[DM-07-090] Hydrographic Geospatial Data Standards

Abstract

Coastal nations, through their dedicated Hydrographic Offices (HOs), have the obligation to provide nautical charts for the waters of national jurisdiction in support of safe maritime navigation. Accurate and reliable charts are essential to seafarers whether for commerce, defense, fishing, or recreation. Since navigation can be an international activity, mariners often use charts published from different national HOs. Standardization of data collection and processing, chart feature generalization methods, text, symbology, and output validation becomes essential in providing mariners with consistent and uniform products regardless of the region or the producing nation. Besides navigation, nautical charts contain information about the seabed and the coastal environment useful in other domains such as dredging, oceanography, geology, coastal modelling, defense, and coastal zone management. The standardization of hydrographic and nautical charting activities is achieved through various publications issued by the International Hydrographic Organization (IHO). This chapter discusses the purpose and importance of nautical charts, the establishment and role of the IHO in coordinating HOs globally, the existing hydrographic geospatial data standards, as well as those under development based on the new S-100 Universal Hydrographic Data Model.

Keywords: Electronic Chart Display and Information System (ECDIS), hydrography, marine spatial planning (MSP), Nautical Cartography, Nautical Chart, Oceanography, S-100, Safety of Navigation

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Explanation

1. The Nautical Chart
2. The Role of the International Hydrographic Organization (IHO)
3. Hydrographic Publications
4. S-100 and Future Developments

1. The Nautical Chart

A nautical chart is a map showing depths, coastline, dangers, conspicuous objects, seabed quality, and other information of the marine and coastal environment used by mariners for

passage planning and navigation. Accurate and reliable charts are essential to seafarers whether for commerce, defence, fishing, or recreation. Written descriptions and maps of the peculiarities of coastal waters, fairways and port entrances, rocks and reefs, and landmarks date back to ancient times. The advances in sciences and technology, including printing, map projections, geodesy, and data collection systems, transitioned the old map sketches of the marine environment, essentially drawings that provided a graphical description and connection of the coasts for orientation, to nautical charts as we know them today.

The advent of and developments in information technology led to the use of electronic charts on ships' bridge, first with scanned (raster) versions of the paper charts and later with the vector Electronic Navigational Charts (ENCs) (Figure 1).

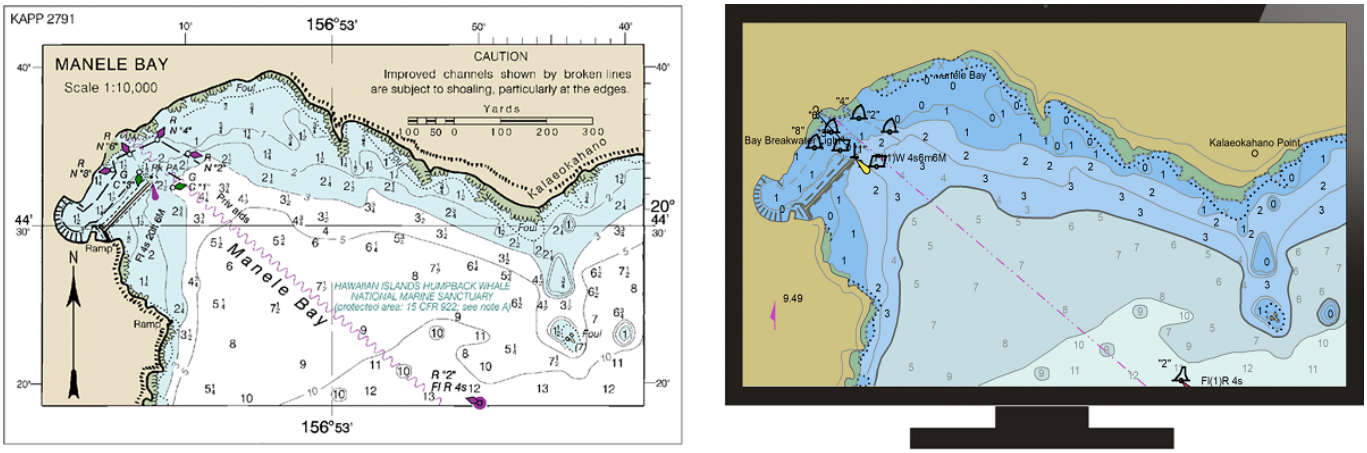


Figure 1. Example of a paper (left) and electronic (right) chart in Manele Bay, Hawaii. Source: authors.

Raster charts could be viewed on a computer screen allowing mariners to easily plot vessel's position using global positioning system (GPS) data. That was a significant improvement compared to the traditional techniques for plotting fixes with visual bearings and ranges from the radar, a task that could take minutes. However, raster charts could not leverage the capability of geospatial information system (GIS) to perform analytical tasks, something that was addressed with the introduction of the ENC. An ENC is a database, standardized as to content, structure, and format. It contains the necessary information available in paper charts and supplementary information useful for safe navigation (IMO, 2006), structured in thematic layers similar to any GIS. The benefit of ENCs is that they allow users of the dedicated information systems on board ships, called Electronic Chart Display and Information Systems (ECDISs), to customize the chart display, plot routes easily, monitor the plotted route, utilize the data layers to perform safety related tasks and provide warnings based on the ship's own characteristics. Another advantage of ENCs is the ease of distributing and applying chart updates, contrary to the tedious manual paper chart updating process.

