TORRES STRAIT
S-100 TEST BED AND SEA TRIALS

S-100 TORRES STRAIT TEST BED PRELIMINARY REPORT MARCH 2026

Contents

1. Summary

This preliminary report presents results from Australia's S-100 Torres Strait Test Bed. It evaluates the operational use of core S-100 Phase I products (S-101, S-102, S-104, S-111, S-124 and S-129) in a high-complexity, environmentally sensitive and pilotage-controlled waterway. Using workshops and high-fidelity bridge simulations (December 2025), mariners assessed usability, interoperability, portrayal, alerts, and performance. Overall, participants reported improved situational awareness with S-100 (especially S-102 bathymetry and S-124 warnings), largely smooth dual-fuel transitions, and clear potential for Phase I products in general, tempered by concerns about display clutter, data provenance, connectivity, and training needs. Findings contribute to IHO product specification development, OEM implementation priorities, human-factors design for ECDIS, and a roadmap for sea trials.

2. Introduction

The following section provides an overview of the trial's context and the Torres Strait as the main sea trial area.

2.1 Background

S-100 is the International Hydrographic Organization's (IHO) Universal Hydrographic Data Model, designed as the next-generation framework for producing, distributing, and using marine geospatial information. It will eventually replace the S-57 standard, now over 30 years old, by providing a modern scalable and interoperable foundation that supports a far broader range of maritime data and services.

S-100 underpins IHO's and IMO's vision for future digital maritime ecosystems, enabling richer, dynamic, and high-resolution information for safer and more efficient navigation, maritime operations, and marine domain awareness. It aligns with modern geospatial standards, allowing cross-domain interoperability with other sectors such as meteorology, oceanography, port operations, and environmental management.

For hydrographic offices and government agencies, S-100 represents a significant shift in data governance, system architecture, and service delivery. It requires coordinated transition planning, capability development, stakeholder engagement, and alignment with global implementation timelines.

2.2 Torres Strait Sea Trial Area

Testing S-100 products in high-complexity maritime environments is essential for demonstrating real-world operational value, improving system design, and validating interoperability across different product types.

The Torres Strait, situated between Australia and Papua New Guinea, is classified as a particularly challenging, shallow, and environmentally sensitive waterway. The northern half of the Strait is only navigable by vessels with a very shallow draught, while deep draught vessels are restricted to using narrow channels in the southern part of the Strait between the various islands off Cape York, primarily the Prince of Wales Channel, immediately north of Hammond Island. Navigation in the Torres Strait is

extremely hazardous due to its complex topography, relatively shallow waters and highly variable tidal regime.

It is a compulsory pilotage area for large commercial vessels and a heavily regulated marine transit corridor, making it an ideal location for advanced e-Navigation trails. The region provides the operational diversity needed to test high-resolution data ingestion, dynamic data overlays, and interoperability behaviour under challenging conditions.
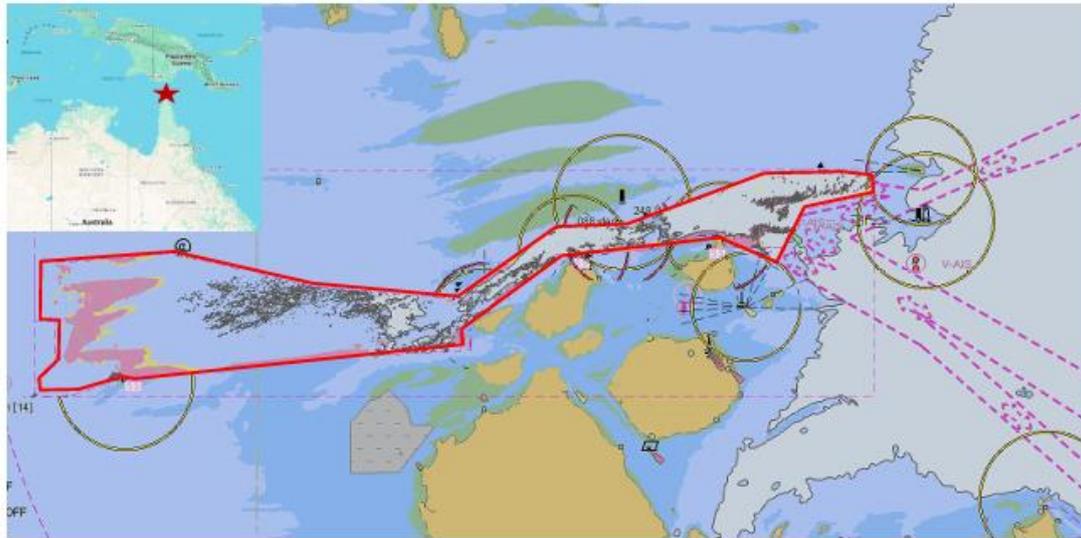

Figure 1 – Torres Strait S-100 Test Bed Area

3. Goals and Requirements

The following section provides information on the purpose and scope of the trial, its goals, requirements, distinguishing features and limitations.

3.1 Purpose and Scope

The Australian S-100 testbed in the Torres Strait is intended to provide robust, operationally realistic evidence about how S-100 Phase 1 and some Phase 2 products perform as an integrated suite when used by mariners in ECDIS.

The scope is intentionally end-to-end. It covers the full chain from multi-agency data provision and distribution through to system ingestion, portrayal, user interaction, alerts and performance in ECDIS, and the operational impacts on the bridge personnel. It also extends beyond shipboard use to explore shore-based and other non-traditional maritime use cases where S-100 data may provide value.

3.2 Goals

The overarching framework for conducting the trials was guided by a set of specific goals:

- Provide evidence-based feedback to improve S-100 Product Specifications (including content, structure, and guidance so they deliver information mariners need for decision making in real operations).
- Evaluate interface design, portrayal, interaction patterns, and alerting behaviours so the integration of multiple S-100 layers improves situational awareness without increasing clutter or alerts fatigue.

- Test and inform distribution and update mechanisms suitable for multi-agency provision, with specific attention to real and near-real time delivery requirements in operational contexts.
- Determine the technical performance impacts of processing and portraying multiple concurrent S-100 layers, higher update rates, and larger datasets, including any operational consequences.

3.3 Requirements

To meet the goals, the testbed must:

- support the simultaneous use of the full Phase 1 S-100 product set within a single ECDIS, allowing interactions between multiple layers to be examined as they would occur in operational use.
- enable a clear comparison between an S-100-enabled environment and current practice, so that differences in situational awareness, workload, and decision making can be attributed to the use of S-100 products rather than to external factors.
- allow assessment of how portrayal, layering, and alerting behaviour affect usability, including whether the integration of multiple S-100 layers introduces screen clutter or contributes to alerts fatigue.
- allow assessment of how the volume and complexity of S-100 data affects ECDIS performance.

Collectively, these requirements are intended to ensure that the testbed produces outcomes that are directly applicable to standards development, system implementation, and future operational use of S-100, both at sea and in emerging maritime applications.

3.4 Distinguishing features of this testbed

Many existing S-100 testbeds focus on individual products, limited geographies, or technical feasibility demonstrations. This testbed is differentiated by two core design choices:

1 **Testing the full set of S-100 Phase 1 products as an integrated package**, rather than in isolation. The intent is to understand product interactions and combined effects on workflows, portrayal, alerts and system performance.
2 **A focus on the complete mariner experience**, not just data correctness or system conformance. This includes whether S-100 products actually help the bridge personnel to perform duties more effectively compared to today's baseline of S-57 ENCs and nautical publications, and whether the integrated display is usable without creating screen clutter or alerts fatigue.

This combination is aimed at producing evidence that can directly influence S-100 PS development, ECDIS implementation, and ECDIS human design considerations.

3.5 Limitations and assumptions

The following limitations have been observed during the planning phase:

- Only one sufficiently mature S-100-capable ECDIS prototype was available and did not fully implement S-100/S-98.
- The processing and portrayal of live feeds (real-time S-129 and S-124 data) were not available in the ECDIS prototype at project start.

- Most participants were Marine Pilots.

- Survey responses are assumed to be truthful and accurate.

4 Methodology

This section presents a summary of the methodology employed during the trials.

4.1 Work structure

The S-100 test bed follows a structured, phased approach to ensure that data, systems, operational procedures, and human-factor outcomes are rigorously assessed in realistic maritime conditions. The approach combines data readiness, controlled testing, live trials and expert user feedback.

Phased test bed delivery	
Phase 0	Preparation and data readiness
Phase 1	S-100 introduction workshop
Phase 2	Controlled simulations and bench testing
Phase 2a	Preliminary test bed report
Phase 3	Live sea trials
Phase 4	System and data evaluation performance
Phase 5	Synthesis, reporting and recommendations
Phase 6	Final test bed report

Some phases are designed to overlap. For instance, Phase 2 may continue alongside Phase 3 for workflows that do not need to be assessed during an actual sea trial, such as route planning workflows.

