

Chapter 1: Data Management -- DRAFT VERSION SDB ADDENDUM

1.1 Introduction

The ocean mapping community has made significant progress in effective data stewardship over the last decade, yet it still lags behind other scientific communities in this area. Marine data collectors sometimes lack the awareness, resources, and/or expertise to fully implement best data management practices on their own, resulting in data being improperly documented, kept out of the public realm, and/or lost. More recently, the expense and difficulty of collecting data and the recognition that these data are used for multiple purposes have prompted efforts from funding agencies and data management communities to overcome these obstacles. The GO-FAIR Initiative, for example, is a stakeholder community that developed and promotes the FAIR Guiding Principles for scientific data management and stewardship to assist data holders in making their data Findable, Accessible, Interoperable, and Reusable (GO FAIR, n.d.). These principles apply to projects and datasets of any size and have been embraced by large international programs, such as the Integrated Ocean Observing System (NOAA IOOS, n.d.). Access to tools such as metadata editors and data packaging software have been developed to reduce data management barriers and help data collectors meet the requirements for data documentation, preservation, and access.

Using data standards ([Appendix A](#)) and metadata promotes data reusability, increases interpretability, clarifies ambiguous meanings, and reduces redundancy/duplication of efforts. This chapter provides overarching guidance and recommendations for effective data management and stewardship, specifically, the metadata and archival techniques necessary for data to be stored and maintained for access and understandability now and into the future by a broad spectrum of users, including the general public. This chapter does not address specific manufacturers or use cases.

1.2 Data Submission to Archives or Repositories

Submission of raw data, processed data, and products to data archives or repositories is strongly encouraged to meet the data documentation, preservation, and access goals outlined above. **Data repositories** are either a space used to store records of continuing value or an institution focused on the care and storage of those records. Many universities, States, and Federal agencies host their own repositories.

In the United States, **National Archives** are data repositories owned and maintained by the Federal Government to meet the data preservation requirements of the National Archives and Records Administration (NARA). While Federal agency archives do not formally meet that definition, NOAA National Centers for Environmental Information (NCEI) does meet several definitions for the term and is referred to as both an archive and a repository. NCEI also adheres to the Open Archival Information System Reference Model (OAIS) (ISO Standard 14721) to ensure

that data are independently understandable for long-term preservation (OAIS Reference Model, n.d.).

Although the guidelines presented in this chapter are widely used best practices that should be considered for all datasets, regardless of where they are stored, data providers should contact the appropriate repository or archive directly for specific submission requirements.

1.3 Minimum Data Submission Requirements for National Archives

Data must have accompanying metadata and be provided in the requested format(s) and folder structure (See [Chapter 1.5](#) for NOAA NCEI example) before publication and archival. Also, processed data must be evaluated, and properly quality assured and controlled by a subject matter expert.

Data submitted to the NOAA NCEI Archive (NOAA NCEI, n.d. a) include:

Data

- See applicable chapters below (Chapters 2–7)
- See [Appendix B](#) for formats by data type

Metadata

- See [Chapter 1.4](#) for minimum metadata requirements
- See [Chapter 1.5](#) and [Table 1.1 Minimum metadata recommended for usability and archiving for all data themes](#). for recommended metadata fields for all data types outlined in Chapters 2–7

Standardized folder structure

- See [Chapter 1.5.1](#) for NCEI example

1.4 Minimum Metadata Requirements

Data are often collected and processed using proprietary software, and calibration settings are instrument-dependent and vary with local and environmental conditions. Therefore, detailed documentation of specific settings and parameters in metadata records is critical to assess data for further processing and interpretation at any point in time. Standardization of metadata is accomplished by using a set of defined information or “attribute” fields arranged in a specific, machine-readable structure or “schema.” This enables the organized storage of metadata records in searchable databases. Although different organizations employ or endorse different metadata schema ([Appendix A](#)), most require a common core set of attributes and are, to some extent, interoperable.

1.4.1 Schema

Repositories and archives maintained by U.S. Federal agencies, including NOAA NCEI, United States Geological Survey (USGS), and other cooperative institutes, require that data submissions include geospatial metadata in a standard endorsed by the FGDC. FGDC-endorsed schemata

include the Content Standard for Digital Geospatial Metadata and several International Organization for Standardization (ISO) geographic metadata standards such as ISO 19139/19115 and extensions ([Appendix A](#)).

These schemata contain mandatory and optional fields to document attributes, including information regarding the survey (e.g., dates of data collection, sensor(s) used, vessel and cruise names), data collection and processing steps, geographic reference, and contacts for lead participants:

Descriptions of the ISO content and organization and guidance for writing metadata (NOAA NCEI, n.d. b; USGS, 2021).

USGS and NOAA resources include metadata templates with guidance documents. Additionally, NOAA hosts an ISO Workbook (NOAA NODC, 2012).

ISO Explorer (a web-based comprehensive explorer for ISO 19115 [ESIP, 2017] and 19115-2 [NOAA NGDC, 2020]) both act as implementation guides.

1.4.2 Spatial Reference

Georeferenced geospatial data should refer to the most current horizontal datum from the National Spatial Reference System. Projection information must be defined in the feature class so that the data project accurately when imported into a geographic information system (GIS).

Geographic data must use the most recent adjustment and epoch of the North American Datum (NAD) of 1983 (currently NAD83(2011), Epoch 2010.00) in either (Universal Transverse Mercator [UTM]; eastings/northings) with the zone specified or as geographic coordinates (latitude/longitude), and adequately documented. Note: Both horizontal and vertical datums will be replaced by the North American Terrestrial Reference Frame of 2022 (NATRF2022), based on the Global Positioning System (GPS)/ Global Navigation Satellite System (GNSS) and a GRAV-D-based geoid (GEOID2022) (NOAA NGS, n.d.).

1.4.3 Core Metadata

1.1 lists and defines the minimum, or core, set of metadata attribute fields that are common across all data types in the SOMP and required for data submission to many data repositories and archives. These metadata attributes should be considered *prior to* data collection or processing to ensure that the information is documented before or at the time of collection/processing. Documenting metadata during the project is strongly encouraged as a best practice and facilitates a more accurate and detailed record. The following chapters will discuss additional required metadata fields specific to each data type.

All survey data, including raw and/or processed mapping data and supplementary data, any associated products, and metadata should be archived together in cruise- or mission-specific directories.

Raw and processed data file formats are currently dominated by industry-standard proprietary acquisition and processing software. Any data collected or processed using proprietary software should be provided in open-file formats to the greatest extent possible (either instead of or in

addition to the proprietary format). Maintaining proprietary formats allows for new processing techniques to be implemented and preservation of the whole, raw dataset. However, this practice can significantly increase data storage needs and effort (e.g., to convert files), so users should decide—prior to acquisition—what file formats will be preserved.

Supplemental data such as sound speed profiles, tides, vessel offsets, vessel track lines/navigation files, cruise reports, log/field notes, etc. are valuable information that provide context and help users fully understand the settings and environment in which the data were collected. Inclusion of all relevant information can aid in the most accurate analysis of the data. Supplemental data can be recorded in a variety of formats and are typically (and preferred) in non-proprietary formats (e.g., ASCII, CSV, PDF). Data products developed from the mapping data (e.g., mosaics, rasters, digital elevation models, maps) are also recorded in a variety of formats and are typically (and preferred as) open-file or easily accessible formats.

1.5 Recommended Core Metadata Fields for All Data Types

Table 1.1 Minimum metadata recommended for usability and archiving for all data themes.

A. General Information

Information Field	Example Text	Description
Survey Name	NF1309	Typically, “shipID, year, cruise number,” survey cruise ID/name.
Vessel Name	Nancy Foster	Name of survey vessel/ vessel name.
Chief Scientist	Transit or John Smith	Transit or chief scientist(s) and affiliation(s).
Chief Scientist Organization	USGS	Transit or agency(ies) / program(s) for which survey is conducted.
Departure Port	US - Puerto Rico - San Juan	City, state for U.S. ports. City, country for international ports, vessel departure port(s).
Arrival Port	US-Charleston, SC	City, state for U.S. ports. City, country for international ports, vessel arrival port(s).
Ship Owner	NOAA	Entity that owns the survey vessel.
Project Name	Corals in the Florida Keys	Specified project name or “Transit.”
Source	NOAA	Source organization of data being provided.

B. Reference

Information Field	Example Text	Description
Citation	NOAA (2010)	Bibliographic information to reference the resource. Ex: Cite as: NOAA (2010): Multibeam collection for M1907_NF_10: Multibeam data collected aboard Nancy Foster from 16-Mar-10 to 15-Apr-10, Charlotte Amalie, U.S. Virgin Islands to San Juan, Puerto Rico. NOAA National Centers for Environmental Information. [url], [access date].

C. Time

Information Field	Example Text	Description
Start Date	2013-09-10	Date only. YYYY-MM-DD, acquisition start date (ISO 8601).
End Date	2014-10-28	Date only. YYYY-MM-DD, acquisition end date (ISO 8601).
Start Time	01:12:22	Time, as XX:XX:XX, hh:mm:ss, in UTC (Coordinated Universal Time), acquisition start time.
End Time	17:30:10	Time, as XX:XX:XX, hh:mm:ss, in UTC, acquisition end time.

D. Location

Information Field	Example Text	Description
Coordinate System	Horizontal: NAD83 UTM Zones 17-20 Vertical: NAVD88	Information about the spatial reference system used. Coordinate system/horizontal datum/vertical datum(s) used for raw and processed data. Describe processing steps used to shift coordinate system or datum, if different from raw data.
Spatial Domain	Latitude: 46.00 to 49.50 Longitude: -84.00 to -92.20	The geographic areal domain of the dataset, i.e., what geographic area does the dataset cover? Provide limits of dataset coverage in latitude and longitude values in the order of westernmost, easternmost, northernmost, and southernmost. List Latitude first followed by Longitude to match nautical standards (Lat/Long).

Horizontal Datum	NAD83	Information about the horizontal reference frame and epoch. If projected data, state projection zone.
Vertical Datum	MLLW	State information about the vertical coordinate reference system (CRS) and epoch. A vertical datum is technically a surface of zero-elevation to which heights of various points are referred in order that those heights be in a consistent system. More broadly, a vertical datum is the entire system of the zero-elevation surface and methods of determining heights relative to that surface. Over the years, many different types of vertical datums have been used. The most dominant types today are tidal datums, geodetic datums and submerged elevation if using Photogrammetric/ stereo SDB.
Sensor Altitude	n/a	Sensor altitude (if towed system).

E. Content

Information Field	Example Text	Description
Entity and Attribute Information	See SOMP Appendix A	Information about the physical parameters and other attributes contained in a resource. Details about the information content of the data-sets, including the entity types, their attributes, and the domains from which attribute values may be assigned, and data fields defined.

F. Credit

Information Field	Example Text	Description
Dataset Credit	NOAA	Recognition of those who contributed to the dataset, cited authors, publishers. Who produced the dataset? Who are the originators of the data-set?
Point of Contact	Nigel Smith	Contact information for an individual or organization that is knowledgeable about the data-set, name, affiliation, email, phone. To whom should users address questions about the data?

G. Purpose

Information Field	Example Text	Description
Abstract	Text Summary	Brief narrative summary of the resource/dataset's contents. Abstract narrative should include information on general content and features; dataset applications: GIS, CAD, image, database; geographic coverage: country/city name; time period of content: begin and end date or single data; and special data characteristics or limitations. Description = abstract and purpose, a characterization of the data-set, including its intended use and limitations. Brief narrative summary of the dataset's contents.
Purpose	Text Summary	Summary of the intentions for which the dataset was developed. Purpose includes objectives for creating the dataset and what the dataset is to support. For example: nautical charting, habitat mapping, geologic interpretation, modeling, etc.

H. Sensors

Information Field	Example Text	Description
Acquisition	Info	Information about instruments, platforms, operations, and other information of data acquisition? How were these data collected?
Navigation	DGPS or GPS	Equipment used in determining data positioning, including accuracy of system (e.g., the make/model). For example, Trimble R10 Integrated GNSS system RTK GPS or Applanix POS MV GNSS-aided inertial positioning system.
Instrument	Reson 7125	Information about instruments, platforms, operations and other information of data acquisition. How were these data collected? Description of the instrument(s), and sensor(s). Report data resolution if applicable to the data type. Ex: Vessel configuration, survey vessel dimensions (length, width, draft) and applied system offsets are critical and may or may not be documented in the raw data, depending on acquisition setup/software. What platforms were the instruments on? Ex: Geometrics G-882 Digital Cesium Marine Magnetometer.

I. Processing

Information Field	Example Text	Description
Processing Steps	Text Summary	Paragraph describing processing performed on data, including software (and version) used, if any—list of process steps, details of data preparation, cleaning, transformation, algorithm used, atmospheric corrections, calibration source information, image processing info., image scene info, type and version of software, etc. Report data resolution if applicable to the data type.

J. Quality

Information Field	Example Text	Description
Data Quality Information	Info	Information about the quality and lineage (including processing steps and sources) of a resource such as attribute accuracy, logical consistency report, or completeness report. Describe any constraints that may have affected data quality during collection (e.g., sea state, software or hardware issues), scope, report, and lineage. How well have the observations been checked? How accurate are the geographic locations, heights, or depths? Where are the gaps in the data? What is missing? How consistent are the relationships among the data? What is the quality of this data set?
Patch Test & System Calibration	Step 1, Step 2...	Description of steps taken to ensure the system is calibrated including time and location of calibration. Complete listing of calibration corrections applied to data. Details of process used to refine system alignment / report. Include 'pre-' and 'post-calibration' settings for context and traceability to previous and later calibrations.
Settings	Sonar settings include	Description of settings used during data acquisition.
Uncertainty Estimation	First order TPU approximation	Equation or description of model for determining uncertainty.

