



Hydrographic Surveying

Exploring Hydrographic Surveying: Technologies and Applications

2026 PSLS Conference

Hershey, PA

Speaker: Matt Sharr

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Overview

- Background and History
- Underwater Acoustics Fundamentals
- Technologies and Platforms
- Survey Products
- Applications

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Overview

- Background and History (~30 minutes)
- Underwater Acoustics Fundamentals (~60 minutes)
- Technologies and Platforms (~30 minutes)
- Survey Products (~30 minutes)
- Applications (~60 minutes)

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Overall Summary

- Almost all inland applications in PA probably require single-beam
 - Aim for most cost-effective and simply to integrate option with your equipment and workflows
 - 200 kHz (single) frequency is likely all you need
 - Try to use reasonable sound speed values
- Water level/vertical datums are key
- UAS-based bathymetric could be force multiplier, particularly for streams, but expensive for smaller companies

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Company and Manufacturer Names

- Numerous company and manufacturer names will be listed or mentioned throughout
 - Helps you all understand some of the options
 - Helps me explain certain topics
 - Not affiliated with anyone but can help make connections

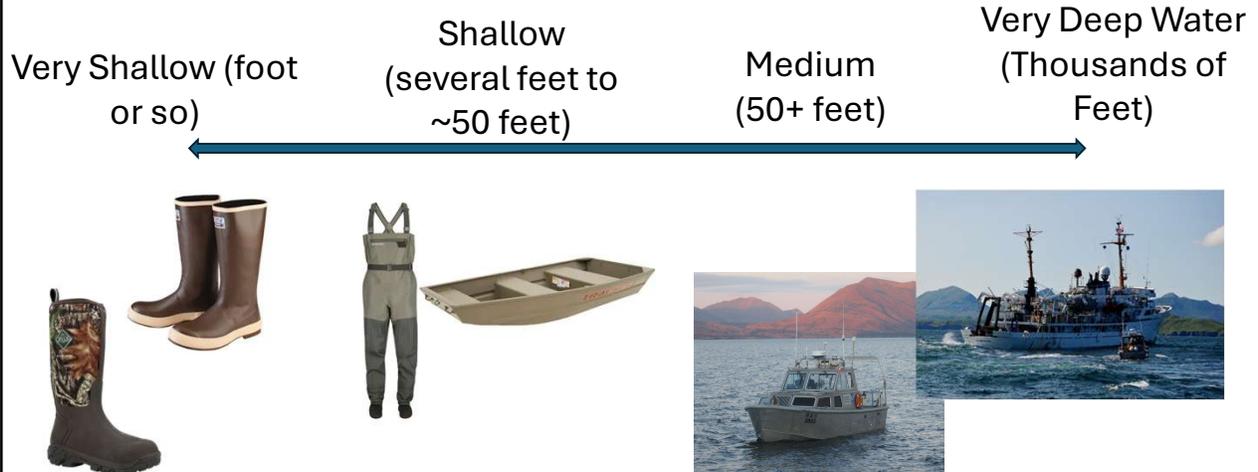
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Hydrography

- Measure of water depth, shape of the seafloor (water body bottom), shoreline, locations of possible obstructions, and other physical features
- My definition:
 - Surveying submerged land / land that is under water
 - Gets at the datum component, not just the water depth
 - Understanding how depth changes in an area

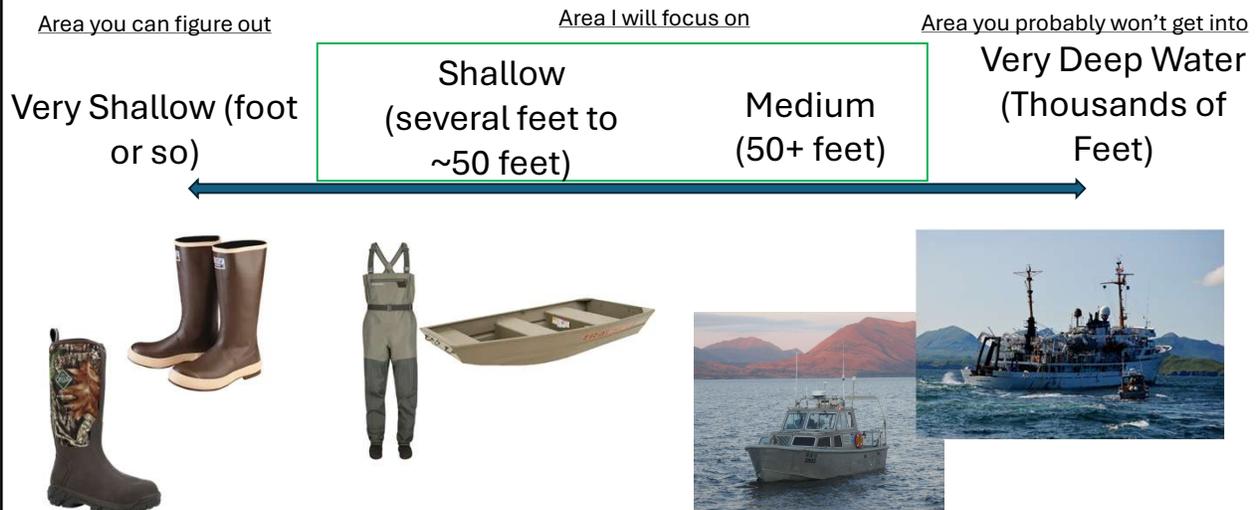
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Hydrographic Surveying



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Hydrographic Surveying

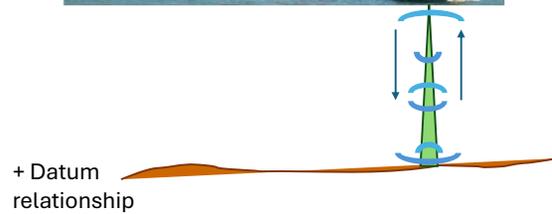


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Hydrographic Surveying

In a nutshell:

- Water depth for a given location
 - Should be referenced to a vertical datum!
- Bathymetry – underwater topography (main goal and product)
- Generally using sound (sonar):
 - Measure two-way travel time
 - Sonar (Sound Navigation and Ranging)



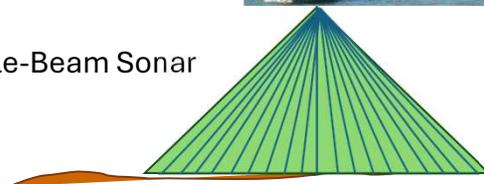
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Hydrographic Surveying



Single-Beam Sonar

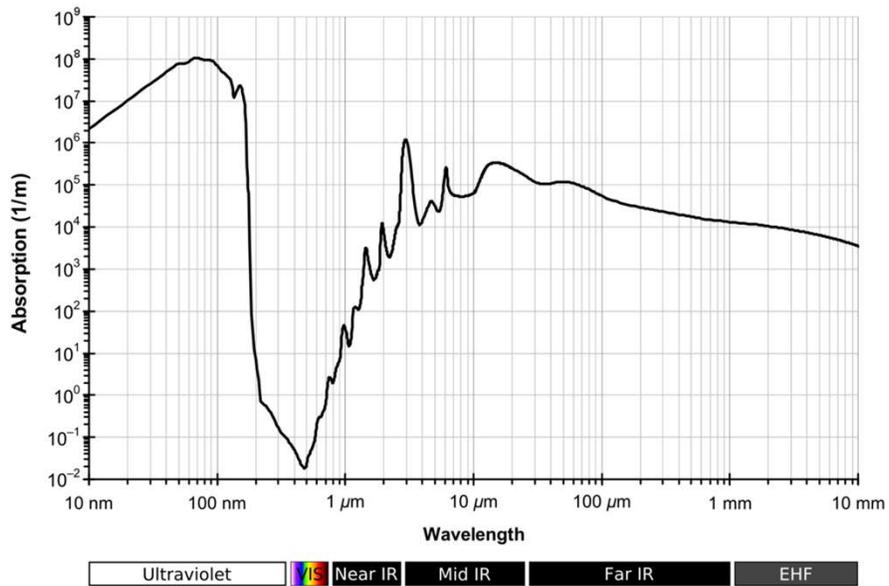
Multi-Beam Sonar



Analogy: Total Station or RTK, versus Laser Scanning

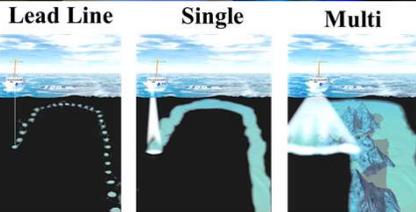
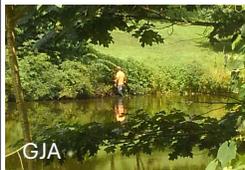
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Reason for using Sound

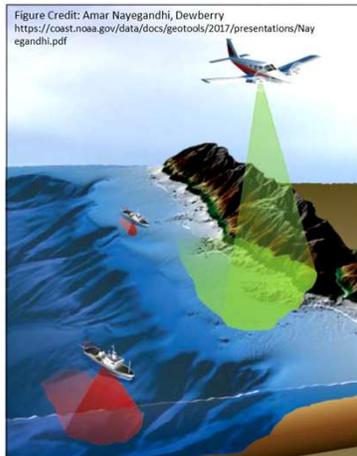


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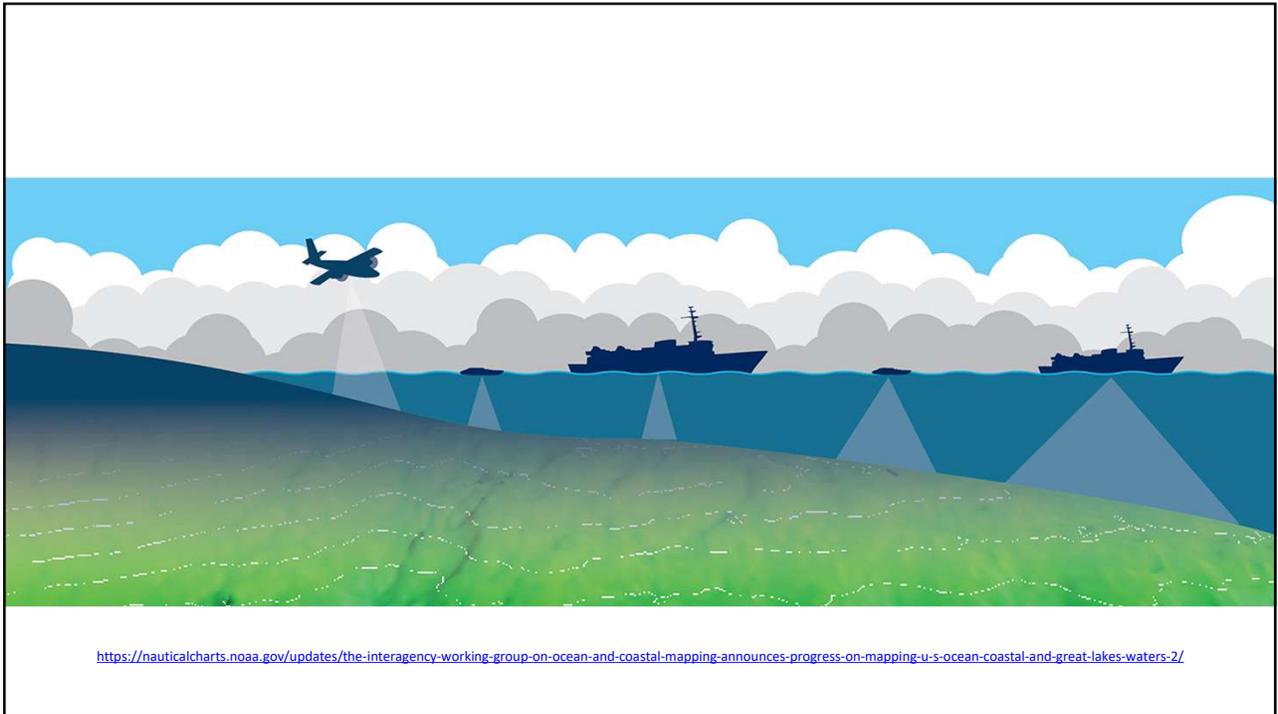
Hydrographic Survey Methods



NOAA



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Modern Survey Equipment

GNSS
Antennas

Interface(s) for logging and
monitoring

"Topside" Electronics

IMU

Transmitter Receiver

Surface Sound Speed

Sound Speed

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Brief History



Egyptian tomb painting, c. 1450 BC.

Sounding
pole



USGS

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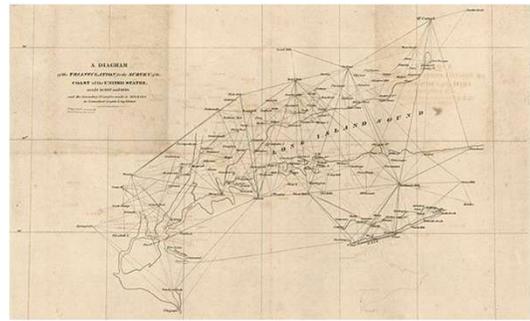
Brief US History

- In the years leading up to the Revolutionary War, ships sailing through modern U.S. coastal waters had to rely on nautical charts with scant information or, too often, they had no charts at all.
- In the 1790s, Congress began authorizing specific and limited surveys of the coast.
- Congress and President Thomas Jefferson tried to rectify that in 1807, by establishing the Survey of the Coast
- Coast Survey was not permanently organized until 1832 -- first hydrographic soundings taken in 1834

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Brief US History

- First complete US hydrographic survey
 - H00001 – Long Island Sound
 - Prospect Point to Throgs Neck
 - Included in first chart printed (1845) *New York-Bay and Harbor and the Environs*
 - Coast Survey didn't have a printing press until 1842



F.R. Hassler, Superintendent

Sounding Sheet No. 1.
(original)

LONG ISLAND SOUND

FROM PROSPECT POINT TO THROGS NECK, N.Y.

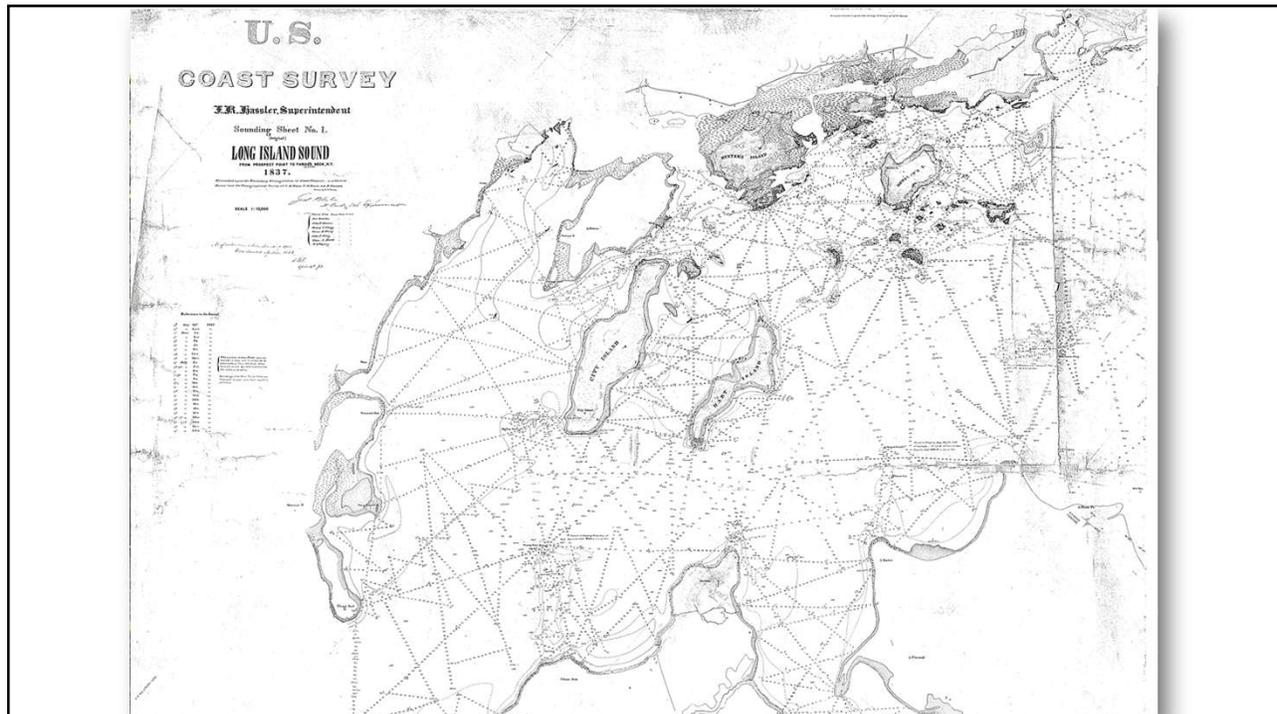
1837.