The project will utilise a combination of different strategies to collect and evaluate data. The most significant ones are listed below:

- Information sessions and workshops
- Interviews (structured and unstructured)
- Laptop and full bridge ECDIS simulations
- Sea trials

4.2 Timeline

The test bed and sea trial will be conducted over an extended period, from August 2025 through December 2026, allowing for comprehensive assessment of S-100 data products and systems performance across a wide range of environmental, seasonal, and operational conditions. The extended timeframe supports collaboration with operational stakeholders, enabling sea trial(s) to be aligned with vessel schedule, pilot availability, and practical window of opportunity in the Torres Strait.

It is expected that testing and sea trials will continue in 2027 and beyond, with a focus on data dissemination, interoperability and the introduction of more 'Phase 2' S-100 products.

4.3 Project Team and Key Stakeholders

The test bed involves a diverse group of organisations and end-users, each contributing essential expertise.

ICSM S-100 Working Group Participants

Key members of ICSM S-100 Working Group, the Australian Hydrographic Office (AHO), the Australian Maritime Safety Authority (AMSA), and OMC international (OMC), provide technical leadership and subject-matter expertise. Their involvement ensures that the test bed aligns with current international standards, reflects real-world regulatory and operational requirements, and contributes meaningful insights back into the ongoing development of S-100 product specifications.

Original Equipment Manufacturer (OEM) Partner

OSI Maritime Systems (OSI), a world leader in marine navigation software, participates as the primary OEM partner, supplying their 'ECPINS 7' ECDIS prototype for the test bed.

Simulation and Testing Facility

Smartship Australia, a specialised maritime training facility and simulation centre, participates by providing their world class full mission bridge simulator and coordinating the execution of all test cases. Smartship provides the controlled high-fidelity environment needed to run scenario-based tests, observe mariner interaction, and replicate a wide range of navigational and environmentally conditions with accuracy and repeatability.

Mariners and end-users

A stable cohort of experienced mariners, pilots and end-users was selected to ensure continuity throughout all planned test bed activities. Their role is central to the test bed, as they provide practical operational insight, professional judgement, and user-focused feedback on the utility and performance of S-100 datasets.

4.3   Products

The test bed incorporates the following key S-100 products:

- S-101 Electronic Navigational Chart (2.0.0)
- S-102 High-Resolution Bathymetry (3.0.0)
- S-104 Water Levels (2.0.0) – *Astronomical predictions (Tide Table equivalent)*
- S-111 Surface Currents (2.0.0) – *Astronomical predictions (Tide Table equivalent)*
- S-124 Navigational Warnings (2.0.0)
- S-129 Under Keel Clearance Management (2.0.0)

4.4   Software

The test bed makes use of the ECPINS 7 prototype, an early implementation of OSI's next generation S-100 capable navigation system. This prototype platform was specifically selected for the test bed because it incorporates preliminary support for multiple S-100 product specifications, enabling an assessment of how future operational ECPINS versions may display, integrate, and manage S-100 datasets in real-world navigational contexts.

The first simulated session was conducted in December 2025 and ECPINS 7 prototype was configured to ingest and visualise the full suite of S-100 datasets prepared for the test bed.

4.5 Simulator Setup and Implementation

In December 2025, the ECPINS 7 prototype was configured within the simulator environment to replicate an operational shipboard navigation system in accordance with standard bridge practices. The system was setup to function as the primary navigational display.

All products relevant to the trial areas were installed and verified prior testing. Chart settings, including safety depth, safety contour, were configured in line with accepted navigational standards. Alarms were enabled and tuned to reflect operational use, ensuring that warnings for hazards and safety limit breaches were correctly generated. Vessel specific parameters such as dimensions, draught, manoeuvring characteristics and under-keel clearance margins were configured to support accurate route monitoring.

The Simulator was loaded with environmental data (tidal and surface current information) to match the content of the S-111 and S-104 datasets.

The simulator interface allowed participants to interact with the system as they would do on board. System performance and mariners' interaction with ECPINS were observed and recorded during the execution of the scenarios to support analysis and validation of outcomes.

4.6 Scenarios

Simulation-based Scenarios:

Scenario title	Description
S100TBTR001 — Dual Fuel Operation: Transition from S-57 to S-101 & validation of ECDIS safety functions	This test evaluates a vessel's DF-ECDIS transition from S-57 to S-101 ENCs while navigating the Torres Strait. It assesses whether the Officer of the Watch (OOW) recognises the transition and maintains situational awareness throughout. The test verifies that safety settings (e.g. safety contour and depth parameters) and safety functions (alerts and indications) remain consistent during the changeover, and that all critical features are clearly portrayed. The scenario also includes a reverse transition—from S-101 back to S-57— to confirm that no safety-critical behaviour or functionality is lost during reversion.
S100TBTR003 — S-100 Product Interoperability (S-101, S-102, S-104, S-111)	Evaluates how S-102 bathymetry, S-104 water levels, and S-111 surface currents integrate with S-101 in ECDIS during transit through the Torres Strait. The OOW toggles layers, uses pick reports, checks day/night modes, and changes time to assess clarity, temporal behaviour, and safety contour responses. It also examines interaction over an S-57 area to observe overlay behaviour and interface usability when datasets mix.
S100TBTR004 — S-100 Interoperability including S-124: Respond to a Navigational Warning	Introduces an S-124 navigational warning (dangerous wreck on route) into a multilayer S-100 setup and assesses how the OOW detects and understands the incoming warning. It compares the chart-based S-124 warning with the corresponding NAVTEX/EGC text message received simultaneously, to assess consistency

	and decision impact. The focus is on clear portrayal, accessible metadata (category/validity/geometry), and minimal clutter while supporting route adjustment decisions.
S100TBTR005 — UKCM (S-129) integration and safety contour assessment	Tests integration of S-129 UKCM ("Go" / "Almost No Go") with S-101/S-102/S-104/S-111 for a deep draft transit in Torres Strait under challenging environmental conditions. A key event is a safety contour alert (11.8 m) near Herald Patches that conflicts with UKCM "Go Area" portrayal, requiring the OOW to assess and resolve the situation. The scenario measures usability, data prioritisation, and operational decision making when multiple layers provide potentially conflicting cues.
S100TBTR008 — Route monitoring/execution with UKCM consideration – passing vessel	Assesses route execution using S-129 UKCM plus S-101/S-102/S-104/S-111 while managing an opposing direction-passing vessel near Varzin Passage. The OOW must monitor UKC restricted areas, maintain situational awareness with incoming vessel and decide on actions to resolve UKC constraints safely. An updated edition of the S-129 dataset, after planned speed changes, is loaded to reflect revised UKC outputs.

4.6.1 Assessment

The test bed used a mixed-method assessment approach, combining structured surveys, scenario-based simulations, and direct observational techniques to evaluate mariner interaction with S-100 data products and realistic conditions.

A suite of five distinct test cases was designed to ensure full coverage of operational behaviours across all S-100 dataset types included in the trial. Each test cases reflected a different navigational challenge or decision-support requirement, enabling the evaluation of:

- Layer interoperability and portrayal behaviours
- Tactical under-keel clearance decision making
- Use of water levels and surface currents
- Interpretation of navigational warnings
- System performance during complex or demanding situations.

These scenarios were intentionally varied to capture a broad spectrum of use-cases representative of real-world navigation in dynamic waterways.

4.6.1.1 Pre- and Post-Simulation Questionnaires

Participants were asked to complete a general knowledge 'baseline' questionnaire before starting with the simulations and 1 scenario-specific questionnaire after each test case simulation. The surveys were designed to capture:

- Baseline familiarity with S-100 concepts

- Expectations about the usefulness of specific S-100 layers
- Perceived clarity and symbology and data presentation
- Changes in situational awareness and decision-making confidence
- Comparative impressions between S-100 datasets and current S-57 equivalents

Collecting pre- and post-session responses enabled measurable assessment or perceptual change and the usability impact of S-100 products.

4.6.1.2 Observations and Behavioural Analysis

During each simulation, facilitators monitored:

- How participants interacted with each S-100 layer
- The sequence and rationale of decision-making
- Points of confusion or hesitation
- Preferences for display configurations or overlays

These observational insights were essential for understanding real-time user behaviour that cannot be captured through surveys alone.

4.6.1.3 Debriefing Sessions

Following each test case, participants engaged in detailed debriefing discussions to provide qualitative insights into system performance and usability. These discussions explored:

- What aspect of data improved situational awareness
- Any challenges encountered during interpretation
- Suggestions for portrayal adjustments or interface enhancements
- Observed benefits or limitations compared with existing navigation tools
- Overall operational confidence when using S-100 layers

The debriefing step enabled deeper exploration of issues and opportunities identified during simulations, providing rich contextual feedback for analysis.

5 Findings

The following sub-sections provide an overview of the preliminary findings of the trials. Section 5.1 focuses on theoretical discussions of the products as part of the information sessions and workshops, while section 5.2 focuses on the findings from the simulator sessions.

5.1 Information session and Workshop

Phase 1 of the Torres Strait S-100 Test Bed project marked the formal launch and provided the participants with an initial introduction of S-100 concepts and products. The session project brought together a group of 10 experienced maritime professionals to explore the current ECDIS use, existing challenges, and their initial impressions on S-100 products.

Information collected before the workshop

A questionnaire was distributed to all participants to complete before the introductory workshop, aiming to assess their S-57 and S-100 knowledge as well as their proficiency in using ECS/ECDIS. The results are summarised in the table below.

