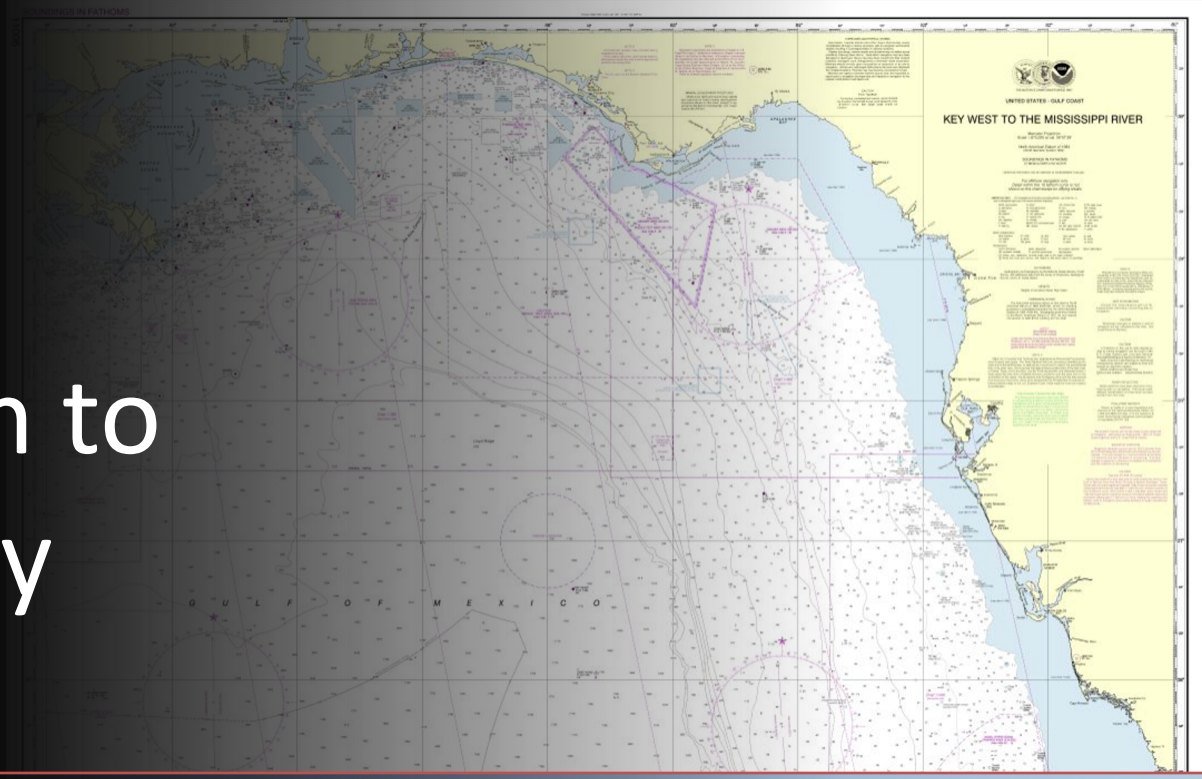
Introduction to Hydrography



Stephan D. Howden
The University of Southern Mississippi

COASTAL OCEAN ENVIRONMENT SUMMER SCHOOL IN GHANA

Objectives

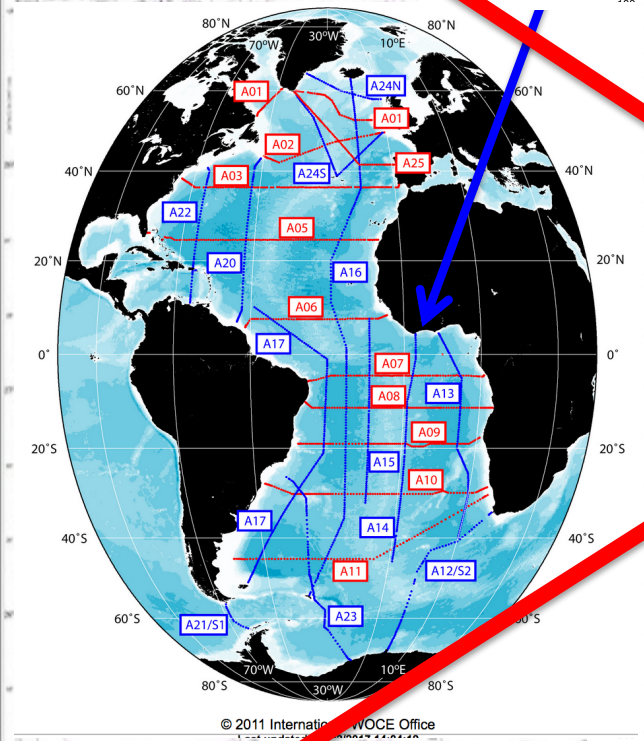
Introduce you to the profession of hydrography

Give you an appreciation for the importance of hydrography

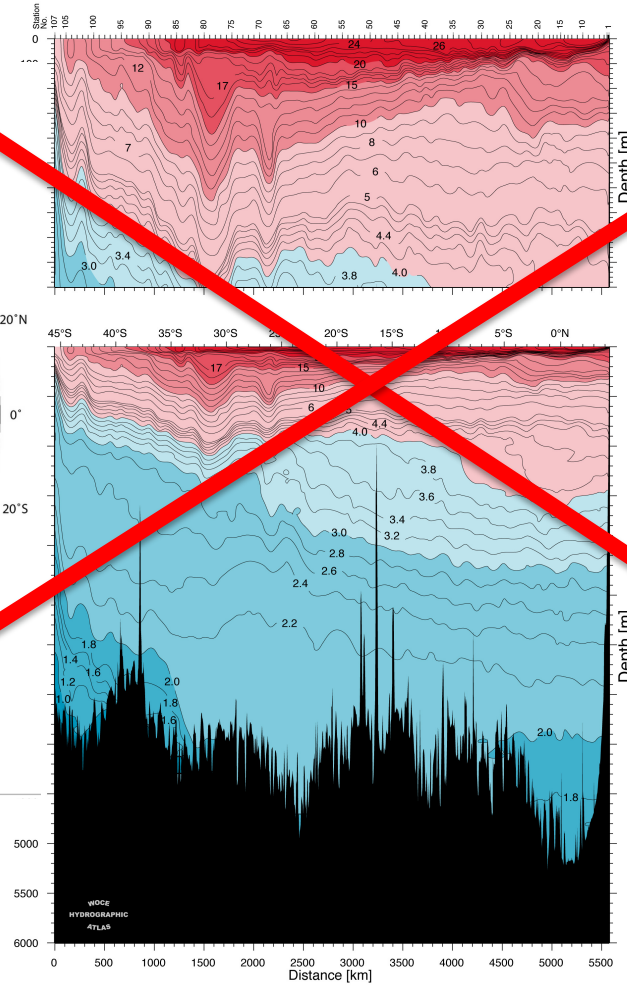
Give you some resources to learn further

What is Hydrography?

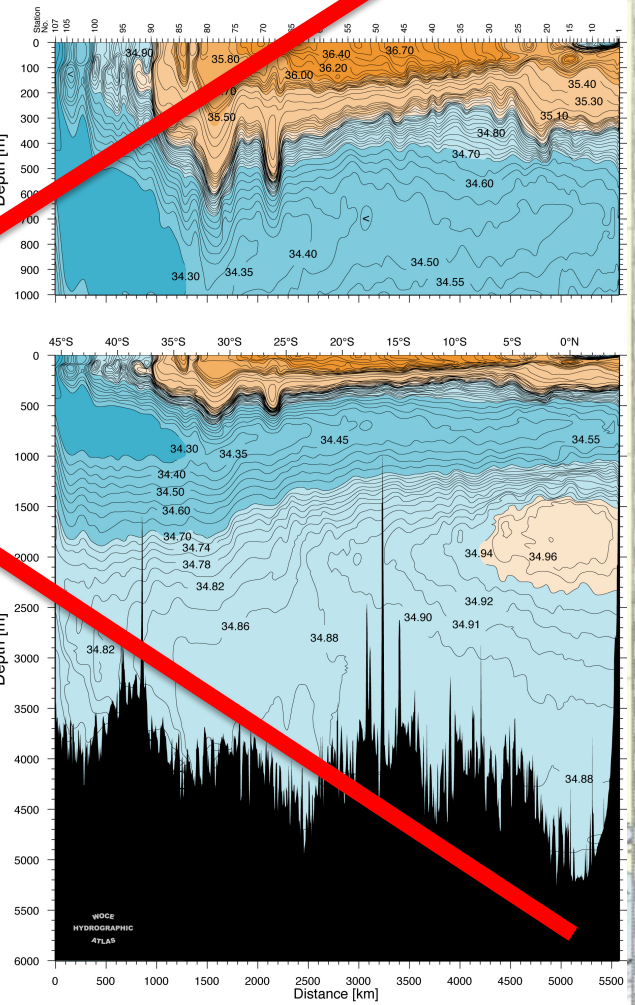
WOCE Section A14



Potential Temperature [°C] for A14 5°W



CTD Salinity for A14 5°W



International Hydrographic Organization*

Established in 1921

The intergovernmental consultative and technical organization to support safety of navigation and protection of marine environment

UN observer status

Recognized as the UN competent technical authority for hydrography and nautical charting.

* IHO Publication M-2

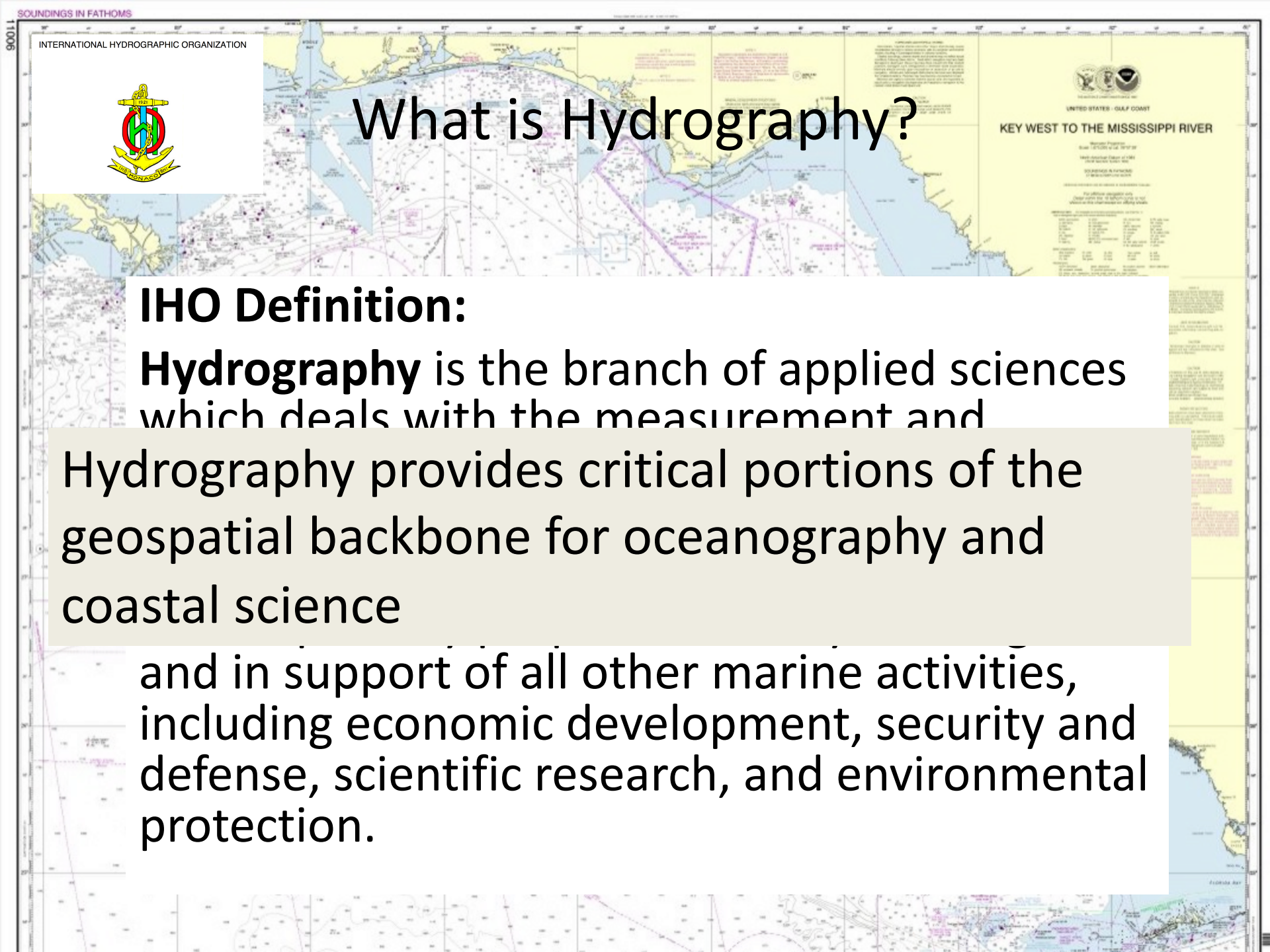
https//iho.int

INTERNATIONAL HYDROGRAPHIC ORGANIZATION

What is Hydrography?