The advantages of ENCs have resulted in a constantly increasing demand for ENCs which from a supplement to paper chart portfolio have become the main navigational tool.

Particularly for certain types of ships involved in international shipping, the use of ENCs loaded on ECDIS has become mandatory in order for the ship to receive the necessary certificates by the competent national authorities (“chart carriage” requirements, IMO SOLAS Regulations). Due to the declining demand for paper charts and the difficulty of compiling and maintaining two products (paper and electronic charts), an international discussion for the future of paper charts is underway (see e.g., NCWG, 2020), while certain HOs have already decided to discontinue their production (e.g., NOAA, 2019).

The production of modern nautical charts, both paper and ENCs, is regulated by standards and specifications developed, agreed, and adopted by coastal nations under the coordination and with the support of the International Hydrographic Organization.

2. THe Role of the International Hydrographic Organization (IHO)

Nautical charts were initially produced by private publishing firms, but in the early 18th century nations begun to realize the need for coordinated and systematic production of high-quality nautical charts to serve trade and maritime safety in general. In 1720, France founded the first hydrographic office (HO) and with other nations doing the same, gradually, the responsibility for supplying charts passed from private publishers to these specially created national organizations (Robinson, 1952). With navigation being an international activity, nations focused on providing mariners with consistent and uniform products (including e.g., data quality, symbols and abbreviations, formatting, updating, and distribution) regardless of the region or the producing nation.

In 1921, 18 coastal nations founded the International Hydrographic Bureau (IHB) to coordinate nautical charting endeavors and ensure the provision of adequate, consistent, and timely products in support of global marine navigation. The name International Hydrographic Organization (IHO) was adopted in 1970 along with the convention of regulations that established IHO’s international legal status and recognition. IHB (also known as “IHO Secretariat”) is since then used to represent the headquarters and administrative staff of the organization located in Monaco. The IHO has currently (as of June 2022) 98 members, shown in blue in Figure 2.

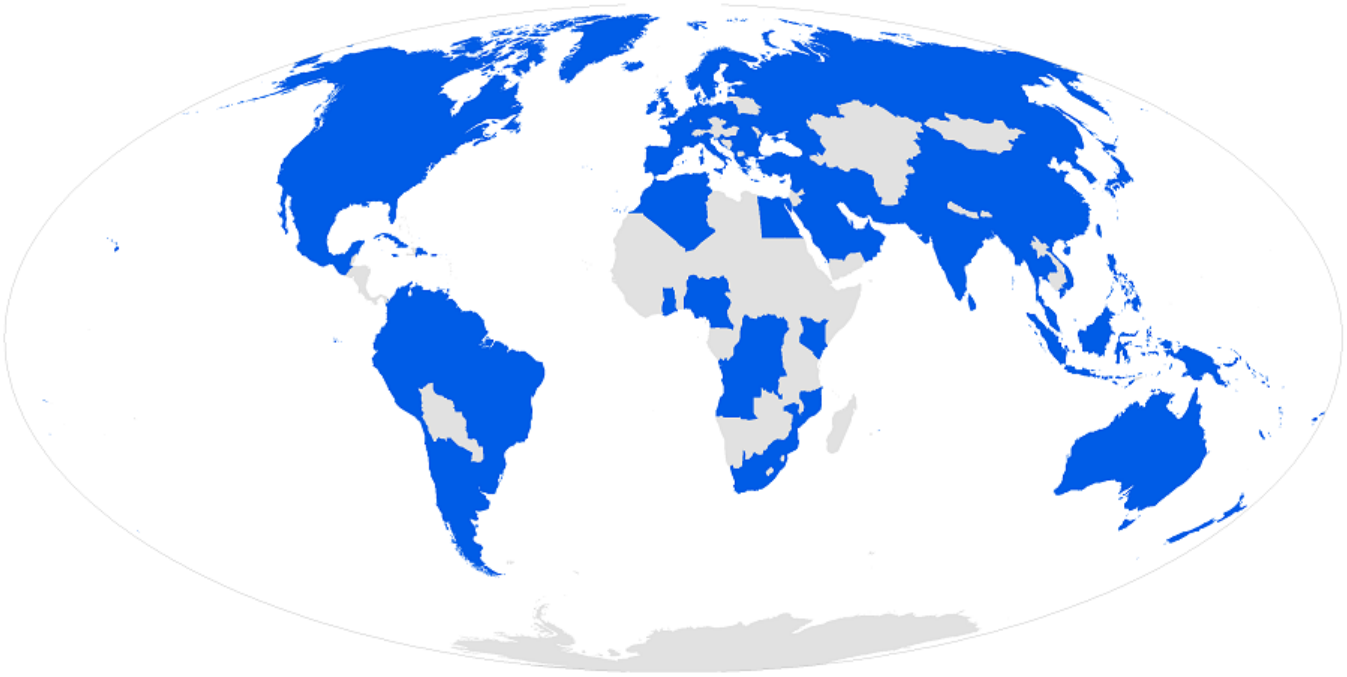


Figure 2. The 98 IHO member states (in blue). Source: authors.