<u>Summary of results</u>

Question	Result
How would you rank your S-57 & ECDIS/ECS proficiency?	Moderate – High
Please list the top 3 things you like most from S-57 & ECDIS.	Ease of use; easy to update; route planning, customisable chart setting; safety contour; radar overlay
How challenging do you currently find it to integrate navigational information from multiple sources (e.g. ENCs, sailing directions, GMDSS equipment, meteorological forecast, VHF communications) during voyage planning or navigation?	Average (not too easy/not too hard)
Please list the top 5 things you believe should be included in the next generation of ECDIS.	High-definition bathymetry, real time, tides, currents, weather. UKC, Navigation warnings - **one stop shop for information** (no need to access physical publications, websites, etc)
	Display of safety settings on home display Clearer route validation reports More user friendly
How would you rank your S-100 knowledge in general?	Medium-Low
What Alerts & Indications would you rate as 'low value' and would like to be removed from ECDIS (rank them in priority order)	Preference is on flexibility to activate/deactivate as needed.
What Alerts & Indications would you like to be added to ECDIS?	Alerts related to transit times (if late or early on expected check points)
	When updates have been added after the passage was created and they intersect the Active Route.
	Weather warnings with a determined threshold
What would be a better way to implement alerts and indications?	Dashboard + End User ability to customise Alert triggering parameters.
Do you use ECS/ECDIS for passage planning?	Majority of YES
How often do you use oceanographic data (e.g. currents) in your voyage planning?	Frequently

Do you have any prior experience with any of the new S-100 products? (Please select all products that you have worked with)	S-101 & S-102 mainly.			

Additional questionnaires were distributed to all participants at the end of the introductory/educational sessions covering the following topics:

- S-101 and its differences with S-57
- S-104 and Water Level adjustments using S-104
- Surface currents (S-111)
- Navigational Warnings (S-124)
- UKCM (S-129)

The results summarised in the table below and it include some general feedback on the use of DF-ECDIS in a multiproduct environment based on the participants limited (passive) exposure during the introductory sessions.

Summary of results Product	Confidence Level (Reported)	Most Liked Aspects	Most Disliked Aspects / Concerns	Desired Enhancements / Suggestions
S-101	Moderate–High	• Familiar S-57-like appearance easing transition • Improved symbology • Ability to interoperate with other overlays	• Limited functionality in initial release due to DF coverage and 'need' to keep S-57 and S-101 data content 'in sync'	• Improved functionality to recognise updated features
S-102	Moderate–High	• High-definition bathymetry & adaptive contours • Enhanced situational awareness • Support for UKC management & interaction with WLA	• Display clutter from dense data • Unclear/hidden data quality • No direct relationship between Pixel colour and depth • At first glance S-102 blue boundary is confusing with WLA boundary	• Clear indication of bathymetry data source origin • Consider complex line style that includes a 'label' for S-102 boundary
S-104	Moderate	• Automatic adjustment of depths • Better understanding of navigable water based on day/time • Clear go/no-go visual cues • Improved UKC management	• Non-real-time or prediction-based data • Clutter and display complexity • Large data transfer requirements • Concern over overreliance for safe entry decisions • At first glance S-102 blue boundary is	• Real-time tidal data based on sensors • Easier identification of the 'type of prediction' used • Consider complex line style that includes a 'label' for S-104 boundary

			confusing with WLA boundary	
S-111	Moderate	• Useful for visualising surface currents • Enhances planning of predicted conditions • Expected to be used for future stage passage analysis	• "Too many directional arrows"—clutter • Need for more accurate modelling & sensor-based inputs • Reliability concerns	• Easier identification of the 'type of prediction' used • Prioritise hydrodynamic modelling and forecasted data
S-124	Moderate–High	• Real-time updates of warnings • Reduced manual plotting workload • Better situational awareness via overlays • Filtering/sorting of warnings • Integration across S100 suite • Easy to understand	• Liability and relation to GMDSS • Better integration with route planning / identification of hazards would be beneficial • Technical architecture for real-time distribution needs to exist and should aim for global coverage • Clarify impact real-time changes in ECDIS on passage plan integrity	• Further clarify procedures and requirements in international regulatory framework (IMO/WWNWS) • Maintain integration for "one stop shop" use cases
S-129	Moderate–High	• Reduces need for separate devices/screens • Real-time UKC updates • Improved situational awareness with ENC overlay • Integrated display with other S100 products	• High data transfer requirements (Satcom load) • Early versions expected to have limitations	• Two-way communication capability in future • Continued refinement through iterative development
ECDIS			• Added complexity; unclear safety display impacts • Non intuitive settings and layer transparency issues • Increased risk of screen clutter and information overload • Additional complexity in tracking the status (active/inactive) of layers and settings.	Ability to load/unload and visualise personal pre-configured settings

Additional Risks

Further details on these issues and general considerations are provided in Annex A.

5.2 Simulator-based Trials

Phase #2 of the Torres Strait S-100 Test Bed assessed mariners' comprehension and interaction with S-100 products using high-fidelity navigation simulations, with ECDIS performance tested across five scenarios.

Participants were requested to complete questionnaires after each run, as outlined in Section 4. There were 11 participants in total, and their backgrounds are summarised in the table below:

Area of expertise	Quantity
Marine Pilot	9
Master > 24m	1
Marine Operations	1

The tables below summarise their responses.

Simulation-Based Scenarios

S100TBTR001 - S-57 & S-101

Question	Responses (Agree/Neutral/Disagree)		
I noticed the transition between ENC product types (S-57 & S-101)	58%	17%	25%
The portrayal of critical safety features was consistent across both ENC types	75%	8%	17%
I found that the portrayal of chart features during the transition between S-57 and S-101 was sympathetic and did not disrupt situational awareness	92%	8%	0%
The functions and features of S-101 feel straightforward to apply during navigation.	67%	33%	0%
S-101 charts provide better information than S-57	92%	8%	0%
S-101 charts provide better portrayal than S-57	92%	8%	0%
The ECDIS interface made it easy to recognise the transition zone.	25%	50%	25%
The ECDIS effectively managed the handover from S-57 to S-101 coverage	75%	25%	0%
Alerts and Indications remain unchanged during and after the transition	67%	33%	0%
The ECDIS interface (e.g. menus, terminology, etc) has significantly changed to handle S-101 ENCs	42%	42%	16%
I believe S-57 & S-101 ENCs can work harmoniously side by side in a Dual Fuel-ECDIS	75%	25%	0%
I would voluntarily change navigation software if it would allow me to load S-101 ENC.	100%	0%	0%
End users will require significant retraining to work in a DF (S-57 & S-101) environment.	58%	33%	9%
Becoming confident and competent in using S-101 will require significant time and familiarisation.	50%	42%	8%

Is there anything in the portrayal or behaviour of S-101 ENCs within the DF-ECDIS that you feel could be improved for better usability or clarity?
• A clear alert/notification should indicate when the system transitions to or from S-57 and S-101, including the availability of additional S-100 layers • On dual supply ECDIS, it should be clearly identified which one is in use. Also, it should be possible to select the definite one

- A simple pop-up dialog (e.g., "Transitioning from S-57 to S-101") would help
- Retaining simple interrogation function of pinpointed targets

Portrayal: for 2digit soundings 1st digit disappears behind dotted circle & overscale symbol (vertical lines) not visible on S-101 chart

Do you have any additional observations or comments?

- Note significant costs to upgrade hardware across the entire industry to enable S100 products.
- The global transition from S-57 to S-101 should be planned to be as short as possible. Stay at S-57 until S-101 coverage is significant.
- S-101 Nav aid symbology is an improvement.
- The dual fuel ECDIS seemed seamless. Good product & information in S-101. Need to be mindful of information overload/clutter.
- Having the ability to individually check charts into display, however, also have say default visual selections such as deep sea, coastal near coastal, tidal windows restricted etc.
- Smooth transition between both formats. Much better visualisation/colours of buoyage.