IHO Definition:

Hydrography is the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and defense, scientific research, and environmental protection.



What is Hydrography?

IHO Definition:

Hydrography is the branch of applied sciences which deals with the measurement and

Hydrography provides critical portions of the geospatial backbone for oceanography and coastal science

and in support of all other marine activities, including economic development, security and defense, scientific research, and environmental protection.

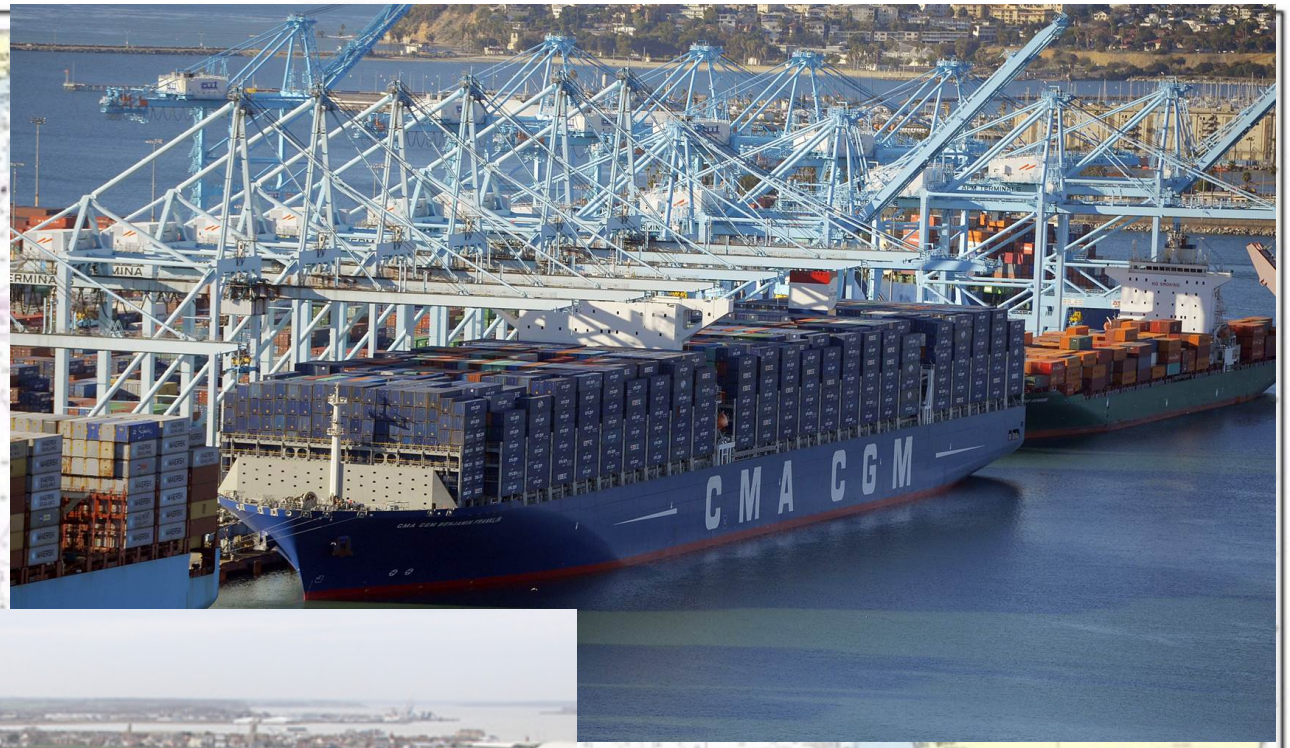
What Do Hydrographers Do?

- Survey the seafloor, lakes and river bottoms
- Survey the shoreline and structures of significance to navigation (e.g., bridges)
- Oceanographic measurements:
  - Water levels
  - Currents of significance to navigation
  - Sound speed profiles
  - Sediment samples,
  - Utilize information from water column acoustic backscatter
  - …
- Create navigational charts
- …

The Importance of Hydrography

- Nautical Charting and supporting safe and efficient navigation of ships
- Development & Maintenance of the Marine Transportation System
- Resource Exploitation
- Maritime Boundary Delimitation
- Coastal Zone Management
- Tsunami flood and inundation modelling
- Maritime Defense and Security
- National Marine Spatial Data Infrastructures
- Environmental Protection
- Recreational Boating
- Tourism
- Habitat Mapping
- Marine science
- …

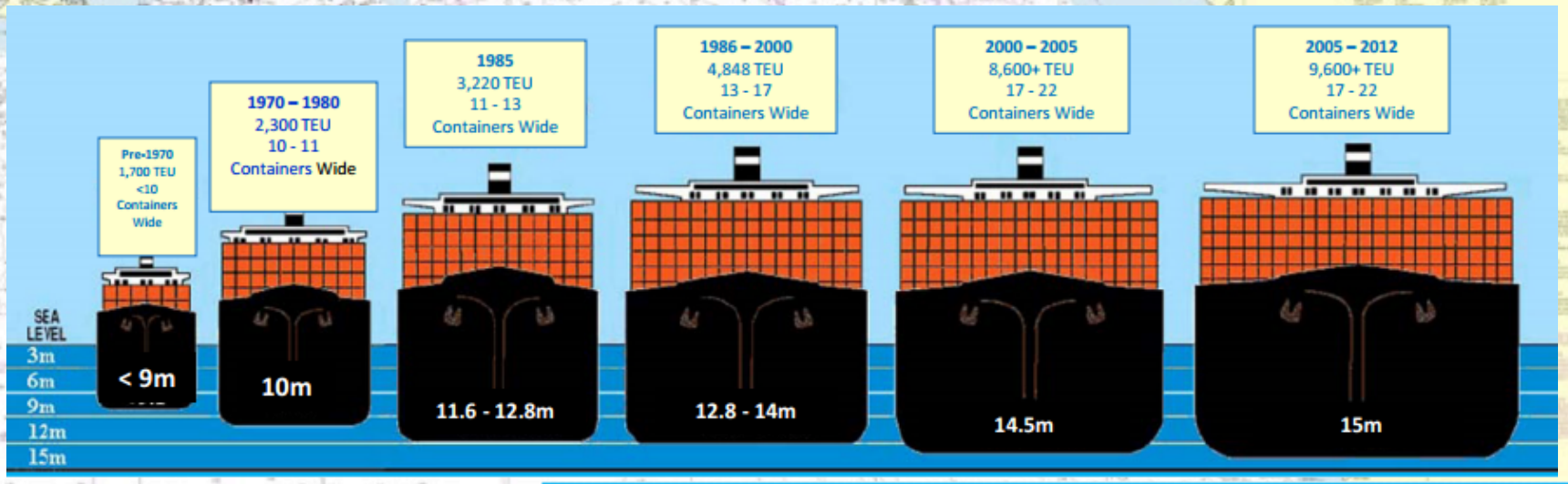
Cargo and container ships rely on accurate charts.



These ships move 95% of all international goods.

Navigating with Smaller Under Keel Clearances Makes Money

Each inch of draft can mean an extra $5M of cargo can be loaded (NOAA/NOS)

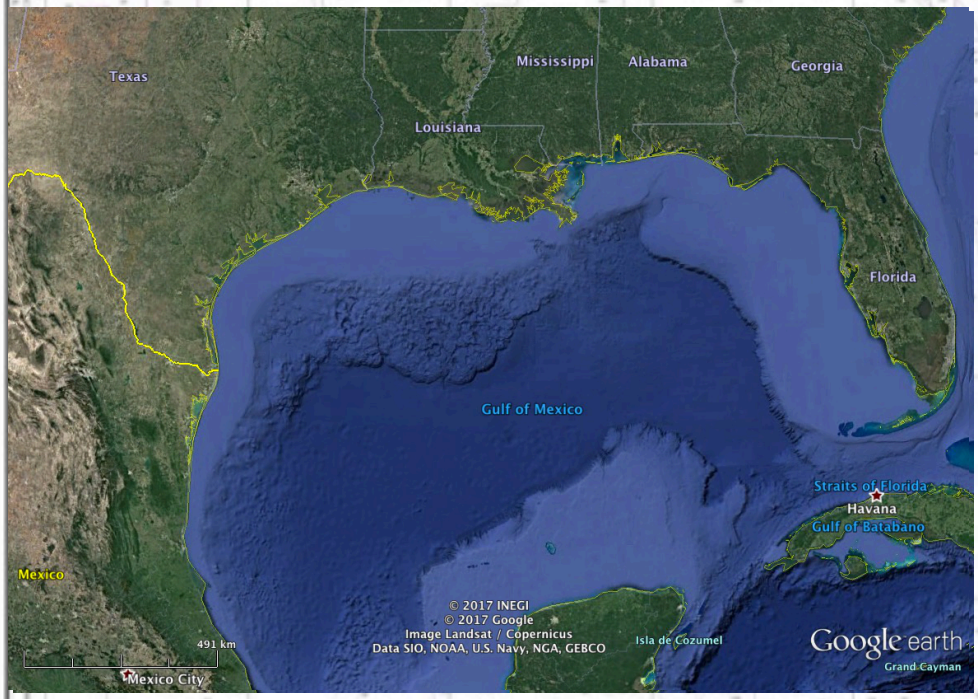


Smaller under keel clearance requires more precise hydrographic data and real-time positioning

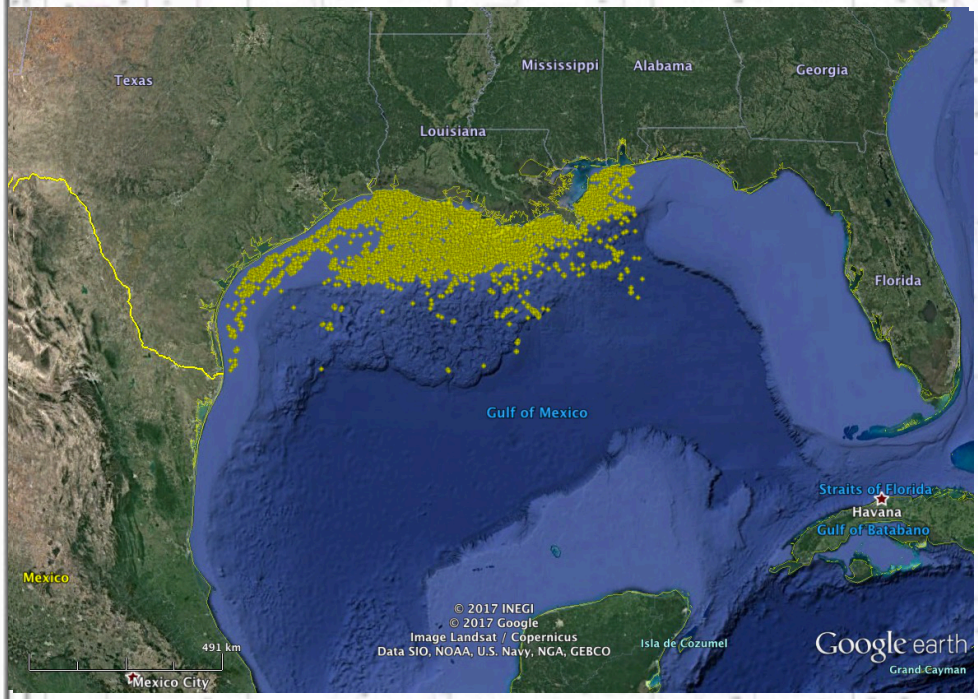
Uncharted waters: Mega cruise ships sail the Arctic: Crystal Serenity Cruise Ship Completes Historic Northwest Passage Arctic Journey – Sep 2016