K. Distribution – Access – Handling

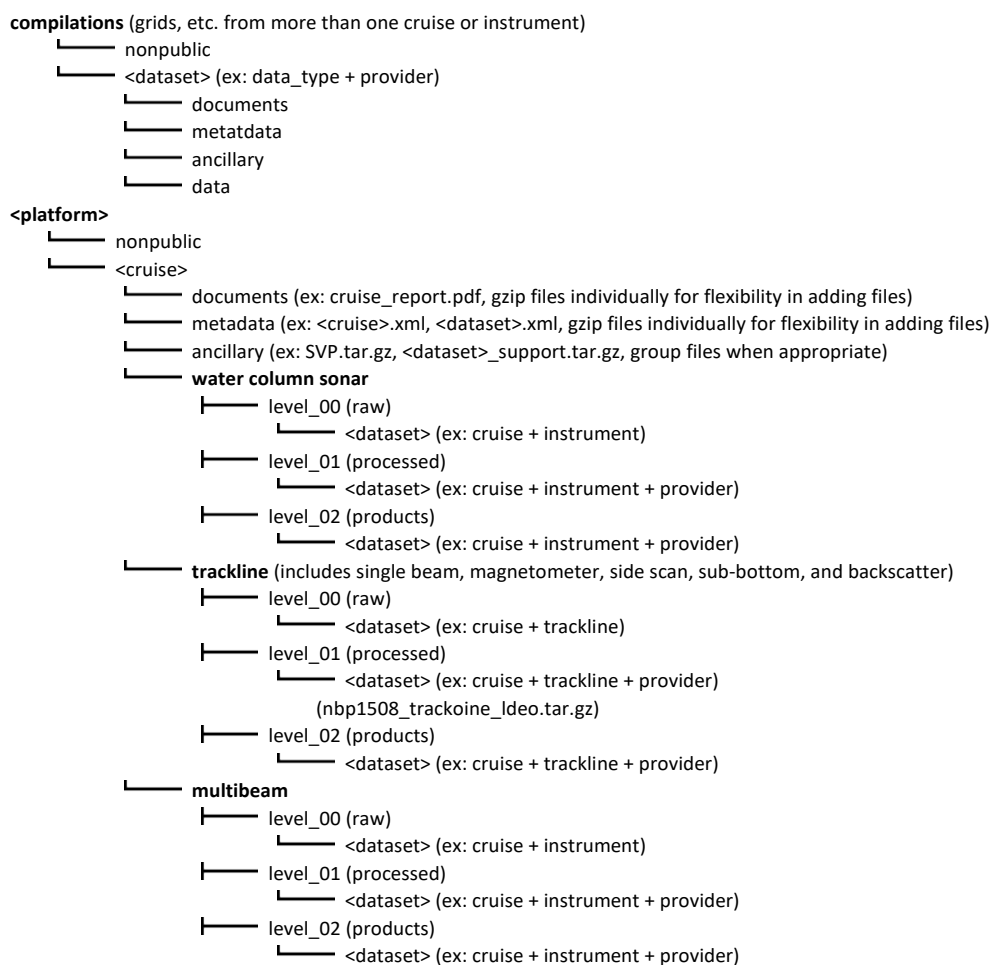
Information Field	Text Summary	Description
Data license identifier	License identifier (e.g., CC0-1.0, CC-BY-4.0)	Assigning a universal data license is highly encouraged, as it removes any ambiguity about how the data may be used, thus facilitating streamlined data handling. Most common licenses in use are: (1) Creative Commons Public Domain Dedication (CC0-1.0), which legally removes copyright from the data, thus ensuring it achieves maximum reach and use. Credit given to the provider is a standard industry practice and courtesy. (2) Creative Commons Attribution 4.0 International (CC-BY-4.0), which allows for data to be used for any purpose but legally requires credit be given (i.e., attribution), so it is slightly more restrictive.
Data license URL	URL (e.g., https://creativecommons.org/publicdomain/zero/1.0/legalcode , https://creativecommons.org/licenses/by/4.0/legalcode)	The URL to the legal code of the data license.
Access Constraints	Yes or No	This field is only necessary if a data license has not been assigned. Are there legal restrictions on access or use of the data? This field should include information about constraints on the use of the metadata and the resource it describes; limitations, restrictions, or statements on the resource fitness for use; temporary data access restrictions (i.e., public, proprietary, sensitive, restricted). ("Access Constraints" for "Proprietary" describe any components of the raw or processed data or mosaics that are proprietary [e.g., raw data files, processed data files, navigation files]. Note that backscatter raw and processed data file formats are currently dominated by industry-standard proprietary acquisition software, whereas the resulting mosaic or raster data are typically an open data format.)
Distribution	Info	Information about the distributor of and options for obtaining the data-set. Who distributes the data?
Responsible Party	Name	Who wrote the metadata?

DOI	DOI: 10.7289/V56T0JNC	Digital Object Identifier. If DOI is not provided, NCEI will create one upon request.
Outside Link	http://www...	Web link to additional information regarding cruise, project, or funding. What are the URLs and other online resources associated with this data set?
Comments	Proprietary hold until Oct 1, 2014	General comments regarding the cruise or dataset, if any.

1.5.1 File Data Submission Folder Structure

One of the essential components of sound data management is an established filing (directory) structure. Established file plans demonstrate consistency and continuity in record keeping (Figure 1.1).

Figure 1.1. Data Type Folder Structure: an example of the folder structure from NCEI for submitting various data types.



1.6 Dataset (Data Theme) – Data Management Protocol

The following are required metadata fields specific to each data type that should be provided in addition to the minimum requirements presented in [Chapter 1.1](#) and [Table 1.1](#).

1.6.1 Bathymetry Data Management

Single beam sonars ensonify the seafloor with a single narrow beam of sound typically directly below the vessel, whereas multibeam sonars ensonify the seafloor with a wide swath of sound, dividing the return from the seafloor into multiple beams across the wide swath. Multibeam sonars cover the space directly under the ship and out to each side and collect two types of data: seafloor depth and backscatter. The seafloor depth, or bathymetry, is computed by measuring the time it takes for the sound to leave the array, reflect from the seafloor, and return to the array. Multibeam and single beam bathymetry raw data (as collected) are recorded in the instrument's vendor-specific file format. Common file formats include, but are not limited to .all, .kml, .imb, .s7k, .xse, and .raw.

The following subchapters and [Chapter 2](#) identify additional information specific to bathymetry data that should be included in a survey report and/or the metadata record. NCEI is the preferred destination for all bathymetric data and products to be included in the U.S. Bathymetry Gap Analysis (NOAA IOCM, n.d.) and to be made publicly discoverable and accessible. We encourage our partners, including those in government, industry, and academia, to collect/process bathymetry data using SOMP guidelines and submit it to NCEI.

1.6.1.1 Minimum Requirements for Bathymetry Data Stewardship and Discovery

At minimum, bathymetry data must include:

- Raw and/or processed data files and/or products in vendor-specific format (e.g., .all, .s7k, .xse). Processed data should be submitted in an open-source format such as .gsf

- Metadata should include all required fields (See [Chapter 1.4](#) for details).

- Submissions should conform to NCEI guidance for archiving (See [Chapter 1.6.2.2](#)).

- Multibeam and single beam data submissions to the NCEI archive should be made by emailing mb.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

- When multibeam or single beam sonar data are to be submitted for archiving at NCEI, data providers should work with NCEI data managers to determine the best method for packaging data.

- One option to assist in data packaging is CruisePack (NOAA NCEI, n.d. c.), a standalone executable, to package sonar and any ancillary data. CruisePack generates consistent and complete metadata to document the data collection process and ensures that data submitted to NCEI are in a standardized format for automated incorporation into the archive.

- NCEI maintains raw multibeam (as collected) data files in the instrument's vendor-specific format (e.g., .all, .s7k, .xse). However, other supplemental data (sound speed profiles,

tides, vessel offsets, cruise reports, etc.) and/or processed versions or products of the multibeam data are also accepted.

Processed multibeam data shall be delivered in an MB-System processed format or another non-proprietary format. The majority of processed data in the multibeam bathymetry database are in MB-System, XYZ, or Generic Sensor Format (GSF) format.

NCEI prefers single beam data to be in M77T format. Other acceptable formats for data or navigation products include GeoJSON, GeoCSV, or American Standard Code for Information Interchange (ASCII) CSV/tab-Delimited (with format documentation).

NCEI ingests raw single beam data but requires associated navigation data in order for it to be discoverable via the Trackline Geophysical Data Viewer (NOAA NCEI, n.d. d.). Navigation information must either (1) be provided in a separate folder under the single beam folder structure, or (2) if multibeam bathymetry was collected during the cruise, the navigation data from the multibeam database may be used. If no navigation information is provided for raw single beam data, then the data will be archived but will remain undiscoverable through NCEI data discovery portals and only accessible upon request to trackline.info@noaa.gov.

If data are intended to be regularly submitted to the NCEI archive in support of the NOMECS Strategy, please email mb.info@noaa.gov to discuss setting up a data submission agreement.

For more detailed information, see the document “Submitting Marine Geophysical Data” (NOAA NGDC, n.d.).

1.6.2 Backscatter Data Management

Seafloor and lakebed backscatter are a measurement of the intensity of the sound echo generated by SSS, SBES, and MBES transducers that *reflect* from the targeted area of the seafloor or lakebed to the instrument’s receiver. This process is explained in detail in the *Backscatter Measurements by Seafloor-Mapping Sonar: Guidelines and Recommendations* report (Lurton and Lamarche, 2015), the definitive resource at this time for backscatter data acquisition and processing practices, and in [Chapter 3: Seafloor and Lakebed Backscatter](#). Use of backscatter data in the water column is discussed in [Chapter 4: Water Column Sonar](#).

Sonar instruments are typically used to acquire water depth measurements (i.e., bathymetry). However, they can also be calibrated to operate at frequencies optimal for recording backscatter or acoustic reflectivity data so that acoustic surveys can potentially yield information about bottom topography and composition contemporaneously.

Raw backscatter data files are processed to yield image mosaics of backscatter intensity indicating the seafloor or lakebed substrate’s composition and texture. These images can then be interpreted and used to map aquatic geological and biological characteristics and habitats, as well as cultural heritage sites (e.g., shipwrecks) and other anthropogenic features (e.g., debris, disposal sites).

However, when raw backscatter (as collected) data files are recorded in the instrument manufacturer’s proprietary file format, calibration settings may vary from survey to survey.

Different software, settings, and methods are also used during image processing and mosaic generation, resulting in non-standard data collection and product generation practices. Given the variability in instruments, settings, and processing used in surveys and interpretation, Lurton and Lamarche (2015) make the following overall recommendations for data preservation and documentation:

Data Format: preserve data in a "... format that allows [the user] to erase all previous corrections and to revert to the raw unprocessed signal... All processing steps should be described in this format." (p. 73)

Metadata Requirements: include settings and corrections applied to the raw data, the backscatter data values assigned by the instrument manufacturer, and details of processing steps used to derive products. (p. 73-74)

Interoperability and re-use of data: develop "... a nomenclature of processing levels of backscatter... [as] a means to better compare final processed products from various origins." (p. 172)

1.6.2.1 Minimum Requirements for Backscatter Data Stewardship and Discovery

At minimum, backscatter data must include:

Raw and/or processed data files.

Metadata (See [Chapter 1.4](#) for details on required metadata fields).

1.6.2.2 Guidance for Archiving Backscatter Data with NCEI

Backscatter data submissions to the NCEI archive should be made by emailing trackline.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

When backscatter data are to be submitted for archiving at NCEI, data providers should work with NCEI data managers to determine the best method for packaging data.

One option to assist in data packaging is CruisePack (NOAA NCEI, n.d. c.), a standalone executable, to package sonar and any ancillary data. CruisePack generates consistent and complete metadata to document the data collection process and ensures that data submitted to NCEI are in a standardized format for automated incorporation into the archive.

For more detailed information, see the document "Submitting Marine Geophysical Data" (NOAA NGDC, n.d.).

1.6.3 Water Column Sonar Data Management

Water column sonar measures acoustic reflectance from scatterers in the ensonified volume, typically using a single beam or multibeam configuration. These instruments are used routinely to map fish schools and other mid-water marine organisms, assess biological abundance, characterize habitat, and map underwater gas seeps.

Most single-beam systems designed for fishery research are calibrated for target strength (TS) with established calibration procedures. Multibeam systems run through a 'normalization'

process that can improve water column data (but they rarely receive full TS calibrations). In either case, the water column mapping range can extend from the transducer to the seafloor (if downward-looking) or to the water surface (if upward-looking); the range can also be limited within the water column by attenuation (related to operating parameters and water properties) and other effects, such as interference and synchronization.

The water column sonar raw (as collected) data files are recorded in the instrument's vendor-specific format. Common and historic file formats for single beam and multibeam, stationary and non-stationary water column sonar systems include, but are not limited to, .wcd, .raw., .ek5, .imb, .s7k, .01A, and .kmwcd.

The following subchapters identify information specific to all water column sonar data types that should be included in the metadata record.

1.6.3.1 Minimum Requirements for Water Column Sonar Data Stewardship and Discovery

Ensure navigation datagrams are included in the water column sonar files; if vessel-based.

Ensure time-synced position information is included as a separate document, if autonomous or not already embedded in the water column sonar files.

Include absorption coefficients and other relevant calibration information (TS calibrations performed before/after data acquisition, file applied during acquisition, etc.).

Other valuable data and metadata to include, if available:

- International Hydrographic Organization (IHO) sea area.
- Conductivity-temperature-depth (CTD) and underway Conductivity-Temperature-Depth (uCTD) profiles.
- Sound speed profiles.

1.6.3.2 Guidance for Archiving Water Column Sonar Data with NCEI

Water column sonar data submissions to the NCEI archive should be made by emailing wcd.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

Data providers must use CruisePack (NOAA NCEI, n.d. c.), a standalone executable to package sonar and any ancillary data, when water column sonar data are submitted to NCEI archiving. CruisePack generates consistent and complete metadata to document the data collection process and ensures that data submitted to NCEI are in a standardized format for automated incorporation into the archive. NCEI will mint a digital object identifier for the sonar instrument on that cruise to provide a permanent citation for the datasets and facilitate proper attribution to the original data provider.

To become a regular data provider to the NCEI archive in support of the NOME Strategy, please email wcd.info@noaa.gov to discuss setting up a data submission agreement.

- For more detailed information, see the “Submitting Marine Geophysical Data” document (NOAA NCEI, n.d. a.).

1.6.4 Side Scan Sonar Data Management

SSS collects a time series of backscatter, just like multibeam sonar does, except that there is no angular discrimination to the backscatter time series. This instrument is used to map seafloor geological and biological characteristics and habitats, as well as cultural heritage sites (e.g., shipwrecks) and other anthropogenic features (e.g., debris, disposal sites). SSS raw data (as collected) files are recorded in the instrument's vendor-specific format. Common file formats include, but are not limited to .xtf, .jsf., .hsx, and .gcf.

The following subchapters identify additional information specific to SSS data to include in the metadata record.

1.6.4.1 Minimum Requirements for Side Scan Sonar Data Stewardship and Discovery

At minimum, SSS data must include:

Raw and/or processed data files in JSF, HSX, or open-source format.

Required metadata (See [Chapter 1.4](#) for details on required metadata fields).

1.6.4.2 Guidance for Archiving with NCEI

SSS data submissions to the NCEI should be made by emailing trackline.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

When SSS data are to be submitted for archiving at NCEI, data providers will work with NCEI Data Managers to determine the best method for packaging data.

NCEI ingests SSS data but requires associated navigation in order for it to be discoverable via the Trackline Geophysical Data Viewer (NOAA NCEI, n.d. d.). Navigation information must either (1) be provided in a separate folder under the side scan folder structure, or (2) if multibeam bathymetry was collected during the cruise, the navigation data from the multibeam database may be used. If no navigation is provided for SSS data, then the data will be archived but will remain undiscoverable through NCEI data discovery portals and only accessible upon request to trackline.info@noaa.gov.

For more detailed information, see the document "Submitting Marine Geophysical Data" (NOAA NGDC, n.d.).

1.6.4.3 Side Scan Sonar Data Formats

The raw and processed side scan sonar data (i.e., mosaics) should be archived to ensure data preservation to the fullest extent (i.e., no information is lost).

- Storage of side scan sonar images and mosaics is preferred to allow for a more thorough examination of data.

1.6.5 Sub-Bottom Data Management

The sub-bottom profiling (SBP) chapter of the SOMP describes the SOPs single channel [seismic] acoustic systems operating within the 0.2 to 24 kHz frequency range. These systems image the

near-surface stratigraphy and seafloor morphology (<100 m) in marine, lacustrine, and fluvial environments. Sub-bottom data are generally collected for shallow geologic assessments and resource management.

Below are suggested SBP data management guidelines and specifications to be followed during data collection, processing, and archiving to ensure the data are transferable and perpetually accessible.

SBP raw data (as collected) are recorded in the instrument's vendor-specific format. Common file formats include .jsf, .keb, and .ses. The industry-standard for seismic data is the SEG-Y Data Exchange format, an open standard maintained by the Society of Exploration Geophysicists (SEG). The latest revision, SEG-Y 2.0 (Hagelund and Levin, 2017), was released in January 2017.

The following chapter identifies additional information specific to SBP data to be included in the metadata record.

- Convert proprietary formats recorded during acquisition to SEG-Y for archiving. Proprietary formats should be retained as well, assuming that these formats will not be accessible into perpetuity. SEG-Y files should be archived uncompressed, as compression algorithms may become unsupported over time.

- The 3200-byte textual file header should be encoded as EBCDIC or ASCII (UTF-8) character code and retain as much information as possible. At minimum, it should include SEG-Y revision level, date of acquisition, geographic location, line identification, signal sweep information, and recording format.

- The 400-byte binary file header should retain as much information as possible relevant to the SEG-Y file acquisition parameters; at minimum, it should include those fields designated as mandatory in the SEG-Y rev. 2.0 standard. It is highly recommended that additional information be retained, including sweep frequencies (start and stop in hertz [Hz]), sweep length in milliseconds (ms), sample interval (ms), and samples per trace to ensure adequate subsequent use of the data. If all traces in a data file are of equal length, set the fixed-length flag in the binary header to improve playback performance.

