “topographic contour”).
- **Attribute Transformation**: Converting attributes to match the target domain’s specifications, such as units of measurement or coordinate systems.
- **Contextual Translation**: Applying domain-specific knowledge to interpret and adapt data, such as linking marine habitat classifications with terrestrial land use categories.
- **Data Quality and Constraints**: Preserving or recalibrating quality metrics and constraints to maintain data integrity after transformation.

3.2. Minimizing Information Loss in Dynamic Data Integration

Integrating dynamic data across land and marine domains requires employing strategies that minimize information loss. This is essential when dealing with datasets that differ in resolution, temporal scales, and semantic contexts. Several approaches support preserving data fidelity and usability:

- **Enriching Data with Semantic Uplift**: Adding context, metadata, and attributes to source data ensures alignment with the target domain's conceptual model, preserving critical information during transformation.
- **Defining Standardized Mapping Rules**: Establishing clear mapping rules guides transformations by accounting for feature types, attribute conversions, and domain-specific semantics, ensuring accurate translation of information.
- **Using Hierarchical Aggregation**: Employing hierarchical structures to aggregate or disaggregate data when transitioning between resolutions or scales minimizes detail loss while maintaining compatibility.
- **Analyzing Error Propagation**: Tracking and quantifying errors during integration helps identify potential points of information loss, allowing for necessary adjustments to reduce their impact.
- **Interpolating and Filling Gaps**: Using advanced interpolation techniques addresses missing values, ensuring spatial and temporal continuity without compromising the integrity of the original data.
- **Establishing Quality Metrics**: Defining cross-domain metrics ensures integrated datasets meet standards for accuracy, resolution, and consistency.
- **Validating Iteratively**: Continuously validating integrated data against benchmarks or through expert reviews helps identify and resolve discrepancies early in the process.
- **Leveraging Standards and Frameworks**: Employing international standards, such as OGC Web API frameworks, facilitates structured integration, reducing potential loss during transformation.

4

BEST PRACTICES DEVELOPMENT

4 BEST PRACTICES DEVELOPMENT

The **D002 Draft Guide and Best Practices Report** outlines a practical path forward for improving the integration of land and sea datasets—particularly in the dynamic and often underrepresented intertidal zone. It builds on globally recognized frameworks such as the **IHO S-100 series**, **OGC standards**, and the **UN-GGIM IGIF-Hydro** strategy.

At the core of this report are five interlinked best practices designed to transform fragmented or siloed coastal data into cohesive, usable resources that support real-world decision-making.

These best practices were developed through collaborative input from domain experts, national mapping agencies, and hydrographic offices involved in the pilot. Their formulation was informed by extensive dialogue with stakeholders from the sponsoring organizations and other institutions across Canada, the UK, and the US. The practices are grounded in operational implementations, cross-jurisdictional governance experiences, and a detailed evaluation of interoperability challenges encountered in the intertidal zone.

They emerged from in-depth analysis of use cases—such as coastal inundation modelling—and are closely aligned with international frameworks like IGIF-Hydro, as well as standards including ISO 19115, S-100, and GeoDCAT. Collectively, they address persistent issues in vertical referencing, metadata harmonization, data accessibility, and fragmented governance.

4.1. Best Practice 1: Unified Geospatial Reference

Accurate integration of coastal data requires all observations—whether from land or sea—to reference a **common geodetic framework**. Disconnected vertical and horizontal datums between topographic and hydrographic datasets remain one of the most persistent technical barriers to land-sea integration. This is especially critical in the context of coastal inundation modelling, where mismatches in reference systems can lead to significant errors in flood risk assessments.

A **Geodetic Reference Frame** provides the essential baseline for referencing features consistently across land, sea, and the coastal interface. Best practices emphasize the use of a **modern vertical control network**, incorporating **GNSS Continuously Operating Reference Stations (CORS)** and geoid-based height systems. These allow elevation data—such as those from LiDAR or bathymetric sonar—to be referenced to a **gravity-based vertical datum**, minimizing distortions from local tidal or ellipsoidal frames.

To harmonize datasets:

- Apply **vertical separation surfaces** to transform between ellipsoidal, geoidal, and tidal datums.
- Prefer the **geoid** as the zero-height reference surface for coastal modelling.

- Where national models exist (e.g., NOAA's *VDatum*, UKHO's *VORF*, CHS's *HyVSEPs*), use these to ensure consistent height referencing across domains.
- Always record the **datum, epoch, transformation method**, and **vertical orientation convention** in metadata.

Land-sea elevation integration is not just about technical accuracy—it's foundational for delivering **trustworthy, interoperable datasets** that can support planning, risk reduction, and long-term resilience. Without a unified reference frame, even the most advanced models or visualizations risk misrepresenting reality.

4.2. Best Practice 2: FAIR Data Principles

Ensure datasets are **Findable, Accessible, Interoperable, and Reusable (FAIR)** by providing comprehensive metadata and aligning with established international standards. When working across land and sea domains, metadata plays a critical role in determining whether data is fit for purpose—particularly when sources differ in coordinate systems, data quality, or lineage.

Each data product should:

- Be accompanied by metadata compliant with **ISO 19115** (Geographic Metadata) or national profiles (e.g., UK GEMINI), including spatial reference systems, vertical datums, accuracy, lineage, and acquisition methods.
- Clearly describe **data quality indicators** and **uncertainty metrics**, especially for elevation datasets.
- Follow **ISO 19131** Data Product Specification for defining intended use and requirements of datasets.
- Include transformation history and any associated accuracy degradation when converting between coordinate systems.

To enable machine-readable access and discovery:

- Register datasets in **federated catalogs** using standards like **GeoDCAT-AP** or **OGC API — Records**.
- Prefer formats and services that support structured discovery, such as **WMS/WCS**, **OGC Tiles**, or **linked data endpoints**.

Where applicable, formats like **Bathymetric Attributed Grid (BAG)** should be used to encapsulate both elevation and vertical uncertainty in a single product.

Adhering to FAIR principles reduces duplication, supports AI-enabled workflows, and builds long-term value into your coastal datasets through transparency and reusability.

4.3. Best Practice 3: Mind the Gap

The **“white ribbon”**—the intertidal zone between land and sea—is often poorly surveyed due to overlapping jurisdictional responsibilities and challenging environmental conditions. This results in persistent data voids that hinder coastal modelling, flood risk assessments, and infrastructure planning.

Where land and marine datasets do not overlap:

- First attempt to fill the gap with **new observations**, such as:
- **Satellite-derived elevation** (e.g., stereo imagery, SDB)
- **Airborne LIDAR**, especially topo-bathy systems
- **Targeted local surveys** using sonar or UAV platforms
- If fresh acquisition is not feasible, **interpolation** techniques (e.g., triangulation, cubic spline) may be applied. However:
- These methods should be selected based on the geomorphology of the area.
- Introduced artefacts or assumptions must be **clearly documented**.
- Error metrics and confidence levels should be quantified and included in metadata.

Note that interpolation is a **last resort**. While cost-effective, it risks misrepresenting seabed morphology, especially in dynamic coastal systems.

When filling gaps:

- Prefer integration of **OGC-compliant formats** (e.g., GeoTIFF, 3D Tiles)
- Use point or vector-based data as a foundation for creating **TIN models**, which preserve accuracy better than raster up/downsampling
- Record all processing steps and assumptions to support data transparency and downstream usage

Closing the white ribbon gap ensures spatial continuity, improves model fidelity, and supports decision-making across land-sea interfaces.

4.4. Best Practice 4: Coordinated Governance

Governance is as critical as technology when it comes to integrating intertidal and coastal data. The coastal zone sits at the boundary of multiple jurisdictions—land agencies, hydrographic offices, environmental authorities—each with different mandates, data standards, and legal frameworks. Without coordinated governance, efforts become fragmented, data remains siloed, and key information gaps persist.

The report emphasizes the importance of:

- **Shared governance models** that clarify roles, responsibilities, and data stewardship across agencies
- **Legal harmonization** across land and marine domains to reduce overlaps, gaps, and contradictions
- **Multi-agency collaboration**, supported by formal agreements, to ensure transparency in data policies, funding, and planning

A recommended framework is the **IGIF-Hydro Umbrella Governance Model**, which:

- Builds on the UN-GGIM's Integrated Geospatial Information Framework (IGIF)
- Aligns national, regional, and local efforts
- Promotes **interoperable data systems**, shared policies, and cross-sector coordination

Adopting such a model enables agencies to:

- Reduce duplication of effort
- Share authoritative data for planning and emergency response
- Support consistent, standards-based coastal data integration across scales

Ultimately, **governance must evolve in parallel with technical capability** to deliver on the promise of a seamless, resilient, and usable land-sea geospatial infrastructure.

4.5. Best Practice 5: Scalable Resolution Management

Land and marine data are frequently collected at **different spatial resolutions**, driven by environmental constraints, technology limitations, or differing mandates. Attempting to force uniform resolution across these datasets can result in **loss of accuracy**, artificial smoothing, or misleading artefacts.

Instead of resampling or generalizing, adopt **scalable and flexible data structures** that preserve detail where needed:

- Use **point clouds** or **vector datasets** as foundational inputs to avoid loss from rasterization.

- Build **TIN (Triangulated Irregular Network)** models to interpolate across varying point densities without upsampling.
- Consider **hierarchical grid systems** such as **Discrete Global Grid Systems (DGGS)** to manage multiscale data integration.

These structures support:

- Integration of high-resolution data in critical zones (e.g., flood-prone coastal settlements)
- Generalization at regional or national scale for planning and monitoring
- On-demand transformation into gridded models for simulation or visualization

When upsampling or downsampling is unavoidable:

- Document the transformation methods and any loss of precision
- Avoid misleading visual continuity across resolution boundaries
- Use caution when interpreting derived products in decision-making workflows

The objective is to **retain local accuracy without sacrificing broader context**. By embracing resolution-aware methods, practitioners can create continuous coastal elevation models that respect the complexity of source data while remaining usable across diverse applications.