Grounded upon the Secondary Triangulation of JAMES PERKINS, and EDWARD MANN, and the Topographical Survey of P. M. BARRETT, H. M. BOYD, and T. HENNER.

Just Blin
St. Louis, Mo.

SCALE 1:10,000

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Brief US History

- Early hydrographic surveys utilize lead lines
 - Lines with depth markings and lead weights attached
- Horizontal position/fix determined with three-point sextant/triangulation



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Sounding Leads: Weights & Leadlines



Sounding Lead Weight
plain finish... available in 2 sizes
★★★★★ 36 reviews
From \$34.95



Pre-Spliced Leadline
available in 3 sizes
★★★★★ 12 reviews
From \$77.00



Waxed Sail Twine / Sewing & Whipping Thread
1/4 lb. bulk spool
★★★★★ 34 reviews
\$11.95



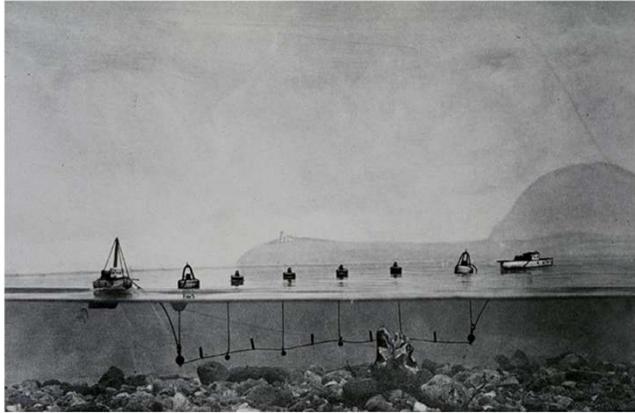
Deluxe NSTM 581 Leadline Kit
30 fathoms / 180-feet
\$794.00

<https://shipcanvas.com/collections/sounding-leads>

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Brief US History

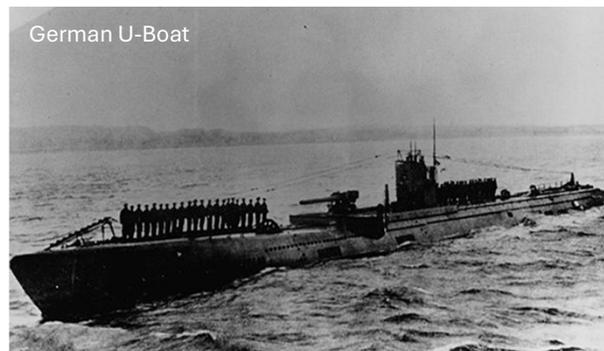
- Wire drag surveys (introduced 1904)



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Brief Acoustics History

- World War I – Acoustic pioneers
 - Passive (listen only) systems first developed by Allies
 - Response to growing covert naval threats
 - Steerable earphones could detect noise and determine direction of submarine/vessel noise
 - Later used similarly for aircraft



<https://monitor.noaa.gov/shipwrecks/world-war-i.html>

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Brief Acoustics History

- Echosounders

- Later, the idea that obstacles or targets could be detected – by transmitting a signal – using active acoustics
- Basics – transmit a sound wave and record the time it takes to come back
- Single beam (type of echosounder) – transmit a short signal below the instrument in a beam (typically 5-15°), and measure the two-way travel time



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Brief Acoustics History

Echosounders

- Greatly more developed during World War II
 - The UK were considerably more advanced in active sonar technology (Royal Navy Allied Submarine Detection Investigation Committee)
- *Physics of Sound in Water (NDRC, 1946; Unclassified, 1964)*

AS EVENTS of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

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Brief Acoustics History

- Post WWII (Cold War), acoustics advanced considerably
 - Nuclear arms race
 - Passive detection of nuclear submarines at long ranges
 - Digital signal processing (1960s)
 - Increased active detection (1990s) with advances in reduced sub noise, with lower frequency systems
- Most civilian systems today trace back to 1960s, 1970s, and 1980s technology

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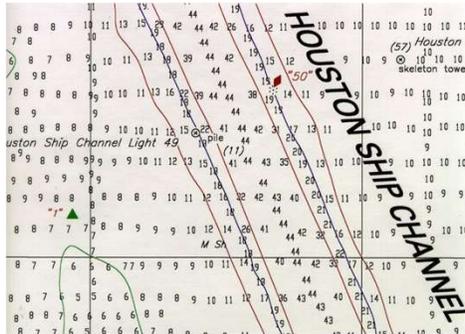
Civilian Acoustics

- Fathometers – sonars for measurement of water depth, mainly used for navigation
- Singlebeam echosounders – similar to fathometer, single measurement of depth directly below system
- Multibeam echosounders – seafloor mapping; multiple depth points determined across a swath
- Sidescan sonar – high-definition acoustic imagery of seabed

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Basic Units and Definitions

- Units – Depth generally in feet, fathoms, or meters
- Depth – typically positive down (vs Heights, which are positive up)



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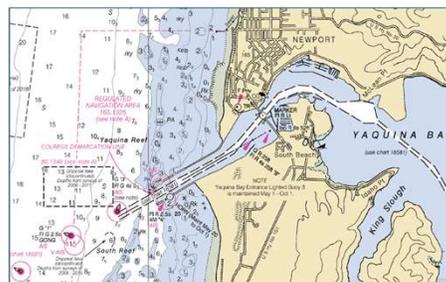
Maritime Units

- Depth (positive down)
 - Feet (int)
 - Fathoms (fa; fm) = 6 ft = 1.8288 m
 - Ft (int) = 0.3048 m
- Distance
 - Nautical Miles (NM) = 1852 meters = 60 minutes (latitude)
 - 1 degree latitude = 60 minutes = 60 nautical miles
 - 1 Nautical mile \approx 1.15 statute miles
 - Ft (int) = 0.3048 m
 - 1000 m = 1 km

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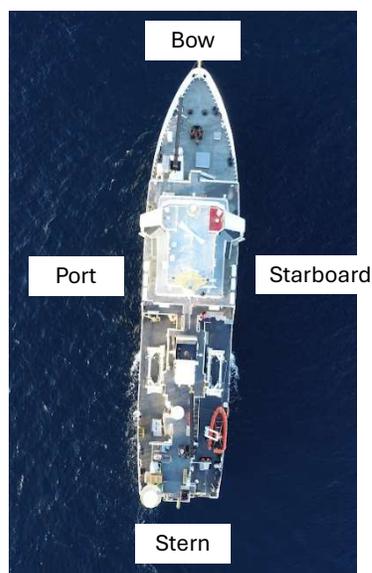
Maritime Units

- Old raster charts (RNC) and smooth sheets (surveys) – feet and fathoms
- Electronic Navigational Charts (ENC) – generally meters only!



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Maritime Terms



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Hydrography Datums

- Vertical – water depth relative to what?
 - Thing we generally focus on
 - E.g., NAVD88, MHHW, MHW, MSL, MLW, MLLW
- Horizontal – E and N, X and Y, Latitude and Longitude
 - E.g., State Plane (PA – N or S)

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Overview

- ~~Background and History~~
- **Underwater Acoustics Fundamentals**
- Technologies and Platforms
- Survey Products
- Applications

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Underwater Acoustics

- Acoustics: the generation, transmission and reception of energy in the form of vibrational waves in matter (de Jong, et al., 2002)
 - Matter can be gas (e.g., air), liquid (e.g., water), or solid
 - The most common example (and what we care about) is sound

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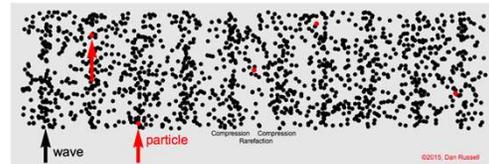
Underwater Acoustics

- Acoustic (sound) waves propagate easily through water
 - Whereas, water highly dissipates other technologies (e.g., radio, radar)
- Propagation speeds are four-five times higher in water than in air
 - ~1500 m/s (4900 ft/s) in seawater
 - Slightly slower in freshwater: ~1450 m/s
 - ~340 m/s (1100 ft/s) in air

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Underwater Acoustics

- Sound is all of the following:
 - A wave
 - Longitudinal wave
 - Mechanical wave
 - Pressure wave

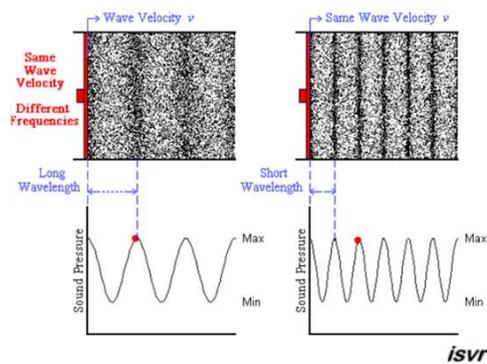


Work by [Dan Russell](#) is licensed under a [Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License](#). Based on a work at <http://www.acs.psu.edu/drussell/demos.html>.

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Wavelength & Frequency

- Wavelength – distance between successive crests/troughs
- Frequency – number of cycles per second (Hz)



https://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-frequency.htm

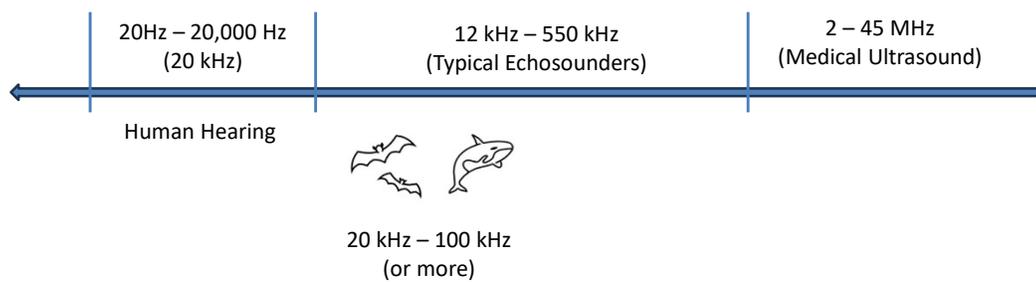
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Frequency Units

Frequency Unit	Conversion from Hz
Hertz (Hz)	1 Hz = 1 Hz
KiloHertz (kHz)	1 kHz = 1,000 Hz
MegaHertz (MHz)	1 MHz = 1,000,000 Hz

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Human Hearing Range



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Echosounders

Kongsberg EM 122: 12 kHz



Kongsberg EM 2040: 200 kHz - 400 kHz



Norbit WINGHEAD i80S:
Nominally 400 kHz



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Echosounders

200 kHz



Seafloor™

38/200 kHz



KONGSBERG

200 kHz



TELEDYNE MARINE
Everywhere you look



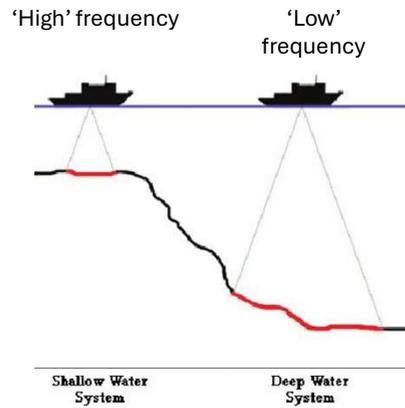
odomhydrographic.com

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Echosounder Frequency

- Frequency vs. Water Depth

- High frequency
 - More easily attenuated
 - Lower depth range
 - High resolution
- Low frequency
 - Less easily attenuated
 - More depth range
 - Lower resolution



Modified from: Thurman, E., Riordan, J. and Toal, D., 2009. Multi-sonar integration and the advent of sensor intelligence. *Advances in Sonar Technology*, pp.151-164.

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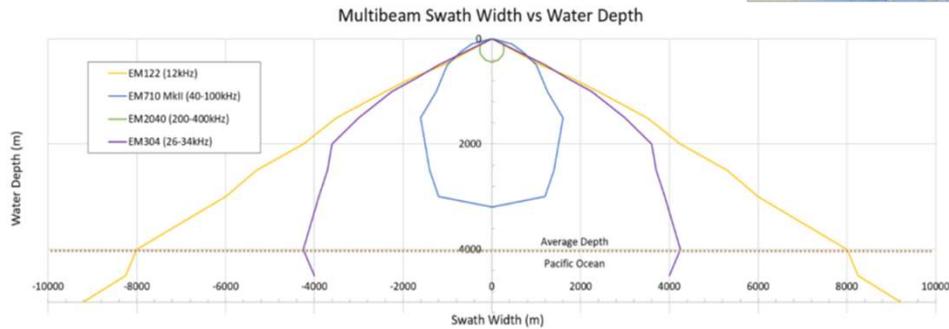
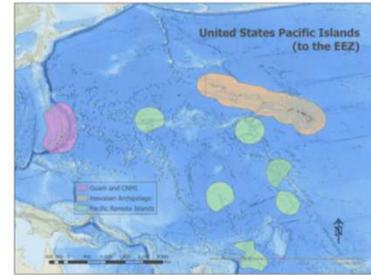
Echosounder Frequency

Application	Typical Frequency Range	Type of Vessel/Deployment
Sub-bottom profiling (geological and geophysical exploration surveys – i.e., oil and gas)	2 - 16 kHz	Often towed, rather than hull-mounted
Deep-water mapping	12-30 kHz	Large, deep-sea going ships
Shallow-water mapping	100 – 200 kHz	Smaller ships/boats
Mapping localized areas or specific objects of interest	200 – 550 kHz	Small boats or even remotely operated boats (can be made very small)

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Echosounders

- “...the optimal equipment used to map the seafloor in waters to a depth of 5,000 m is very different from the instruments and platforms used to map in 50 m”

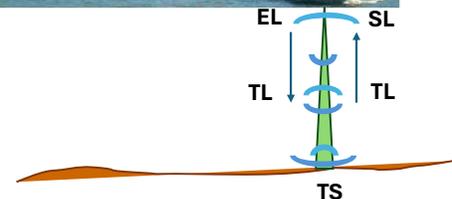


Sharr, M., Owen, H., Urquhart, K., Brogan, K., Greenaway, S., White, S., Kum, J. and Head, M., 2020. A plan to finish mapping the Pacific US Exclusive Economic Zone.