_S100-TB-TR-003 -_ S-101, S-102, S-104, S-111

Question	Responses (Agree/Neutral/Disagree)		
The availability of S-102 improved my situational awareness.	100%	0%	0%
The interaction between S-102 and S-101 (suppression & substitution of depth related information) worked effectively and to my expectations.	90%	10%	0%
I was able to visualise/retrieve the quality/accuracy of the S-102 data in use.	70%	30%	0%
Switching between day and night modes did not affect my ability to interpret critical navigation information.	70%	10%	20%
The availability of S-102 data in constrained areas can positively impact decision making in emergency situations.	100%	0%	0%
The interoperability between S-104, S-102 and S-101 worked effectively and to my expectations.	80%	10%	10%
The availability of S-104 data improved my situational awareness.	80%	20%	0%
I was able to easily and quickly identify the source of the depth information on the screen (e.g. S-101; S-101+S-102; S-101+S-102+S-104).	60%	40%	0%

It was easy for me to understand the source and the accuracy of the S-104 data in use (e.g. real time measurements; hydrodynamic forecasts; Astronomical predictions).	80%	20%	0%
The availability of S-104 based on Astronomical Predictions can be useful during Route Monitoring.	80%	20%	0%
The availability of S-104 based on Astronomical Predictions can be useful during Route Planning.	90%	10%	0%
The availability of S-111 datasets improved my situational awareness.	70%	30%	0%
It was easy for me to understand the source and the accuracy of the S-111 data in use (e.g. real time measurements; hydrodynamic forecasts; Astronomical predictions).	60%	40%	0%
The availability of S-111 based on Astronomical Predictions can be useful during Route Monitoring.	70%	20%	10%
The availability of S-111 based on Astronomical Predictions can be useful during Route Planning.	80%	20%	0%
S-111 symbology is intuitive.	90%	10%	0%
The density of surface currents arrows displayed during the simulation was adequate.	80%	20%	0%
The density of surface currents arrows displayed during the simulation was inadequate (too many) and compromised the clarity of the charted information.	40%	40%	20%
The density of surface currents arrows displayed during the simulation was inadequate (not enough) and it made it difficult for me to identify the forces at play.	10%	30%	60%
The functions and features of S-102 feel straightforward to apply during navigation.	90%	10%	0%
The functions and features of S-104 feel straightforward to apply during navigation.	60%	40%	0%
The functions and features of S-111 feel straightforward to apply during navigation.	70%	30%	0%
All product overlays were loaded smoothly and did not cause any interruptions to the ECDIS performance.	30%	60%	10%
The loading time of S-111 datasets was acceptable.	40%	40%	20%
The loading of S-111 datasets did not freeze the ECDIS display.	80%	10%	10%
Areas covered by S-102 are easily identifiable.	100%	0%	0%
I agree with S-102 data to be loaded by default but having an easy way to turn it ON/OFF as necessary.	90%	10%	0%
I would feel comfortable using S-102 & S-104 with minimal additional training.	70%	20%	10%
I would feel comfortable using S-111 with minimal additional training.	70%	20%	10%
Current ECDIS design and GUI will be able to effectively handle S-100 operational needs.	40%	40%	20%
The design of S-100 ECDIS will require significant research, and most likely, redesign efforts to ensure they have a positive (not negative) impact on mariners and bridge operations.	80%	20%	0%
Becoming confident and competent in using S-102 will require significant time and familiarisation.	30%	20%	50%

Becoming confident and competent in using S-104 will require significant time and familiarisation.	50%	20%	30%
Becoming confident and competent in using S-111 will require significant time and familiarisation.	30%	40%	30%

Do you have any additional observations or comments?
- Still needs conversation before coming to operational   - S-102 enhanced safety contours are beneficial. Area accuracy of S-102 should be available   - Additional layers on S-100 seems to be of great value for navigation safety and situational awareness. However, the standards should clearly define minimum hardware specs in terms of CPU powered, screen refresh rate etc to allow uninterrupted operations without any lag or slow down. Also, equipment reliability for continuous operations with replacement at identified running hours   - Include textual description near separation line between S-102 and S-104 areas.   - Features incorporated in the S-111 will be very useful for ease of use and safety of navigation.   - Regarding tides, it would be better to have choice to select between changing the depth soundings and indicating the tide values with charted depth   - Astronomical sounding could change colour to blue or such, maybe alternate between default soundings

S100-TB-TR-004 - S-101, S-102, S-124

Question	Responses (Agree/Neutral/Disagree)		
I became aware of new information being added to the ECDIS in a timely and clear manner.	100%	0%	0%
The S-124 warning being displayed directly on the ENC improved my situational awareness.	83%	17%	0%
I felt confident integrating S-124 information with other S-100 data.	75%	25%	0%
I trusted the accuracy and relevance of the S-124 warning.	58%	33%	9%
The S-124 warning directly influenced my decision-making.	83%	17%	0%
The ECDIS displayed S-124 information clearly and without errors.	75%	25%	0%
The associated metadata (e.g., description, category, validity) was easy to access and interpret.	42%	33%	25%
The S-124 portrayal was distinct but integrated with S-101 and S-102 data.	75%	25%	0%

Alerts/indicators related to S-124 functioned as expected.	58%	33%	9%
The portrayal of S-124 information contributes to display clutter on the ECDIS.	58%	33%	9%
I feel that S-124 warnings may obstruct other important chart features and potentially create unsafe situations.	42%	16%	42%
The functions and features of S-124 feel straightforward to apply during navigation.	92%	0%	8%
S-124 improved my situational awareness and reduced uncertainty compared to traditional warnings (NAVTEX/EGC).	58%	33%	9%
I would feel comfortable integrating S-124 into voyage planning with minimal additional training.	67%	16.5%	16.5%
Operational use of S-124 alongside other S-100 data would enhance navigational safety.	75%	25%	0%
I trust S-124 as a reliable replacement for existing NAVTEX/EGC services.	33.3%	33.3%	33.3%
The introduction of S-124 information did not disrupt my established navigation workflow.	50%	25%	25%
I felt confident in deciding how to respond operationally to the S-124 warning.	75%	25%	0%
Even though S-124 is not an officially recognised MSI source, I found it helpful and reliable when used alongside NAVTEX/EGC.	84%	8%	8%
Becoming confident and competent in using S-124 will require significant time and familiarisation.	67%	16.5%	16.5%

Do you have any further comments on the operational Use of S-124?
It is unclear now the method of delivering information to ECDIS. If it will be internet, there are doubts of reliability of communication

S100-TB-TR-005 - S-101, S-102, S-104, S-111, S-129

Question	Responses (Agree/Neutral/Disagree)		
I had a clear and shared situational picture with the pilot/bridge team.	91%	9%	0%
The availability of S-129 dataset, alongside the other S-100 datasets and safety contours, improved the quality of route planning.	63%	9%	18%
I felt the workload was manageable during the scenario.	82%	9%	9%
The ECDIS interface made it easy to manage UKC using the S-129 layer.	82%	18%	0%
The ECDIS interface made it easy to manage multiple S-100 layers, including S-129.	64%	36%	0%
The ECDIS interface made it easy to manage both S-129 information and safety contours.	73%	27%	0%
Information in the S-129 dataset were portrayed clearly and effectively on the ECDIS.	91%	9%	0%
The "plain boundary" portrayal option for the UKC Plan Area feature boundary helped distinguish the UKC Plan Area from boundaries in other layers.	73%	27%	0%
Safety-related information was clear and unambiguous.	73%	27%	0%
Visual presentation of S-129 data did not feel cluttered or overwhelming.	73%	18%	9%
I was confident in resolving any conflicting information	64%	36%	0%
I trusted the prioritised dataset(s) for decision-making.	73%	27%	0%
The system supported effective resolution of discrepancies.	55%	45%	0%
The functions and features of S-129 feel straightforward to apply during navigation.	82%	18%	0%
Becoming confident and competent in using S-129 will require significant time and familiarisation.	64%	27%	9%

Do you have any additional observations or comments?
• Big chance of information overload. Some information could result in distraction. • Display of S-129 in night palette not clear. Value integrated display of UKCM information on PPU. • S-129 is likely to be used by a narrow user group (ports, pilots). Production and Interpretation of data require substantial infrastructure and knowledge. Training essential. Data clutter starts to become an issue. • The biggest problem I see is the communication link

S100-TB-TR-008 - S-101, S-102, S-104, S-111, S-129

Question	Responses (Agree/Neutral/Disagree)		
I had a clear and shared situational picture with the pilot/bridge team.	78%	22%	0%
The availability of S-129 dataset, alongside the other S-100 datasets, improved the quality of route monitoring/execution.	89%	11%	0%
I felt the workload was manageable during the scenario	67%	33%	0%
The ECDIS interface made it easy to manage UKC using the S-129 layer, during route monitoring/execution	78%	22%	0%
The ECDIS interface made it easy to manage multiple S-100 layers, including S-129, during route monitoring/execution.	78%	22%	0%
Information in the S-129 dataset was portrayed clearly and effectively on the ECDIS	78%	22%	0%
The "plain boundary" portrayal option for the UKC Plan Area feature boundary helped distinguish the UKC Plan Area from boundaries in other layers	78%	22%	0%
Safety-related information was clear and unambiguous	78%	22%	0%
Visual presentation of S-129 data did not feel cluttered or overwhelming	56%	44%	0%
I was confident in resolving any conflicting information	67%	33%	0%
I trusted the prioritised dataset(s) for decision-making	67%	33%	0%
The system supported effective resolution of discrepancies	67%	33%	0%
The bridge team resolved the situation (i.e. UKC restrictions and passing vessel) effectively	67%	33%	0%
Communication and coordination were clear throughout the scenario.	56%	44%	0%
The S-100 products felt integrated into existing navigational processes	89%	11%	0%
I would feel comfortable using these tools with minimal additional training	67%	11%	22%

Do you have any further comments?
• Useful to complement existing UKCM service system interface for OOW
• UKC data, particularly dynamic UKC systems, are complex systems. Understanding and interpretation require substantial training.

- These products are likely to be limited to small user groups (pilots, local users).

6 Conclusions and Recommendations

The following section summarises the conclusions and recommendations based on the data from the questionnaires, observations and interviews.

Further details and general considerations are provided in Annex A and will require more time to process.