Viewed online 10/27/16
www.cruisecritic.com

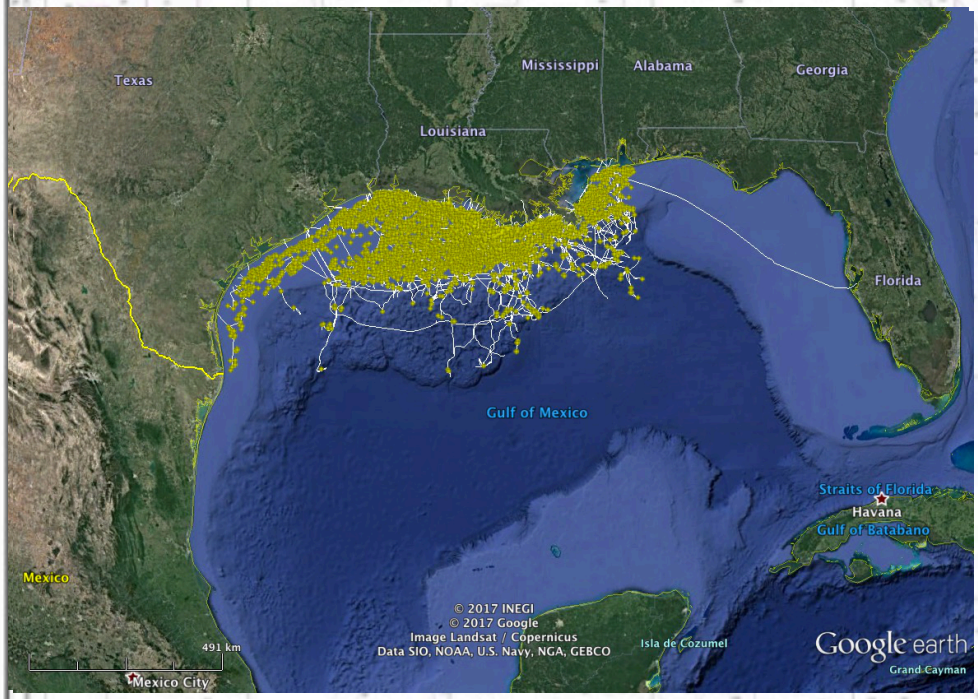
Resource Exploitation
Oil/Gas



Resource Exploitation
Oil/Gas



Resource Exploitation
Oil/Gas



Resource Exploitation
Offshore Wind Farms

Maritime Boundaries Delimitation

As summer arctic ice cover diminishes, seafloor resources become available and new shipping routes open up.

Global Warming Triggers an International Race for the Arctic

As the ice melts, national rivalries heat up over oil and gas deposits and shipping routes.

By Thomas Omestad Oct. 9, 2008 Leave a Comment SHARE

How Best for Coastal and Offshore Aquaculture to Help Feed a Growing Population?

- Half all fish for human consumption now comes from aquaculture
- Food security for the growing world population will be significantly positively impacted by aquaculture

State of the Worlds Fisheries and Aquaculture 2016, Food and Agriculture Organization of the United Nations

NCCOS | National Centers For Coastal Ocean Science

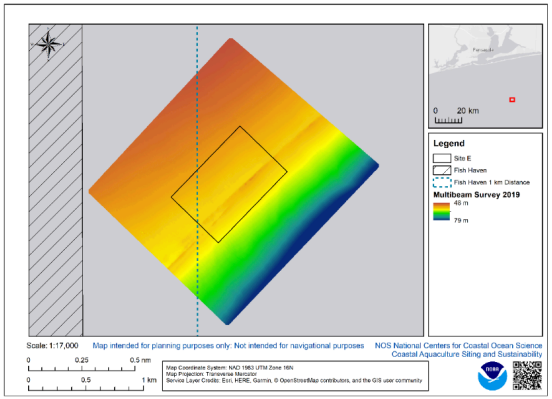
Hydrography provides baseline environmental data for aquaculture siting

Preliminary Results

Baseline Environmental Survey

MANNA FISH FARMS, INC.

STORM SAFE Submersible Cage System



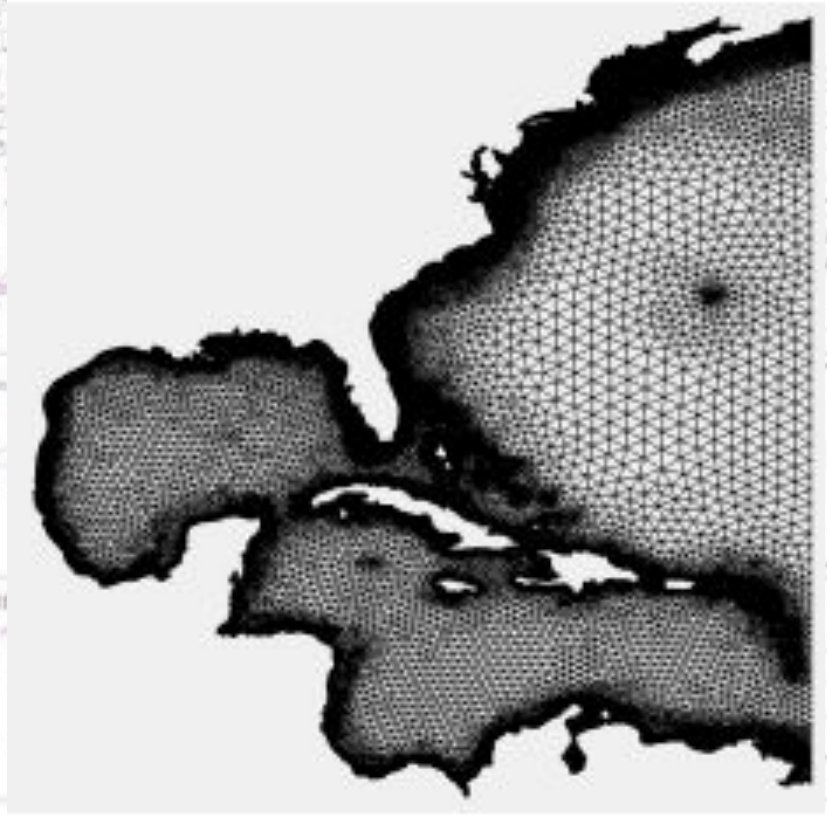
Results of multibeam survey completed April 2019

- Surveyed 0.5 km beyond area of interest
- 2-m resolution
- Depths confirmed 55 m
- Minimal slope across site
- Small ridge detected
- Sand substrate

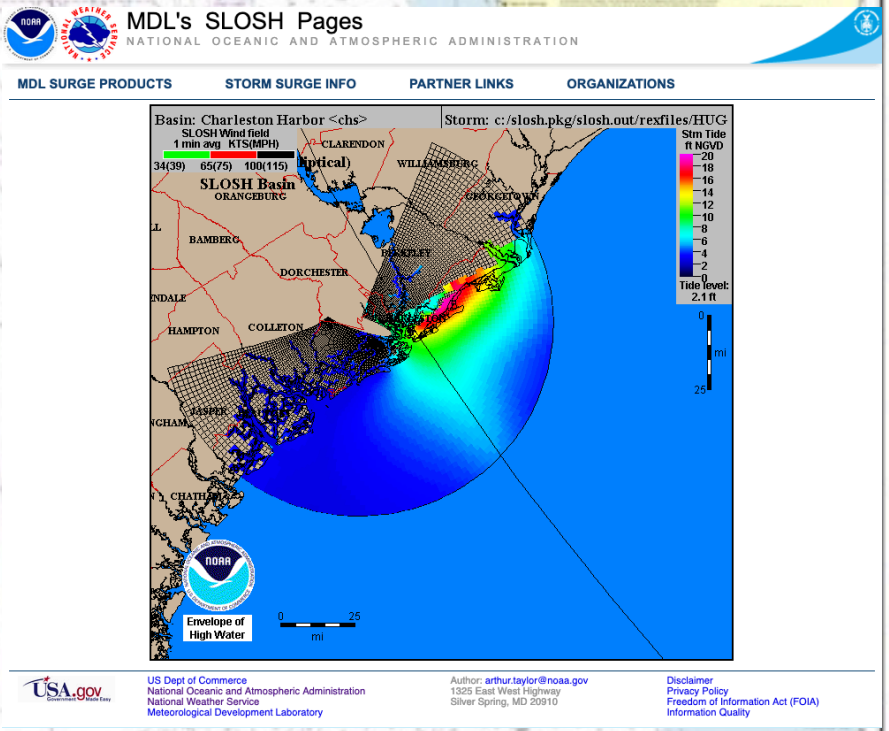
Side-scan and sub-bottom survey May 2019

Accurate Bathymetry and Coastlines Crucial for Numerical Models

Model Grid Requires Depths and Coastline

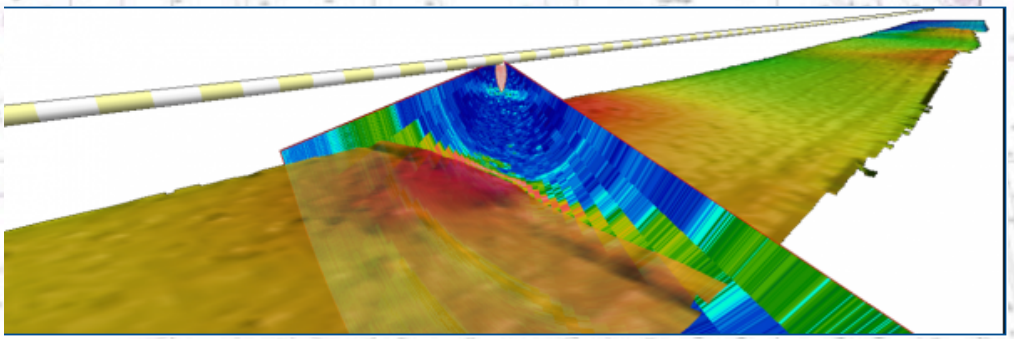


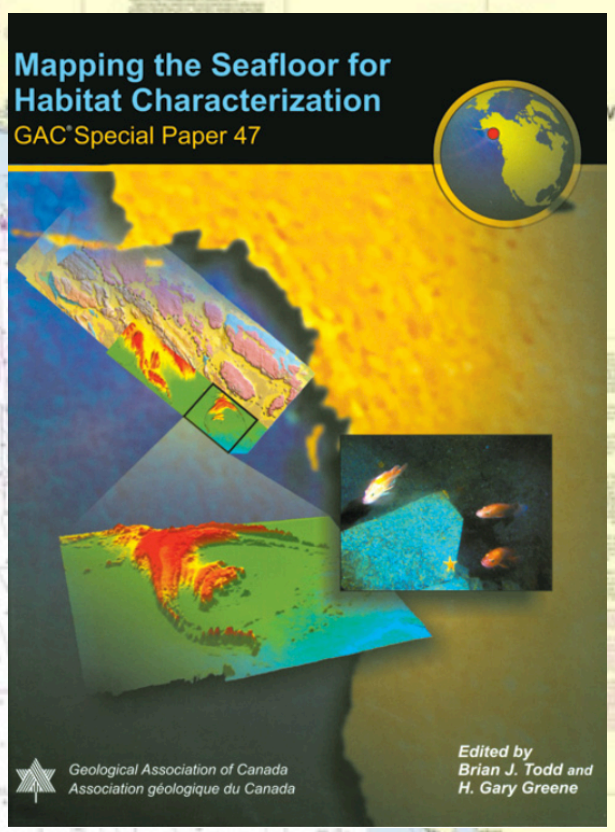
Example Model Storm Surge Output



https://adcirc.org/products/grids/

Water column acoustic backscatter gives information on water column constituents: density layers, zooplankton, fish, …