4.6. Supporting Content

For expanded technical context, implementation guidance, and case-based insights, refer to the full **Draft Guide and Best Practices Engineering Report** (~39 pages, 30–40 min read). It covers:

- Topo-bathymetric surface integration techniques
- Data product specifications and quality standards
- Governance and institutional models
- Geodetic reference frames and vertical transformation methods
- Audience-focused implementation approaches and design principles
- A case study on coastal inundation modelling
- Appendices covering:
  - Communities of Practice (UK, Canada, US)
  - Land and marine data characteristics

- Future directions (e.g., vertical land motion, semantic alignment)
- Comparison of S-57 and land data (UK)
- Introduction to Discrete Global Grid Systems (DGGS)

You may access the full report here: **Read Online (HTML) | Download PDF**

5

TECHNICAL DEMONSTRATIONS

5 TECHNICAL DEMONSTRATIONS

To validate and operationalize the best practices outlined above, three technical demonstrations were conducted by pilot participants. These demonstrations explore real-world challenges and solutions in harmonizing terrestrial and marine geospatial data in intertidal and coastal zones. Each prototype highlights specific aspects of integration—ranging from vertical referencing and data interoperability to decision support and monitoring systems.

The demonstrations reflect the capabilities of different platforms and partners working within varied coastal environments. They serve as practical examples of how the best practices can be applied to support coastal resilience, hazard mitigation, and spatial planning at both national and regional scales.

The following sections summarize the purpose, implementation, and outcomes of each demonstration.

5.1. Compusult (D100): Coastal Erosion Monitoring and Prediction

5.1.1. Purpose

The purpose of Compusult's demonstration for this project is to showcase the integration of terrestrial and marine data sets into a unified operational picture, and to explore challenges encountered when integrating land and sea data from heterogeneous sources.

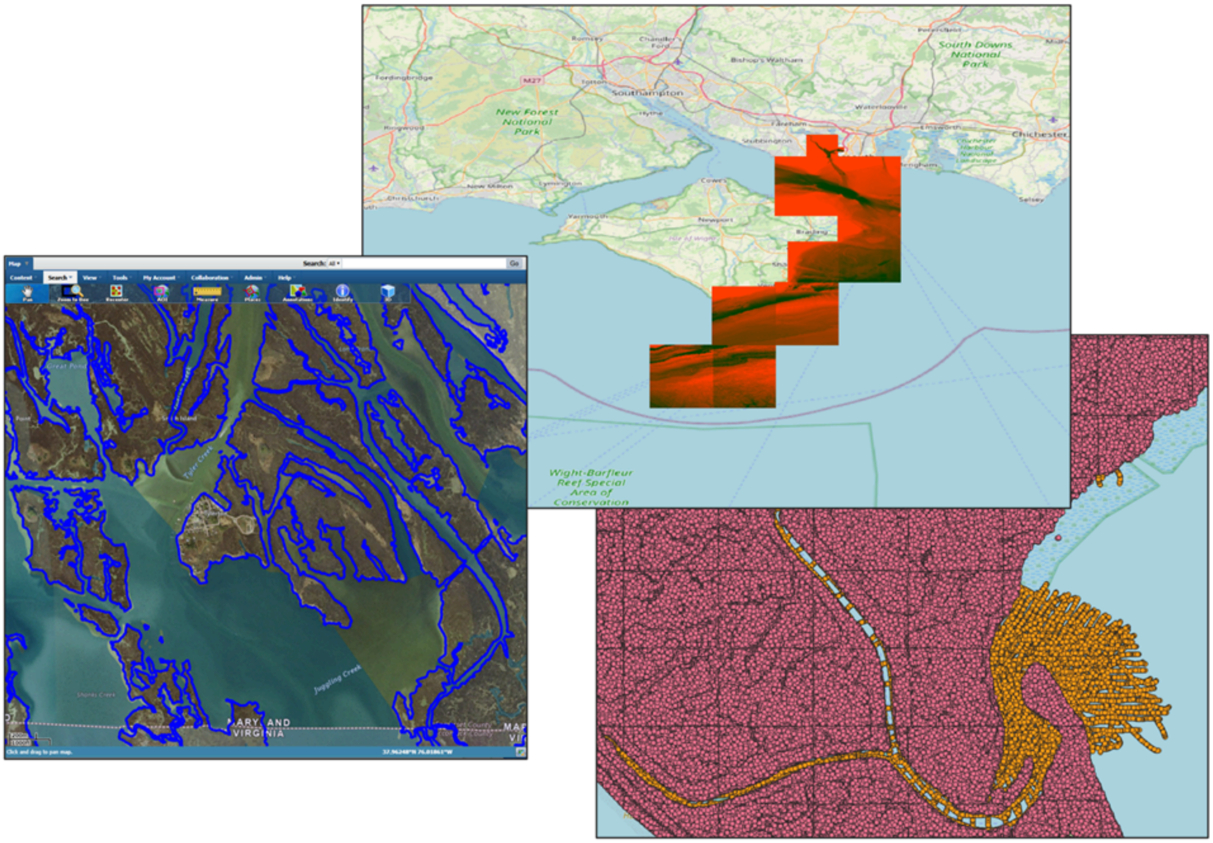

Figure 3 — Examples of Land-Sea Data Integration

5.1.2. Scenario Description

The demonstration illustrates two primary use cases leveraging Compusult's Web Enterprise Suite (WES) platform.

5.1.2.1. Land and Sea Data Integration Scenario

In this scenario, a geospatial analyst integrates terrestrial and marine data from multiple sources into a common operational picture.

WES is utilized to create data portfolios centered on thematic or geographic areas of interest. For this demonstration, two portfolios were created: one for The Solent (UK) and one for Chesapeake Bay (USA). Diverse land and sea datasets have been harmonized into a unified map-based view.

5.1.2.2. Vessel Navigation Scenario

In this scenario, a search and rescue vessel with a draught of 1 meter must navigate the intertidal waters of The Solent.

Compusult's implementation of an OGC API Process and OGC API Map facilitates identification of navigable waters based on terrain elevation, bathymetric soundings, and tidal conditions. A similar approach was applied to the Chesapeake Bay region.

5.1.3. Technical Objectives

The technical objectives were to:

- Aggregate terrestrial and marine data from disparate sources into a unified operational picture.
- Prototype an OGC API Process combining land and sea data for navigability analysis in intertidal zones.
- Demonstrate the application of OGC standards for dynamic, standards-based spatial querying and visualization.

An instance of WES was configured to serve as the demonstration platform for these objectives.

5.1.4. Platform

Figure 4 — Web Enterprise Suite (WES)

Compusult's Commercial-Off-The-Shelf (COTS) Web Enterprise Suite (WES) serves as the demonstration platform.

WES is a modular system built upon Open Geospatial Consortium (OGC) and ISO standards, supporting integration with a wide variety of commercial and open-source geospatial tools and services.

Web Enterprise Suite product information is available at https://www.webenterprisesuite.com.

The WES demonstration portal for FMSDI 5 can be accessed at https://wes-ogc.compusult.com.

5.1.4.1. Data Integration Portfolios

Two thematic portfolios were developed to demonstrate land and sea data integration:

5.1.4.1.1. The Solent, UK

The portfolio integrates datasets from:

- Ordnance Survey Maps API
- UKHO S-102 Bathymetric Surface
- UKHO Seabed Mapping Service
- UKHO Wrecks and Obstructions (Shapefiles)

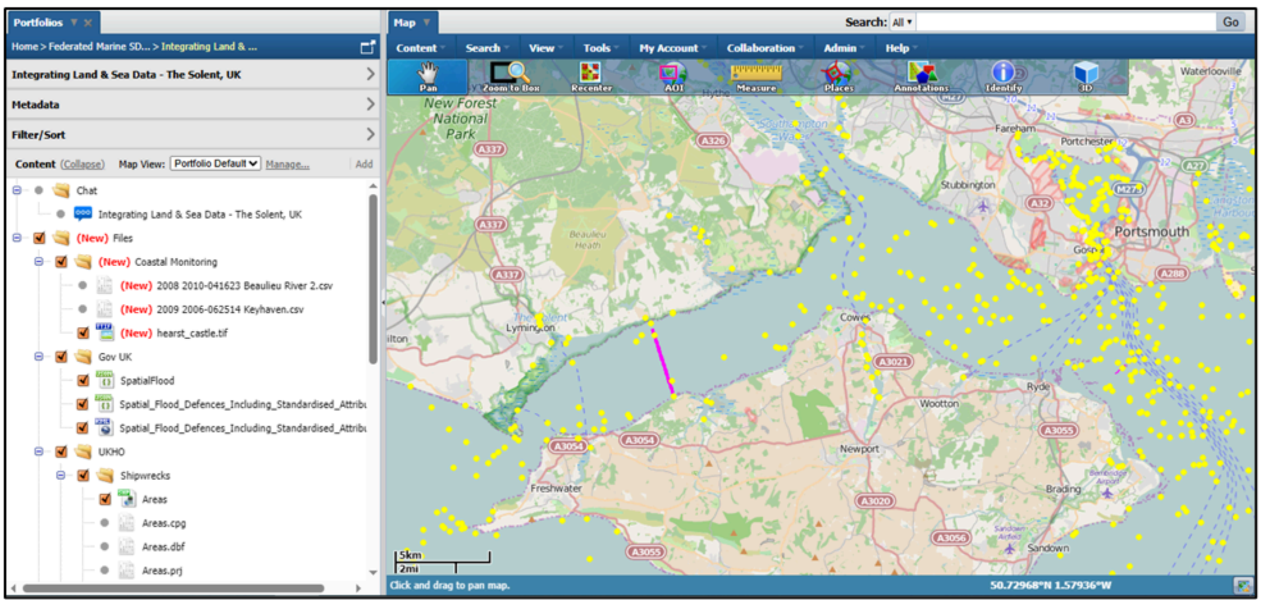

Figure 5 — Data Integration Portfolio - The Solent, UK

5.1.4.1.2. Chesapeake Bay, USA

The portfolio integrates datasets from:

- US Geological Survey (USGS) Imagery Topo Map
- NOAA National Geodetic Survey (NGS) Continually Updated Shoreline Product (CUSP)
- NOAA Historical Composite Shoreline