6.1 Conclusions

Dual-Fuel S-57/S-101 Transition

<u>General findings</u>

> ➢ Transition was generally smooth and operationally acceptable

Participants consistently reported that the transition between S-57 and S-101 was sympathetic, did not disrupt situational awareness, and preserved critical safety information. For example, "the portrayal of chart features during the transition… did not disrupt situational awareness" (92% agreement).

> ➢ S-101 was perceived as an improvement over S-57

Mariners strongly preferred the richer portrayal and information content of S-101: "S-101 charts provide better information than S-57" (92% agreement) and "better portrayal" (92% agreement).

> ➢ Safety functions remained stable across the transition

Most participants agreed that alerts and indications behaved consistently across both ENC types (67% agreement) and that the ECDIS handled the handover effectively (75% agreement).

> ➢ Dual-fuel operation is viable

Participants believed S-57 and S-101 can "work harmoniously side by side" (75% agreement), reinforcing that dual-fuel ECDIS is operationally feasible during the transition period.

> ➢ Users are motivated to adopt S-101

Notably, 100% of participants said they would voluntarily change navigation software to enable S-101 loading, indicating strong user pull for the new standard.

<u>Identified Gaps or Issues</u>

> ➢ *Lack of clear transition cues*

A major gap is the absence of explicit system notifications when switching between S-57 and S-101. Participants explicitly requested: "A clear alert/notification should indicate when the system transitions to or from S-57 and S-101…". This includes clear identification of which ENC type is currently

in use; ability to manually select the preferred dataset when both exist; a simple pop-up such as "Transitioning from S-57 to S-101".

➢ *Difficulty recognising the transition zone*

Only 25% agreed that the ECDIS made it easy to recognise the transition zone, while 50% were neutral and 25% disagreed. This indicates insufficient visual or behavioural cues in the interface.

➢ *Portrayal inconsistencies and symbol clarity issues*

Participants noted specific portrayal problems, including: two-digit soundings where the first digit disappears behind the dotted circle; overscale symbols not visible on S-101 (ECPINS implementation gap). These issues reduce clarity during mixed-coverage navigation.

➢ *Interface complexity and non-intuitive settings*

42% agreed and 42% were neutral that the ECDIS interface had "significantly changed" to handle S-101, suggesting uncertainty and inconsistency in UI design. Users also reported: non-intuitive settings; transparency/layer management issues; need for simpler interrogation tools (e.g., pick reports).

➢ *Training burden and learning curve*

Despite a general agreement that S-57 and S-101 work harmoniously together and have the same 'look and feel, there was a 50% view that S-101 would require significant training efforts.

This reflects a human-factors gap in the transition strategy.

➢ *Risk of information overload*

Participants warned about clutter and the need to manage additional S-100 layers carefully: "Need to be mindful of information overload/clutter." This is especially relevant when S-101 is used alongside S-102, S-104, and S-111.

<u>*The following aspects have not been tested yet:*</u>

- ENC updates and the use of 'Update Information' features
- Automatic temporal degradation of CATZOC
- Alternative CATZOC symbology as proposed by the University of New Hampshire research
- Use of 'Uncertainties' during route planning and route monitoring
- S-101 loading algorithm alongside OEM's S-57 equivalent

S-102, S-104 and Water Level Adjustments (WLA)

<u>General findings</u>

- Vast majority agreed that S-102 & S-104 (WLA) improved situational awareness.
- Adaptive contours and high-definition bathymetry were strongly valued. Clear go/no-go visual cues supported rapid decision-making

- Effective interaction with S-101, with 90% agreeing suppression/substitution of depth info worked as expected.
- Emergency decision-making benefits, with 100% agreeing S-102 and S-104 help in constrained/emergency situations.
- Useful for both route monitoring (80%) and route planning (90%) when based on astronomical predictions.
- 90% of users found S-102 functions straightforward.

Overall, S-102 is seen as a high-value, high-impact product that meaningfully enhances navigation and S-104 is viewed as a valuable decision-support layer, especially when combined with S-102 for UKC management

Identified Gaps or Issues

- Clutter and visual overload when dense bathymetry is displayed. "Display clutter from dense data."
- No easy way to view quality patterns, unlike CATZOC for ENCs.
- S-102 overrides S-101 depths, even when S-101 is newer—risking outdated bathymetry being shown.
- Potential for "fake precision" if producers interpolate sparse data into fine grids.
- Large data volumes, creating bandwidth and storage challenges.
- Although most participants felt comfortable using S-102 and or S-104, they recognised WLA functionality would require a good level of training.
- Non-real-time or prediction-based data reduces trust. "Non-real-time data… may not account for rapidly changing conditions."
- Risk of over-reliance, with concerns about using S-104 astronomical predictions for safe-passage decisions.
- Vertical datum mismatches between S-104 and S-101/S-102 pose serious safety risks.
- Coverage boundary complexity, especially where S-102 and S-104 overlap.

The following aspects have not been tested yet:

- Use of compound S-102 & S-104 'uncertainties' during rout planning and route monitoring.
- Impact of lack of 'quality indicators' in S-102 (like CATZOC in S-101)

S-111 Surface Currents

General findings

- Participants valued the ability to visualise surface current direction and strength directly on the chart. This aligns with broader feedback that mariners want "high-definition, real-time tide and current information" as part of next-generation ECDIS.
- S-111 was viewed as part of a combined decision-support environment, especially for UKC and constrained-waterway navigation.

Identified Gaps or Issues

- Participants raised concerns about clutter for S-102 and S-104, and the same issue applies to S-111 when multiple dynamic overlays are active.
- Uncertainty about how current models were generated, the reliability of predictions, and whether the data is real-time or forecast-based.
- Time intervals between predictions need clear time-stamping visualisation by the end user to avoid misinterpretation of 'refresh rate' (e.g. real time vs every 30 minutes).
- *There was consensus that S-111 portrayal and functionality are easy to understand and would require minimum training.*

The following aspects have not been tested yet:

- Nil.

S-124 Navigational Warnings

General findings

The evaluation of S-124 navigational warnings showed notably strong results. Participants responded positively to the portrayal of navigational warning, reporting improved situational awareness and better integration with other S-100 products. They generally trusted the accuracy and usefulness of the warnings and felt comfortable using S-124. While concerns were raised about the information density in some cases, most mariners indicated that S-124 would likely enhance navigational safety once operationalised.

Identified Gaps or Issues

Gaps were identified in the partial implementation of S-98 requirements for managing S-124 warning datasets. Participants were briefed on the current S-98 requirements, including the ability to filter warnings and access an overview of all active warnings via a list view and agreed that these features would be essential. Additionally, the prototype ECDIS did not yet support real-time reception of warnings; instead, this feature was simulated by creating a warning with a validity period that would become active during the exercise. While the automated loading of S-124 datasets based on their validity period proved generally useful, it was emphasised that clear notifications must be visible to end-users when new warnings are received and that it should be easy to manage warnings received from different providers. Additionally, participants expressed uncertainty regarding how real-time S-100 warnings will be delivered in the future, though these concerns could be addressed by referencing ongoing work at the IMO and the development of a new IP-based connectivity framework. Finally, it was recommended that S-124 should generate appropriate alerts when warnings affect planned routes.
Participants agreed that substantial S-124 training would be required before its operationalisation.

GMDSS equivalency

In addition, participants noted that existing vessel procedures would need to be revised to support the combined use of S-124 and traditional text-based warnings delivered via GMDSS. While there was a fair degree of confidence that S-124 could enhance situational awareness over NAVTEX and EGC,

opinions varied regarding whether S-124 is yet able to reliably replace current methods. Given that S-124 is not yet an officially recognised source of Maritime Safety Information, the exercise also explored whether participants would feel comfortable using it and if they believed it would improve navigational safety when used in conjunction with NAVTEX and EGC. Overall, most participants indicated they would be comfortable with this approach.

The following aspects have not been tested yet:

- S-98 requirements for S-124 (notification of new warnings, display list of warnings, filter warnings)
- Transmission of navigational warnings in real-time from end-to-end
- Use of S-124 data sets from multiple providers

S-129 Under Keel Clearance Management

General findings

- Participants recognised S-129 as a major enhancement for safety and situational awareness, especially in shallow or restricted waters. It was viewed as a natural evolution of existing UKC services, offering integrated, dynamic guidance within ECDIS.
- Mariners appreciated the potential to consolidate UKC information into a single navigational display. It was noted that S-129 would reduce the need for separate devices or shore-based tools by providing UKC assessments directly within the S-100 environment.
- Participants indicated that S-129 would be valuable not only during real-time navigation but also for planning future stages of a voyage, especially when combined with S-102 and S-104.
- The workshop notes highlight that mariners expect S-129 to improve decision-making, enhance safety margins, and support more efficient transit timing.
- S-129 was seen as complementary to S-102 bathymetry, S-104 water levels, and S-111 currents, forming a coherent UKC decision-support suite.

Identified Gaps or Issues

- Participants noted that S-129 may require large data volumes, especially when updated frequently. This raises concerns about satellite bandwidth, update delays, and operational feasibility in remote regions.
- A key scenario described in the document involves a conflict between:
  - an S-101 safety contour alert (11.8 m), and
  - an S-129 "Go Area" indication.
  This highlights the need for clear prioritisation rules and consistent portrayal when multiple layers provide overlapping or contradictory guidance.
- Risk of information overload
- Participants agreed that S-129 has strong potential but, it will require focused training and thoughtful user interface design.