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Active Sonar

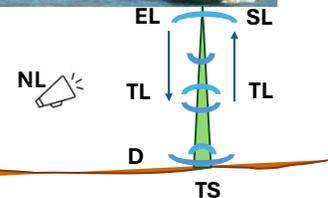
- Basic sonar equation components:
 - Echo level (EL)
 - Source level (SL)
 - Transmission loss (TL)
 - Spreading and absorption
 - Target Strength (TS)
- All are in units of DeciBels



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Active Sonar

- Basic sonar equation components:
 - Echo level (EL)
 - Source level (SL)
 - Transmission loss (TL)
 - Spreading and absorption
 - Target Strength (TS)
 - Noise level (NL)
 - Direction (D)
- All are in units of DeciBels



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Active Sonar

- Common sense sonar equation components:
 - Echo level (EL)
 - If a sound is strong enough to be detected
 - Source level (SL)
 - Power of the transmitted signal
 - Transmission loss (TL) – function of distance, frequency, and chemical reactions in the water
 - Why you can't use a high frequency system in deeper water
 - Target Strength (TS) – physical nature of the target (size, material, shape)
 - Hard bottom will reflect more energy than soft bottom
 - Noise level (NL) – other noise sources in the area could cause issues
 - Like talking on a cell phone on a windy day

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Passive Sonar

- Listen only
- Many applications outside of hydrographic survey
- Useful for looking into system performance and other potential installation
- Generally, not applicable for us

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Sound Speed

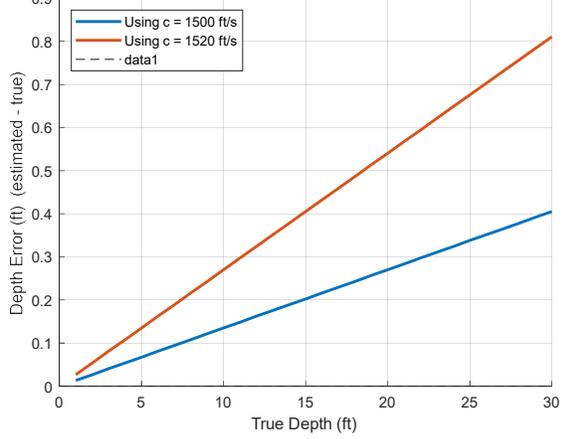
- Measuring two-way travel time generally requires knowledge of the speed at which a sound wave will move through the water
 - Freshwater speed of sound: about 1480 m/s
- Generally, varies based on:
 - Depth
 - Temperature
 - Pressure
- Measured using sound speed sensor

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Sound Speed

- Potential error example:
 - Correct sound speed = 1480 m/s
 - Sonar using 1500 and 1520 m/s

Depth Error vs True Depth for Incorrect Sound Speeds (True c = 1480 ft/s)



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Sound Speed

Indirect

- Measure components individually
 - Conductivity
 - Temperature
 - Depth (pressure)



SonTek CastAway-CTD



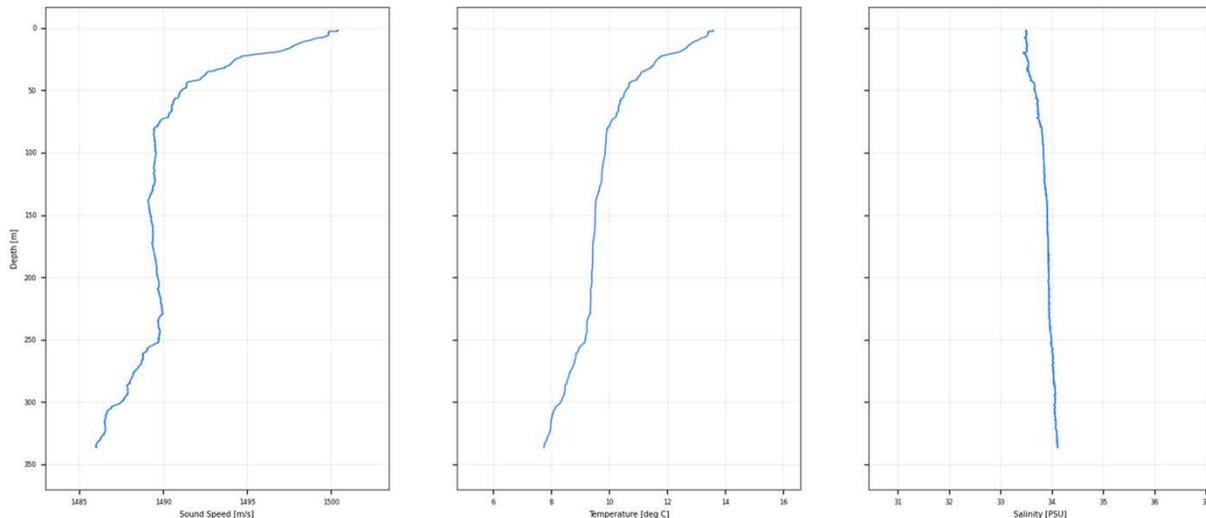
Direct

- Known distance between small transducers
- Typically used with multibeam (i.e., surface sound speed)



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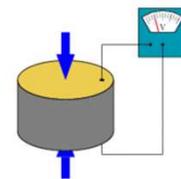
Indirect Sound Speed



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Transducers

- A transducer is simply a device that converts energy from one form to another
- Made of piezoelectric elements
 - “Piezoelectric” = electricity caused by pressure
- What a transducer does in an echosounder
 1. Converts electrical signal into acoustic signal
 2. Sends acoustic signal into water
 3. Receives acoustic signal echo
 4. Converts acoustic signal back to electric signal



Piezoelectric disk generates a voltage when mechanical stress is applied and vice versa (from Wikipedia)

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Transducer Components

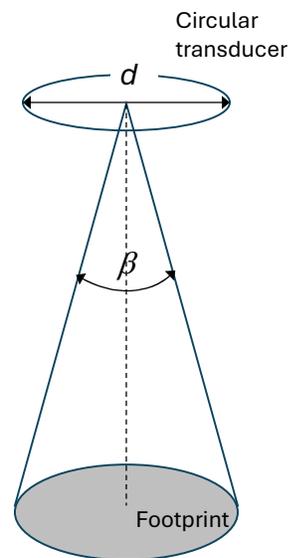
- Transmitter
- Receiver
- Combined transmitter & receiver



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Beam Resolution

- For a circular transducer, the beamwidth corresponds with the wavelength (and frequency) and diameter
- In general, this is why higher frequency results in better resolution



Adapted from de Jong et al. (2010)

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Beam Resolution

- 200 kHz Specification example

SPECIFICATIONS

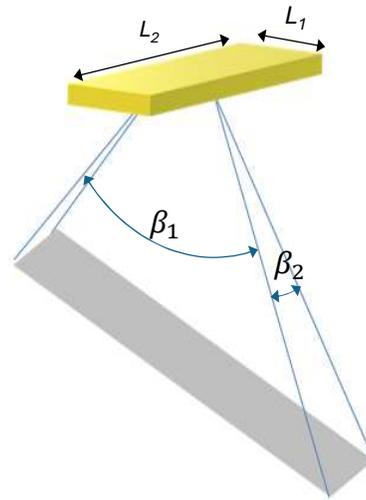
- ▶ Frequency: 200 KHz
- ▶ Beam Width: 9° (-3dB)
- ▶ Ping Rate: 1Hz
- ▶ Depth Accuracy: 1cm
- ▶ Output formats: NMEA0183, ASCII, ODOM, ATLAS, Sonarmite
- ▶ Range: 0.15m - 100m
- ▶ I/O: Serial(DB9), Bluetooth
- ▶ Power: Internal Battery 14.4V, 45 Wh
- ▶ Compatibility: Trimble, Leica, Topcon, Sokkia, Epoch, Carlson, HYPACK, QPS, EIVA, PDS 2000.
- ▶ Topside - 1lbs(0.45kg), 6.9x4.5x3.4" (175.26x 114.3x 86.36mm)
- ▶ Transducer - 1lbs (0.45kg), 5x2.75x3.75" (127x69.85x95.25mm)
- ▶ Transom Mount: 4lbs (1.81kg), 11x5x8" (279x127x203.2mm)

Seafloor Systems, Incorporated | 4475 Golden Foothill

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Beam Resolution

- For a rectangular transducer, the beamwidth corresponds with the wavelength and length
- Again, why higher frequency results in better resolution

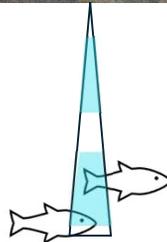


Adapted from de Jong et al. (2010)

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Angular vs Range Resolution

- Range Resolution: How close can two targets be in the range direction and still be distinguishable?



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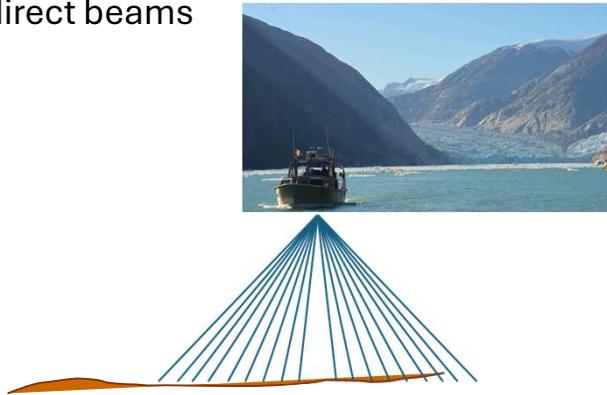
Transducer Design Tradeoffs Summary

- High Frequency
 - Better resolution (angular and horizontal)
 - Transducer can be small, light, and low cost
 - However, can't map as deep, due to greater attenuation with distance
- Low frequency
 - Can map deeper (less attenuated with distance)
 - However, transducers must be larger, heavier, more expensive, and poorer resolution

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Multibeam

- Multibeam echosounders (MBES)
- At a high level, multibeam utilizes interference patterns and timing to 'steer' or direct beams



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Multibeam

- Signal processing on the receiving end is used to form multiple receive beams
 - Basically, listening selectively in different directions at the same time



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Multibeam

- We tend to draw (and think of) multibeam systems as if there were individual transmitted beams – similar to lidar
- In reality, there is really only a single transmit beam (1 ping) in the water at a time, which is wide in the across-track direction

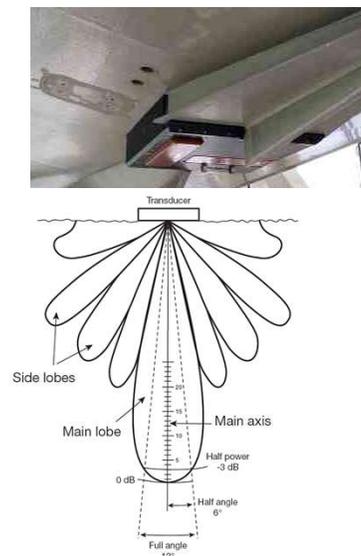


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Multibeam Beam Pattern

Components

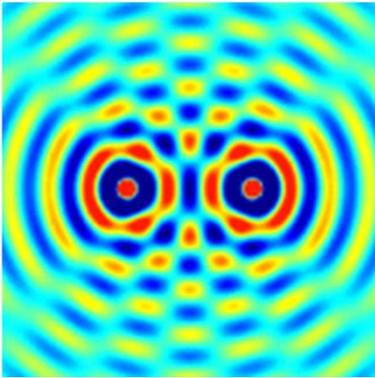
- **Lobes**
 - Angles where there is a maximum
 - Usually one main lobe and multiple side lobes (which are generally unwanted, but unavoidable)
- **Nulls**
 - Between lobes
 - Angles where there is a minimum
- Can form beams when transmitting and receiving



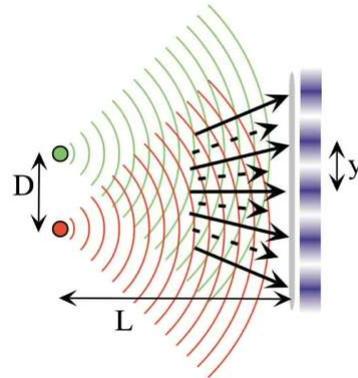
<http://www.acousticsunpacked.org/AcousticBackground/AcousticTransducers.html>

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Multibeam Interference Patterns



https://en.wikipedia.org/wiki/Wave_interference



https://www.phys.uconn.edu/~gibson/Notes/Section5_4/Sec5_4.htm

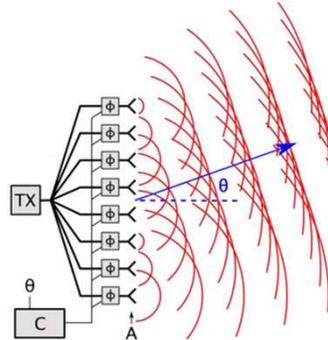
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Beam Steering

- Goal:
 - Concentrate the output energy in a desired direction from the axis
 - Steer the beam (main lobe) left or right, for example
- Achieved by phasing/timing the array elements
 - Change the phase or timing of elements in the array (Tx or Rx array) enables steering the beams
 - Key concept in multibeam
 - Need accurate measure of sound speed

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Phased Transmit Array (generally not how MBES works)

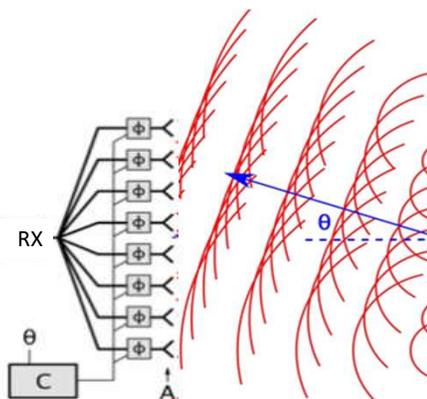


- Phase the array elements to steer the beam without having to physically move the array
- Could be transmit or receive array

https://en.wikipedia.org/wiki/Phased_array

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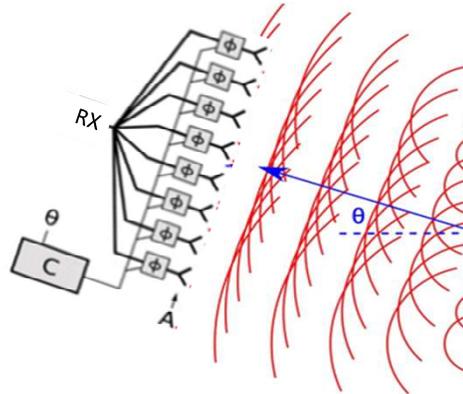
Phased Receive Array



https://en.wikipedia.org/wiki/Phased_array

66

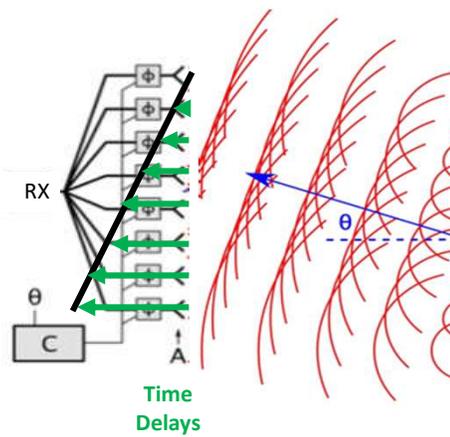
Phased Receive Array



https://en.wikipedia.org/wiki/Phased_array

67

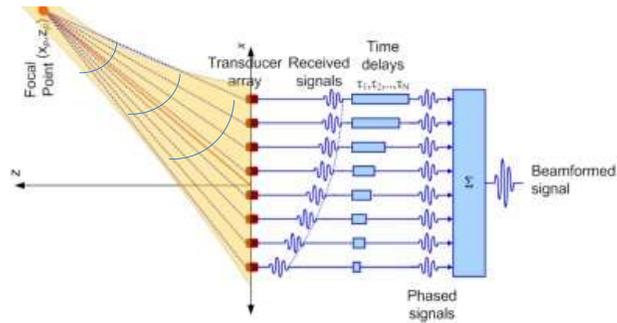
Beamsteering (Time Delays)



https://en.wikipedia.org/wiki/Phased_array

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Beamsteering

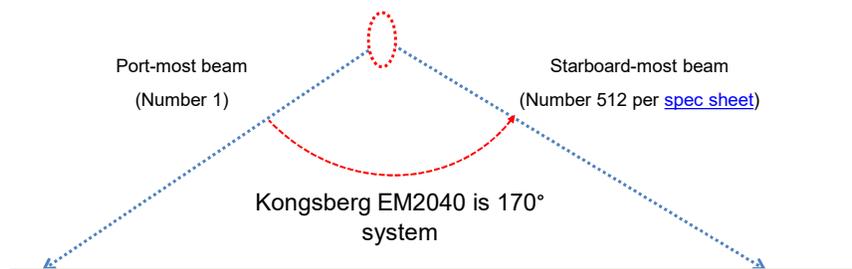


Martinez, Jairo & Sisman, Alper & Onen, Onursal & Velasquez, Dean & Guldiken, Rasim. (2012). A Synthetic Phased Array Surface Acoustic Wave Sensor for Quantifying Bolt Tension. Sensors (Basel, Switzerland). 12. 12265-78. 10.3390/s120912265.