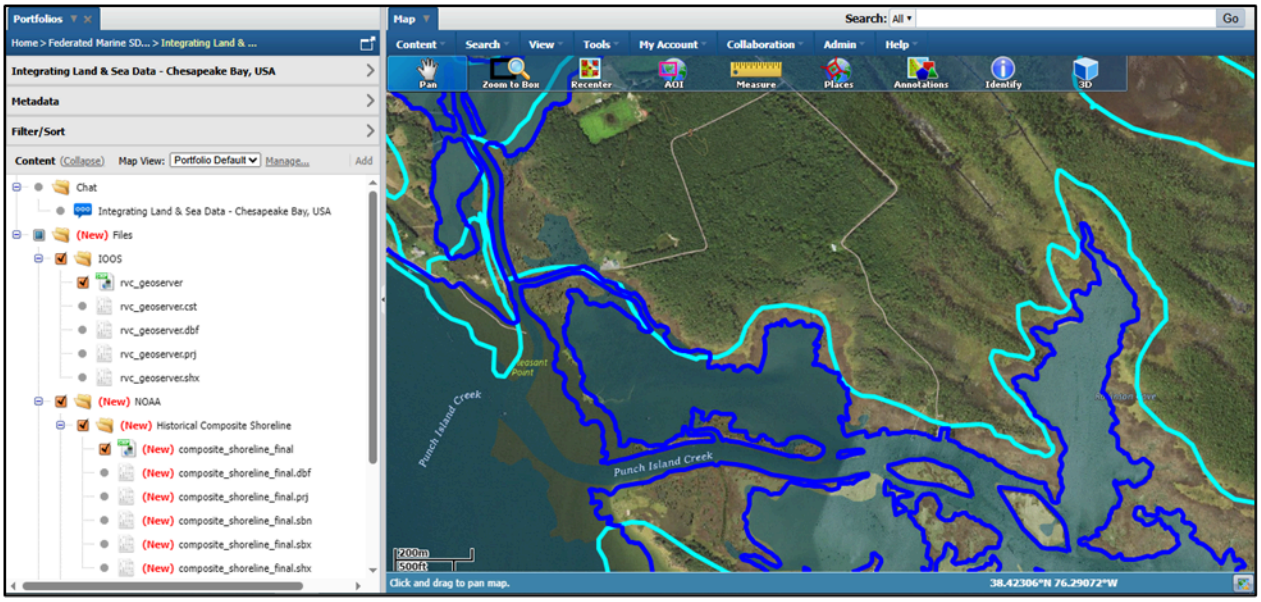

Figure 6 — Data Integration Portfolio - Chesapeake Bay, USA

5.1.4.2. Vessel Navigation Visualization

The vessel navigation service implements an OGC API Process and OGC API Map to visualize navigable waters in intertidal zones of The Solent and Chesapeake Bay.

5.1.4.2.1. OGC API – Processes

An OGC API Process calculates navigable and non-navigable waters.

User inputs include:

- Area of interest
- Vessel draught (in meters)
- Simulated tidal surge (in meters)
- Date and time (for historical tide data)

Datasets used:

- Digital Elevation Model derived from National Coastal Asset Register
- UKHO Admiralty Seabed Mapping Service bathymetry
- OceanWise tidal data (real-time and historical)

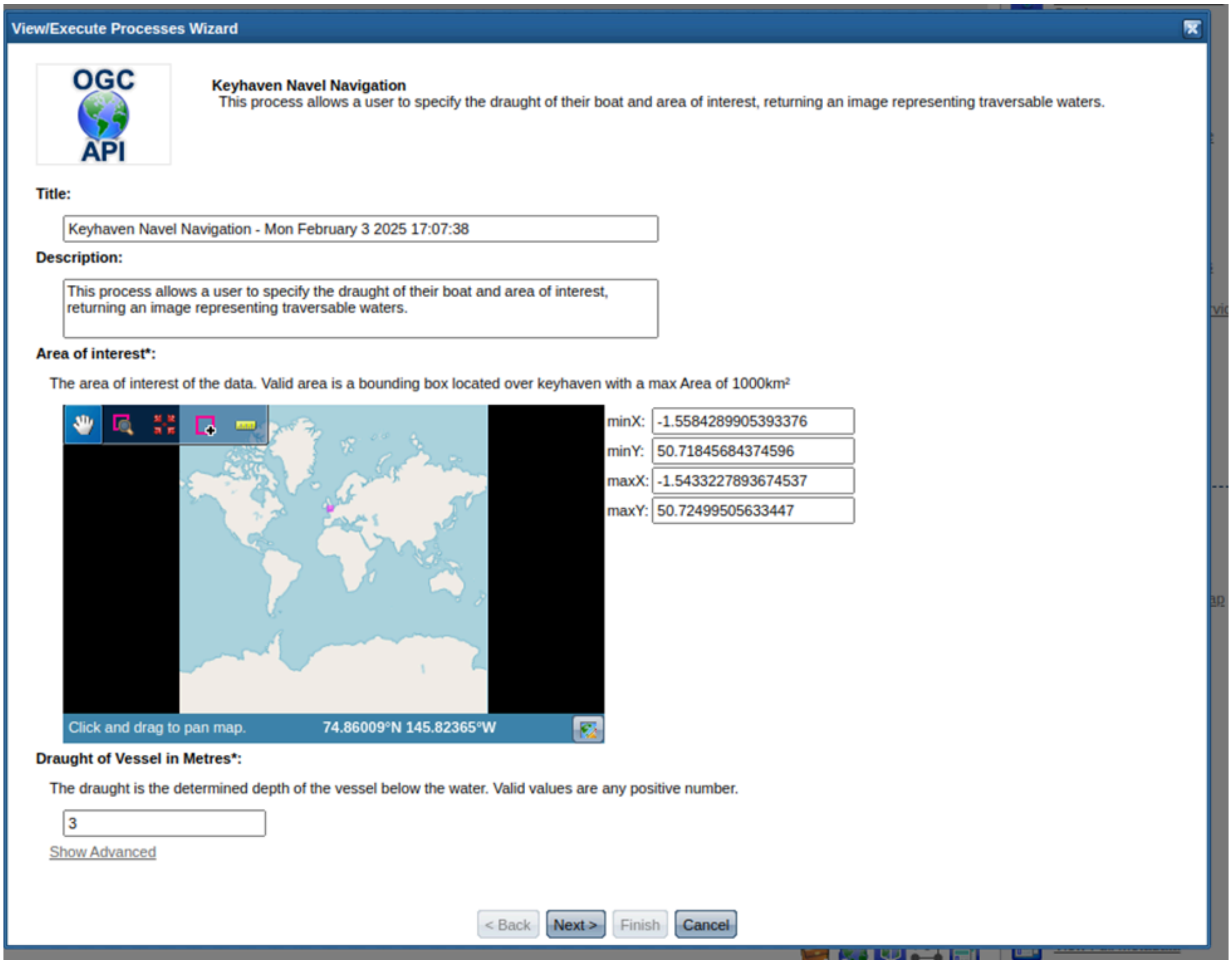

Figure 7 — Process Wizard

5.1.4.2.2. OGC API – Maps

The vessel navigation process outputs an OGC API Map:

- Navigable waters shown in blue
- Non-navigable waters shown in red
- Intertidal zones represented with a light gray ribbon

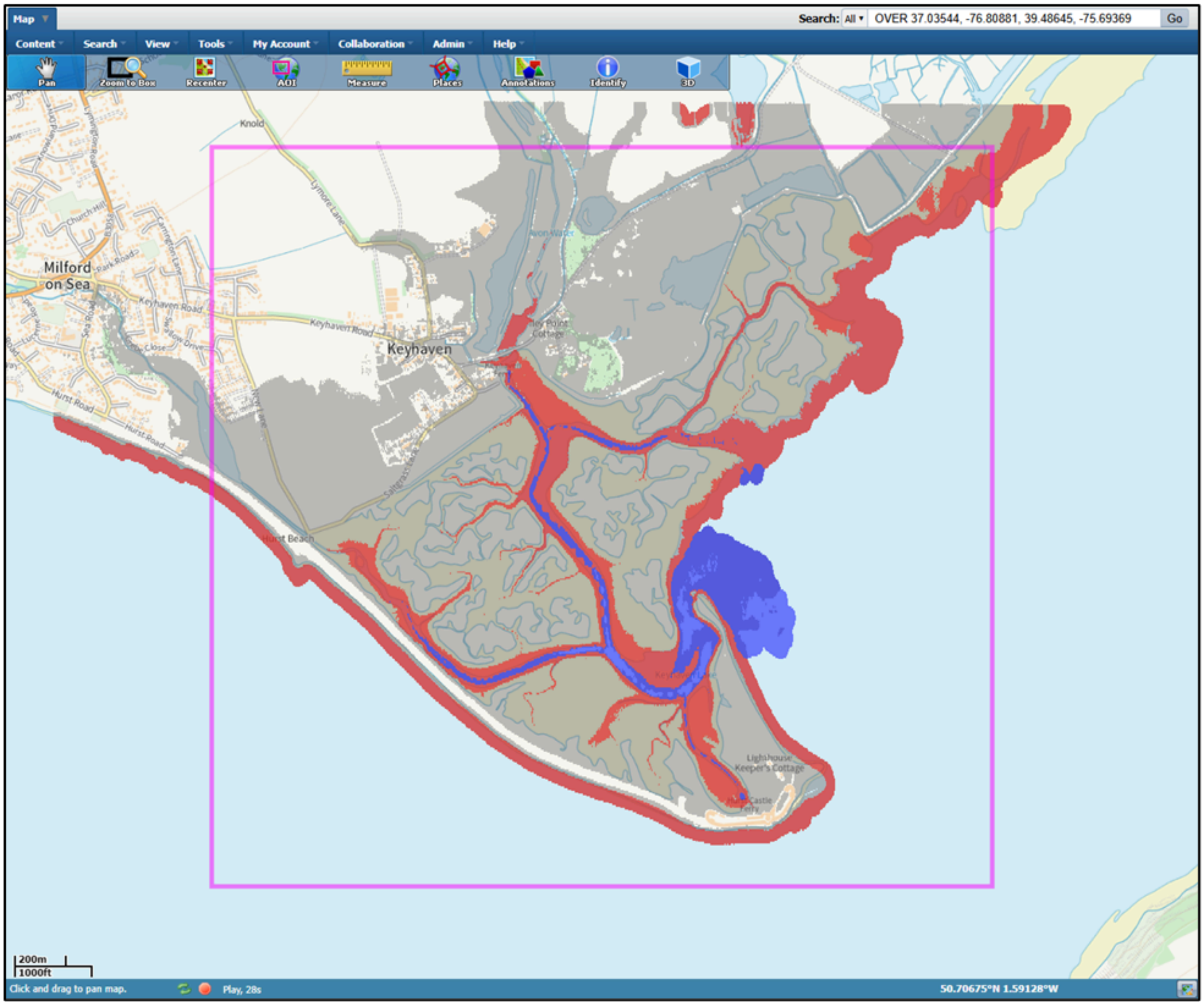

Figure 8 — Vessel Navigation Scenario Map

5.1.4.2.3. Cesium 3D Map Client

The WES 3D client visualizes the vessel navigation scenario in a three-dimensional environment using CesiumJS.