The IHO has a purely consultative and technical nature. It provides a forum for cooperation for the improvement of products and services through the discussion and resolution at the international level. The goals of the IHO can be summarized as (NOAA, 2018):

1. The coordination of the activities of national Hydrographic Offices.
2. The adoption of reliable and efficient methods of carrying out and exploiting hydrographic surveys.
3. The greatest possible uniformity in nautical charts and documents.
4. The development of the sciences in the field of hydrography and the techniques employed in descriptive oceanography.
5. The promotion of measures aimed at establishing or strengthening the hydrographic capabilities of developing countries.

3. Hydrographic Publications

The IHO, through its specialized working groups and committees, drafts, publishes, and maintains various publications that regulate the charting workflow from data collection and processing to product distribution. IHO publications are arranged under five groups: Bathymetric (code names beginning with letter “B” in Table 1), Capacity Building (“C”), Miscellaneous (“M”), Periodic (“P”), and Standards and Specifications (“S”) (Table 1 and Table 2). Bathymetric publications are mainly related to the General Bathymetric Chart of the Oceans (GEBCO) and include the GEBCO map (B-1), the IHO-IOC GEBCO Cookbook (B-11) with various data processing methods, as well as publications providing guidance on topics such as naming new undersea features (B-6) and the collection and sharing of crowdsourced bathymetry (B-12). Capacity building publications aim to improving the

hydrographic and charting capabilities of newly established or developing HOs. Miscellaneous publications include basic IHO documents and information such as the IHO Convention and rules for the IHO council and assembly (M-1), the need for national hydrographic offices (M-2), IHO staff regulations (M-7), and the IHO resolutions (M-3) that contains technical resolutions governing various HO activities. Periodic publications include things such as the IHO peer-reviewed journal (named “International Hydrographic Review”) (P-1), annual report (P-7), and yearbook (P-5) that contains detailed information of the member states’ HOs and their key personnel. Standards and Specifications comprise a wealth of documents that serve as the backbone of today’s hydrographic and nautical charting workflows and products. They are either directly adopted (“as-is”) by national HOs in their workflows or serve as the reference for developing relevant national standards/specification (e.g., NOAA Nautical Chart Manual (NOAA, 2018) and NOAA Hydrographic Survey Specifications and Deliverables (NOAA, 2017)), to ensure the production of consistent, uniform, and high-quality nautical charts and documents.

Table 1. IHO Bathymetric, Capacity Building, and Miscellaneous Publications (as of June 2022)

Reference	Title
B-1	General Bathymetric Chart of the Oceans (GEBCO)
B-4	Information Concerning Recent Bathymetric Data (online publication)
B-6	Standardization of Undersea Feature Names (Guidelines, Proposal Form Terminology)
B-8	Gazetteer of Geographical Names of Undersea Features
B-9	GEBCO Digital Atlas
B-10	The History of GEBCO
B-11	IHO-IOC GEBCO Cook Book
B-12	Guidance on Crowdsourced Bathymetry
C-6	Reference Texts for Training in Hydrography (under preparation)
C-13	Manual on Hydrography
C-16	National Hydrographic Regulations
C-17	Spatial Data Infrastructures: “The Marine Dimension” - Guidance for HOs
C-33	Reference book about tide theory and practice
C-47	Training Courses in Hydrography and Nautical Cartography
C-51	Manual on Technical Aspects of the UN Convention on the Law of the Sea
C-55	Status of Hydrographic Surveying and Nautical Charting Worldwide
M-1	Basic Documents of the IHO
M-2	The Need for National Hydrographic Services
M-3	Resolutions of the IHO
M-7	Staff Regulations
M-10	The IHO and its Secretariat - an Updated History
P-1	International Hydrographic Review
P-5	IHO Yearbook
P-6	Proceedings of the 2nd Session of the IHO Assembly 2020
P-7	IHO Annual Report - 2020 Part 1 & 2

Table 2. IHO Standards and Specifications Publications (as of June 2022)