Seafloor acoustic backscatter gives information sediment and seafloor habitat

University of New Hampshire Center for Coastal and Ocean Mapping

Datums Required for Georeferencing Hydrographic Data

Reference Frames for Positioning for Hydrography

- Vessel – used for relative positioning of sensors (echosounders, GNSS antennas, intertial measurement units, …) on a vessel
- Ellipsoidal/Geodetic
  - Traditionally used for horizontal positioning on the earth
    - Latitude, longitude, basis 2-D for map projections
  - More modern geodetic datums used for 3-D and 4-D positioning
- Orthometric
  - Based on geopotential of earth
  - Traditionally used for vertical positioning
- Tidal
  - Based on sea-level measurements and tidal stages
  - Used for vertical positioning and horizontal positioning for many cadastral applications
- Other – specialized vertical datums for vertical positioning on lakes and rivers

Vessel Coordinate System

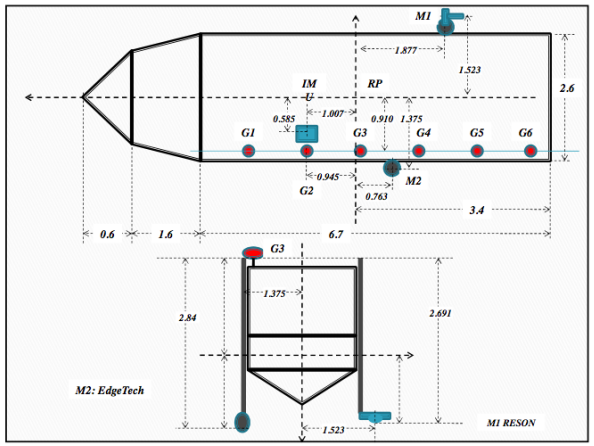
Determine a Vessel Frame of Reference for Instruments for Multibeam Adaptation and Geolocate Soundings

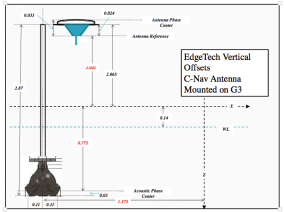
Surveying Vessel & Instrumentation

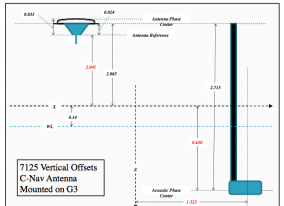


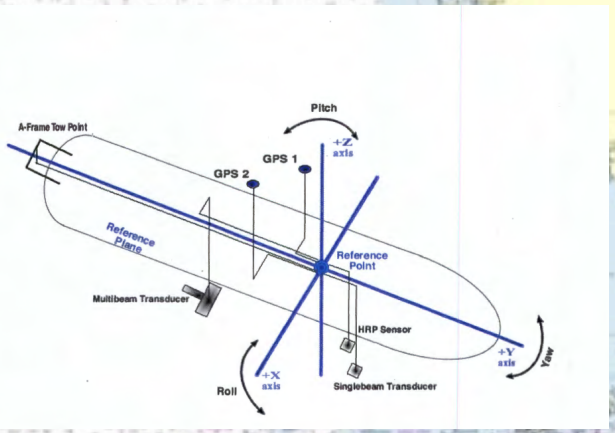

Survey Vessel

Vessel Coordinate System



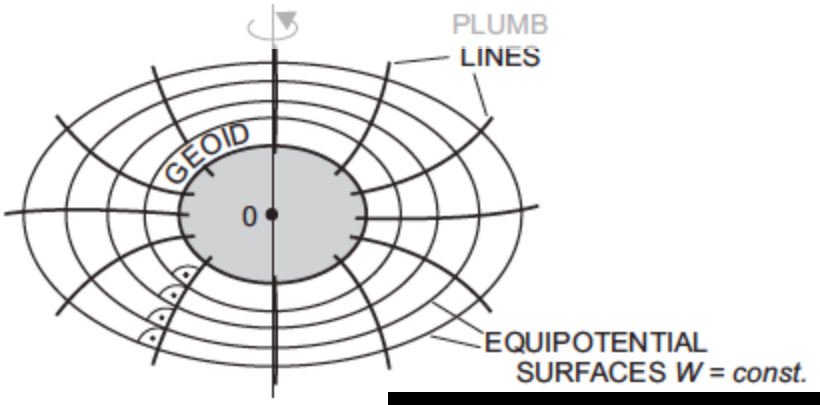




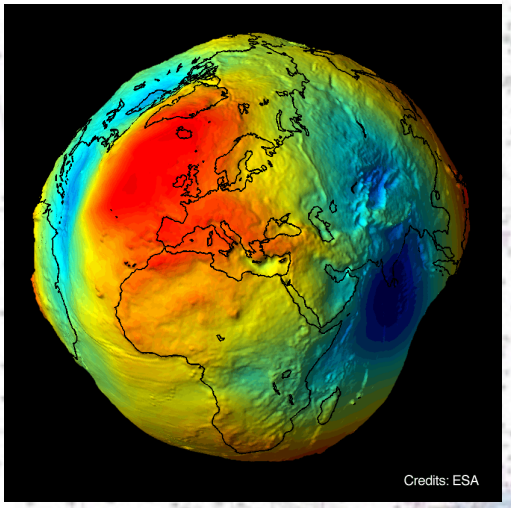


The Geoid

The Geoid- the equipotential surface of the geopotential that best fits global mean sea level (MSL).
- Would coincide with MSL if no forcing or geostrophic balance



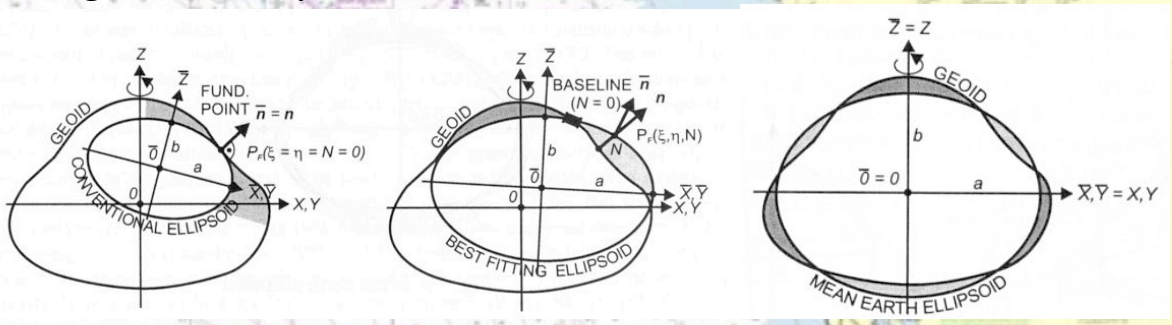
Modern geoid from earth gravity model (European Space Agency) with exaggerated relief from the elliposid



Horizontal/3-D Datums: Geodetic Datums

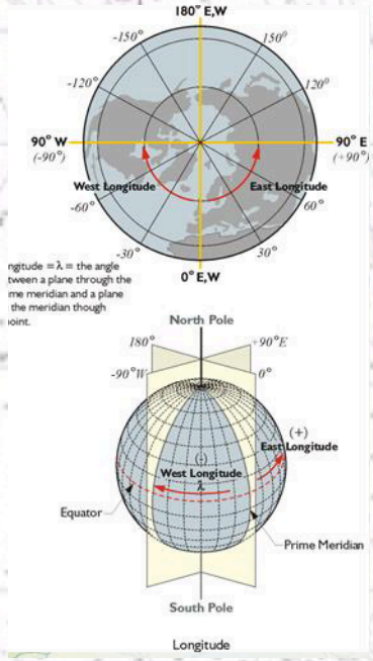
Historical: Best Fit to National or Regional Survey Network/Geoid

Modern: Best Fit to Global Geoid



Source: Torge (2011).

Horizontal positioning (latitude and longitude) of vessel and soundings, and vertical positioning of soundings for Ellipsoidally Referenced Surveys (ERS).

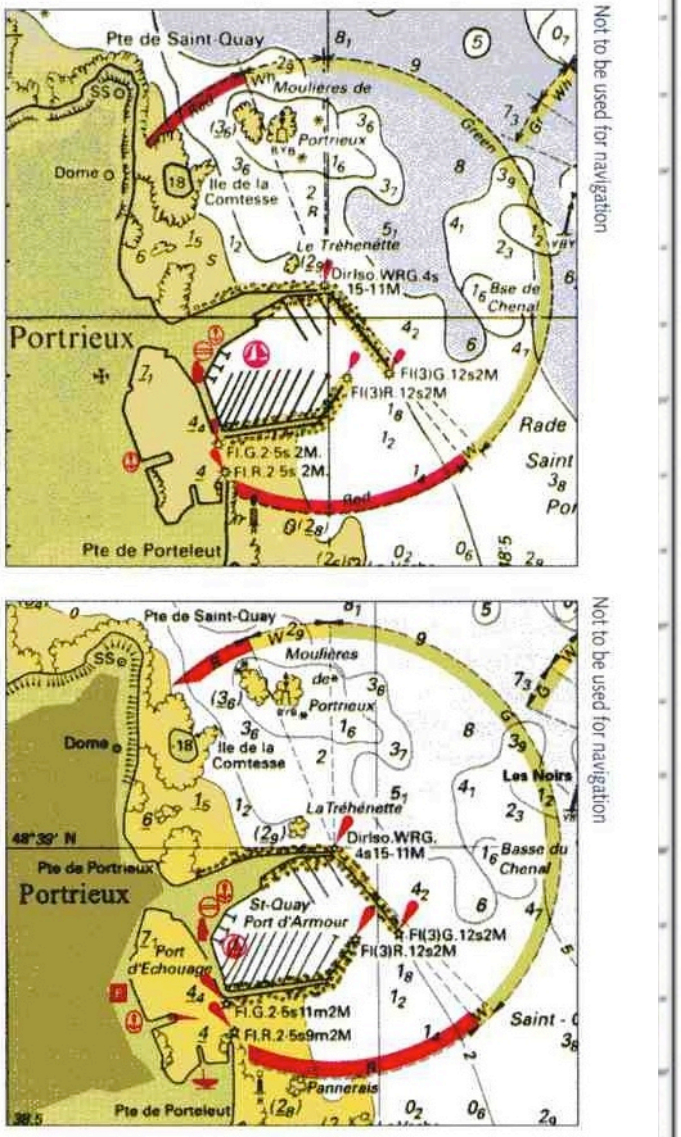


Modern Geodetic Datums Used in Africa:

- World Geodetic System 1984
- African Geodetic Reference Frame

Different Geodetic Datums, Different Latitude and Longitude

Two recent chart editions, two different datums: European Datum (ED 1950) and WGS84.



Source: Nigel Calder, How to Read a Nautical Chart, McGraw-Hill, 2003, 237pp.

Orthometric Datums

The Geoid- the equipotential surface of the geopotential that best fits global mean sea level (MSL).