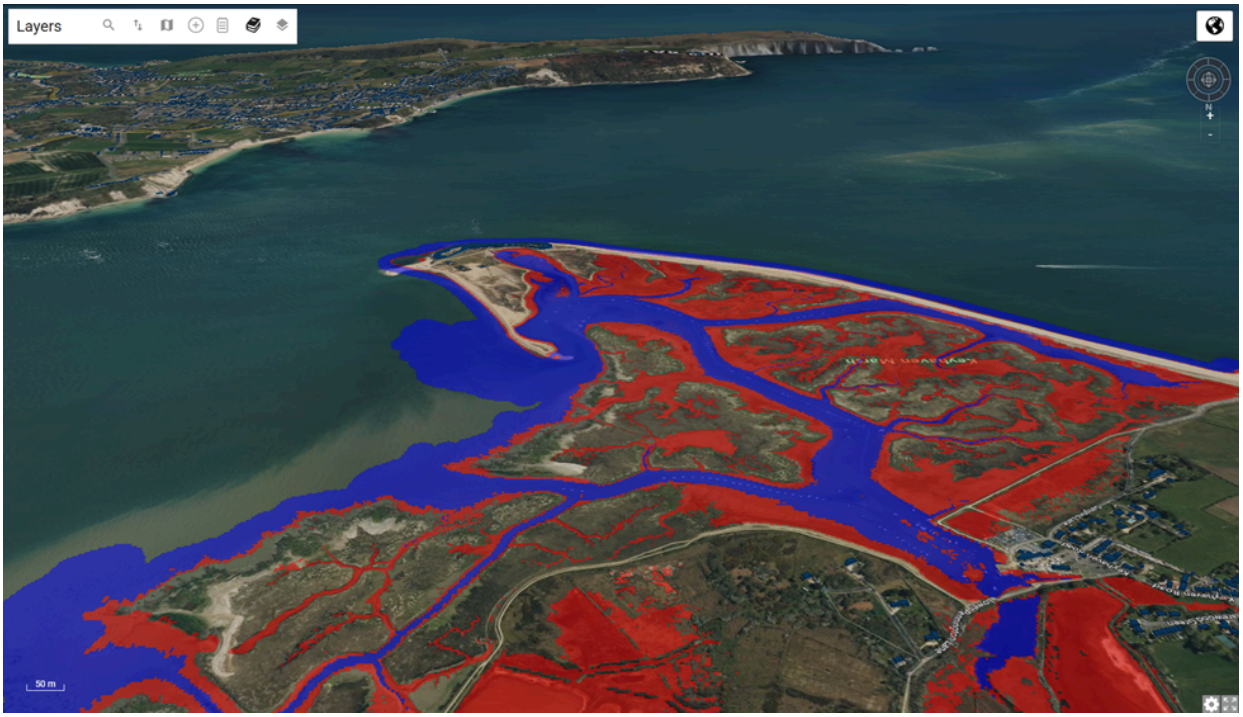

Figure 9 — WES 3D Map Viewer

5.1.5. Standards Employed by Platform

WES supports a wide variety of standards and specifications, including OGC and ISO standards. In particular, the following table identifies some of the standards used to implement the demonstration for FMSDI5.

Table 1 — Standards Employed at Compusult Demonstrator

STANDARD	USAGE
OGC API – Processes	The demonstrator uses an OGC process to generate map layers for the vessel navigation scenario.
OGC API – Maps	An OGC map is produced as the output of the vessel navigation process.
OGC Web Map Service (WMS) / Web Map Tile Service (WMTS)	WMS and WMTS are used to render base maps and other map layers in the demonstrator.
OGC GeoPackage	Portfolio data can be downloaded as a GeoPackage.
OGC Catalog Services for the Web (CSW)	CSW is used to search and manage services in the WES Catalog.
Keyhole Markup Language (KML)	KML files are added to a WES Portfolio and rendered in a map view.

STANDARD	USAGE
S-100 Universal Hydrographic Data Model (S-102 Bathymetric Surface)	S-102 raster imagery was used to construct the depth model for the vessel navigation scenario.
Esri Shapefile	Shapefiles are added to a WES Portfolio and rendered in a map view.

5.1.6. Gaps and Lessons Learned

5.1.6.1. Data Gaps

Available elevation datasets extended only to the low water mark, requiring bathymetric data supplementation. Observed non-uniformity in bathymetric coverage necessitated interpolation to ensure complete visualizations.

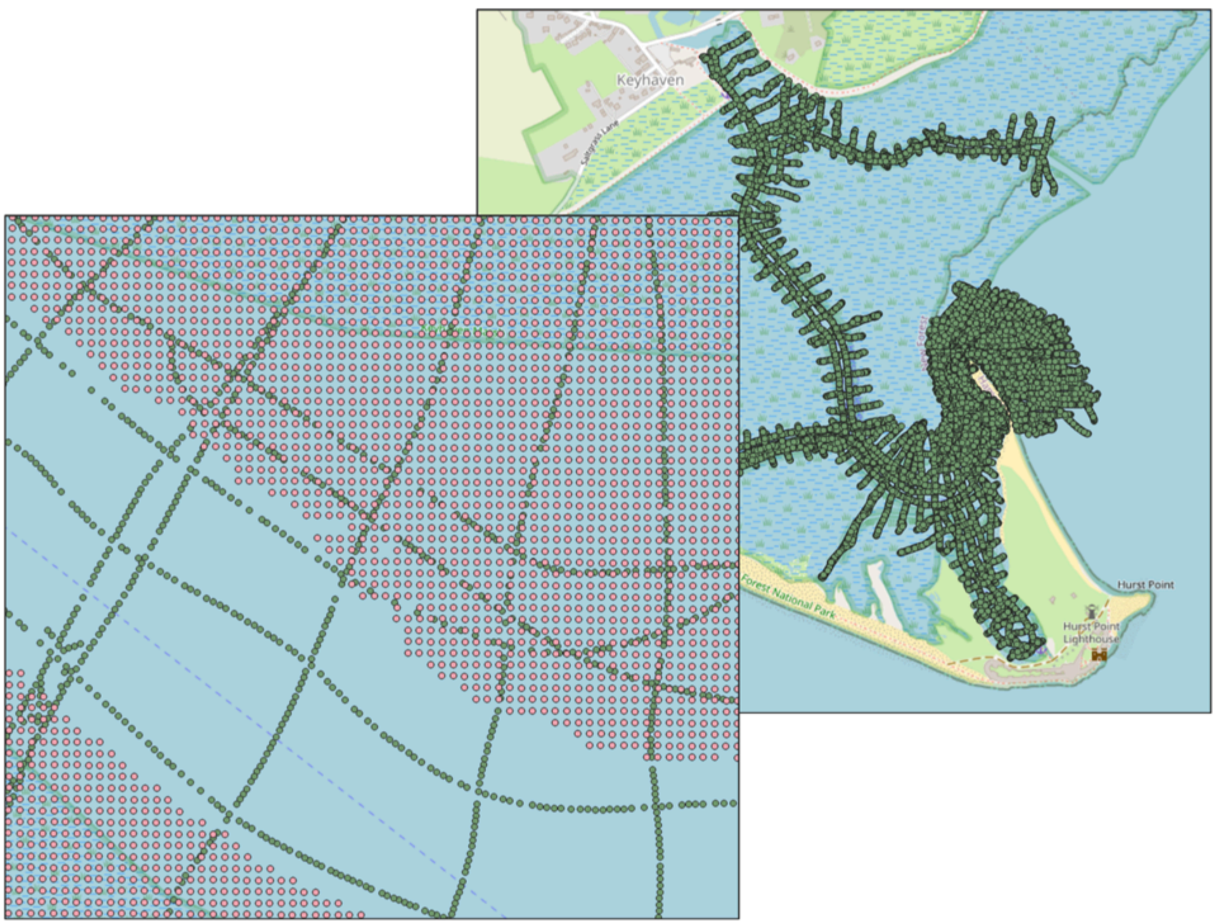

Figure 10 — Elevation and Bathymetry Data Gaps

5.1.6.2. Model Differences

Discrepancies were observed between different shoreline data models (e.g., NOAA CUSP vs. Historical Composite Shoreline), attributed to shoreline evolution and differing data capture methodologies.