Reference	Title
S-4	Regulations for International (INT) Charts and Chart Specifications of the IHO
S-4 INT 1	Symbols and Abbreviations used on Paper Charts
S-4 INT 2	Borders, Graduation, Grids and Linear Scales
S-4 INT 3	Use of Symbols and Abbreviations
S-5A / 5B	Standards of Competence for Category "A" / “B” Hydrographic Surveyors
S-8A / 8B	Standards of Competence for Category "A" / “B” Nautical Cartographers
S-11	Guidance for the Preparation and Maintenance of International (INT) Chart and ENC Schemes and Catalogue of International (INT) Charts
S-12	Standardization of List of Lights and Fog Signals
S-23	Limits of Oceans and Seas (1953). Sheet maps 1, 2, and 3.
S-32	Hydrographic Dictionary
S-32 App 1	Hydrographic Dictionary - Glossary of ECDIS Related Terms
S-44	IHO Standards for Hydrographic Surveys
S-49	Standardization of Mariners' Routing Guides
S-52	Specifications for Chart Content and Display Aspects of ECDIS
S-53	Joint IMO/IHO/WMO Manual on Maritime Safety Information
S-57	IHO Transfer Standard for Digital Hydrographic Data
S-58	ENC Validation Checks
S-60	User´s Handbook on Datum Transformations involving WGS 84
S-61	Product Specification for Raster Navigational Charts (RNC)
S-62	List of IHO Data Producer Codes (current edition)
S-63	IHO Data Protection Scheme
S-64	IHO Test Data Sets for ECDIS
S-65	ENCs: Production, Maintenance and Distribution Guidance
S-66	Facts about Electronic Charts and Carriage Requirements
S-67	Mariners’ Guide to Accuracy of Depth Information in ENC
S-97	IHO Guidelines for Creating S-100 Product Specifications
S-99	Operational Procedures for the Organization and Management of the S-100 G.I. Registry
S-100	IHO Universal Hydrographic Data Model
S-101	ENC Product Specification
S-102	Bathymetric Surface Product Specification
S-104	Water Level Information for Surface Navigation Product Specification
S-111	Surface Currents Product Specification
S-121	Maritime Limits and Boundaries Product Specification
S-122	Marine Protected Areas
S-123	Marine Radio Services
S-127	Marine Traffic Management
S-129	Under Keel Clearance Management

Among the publications in Table 1 and Table 2, C-13, S-4, S-44, S-52, S-57, S-58, and S-63 can be considered as the cornerstone of the current workflow and products. IHO Publication **C-13 Manual on Hydrography** provides knowledge on the concepts involved in

hydrography and guidance to plan and execute hydrographic surveys. In its seven chapters, C-13 refers to the principles and the techniques used in hydrographic surveying, positioning, depth determination, sea floor classification and objects detection, water levels and flow, topographic surveying, as well as details on the hydrographic practice and other relevant information.

The **S-44 IHO Standards for Hydrographic Surveys** specifies the minimum standards to be achieved in a hydrographic survey depending on the navigational importance of the area to be surveyed. Surveys are classified in five “Survey Orders”, i.e., Exclusive, Special, 1a, 1b, and 2, where “Exclusive” is for areas with strict ship draft clearance and maneuverability criteria and “2” when a general description of the seafloor is adequate. S-44 determines the acceptable uncertainties of depth measurements, feature search, feature detection, and bathymetric coverage for each of the five survey orders. Besides the bathymetry related information, S-44 specifies the permissible uncertainty of measurements for coastline, fixed and floating objects, overhead clearances, angular measurements, and water flow direction and speed, as well as the sea bottom sampling frequency.

S-4 Regulations for International (INT) Charts and Chart Specifications of the IHO is the fundamental IHO document for nautical chart compilation. S-4 is the amalgamation of the cartographic knowledge as acquired in the span of decades. It provides guidelines for every aspect of chart compilation including: chart construction (dimensions, scale, title, notes, compass rose, source diagram); utilized units (positions, bearings); use of color (black, magenta, yellow, grey, blue, and green); requirements for the representation of topography (land, natural coastline and man-made constructions, buildings, landmarks, etc.); hydrography and aids to navigation (depths, depth curves, recommended tracks and fairways, etc.); generalization guidelines for various chart features; text (language, geographic names, numbers, styles and fonts); chart maintenance; etc. It also specifies regulations for the production of international charts and more specifically the scheming principles, producers, numbering, specifications, maintenance, exchange of reproduction material, and financial aspects (e.g., arrangements between producers and printers). Integral part of S-4 are the **INT 1 Symbols and Abbreviations used on Paper Charts**, **INT 2 Borders, Graduation, Grids and Linear Scales**, and **INT 3 Use of Symbols and Abbreviations**.

When S-4 was prepared, the nautical charts and the specifications therein referred exclusively to paper charts. The effort for the development of electronic charts presented additional specification requirements which led to the S-57 Electronic Navigational Chart (ENC) Product Specification and the S-52 Specifications for Chart Content and Display Aspects of ECDIS. Both S-52 and S-57 make full use of the background information already contained in S-4 and include cross-references where appropriate, while adjustments were made to S-4 to reflect better the existence and content of vector charts (IHO, 2021).

S-57 IHO Transfer Standard for Digital Hydrographic Data is the data format used for the transfer of digital hydrographic data between national HOs and its distribution to manufacturers, mariners, and other data users. The major components of S-57 are the Theoretical Data Model, Data Structure, Object Catalogue, ENC Product Specification, and Use of the Object Catalogue for ENC (IHO, 2020). Developed based on the ISO 8211 Standard, S-57 was formally adopted in May 1992 and since that time it became the underpinning standard for ENCs. The S-57 ENC Product Specification defines how

hydrographic offices will construct an ENC and how it should be physically encoded to files. The S-57 ENC is based on the S-57 object model that defines real world entities as a combination of descriptive and spatial characteristics in terms of feature and spatial objects. Feature objects contain descriptive attributes and no information about the shape and position of a real-world entity, whereas the spatial objects contain vector geometry and may also have descriptive attributes.