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Multibeam

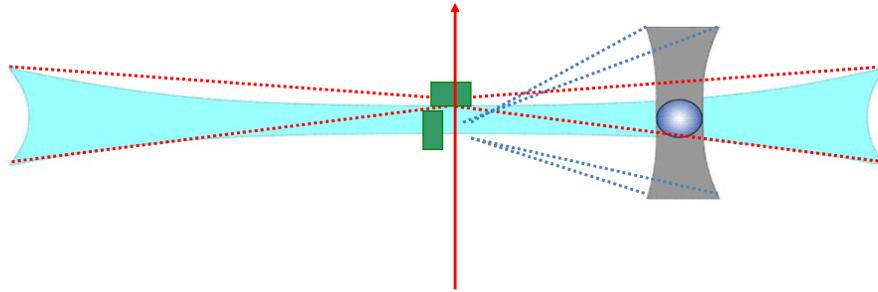
- The angle of the beam along swath which the acoustic pulse traveled (i.e., beam angle)



Note: Most systems can steer beyond 120° (60° per side) total swath angle, but there is more noise in outer beams.

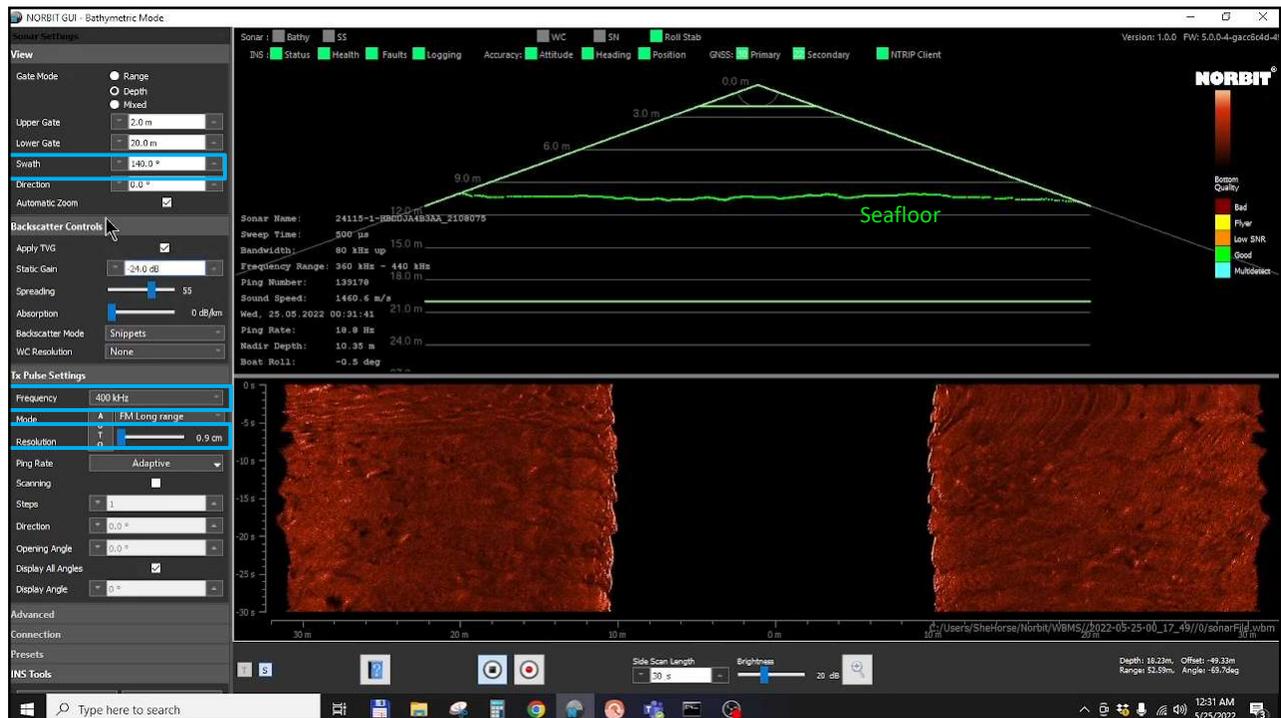
70

Multibeam Resolution



- Transmit energy (“Ping”) is released across the entire swath
 - Transmit shown in BLUE
 - Receive shown in GREY
 - Intersection of transmit and receive samples is what we call a “Beam”
The area this covers on the seafloor is called a “footprint”
 - This process is called beam forming

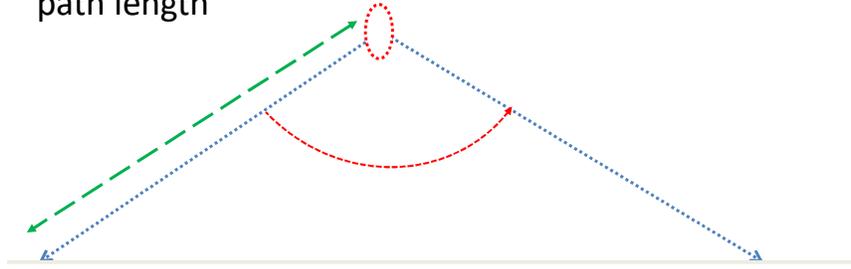
71



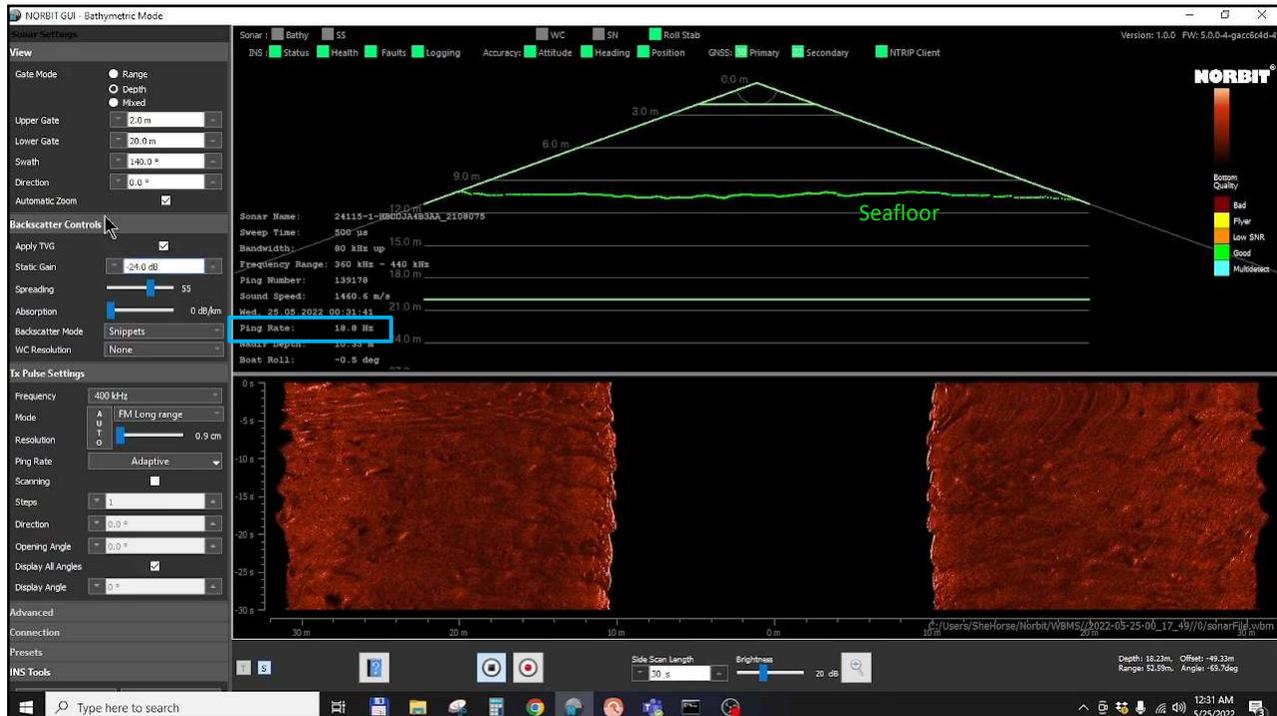
72

Multibeam Ping Rate

- Ping Rate – how often (Hz) a system is able to ping (transmit and receive) before sending the next ping
- Dependent on depth, terrain, and distance of the longest path length



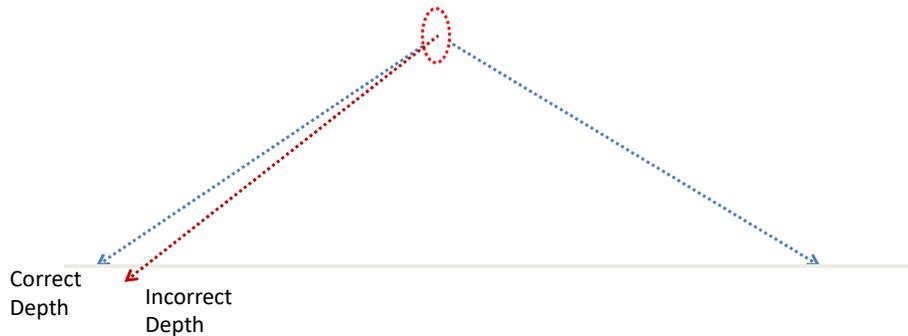
73



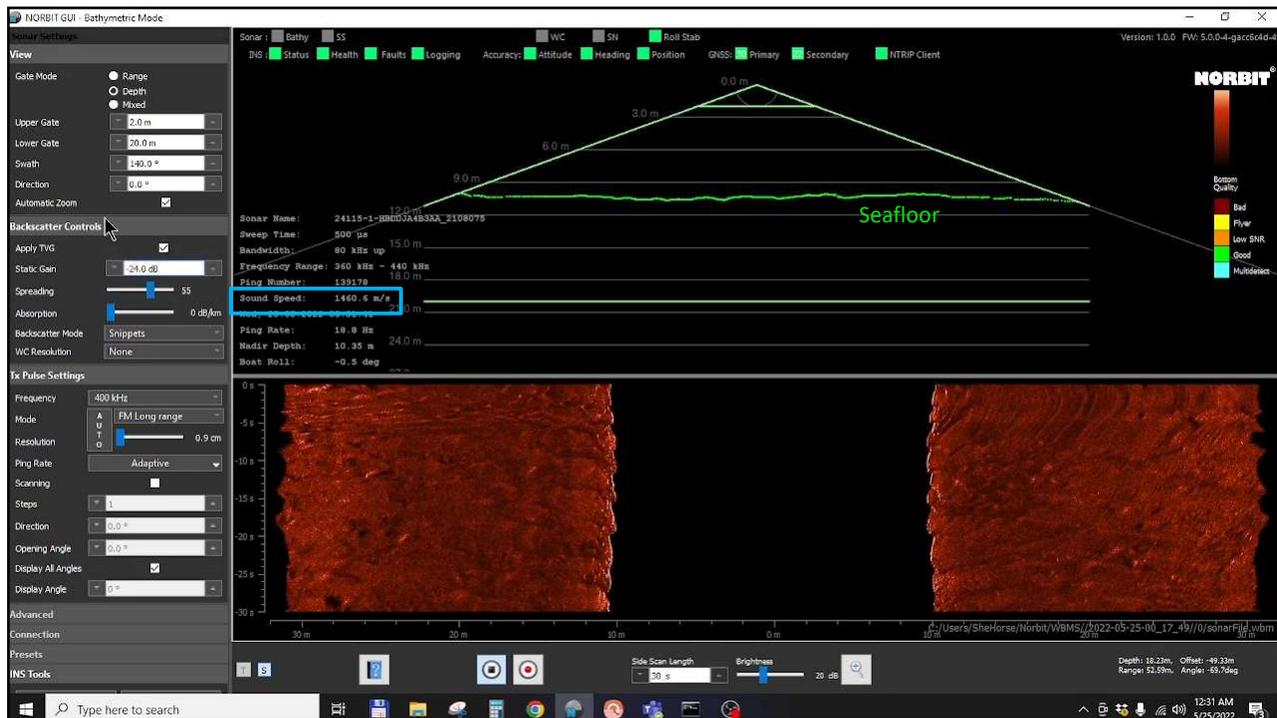
74

Sound Speed and Beamsteering

- The error in steering angle grows, and the more a beam is steered, the more you must worry about surface sound speed
- Otherwise, incorrect sound speed will cause error in the resulting depth

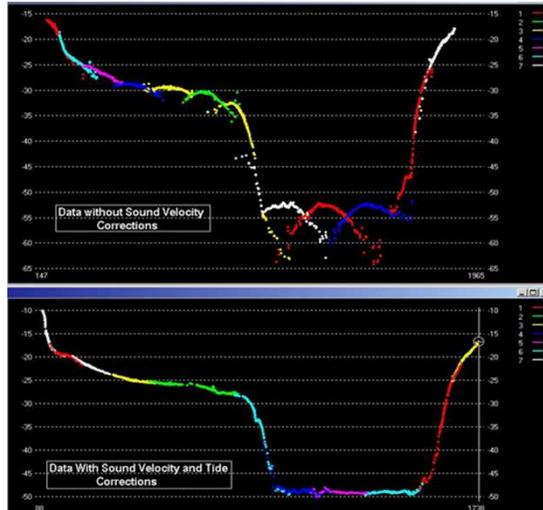


75



76

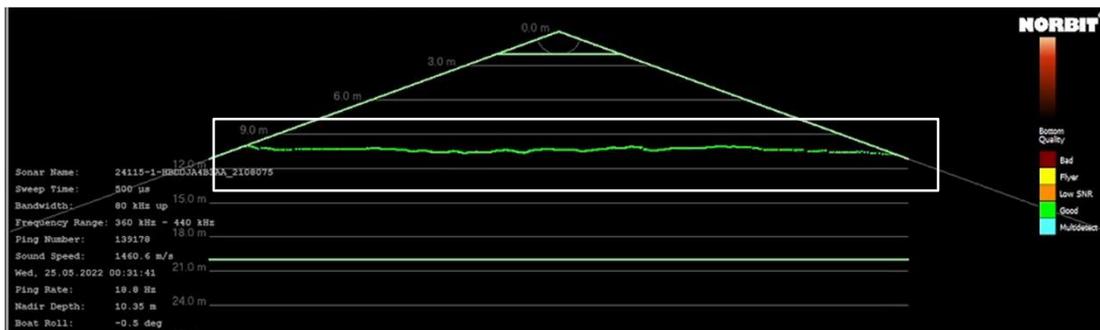
Sound Speed and Beamsteering



<https://www.hypack.com/about-hypack/blog/hypack-news-blog/2018/02/sound-velocity-vertical-errors-and-what-to-expect>

77

Bottom Detection – The Goal

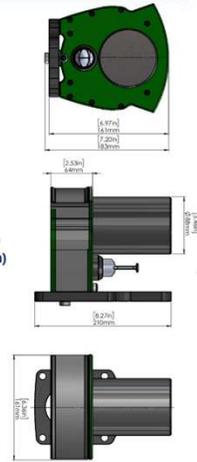


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Multibeam

SPECIFICATIONS

▶ Frequency Range	400-550 kHz
▶ Swath Coverage	Up to 130°
▶ Number of RX Beams	256
▶ Along-Track Beam Width	1.45°
▶ Across-Track Beam Width	1°
▶ Range	> 200m
▶ Beam Distribution	Equi-Distant and Equi-Angular Beam Distribution
▶ Roll Stabilization	Yes
▶ Pressure Rating	100m
▶ GNSS / INS	INS Integrated into Sonar
▶ Position:	HOR: ±(8mm +1ppm X Distance from RTK Station) VER: ±(15mm +1ppm X Distance from RTK Station) (Assumes 1m GNSS Separation)
▶ Heading Accuracy	0.08° (RTK) with 2m Antenna Separation
▶ Pitch / Roll Accuracy	0.03° Independent of Antenna Separation
▶ Heave Accuracy	5cm or 5% (Real Time)
▶ Ping Rate	50 Hz
▶ Outputs	Bathymetry, Sidescan
▶ Compatible With	Qinsy, HYPACK, EIVA, Other Prominent Brands
▶ Weight	3.5kg (Air), 1.1kg (Water)
▶ Topsides Rating	IP67 (Dust & Water Tight, Submersible up to 1m)



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Main Error Sources

- Spreading
- Absorption
- Scattering
- Propagation loss
- Beamwidth
- Sound Speed
- Target Strength
- Multiple Paths
- Horizontal Positioning
- Vertical Offsets
- Datum
- Noise