The following aspects have not been tested yet:

- The simultaneous use of S-102/S-104 & S-129 datasets was briefly explored and it showed some pros and cons. This topic deserves more time and consideration.
- Transmission of S-129 from end-to-end (UKCM provider to ECDIS) in real-time

Training and complexity

The questionnaires featured two statements asked about all phase I products:

- The functions and features of S-1XX are straightforward to apply during navigation.
- Becoming confident and competent in using S-1XX will require significant time and practice.

These statements were designed to examine how much familiarisation is needed and to assess the complexity of the products. This helps indicate how both the portrayal and the ECDIS User Interface affect ease of use and information accessibility. The results are shown in Figure 2.
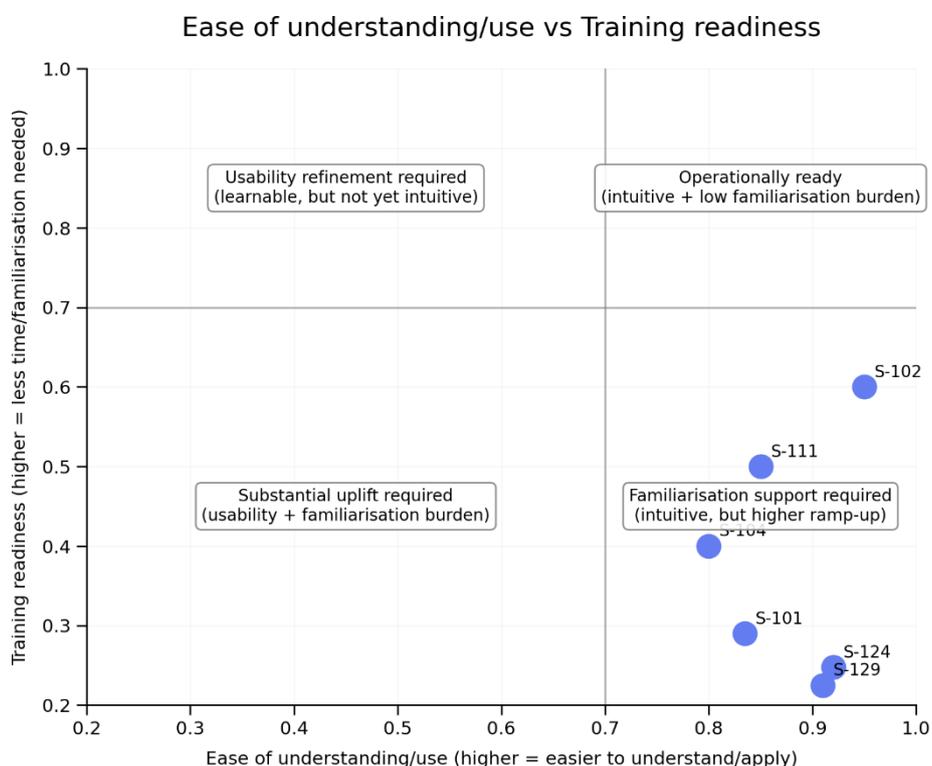

Figure 2– Comparison of ease of understanding and training readiness for Phase I products.

Although, all product lines were found to be intuitive to understand in general, end users think they would require a good amount of training and familiarisation before the can use them in an operational environment.

S-102 stands out as the easiest product to understand, therefore the one that would require the less amount of familiarisation training.

S-102 and S-111 are ahead when it comes to training readiness.

S-104 appears to be the most challenging to grasp, likely because it is not directly displayed on the screen (apart from an indicator showing its availability or use) although it influences the portrayal of other products and information available.

Notably, it is surprising that S-101 does not lead in terms of ease of understanding or training readiness. This outcome is probably a result of S-101 being introduced at the same time than the S-100 ECDIS familiarisation session (which, for most participants, was their initial exposure to S-100 ECDIS).

While S-124 (alongside S-102) performs strongly in terms of ease of use, both S-124 and S-129 show lower training readiness. This may be attributed to S-124 replacing or supplementing the receipt of text-based Navigational Warnings via the GMDSS - so introducing S-124 would affect these established procedures.

Similarly, S-129 delivers UKCM information that has traditionally been accessible only on PPUs and, making it available through ECDIS, would likely also require adjustments to current workflows.

Additionally, as both products will be provided in real-time, extra familiarisation may be necessary for the equipment used for connectivity and for configuring these services within the ECDIS.

Overall outcomes

Findings after Phase 2 of the project indicate strong user acceptance of S-100 products, clear safety and situational awareness benefits, and consistent recognition for the need of training, interface optimisation, and careful management of display complexity. These insights reinforce the value of ongoing simulations and iterative refinement as the maritime community progresses towards full S-100 operational capability.

6.2 Recommendations
The results from Phase 1 and Phase 2 demonstrate steady progress toward operational readiness for S-100 products, as well as clear patterns in user perceptions, capability gaps and system performance.

6.2.1 Recommendations for Product Specification Development
A main goal of the Torres Strait testbed is to provide feedback to IHO's project teams that are responsible for the development of the S-100 product specifications.

Recommendations for each product have been captured in the table below.

Product	Recommendations
S-101	• Nothing significant at this point in time - Pending further testing & analysis
S-102	• It is recommended to consider the introduction of a CATZOC layer and appropriate portrayal • Consider a line style that includes a textual label to indicate S-102 coverage • Strongly recommend producers not to interpolate data. S-102 'for navigation' should only be produced from A1/A2 surveys to avoid safety contours/depths being made up in a product that is expected to be heavily relied upon to 'push the boundaries'.
S-104	• Consider a line style that includes a textual label to indicate S-104 coverage
S-111	• Nothing significant at this point in time - Pending further testing & analysis
S-124	• Continue to work with other relevant groups and committees, as well as other organisations to establish the connectivity framework and standardise the

		development of a technical service specification for S-124 real-time data exchange
	•	Investigate whether S-124 needs further work in the context of alerts and confirm whether S-124 features are sufficiently covered when scanning routes for navigational hazards
S-129	•	Pending further analysis
S-98	•	Evaluate the best methodology to inform mariners of S-104 & S-111 refresh frequency (e.g. 20mins) and the 'source of information' (e.g. Real Time, Astronomical Prediction, 48h forecast'.
	•	Improve the portrayal of S-102 and the WLA boundaries to facilitate identification
	•	Consider any changes to S-98 that supports the management of many different S-124 providers delivering updates in real-time
	•	Consider the development of functionality to indicate transitions between S-57 and S-101 data in DF ECDIS

	•	Further investigate S-102/S-104 safety depth Alerts within S-129 operational areas. Options include:
		    o to 'silence' Alerts;
		    o introduce S-129 Alerts for No-Go Areas and prioritise them over S-102/S-104;
		    o do not modify S-98 or any of the PS but make sure S-100 Training deep dives into the operational interactions between all these products when simultaneously available in the same operational area. The testbed identified the need for clear prioritisation rules and consistent portrayal when multiple layers provide overlapping or contradictory guidance

6.2.2 Recommendations for the IHO Secretariat

The following topics have been identified as priority actions:

- Accelerate the proceedings to realise the sunset of S-57 to:
  - Allow data producers exploit several S-101 specific encoding options that could, otherwise, impact Dual Fuel ENC synchronisation and harmonisation (e.g. temporal downgrade of ZOC).
  - Reduce data producers' DF ENC workload
- Work with the IMO to accelerate the development of new 'ECDIS Generic' training courses and educational material.
- With TWCWG and NIPWG guidance, work with IALA, IMO, IEC, WMO, RENCs and VARs to accelerate the implementation of distribution channels, methodologies and technical standards to realise real-time distribution of key operational datasets to ships (e.g. water levels, UKCM, Navigation Warnings).

6.2.3 Recommendations for OEMs

It is advisable for OEMs (ECDIS manufacturers) to take the following items into consideration:

- Whenever possible, update the GUI to make it easier to use several S-100 products and layers, rather than simply adding to existing S-57 menus and submenus.

- Help users quickly identify S-102 data sources and clarify if S-104 and S-111 data are predictions or live information through implementation of user-friendly GUIs.
- Continue to engage in trials and testbeds to receive user feedback on improved functionalities or new features.

6.2.4 Recommendations for IMO

IMO should consider the following recommendations:

- Continue to develop the framework for real-time connectivity framework and clarify the use of S-100 products in the context of existing regulation (e.g., S-124 vs. GMDSS).
- Accelerate the proceedings to realise the gradual transition of existing SOLAS vessels to S-100 ECDIS.

6.2.5 General recommendations for training and familiarisation

- IMO and Training institutions to speed up development of training material in support of DF ENC navigation (Module 1)
- IMO and Training institutions to speed up development of training material in support of WLA in S-100 systems (Module 2)
- IMO and Training institutions to develop training material on the use of 'Other' S-100 layers (Module 3)

6.2.6 Recommendations for Hydrographic Offices and data producers

HOs and data producers should consider the following recommendations:

- Assess the volume of data generated and develop appropriate distribution strategies for managing larger data sets.
- Assess the impact of connectivity failures for real-time S-100 services.