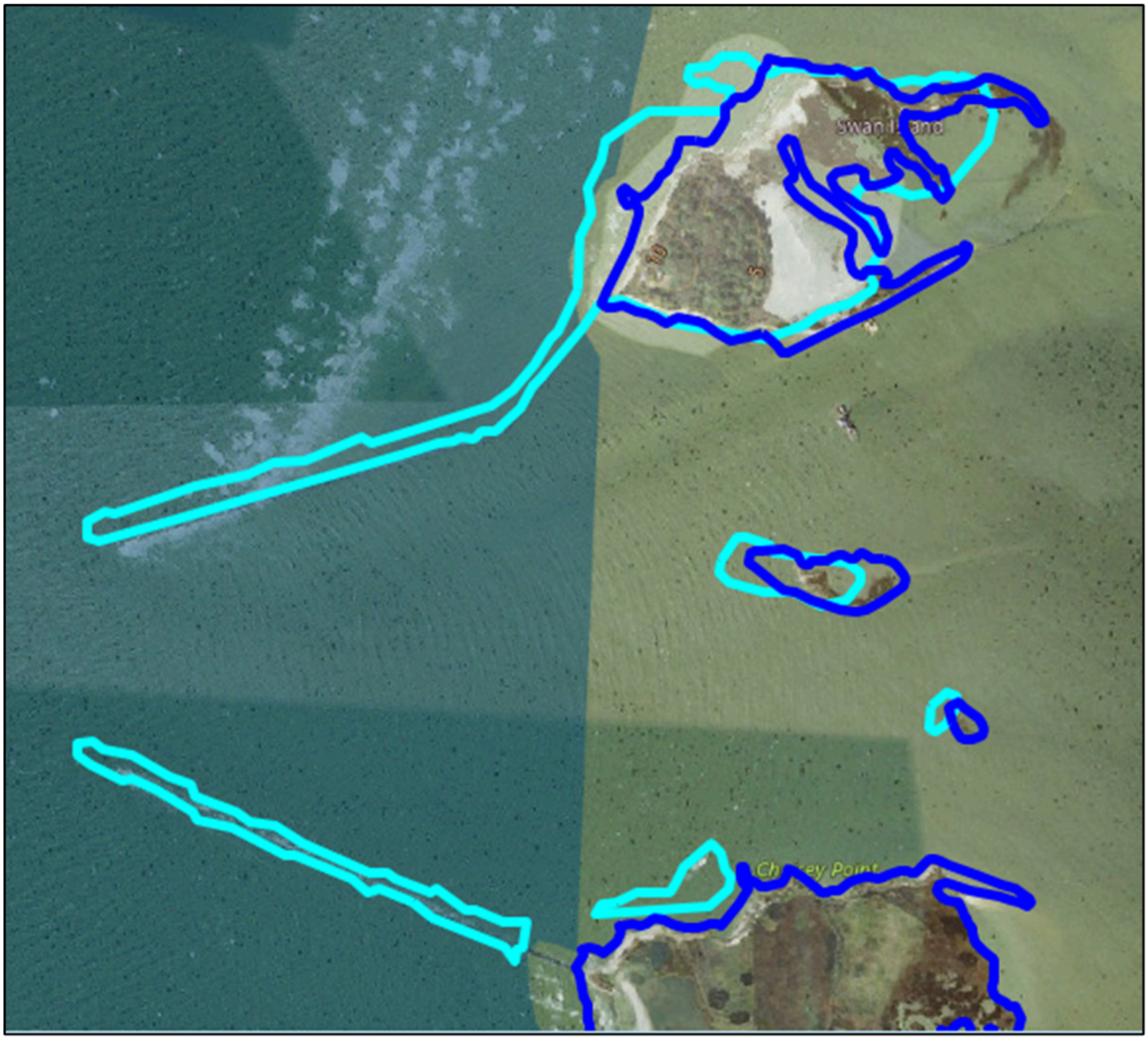

Figure 11 — Differences Between Shoreline Models

5.1.6.3. Vertical Datum Consistency

Inconsistencies were encountered when tidal data lacked vertical datum specifications. Early iterations assumed Ordnance Datum Newlyn (ODM), causing errors. After correction to Southampton Chart Datum (-2.74m), water depths displayed correctly.

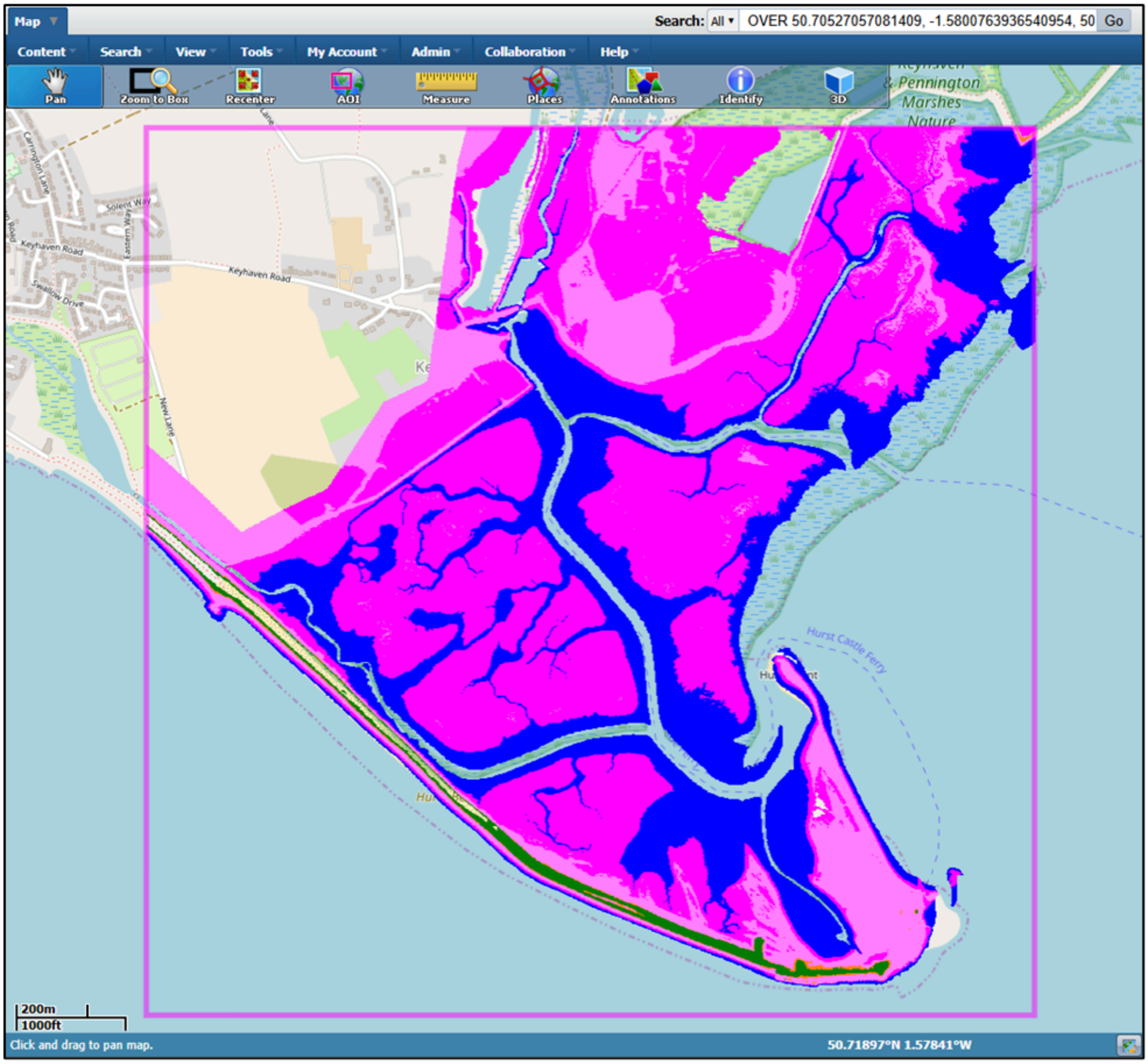

Figure 12 — Vessel Navigation Scenario with Incorrect Vertical Datum

5.1.6.4. Infrastructure Considerations

The vessel navigation process currently does not account for man-made flood control structures such as berms or sea walls, occasionally resulting in navigability mapping beyond such barriers.

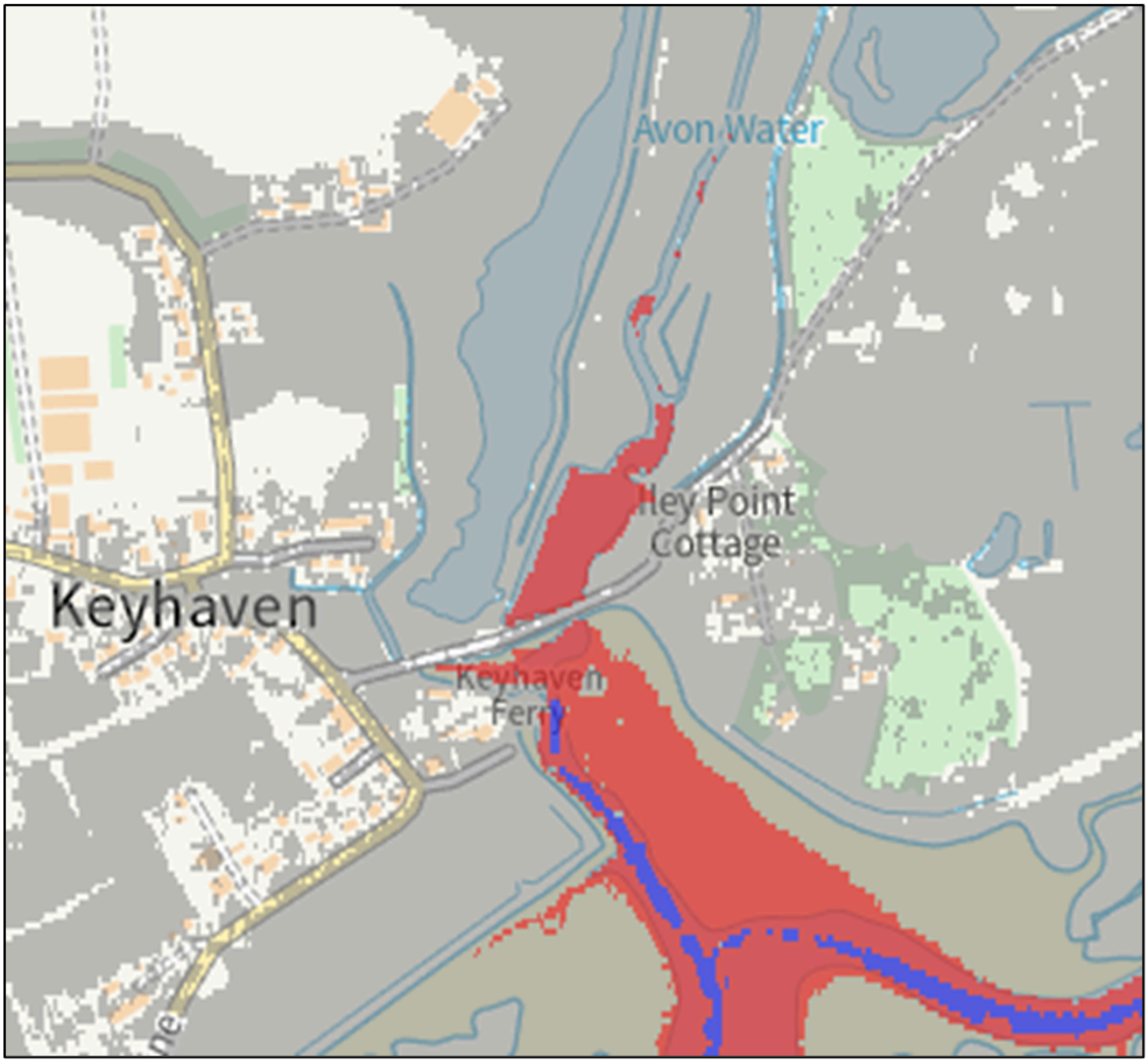

Figure 13 — Flood Control Infrastructure Considerations

5.1.7. Recommendations and Next Steps

Building on the outcomes of the pilot, the next steps and proposed improvements are as follows:

- Expand portfolios with additional land and sea datasets.
- Supplement bathymetry to address data gaps.
- Generate additional navigability maps simulating different tidal or storm surge conditions.
- Enhance the vessel navigation process to account for infrastructure barriers.
- Integrate vector datasets into the 3D client view.