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Overview

- ~~Background and History~~
- ~~Underwater Acoustics Fundamentals~~
- **Technologies and Platforms**
- Survey Products
- Applications

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Echosounders

- Echosounder frequency and type will depend on project requirements

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Echosounder Frequency

- For singlebeam – 200kHz system or higher is likely perfectly fine for any application
- For multibeam – water depth and resolution should be a larger consideration

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Broad Types of Echosounders

- Single beam
- Multibeam
- Side scan
- *Sub bottom*
- *Marine/fisheries acoustics*
- *Acoustic beacons*
- *Passive sonars*
- *Oceanography sonars (e.g., doppler, SOFAR)*

84

Hydrographic Surveying Platforms

Very Shallow (foot or so)



Shallow (several feet to ~50 feet)



Medium (50+ feet)



Very Deep Water (Thousands of Feet)



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Compact System Manufacturers

Compact/Autonomous/Remote

- Seafloor Systems
 - See Keystone Precision
- Others



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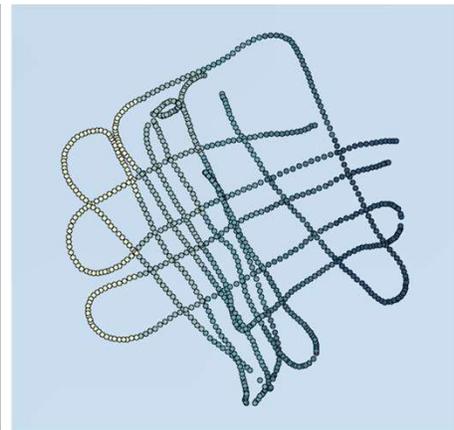
Acoustics Manufacturers

- Seafloor Systems
- Kongsberg
- Reson
- R2 Sonic
- Norbit
- EdgeTech
- Teledyne



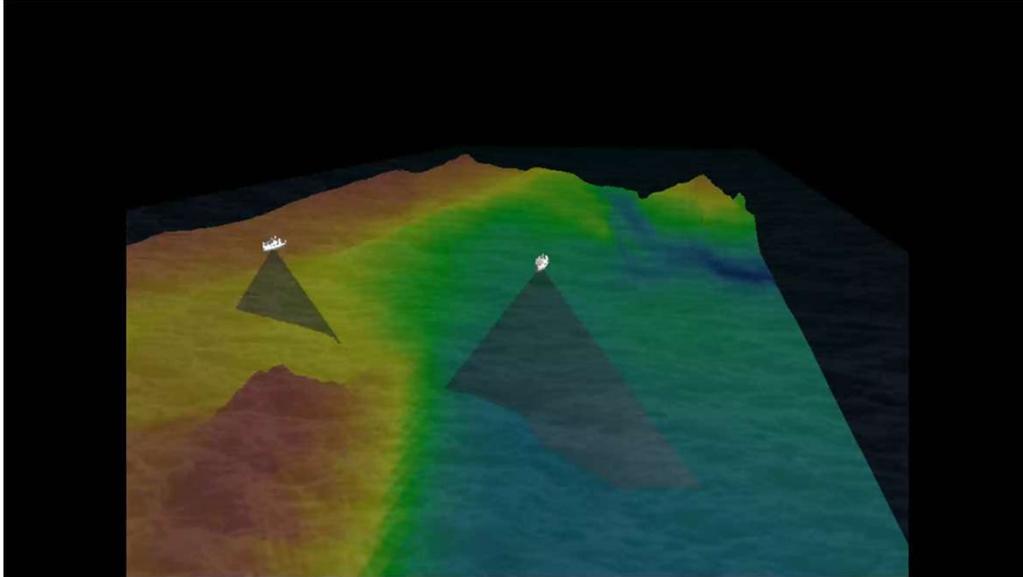
87

SBES Acquisition



88

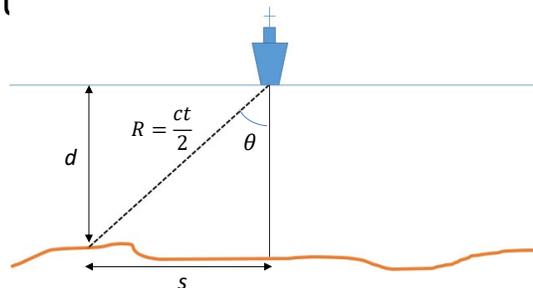
MBES Acquisition



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Swath Geometry

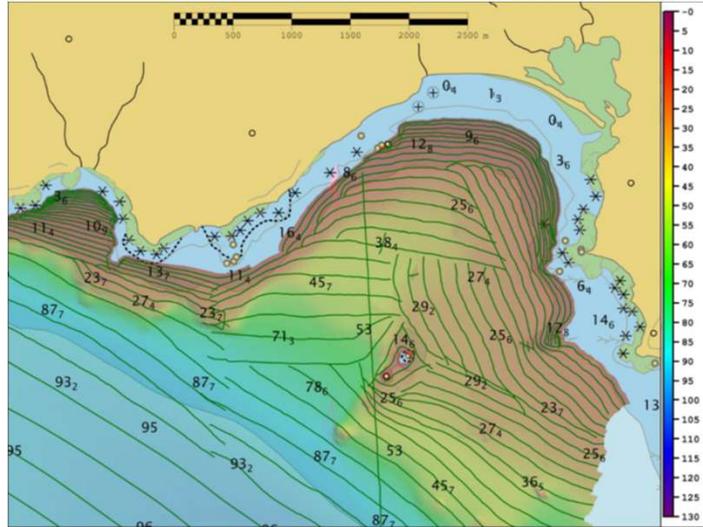
- Generally, one 'ping' transmitted and the next ping isn't transmitted until the last returns
- What is the furthest swath?



Adapted from TU Delft Seafloor Mapping

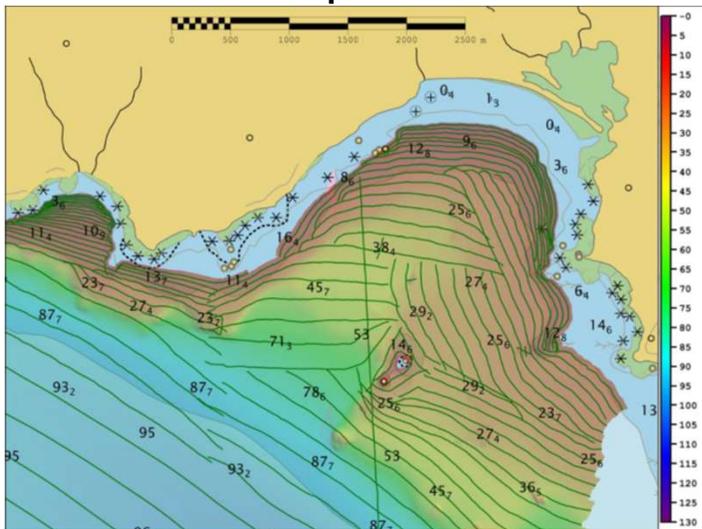
90

Example of Resulting Multibeam Line Spacing due to Depth



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MBES Acquisition



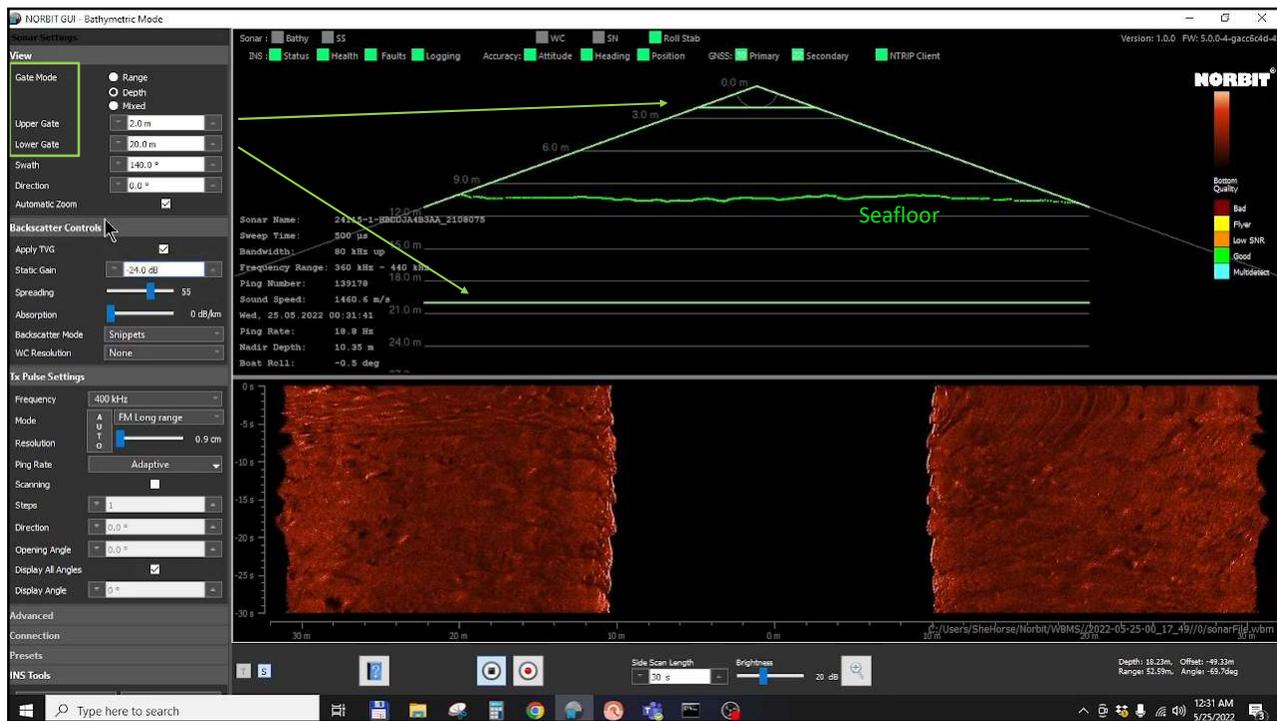
Example of NOAA survey launch track lines and multibeam sonar coverage (depths in meters) overlaid on Electronic Navigational Chart (ENC)



NOAA Hydrographers Acquiring Data



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Positioning

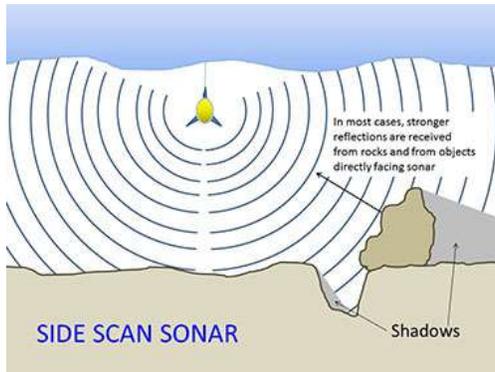
- GNSS-aided INS
- Single GNSS receiver and vertical offset to singlebeam
- Total Station



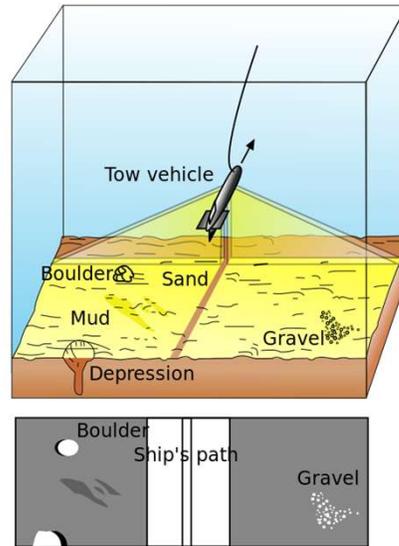
94

Side Scan

- Underwater acoustic imagery



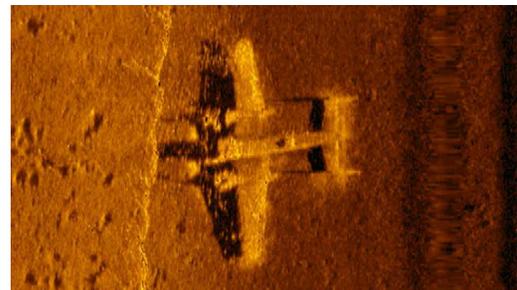
<http://www.nauticalcharts.noaa.gov/hsd/SSS.html>



https://en.wikipedia.org/wiki/Side-scan_sonar

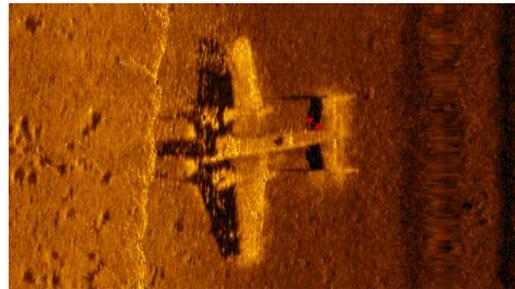
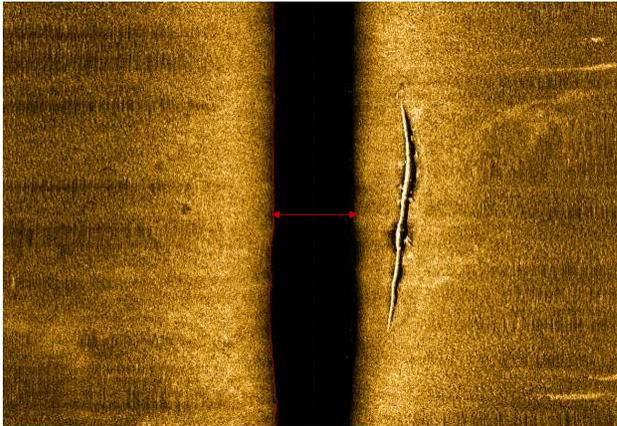
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Side Scan



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Side Scan



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Side Scan Limitations

- Not nearly as good for bathymetry (i.e., accurate soundings) as for imagery
 - Primarily for interpretation and inspection
- Not motion compensated
- Operational challenges
 - Often want to tow SSS towfish close to seafloor to get best imagery

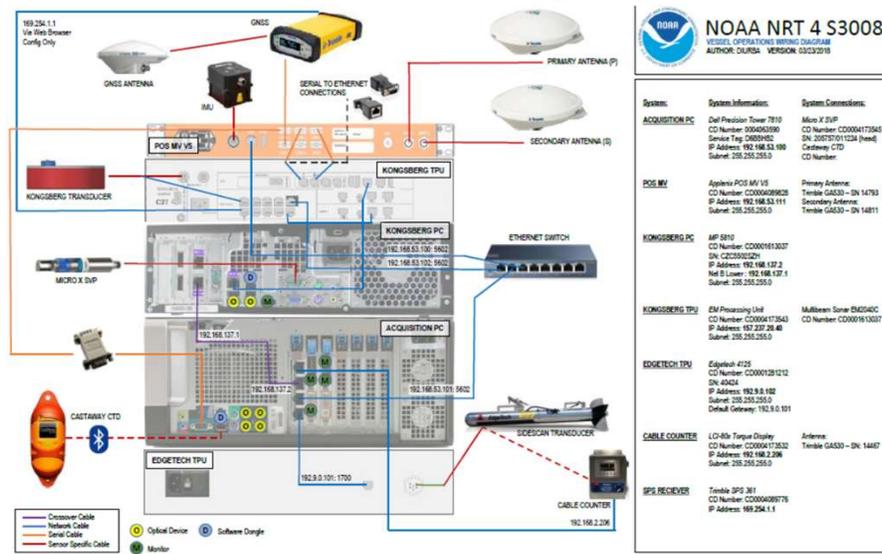
98

Simple System Integration

- Purchase 200kHz single beam compatible with your data collector
- Setup data collector to communicate with single beam
- Use GNSS receiver

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More Complex System Integration



NOAA Field Procedures Manual

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Creative Integrations



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Things to look out for...