- Would coincide with MSL if no forcing or geostrophic balance

Orthometric Height – height above the geoid following a vertical tangent path to the gravity vectors - commonly used for terrestrial elevations

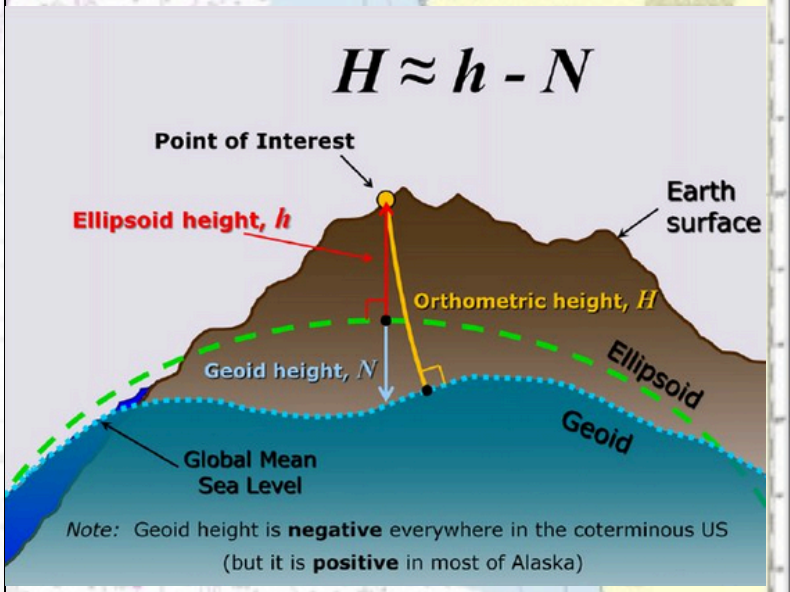


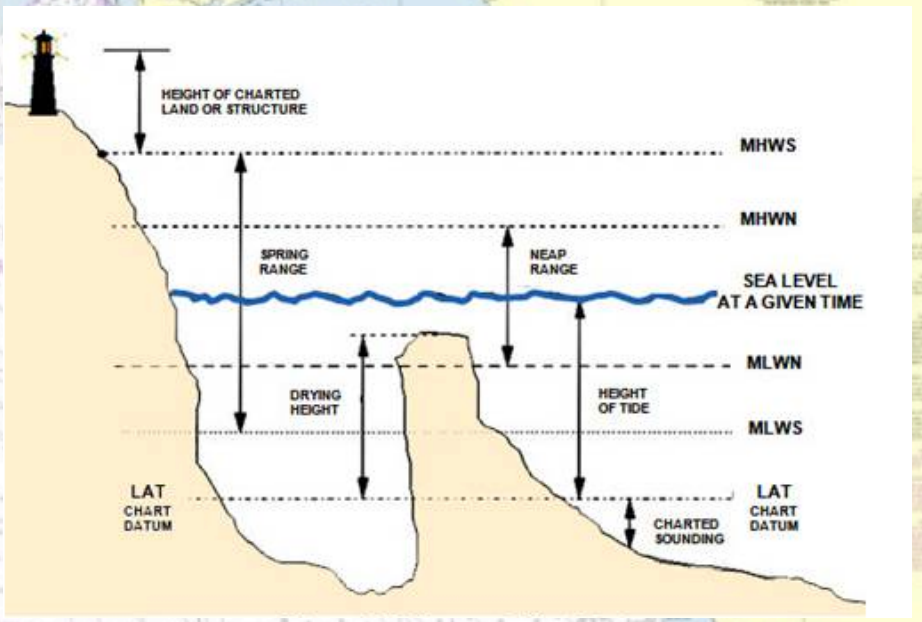
Figure Source: Richard Snay

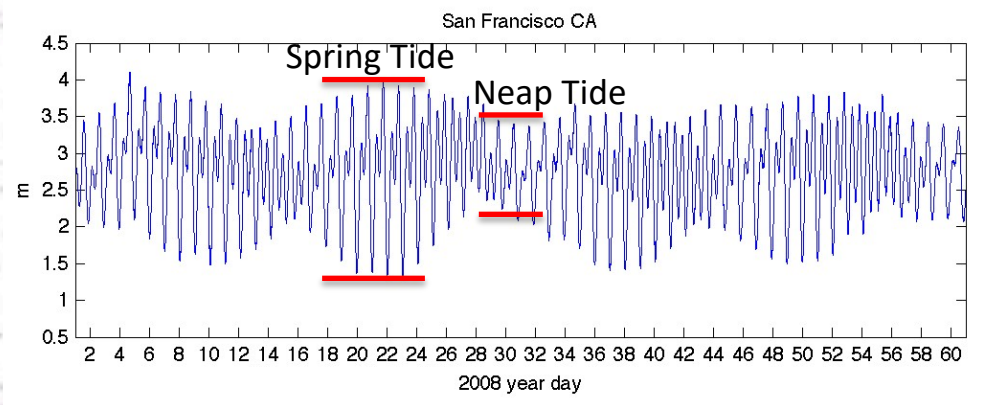
Tidal Datums

There are many different tidal datums defined over particular time periods, or epochs. Examples:

- Mean Sea Level: arithmetic mean of hourly heights
- Mean High Water: average of all high water heights
- Mean Low Water: average of all low water heights observed over the NTDE.
- Mean Lower Low Water: average of the lower low water heights
- Mean Low Water Springs: average of low waters during spring tide
- Lowest Astronomic Tide: Lowest tide level from harmonic analysis

Vertical datums for soundings ("chart datum") and overhead obstructions are tidal datums. IHO recommends Lowest Astronomic Tide (LAT) for chart datum.





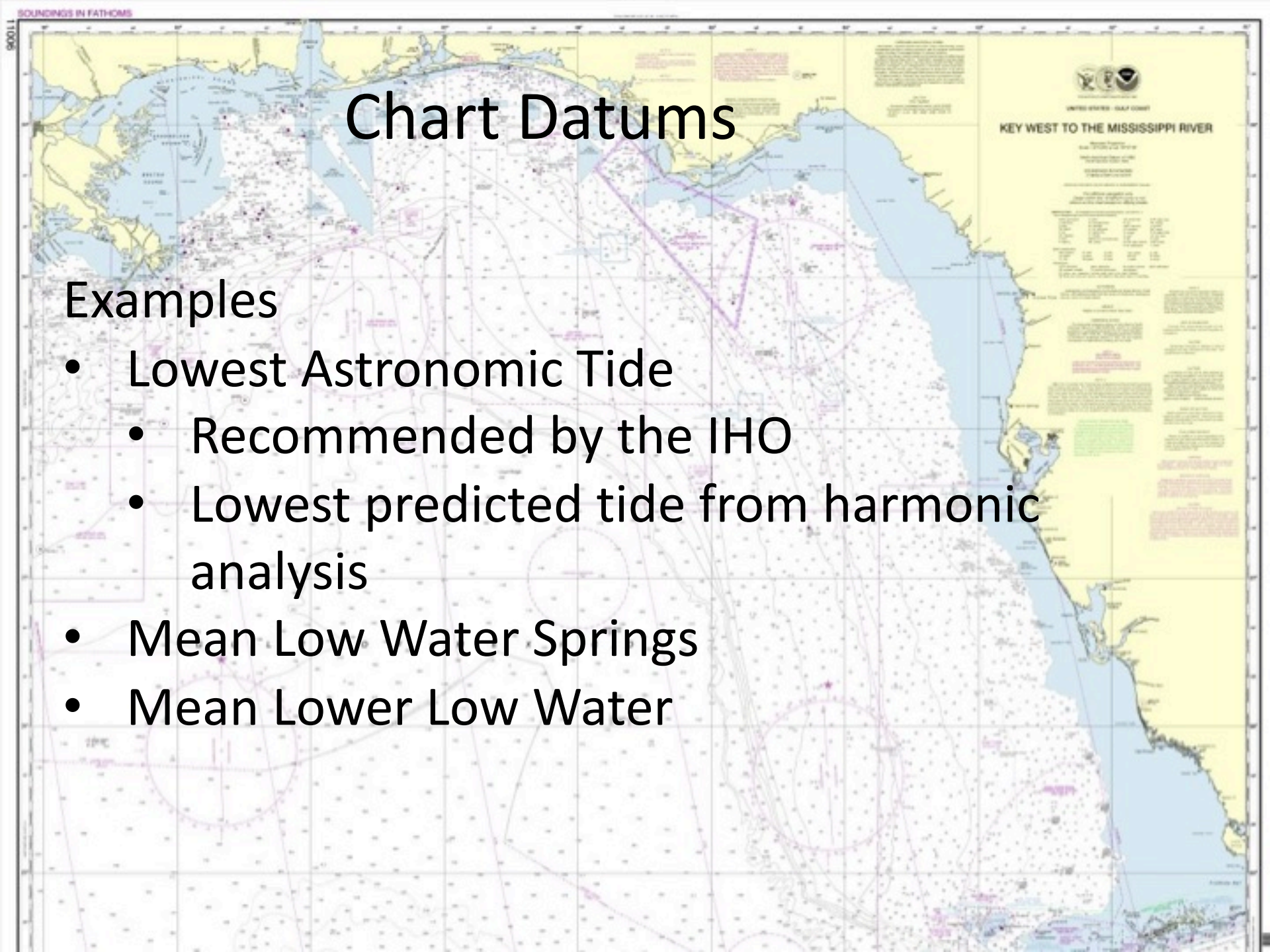
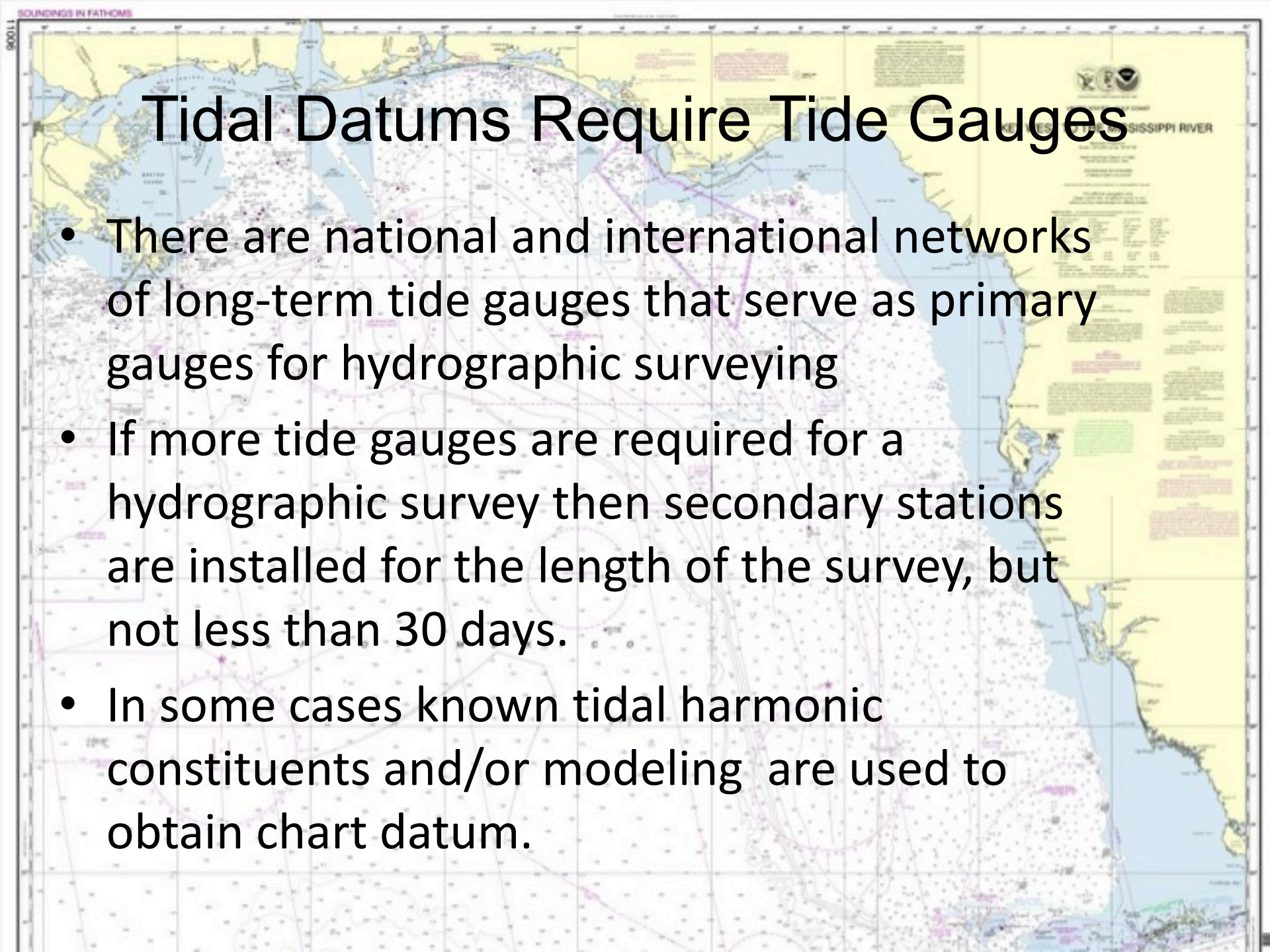


Chart Datums

Examples

- Lowest Astronomic Tide
  - Recommended by the IHO
  - Lowest predicted tide from harmonic analysis
- Mean Low Water Springs
- Mean Lower Low Water



Tidal Datums Require Tide Gauges

- There are national and international networks of long-term tide gauges that serve as primary gauges for hydrographic surveying
- If more tide gauges are required for a hydrographic survey then secondary stations are installed for the length of the survey, but not less than 30 days.
- In some cases known tidal harmonic constituents and/or modeling are used to obtain chart datum.