- The 240-byte trace header(s) should be populated using the SEG-Y standard. It is highly recommended that the source coordinates for each trace be included in the trace header, as well as recorded externally through the positioning device (e.g., GPS). When archiving positioning data, such as including an explicitly defined coordinate referencing system with the International Association of Oil and Gas Producers (IOGP) European Petroleum Survey Group (EPSG) Geodetic Parameter Dataset code (IOGP Geomatics Committee, n.d.), practice extreme care.

- Archive SEG-Y data with (1) minimal post-acquisition processing applied and (2) fully annotated data-file iterations with processing filters (e.g., automatic gain control [AGC], bandpass, etc.).

- Collect SBP files using the acquisition system-provided formats, even if they are proprietary file types.

Record swept-frequency data in both envelope and analytic (also known as full waveform) formats. Envelope data records are helpful in determining the “big picture”, while full-waveform records are helpful in investigating finer details.

Published SBP data should be archived and disseminated in SEG-Y format to facilitate accessibility and usability by the widest audience of users.

1.6.5.1 Minimum Requirements for Sub-Bottom Data Stewardship and Discovery

At minimum, SBP data must include:

Raw and/or processed data files in SEG-Y format.

Required metadata (See [Chapter 1.4](#) for details on required metadata fields).

1.6.5.2 Guidance for Archiving with NCEI

SBP data submissions to the NCEI should be made by emailing trackline.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

When SBP data are to be submitted for archiving at NCEI, data providers should work with NCEI Data Managers to determine the best method for packaging data.

NCEI encourages data providers to submit SBP data in SEG-Y format as NCEI relies on SEG-Y for extracting navigation necessary to generate track lines that display the location of the data in the Trackline Geophysical Data Viewer (NOAA NCEI, n.d. d.).

Data submitted in unsupported formats will still be accepted but will not be discoverable through the web services provided at NCEI. These data are accessed from the archive upon request to trackline.info@noaa.gov.

For more detailed information, see the document “Submitting Marine Geophysical Data” (NOAA NGDC, n.d.).

1.6.6 Magnetometry Data Management

A magnetometer is a passive instrument that detects variations in the Earth's magnetic field. This instrument has many applications, including structural geological mapping, energy and mineral exploration, archaeology, and munitions detection. Magnetic raw data (as collected) are time-series data. Common file formats include but are not limited to .csv and .txt. Present magnetic data in a format that can be imported and viewed in a GIS platform.

The following chapter identifies additional information specific to be included with magnetometer data.

1.6.6.1 Magnetometer Protocol (Data Standard)

For magnetometer time-series data to be useful and easily understood, consistency is important. Using the column headers as described in Table 1.2 will aid data collectors and users in ensuring the utility of data:

Table 1.2. Minimum magnetometer data file headers necessary for magnetometer data records.

Column Header	Example	Description
Latitude	42.123456	Towfish location when magnetic reading was recorded. Latitude expressed to six decimal places. Locations in the Northern Hemisphere expressed in positive numbers. ISO 6709
Longitude	-80.123456	Towfish location when magnetic reading was recorded. Longitude expressed to six decimal places. Locations west of the prime meridian expressed in negative numbers. ISO 6709
Date	2022-01-02	Date, in year-month-day, in UTC Time, when the magnetic reading was recorded. ISO 8601
Time	09:13:23.05	Time, as hh:mm:ss.ss, in UTC, when the magnetic reading was recorded. ISO 8601
Reading	420145.07	Raw magnetic reading for the magnetic sensor. Multiple sensors should have separate columns for each sensor. Multi-sensor data should indicate from which sensor the reading was derived.
Altitude/Depth	10.3/-20.5	Sensor altitude or depth in meters. If both values were recorded, separate into two columns. If multiple sensor data were recorded, include separate columns for each sensor.
Line	1	Survey dependent line name or number to denote all readings recorded sequentially on a particular line.

See [Appendix B](#) for detailed data standards and structure.

For effective processing, it is critical to capture time and date for correlation of the time-series data with other background field interference. Time and date should be recorded in two separate fields and use only UTC/date, not local time/date ([Appendix A](#)).

Other metadata are especially useful in processing and interpreting magnetic data. For example, in data collected by multiple instrument gradiometer arrays, noting which instrument collected which sample will allow for refinement of an anomaly's location in geographic space: the instrument with the higher variance from the background field was closer at that precise moment to the ferromagnetic material causing the anomaly.

1.6.6.2 Minimum Requirements for Magnetometer Data Stewardship and Discovery

At minimum, magnetometer data must include:

- Raw and/or processed data files.

- Required metadata (See [Chapter 1.4](#) for details on required metadata fields).

- Submissions should conform to NCEI guidance for archiving (See [Chapter 1.6.6.1](#)).

- Magnetometer data submissions to the NCEI should be made by emailing trackline.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

When submitting magnetometer data for archive at NCEI, data providers should work with NCEI Data Managers to determine the best method for packaging data.

For more detailed information, see the document “[Submitting Marine Geophysical Data](#)” (NOAA NGDC, n.d.).

1.6.7 Satellite-Derived Bathymetry (SDB) Data Management

Satellite-Derived Bathymetry (SDB) is the estimation of shallow water depths from active and passive satellite sensors. It can be referred to as Derived Bathymetry for non-satellite based applications, i.e. airborne. It allows users to obtain shallow water bathymetry data at a lower cost compared to hydrographic (or other) survey campaigns and can be used for areas that are physically inaccessible or difficult to survey by other means. This is of particular importance for areas that are dangerous or difficult to reach, or those that require frequent updates. It can be especially useful in uncharted waters to improve safety prior to acoustic surveys. ([IHO Satellite Derived Bathymetry Best Practices Guide B-13](#)).

The following chapter identifies additional information specific to be included with satellite-derived bathymetry data.

1.6.7.1 Minimum Requirements for SDB Data Stewardship and Discovery

At minimum, Satellite Derived Bathymetry (SDB) data must include:

SDB derived products such as grids, images, and other derived data products (e.g., .all, .s7k, .xse). Data files should be submitted using open source formats such as .GeoTIFF (preferred), .TIFF, .bag (bathymetric attributed grid), .NetCDF (binary grid), .asc (ESRI ASCII Raster grid), .xyz (lat/lon/depth), .pdf, or .jpeg.

Metadata should include required fields listed (B - K) in Table 1.1 in addition to those fields listed in Table [1.3](#) below.

Submissions should conform to NCEI guidance for archiving (See [Chapter 1.6.2.2](#)).

Table 1.3 Recommended “General Information” metadata for usability and archiving for Satellite Derived Bathymetry (SDB) data.

Information Field	Example Text	Description
Dataset Name	NMA202502	Typically, “Sea Area / Location and date,” survey cruise ID/name.
Dataset Source	NOAA	Source and credit organization of data being provided.
SDB Method	Spectral, Photogrammetric, or Wave Kinematics	Example text: Satellite mission (WorldView, Landsat, etc..) acquisition date, method used, software, processing steps.
Sensor	MS (multispectral), HS (hyperspectral), PAN (panchromatic), SAR (Synthetic Aperture	Information about instruments, platforms, operations and other information of data acquisition. How were these data collected? Description of the instrument(s), and sensor(s).

	Radar), Sat Video Imagery	Report data resolution if applicable to the data type. Vessel configuration, survey vessel dimensions (length, width, draft) and applied system offsets are critical and may or may not be documented in the raw data, depending on acquisition setup/software. What platforms were the instruments on? Ex: Geometrics G-882 Digital Cesium Marine Magnetometer
Product Resolution	1-100m	Grid size resolution of the product dataset
Depth Penetration	~1 Secchi Disk	

1.6.7.2 Guidance for Archiving with NCEI

SDB data submissions to the NCEI archive should be made by emailing mb.info@noaa.gov to alert a data manager of incoming data, set up the data submission, and/or ask any questions.

When SDB data are to be submitted for archiving at NCEI, data providers should work with NCEI data managers to determine the best method for packaging data.

If data are intended to be regularly submitted to the NCEI archive in support of the NOMECS Strategy, please email mb.info@noaa.gov to discuss setting up a data submission agreement.

1.7 References

- ESIP. 12 September 2017. "MD Metadata." http://wiki.esipfed.org/index.php/MD_Metadata
- GO FAIR. n.d. "FAIR Principles." www.go-fair.org/fair-principles/.
- NOAA IOOS. n.d. "Access IOOS Data." <https://ioos.noaa.gov/data/access-ioos-data/>
- NOAA NCEI. n.d. a. "Contributing Geological and Geophysical Data."
<https://www.ncei.noaa.gov/products/contribute-marine-geological-geophysical-data>
- NOAA NCEI. n.d. b. "Metadata." <https://www.ncei.noaa.gov/resources/metadata>.
- NOAA NGDC. 9 January 2020. "MI Metadata."
https://www.ngdc.noaa.gov/wiki/index.php/MI_Metadata.
- NOAA NODC. January 2012. "Part 2: Extensions for Imagery and Gridded Data. Workbook." *ISO 19115-2 Geographic Information—Metadata*.
https://www.ncei.noaa.gov/sites/default/files/2020-04/ISO%2019115-2%20Workbook_Part%20II%20Extentions%20for%20imagery%20and%20Gridded%20Data.pdf.
- OAIS Reference Model. n.d. "Home." <http://www.oais.info/>.
- USGS. 21 June 2021. "Metadata Creation." *Data Management*.
<https://www.usgs.gov/products/data-and-tools/data-management/metadata-creation>.

Bathymetry

- IHO. September 2022. "S-44 Edition 6.1.0." https://iho.int/uploads/user/pubs/standards/s-44/S-44_Edition_6.1.0.pdf.
- NOAA. 2024. *Hydrographic Surveys Specifications and Deliverables*.
https://nauticalcharts.noaa.gov/publications/documents/HSSD_2024-1-01.pdf.
- NOAA IOCM. n.d. "U.S. Bathymetry Coverage and Gap Analysis."
<https://iocm.noaa.gov/seabed-2030-bathymetry.html>.
- NOAA NCEI. n.d. c. "CruisePack." <https://www.ncei.noaa.gov/products/cruisepack>.
- NOAA NCEI. n.d. d. "Trackline Geophysical Data."
<https://www.ncei.noaa.gov/maps/geophysics/>.
- NOAA NGDC. n.d. "Submitting Marine Geophysical Data to the NOAA National Centers for Environmental Information & the Co-Located IHO Data Center for Digital Bathymetry."
<https://www.ngdc.noaa.gov/iho/SubmittingMarineGeophysicalData.pdf>.

Backscatter

- LaFrance Bartley, M., T. Curdts, and S. Stevens. 2019. *Procedures and Criteria for Evaluating Benthic Mapping Data: A Northeast Coastal and Barrier Network Methods Document*. Natural Resource Report NPS/NCBN/NRR—2019/2050. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/DownloadFile/633175>.
- Lurton, X., Lamarche, G. 2015. *Backscatter measurements by seafloor-mapping sonars. Guidelines and Recommendations*. <https://geohab.org/wp-content/uploads/2018/09/BWSG-REPORT-MAY2015.pdf>.
- NOAA NCEI. n.d. c. "CruisePack." <https://www.ncei.noaa.gov/products/cruisepack>.

NOAA NGDC. n.d. "Submitting Marine Geophysical Data to the NOAA National Centers for Environmental Information & the Co-Located IHO Data Center for Digital Bathymetry." <https://www.ngdc.noaa.gov/iho/SubmittingMarineGeophysicalData.pdf>.

Water Column Sonar

Demer, D.A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., et al. 2015. "Calibration of acoustic instruments." *ICES Cooperative Research Report No. 326*. <http://dx.doi.org/10.25607/OBP-185>.

ICES. 2016. "A metadata convention for processed acoustic data from active acoustic systems." *Series of ICES Survey Protocols SISP 4-TG-AcMeta*. <https://doi.org/10.17895/ices.pub.7434>.

NOAA NCEI. n.d. a. "Contributing Geological and Geophysical Data."

<https://www.ncei.noaa.gov/products/contribute-marine-geological-geophysical-data>.

NOAA NCEI. n.d. c. "CruisePack." <https://www.ncei.noaa.gov/products/cruisepack>.

Side Scan Sonar

LaFrance Bartley, M., T. Curdts, and S. Stevens. 2019. *Procedures and Criteria for Evaluating Benthic Mapping Data: A Northeast Coastal and Barrier Network Methods Document*. Natural Resource Report NPS/NCBN/NRR—2019/2050. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/DownloadFile/633175>.

Lurton, X., Lamarche, G. 2015. *Backscatter measurements by seafloor-mapping sonars. Guidelines and Recommendations*. <https://geohab.org/wp-content/uploads/2018/09/BWSG-REPORT-MAY2015.pdf>.

NOAA NCEI. n.d. d. "Trackline Geophysical Data."

<https://www.ncei.noaa.gov/maps/geophysics/>.

NOAA NGDC. n.d. "Submitting Marine Geophysical Data to the NOAA National Centers for Environmental Information & the Co-Located IHO Data Center for Digital Bathymetry." <https://www.ngdc.noaa.gov/iho/SubmittingMarineGeophysicalData.pdf>.

Sub-bottom

Hagelund, R., and Levin, S. (2017). SEG-Y_r2.0: SEG-Y Revision 2.0 Data Exchange Format. SEG Technical Standards Committee. https://seg.org/Portals/0/SEG/News%20and%20Resources/Technical%20Standards/seg_y_rev2_0-mar2017.pdf.

IOGP Geomatics Committee. n.d. "About the EPSG Dataset." *EPSG Dataset: v10.081*. <https://epsg.org/home.html>.

NOAA NCEI. n.d. d. "Trackline Geophysical Data."

<https://www.ncei.noaa.gov/maps/geophysics/>.

NOAA NGDC. n.d. "Submitting Marine Geophysical Data to the NOAA National Centers for Environmental Information & the Co-Located IHO Data Center for Digital Bathymetry." <https://www.ngdc.noaa.gov/iho/SubmittingMarineGeophysicalData.pdf>.

Magnetometer

Amasci Creative Limited. n.d. "Geophysical Metadata Log Template." Geomatrix Earth Science Limited. www.geomatrix.co.uk/tools/geophysical-metadata-log-template/.

- BOEM. 27 May 2020. *Guidelines for Providing Archaeological and Historic Property Information: Pursuant to 30 CFR Part 585*.
<https://www.boem.gov/sites/default/files/documents/about-boem/Archaeology%20and%20Historic%20Property%20Guidelines.pdf>.
- INCITS. No date. "Geographic Information - Temporal Schema."
<https://webstore.ansi.org/Standards/INCITS/INCITSISO191082002R2013>.
- INCITS. No date. "Geographic Information - Observations And Measurements."
<https://webstore.ansi.org/Standards/INCITS/INCITSISO1915620112012>.
- NOAA NGDC. n.d. "Submitting Marine Geophysical Data to the NOAA National Centers for Environmental Information & the Co-Located IHO Data Center for Digital Bathymetry."
<https://www.ngdc.noaa.gov/iho/SubmittingMarineGeophysicalData.pdf>.
- Ponce, D.A., Denton, K.M., and J.T. Watt. 2016. *Marine magnetic survey and onshore gravity and magnetic survey, San Pablo Bay, northern California*. U.S. Geological Survey Open-File Report. <http://dx.doi.org/10.3133/ofr20161150>.
- Reay, S., D.C. Herzog, S. Alex, E.P. Kharin, S. McLean, M. Nosé, and N.A. Sergeyeva. 2010. "Magnetic Observatory Data and Metadata: Types and Availability." In *Geomagnetic Observations and Models*, edited by M. Mandea and M. Korte. IAGA Special Sopron Book Series, vol 5. Dordrecht: Springer. https://link.springer.com/chapter/10.1007/978-90-481-9858-0_7.
- U.S. Department of the Navy. n.d. "Naval History and Heritage Command Methods and Guidelines for Conducting Underwater Archaeological Fieldwork."
<https://www.history.navy.mil/research/underwater-archaeology/sites-and-projects/Guidelines.html>.
- U.S. Geological Service. 2010. "Open-File Report 2009-1100, Version 1.1: Metadata."
<pubs.usgs.gov/of/2009/1100/metadata.html>.