- Provide easy access for participants via direct portal links.

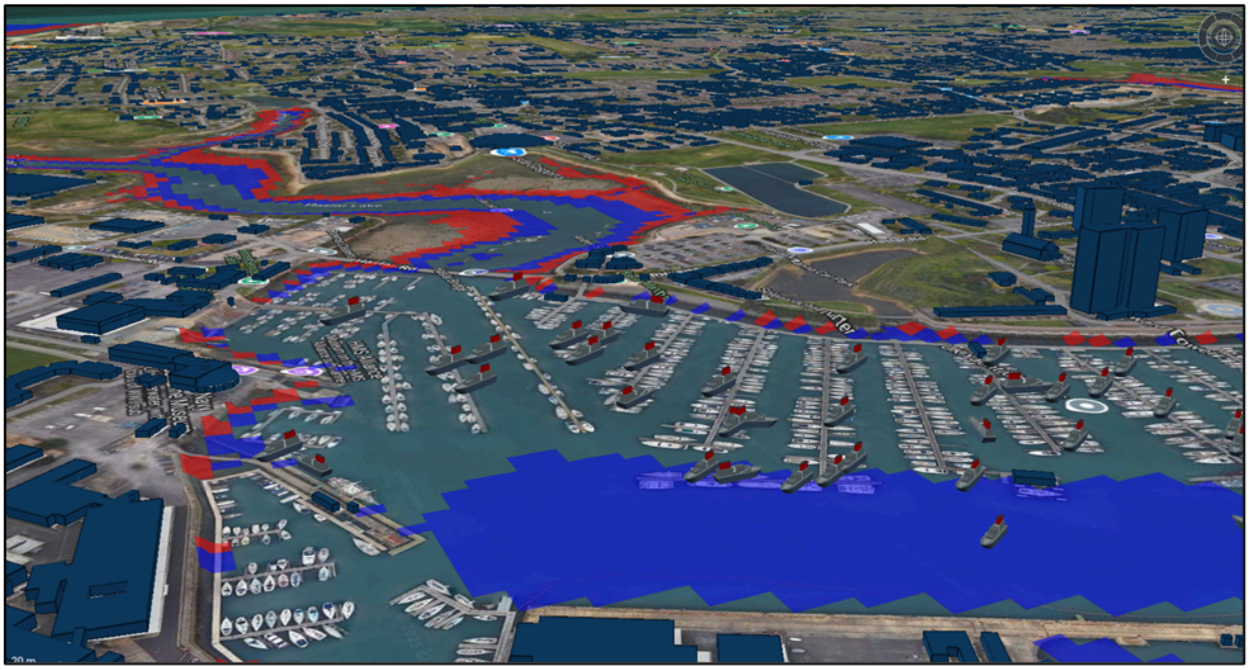

Figure 14 — 3D Client View - Portsmouth Harbour

5.1.8. Platform Quick Start

5.1.8.1. Platform Landing Page URL

The WES Demonstration Portal for FMSDI5 is available at:

https://wes-ogc.compusult.com

Account is required for access. Users may request an account via the portal's registration form.

5.2. Pangaea (D100): Trusted Data Interoperability for Port Operations

5.2.1. Purpose

The purpose of Pangaea's demonstration is to address the data integration challenges inherent to the intertidal zone — a highly dynamic and operationally significant environment

— by leveraging Discrete Global Grid Systems (DGGS) for scalable, standards-based data interoperability across land and sea domains.

5.2.2. Scenario Description

5.2.2.1. A Tale of Two Intertidal Zones

This demonstration focuses on two distinct intertidal regions: **The Solent (UK)** and **Chesapeake Bay (USA)**. Both locations present operational, environmental, and infrastructural challenges due to the dynamic nature of the land-sea interface.

5.2.2.1.1. The Solent, UK

Located in southern England, The Solent is shaped by a unique double high water phenomenon (M4/M2 harmonic interaction), leading to extended tidal plateaus and complex intertidal dynamics.

Primary Intertidal Characteristics

- Extensive mudflats and salt marshes, particularly within Southampton Water.
- Double high water effect causes prolonged tidal stasis during ebb, increasing operational complexity.

Infrastructure Implications

- Prolonged high water affects maintenance schedules for quay walls and marine infrastructure.
- Frequent wet-dry cycles accelerate corrosion, particularly in splash zones.

Navigation Considerations

- Intertidal mudflats influence channel boundaries and sediment transport.
- Dynamic margins require continuous monitoring for safe navigation.

Environmental Management

- The area includes protected habitats such as the Solent Maritime SAC.
- Balancing port operations with habitat preservation remains a key challenge.

Operational Adaptations

- Maintenance and inspection are aligned with tidal windows.

- Berthing and dredging strategies adapt to sediment movement and tidal shifts.

5.2.2.1.2. Chesapeake Bay, USA

North America's largest estuary, Chesapeake Bay, features expansive intertidal flats and significant hydrological variability across its length.

Primary Intertidal Characteristics

- Variable tidal range (0.6–2.8 feet), with fine-scale elevation gradients.
- Seasonal and episodic changes impact salinity, substrate, and shoreline morphology.

Infrastructure Implications

- Flood defenses and drainage systems face increasing stress from backflow and sea-level rise.
- Maintenance costs are rising due to saltwater intrusion and corrosion.

Navigation Considerations

- Shifting sediment patterns reduce channel reliability.
- High turbidity and tide-dependent access challenge vessel operations.

Environmental Management

- Overlapping jurisdictions create regulatory complexity.
- Restoration must reconcile short-term protection with long-term resilience.

Operational Adaptations

- "Tide-smart" infrastructure is increasingly adopted.
- Real-time data systems inform coastal decision-making and public outreach.

5.2.3. The Challenge of the Intertidal Zone

The intertidal zone is characterized by rapid and nonlinear environmental variability. It represents a complex data integration challenge due to the diversity of data sources, resolutions, spatial references, and collection methodologies. These differences create silos and compatibility issues that hinder actionable insight.

The conventional solution — harmonizing datasets before querying — is slow, inefficient, and not scalable.

5.2.4. Our Approach

Pangaea Innovations addresses these challenges by using **Discrete Global Grid Systems (DGGS)** to enable spatial data integration without prior harmonization.

DGGS technologies provide a common indexing framework across spatial, temporal, and vertical reference systems. This allows diverse datasets (in type, resolution, and coordinate system) to be queried, discovered, and integrated using **Zone ID lookups** rather than complex spatial joins.

For this project, we assessed the comparative value of **2D, 3D, and 4D DGGS infrastructures**, with the 4D (spatiotemporal) DGGS ultimately proving most effective for FMSDI interoperability challenges.

5.2.5. Technical Objectives

The main technical objective was to evaluate DGGS as a mechanism to support **cross-domain data integration** within the intertidal zone, preserving data integrity and semantic fidelity without requiring harmonization.

Specific goals included:

- Managing horizontal and vertical datum variations across datasets
- Bridging data format and schema differences
- Representing 3D/4D infrastructure features in DGGS
- Comparing the performance and expressiveness of 2D, 3D, and 4D DGGS frameworks

5.2.6. Platform

The TerraNexus FMSDI5 demonstrator is a CesiumJS application viewer embedded into a Django web application. t enables users to conduct OGC API DGGS queries over indexed terrestrial and marine data collections.

Users can define Areas of Interest (AOIs) via bounding boxes or DGGS Zone IDs. The platform then:

- Queries all DGGS-enabled collections for intersecting zones
- Automatically issues OGC API DGGS Zone Data Requests using link templates
- Renders responses as 4D visualizations (e.g., point clouds, 3D buildings) within the Cesium viewer

5.2.6.1. Platform Landing Page URL

The TerraNexus FMSDI5 Demonstration Platform is accessible at:

https://terranexus.pangaeainnovations.com/fmsdi25

Figure 15 — Terranexus The Solent DGGS

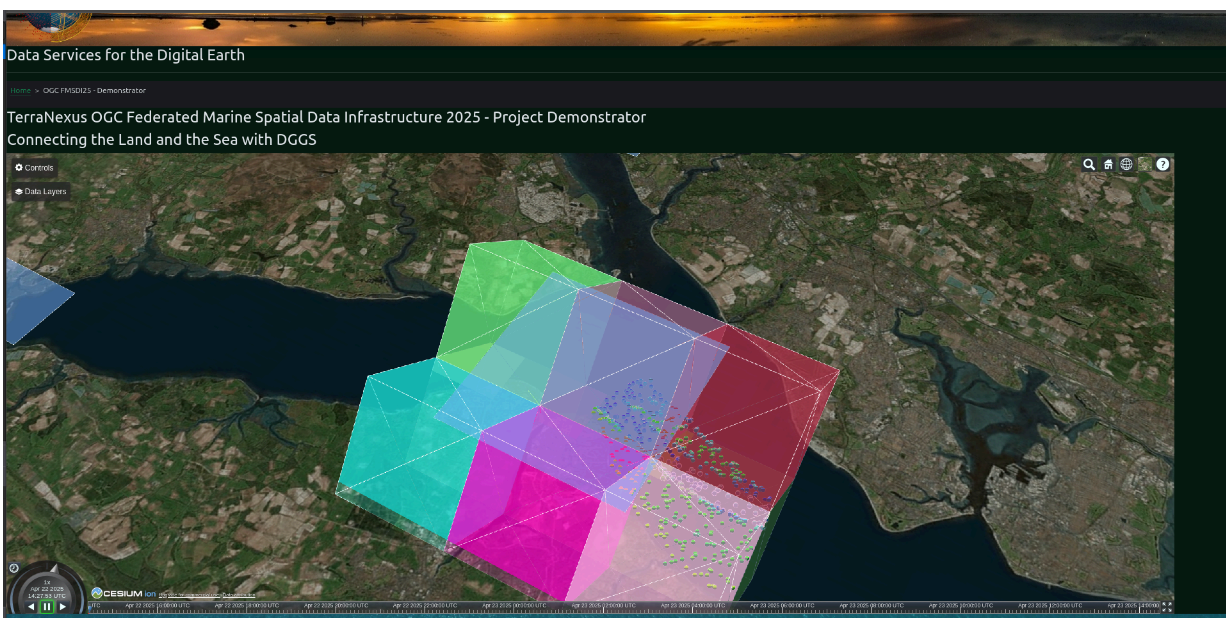

Figure 16 — TerraNexus Federated Marine Spatial Data Infrastructure Demonstrator — Shaded DGGS Zones