The **S-52 Specifications for Chart Content and Display Aspects of ECDIS** determines how ENC data is displayed on ECDIS screens. This includes look-up tables, conditional rules, and symbology, such as pictorial symbols, line styles, colors, and other visual cues. S-52 ensures that chart information is displayed the same way regardless of the model of the ECDIS used on board. Figure 3 illustrates sample paper and their respective electronic chart symbols.

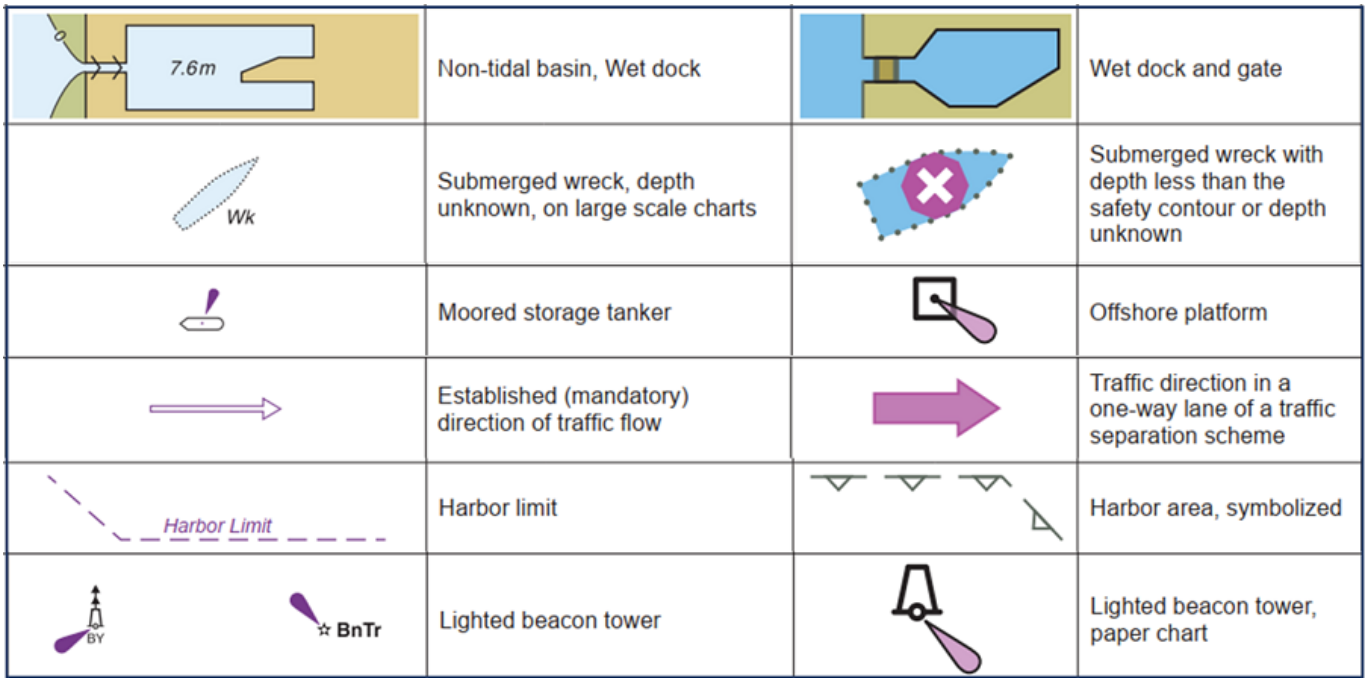


Figure 3. Selected paper chart (left two columns) and their respective ENC (right two columns) symbols and description. Source: authors.

The **S-58 ENC Validation Checks** sets out the minimum validation checks that ENC producers must perform before ENCs are released. The validation checks are intended to ensure that the ENC is compliant with the S-57 product specification and that there are no irregularities in an ENC that could cause an ECDIS to malfunction (UKHO, 2017). Irregularities can include intersecting geometries, polylines' point density, depths on land, etc. Due to that not all irregularities are equally important to the operation of the ECDIS, they are classified into three error categories: Critical Error, Error, and Warning. Warnings can exist within a published ENC (e.g., polyline point density) but not Critical Errors (e.g., intersecting depth curves) which must be fixed by the producing HO before ENC release. The list of validation checks in S-58 is not exhaustive; new checks are added and others are upgraded/downgraded from one category to another as a result of the lessons learned from

real-world situations and research in the field (Kastrisios et al., 2020).

S-63 IHO Data Protection Scheme is the standard for encrypting, securing, and compressing ENCs. S-63 publication aims to prevent unauthorized use of data by encrypting the ENC information ("Piracy Protection"), to restrict access to ENC information to only those cells that a customer has been licensed for ("Selective Access"), and to provide assurance that the ENC data has come from approved sources ("Authentication"). For the end-user, the above three ensure that only data from official sources is authenticated, thereby reducing the risk of using inaccurate data that is posed by unofficial ENCs, and the risk of malware being introduced to a ship's IT systems (UKHO, 2017). Most HOs encrypt their ENCs before release in the S-63 format, whereas fewer choose to make them available unencrypted (S-57 format).