Satellite-Derived Bathymetry

- International Hydrographic Organization (IHO). *Satellite-Derived Bathymetry Best Practice Guide (B-13)*, Ed. 1.0.0 (March 2024),
https://iho.int/uploads/user/pubs/bathy/B_13_Ed100_032024.pdf.

Chapter 2: Bathymetry – DRAFT VERSION SDB ADDENDUM

2.1 Introduction

The SOMP bathymetry guidelines aim to provide a standard set of requirements to ensure that all seafloor mapping efforts advance the National Strategy to Map, Explore, and Characterize the U.S. EEZ (NOMECC, 2020). This chapter provides overarching guidance and recommendations for collecting, processing, and delivering bathymetric data acquired by multibeam, single beam, phase-discriminating sonar, lidar systems, and satellite derived bathymetry (SDB). It summarizes best practices for reporting positioning, system calibration and QA/QC techniques, coverage and resolution, uncertainty, tides and water levels, and general gridded data specifications. Various references were consulted for source material, including IHO S-44 (2022), the NOAA Office of Exploration and Research (OER) Deepwater Exploration Mapping Procedures Manual (NOAA OE, 2020), the NOAA Office of Coast Survey (OCS) Specifications and Deliverables (NOAA OCS, 2024, 2025), Australian Multibeam Guidelines (Picard et al., 2018), Norwegian Mapping Authority Hydrographic Service (NMAHS) (MAREANO Programme, 2017) and the IHO Guidance to Satellite Derived Bathymetry (B-13 “Satellite-Derived Bathymetry Best Practice Guide”) as well as Theoretical Basis Documents for satellite lidar bathymetry (NASA 2024, 2025) . This chapter does not address manufacturer-specific recommendations or recommendations about specific use cases.

2.2 Overview

Bathymetry is the science of measuring the depth of water in ocean, river and lake environments. Bathymetric maps, which illustrate land features underwater, are the fundamental first step in ocean mapping, exploration, and characterization operations. The applications of bathymetry are vast and include the study of underwater hazards like landslides and faults as well as important seafloor habitats like steep-sided trenches, canyons and seamounts, and channels cutting through abyssal plains. Bathymetric data are the backbone of nautical charts for the safety of surface navigation and subsurface vessels as well as for general reconnaissance, coastal research, adaptive planning and sustainable sharing of coastal resources, including benthic habitat and fishing rights. It also plays essential roles in the delineation of international maritime boundaries, management of sediments for navigation, flood risk management, environmental stewardship, identification of offshore resources such as gas and oil reserves, tsunami inundation and storm surge modeling, and the safe planning and maintenance of submarine communication cables that transmit the vast majority of information around the globe.

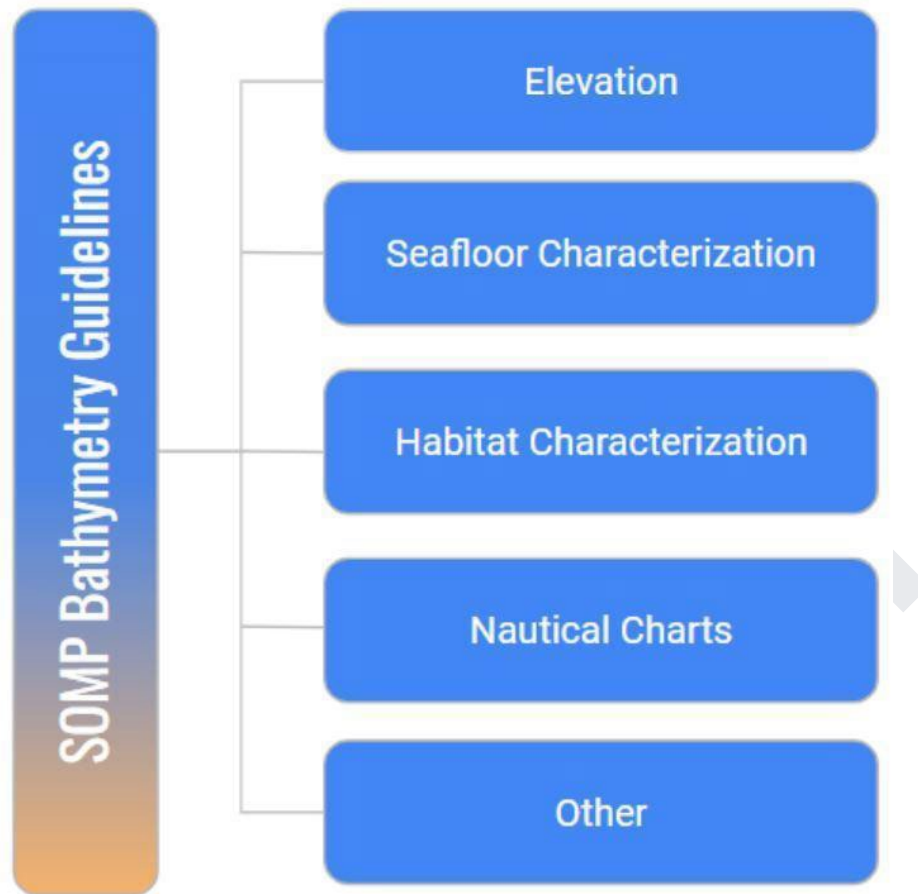


Figure 2.1. SOMP bathymetry guidelines chart: bathymetry guidelines cover elevation, seafloor characterization, habitat characterization, nautical charts, and other topics.

Bathymetric data throughout the vast oceans and coastal regions are mainly collected using multibeam, single beam, split-beam, and interferometric systems while lidar systems (airborne and satellite) and satellite multispectral imagery are effective in the shallow near-shore coastal zones.

Different sonar frequencies of bathymetric systems are optimal for different depths:

- Lower-frequency systems (~12 kHz) achieve efficient mapping coverage at full ocean depths, including the deepest parts of the ocean trenches;
- Mid-range frequency systems (~30 kHz) efficiently target water depths from 200–6000 m;
- High-frequency systems (~100–700 kHz) are most useful for depths less than 200 m; and

Lidar bathymetry is appropriate in relatively clear water for depths up to 70 m with the best possible system of optical depth capacity of 4.0. Actual depth performance is dependent on water clarity and design of the bathymetric lidar system.

For this chapter, technical terms will follow the definitions in the IHO Hydrographic Dictionary (Hydrographic Dictionary Working Group, 2019).

Satellite-Derived Bathymetry (SDB) is the estimation of shallow water depths from active and passive satellite sensors. It can be referred to as Derived Bathymetry for non-satellite based applications, i.e. airborne. Derived bathymetry's primary difference from the traditional survey techniques is the fact that the depths are estimated, not measured. It allows users to obtain shallow water bathymetry data at a lower cost compared to hydrographic (or other) survey campaigns and can be used for areas that are physically inaccessible or difficult to survey by other means. This is of particular importance for areas that are dangerous or difficult to reach, or those that require frequent updates. It can be especially useful in uncharted waters to improve safety prior to acoustic surveys. (IHO).

Another emerging category of approach involves use of machine learning (ML) algorithms. As more research becomes available this section will evolve.

2.3 Bathymetric Data Sources

The IHO Hydrographic Dictionary (document S-32) and the IHO SDB Best Practices Guide B-13 provide authoritative definitions for the following bathymetric data sources covered in the Bathymetry Chapter of the SOMP: SBES, MBES, Interferometric Sonar, lidar systems (airborne and satellite) and SDB.

2.3.1 Single Beam Echosounder (SBES)

SBESs transmit and receive a sound pulse within a single, narrow, and (generally) downward looking field of view to provide one bottom detection per ping cycle.

The types of SBES used vary across Federal agencies. Most mapping and surveying grade systems are dual-frequency, using both a high and a low frequency with beamwidths between 3–8 degrees for high frequency and 20–30 degrees for low frequency. Provided the magnitude of vessel roll and pitch is less than half of the sonar beamwidth, and the total heave is less than 0.5 m, these attitude characteristics will have little effect on sounding accuracy. If the system is not equipped with an attitude sensor to correct data for vessel motion, SBES should not be used when vessel roll and pitch angles exceed sonar beam width or total heave exceeds 0.5 m.

Most SBES systems output calculated depth values rather than the two-way travel time of each sonar ping, which requires configuration with a value for the speed of sound through the water column. It is recommended that field units configure SBES systems using a standard estimate for their given operating area, which must be preserved in the vessel configuration file of the metadata (e.g., 1500 m/s for the speed of sound in seawater). SBES data should then be corrected using full sound speed profiles acquired during the survey in post-processing.

2.3.2 Multibeam Echosounder (MBES)

MBES is a swath-sounding system in which the equipment emits a timed pulse of sound that is narrow in the fore-aft direction and wide in the across-track direction. The reflected sound is detected by several receivers arranged as an array; signal processing algorithms are used for subsequent beamforming.

For each received beam, the time interval between transmission and reception of the reflected sound is converted into a range using a measured or predicted sound speed profile. System geometry, navigation, attitude data, and corrections for sound refraction are then used to convert each range and received beam angle into positions and depths on the seafloor.

2.3.3 Interferometric Sonar

Interferometric sonar is a swath-sounding system in which the equipment emits a timed pulse of sound that is narrow in the fore-aft direction and wide in the across-track direction, typically with one beam projected to each side of the sonar. The system rapidly samples the reflected sound following each emission. For each sample, the phase difference of the reflected sound arriving at two (or more) receivers located a known distance apart is measured and used to compute the acoustic angle of arrival. Also, the time difference between the emission and reception for each sample is converted to a range using a measured or predicted sound speed profile. System geometry, navigation, attitude data, and corrections for sound refraction are then used to convert each range and angle pair to positions and depths on the seafloor.

2.3.4 Airborne Lidar

Airborne lidars can be used to measure the depths of moderately clear, nearshore coastal waters, lakes, and rivers from a low-altitude aircraft using scanning, pulsed green laser beam.

The lasers used in bathymetric lidar are nearly always green (typically, 532 nm), since the near infrared lasers that are widely used in topographic-only lidar systems do not work for bathymetric mapping. The round-trip time-of-flight of photons emitted from each laser pulse to the water surface and seafloor is measured by receivers in the aircraft, with corrections made for atmosphere and water column refraction. With this information and the speed of light in air and water, accurate water depth can be calculated (Irish and Lillycrop, 1999).

Airborne Topo-bathy lidar systems seamlessly collect land elevation data near the shore, across the land-water interface, and into the water as deep as 70 m. The primary limitations on depth performance are airborne lidar system specifications and water clarity. Breaking waves that create white water and entrain sediment in the water column, turbidity plumes, kelp, and dark substrate may inhibit continuous data coverage.

2.3.5 Satellite lidar

Satellite based lidars can be used to measure the depths of optically clear, nearshore coastal waters, lakes, and rivers from an Advanced Topographic Laser Altimeter System (ATLAS) photon-counting lidar.

As with airborne lasers, the satellite lidar discussed here, NASA's Ice, Cloud, and Land Elevation Satellite (ICESat-2), also uses a 532nm green laser to calculate accurate water depth (NASA ICESat-2 Algorithm Theoretical Basis Documents, ATL13, ATL24).

The ATLAS sensor suite has a single laser which is passed through a diffractive beam splitter into 6 component beams (3 strong / 3 weak) that trace six ground tracks with a repeat revisit time of 91 days in polar regions and non-repeat elsewhere. Each strong/weak beam pair is approximately 90 m apart, with ~ 3 km distance between pairs.

Currently there are three ICESat-2 bathymetric products: 1) [SCuBA](#) 2019-2024 (developed by NGA, Walker et al 2020, Ouellette et al 2023), 2) ICESat-2 ATL24 (funded by NASA and developed by Magruder, L. A. and Parrish, C. E., 2022), and 3) ICESat-2 ATL13 (developed by NASA, Jasinski et al, 2025). Walker, M., Magruder, L., Neuenschwander, A. and Klotz, B., 2020. Satellite Computed Bathymetry Assessment-SCuBA. *AGU Fall Meeting Abstracts, 2020*, C030-0020.

2.3.6 Satellite-Derived Bathymetry (SDB)

Bathymetry, derived from satellite-based sensors employing Electro-optical* and Synthetic Aperture Radar (SAR) techniques is broadly referred to as SDB. Most optical approaches require receiving a detectable response from the seafloor in the imagery, which limits their application to relatively clear, shallow areas. In very clear waters, the achievable depth limit may be down to approximately 30 m. Imagery requirements vary by technique but typically include restricting the presence of clouds and cloud shadows, as well as ice, sun glint, haze, and breaking waves. One common type of SDB approach uses the physics of light attenuation through logarithms or ratios of logarithms of reflectance in multiple spectral bands or an optimization solution to several equations. Another category of approach involves stereo photogrammetry and relies on the ability to match seafloor features across multiple, overlapping images. Yet another type of approach is referred to as wave kinematics bathymetry. Unlike the other SDB categories listed above, the wave kinematics approach does not require that the seafloor be visible in the imagery. SAR based approaches require analysis of surface wave heights impacted by water depth, and/or the gravity gradients of undulating bottom topography, although spatial resolution is high.

*Please note that for the purposes of this document, we are using "electro-optical" in place of "electromagnetic radiation energy" (as used in the IHO SDB Best Practices document) to describe SDB techniques.

2.4 General Protocols

2.4.1 Data Management

Management of bathymetric data is necessary for efficient use, future access, and validation of analytical and interpretative results. Raw and processed data should be archived to ensure data are preserved to the fullest extent.

See [Chapter 1.6.1.1](#) for minimum bathymetric data requirements and management (e.g., recommended file formats, metadata, data archiving). See Chapter 2.7 for protocols relating to SDB.

2.4.1.1 Raw Data Acquisition

The following information should be associated with raw data (as collected):

- Sonar settings:
 - o Operational frequency (report both frequencies if dual-frequency system)
 - o Ping rate
 - o Swath range
 - o Gains or corrections (e.g., time varied gain [TVG])
- Attitude and positioning:
 - o Specifications of the navigation system(s)
 - o Accuracy
- Spatial reference of raw data (and navigation system, if different):
 - o Coordinate system and horizontal datum

2.4.2 Sensor Installation Surveys

Surveying and documenting the alignment of mapping sensors is fundamental for establishing and maintaining high data quality. Sonar and lidar installations must be surveyed to establish the linear and angular offsets between sonar arrays or lidar sensor reference points, GPS/GNSS antennas, and motion sensors within a uniform mapping reference frame (typically oriented with the vessel, vehicle, or sensor platform). Such surveys are conducted initially during the installation process and when any of the equipment has changed or is suspected of having changed (e.g., after dry dock or removal for factory calibration). It is crucial that sensor installation surveys are conducted with a high degree of precision and accuracy and are reported in a clear and standardized way that directly supports correct sensor configuration. The Multibeam Advisory Committee (MAC) Recommendations provide best practices for Reporting Vessel Geometry and MBES System Offsets in a template (MAC, 2021).

At a minimum, vessel configuration and offset information should be presented as a text file (e.g., ASCII) or spreadsheet (e.g., .csv, .xlsx) AND a schematic file (e.g., .jpg, .bmp, .tiff). The files should contain details of survey vessel dimensions (length, width, draft) and offsets of survey instruments. Provide multiple files if using more than one vessel or configuration.

2.4.3 Positioning

Positioning is the fundamental framework and starting point for every mapping operation. The position of any point is referenced using either geodetic coordinates defined by latitude, longitude, and ellipsoid height or Cartesian coordinates (x, y, z). The coordinate system should be specified in metadata and documentation describing the survey.

Positions should reference a geodetic reference frame, which can be either a global (e.g., International Terrestrial Reference System [ITRS], WGS84) or a regional (e.g., ETRS89, NAD83) reference system.

Coordinates calculated through GNSS and the GPS contain inherent errors from signal transmission delays due to the atmosphere and must be corrected during bathymetric surveys by applying differential GPS (DGPS) correctors. Several manufacturers provide these data via subscription to DGPS receivers used in the offshore environment. Once the corrections are applied, inherent errors should be reduced to the sub-decimeter level.