International Sea-Level Data Centers

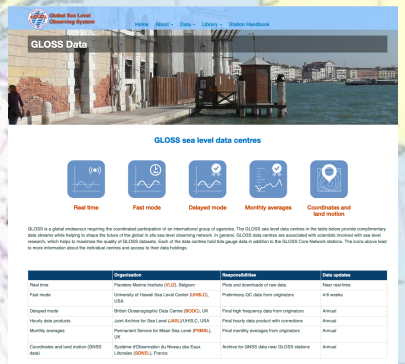
Global Sea Level Observing Center (GLOSS)
https://www.gloss-sealevel.org/

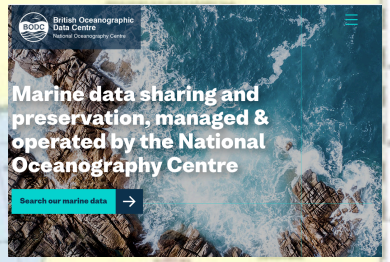
Permanent Service for Mean Sea Level (PSMSL):
https://www.psmsl.org/

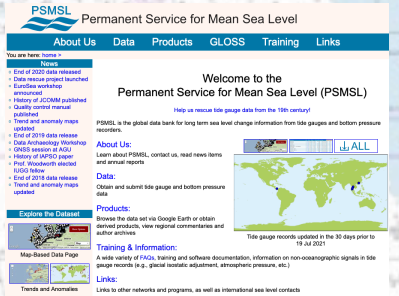
University of Hawaii Sea Level Center:
http://uhslc.soest.hawaii.edu

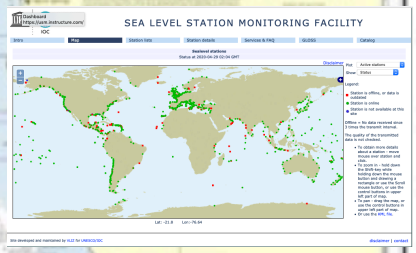
British Oceanographic Data Centre
https://www.bodc.ac.uk/

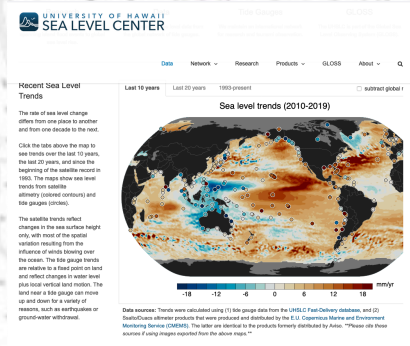
Sea Level Station Monitoring
http://www.ioc-sealevelmonitoring.org/









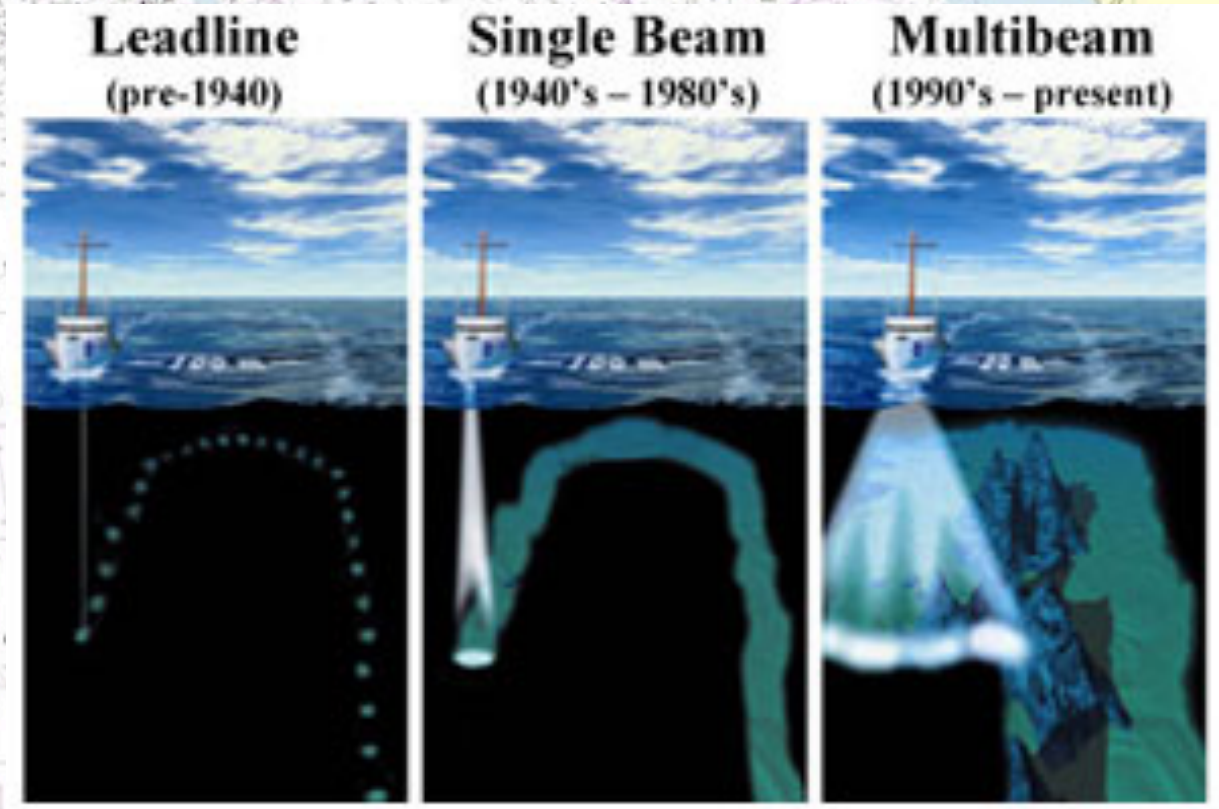


Secondary Gauge Installation for a Hydrographic Survey

Primary Methods of Hydrographic Surveying

- Lead line (old method)
- Acoustic – Single beam echosounder
- Acoustic – Multibeam echosounder
- Airborne LIDAR (Light Detection and Ranging)
- Satellite radar altimetry – does not provide bathymetry to IHO specifications, but provides data where no other available

Mapping the Seafloor From Leadline to Multibeam

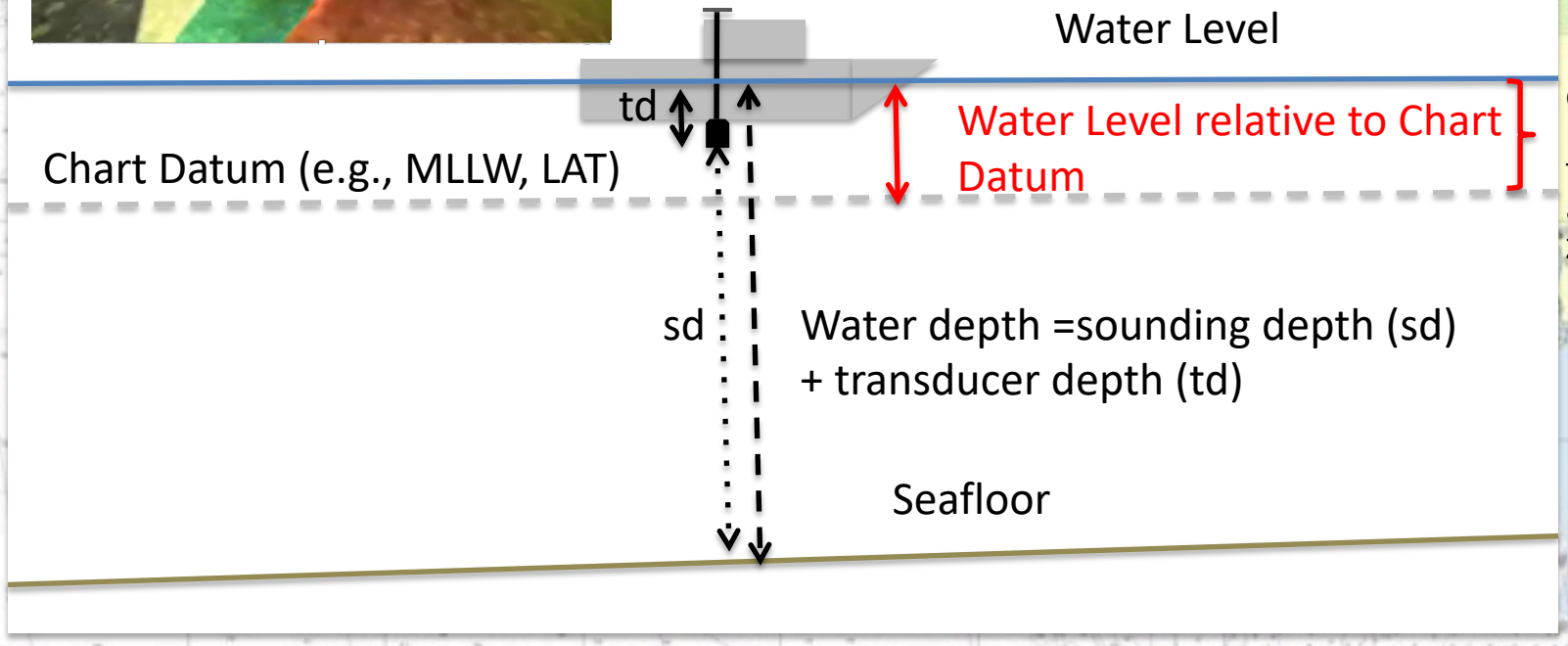


Depth from acoustic two-way travel time

https://www.nauticalcharts.noaa.gov/hsd/images/SW_History_lead2mb.jpg

Multibeam Surveying

Mapping of Seafloor & Sounding Reduction: Traditional Survey



Crucial Information: Tide gauges & Tidal Zoning

Other Complicating Factors

- Vessel Heave
  - mitigate with low pass filter
- Vessel Pitch and Roll
  - Measure and remove if necessary
  - Multibeam system can remove through beam forming
- Vessel Squat
  - Measure and remove if necessary
- Vessel Dynamic Draft
  - Measure and remove if necessary
- Sound speed variations and refraction
  - Measure sound speed profiles