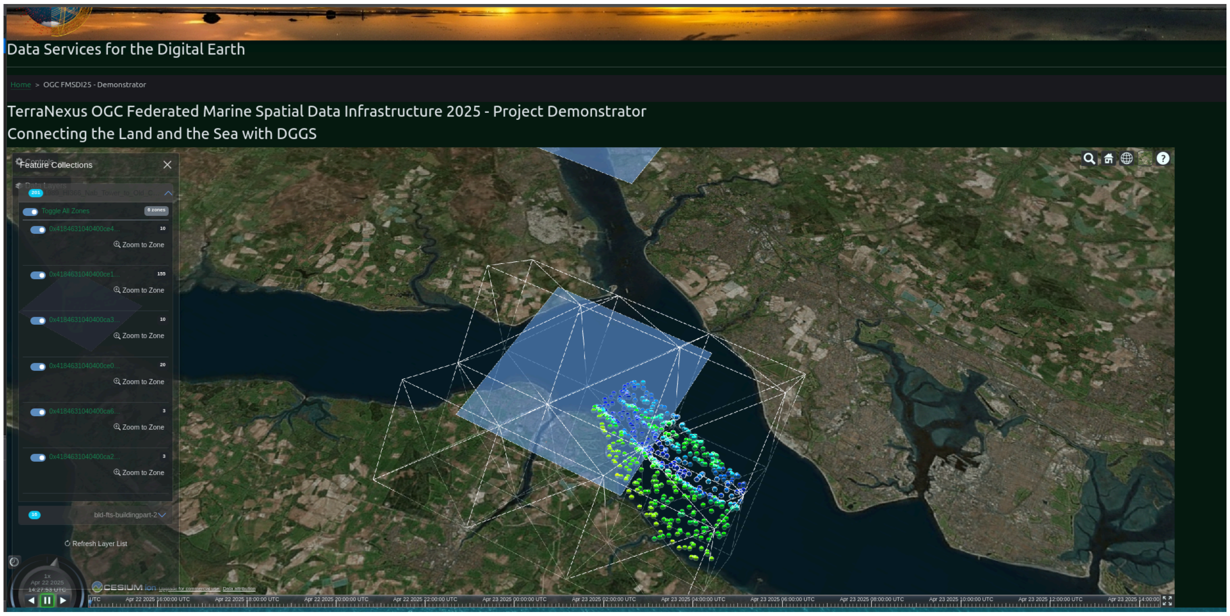

Figure 17 — TerraNexus Federated Marine Spatial Data Infrastructure Demonstrator — Wireframe DGGS Zones

The screenshots illustrate marine and terrestrial datasets queried and visualized through DGGS-indexed OGC APIs.

- **Marine data:** UKHO S-100 bathymetry (1989_HI366_Nab_Tower_to_Old_Castle_Point_Blk2, CSV)
- **Terrestrial data:** Ordnance Survey bld-fts-buildingpart-2 (OGC API Features)

A DGGS Zone query (bounding box around Cowes, Isle of Wight) retrieves intersecting zones. These zones trigger linked API calls to fetch data, which are rendered in the viewer. The UKHO data appears as a point cloud colored by depth; infrastructure data appears as building footprints or 3D forms.

NOTE: Key Insight: This approach executes complex, multi-format, multi-CRS spatial queries across jurisdictions using a simple DGGS index lookup, with no need for prior harmonization.

The two screenshots differ only in visual style:

- Shaded Zones: Translucent polygon fills
- Wireframe Zones: Transparent, with edge outlines showing tessellation structure

5.2.7. Standards Employed

Table 2 — Standards Employed at Pangea Demonstrator

STANDARDS ORGANISATION	STANDARDS USED
Open Geospatial Consortium (OGC)	OGC Abstract Specification – Topic 21 – Discrete Global Grid Systems - Part 1: Core Reference System and Operations (Published) - Part 2: 3D Equal Volume DGGS (Draft) - Part 3: Spatio-Temporal DGGS (Draft) - Part 4: Axis-Aligned DGGS (Draft) OGC API Discrete Global Grid Systems (In-Press) OGC API Features, Common, Processes, Tiles OGC Features and Geometries JSON – Part 1: Core
International Standards Organization (ISO)	ISO 19170 series: - Part 1: Core (Published) - Part 2–4: 3D, 4D, Axis-Aligned DGGS (Drafts)
Internet Engineering Task Force (IETF)	GeoJSON – RFC 7946 (2016)
World Wide Web Consortium (W3C)	JSON-LD 1.1, PROV-O Ontology
International Hydrographic Organization (IHO)	S-100 Universal Hydrographic Data Model

5.2.8. Gaps & Lessons Learned

Key challenges and lessons observed during the pilot are detailed below:

- 4D DGGS are essential to support dynamic spatial integration across domains and time.
- 2D and 3D DGGS lack the temporal indexing capacity required for evolving environments.
- Standards like GeoJSON + OGC APIs enable machine-to-machine interoperability without harmonization.
- Indexing static infrastructure in 4D DGGS requires constraint mechanisms to avoid data over-tagging.
- Inconsistent or missing vertical datum metadata remains a major barrier to automation.
- Tools to support vertical datum transformation at scale are still lacking.

5.2.9. Recommendations and Next Steps

To address the identified challenges and advance the capabilities demonstrated, the following actions are recommended:

- Develop visualization tools purpose-built for DGGS to expose backend integration benefits.
- Implement flexible tiling approaches that support both static (buildings) and dynamic (tide) data.

- Advance IPT (Integrity, Provenance, Trust) architectures to enable federated authentication and data quality tracking.
- Invest in 4D tiling strategies and scalable spatio-temporal indexing methods to manage complexity and data growth.

5.3. TCarta (D100): Space-Based Remote Sensing for Intertidal Awareness

5.3.1. Purpose

The purpose of this demonstration is to illustrate the use of satellite-derived hydrospatial data to improve the accuracy, accessibility, and currency of information related to the intertidal zone. The approach highlights the capabilities of space-based sensors to capture dynamic shoreline and bathymetric features in a cost-effective and scalable manner.

5.3.2. Scenario Description

TCarta's demonstration focuses on two interrelated scenarios in the coastal zone surrounding Hurst Spit in The Solent (UK):

5.3.2.1. Intertidal Awareness at Hurst Spit, UK

Using space-based sensors, TCarta demonstrates how remotely sensed data can enhance situational awareness of tides, shoreline dynamics, and intertidal conditions.

5.3.2.2. Satellite-Derived Hydrospatial Data Provision

The demonstration also illustrates the generation and delivery of space-based bathymetric and shoreline datasets through standard web services for integration with third-party platforms.

5.3.3. Technical Objectives

5.3.3.1. Intertidal Shoreline Dynamics – Hurst Spit

The primary goal was to produce a series of dynamic shoreline vectors using optical and radar satellite imagery, each tied to a specific tidal height at time of collection.

Sub-objectives included:

- Deriving **Normalized Difference Water Index (NDWI)** products from **Planet Labs multispectral imagery** to delineate the waterline.
- Extracting **shoreline vectors from SAR** using TCarta's proprietary shoreline extraction workflow with **Capella synthetic aperture radar (SAR)** data.
- Associating each shoreline vector with **tide-gauge and water-level model data** using an API.
- Deploying a **web mapping application** to visualize:
  - Time-dependent shoreline vectors
  - Real-time water levels **Comparative views of other bathymetric and terrestrial datasets

5.3.4. Technical Objectives

5.3.4.1. Hurst-Spit, The Solent, UK

The primary technical goal of this effort was to produce multiple shoreline vectors using space-based sensors, with the collection of these data synchronized with tide-gauges and water-level models in order to produce multiple coastline vectors which can dynamically represent the shoreline at a given point in time, based on the current water height.

To do so, several technical sub-objectives were pursued:

- Use Planet Labs multispectral imagery to derive Normalized Difference Water Index (NDWI) products, exposing the land-sea interface at the time of collection.
- Use Capella SAR data to extract the shoreline at the time of collection using a proprietary TCarta SAR Shoreline toolbox workflow.
- Attribute each shoreline vector with the known water level, based on live tide-gauge data and water-level models, via an application programming interface (API).
- Use a web-mapping application to:
  - Enable both visualization of tide-zone vectors and live, temporally-relevant water level information.
  - Compare and contrast other coastline/bathymetric/terrestrial datasets.
  - Facilitate discussion of how space-based sensors can be used to improve coastal monitoring.