The navigation system should continuously determine the position of the survey platform. Uncertainty of the navigation system and QC methods should conform to the requirements defined by the IHO (IHO, 2022). Position fixes should be digitally logged continuously along the platform track. Geodesy information should be present and consistent.

2.4.3.1 Geodetic Control

Horizontal control generally refers to the terrestrial network of geodetic marks that support two dimensional mapping positioning and how field units position mapping data relative to a datum. Vertical control activities are conducted to support water level gauge installations, water level measurements, Ellipsoidally Referenced Survey (ERS), and vertical accuracy validation.

Positions should reference a geodetic reference frame, either global (e.g., ITRS, WGS84) or regional (e.g., ETRS89, NAD83). With frequent updates to geodetic reference systems, the epoch for surveys with low positioning uncertainty should be recorded. If horizontal positions reference a local horizontal datum, the name and epoch of the datum should be specified and tied to a realization of the ITRS or equivalent global geodetic reference frame (e.g., ITRS, WGS84, ETRS89, April 2024 47 NAD83 realizations). The transformations between reference frames/epochs, especially for surveys with low uncertainty, should be considered.

2.4.3.2 Ellipsoidally Referenced Survey (ERS) Control

ERS is possible through GNSS-based sub-decimeter vertical control using a method of integer ambiguity resolution-enabled carrier-phase kinematic positioning. Differential and related carrier-phase methods based upon precise point positioning (PPP) kinematic GNSS methods are permitted from a real-time kinematic (RTK) service or via post-processing. Post-processed vertical control has the advantage of enhanced QC: quasi-independent forward- and reverse time processing reduces the uncertainty in the vessel height solution otherwise present in RTK based (forward-only) positioning.

The use of GPS over other GNSS (e.g., GLONASS) is preferred; however, if the availability of five or more GPS satellites is infrequent in a particular survey environment, a hybrid GPS-GNSS solution may be used. Inertially-aided systems help to ensure success in ERS regardless of the GNSS technique utilized; tightly-coupled inertial-aided GNSS is vital to overcome positioning problems associated with intermittent loss of individual satellite signals.

2.4.3.3 Tools

Software tools like Vertical Datum Transformation (VDatum; under development by NOAA's National Ocean Service [NOS]) convert elevation data from various sources into a standard reference system.

A standard reference system is vital because irregularities can occur when data products are created from different data sources. The capability of programs such as VDatum to transform and fuse various elevation data benefits coastal applications, including inundation modeling (e.g., storm surge, tsunami, sea level rise impacts), ecosystem management and coastal planning, hydrographic surveying, and ocean mapping using Kinematic GPS for vertical referencing, and shoreline delineation from lidar data.

VDatum coverage is accessible to the public and complete in all coastal regions of the continental United States (including the Great Lakes), Puerto Rico, and the U.S. Virgin Islands. In 2019 a Southeast Alaska regional model was added, and coverage will be developed for Hawaii, Alaska, and the Pacific U.S. territories once foundational geodetic and tidal data are established to allow for valid model construction.

In addition, current models are being revisited to include additional foundational geodetic and tidal data that will assist in improving transformational components of the VDatum models, assist refining and validating the uncertainty associated with models, and support a broader range of applications. The goal is to develop a VDatum utility throughout the country that will foster more effective sharing of elevation data and, eventually, link such data through national databases. VDatum is available online (NOAA, n.d. a.) as an application programming interface (API) (NOAA, n.d. b.) and as downloadable software (NOAA, n.d. c.).

2.4.5 Resolution and Coverage Types

The following coverage and resolution recommendations are not intended to interfere with or supersede mission-specific requirements.

Bathymetric coverage is the mapped spatial extent of depth measurement based on the combination of the survey pattern and the area of detection of the bathymetric data source.

The NOME Council recognizes the IHO as a leading industry source and authoritative subject matter expert for bathymetry (IHO, 2022). The IHO is an intergovernmental organization that works to ensure all the world's seas, oceans, and navigable waters are surveyed and charted. The IHO coordinates national hydrographic offices' activities and sets standards to promote uniformity in nautical charts and documents. It issues survey best practices and provides guidelines to maximize the use of hydrographic information.

The SOMP identifies the *IHO Standards for Hydrographic Surveys, S-44* 6th Edition as the leading source of standards and recommendations for hydrographic surveying and ocean mapping bathymetric data standards. This publication specifies minimum standards according to the intended use and encourages the use of IHO S-44 for purposes beyond the safety of navigation. It introduces the concept of a Specification Matrix in Chapter 7.5 of parameters and data types designed to cater to a range of needs (IHO, 2022).

Minimum bathymetry standards and feature detection requirements are defined in [IHO S-44 Table 1 \(IHO, 2022\)](#).

IHO S-44's Specification Matrix Chapter 7.6 provides a range of selectable criteria for bathymetric parameters and other data types collected (IHO, 2022). It allows flexibility and accommodation of new and emerging technologies and inclusion of hydrographic surveys conducted for purposes other than safety of navigation.

The following bathymetric data coverage types are recommended as minimum coverage standards: Complete or 100% Coverage, Set Line Spacing, and Trackline (transit and reconnaissance).

2.4.5.1 Complete or 100% Coverage

Complete or 100% Coverage: 100% bathymetric coverage implies that depth measurements are mapped to the horizontal and vertical standards specified in IHO S-44 Table 1, such that they provide a depiction of the vast majority of the bottom and can be considered as "full" bathymetric coverage (IHO, 2022).

Bathymetric coverage of less than 100% should follow a systematic survey pattern to maximize even distribution across the survey area. Additionally, the nature of the bottom (e.g., roughness, type) and the requirements for safety of surface navigation in the area must be taken into

account early and often to determine whether bathymetric coverage should increase to meet the Complete Coverage requirements in the area.

2.4.5.2 Set Line Spacing

Set Line Spacing is recommended when acquiring bathymetric data in areas too shallow for efficient full-bottom coverage bathymetry and can be accomplished with single beam, multibeam, or lidar. Set line spacing can be used as verification lines to identify areas of change; or in conjunction with remote sensing data like satellite derived bathymetry to provide a general understanding of the bathymetric contours of the area.

Nearshore environments are inherently dangerous, and the safety of personnel and equipment shall always be the primary objective and consideration when conducting shallow water operations. Field operations should not be attempted unless conditions are favorable.

2.4.5.3 Trackline Data Coverage/Transit Data

While the platform is transiting, sonar data, including multibeam data, should be collected to maximize total geographic coverage and contribute to the goals of the NOMECS Strategy. The sonar data collection principles described in this chapter should be utilized during transit data collection.

When real time sound speed data collection is not possible, Sound Speed Manager, (freeware created and maintained by NOAA and the University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center) can be used to extract sound speed profiles from the World Ocean Atlas (and other sources), and send them automatically to the multibeam acquisition system to provide an approximate reference.

2.4.5.4 Crosslines

Crosslines are used to confirm internal consistency between survey lines and should be run orthogonally to the main scheme lines of a survey. Where practicable, conduct a crossline in each focused survey area; however, this may not be possible depending on the overall cruise or survey goals. At a minimum, one crossline per cruise should be conducted and should cross roughly the full range of depths found in the focus survey areas. If possible, the cross line should be run early in the survey to identify (and resolve) potential problems sooner rather than later. For lidar, fly crosslines for flight blocks that take longer than a day. Many software packages that process bathymetric data offer a crossline analysis tool and report sounding comparisons to the 95% confidence level for each IHO order specification.

2.4.5.5 Tides and Water Levels

Current and tidal information is essential for planning and performing coastal mapping operations where tidal levels may be tightly linked to positioning and the mapping system data

quality. However, observing current and tidal levels is considered an integral part of coastal mapping operations when conducting bathymetric data acquisition operations in waters shallower than 200 meters or as specified as a project requirement.

For deeper water surveys (>200 m), the tidal range is generally a small percentage of water depth; it is therefore considered negligible and the application of tidal correctors is optional. Document the application or non-application of tides in the survey/dataset documentation with the vertical datum specified as Mean Sea Level (MSL).

Tidal data may be required for analysis for the future prediction of tidal heights and the production of Tide Tables, in which case observations should cover as long a period as possible and preferably not less than 30 days. Whenever surveyed/predicted tides or water levels are used to reduce soundings to a datum, TVU calculations should incorporate the uncertainty of these time series. In most circumstances, observed values are preferred over predicted.

If wave or water clarity conditions prohibit seamless data collection across the land/water interface, collect topo-bathy lidar near low tide. Water clarity and wave conditions may change with tide level, so data may be collected at both high and low tide to achieve seamless data across the land/water interface.

Detailed guidance and recommendations for time series water level data and associated water level reducers that can be applied to bathymetric soundings for correction to chart datum can be found in the following reference documents: [NOAA Hydrographic Survey Specifications and Deliverables \(NOAA OCS, 2022\)](#); [NOAA Field Procedures Manual \(NOAA OCS, 2021\)](#); [International Hydrographic Organization \(IHO S-44 Edition 6.1.0\)](#).

2.4.5.6 Uncertainty Standards

Precise and accurate measurements are fundamental for quality bathymetric data. Synchronization of multiple sensors with the sonar system is essential for meaningful spatial data analysis. All measurements, however careful and scientific, are subject to some uncertainties. Uncertainty analysis of the survey systems and data must be conducted to meet accuracy and resolution standards and requirements. Position uncertainties must be expressed at the 95% confidence level and should be recorded together with the survey data.

The capability of the mapping system should be demonstrated by a total propagated uncertainty (TPU) calculation which may be separated into total horizontal uncertainty (THU) and total vertical uncertainty (TVU) components.

The SOMP recommendations for Uncertainty Standards are based on the IHO Standards for Hydrographic Surveys as outlined in Special Publication 44 (S-44), 6th Edition, which provides suggested minimum standards to follow. Uncertainty standards and methods should conform to the requirements as defined by the IHO (IHO, 2022).

2.5 Multibeam Protocols

2.5.1 Sensor Installation Surveys

Surveying and documenting the alignment of mapping sensors is fundamental for establishing and maintaining high data quality. Sonar and lidar installations must be surveyed to establish the linear and angular offsets between sonar arrays or lidar sensor reference points, GPS/GNSS antennas, and motion sensors within a uniform mapping reference frame (typically oriented with the vessel, vehicle, or sensor platform). Such surveys are conducted initially during the installation process and when any of the equipment has changed or is suspected of having changed (e.g., after dry dock or removal for factory calibration). It is crucial that sensor installation surveys are conducted with a high degree of precision and accuracy and are reported in a clear and standardized way that directly supports correct sensor configuration. The Multibeam Advisory Committee (MAC) Recommendations provide best practices for Reporting Vessel Geometry and MBES System Offsets in a template (MAC, 2021).

At a minimum, vessel configuration and offset information should be presented as a text file (e.g., ASCII) or spreadsheet (e.g., .csv, .xlsx) AND a schematic file (e.g., .jpg, .bmp, .tiff). The files should contain details of survey vessel dimensions (length, width, draft) and offsets of survey instruments. Provide multiple files if using more than one vessel or configuration.

2.5.1.1 Raw Data Acquisition

The following information should be associated with raw data (as collected):

- Sonar settings:
 - Operational frequency (report both frequencies if dual-frequency system)
 - Ping rate
 - Swath range
 - Gains or corrections (e.g., time varied gain [TVG])
- Attitude and positioning:
 - Specifications of the navigation system(s)
 - Accuracy
- Spatial reference of raw data (and navigation system, if different):
 - Coordinate system and horizontal datum

2.5.2 System Geometry Review

Periodic reviews of the vessel/vehicle's sensor offset survey against the navigation/attitude and multibeam sensor configurations will ensure that all fields are interpreted correctly. Periodic review will catch unintended modifications introduced, for example, during software upgrades or by new users who may change installation parameters. If changes are found, assess recent

data (since the last system geometry review) to identify when and why the change was made and determine whether data collected with the changed parameters need to be flagged or modified April 2024 51 for downstream users. For example, incorrectly interpreted or modified waterline configuration leads to a bulk offset in bathymetry that must be documented (and corrected prior to further data collection).

2.5.2 Multibeam System Calibrations and Health Checks

To maintain maximum productivity and accuracy of data, the following system calibrations and health checks are recommended.

2.5.2.1 Inertial Motion Sensor Calibration

Following the manufacturer's service schedule is best practice to maintain up-to-date factory calibrations for the inertial motion sensor. For inertial motion systems providing GNSS-aided heading, an antenna baseline calibration should be conducted at least once annually, following any significant repair periods, or if a heading misalignment is suspected. Note any such calibrations in all documentation or metadata associated with the bathymetric dataset.

2.5.2.2 Multibeam Calibration Patch Test

Conduct a patch test at least once a year to resolve any angular misalignments of the multibeam or ancillary equipment (e.g., transducers, inertial motion sensor, antennas) or if any equipment is changed or disturbed. The patch test determines if there are any residual biases or errors in navigation timing, pitch, roll, and heading/yaw and resolves each bias individually in that order. The results of each test should be applied in the sonar acquisition software before data collection for the following test and should be documented in metadata.

Apply the results of the geometric calibration to the motion sensor installation angles configured in the data acquisition software. This approach is recommended for several reasons:

- The motion sensor typically has greater installation angle uncertainty than the transmit antenna (TX) and receive antenna (RX) arrays due to the relatively short baselines on the housing.
- The TX and RX array installation angle uncertainties are typically very low owing to the leveling processes carried out during installation and the long survey baselines (in the case of low-frequency, hull-mounted arrays).
- And perhaps most importantly, small installation biases cannot be determined independently for the TX or RX arrays from the calibration data.

While the motion sensor software is configured with motion sensor installation angles directly from the vessel survey, the multibeam calibration results are applied to the motion sensor installation angles within the multibeam acquisition software because they reflect the combined impact of these biases only on the multibeam data and not any other sensors on board.

If calibration results indicate a residual bias greater than 0.1 degree, conduct another calibration to verify the new angular offset values. Conduct the second calibration with the initial results applied in the acquisition software, using an iterative process to fine-tune and verify the installation angles. The accuracy of the results depends on the bathymetric features of the calibration area and the oceanographic conditions. Therefore, it is best to choose calibration areas where sound speed conditions are relatively stable, and sea states are mild throughout the tests. Although unlikely, if a new inertial motion system calibration (e.g., factory inertial measurement unit (IMU) calibration or antenna baseline calibration) during the field season results in new offsets, then it is recommended that a new patch test also be conducted to account for the new motion sensor configuration and performance.

If the angular offsets are applied in the multibeam acquisition software and accounted for during data acquisition, do not reapply them later in multibeam cleaning/processing software.

Any defined feature can be used for a patch test; a well-defined slope at approximately 10 to 20% or more grade will provide the best results. Wrecks can be used; however, it is recommended that the wreck be well defined to remove any ambiguity when processing the calibration data. Features in debris fields or other cluttered areas should be avoided because of likely ambiguity.

Navigation timing error and pitch tests can cover a wide range of depths, as long as swath coverage extends to at least ~45 degrees in the direction of overlapping coverage (the 'corridor' for assessing the alignment of soundings). Run the lines at different speeds, varying up to 5 knots, to delineate the along-track profiles when assessing time delay. Navigation timing error bias could also be determined from running lines over a distinct feature (i.e., shoal) on the bottom, as long as the feature is ensonified by the vertical (nadir) beam.

Conduct roll tests in depths where the multibeam can achieve full angular swath width (i.e., before 'roll-off' of the coverage-versus-depth curve) to accentuate the outer swath differences resulting from roll biases.

Determine heading (yaw) bias from two or more adjacent pairs of reciprocal survey lines, made on each side of a submerged object or feature (i.e., shoal), in relatively shallow water. Avoid features with sharp edges. Overlap adjacent swaths by 10–20% while covering the shoal and run lines at a speed to ensure significant forward overlap.

Conduct system accuracy testing in an area similar in bottom profile and composition to the survey area and during relatively calm seas to limit excessive motion and ensure suitable bottom detection.

Example patch test procedure for each line set is shown in [Figures 2.2, 2.3, and 2.4](#).