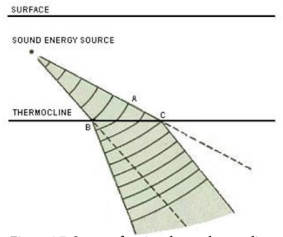
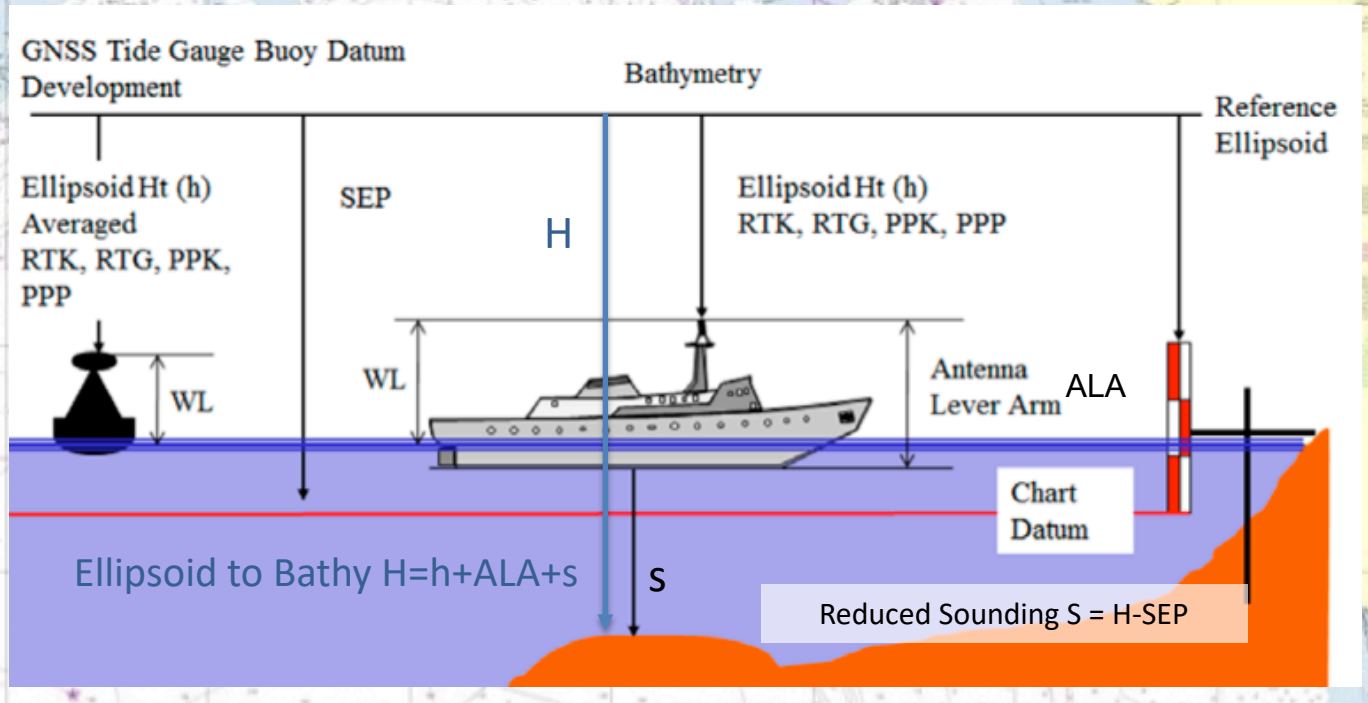


Figure 4.7: Sonar refraction due to thermocline.

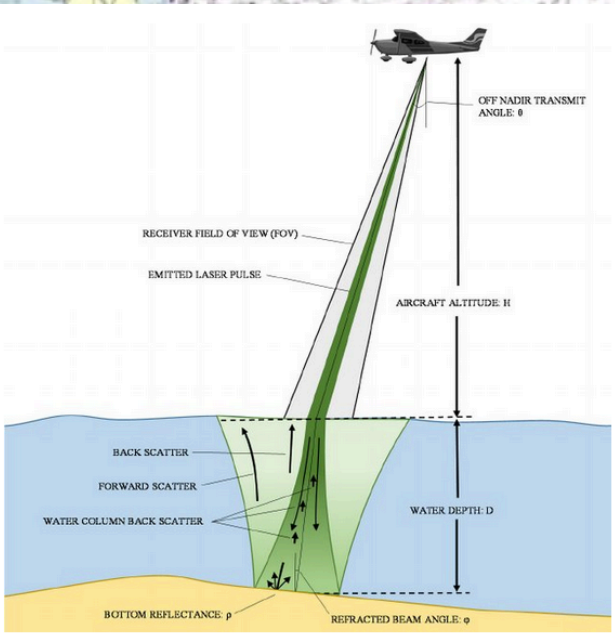
Ellipsoidally Referenced Survey

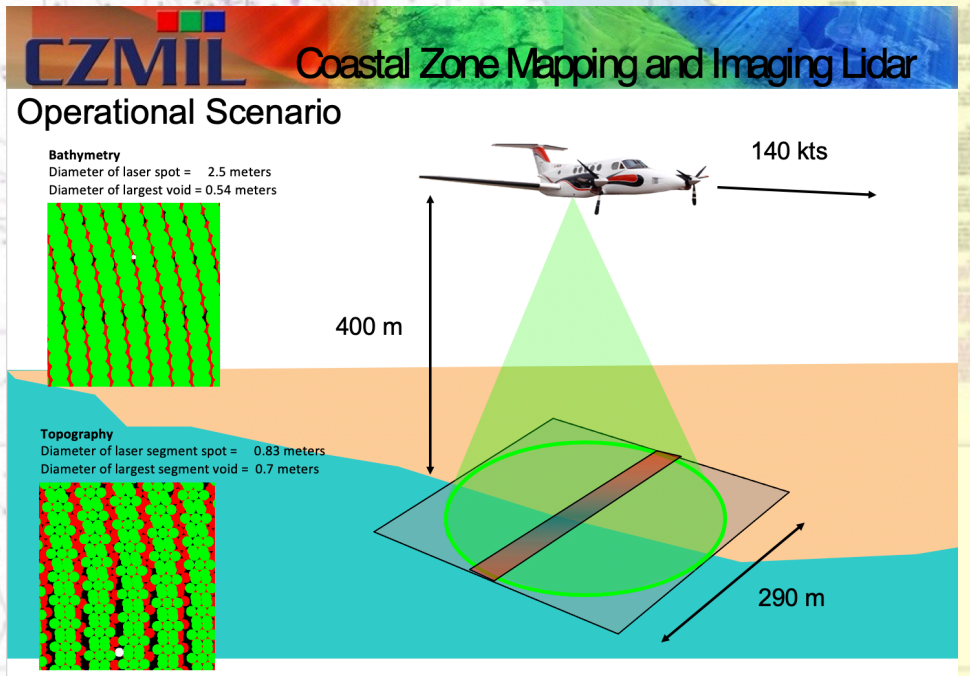
Decoupling Tides from Hydrographic Surveying



- Water depths are measured to the reference ellipsoid
- The separation between the ellipsoid and chart datum ("separation model") may be determined by others (e.g., NOAA in the United States)
- The separation model is used to convert, or reduce, the water depths to chart datum.
- Heave, dynamic draft , squat and water level above chart datum not needed

Mapping the Seafloor From Airborne LIDAR





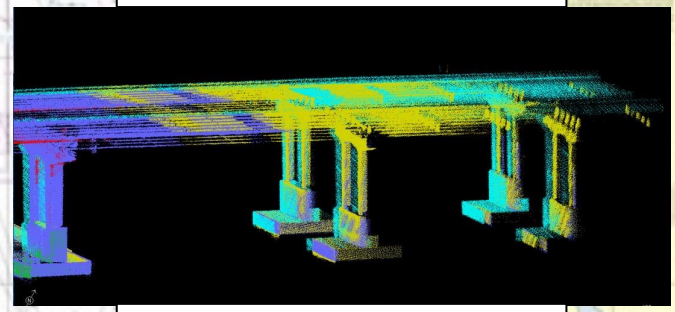
Kashani, A. G., Olsen, M. J., Parrish, C. E., & Wilson, N. (2015). A review of LiDAR radiometric processing: From ad hoc intensity correction to rigorous radiometric calibration. *Sensors*, *15*(11), 28099-28128.

Shorelines, Aids to Navigation (ATON) & Overhead Obstructions

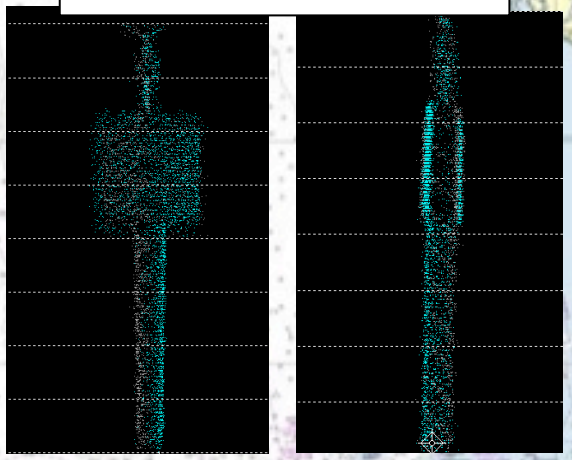
In addition to land surveying and photogrammetry, LIDAR is an efficient way to survey shorelines, ATONs and overhead obstruction

Velodyne LIDAR on USM vessel

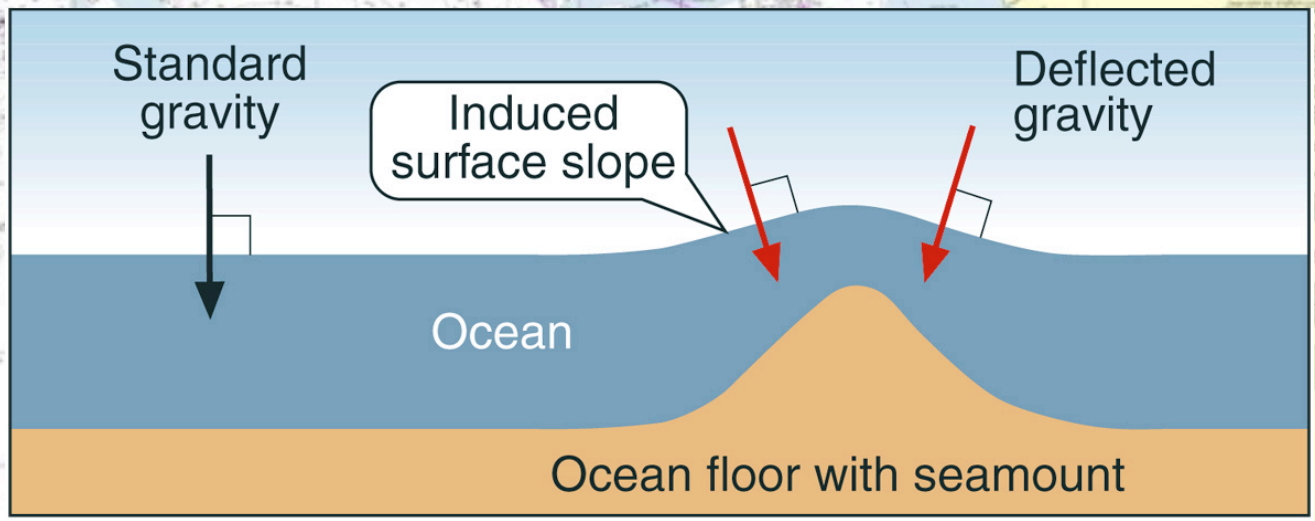
Bridge



ATONS



Satellite Altimetry and Bathymetry



Space radar can sense ocean surface slopes, manifestations of gravity anomalies in the form of deflections of the vertical. These may be correlated with sea floor structure.

Figure from Smith (2003)

Maritime Defense and Security

World oceans altimetry-mapped – 5 km resolution

Moon radar-mapped -100m

Mars radar-mapped – 20m

Venus radar-mapped – 100m

USS San Francisco Accident

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News Notes

Science and Society

Submarine hits unmapped mountain

A U.S. Navy submarine cruising 350 miles south of Guam hit an unmapped seamount, leaving one person dead and more than 20 people injured on Jan. 8. The USS San Francisco had been operating under normal procedures without radar, to avoid surveillance, while using U.S. Navy seafloor maps and satellite imagery. Surface photography seemingly had captured the shadow of the seamount, as it almost breaks above sea level, but had placed the underwater mountain several hundred meters away from its actual position. The vast majority of seamounts in the world's oceans remain unexplored. Photo courtesy of U.S. Navy; by Photographer's Mate 2nd Class Mark Allen Leonesio.