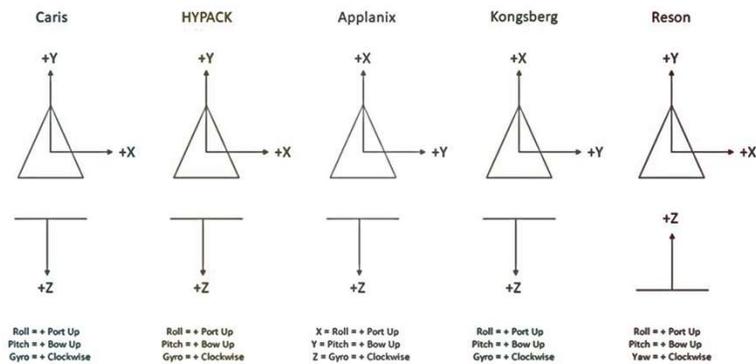
Figure 1. Diagram showing multibeam (MB) transducer, heave, roll, pitch (HRP) sensor, and positioning sensors (GPS) relationships to the motion reference point (RP). Heave, roll and pitch motions and axis conventions are also demonstrated. HF transducer represents a single-beam sonar. The multibeam (MB) transducer is offset to port in this diagram. One of the more difficult integration issues solved during installation and testing of multibeam sonar systems is alignment of the various components both physically and in terms of computational assumptions. **Multibeam vendors, software companies, and sensor manufacturers do not use a standard set of axes nor rotational sign conventions.** Multibeams installed aboard NOAA hydrographic ships have used the convention of X positive to starboard, Y positive forward, and Z positive up (easy to remember - "Heave Up"!). Roll rotation is positive when port side moves up, and pitch is positive when the bow moves up.

NOAA Technical Memorandum NOS CS 3: MULTIBEAM SONAR DATA ACQUISITION SYSTEMS: A SIMPLIFIED CONCEPTUAL MODEL

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Things to look out for...

Manufacturer Reference Frames



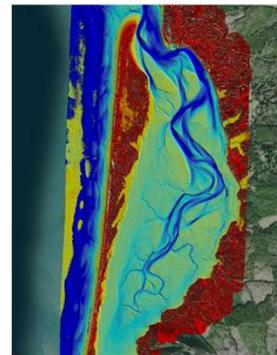
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Hydrographic Survey Software

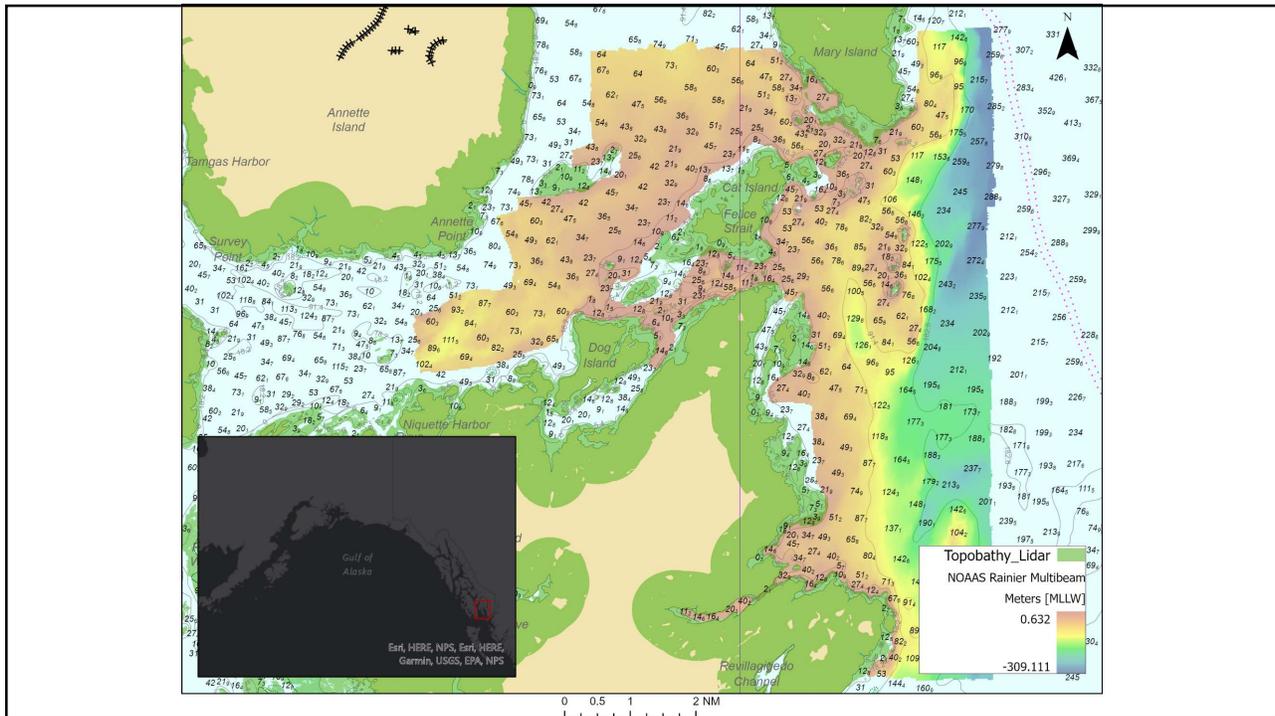
- QPS
 - Qinsy (acquisition)
 - Fledermaus (backscatter)
 - Qimera (processing)
- Teledyne CARIS (processing)
- Xylem HYPACK (acquisition and processing)
- Chesapeake SonarWiz (acquisition)
- Trimble

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Bathymetric Lidar



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Bathymetric Lidar Manufacturers

- YellowScan
- Riegl
- Leica
- Teledyne Optech



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Topobathymetric Lidar

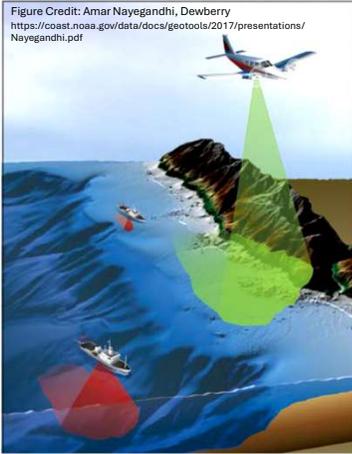
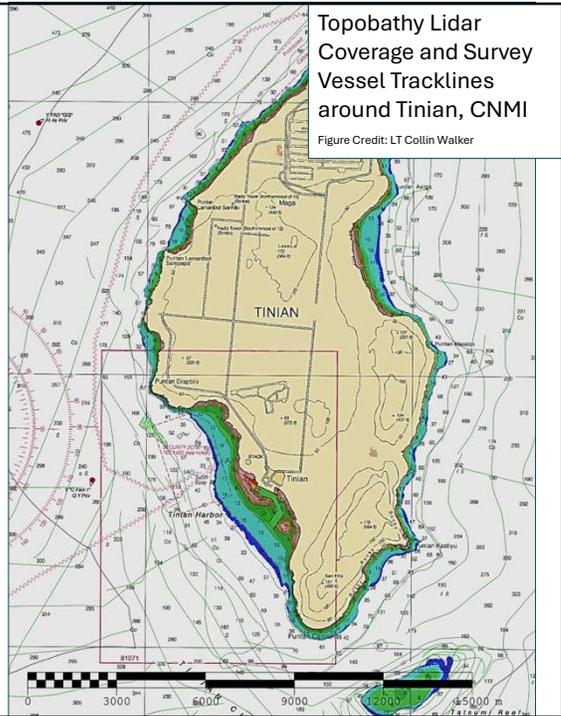


Figure Credit: Amar Nayegandhi, Dewberry
<https://coast.noaa.gov/data/docs/geotools/2017/presentations/Nayegandhi.pdf>

Min (m)	Max (m)	Start	End
-5	1	(255, 192, 203, 255)	(255, 192, 203, 255)
1	2	(255, 0, 0, 255)	(255, 0, 0, 255)
8	20	(50, 205, 50, 255)	(50, 205, 50, 255)
20	40	(64, 224, 208, 255)	(64, 224, 208, 255)
40	80	(0, 0, 255, 255)	(0, 0, 255, 255)

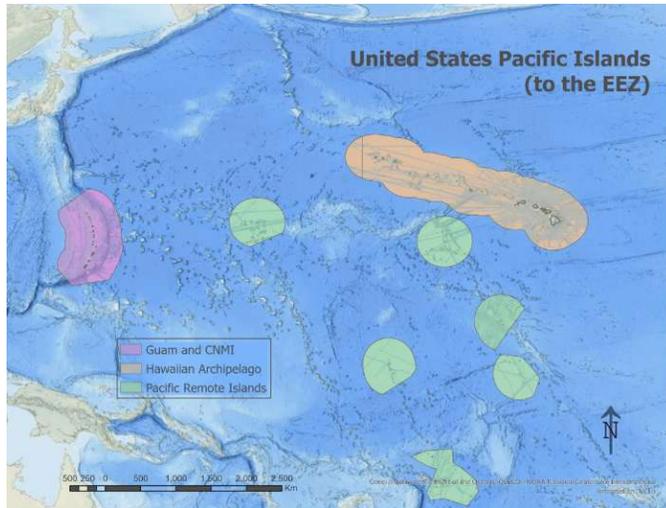
Tinian Lidar Coverage Depth Ranges (Tinian)



Topobathy Lidar Coverage and Survey Vessel Tracklines around Tinian, CNMI
 Figure Credit: LT Collin Walker

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Lidar Efficiency: Pacific Mapping Planning



Sharr et al., (2020)

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Lidar Efficiency

Sharr et al., (2020)

REGION: US Pacific Islands	Days with MBES Systems Only (no Lidar)							TOTAL
	200 to 400 kHz			0m-200m	30 to 100 kHz 200m-1500m	12 to 30 kHz 1500m-3000m	12kHz 3000m+	
	4m-25m	25m-40m	40m-200m					
<i>Guam and CNMI</i>	28	3	5	36	5	14	53	109
<i>Northwestern Hawaiian Is</i>	851	361	157	1,369	10	5	228	1,612
<i>Main Hawaiian Islands</i>	20	4	13	37	1	0	40	78
<i>Pacific Remote Islands</i>	48	3	1	53	2	11	358	423
TOTAL (Days)	948	371	177	1,495	19	30	679	2,223

REGION: US Pacific Islands	Lidar TOTAL 0m-40m	Days Per Acquisition System				Vessel TOTAL 40m-3000m+
		200 to 400 kHz 40m-200m	30 to 100 kHz 200m-1500m	12 to 30 kHz 1500m-3000m	12kHz 3000m+	
<i>Guam and CNMI</i>	-	5	5	14	53	78
<i>Northwestern Hawaiian Is</i>	249	157	10	5	228	400
<i>Main Hawaiian Islands</i>	-	13	1	0	40	54
<i>Pacific Remote Islands</i>	22	1	2	11	358	372
TOTAL (Days)	271	177	19	30	679	905

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Water Clarity – the single greatest limiting factor in bathymetric lidar

Buck Island, USVI



$$K_d = 0.06 \text{ m}^{-1}$$

Secchi depth = 30 m

Cameron, Louisiana



$$K_d = 0.6 \text{ m}^{-1}$$

Secchi depth = 2 m

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Quantifying Water Clarity

Secchi Depth



Diffuse attenuation coefficient, K_d

Water Type	$K_d(m^{-1})$
Very clean	0.07
Clean	0.1
Typical	0.15
Typical	0.2
Dirty	0.3
Very Dirty	0.5

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Technical specifications.

Laser scanner	YellowScan	Max. data generated ⁽¹⁾	Up to 300 000 points / sec
GNSS inertial solution	SBG Quanta Micro	Echoes per shot	Full waveform / Up to 15
Precision ^{(1) (2)}	3 cm	Shots per second	Up to 20 000
Accuracy ^{(2) (3)}	3 cm	Scanning frequency	Up to 50 Hz <i>(selectable)</i>
Typ. flight speed	5 m/s	RGB camera <i>(for colorization purposes)</i>	Global shutter embedded camera
Typ. flight height	80 m	Weight	3.7 kg (8.15 lbs)/batt. excl.
Max. rec. flight height	100 m	Size	L 350 x W 160 x H 190 mm
Point density	20 pts/sqm @ 80 m AGL 5 m/s	Battery autonomy	45 min. typ.
Laser range	Up to 120 m	Power consumption	120 W
Laser wavelength	532 nm	Operating temperature	5° to +40 °C
Scanner field-of-view	40°	Laser class	Class 3B - Avoid direct exposure to beam
Max. Depth	2 Secchi		

(1) Precision, also called reproducibility or repeatability, accounts for the variation in successive measurements taken on the same target.
 (2) Accuracy is the degree of conformity of a measured position to its actual (true) value.
 (3) 1° to @ 50 m, nadir. Values computed in topography, bathymetric performance may vary.
 (4) Theoretical maximum of points with all shots yielding the maximum number of echoes.
 May vary depending on flight and survey conditions, and surveyed environment.

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RIEGL VQ-860-G Technical Data

Export Classification

The Topo-Bathymetric Airborne Laser Scanner VQ-860-G has been designed and developed for commercial topographic, hydrographic and bathymetric surveying applications.

Laser Product Classification

Class 3B Laser Product according to IEC60825-1:2014
The following clause applies for instruments delivered into the United States. Complies with 21 CFR 1040.10 and 1040.11 except for conformance with IEC 60825-1 Ed.3, as described in Laser Notice No. 54, dated May 8, 2019.

The VQ-860-G is subject to export restrictions as set up by the Wassenaar Arrangement. It is classified as dual-use good according to position number 6A83 of the official Dual-Use-List to be found on site <http://www.wassenaar.org>.
Within the European Union, (Regulation (EU) No. 2021/621) implements the export restrictions of the Wassenaar Arrangement. The corresponding position number is 6A0083.



NOHD ^{1) 2) 3)}

54 m/20 m (reduced mode)

1) NOHD - Nominal Ocular Hazard Distance
2) beam divergence 6 mrad, laser PRR 50 kHz

3) provided that the instrument is operated on a moving platform

Range Measurement Performance

Measuring Principle

echo signal digitization, online waveform processing, full waveform recording, time-of-flight measurement, multiple target capability

Measurement Rate ⁴⁾	100 kHz (reduced)		50 kHz (reduced)		5 kHz ⁷⁾		0.5 kHz ⁷⁾	
	1.8	2.0	2.3	2.5	2.7 (enhanced by averaging)		3.0 (enhanced by averaging)	
Max. Water Depth Penetration in Secchi Depths ⁶⁾ (Flight altitude 75m above water level)								

Minimum Range
Accuracy ^{8) 9)}
Precision ¹⁰⁾
Laser Pulse Repetition Rate
Echo Signal Intensity
Number of Targets per Pulse
Laser Wavelength
Laser Beam Divergence
Receiver Field of View
Laser Beam Footprint (Gaussian Beam Definition)

50 m
20 mm
15 mm
50 kHz to 100 kHz
for each echo signal, high-resolution 16 bit intensity information is provided
online waveform processing: up to 15 ¹¹⁾
532 nm, green
selectable, 1 up to 6 mrad ¹²⁾
selectable, 3 up to 18 mrad
50 mm @ 50 m, 100 mm @ 100 m, 150 mm @ 150 m ¹⁴⁾

Scanner Performance

Scanning Mechanism
Scan Pattern
Off Nadir Scan Angle Range
Scan Speed (selectable)
Angular Step Width $\Delta \theta$ (selectable)
between consecutive laser shots
Angle Measurement Resolution

rotating scan mirror
nearly elliptic
 $\pm 20^\circ = 40^\circ$ perpendicular to flight direction, $\pm 14^\circ = 28^\circ$ in flight direction
10 - 100 lines/sec (lps) ¹⁴⁾
 $0.072^\circ \leq \Delta \theta \leq 0.72^\circ$ (for PRR 50 kHz) ^{15) 16)}
0.001" (3.6 arcsec)

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Overview

- ~~Background and History~~
- ~~Underwater Acoustics Fundamentals~~
- ~~Technologies and Platforms~~
- **Survey Products**
- Applications