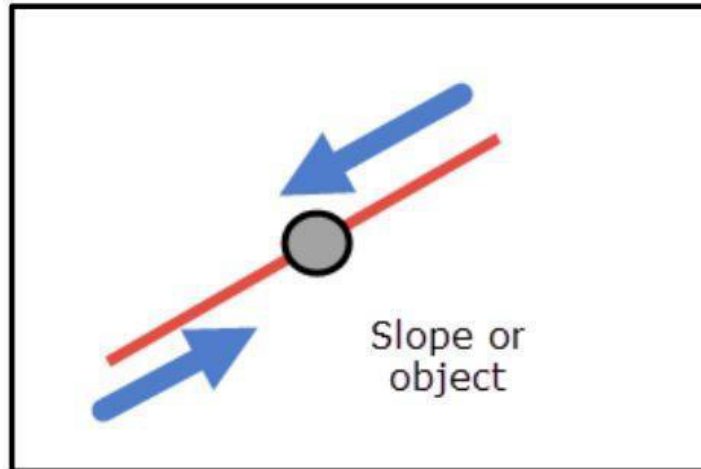


Figure 2.2. Pitch: run one line twice in opposite directions at the same speed over a steep, well-defined slope. Compare the nadir profiles of the swaths.

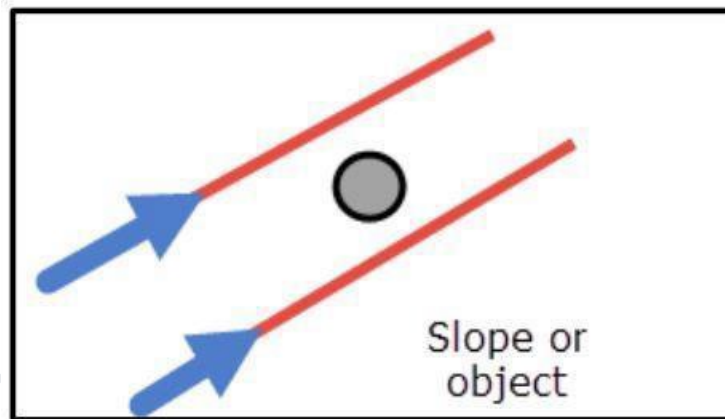


Figure 2.3. Heading/yaw: run two offset lines in the same direction and speed over a steep, well-defined slope, with the outer third of the two swaths overlapping. Compare the along-track profile midway between the two lines.

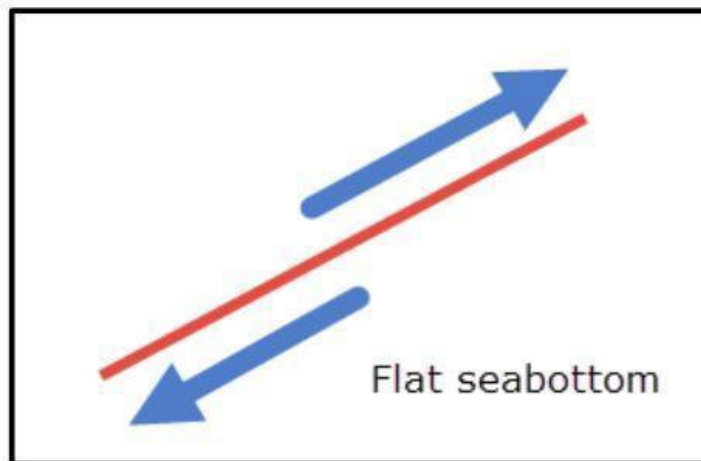


Figure 2.4. Roll: run the same line twice in opposite directions at the same speed over a flat seafloor area. Compare the across-track profiles of the swaths.

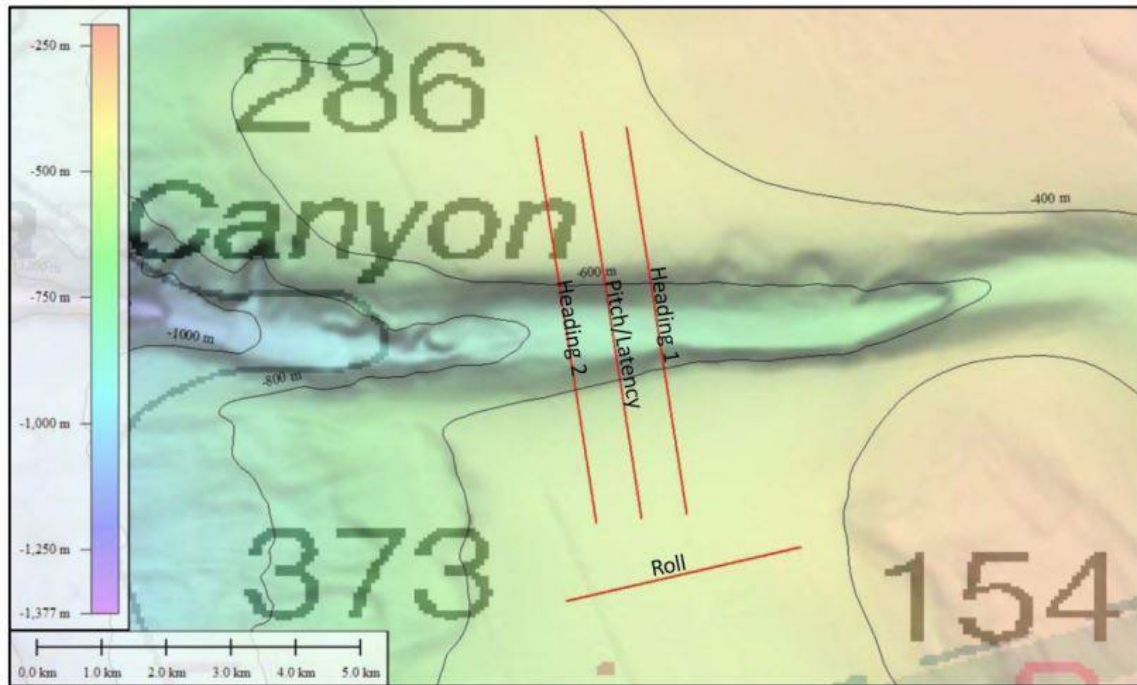


Figure 2.5. Sample patch test line plan: note the definition of slope for all biases except roll, which is on a flat area. Image source: Paul Johnson, NSF-funded Multibeam Advisory Committee (National Science Foundation).

The order in which these biases are determined may affect the accurate calibration of the multibeam system. Conduct the calibration tests in the following order with the hydrographer determining the biases in the following order: navigation timing error, pitch, roll, and heading (yaw).

There are several methods of achieving corrector values. One method is utilizing software that determines the values automatically (e.g., using cleaned data to provide offsets that minimize root mean square [RMS] errors between test lines). Another method is to have three or more observers generate individual sets of values and use quantitative methods to develop a mean value for each corrector. Ideally, the final offsets are based on the agreement between automatic patch test tools and manual assessments by multiple observers. This process may be iterative, applying preliminary results and refining each test in the post-processing software until no further changes are warranted. Confirm offsets larger than 0.1 degrees with additional data collection (with preliminary results applied).

Final values derived from the patch test should be entered into the acquisition software and confirmed (without duplicating) in the processing suite.

2.5.2.3 Relative Backscatter Calibration

Use a relative backscatter calibration method to ensure consistency of the backscatter of a single system with different settings (Lurton et al., 2015). This method involves collecting multibeam data in a relatively flat, hard, and homogeneous seafloor region in a specific pattern consisting of reciprocal lines with various settings for pulse length and power applied. The results are then processed and can be applied during data collection or post-processing, depending on the particular multibeam system.

This procedure helps to normalize differences in backscatter values resulting from variable frequencies and pulse durations employed within sectors and among ping modes used during multibeam data acquisition. A successful relative backscatter calibration helps to produce a visually appealing backscatter mosaic image that displays the relative changes in backscatter that are representative of changes in the seafloor properties rather than changes in echosounder modes and transmit parameters.

2.5.2.4 Sound Speed Sensor Calibration

Sensors that determine sound speed should be calibrated according to the manufacturer's recommendation (typically annually). Calibration documentation provided by the manufacturer should accompany these data in the NOAA archive and any survey reports.

2.5.2.5 Multibeam Speed Noise Testing

Significant limitations on multibeam performance can stem from elevated noise levels due to hull design, engines, and other machinery; sea state; biofouling; electrical interference, etc. Periodically, a series of tests should be run to track RX noise and RX spectrum to characterize the vessel's platform noise environment over a range of speeds or operating parameters (e.g., different engine lineups, if more than one is used during mapping operations).

Conduct these tests in calm to mild sea states, with low currents, and in the absence of rain and high winds to isolate the impacts of elevated sea states and weather on noise levels (which can be substantial). Pay attention to the vessel's orientation concerning swell, as pitching into a significant swell (or, in some cases, steering noise at oblique angles to the swell) can impact the results. Run separate tests to assess noise levels versus vessel heading relative to the prevailing swell, allowing surveyors to identify vessel orientations that may reduce noise levels and improve mapping data.

The noise floor can vary for each system; therefore, absolute noise thresholds are difficult to define across systems. The best indicator that the noise floor is too high is an apparent reduction in swath coverage and degradation of the data. Therefore, speed-noise tests are most valuable when compared to previous tests to monitor changes in the platform noise levels (e.g., due to engine lineup or other machinery alterations, especially pre- and post-shipyard), track the health of the system (e.g., RX element failure), and provide an early indication of potential performance reduction over time. The NSF-funded MAC (GitHub oceanmapping community, 2022) provides

guidance and software tools for collecting RX noise level data for Kongsberg systems; other manufacturers may provide similar resources.

2.5.2.6 Extinction Testing

Extinction testing is conducted annually or opportunistically on transits to determine the coverage achievable by the multibeam sonar across the full range of operational depths (i.e., from shallow water out to full extinction, if possible). This information is helpful for line planning and provides an early indication of performance degradation. Reductions in coverage can indicate increased vessel noise levels or other hardware issues, such as reduced transmission strength.

Repeating transit lines over a wide range of depths (e.g., transits in and out of a particular port on the same course) can provide a valuable comparison of swath coverage over the years. It is beneficial to collect pre- and post-shipyard data to ensure no changes in vessel noise that may limit swath coverage (or to document any improvement, such as from hull and transducer cleaning).

Several multibeam processing packages offer coverage assessment tools that can be used with cleaned data from various formats within a processing project. The MAC (GitHub oceanmapping community, 2022) provides guidance and software tools for collecting and assessing swath coverage data with Kongsberg systems; other manufacturers may provide similar resources.

2.5.3 Hardware Maintenance

2.5.3.1 Transducer Face Cleaning

Heavy biofouling can impact transmit and receive levels and severely degrade the signal-to-noise ratio. Thus, the face of the transducers (both the transmit and receive arrays) and hull areas near the arrays should be visually inspected by scuba divers throughout the year for significant biofouling. Cleaning may be necessary multiple times per year and must be done per the manufacturer's recommendations to remove biofouling without damaging the transducer faces.

During every dry dock, the transducers should be cleaned and painted with anti-fouling paint, and the epoxy material adhering the transducers to the hull should be replaced as necessary to reduce the potential for cavitation due to non-smooth surfaces. It is critical that all transducer cleaning and painting steps strictly follow the manufacturer's procedures for preparation, paint type, and thickness of application. The mass of the paint on the transducer face directly impacts its frequency response; misapplication can severely degrade the adequate TX power and RX sensitivity, resulting in significantly reduced coverage and accuracy.

2.5.3.2 Impedance Testing

Most transducers have a useful life of roughly 10 years before showing performance degradation. Impedance testing, conducted by the sonar manufacturer, should be done throughout the system's life to monitor system health. The manufacturer can advise appropriate testing intervals.

Some systems offer self-testing functions that should be run routinely (e.g., before and after each survey) and may offer proxies for impedance testing. These are not substitutes for direct impedance analyses of individual transducer channels but may help to alert users to new element failures or general trends across an array. The MAC (GitHub oceanmapping community, 2022) provides guidance and software tools for collecting and assessing Built-In Self-Tests (BISTs) for TX and RX Channels data with Kongsberg systems; other manufacturers may provide similar resources.

2.5.4 Sound Speed Correction

2.5.4.1 Vertical Sound Speed Profiling

It is necessary to know the speed of sound through the water column to resolve the depth from the two-way travel time of the ping:

$$\text{Range} = [(\text{Two-way travel time})/2] * \text{speed of sound.}$$

When profiling at oblique angles, variations in sound speed will also change the path of sound through the water, affecting not just the observed range but also the lateral position of the observed sounding; thus, sound speed profiles are essential for MBES. As the speed of sound varies depending on environmental conditions, it must be captured at frequent enough intervals to resolve the spatial and temporal variability of the area.

Sound speed profiles can be collected with various instruments, such as CTDs, expendable bathythermographs (XBT), XSVs, MVPs, and Remotely operated vehicles (ROV)-mounted sensors. Process profiles into a format that can be applied in the multibeam acquisition software; at a minimum, this can typically be done with software provided with the sound speed sensor or through profile processing tools in the multibeam acquisition software. More streamlined approaches for processing and monitoring sound speed are available with third-party software such as Sound Speed Manager (HydrOffice, 2023). HydrOffice, led by the University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center, with significant April 2024 58 collaboration with NOAA and other agencies worldwide, provides open-source tools to support ocean mapping, including planning and processing sound speed profiles (HydrOffice, 2023).

2.5.4.2 Surface Sound Speed Measurement

Sound speed at the level of the transducer is a critical component for beam steering, and any error in the launch angle of the beams will propagate throughout the entire water column. Observe sound speed at the transducer and input to the sonar system in real-time for application (i.e., beamforming) during acquisition.

Monitor the surface sound speed in the acquisition software, with particular attention to differences from the most recent sound speed profile at that depth. Sound Speed Manager

(HydrOffice, 2023) can monitor these changes and plan for new profiles, as well as confirm that the surface sound speed value is applied at the correct depth in the profile (thereby also confirming other parameters, such as waterline).

2.6 Lidar Protocols

These lidar protocols are derived from the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) Topo-Bathy Lidar Specification, currently under development by JALBTCX partner agencies U.S. Army Corps of Engineers (USACE), Naval Oceanographic Office (NAVOCEANO), NOAA, and USGS.

2.6.1 Collection Requirements

Although lidar collection parameters are highly dependent on the environment of the project area and numerous other factors, this chapter defines those collection requirements that must be met to achieve consistent topo-bathymetric lidar collection for IWG-OCM.

2.6.1.1 Collection Area

The collection area, or Defined Project Area (DPA), is defined by the area of interest, plus a buffer of 100 m. Data collection and deliverables are required for all production flight lines. The DPA should include any ground truth observations used to validate the accuracy of a survey.

2.6.1.2 Quality Level

Table 2.1 contains reasonable specifications for THU, TVU, sample density, and system depth performance. The cells highlighted in green are the typical acceptable level for each parameter to meet the requirements of the JALBTCX partner agencies (USACE, NAVOCEANO, NOAA, and USGS). These specifications apply to bathymetric lidar data and bathymetric data collected as part of a topo-bathymetric lidar survey.

Table 2.1. Specification matrix for uncertainties of THU, TVU, sample density, and system depth performance for bathymetric data. All uncertainties are given at the 95% confidence level. For each bathymetric parameter, the matrix includes a range of values for parameter uncertainty. Cells outlined in black are minimum specifications to meet interagency requirements.