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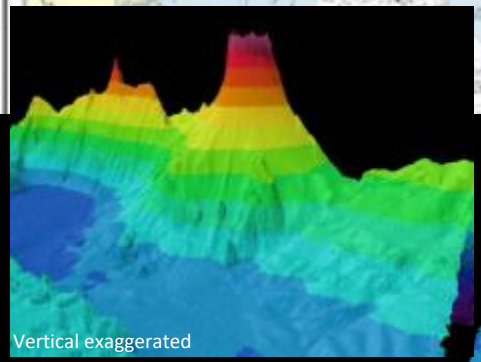
San Francisco Grounding Location Survey

SFO Grounding Survey Polygon

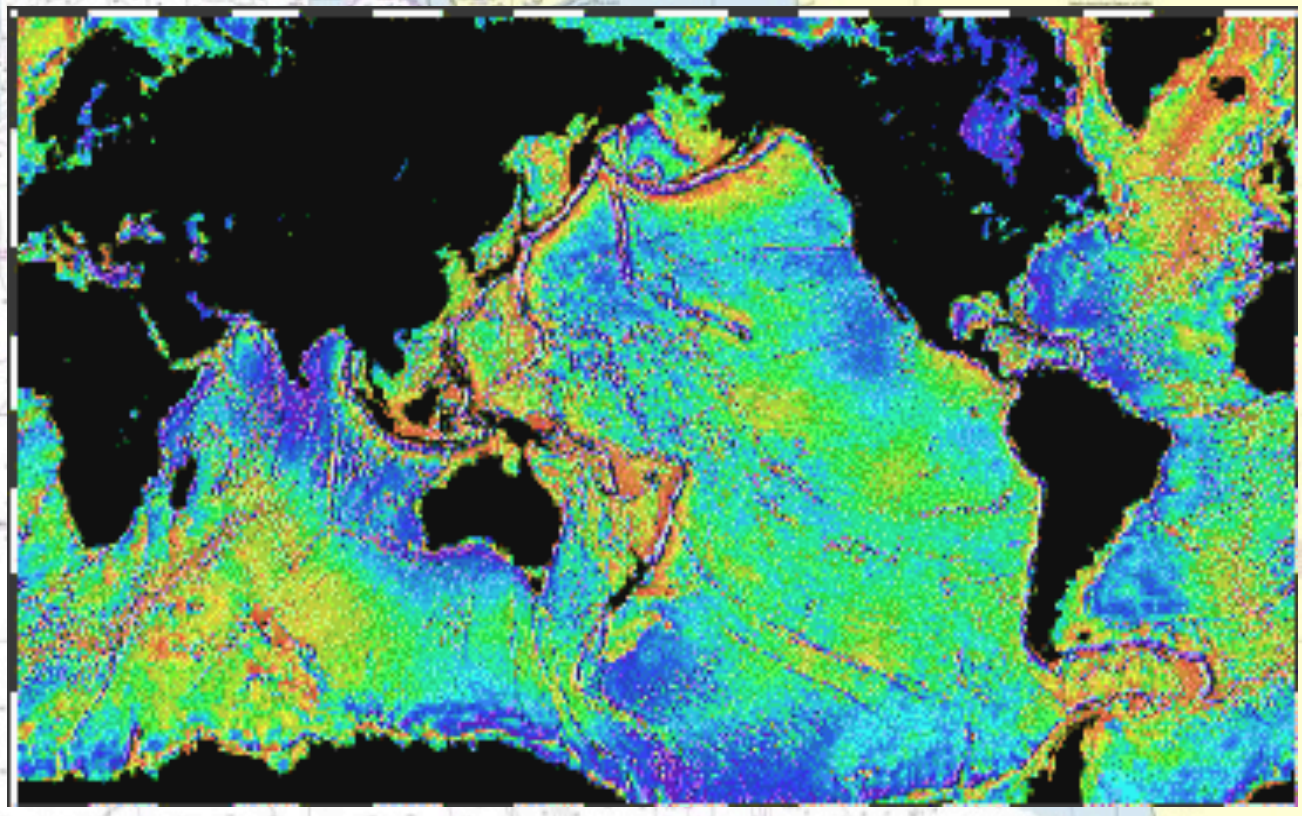


SFO Grounding

New feature

Maritime Defense and Security

Bathymetric Model from Satellite Altimetry



Smith and Sandwell Altimetry Model used to establish potential hazards to Navigation

Hydrographic Survey Standards

- The IHO has standards for 5 orders of surveys that are focused on surveys taken to create or update nautical charts
- National governments may set their own standards
- Private clients may set their own standards

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A principal Aim of the IHO is to ensure that all the world's seas, oceans and navigable waters are surveyed and charted.

The **Mission** of the IHO is to create a global environment in which States provide adequate and timely hydrographic data, products and services and ensure their widest possible use.

The **Vision** of the IHO is to be the authoritative worldwide hydrographic body which actively engages all coastal and interested States to advance maritime safety and efficiency and which supports the protection and sustainable use of the marine environment.

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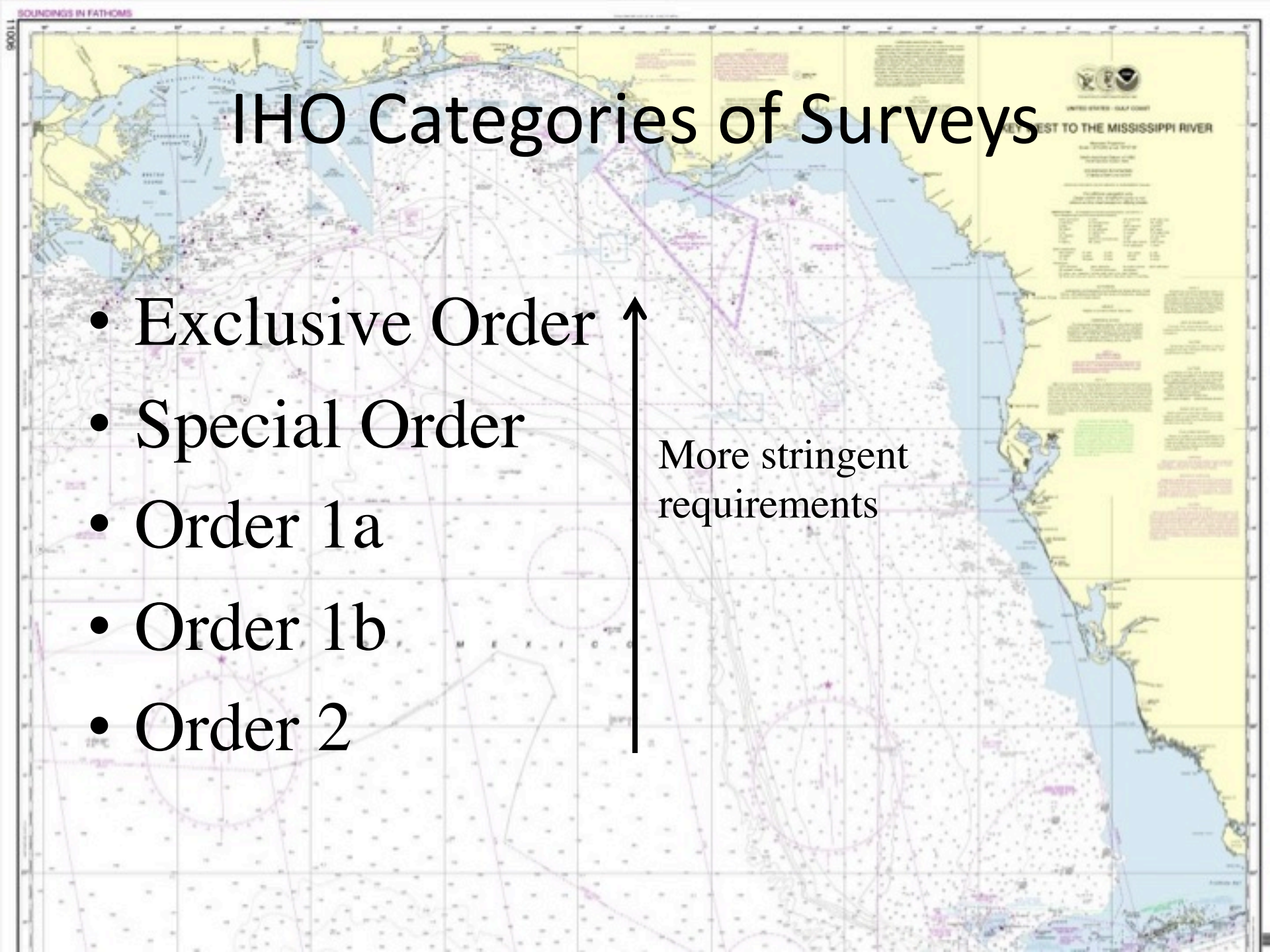
IHO Water Level Requirements

Reference S-44 IHO Standards for Hydrographic Surveys

IHO Categories of Surveys

- Exclusive Order
- Special Order
- Order 1a
- Order 1b
- Order 2

More stringent requirements



7.3 TABLE 1 - Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys

To be read in conjunction with the full text set out in this document, m = metres, all uncertainties at 95% confidence level, * = Matrix Reference.

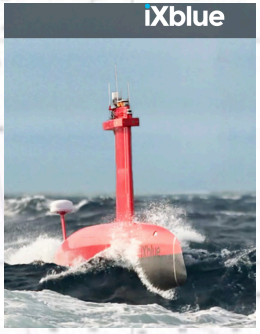
Reference	Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Chapter 1	**Area description** (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.	Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Section 2.6	**Depth THU** [m] + [% of Depth]	20 m + 10% of depth *Ba5, Bb2	5 m + 5% of depth *Ba8, Bb3	5 m + 5% of depth *Ba8, Bb3	2 m *Ba9	1 m *Ba10
Section 2.6 Section 3.2 Section 3.2.3	**Depth TVU** (a) [m] and (b)	a = 1.0 m b = 0.023 *Bc7, Bd4	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.25 m b = 0.0075 *Bc10, Bd8	a = 0.15 m b = 0.0075 *Bc12, Bd8
Section 3.3	**Feature Detection** [m] or [% of Depth]	Not Specified	Not Specified	Cubic features > 2 m, in depths down to 40 m; 10% of depth beyond 40 m *Be5, Bf3 beyond 40m	Cubic features > 1 m *Be6	Cubic features > 0.5 m *Be9
Section 3.4	**Feature Search** [%]	Recommended but Not Required	Recommended but Not Required	100% *Bg9	100% *Bg9	200% *Bg12
Section 3.5	**Bathymetric Coverage** [%]	5% *Bh3	5% *Bh3	≤ 100% *≤ Bh9	100% *Bh9	200% *Bh12

New Directions in Hydrography

- New techniques & technologies for shallow water mapping
  - Drones
  - Digital cameras and structure from motion
  - Compact LIDAR systems
- Citizen science and crowd-sourcing
- Uncrewed vessels

Reigl BathyCopter

Saildrone



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Summary

- Hydrography provides the geospatial framework for oceanography and coastal sciences
- Hydrographic surveying is moving from being focused on mapping the seafloor for nautical charts to exploiting all of the information in the backscatter from the seafloor and water column for multiple uses (“map once, use many times”)
- Hydrographic practices are evolving along with the technology

SEABED 2030

- Collaborative project Nippon Foundation of Japan and General Bathymetric Chart of the Oceans (GEBCO)
- UN Ocean Decade Action

Resources

- IHO www.iho.int
  - Publications https://www.iho.int/iho_pubs/IHO_Download.htm
    - C-47 TRAINING COURSES IN HYDROGRAPHY AND NAUTICAL CARTOGRAPHY https://iho.int/uploads/user/pubs/cb/c-33/C47E-SEPT09-UPDATED-APRIL11.pdf
- NOAA Office of Coast Survey
  - https://www.nauticalcharts.noaa.gov/index.html
  - https://nauticalcharts.noaa.gov/publications/standards-and-requirements.html
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