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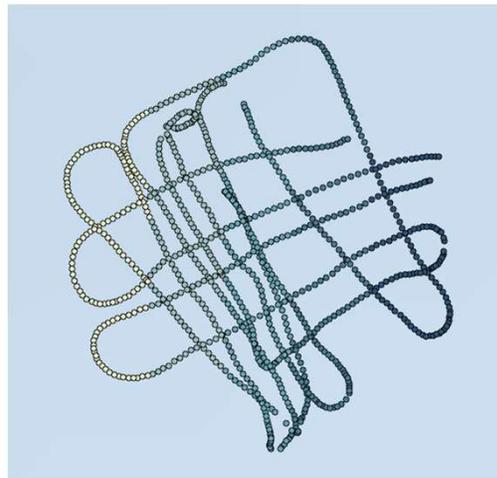
Types of Products

- Point data
- Point cloud
- Surface (DEM, DSM, DTM)
- Imagery

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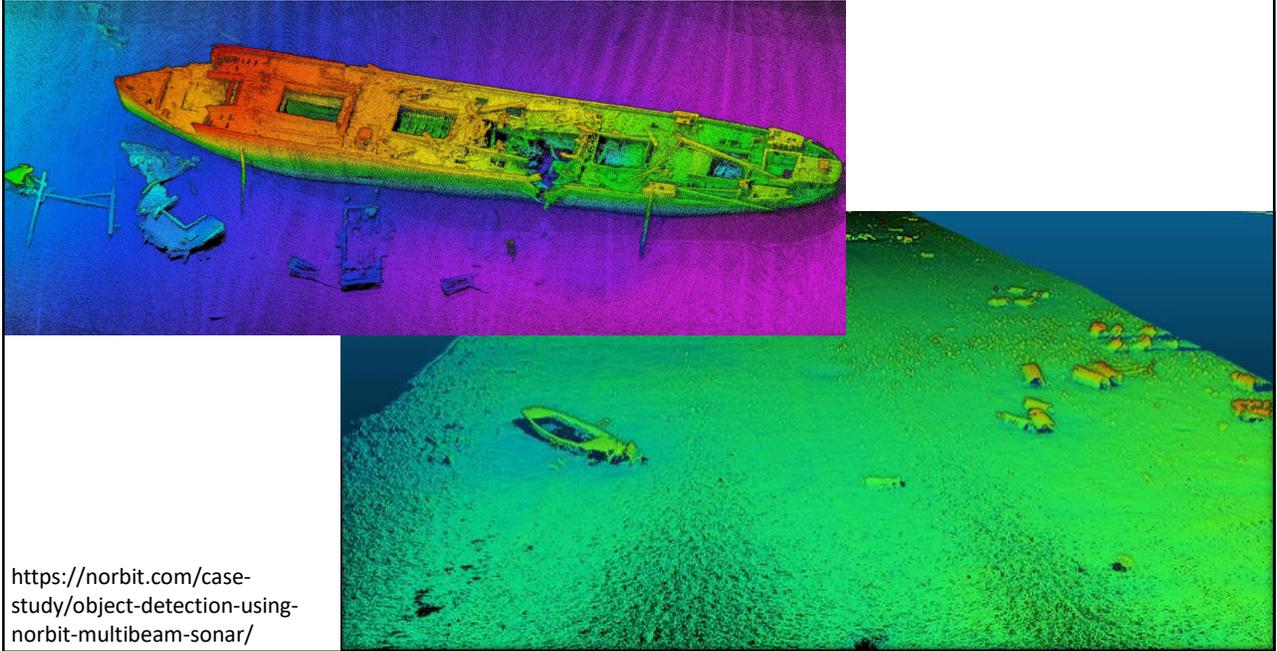
Point Data or Sparse Point Cloud

- What you'll get with single beam
- Probably enough for a lot of applications



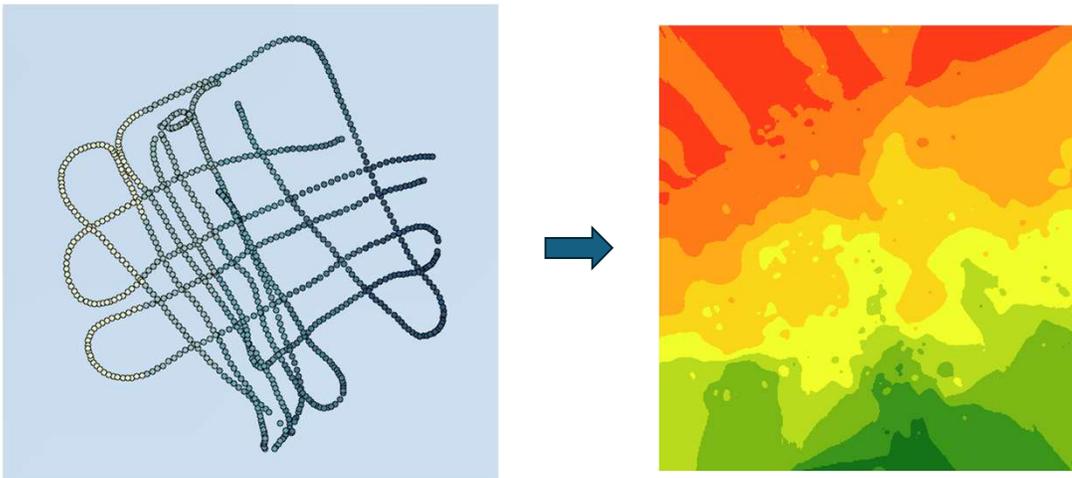
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Dense Point Clouds



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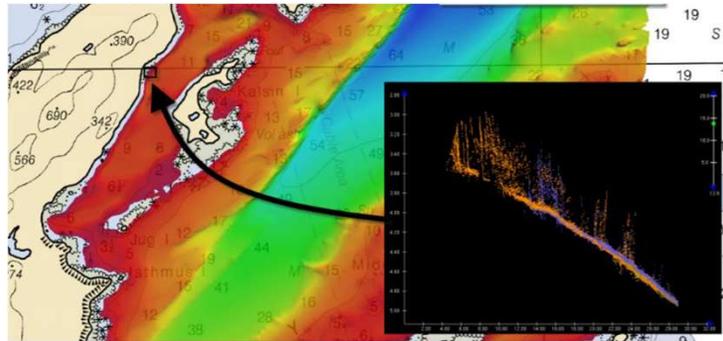
Singlebeam Interpolation



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Multibeam Interpolation

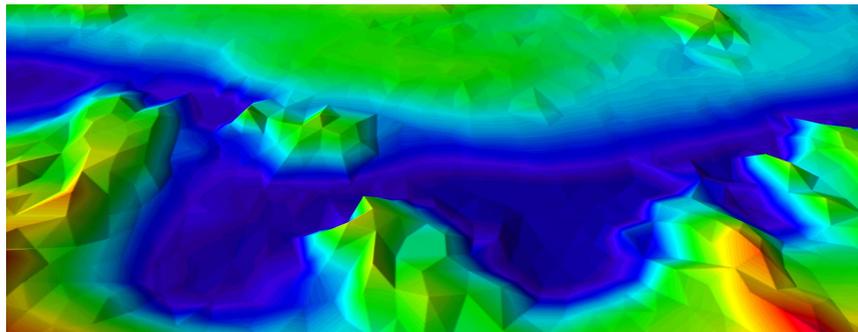
- Interpolation typically done using a statistical approach
 - E.g., CUBE



NOAA Field Procedures Manual

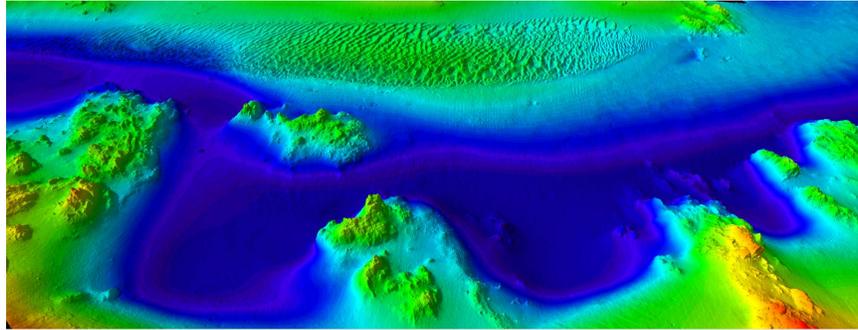
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Sounding Density: Single Beam



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Sounding Density: Multibeam



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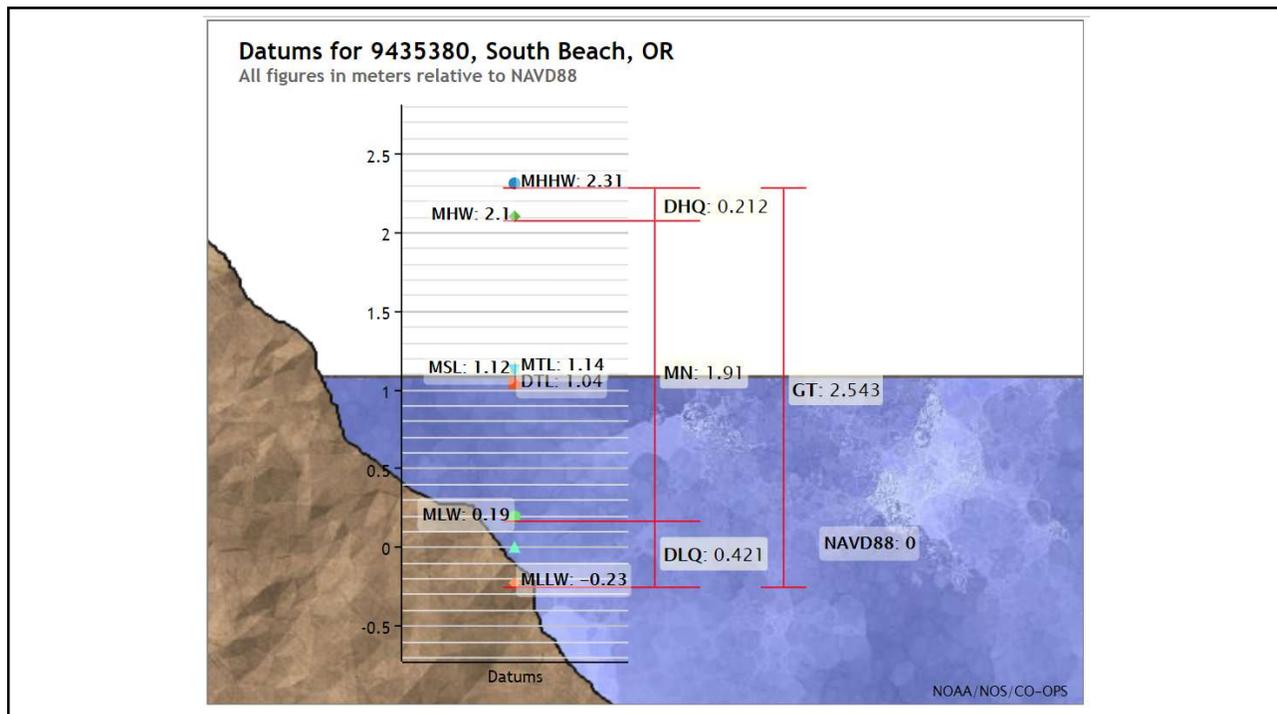
		Advantages	Disadvantages
	Single beam	<ul style="list-style-type: none"> • Don't need to worry about refraction (sound speed) as much, because you're ranging straight down • Good for shallow water, where multibeam is not efficient • Simple setup • Can likely use existing equipment 	<ul style="list-style-type: none"> • Can miss objects between echo sounding lines • Wider beam width
	Multibeam	<ul style="list-style-type: none"> • Full bottom coverage • Better analysis and interpretation <ul style="list-style-type: none"> • Can see what is going on down there • Increased capabilities 	<ul style="list-style-type: none"> • Comes with a lot of overhead • Very sensitive to refraction (sound speed) • Requires motion sensing • Expensive • Large data volumes and processing times • More can go wrong

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Vertical Datums

- Without a vertical datum, you only know what depth at a specific instance (epoch) in time
- All data must be referenced to specific vertical datum
 - E.g., NAVD88 (Geoid 18), Mean High Water, Mean Lower Low Water

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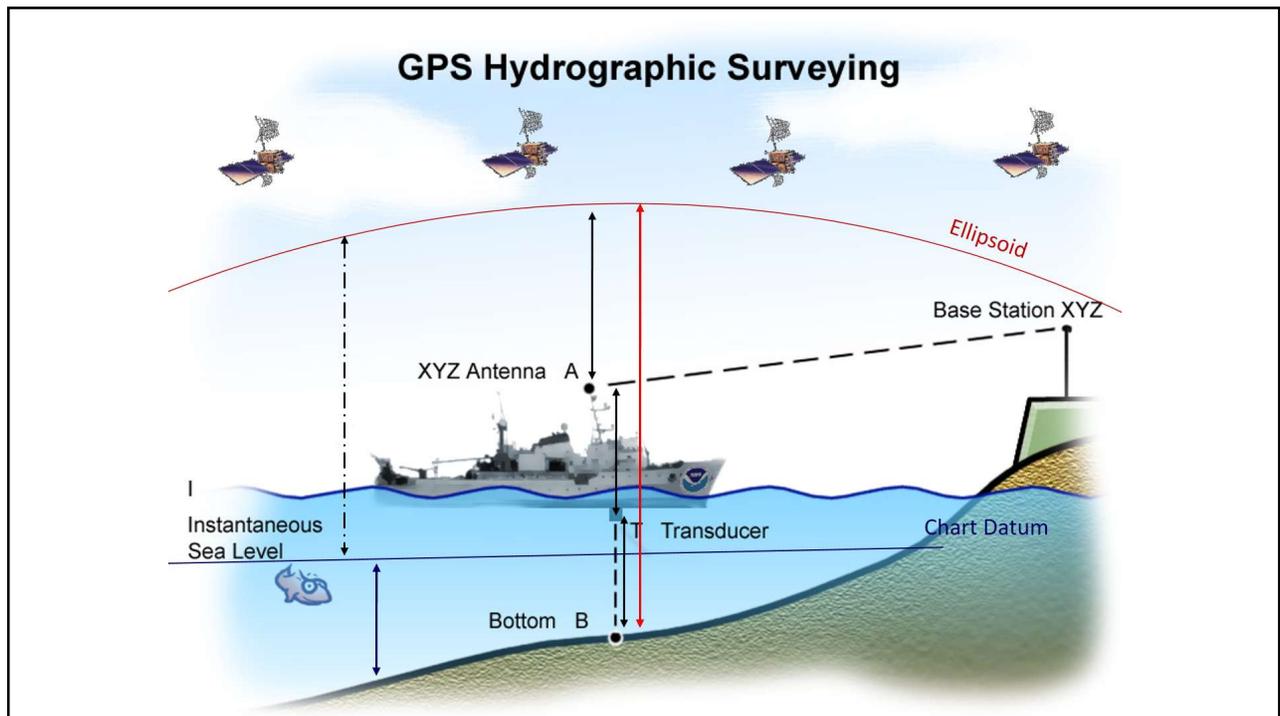
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Water Level Reference



Instantaneous water level: line where land and water touch *at one instant in time*

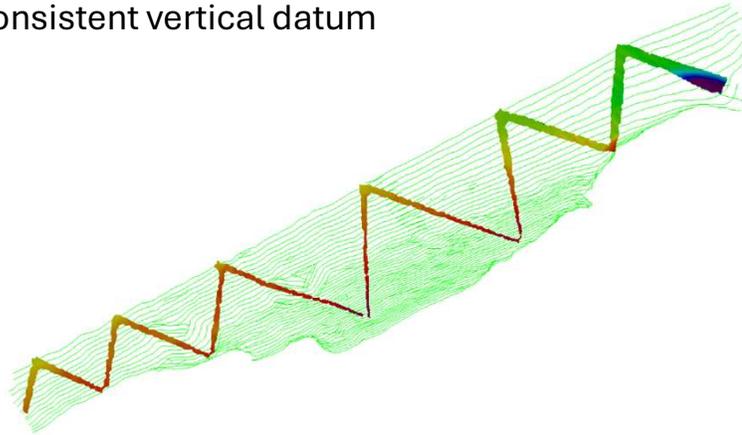
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Crosslines: QC