4. S-100 and Future Developments

S-57 has served nautical charting for about three decades, however it suffers from an inflexible regime, inability to support gridded bathymetry or time-varying information, and the sole purpose for the production and exchange of ENC data (Alexander et al., 2007). In response to the identified limitations of S-57, in 2000 the IHO approved a major revision to S-57 that led to the development of a new framework for hydrographic geospatial data standards, the S-100 Universal Hydrographic Data Model. S-100, adapted by member states in 2010, is a versatile standard framework aligned with the ISO 19100 Geographic Information / Geomatics series of standards. S-100 supports a wide variety of hydrographic and marine information and extends products' use to other marine related geospatial applications beyond the core hydrographic (IHO, 2018b) such as coastal zone management and marine spatial planning (see Contarinis & Kastrisios, 2022). S-100 is inherently more flexible than S-57; it makes provision for things such as the use of imagery and gridded data types, enhanced metadata and multiple encoding formats, while it provides a more flexible and dynamic maintenance regime for objects, attributes, and portrayal via a dedicated on-line registry (Powell, 2011). The associated IHO GI Registry contains the following components (IHO, 2018b):

- Feature Concept and Data Dictionary Register
- Portrayal Register
- Metadata Register
- Producer Code Register.

S-100 can be used by other data providers for their maritime-related (non-hydrographic) data and information. For instance, S-100 has been adopted by the United Nations' International Maritime Organization (IMO) to be the basis of IMO's Common Maritime Data Structure of e-navigation (Hahn et al., 2016). E-navigation aims to improve the sharing of marine information through the use of modern technology and includes marine data such as ENCs, bathymetric, tidal, meteorology, radar-image, and Automatic Identification System (AIS) data (Contarinis et al., 2020).

S-100 provides the framework for the development of the next generation of ENCs that will replace the current S-57 ENCs. **S-101 ENC Product specification** introduces functionalities not available in S-57 product specification. S-101 draws upon the concepts of S-100 for exchangeable and dynamic feature and portrayal catalogues, and richer

geometric models, information types and complex attributes (Powell, 2011). This will allow ENC producers to overcome known encoding shortcomings in S-57, such as the overuse of caution areas, and for more efficient data handling and better portrayal within ECDIS. The biggest advantage of S-101 is the machine readable and dynamic feature and portrayal catalogues that allow for easy and continuous updates. The use of complex attributes and information type enhances the encoding, transfer, and portrayal of data. Complex attributes, derived from the ISO 19000 attributeOfAttribute, allow for the aggregation of simple or complex attributes. The aggregation is defined by means of attribute bindings that may be represented by a composition (e.g., BuoyLateral/topmark and topmark/shapeInformation in Figure 4(a)) or a local attribute (e.g., BuoyCardinal attributes topmark and featureName in Figure 6(b)) (IHO, 2018a). The information type provides information about a feature by association, without any spatial attribution. For instance, a buoy can be associated with a related note instead of encoding a caution area, as was the practice in S-57.