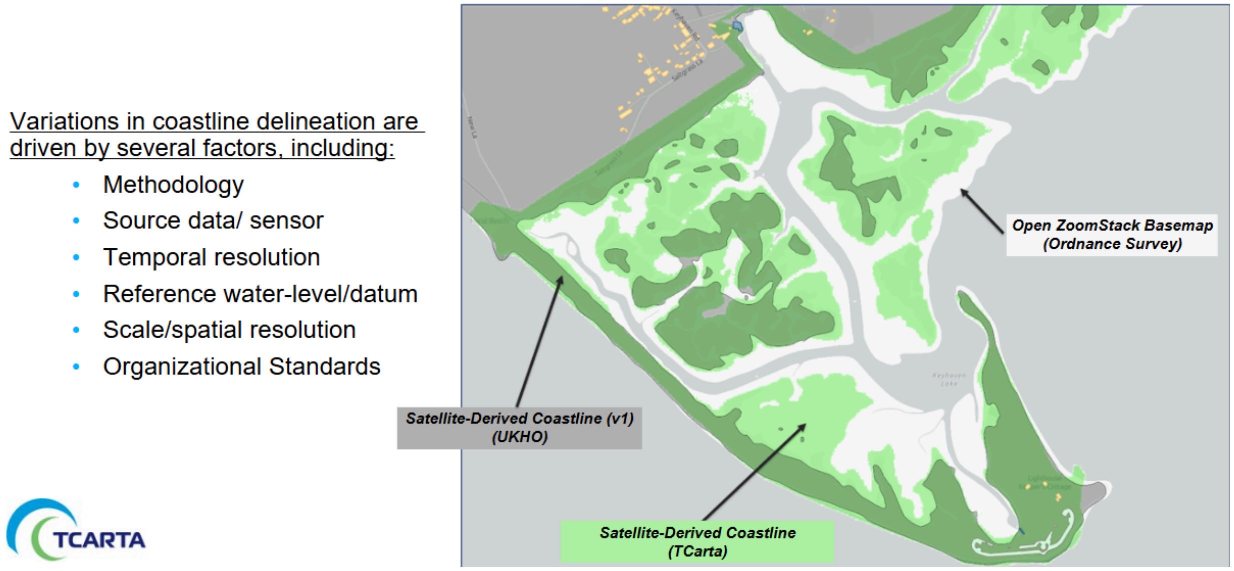

Figure 18 — Shoreline Variability – Hurst Spit, UK

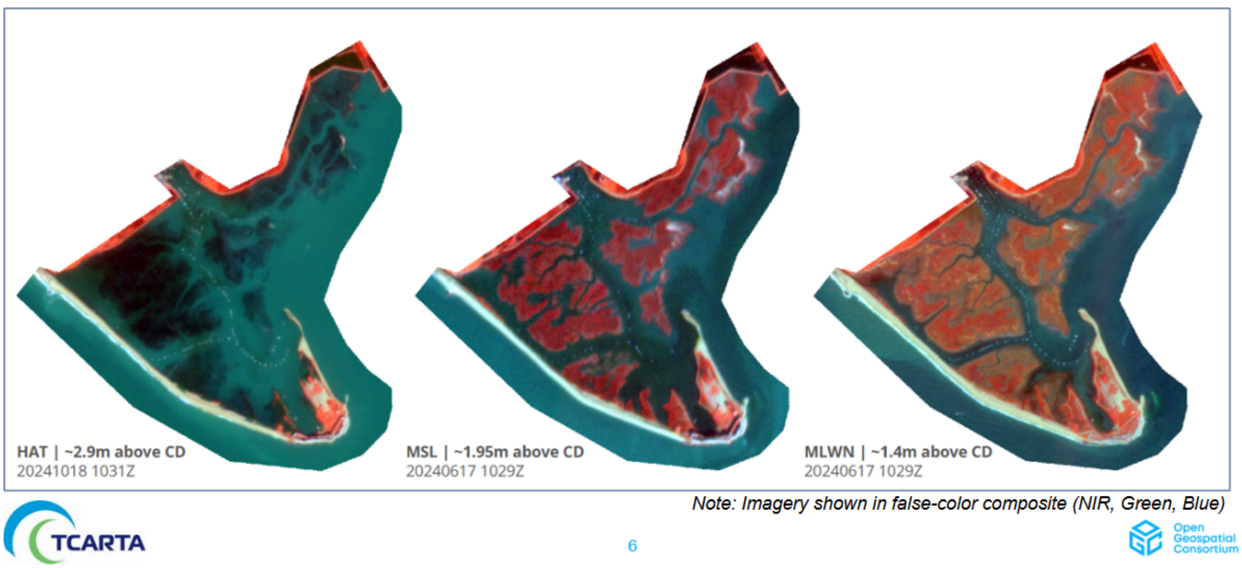

Figure 19 — Hurst Spit Tide Ranges

5.3.4.2. Space-Based Bathymetry and Intertidal Mapping

A secondary technical objective was to generate bathymetric and intertidal datasets using publicly available and commercial satellite imagery.

Sub-objectives:

- Generate sub-tidal and intertidal coverage using Sentinel-2 and Planet Labs imagery.
- Integrate in situ bathymetric datasets (UKHO, Ordnance Survey, NOAA) to validate and improve vertical accuracy.

- Deliver outputs via an OGC Web Coverage Service (WCS) for consumption by partner demonstrators and visualization platforms.

5.3.5. Platform

TCarta deployed a custom **ArcGIS Enterprise portal** as the demonstration environment. The main application uses the **time-slider "instant app"** template, enabling real-time comparison of shoreline vectors based on current water levels.

Shoreline vector updates and tidal information are served dynamically using the **ArcGIS Python API**.

Figure 20 — Hurst Spit Tide Ranges Dynamic View (the dynamic view is shown at the html version of the report)

5.3.5.1. Platform Landing Page URL

The dynamic shoreline viewer is accessible at:

https://arcgis.tcarta-gis.com/portal/apps/instant/slider/index.html?appid=baa6b39ef7034ecc957fcfb4f8ac9bde

5.3.6. Standards Employed

Table 3 — Standards Employed at TCarta Demonstrator

STANDARDS ORGANISATION	STANDARDS USED
Open Geospatial Consortium (OGC)	OGC WCS (Web Coverage Service) for data delivery, OGC GeoPackage (Ordnance Survey basemap and coastlines), OGC API – Common (UKHO data access)
Internet Engineering Task Force (IETF)	GeoJSON (used in update routines for shoreline layers)
International Hydrographic Organization (IHO)	IHO CATZOC (for assessing vertical/horizontal accuracy)
International Standards Organization (ISO)	ISO 19139 metadata schema for dataset and feature descriptions

5.3.7. Gaps & Lessons Learned

The demonstration revealed several technical and operational gaps, summarized as follows:

- Shoreline vectors tied to specific tidal benchmarks may not represent exact current water levels due to limited tide-gauge precision and spatial averaging.
- Non-harmonic tide stations (e.g., near Hurst Spit) rely on proxy data from primary stations, introducing uncertainty.
- Multispectral shoreline delineation is sensitive to **adjacency effects, vegetation, and seasonal variation**.
- **SAR** offers an alternative to optical methods but is affected by METOCEAN factors such as surface roughness.
- EO imagery can show **intra-scene water level variability** due to wide swath widths, even within a single timestamp.

5.3.8. Recommendations and Next Steps

Based on the lessons learned, the following recommendations are proposed to guide further development:

- **Persistently updated shorelines** derived from EO sensors are technically feasible and operationally valuable.
- Rather than relying on static shoreline products, we recommend establishing **dynamic shoreline datasets** tied to datums and timestamps.
- Space-based shoreline and bathymetry vectors should be **attributed with time and vertical reference system** to support land/sea integration.
- **SAR-derived shorelines** can complement tide-gauge networks, especially in areas lacking harmonic stations or ground infrastructure.

6

STAKEHOLDER ENGAGEMENT

6 STAKEHOLDER ENGAGEMENT

Stakeholder engagement played a central role in shaping the FMSDI 5 Pilot, with active involvement from national hydrographic offices, mapping authorities, research institutions, and technology providers. Early consultations helped define the **use cases** and **priority challenges**, ensuring that the pilot addressed real-world interoperability gaps across the land-sea interface. Agencies such as **UKHO**, **NOAA**, **NGA**, **USGS**, **CHS**, and **Ordnance Survey** provided both strategic direction and access to **authoritative datasets**, while solution developers engaged in iterative dialogue to refine technical demonstrations based on operational needs. This collaborative model fostered alignment between data producers, users, and standardization bodies, ensuring the pilot's outcomes were both technically sound and practically relevant.

Beyond technical collaboration, the pilot emphasized cross-border and inter-agency coordination, promoting **open data exchange**, shared terminology, and federated data access mechanisms. The approach strengthened trust among institutions by showcasing **transparent methodologies**, open standards compliance, and reproducible workflows. Engagement extended to coastal planners, port authorities, and environmental regulators, who provided feedback on visualization tools, **vertical datum handling**, and usability in real-time decision contexts. This multi-level stakeholder integration not only increased the **impact of the pilot outcomes** but also laid a foundation for **scalable adoption** and **long-term sustainability** of the federated marine spatial data infrastructure.

7

OUTLOOK

7 OUTLOOK

Building on the results of the FMSDI 5 Pilot, future efforts will focus on operationalizing the demonstrated approaches at national and regional scales. This includes the adoption of **Discrete Global Grid Systems (DGGS)** and dynamic data integration frameworks within existing coastal and marine spatial data infrastructures. Ongoing work will prioritize the development of scalable, real-time workflows that support continuous shoreline monitoring, vertical datum harmonization, and 4D spatiotemporal data services.

Future pilots are expected to expand collaboration among hydrographic offices, terrestrial mapping agencies, and earth observation providers, emphasizing data federation, open APIs, and standards alignment with **IHO S-100** and **OGC API** ecosystems. Enhanced stakeholder engagement, particularly among coastal communities, ports, and environmental regulators, will ensure that technical innovations are matched with actionable governance models.

Moreover, integration with emerging initiatives—such as the **UN-GGIM IGIF-H**, the UN Decade of Ocean Science for Sustainable Development, and Digital Twin Ocean frameworks—will guide the evolution of a global, federated Marine SDI. These advances aim to enable smarter decision-making in climate resilience, maritime operations, and ecosystem preservation, reinforcing the need for interoperable, trustworthy, and ethically governed geospatial systems bridging land and sea.

8

SECURITY, PRIVACY AND ETHICAL CONSIDERATIONS

8 SECURITY, PRIVACY AND ETHICAL CONSIDERATIONS

During the course of this project, a thorough review was conducted to identify any potential security, privacy, and ethical concerns. After careful evaluation, it was determined that none of these considerations were relevant to the scope and nature of this project. Therefore, no specific measures or actions were required in these areas.

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ANNEX A (NORMATIVE) ABBREVIATIONS/ACRONYMS

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API	Application Programming Interface
CEOS	Committee on Earth Observation Satellites
CMMI	Capability Maturity Model Integration
Delft3D	A hydrodynamic, sediment transport, and morphology simulation system
DEMs	Digital Elevation Models
DGGS	Discrete Global Grid Systems
DGPS	Differential Global Positioning System
DSSM	Data Stewardship Maturity Matrix
EMODnet	European Marine Observation and Data Network
FAIR	Findable, Accessible, Interoperable, and Reusable
GML	Geography Markup Language
GNSS	Global Navigation Satellite System
IHO	International Hydrographic Organization
ITRF2020	International Terrestrial Reference Frame 2020
NOAA	National Oceanic and Atmospheric Administration
OGC	Open Geospatial Consortium
OGC API	Open Geospatial Consortium Application Programming Interface
SAR	Synthetic Aperture Radar
SWAN	Simulating WAves Nearshore
UN-GGIM	United Nations Global Geospatial Information Management

UN OBPS	United Nations Decade of Ocean’s Best Practices
VDatum	Vertical Datum Transformation (US)
VORF	Vertical Offshore Reference Frames (UK)
WGS84	World Geodetic System 1984