7   Next Steps

Building on outcomes so far, the next stage of the Torres Strait S-100 test bed will focus on expanding the depth of S-100 Product Specification evaluation.

A key next step will be the expansion of simulation and test bed activities beyond the Torres Strait. Testing in new geographic areas will enable validation of S-100 products across a broader range of environmental, hydrographic, and traffic conditions, including areas with differing tidal regimes, bathymetric complexity, traffic density and port approaches.

Future simulation phases will place increased emphasis on Phase 2 S-100 Product Specifications and real-time data provision. Testing will move beyond introductory exposure toward more decision-dense, workload-intensive scenarios, examining how multiple S-100 datasets interact under real-world constraints. This will support validation of interoperability, portrayal clarity, alert management, and cumulative impact of multi-layered S-100 information on mariner performance.

The next steps will ensure that S-100 products are not only technically compliant but also operationally effective, usable, and trusted as the maritime sector progresses toward full S-100 operational capability.

Sea trials arrangements are currently under negotiation with a bulk carrier operator for Q2 2026.

Annexes

Annex A – Detailed Summary of Issues

Product	Type (short)	Risk / challenge (summary)	Category
All S-100 products	Service architecture unresolved	Concepts like service discovery, identity/access and use of the Maritime Connectivity Platform are still being worked out, so the end-to-end architecture for frequent S-100 updates is not yet mature.	Architecture & infrastructure
All S-100 products	Conservative culture & mixed tools	Maritime practice is conservative and still heavily mixed between paper, S-57 and digital tools, so introducing S-100 risks inconsistent adoption and resistance to change.	Change management
All S-100 products	Real-time comms not standardised	There is no fully agreed, standard real-time communication path for highly time-sensitive S-100 services; existing "normal" channels are too slow for some use cases.	Communications & infrastructure
Combined use of S-100 products	Complexity of depth/UKC trio	These three are described as the most complex S-100 products; understanding how they interact (depths, bathymetry, water level, uncertainties, datums and coverage) is challenging even for experts.	Complexity & training
All S-100 products	Data consistency between agencies	Different organisations may provide different S-100 datasets for the same area; even with harmonisation, human error can leave them out of sync, so over-reliance on any single product is risky.	Data management & quality
All S-100 products	Multi-stakeholder coordination	In federal / multi-agency environments and with private providers, responsibilities for producing and maintaining different S-100 layers are complex, raising governance and coordination risk.	Governance & roles

Combined use of S-100 products	Locked-down systems	Some ships may have ECDIS settings locked by company policy or OEM; pilots then cannot adjust contours or layers to local schemes, leaving a mismatch between expected and actual safety margins.	Governance & safety
All S-100 products	Overlaps between producers	Where multiple producers provide overlapping products of the same type (initially ENCs, potentially others), ECDIS currently just selects one; future ideas to let mariners choose might add responsibility and confusion.	Governance & UX
Combined use of S-100 products	Cognitive load in risk-averse world	With explicit uncertainties from all three products, mariners must weigh layered risk information; in a highly risk-averse legal environment there is a tendency to assume the worst, which may be operationally difficult.	Human factors / decision-making
All S-100 products	Information overload	If many S-100 layers are enabled, ECDIS can become cluttered and distracting, potentially reducing situational awareness instead of improving it.	Human factors / UX
All S-100 products	Menus, layers, sub-menus	More S-100 products mean more menus and clicks; current UI concepts do not scale well and increase the chance that critical settings are buried or mis-set.	Human factors / UX
Combined use of S-100 products	Information overload & distraction	Multiple dynamic layers (high-res bathymetry, real-time water level and UKCM) can distract from basic navigation; mariners are unsure when to enable which layer (e.g. only below certain UKC thresholds) and fear information overload.	Human factors / UX
All S-100 products	Vendor timing risk	ECDIS vendors face a fine line between investing too early in immature standards and being late for the 2029 requirements, creating schedule and cost risk for everyone depending on their products.	Implementation & commercial
All S-100 products	Limited early availability	Initial availability of S-100 data and S-100-capable systems will be patchy and grow only gradually, so early adopters face mixed coverage and capabilities through the transition period.	Implementation & roadmap

Combined use of S-100 products	ECDIS–PPU settings mismatch	There is no standard way to exchange S-100 settings between ECDIS and pilot PPUs; achieving a shared picture requires manual alignment, which is error-prone and varies with different OEM menus.	Interoperability & UX
Combined use of S-100 products	Court-of-law hindsight	Officers fear being criticised after an incident for not having a particular layer switched on, even if enabling every layer would have been impractical and overloaded the display.	Legal & human factors
All S-100 products	Unofficial vs official data	Many S-100-like datasets (especially S-104, S-102, and S-129) may come from non-official sources; current UIs do not always give a strong, explicit warning, so mariners can end up relying on unofficial data without fully realising.	Legal & liability / UX
Combined use of S-100 products	Safety contour sensitivity to settings	A valid passage plan in constrained waters depends on having safety contour, S-102 and S-104 configured exactly as required; mis-set contours or missing layers directly compromise safety.	Safety & human factors
All S-100 products	Standards still in flux	Several S-100 products and related performance standards (e.g. phase-2 products, S-98 behaviours) are still under development, so early implementations risk rework or inconsistent behaviour later.	Standards / specification
All S-100 products	Awareness gap	Many officers reportedly do not even know S-100 is coming; there is a serious risk that they will "play" with new layers because they are available, not because they understand or need them.	Training & change management
All S-100 products	Training burden	The number and complexity of S-100 products mean a very large training requirement for bridge teams, pilots and shore staff over many years.	Training & competence
S-101			

S-101	Dual-fuel operational complexity	S-57 and S-101 will co-exist for years; to avoid confusing mariners, portrayal and behaviour must remain similar, which constrains how quickly S-101 can evolve.	Change management / UX
S-101	Over-trust in "blue area"	Many officers reportedly treat the "blue area" on ENCs as gospel rather than critically assessing data quality and uncertainty; this mentality carries over into S-101 and interacts poorly with richer S-100 layers.	Culture & training
S-101	Misplaced objects in poor ZOC	In lower-quality or downgraded ZOC areas, charted object positions may be significantly off; mariners are told to apply "extra caution" and contact the office, which relies heavily on human judgement.	Data quality & human factors
S-101	Temporal ZOC downgrade vs planning	Time-dependent ZOC downgrades can disrupt long-term planning (e.g. cruises) and may change very close to arrival; operators fear last-minute loss of access and the associated operational and commercial impact.	Data quality & planning
S-101	Bridge clearance datum issues	Existing ENC bridge clearances use one tidal reference, while S-104 water level uses another; until datums are aligned, using S-104 to adjust clearances is unsafe and must be blocked.	Datum & specification
S-101	Need to re-run safety checks	ZOC downgrades only affect the quality metadata, not charted depths; mariners must re-run safety/route checks to see the effect, creating a risk that changes are missed between planning and arrival.	Process & human factors
S-101	Dual-fuel production workload	Hydrographic offices must create and maintain a full S-101 ENC portfolio in parallel with S-57, keeping them in sync; this is a major ongoing workload and potential source of mismatched content.	Production & resources

S-101	Limited re-survey capacity	Temporal ZOC is partly a workaround for limited survey resources; quality information is modelled rather than constantly refreshed, so metadata may lag reality and needs careful interpretation.	Resources & data quality
S-101	Alert consistency vs S-57	There is explicit concern that a ship on S-57 could receive an alert where a ship on S-101 does not, for the same situation, if alert logic diverges – a serious safety and liability risk.	Safety logic / legal
S-101	Look-ahead ignores ZOC	Once a route is activated, the look-ahead function does not dynamically re-apply ZOC/quality logic; any later changes in quality are not reflected unless checks are manually repeated.	Specification & UX
S-101	Uncertainty model (horizontal only)	The current S-101 implementation of the IMO "uncertainty" requirement expands the route corridor using only horizontal ZOC; vertical depth uncertainty is not considered.	Specification limitation
S-101	S-101-only limitation	When only S-101 is present (no S-102/S-104), the uncertainty handling in route/safety checks is incomplete and under-represents the true UKC risk, despite appearing to account for "uncertainty".	Specification limitation / human factors
S-101	New symbology training	New or changed S-101 symbols (VTS areas, environmental areas, wind farms, moorings, emergency wreck marks, etc.) require training; without it, mariners may misinterpret features.	Training & competence
S-101	Scale-switching inconsistency (legacy)	In S-57, ECDIS vendors decide when to switch between scales; behaviour differs by system and can drop charts "too early/late". S-101 attributes aim to fix this, but inconsistency remains where S-57 is still in use.	UX / implementation