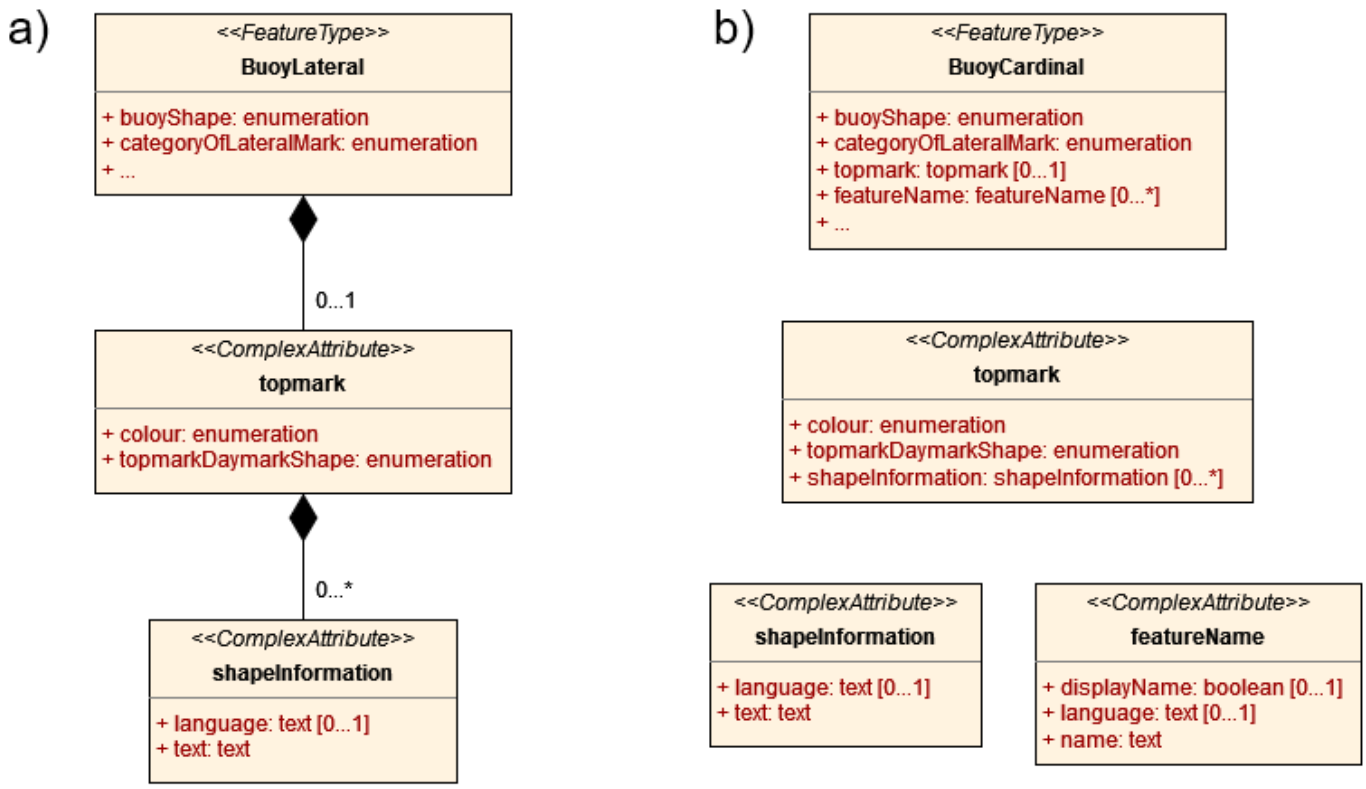


Figure 4. Example of complex attributes in S-101. (a): The complex attribute topmark has three sub attributes, one of which (shape information) is itself complex. The Buoy Lateral feature may optionally include one instance of topmark. (b): The Buoy Cardinal feature may include one instance of topmark and one or more instances of feature name. (IHO, 2018a). Source: IHO, 2018a.

S-101 will gradually replace the S-57 while it is expected that in 2030 S-57 will be discontinued. S-101 ENCs will serve as the base layer within an S-100 enabled ECDIS, but its true potential will be realized with the additional products that will interact with S-101, such as the S-102, S-104, and S-111.

The **S-102 Bathymetric Surface Product Specification**, released in 2012, was the first

official hydrographic geospatial standard built on the S-100 framework. Incorporating aspects of the navigation surface concept (Smith et al., 2002), a S-102 bathymetric surface product is a digital elevation model which represents the seafloor in a regular grid structure. It can be used alone or as an important element/source for future S-100 conformant ECDIS navigation. It comprises the content model (spatial structure and metadata), encoding structure, portrayal, and exchange file format for a bathymetric surface product. The primary purpose of the Bathymetric Surface Product is to provide high resolution bathymetry in gridded form in support of safety of navigation, and, secondly, for other maritime applications. S-102 datasets enhance the mariner's ability to delineate and display, directly from the grid, safe and unsafe depth zones particular to the specific ship parameters (based on a "go"/ "no-go" concept), rather than utilizing the existing depth contours in the S-57 dataset.

The ability to delineate ship specific navigable depth areas is further enhanced by other S-100 based products, such as the **S-104 Water level Information for Surface Navigation** and the **S-111 Surface Currents**. The former encapsulates the tidal and water level data for use in an ECDIS as complement to S-101 and S-102 to calculate the available water depth below ship keel, and the latter that of currents which affect the motion of vessels. Besides the above, several other standards for S-100 dependent products (with allocated numbers in the format of S-1xx, S-2xx, S3xx, S4xx, and S-5xx for the different parent organizations) have been developed or are under development by relevant IHO bodies, as summarized in Table 3 (see (IHO, n.d.))

Table 3. Planned S-100 dependent products and allocated Product Specification numbers for the different parent organizations

International Hydrographic Organization (IHO) (S-101 to S-199)	
S-101 Electronic Navigational Chart (ENC)	S-124 Navigational Warnings
S-102 Bathymetric Surface	S-125 Marine Navigational Services
S-103 Sub-surface Navigation	S-126 Marine Physical Environment
S-104 Water Level Information for Surface Navigation	S-127 Marine Traffic Management
S-111 Surface Currents	S-128 Catalogue of Nautical Products
S-112 Open - (see Decision HssC9/38)	S-129 Under Keel Clearance Management
S-121 Maritime Limits and Boundaries	S-130 Polygonal Demarcations of Global Sea Areas
S-122 Marine Protected Areas	S-131 Marine Harbour Infrastructure
S-123 Marine Radio Services	S-164 IHO Test Data Sets for S-100 ECDIS
International Association of Light Authorities (IALA) (S-201 to S-299)	
S-201 Aids to Navigation Information	S-240 DGNSS Station Almanac
S-210 Inter-VTS Exchange Format	S-245 eLoran ASF Data
S-211 Port Call Message Format	S-246 eLoran Station Almanac
S-212 VTS Digital Service	S-247 Differential eLoran Reference Station Almanac
S-230 Application Specific Messages	
Intergovernmental Oceanographic Commission (IOC) (S-301 to S-399)	
None proposed yet	
Inland ENC Harmonization Group (IEHG) (S-401 to S-402)	
S-401 IEHG Inland ENC	S-402 IEHG Bathymetric Inland ENC