A. Relationship of parameter values to standing Hydrographic Survey Orders established in the International Hydrographic Organization S-44 Standards for Hydrographic Surveys

		Range of Values						
Parameters	Depth THU (m)	20	10	5	2	1	0.5	0.25

Depth THU (% of depth)	10	5	2	1	0.5	0.25	0.1
Depth TVU "a"* (m)	1	0.5	0.3	0.25	0.2	0.15	0.1
Depth TVU "b"* (m)	0.023	0.020	0.013	0.010	0.0075	0.0040	0.0020
Sample Density (m⁻²)	0.04	0.25**	2	3	5	10	20

	- IHO Order 2
	- IHO Order 1a/b, Bathy QL 4b
	- IHO Special Order, Bathy QL 0b/1b
	- IHO Exclusive Order
	- Both IHO Special Order, Bathy QL 0b/1b and IHO Exclusive Order

B. Relationship of parameter values to the Interagency Working Group on Ocean and Coastal Mapping Bathymetric Lidar Quality Levels

		Range of Values						
Parameters	Depth THU (m)	20	10	5	2	1	0.5	0.25
	Depth THU (% of depth)	10	5	2	1	0.5	0.25	0.1

Depth TVU "a"* (m)	1	0.5	0.3	0.25	0.2	0.15	0.1
Depth TVU "b"* (m)	0.023	0.020	0.013	0.010	0.0075	0.0040	0.0020
Sample Density (m⁻²)	0.04	0.25**	2	3	5	10	20

	- Bathy QL 0b/1b (1b has lower sample density)
	- Bathy QL 2b/3b (3b has lower sample density)
	- Bathy QL 4b
	- Both Bathy QL 0b/1b and Bathy QL 2b/3b
	- Both Bathy QL 2b/3b and Bathy QL 4b

THU =

total horizontal uncertainty

*TVU = total vertical uncertainty ($\pm \sqrt{a^2 + (b * d)^2}$; a = portion of uncertainty that does not vary with depth; b = a coefficient representing that portion of uncertainty that varies with depth; d = depth; $b * d$ = portion of uncertainty that varies with depth)

** - Note that in optically deep water, bathymetric lidar systems produce data at lower sample density.

2.6.1.4 Multiple Returns

Data collection should be capable of multiple returns per measurement (pulse, waveform, or pixel) for the determination of water surface, seafloor, and midwater returns.

2.6.1.5 Data Voids

Data voids may result from operational or environmental conditions, including:

- Water clarity
- Turbidity plumes

- Bubbles and sediment entrained in the water column and surface foam from breaking waves
- Areas of low bottom reflectivity, such as mud or submerged aquatic vegetation
- Aircraft motion

Careful planning ensures complete data coverage.

2.6.1.6 Spatial Distribution and Regularity

Plan and execute collections to produce aggregate bathymetric point data that approach a uniform, regular lattice of points.

2.6.1.7 Collection Conditions

Consider the following collection conditions relative to survey intent:

- Cloud and fog between the aircraft and ground
- Snow and ice cover on land and water
- Extensive flooding or any other type of inundation
- Leaf-on or leaf-off vegetation condition
- High or low tides, water level, or river flow
- Submerged aquatic vegetation biomass

2.6.1.8 Depth Range

Depth performance of airborne lidar bathymeters varies based on system design factors such as laser power, optical element size, and receiver sensitivity. Estimated lidar system depth performance should be evaluated against desired depth range and expected water clarity in the project area to ensure the system selected is capable of meeting survey objectives. Consider minimum depth performance to ensure seamless coverage from land to water.

2.6.2 Data Processing and Handling

Elevations and depths should be reported in metric units.

2.6.2.1 Time of GPS Data

Record GPS data as Adjusted GPS Time (Standard [satellite] GPS time minus 1×10^9) at a precision sufficient to allow unique timestamps for each pulse.

2.6.2.2 Datums

The CRS for latitude, longitude, and ellipsoid heights should be NAD 83 using the most recent adjustment published by the National Geodetic Survey (NGS) (currently NAD 83, epoch 2010.00, realization of 2011).

The vertical datum for orthometric heights should be NAVD 88. The geoid model used to convert between ellipsoid and orthometric heights should be the latest hybrid geoid model of NGS, supporting the latest realization of NAD 83 (currently [2017] GEOID model).

Use alternate vertical datums in areas where a current geoid model is unavailable, including Alaska, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Hawaii, Puerto Rico, U.S. Virgin Islands.

2.6.2.3 File and Point Source Identification

At the time of its creation and before further processing, each swath should be assigned a unique file source ID. Each point within the swath should be assigned a point source ID equal to the file source ID. The point source ID on each point shall be persisted unchanged throughout all processing and delivery.

2.6.2.4 Positional Accuracy Validation

Before the classification and development of derivative products from point data, the absolute and relative accuracy of the point data should be verified.

2.6.2.5 Relative Vertical Accuracy

Relative vertical accuracy refers to the internal geometric quality of a lidar dataset without regard to surveyed ground control.

2.6.2.6 Intr swath Precision (Smooth Surface Precision)

Intr swath precision should be assessed on large, flat, hard-surfaced, open areas (for example, parking lots or large rooftops) containing only single return lidar points and for the entire swath width.

2.6.2.7 Interswath (Overlap)

Interswath consistency should be assessed at multiple locations within swath overlap in non-vegetated areas of only single returns and with terrain slopes of less than 10 degrees for the following:

- Adjacent, overlapping parallel swaths
- Project swaths in opposing flight directions
- Crosslines
- Adjacent, overlapping flight blocks, i.e., lifts

2.6.2.8 Absolute Vertical Accuracy

The absolute vertical accuracy of the lidar data and the derived digital elevation model (DEM) should be assessed and reported under the American Society for Photogrammetry and Remote Sensing (ASPRS, 2014) for topographic data collected ancillary to bathymetry and wading depths.

Four absolute accuracy values shall be assessed and reported:

- Non-vegetated Vertical Accuracy (NVA) for the point data.
- Vegetated Vertical Accuracy (VVA) for the point data.
- NVA for the DEM.
- VVA for the DEM.

Assess NVA and VVA for the point data by comparing checkpoints to a triangulated irregular network (TIN) constructed from ground-classified lidar points.

Assess NVA and VVA for the DEM by comparing checkpoints to the final bare-Earth surface.

For bathymetric lidar and sonar surveys, data should meet IHO S-44 Standards for Hydrographic Surveys.

2.6.2.9 Point Classification

The minimum required classification scheme for lidar data is found in Table 2.2. All points within the minimum classification scheme that are not flagged as withheld should be classified appropriately.

2.6.2.10 Classification Consistency

Point classification should be consistent across the entire project, with no noticeable variations in the character, texture, tiles, swaths, lifts, or other non-natural division classification quality.

2.6.2.11 Intensity Values

Intensity values are required for each bottom return where water conditions allow.

2.6.2.12 Tiles

Establish and use a single non-overlapping project tiling scheme for all tiled deliverables. The tiling scheme should use the same CRS and units as the point data. The tile size shall be an integer multiple of the cell size for raster deliverables. Index the tiles in x and y to an integer multiple of the x and y dimensions of the tile. Edge-match the tiled deliverables seamlessly, without gaps, and conform to the project tiling scheme without added overlap.

2.6.2.13 Point Duplication

Do not duplicate lidar points (x, y, z, and timestamp) within the project. Near duplication (a group of points duplicated but with a slight but consistent spatial offset) will be regarded as duplication.

Table 2.2. Bathymetric/topographic lidar data classification scheme.

Code	Description
1	Processed, but unclassified
2	Bare-Earth ground

7	Low noise (low or high; manually identified, if necessary)
9	Water (topographic sensor)
17	Bridge deck
18	High noise (high manually identified, if necessary)
20	Ignored ground (typically breakline proximity)
21	Snow (if present and identifiable)
22	Temporal exclusion (topographic sensor;) typically non-favored data in intertidal zones)
40*	Bathymetric Point, Submerged Topography (e.g., seafloor or riverbed)
41	Water Surface (sea/river/lake surface from bathymetric or topographic-bathymetric lidar; distinct from Point Class 9, which is used in topographic-only lidar and only designates “water,” not “water surface”)
42	Derived water surface (synthetic water surface location used in computing refraction at water surface)
43	Submerged object, not otherwise specified (e.g., wreck, rock, submerged piling)
44	IHO S-57 object, not otherwise specified
45	No-bottom-found (bathymetric lidar point for which no detectable bottom return was received)
64	Submerged Aquatic Vegetation
65	Denotes bathymetric bottom temporal changes from varying lifts, not utilized in bathymetric point class

2.6.3 Deliverables

Delivery is required for all ancillary products that support the processing of the lidar dataset, including imagery and all metadata associated with the data.

2.6.3.1 Metadata

Product metadata files shall comply with ISO 19115-1:2014 Geographic information - Metadata - Part 1: Fundamentals.

Record the CRS, epoch, realization, geoid model, NGS model filenames, or information describing alternate vertical datum separation from ellipsoid in metadata.

2.6.3.2 Reports

Report deliverables shall include the following:

- A survey report detailing the collection of all ground survey data
- A lidar mapping report that describes:
 - Data acquisition and processing
 - GNSS-inertial processing
 - Point cloud creation
 - Geometric quality
 - Production

2.6.3.3 Classified Point Data

2.6.3.3.1 ASPRS LAS File Format

All point deliverables should be in LAS format, version 1.4-R15, using Point Data Record Format 6, 7, 8, 9, or 10. Data producers are encouraged to review the LAS specification version 1.4–R15 in detail (ASPRS, 2011). LAS files should conform to the following items:

- Include a unique identifier for the dataset in the LAS file(s) as a Globally Unique Identifier (GUID).
- Correct and properly formatted geo-reference information as Well-Known Text (WKT) (OGC, 2001) included in all LAS file headers.
- The encoding tag in the LAS header should be set properly. See LAS specification version 1.4–R15 (ASPRS, 2011) for additional information.
- Intensity values in 16-bits. See LAS specification version 1.4–R15 (ASPRS, 2011) for additional information.
- Tiled delivery, without overlap, using the project tiling scheme.
- Classification, as defined above, is at a minimum.

2.6.3.3.2 Use of the LAS Withheld Bit Flag

The withheld bit flag, as defined in LAS specification version 1.4–R15 (ASPRS, 2011), shall only be used to identify points that cannot be interpreted as valid surface returns. Examples include outliers, blunders, geometrically unreliable points, aerosol back-scatter, laser multi-path, airborne objects, and sensor anomalies. Preferred data delivery treatment is to exclude withheld points from delivered data.

2.6.3.4 Bathymetric Lidar Waveform

If collected, deliver bathymetric lidar waveforms. Deliver waveforms in:

- LAS deliverables using external auxiliary files with the extension “.wdp” to store waveform packet data. See LAS specification version 1.4–R15 (ASPRS, 2011) for additional information, or
- Alternate, well-documented, open-source formats, such as *.cpf

2.6.3.5 First-Return Surface (Raster Digital Surface Model)

Use lidar point data falling into the “processed but unclassified,” “bare earth,” and “bathymetric point, submerged topography” classes to generate the first-return digital surface model (DSM). Generate the first-return DSM to the limits of the DPA in a 32-bit floating-point GeoTIFF raster format. GDAL version 2.4.0 should be used to populate GeoTIFF keys and tags, or as otherwise agreed in advance and specified in the Task Order. Deliver DEM data in the same CRS and tiling scheme as the lidar data, with no edge artifacts or mismatches.

Georeference information should be delivered in or accompany each raster file, as appropriate for the file format. This information should include horizontal and vertical systems; the vertical system name should include the geoid model used to convert from ellipsoid heights to orthometric heights.

Remove bridges; the bare-Earth surface below the bridge should be a continuous, logical interpolation of the apparent terrain lateral to the bridge deck. The bare-Earth interpolation shall begin at the junction of the bridge deck and approach structure where abutments are clearly visible.

Roads or other travel ways over culverts should remain intact on the surface.

2.6.3.7 Breaklines

Deliver breaklines used to enforce a logical terrain surface below a bridge.

2.7 SDB Protocol

For the purposes of this standard, we will focus on the satellite data itself and not the system calibration and maintenance as satellites used to create SDB do not require system calibration and maintenance, etc. in the same way as discussed with multibeam and lidar sensors.

2.7.1 Satellite overview and data collection

Modern SDB-capable satellite platforms use nadir pointing push-broom instruments with some exceptions and record reflected sunlight in visible and near-infrared wavelengths. Multispectral sensors typically capture approximately 4-13 discrete spectral bands and have spatial resolutions ranging from 2 to 30 meters. Hyperspectral sensors can capture hundreds of narrow spectral bands albeit often at coarser spatial resolutions. Data are collected along swaths between 16 and 290 kilometers wide, which allow for a range of revisit times from daily to weekly depending on orbit geometry and the number of satellites in the constellation.

2.7.1.1 Source

The most commonly used multi-spectral satellites used in the federal mapping community are the European Space Agency’s Sentinel-2 (e.g. Multispectral Imager [MSI]), NASA’s Landsat 7, 8 and 9 (Operational Land Imagery [OLI]), and Maxar’s World View 2. Sentinel-2 and Landsat are typically used more frequently because image products are freely available and do not have as many restrictions as the others. For example, Sentinel-2 provides several image products with different types of processing and spatial resolutions that are readily available for download (Levels 1C, 2A, and 3). Specifications for these satellites are listed in the annex of the [IHO SDB Best Practices Guide B-13](#). Any new satellites used operationally will be added to this document periodically.

** Any specific software, sensor, system, etc. mentioned in this document does not imply endorsement by the federal government.*

2.7.2. Techniques/Methods

All SDB methods can be grouped into three major categories as follows: (1) Spectral SDB/Spectral Radiance (e.g., Radiative Transfer Equation (RTE) optimization, RTE empirical, band ratio, etc.); (2) Photogrammetric; and (3) Wave Kinematics.

Note: Additional bundle adjustments are recommended for photogrammetric methods.

Table 2.3 contains a condensed list of SDB techniques and parameters to highlight the differences or commonalities between methods

Table 2.3: Relationship between techniques and parameters for SDB

SDB Parameters	Spectral SDB		Photogrammetric	Wave Kinematics
	Band Ratio	RTE Optimization		
Sensors Used	MS, HS	MS, HS	MS and PAN Sat Video Imagery	MS Sat Video Imagery SAR
Limitations	* see section 2.7.2.1			
In-situ data required	Yes	No	No	No - MS/SatVideo Yes - SAR
Product Resolution	Med: (10-30m) High: (1-4m)	Med: (10-30m) High: (1-4m)	High: (1-4m)	High to course: (1-100m)
Depth Penetration	~1 Secchi Disk	~1 Secchi Disk	~1 Secchi Disk	up to 40m for MS/video ~10 to 70m for SAR
Vertical RMSE	* see section 2.7.6			

*MS (Multispectral), HS (Hyperspectral), PAN (Panchromatic), SAR (Synthetic Aperture Radar)

Note: Satellite-lidar is currently not being considered as a standard SDB method. However, it is recognized as a highly accurate source for referencing and validation of SDB products that are derived from one of the four other major methods, especially in remote regions. Continued advances in the use of ICESat-2 ATLAS observations in combination with coincident multispectral imagery continue to make it an ideal asset for remote regions.

For an in depth write up of the four techniques see section 2.7.10.

2.7.2.1 General Environmental and Other Limitations

SDB approaches have both environmental limitations and unique algorithm constraints. The SDB approaches that are foundationally based on ocean optics (Spectral SDB/Radiance and Photogrammetric) are limited by spectral contributions from the environment, such as clouds, shadows (from clouds, subsea features, constituents in the water column), ice, sun glint, turbidity, waves, sea surface and haze, which all can vary in magnitude. Typically, if any of these contributions represent a significant portion of the spectra, the optical approaches will not be feasible and/or contain larger errors. Wave Kinematics approaches differ in that the presence of surface waves are required (versus the preference to calm seas in optical approaches) and that the presence of turbidity does not significantly impact depth estimates.

The algorithms that are used across the SDB approaches have unique requirements and/or constraints which are generalized below.

Band-Ratio: This approach is based on statistical relationships between reflectance and depth. It often requires in-situ or known depth data within the scene in order to derive light attenuation coefficients to estimate depth. In terms of the amount of restriction mentioned above depends on the approach used. The compositing approach for band ratio solution inherently removes a lot of the faulty data.

RTE optimization: This approach is based on ocean radiative transfer physics and theory. It requires high spectral resolution data, i.e., hyperspectral, and knowledge of the nature of the water constituents (which can vary seasonally and over time) and bottom type to derive water depth, many of which are not freely available. Variations in water optical properties, surface reflection, and atmospheric conditions cannot be removed from all pixels, so constant conditions are assumed for one or more of these. RTE optimization is often referred to as physics based SDB.