S-101	Update-info clutter	Current update highlighting can flood the screen with geometry flagged as "changed", masking the truly important changes; until S-101's new update-information feature is widely used, safety-critical changes can be obscured.	UX / safety
S-102			
S-102	Excessive data volume	Whole-country, high-resolution S-102 coverage for all ships would mean very large datasets and frequent updates; this is considered impractical and requires more selective service design.	Communications & infrastructure
S-102	Large daily files	Practical examples show very large daily S-102 volumes (along with S-104/S-111), driving significant bandwidth and storage requirements onboard.	Communications & infrastructure
S-101/S-102	S-102 always overrides S-101	Where S-102 exists, its depths always replace S-101 values, regardless of edition date; if S-102 is older or not synchronised with the ENC, newer S-101 survey info can be overridden by older S-102 values.	Data consistency & safety
S-102	"Fake precision" surfaces	Nothing prevents a producer from publishing a "1 m grid" S-102 surface built from sparse soundings and interpolation, giving a misleading impression of data richness and accuracy, especially offshore.	Data quality & governance
S-101/S-102	Keeping products consistent	Different business models (S-102 as rapid-update vs fully synchronised) risk "two versions of the truth" across S-101 and S-102; maintaining consistent contours and depths is non-trivial.	Governance & data management
S-102	Auto-loading base layer	S-102 loads automatically by default; mariners may be using S-102-driven safety contours without fully understanding it or may disable it and be blamed for any issues, shifting safety responsibility onto individuals.	Human factors / policy

S-102	Uncertainty still limited horizontally	Bringing S-102 vertical uncertainty into safety contour calculations improves things, but horizontal position uncertainty is not adjusted; the information is "not clearly transferable", pointing to remaining limitations.	Specification limitation
S-102	No CATZOC-like view	S-102 has no dedicated, easy-to-view quality layer like CATZOC; confidence is only in pixel uncertainties, so mariners cannot quickly see the quality pattern of the surface. This has been raised as an issue.	Specification limitation / UX
S-102 (with S-101)	Obscuring S-101 cues	When S-102 is on, it acts as a base layer and obscures S-101 depth area colours and shallow-water patterning; familiar visual cues are hidden, risking user confusion.	UX / human factors
S-104			
S-104	File size & comms load	Real-world services show S-104 data volumes of around a gigabyte per region per day, with frequent refreshes; when combined across coastal states , it doesplace heavy demands on shipboard bandwidth and storage.	Communications & infrastructure
S-104	Scaling to many stations	Even when split into shorter time windows, S-104 for many stations still results in very large total volumes, particularly for hydrodynamic, near real-time products.	Communications & infrastructure
S-104 (real-time)	No standard real-time path	For truly real-time water-level services, there is currently no standardised distribution path fast enough; normal channels are too slow, so real-time ambitions are not yet operational.	Communications & infrastructure
S-101/S-102/S-104	Vertical datum mismatches	If S-104 and S-101/S-102 are referenced to different vertical datums (e.g. MSL vs LAT), combining them numerically would produce wrong UKC; the system must detect and block such combinations, underlining the seriousness of the risk.	Datum & safety

S-104	Time-step interpretation	S-104 data is applied in discrete time steps (e.g. every 20 minutes); if mariners assume continuous updating, they may misjudge rapidly changing conditions between time slices.	Human factors
S-101/S-102/S-104	Complex uncertainty model	Combining depth, bathymetry and water-level uncertainties produces a sophisticated but cognitively demanding model; mariners question how to interpret it and may default to over-conservative or simplistic assumptions.	Human factors & training
S-104	"Better off without" perception	Some mariners explicitly feel they might be better off without water-level adjustment because it adds another difficult factor to manage; this is clear negative feedback on the practical usability of S-104.	Human factors / acceptance
S-104 (with non-official data)	Legal status of extra real-time data	When manufacturers or users combine non-official real-time water-level sources with S-104 to modify depths, it is unclear whether performance standards are met; some systems label this as "use at your own risk", shifting liability.	Legal & liability
S-104	No live gauge ingestion yet	Direct ingestion of live gauge data into S-104-based systems is not yet supported, even though everyone wants it, limiting how "real-time" UKC decisions can be.	Specification & infrastructure
S-101/S-102/S-104	Adjustment only via S-102	S-104 adjustments are applied through S-102; with S-101 alone, the ENC depths are not changed. Users can easily misunderstand and believe the chart has been adjusted when only a value in a report has changed.	Specification & UX
S-104	Astronomical only (current)	Current S-104 use is limited to astronomical tide predictions (tide-table equivalent); real-time or near-real-time forecasts are "next version" and not yet resolved, limiting dynamic decision-making.	Specification limitation

S-104	Not loaded by default	S-104 is not enabled by default; astronomical predictions would constantly change the chart picture. This opt-in model risks inconsistent or forgotten use of water-level-adjusted safety contours.	UX / operational practice
S-102/S-104	Coverage boundary complexity	Different line patterns show S-102 coverage, S-104 coverage and overlap areas; water-level adjustments apply only in the overlap. Misunderstanding these boundaries could lead to users assuming adjustments where none apply, or vice versa.	UX / training
S-111			
S-111	Large temporal datasets	Like S-104, temporal S-111 grids can be very large and need frequent refresh, driving high bandwidth and storage requirements, especially for near real-time hydrodynamic products.	Communications & infrastructure
S-111 (real-time)	Real-time uncertain	Real-time S-111 support is mentioned only as a future possibility; lack of clarity on if/when it will be supported limits planning for dynamic current-based services.	Roadmap / specification
S-124			
S-124	No real-time dissemination system	Although S-124 datasets can be produced, there is not yet a mature, standard real-time distribution system to push updates to ships, limiting how dynamic the service can be.	Communications & infrastructure
S-124	Major change if GMDSS removed	Moving to S-124 as the sole source of warnings would radically change operations and SAR arrangements; given global harmonisation needs, any such move must be very carefully managed.	Governance & change

S-124	Watch handover risk	A watchkeeper may read and acknowledge a warning, but nothing ensures later watchkeepers see it; new warnings may not be consistently briefed, weakening the link between approved routes and evolving risk.	Human factors / procedures
S-124	Duplicate workflow	Even when S-124 has plotted warnings on ECDIS, mariners must still print, read and manually process GMDSS texts; this is seen as extra work and undermines perceived benefit.	Human factors / workload
S-124	Patchy global adoption	Only a subset of Member States currently plan to implement S-124; ships will face a patchwork of areas with and without S-124, complicating training and expectations.	Implementation / coverage
S-124	Liability vs GMDSS	If S-124 and GMDSS text ever diverge, the GMDSS text is what counts legally; this creates caution about relying on S-124, even when it appears more user-friendly.	Legal & liability
S-124	Not MSI yet	S-124 is not currently recognised as maritime safety information; GMDSS text warnings remain legally binding, so S-124 cannot replace them and only adds an extra layer for now.	Legal & regulatory
S-124	No automatic "route compromised" flag	Participants expect the system to indicate when a new S-124 warning intersects a route and requires re-approval; this does not yet exist, leaving route status formally "OK" when, in reality, it should be reviewed.	Safety logic / UX
S-124 (with S-101)	No hazard logic integration	S-124 objects are purely informational overlays and do not participate in anti-grounding, safety contour or route-check logic; new hazards on the track will not automatically trigger a "route compromised" status.	Specification limitation / safety

S-124	Behaviour not standardised	The standard mostly defines how to read and display S-124, not how ECDIS should behave; behaviour is being defined in S-98, which is still under revision, so early vendor implementations may differ.	Standards / interoperability
S-129			
S-129	Real-time bandwidth load	Real-time UKC overlays can require updates every minute or faster, leading to a few MB per minute of data over satellite or similar links; this is a significant bandwidth and cost challenge.	Communications & infrastructure
S-129	Connectivity dependence	S-129 is the only S-100 layer that is truly route- and vessel-specific in real time and thus highly dependent on reliable connectivity; because connectivity cannot be guaranteed, S-129 cannot realistically be mandatory yet.	Communications & policy
S-129	Unequal infrastructure	In some choke points (e.g. Torres Strait) special telecom infrastructure is funded to support UKCM; such investment is unlikely everywhere, so geographic access to robust S-129 services will be very uneven.	Coverage & equity
S-129 + S-101/S-102	Underpinning bathymetry consistency	For S-129 to be trusted, its bathymetry must match S-101/S-102; if different data sources are used, ENC and UKCM layers can show conflicting seabed pictures, which is dangerous.	Data consistency & safety
S-129	Hydrodynamic model trust	Some participants express clear "reserves" about hydrodynamic UKCM overlays and would rather rely on real-time gauge-based information, signalling scepticism about model outputs.	Data trust & acceptance
S-129	Route-assumption dependence	The red "no-go" areas in S-129 are based on assumptions about the vessel following a specific route; ships often deviate, so the visual picture may not match the actual track, and users do not always know how it was calculated.	Human factors / model limitations

S-129	Official vs unofficial status	UKCM products may be produced by ports or companies without an official producer code; these are treated as unofficial aids to navigation, used at the ship's risk, which limits confidence and standardised use.	Legal & governance
S-129	"Aid to navigation" legal stance	Many S-129 services will remain as "aids to navigation" rather than official products; if things go wrong, the liability lies with the user rather than the provider, which can make companies wary about relying on them.	Legal & liability
S-129 vs S-102/S-104	Conflicting no-go areas	S-129, S-102 and S-104 can produce different safety contours and no-go areas; it is unclear "which wins", risking conflicting guidance and confusion about the authoritative picture.	Safety logic & governance