International Hydrographic Organization (IHO) (S-101 to S-199)	
Joint Technical Commission for Oceanography and Marine Meteorology (WMO/IOC JCOMM) (S-411 to S-414)	
S-411 JCOMM Ice Information	S-413 Weather and Wave Conditions
S-412 JCOMM Weather Overlay	S-414 Weather and Wave Observations
International Electrotechnical Commission - Technical Committee 80 (IEC-TC80) Numbers (S-421 - S-430)	
S-421 Route Plan	
NATO Geospatial Maritime Working Group for Additional Military Layers Numbers (S-501 to S-525)	
None proposed yet	

NOAA/Office of Coast Survey and the Ministry of Fisheries of the Republic of Korea have been working on developing a S-100 test bed to help further the development of S-100 related products and the testing of S-100 interoperability within navigation systems. In August of 2019, the two offices, along with the United Kingdom Hydrographic Office and the Canadian Hydrographic Service, performed the first sea trials of S-100 based products toward harmonized navigation products. The primary goal of the S-100 sea trial was to test a prototype S-100-based ECDIS capable of ingesting and displaying S-101, S-102, S-111, S-122, S-124, and S-129 datasets. (Powell, 2019)

References

Alexander, L., Brown, M., Greenslade, B., & Pharaoh, A. (2007). Development of IHO S-100. The new IHO geospatial standard for hydrographic data. International Hydrographic Review, 8(1), 56–62.

Contarinis, S., & Kastrisios, C. (2022). Marine Spatial Data Infrastructure. In J. P. Wilson (Ed.), The Geographic Information Science & Technology Body of Knowledge. (1st Quarter 2022 Edition), John P. Wilson (Ed.).

Contarinis, S., Pallikaris, A., & Nakos, B. (2020). The Value of Marine Spatial Open Data Infrastructures—Potentials of IHO S-100 Standard to Become the Universal Marine Data Model. Journal of Marine Science and Engineering (Vol. 8, Issue 8, p. 564).

Hahn, A., Bolles, A., Fränzle, M., Fröschle, S., & Hyoung Park, J. (2016). Requirements for e-Navigation Architectures. International Journal of E-Navigation and Maritime Economy, 5, 1–20.

IHO (International Hydrographic Organization). (2018a). IHO Electronic Navigational Chart Product Specification. IHO Publication S-101 (1.0.0). Monaco:International Hydrographic Organization. Monaco.

IHO (International Hydrographic Organization). (2018b). S-100 - Universal Hydrographic Data Model (4.0.0). Monaco: International Hydrographic Organization.

IHO (International Hydrographic Organization). (2020). S-65: Electronic Navigational Charts (ENCs) “Production, Maintenance and Distribution Guidance" (2.1.0). Monaco:

International Hydrographic Organization.

IHO (International Hydrographic Organization). (2021). S-4: Regulations of the IHO for International (INT) Charts and Chart Specifications of the IHO (I. H. Organization (ed.); 4.9.0). Monaco: International Hydrographic Organization.

IHO (International Hydrographic Organization). (n.d.). S-100 based Product Specifications. Allocations of S-100 Dependent Product Specification Numbers. Retrieved May 10, 2022

IMO (International Maritime Organization). (2006). Adoption of the revised performance standards for Electronic Chart Display and Information Systems (ECDIS), IMO Resolution MSC.232(82). London: International Maritime Organization.

International Hydrographic Organization (IHO). (2020). The Future of the Paper Nautical Chart - Final Report. Nautical Cartography Working Group. International Hydrographic Organization. Monaco.

Kastrisios, C., Calder, B. R., & Bartlett, M. (2020). Inspection and Error Remediation of Bathymetric Relationships of Adjoining Geo-Objects in Electronic Navigational Charts. Proceedings of the 8th International Conference on Cartography and GIS, Nessebar, Bulgaria, Bulgarian Cartographic Association. (pp. 116–123).

National Oceanic and Atmospheric Administration (NOAA). (2017). Hydrographic Surveys Specifications and Deliverables (HSSD). National Oceanic and Atmospheric Administration. Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). (2018). Nautical Chart Manual. Volume 1 - Policies and Procedures. National Oceanic and Atmospheric Administration. Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). (2019). Sunsetting Traditional NOAA Paper Charts - End of Paper and Raster Nautical Chart Production Introduction of NOAA Custom Charts. National Oceanic and Atmospheric Administration. Silver Spring, MD. .

Powell, J. (2011). The New Electronic Chart Product Specification S-101: An Overview. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 5(2), 167–171.

Powell, J. (2019). S-100 sea trials: working toward harmonized navigation products. Office of Coast Survey, National Oceanic and Atmospheric Administration (NOAA).

Robinson, A. H. W. (1952). The Evolution of the English Nautical Chart. Journal of the Institute of Navigation, V(4).

Smith, S. M., Alexander, L., & Armstrong, A. (2002). The Navigation Surface: A New Database Approach to Creating Multiple Products from High-Density Surveys.

International Hydrographic Review, 976..

United Kingdom Hydrographic Office (UKHO). (2017). S-57, S-63 and S-52: The latest IHO Standards and what they mean. United Kingdom Hydrographic Office, Admiralty Maritime Data Solutions.