Photogrammetry based: This approach requires stereo imagery for triangulation, which is not freely available. In addition, the results can be impacted by satellite attitude jitter.

Wave Kinematic: This approach requires long time series observations which are not freely available. In addition, due to the underlying frequency analysis and resulting coarser spatial resolution, bathymetric estimation may have a shoreline bias, particularly if the shoreline is

abrupt and high sloping. Many existing applications of this approach are conducted on areas with exposed shorelines; further testing needs to be done on enclosed and semi-enclosed beaches. Lastly, areas with small tidal ranges and narrow surf zones are not ideal.

2.7.3 Pre-Processing (Calibration and Corrections)

To use optical satellite image to estimate water depth, several pre-processing steps are needed. Most of the standard level 1 image products are already pre-processed for basic radiometric calibration, ortho rectification, and top-of-the-atmosphere reflectance (TOAR) conversion. Atmospheric correction should be applied to the level 1 image product. However, there are many types of abnormal pixels that are not corrected by generic atmospheric correction, and they should not be used for SDB. Those pixels need to be corrected, if the degree of contamination is weak or moderate. Otherwise, they need to be isolated and discarded.

Some specific pixel issues are cloud and cloud shadow, sun glint, sky reflectance, and floating objects. Cloud and cloud shadow pixels should be identified and discarded, although very thin pixels around the cloud or cloud shadow patch may be used after correction. Sun glint (reflected sunlight) is predictable based on the angles of the sun and sensor. However, surface waves create unpredictable, localized glint. These glint-affected pixels cannot be corrected and should be removed. Atmospheric correction usually doesn't fix sky reflectance. Surface waves cause variations in sky reflectance, creating a "ripple effect." This ripple effect can be corrected using near-infrared (NIR) reflectance. Floating seagrass, emergent macroalgae, boats, and boat wakes should be isolated and discarded.

2.7.3.1 Radiometric

Satellite derived bathymetry utilizes the visible wavelengths region because of the rapid increase of water absorption starting from 600 nm to near infrared (NIR). The spectral bands in the red and NIR region are useful only for a very shallow bright bottom to overcome very high absorption by water. In general, the water leaving signal is very weak except for the case of very shallow bright bottom. Thus, signal to noise ratio is a critical factor that determines the uncertainty of SDB results. Signal to noise ratio is measured by selecting a homogeneous region of the image and dividing the mean reflectance value by the standard deviation of the reflectance. The radiometric accuracy may need to be evaluated against a reference sensor. Landsat OLI or Sentinel-2 MSI sensor data are known to have sufficient quality for use as a reference. A target sensor image and matching reference sensor image can be scatter-plotted to evaluate its linearity. In this case, TOAR can be used instead of surface reflectance (SR) after atmospheric correction to avoid the specific effects due to the different atmospheric processors. If a systemic error is found, it is recommended to make a linear correction of the sensor reflectance to match that of OLI or MSI.

2.7.3.2 Atmospheric correction

Atmospheric correction refers to surface reflectance, which is the TOAR corrected for the scattering and absorption of the molecular gases and aerosols. The correction means to compensate for non water-leaving reflectance. The main assumption of the atmospheric correction is to consider the water-leaving radiance in the near-infrared (NIR) is negligible. In a typical approach, the effects of Rayleigh scattering and gaseous absorption are removed first and then aerosol contribution is approximated using aforementioned dark water assumption (negligible in the NIR). Commonly used atmospheric processors are ACOLITE, iCOR, SeaDAS, POLYMER etc. Correction for reflectance off the water surface (sun glint is an extreme version of this) happens at the same time for some atmospheric processors.

2.7.3.3 Glint

The sun-sea-sensor remote sensing geometry may result in specular sun glint. High resolution imagery often has spatially resolved sun glint. If SWIR channels are available, an estimate of the glint can be made and extrapolated to the shorter wavelength channels using a modeled reflectance spectra. While Sun-sea-sensor geometry precisely determines the amount of moderate level of sky reflectance, beyond that level it that is generally considered glint and it cannot be resolved when waves are present (i.e. attempting to correct for glint is very difficult unless it is a flat sea surface). However, the water surface wave distribution makes the problem complicated. Due to its dominant magnitude, even though the glint is corrected, often the remaining water-leaving reflectance is severely distorted.

2.7.3.4 Surface reflectance of skylight

While glint is the specular reflection of the direct solar beam at the water surface to the sensor with very high magnitude, the sky reflectance reflected from the water surface is much weaker. The physical principle of the sky reflectance is the Fresnel reflectance of the downwelling sky reflectance at the water surface to the sensor. Both the increasing off-nadir viewing angle from the scene center and the quickly varying local normal angle of the surface wave creates varying Fresnel reflectance. Since it is a weak signal, it is realistic to correct the surface ripple effect using the NIR band as a reference to estimate the amount of spectral correction using an atmospheric model. As noted above, the surface reflectance methods involve similar problems and solutions as atmospheric correction.

2.7.3.5 Floating macroalgae

Pixels contaminated by floating macroalgae practically block water-leaving signal and can resemble terrestrial vegetation. Thus, very high NIR reflectance is a characteristic feature. It is relatively easy to detect, and it is not possible to spectrally correct and retrieve water-leaving reflectance.

2.7.3.6 Cloud and cloud shadow

Cloud pixels are relatively easy to identify due to their unique spectra, although very thin cloud pixels around the edge of cloud patches have substantial ambiguity, making them challenging to discriminate. Cloud shadow pixels result when the direct solar beam is blocked and only diffuse sky irradiance is exposed; thus water-leaving reflectance is much lower compared to non-shadow pixels. While it is possible to identify cloud shadow pixels based on spectral properties, additional information of solar zenith and azimuth angles facilitates finding affected pixels by numerically predicting the rough location of shadow from the cloud pixels.

2.7.3.7 Boat waves and breaking waves

Boat wakes and similar breaking wave pixels are characterized by high reflectance over the VNIR wavelength region. Especially along the coastline, substantial areas of breaking waves exist; pixels should not be used in SDB estimations. Typical land-water discrimination indices like Normalized Difference Water Index (NDWI) that uses green and NIR bands may fail for the very bright breaking wave pixels. Thus, the magnitude of the spectral signature and spatial context needs to be used simultaneously.

2.7.3.8 Geometric error correction

One of the quality assurance items is to check the relative geometric difference against a good geometric reference image such as Landsat OLI and Sentinel-2 MSI. Unlike fast varying land pixels with many sharp edges, the water images have mostly slow gradients. Thus, as long as the relative geometric difference is less than a pixel, the induced error in SDB and derived products is negligible. However, if the georeferencing error is greater than that, it will affect the validation statistics, but the effect is only pronounced along the boundary or edges of the fast-varying features. To quantify relative georeferencing differences a cross-correlation matrix is used.

2.7.4 Referencing SDB

Per section 2.4.3 on Depth Reduction in the [IHO SDB Best Practices Guide B-13](#), information on water levels is necessary to transform the SDB data to a hydrographic vertical datum.

From a band ratio algorithm perspective, choosing reference data from stable areas is highly recommended.

If the reference data is referenced to a vertical datum, then the above vertical transformation is not necessary; the SDB data will adopt the vertical reference frame of the reference dataset.

Please note: This does not apply to stereo SDB, RTE optimization, and wave kinematics because calibration data is not needed.

2.7.5 Extinction depth

The maximum retrievable depth, or the extinction depth limit, is defined by optically deep water in which a bottom reflectance signal cannot be returned either due to turbidity, depth, or a combination of both.

2.7.6 Absolute Accuracy

Generally, for SDB in very shallow waters up to 10 m depth or less, Vertical Root Mean Square Error (RMSE) is greater than 10% of maximum depth, while for waters with depth greater than 10 m, the RMSE is less than 10%. Typically, RMSE will be low nearshore (except near the shoreline where there are often breaking waves, bubbles, foam, surf, etc.) and then steadily increase with depth up to the extinction depth, but this relationship is not monotonic. If the SDB results are carefully aligned or calibrated against very high vertical accuracy data, such as data obtained from airborne lidar, spaceborne lidar (e.g. ICESat-2), or sonar, then the resulting RMSE can approach or be less than 10% for any considered maximum depth.

2.7.7 Uncertainty

The standard for SDB uncertainty, similar to other standards for MBES and lidar, is to acknowledge that the uncertainty position is affected by many different parameters and that the contributions of all parameters to the total propagated uncertainty (TPU) should be accounted for. The total horizontal and vertical uncertainty should be assessed and a statistical method that combines all uncertainty sources should be adopted with the positional uncertainty at the 95% confidence level.

2.7.8 Validation

Per section 2.4.7 validation and comparison with survey data in the [IHO SDB Best Practices Guide B-13](#), SDB must be compared to independent control data to assess the overall accuracy and be considered appropriate for federal use.

Since most federal applications of SDB are interested in deriving continuous bathymetry surfaces, airborne lidar is preferred as it is designed to collect data with sufficient density to obtain a continuous bathymetry surface.

The spaceborne lidar, such as ICESat-2 (see section 2.3.6 in the IHO SDB Best Practices guide B-13), is also helpful as it can be dense along transection. However, it collects data on transects that are 90 m apart between a set of pairs; 3 km apart between different pairs. This collection will never be a temporally controlled continuous surface, but it can be used to tie down SDB as a second option if lidar or sonar data do not exist.

One advantage is that ICESat-2 can repeatedly monitor high targets in remote areas such as high latitude coasts not easily accessible by aircraft or ships.

2.7.9 Metadata

See Chapter 1 Data Management Sections 1.4-1.6.

Note that there are a variety of options indicating types of data and methods used for SDB that are not reflected in section 1.6 such as type of satellite, algorithm used, atmospheric corrections methods, calibration source, image processing type, image scene details, software type and version, and TPU value/estimate etc*.

2.7.10 SDB Techniques

2.7.10.1 Spectral SDB algorithms

Spectral SDB algorithms or spectral radiance, such as RTE optimization, RTE empirical, and band ratio performance depends on water clarity, image quality and lighting condition.

Physics based approaches use hyperspectral and multispectral imagery and is independent of any prior bathymetry data but needs prior knowledge of the substrate.

Note: some researchers and organizations define various subcategories (e.g. physics-based, empirical, semi-empirical), any such categorization is somewhat arbitrary. The distinction between "physics-based" optimization and "band ratio" is small compared to the separation of those from the others, and the table in section 2.7.2 ignores the non-optimization solutions to the radiative transfer equation (RTE).

2.7.10.2 Photogrammetry based Method

Bundle adjustment is specific to stereo reconstructions and ensures that the observations in multiple images of a single ground feature are self-consistent by refining camera pose estimation and attitude (parameters of relative motion and 3D coordinates), and optical characteristics of the camera(s) employed to acquire the images. This is important because satellite position and orientation errors can directly affect the accuracy of the digital elevation models derived with photogrammetry by introducing systematic errors and sometimes even more severe distortions such as the "dome-shape" effect. Bundle adjustment effectively minimizes the reprojection error, the error between the estimated, back-projected pixel locations of the 3D objects and their actual measured locations in the captured images. This is known as refining the extrinsic camera parameters.

Bundle adjustment can also optimize camera intrinsic parameters, such as optical center, focal length, and distortion when input cameras are either pinhole, optical bar, or the Community Sensor Models (CSM) established by the U.S. defense and intelligence community such as Linescan, Frame, Pushframe, and Synthetic Aperture Radar (SAR), similar with the intrinsic bundle adjustment used in structure-from-motion computer stereo-vision reconstructions.

In other words, bundle adjustment amounts to jointly refine all initial camera parameter estimates to predict as accurately as possible the locations of the observed features in the set of available images by minimizing the reprojection error.

For more information, please see the Chapter 2 Annex.

2.8 References

- American Society for Photogrammetry and Remote Sensing. 2011. *LAS Specification 1.4 - R15*. https://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf.
- American Society for Photogrammetry and Remote Sensing. 2015. *Photogrammetric Engineering & Remote Sensing*. 81(3). https://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf.
- GitHub oceanmapping /community. 11 July 2022. "Assessment Tools." <https://github.com/oceanmapping/community/wiki/Assessment-Tools>.
- Hydrographic Dictionary Working Group. 2019. "S-32 IHO - Hydrographic Dictionary / Multilingual Reference for IHO Publications." <http://iho-ohi.net/S32/engView.php>.
- IHO. September 2020. "S-44 Edition 6.10.0." https://iho.int/uploads/user/pubs/standards/s-44/S-44_Edition_6.1.0.pdf
- IHO. 2022. "Organization." <https://iho.int/en/>.
- Irish, J.L. and W.J. Lillycrop. 1999. "Scanning laser mapping of the coastal zone: the SHOALS system." *ISPRS J. Photogrammetry Remote Sens.* 54(2-3): 123-129. [https://doi.org/10.1016/S0924-2716\(99\)00003-9](https://doi.org/10.1016/S0924-2716(99)00003-9).
- Lurton, X., Lamarche, G. 2015. *Backscatter measurements by seafloor-mapping sonars. Guidelines and Recommendations*. <https://geohab.org/wp-content/uploads/2018/09/BWSG-REPORT-MAY2015.pdf>.
- Magruder, L. A. and Parrish, C. E., "Development of ATL24: The newest ICESat-2 along-track data product for bathymetry.", vol. 2022, Art. no. C35D-0907, 2022.
- MAREANO Programme. 2017. *Appendix B: Technical Specifications*. Norwegian Mapping Authority Hydrographic Service. https://mareano.no/resources/files/om_mareano/arbeidsmater/standarder/Appendix-B-Technical-Specifications-1.pdf.
- HydrOffice. 2023. "HydrOffice: A Research Framework for Ocean Mapping." <https://www.hydrooffice.org/>.
- Multibeam Advisory Committee (MAC). 5 November 2021. *Recommendations for Reporting Vessel Geometry and Multibeam Echosounder System Offsets*. <https://github.com/oceanmapping/community/blob/main/MAC%20Survey%20Report%20Recommendations%20v1p0.pdf>.
- NOAA. n.d. a. "Welcome to VDatum!" <https://vdatum.noaa.gov/welcome.html>.
- NOAA. n.d. b. "VDatum API Documentation." *Vertical Datum Transformation: Integrating America's Elevation Data*. <https://vdatum.noaa.gov/docs/services.html>.
- NOAA. n.d. c. "NOAA/NOS's VDatum Terms of Use (Effective as of November 15, 2013)." https://vdatum.noaa.gov/download_agreement.php.

NOAA OCS. HSSD 2025. *Hydrographic Survey Specifications and Deliverables*.
https://www.nauticalcharts.noaa.gov/publications/documents/HSSD_2025-0-00.pdf.

NOAA OCS. FPM 2021. *Field Procedures Manual*.

Ouellette, G., Fargo, K., Charry, H. (2023). Satellite computed bathymetry assessment – Developing satellite LiDAR methods to enhance coastal bathymetry coverage. *The International Hydrographic Review*, 29(2), pp. 208-212. <https://doi.org/10.58440/ihr-29-2-n05>

https://nauticalcharts.noaa.gov/publications/docs/standards-and-requirements/fpm/field_procedures_manual_2020.pdf

NOAA OER. 2020. *NOAA OER Deepwater Exploration Mapping Procedures Manual*.
<https://doi.org/10.25923/jw71-ga98>.

National Ocean Mapping, Exploration, and Characterization Council of the Ocean Science and Technology Subcommittee and Ocean Policy (NOMECS). June 2020. “National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone.”
<https://oeab.noaa.gov/wp-content/uploads/2021/01/2020-national-strategy.pdf>.

Picard, K., et al. 2018. *Australian Multibeam Guidelines*. Geoscience Australia, Canberra. <https://dx.doi.org/10.11636/Record.2018.019>.

International Hydrographic Organization (IHO). *Satellite-Derived Bathymetry Best Practice Guide (B-13)*, Ed. 1.0.0 (March 2024),
https://iho.int/uploads/user/pubs/bathy/B_13_Ed100_032024.pdf.