- *Using a consistent vertical datum



NOAA Field Procedures Manual

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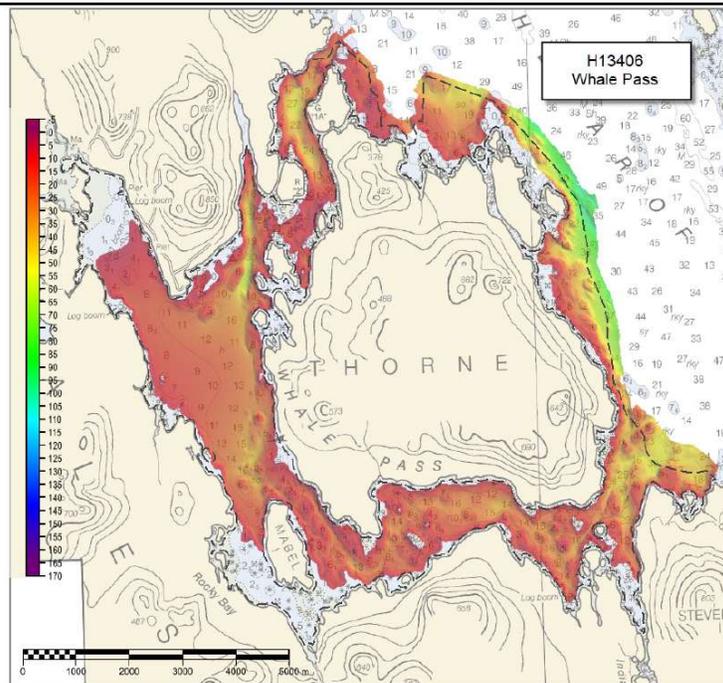
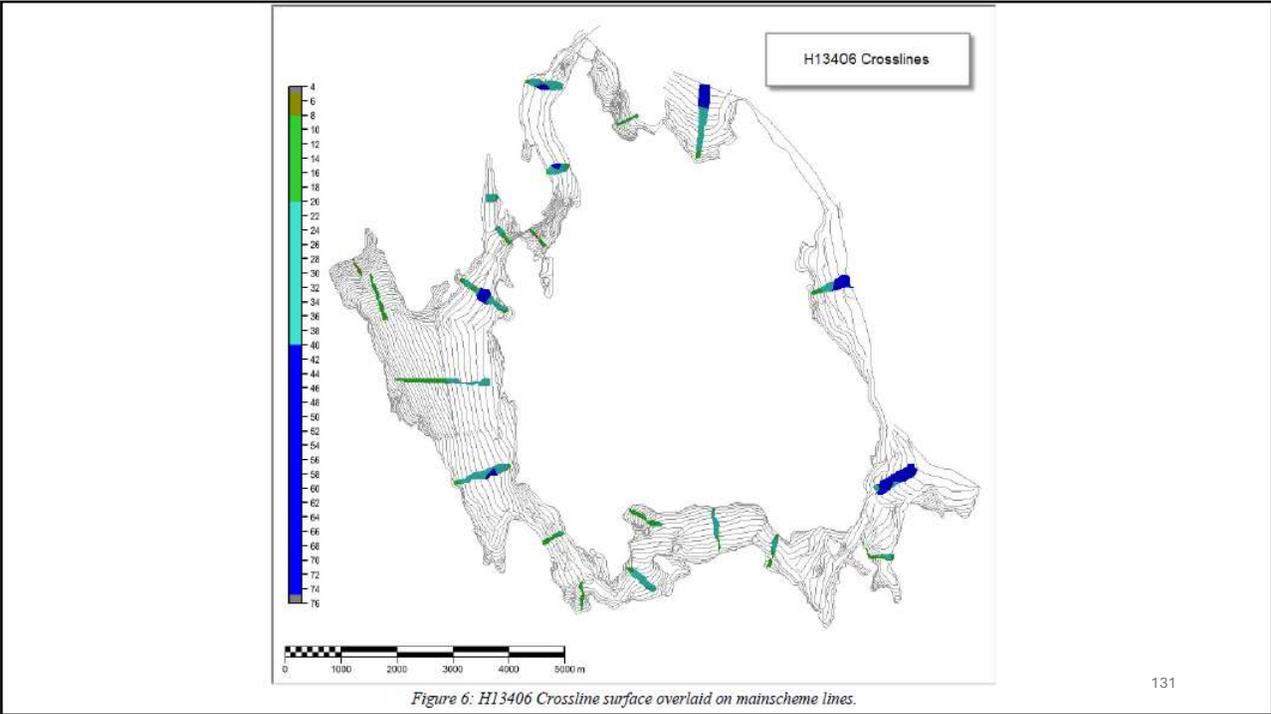


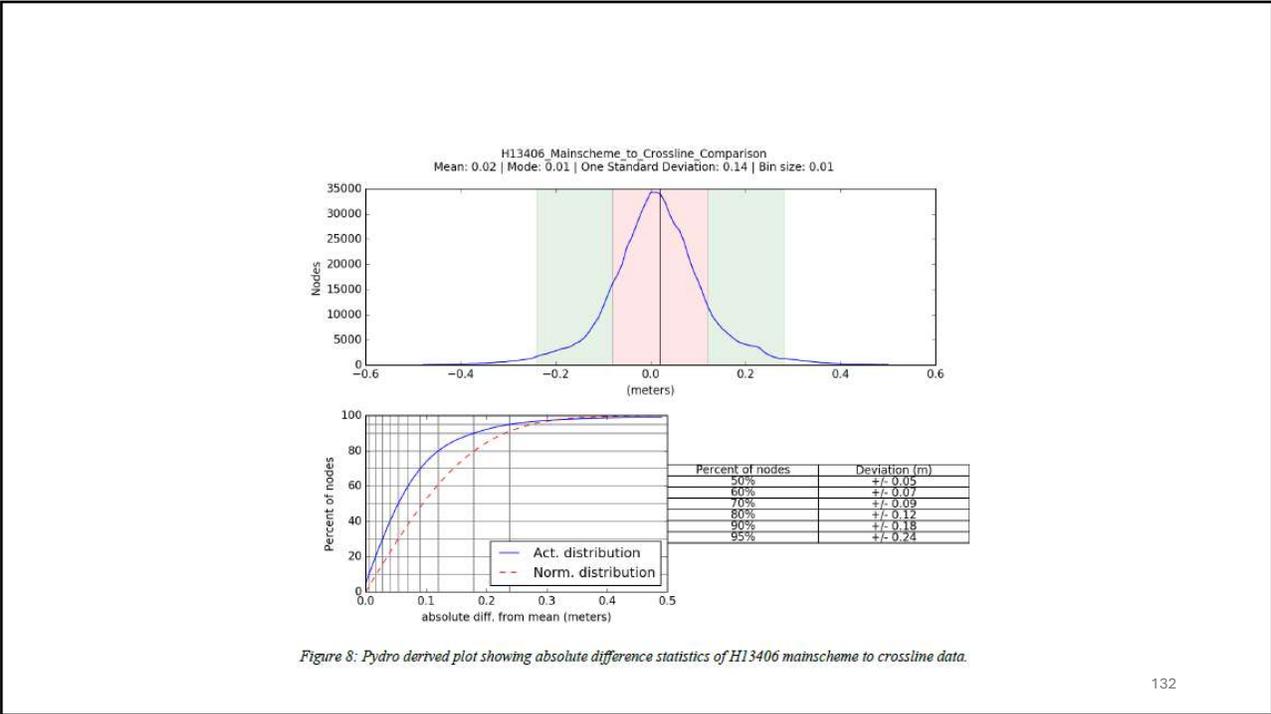
Figure 4: H13406 survey coverage (Chart 17382).

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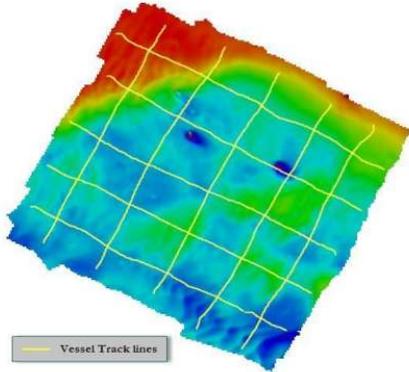


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Reference Data



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

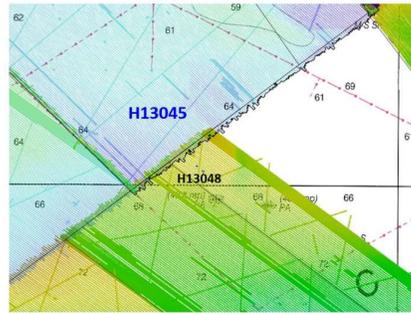


Figure 13- Difference between H13045 and H13048

https://data.ngdc.noaa.gov/platforms/ocean/nos/coast/H12001-H14000/H13045/DR/H13045_DR.pdf

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Underwater Acoustics & Technology

$$y(x, t) = A \cos(kx - \omega t + \phi) \quad \text{equation for a wave}$$

$$e^{it} = \cos t + j \sin t \quad \text{Euler's Formula}$$

$$\lambda = \frac{c}{f} \quad \text{Wavelength, speed, frequency}$$

$$\text{dB} = 10 \log_{10} \left(\frac{\text{value}}{\text{reference value}} \right) \quad \text{DeciBels}$$

$$\delta x = 2D \tan \left(\frac{\beta}{2} \right) \quad \text{Horizontal Resolution}$$

$$\delta z = \frac{c \Delta T}{2} \quad \text{Range Resolution}$$

$$P = 4\pi r_0^2 I_0 = 4\pi r_1^2 I_1 \quad \text{Spreading Loss}$$

Absorption loss = αr
 α = absorption coefficient in dB/km or dB/m
 r = distance in km or m

$$c = \sqrt{E/\rho} \quad \text{Sound Speed}$$

$$c_{avg} = \frac{z - z_0}{\int_{z_0}^z \frac{1}{c(z)} dz} \quad \text{Harmonic Mean}$$

$$\text{EL} = \text{SL} - 2\text{TL} + \text{TS} \quad \text{Sonar equation}$$

$$\text{EL} = \text{SL} - 2\text{TL} - (\text{NL} - \text{D}) + \text{TS} \quad \text{Sonar equation variant}$$

$$\beta = \frac{65}{d} \quad (\text{deg}) \quad \text{Circular Beamwidth}$$

$$\beta_1 = \frac{50}{L_1} \quad (\text{deg}) \quad \text{Rectangular Beamwidth}$$

$$\beta_2 = \frac{50\lambda}{L_2} \quad (\text{deg})$$

$$\delta z = \frac{c \Delta T}{2} \quad \text{Range Resolution}$$

$$t_{delay} = \frac{m d}{c} \sin \theta \quad \text{Beam steering Time Delay}$$

$$d = R \cos \theta = \frac{ct}{2} \cos \theta \quad \text{Swath Geometry}$$

$$s = R \sin \theta = \frac{ct}{2} \sin \theta \rightarrow s = d \tan \theta$$

$$K_d(\lambda) = -\frac{1}{E(\lambda)} \frac{\partial E(\lambda)}{\partial z} \quad \text{Kd}$$

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Overview

- ~~Background and History~~
- ~~Underwater Acoustics Fundamentals~~
- ~~Technologies and Platforms~~
- ~~Survey Products~~
- **Applications**

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Applications

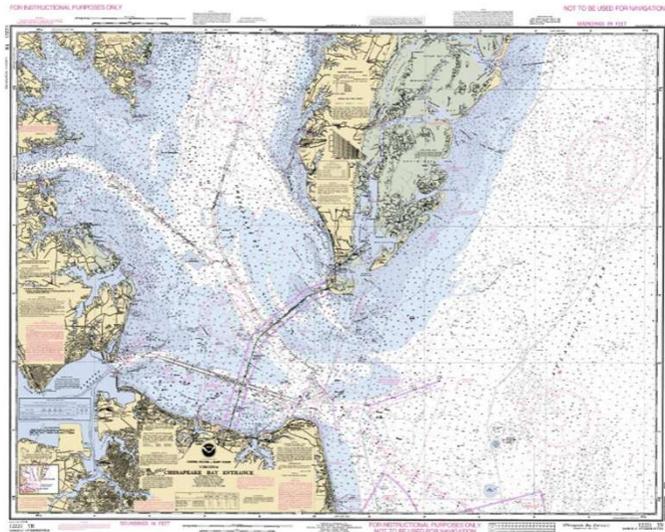
- Applications of underwater acoustics are endless

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Hydrographic Surveying

NOAA nautical chart 12221
Entrance to Chesapeake Bay

- Original (and still primary) purpose:
 - Nautical charting
- Now, many more applications



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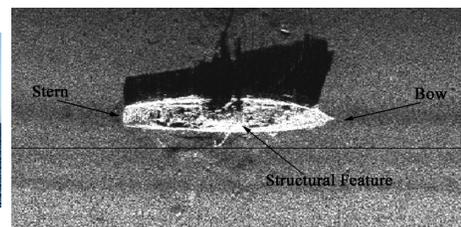
Other Applications of Hydrographic Surveys (Beyond Charting)

- Dredging
- Various Engineering and Construction Projects
- Boundary
- Hydrology
- Port and harbor security
- Oil and gas
 - Exploration
- Cable route surveying
- Habitat Mapping
- Marine archaeology

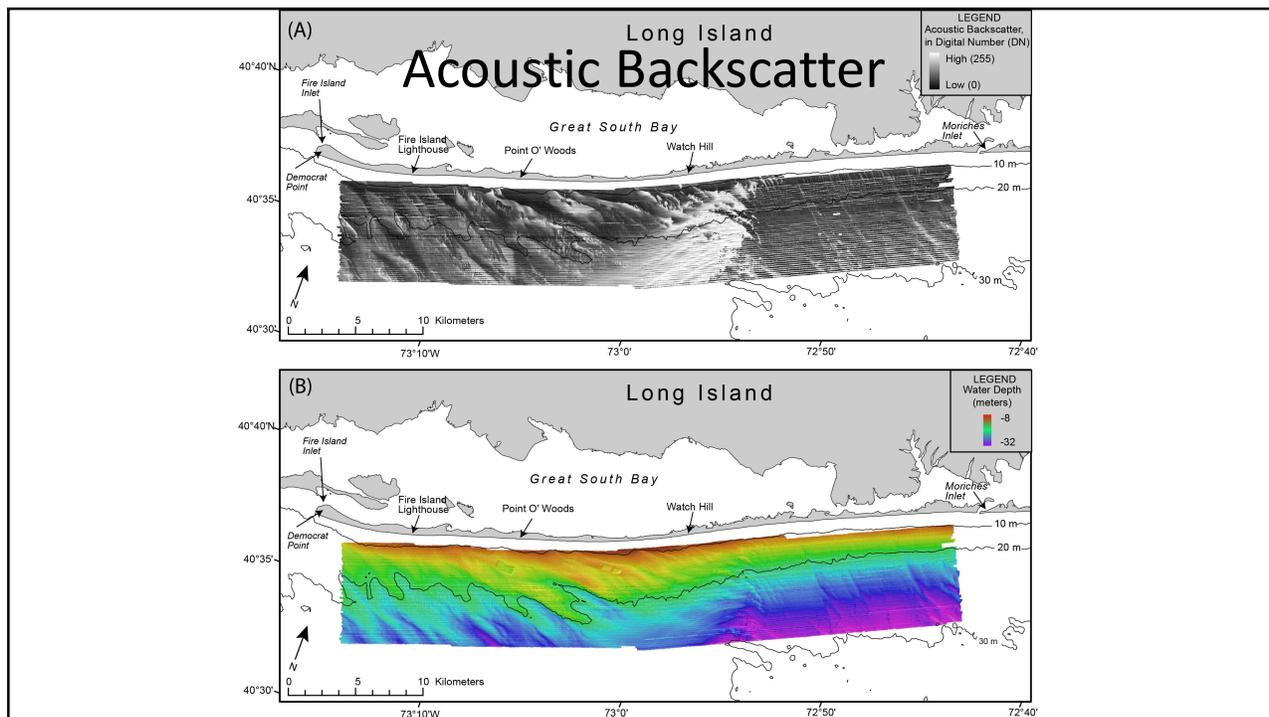
Credit: GJA



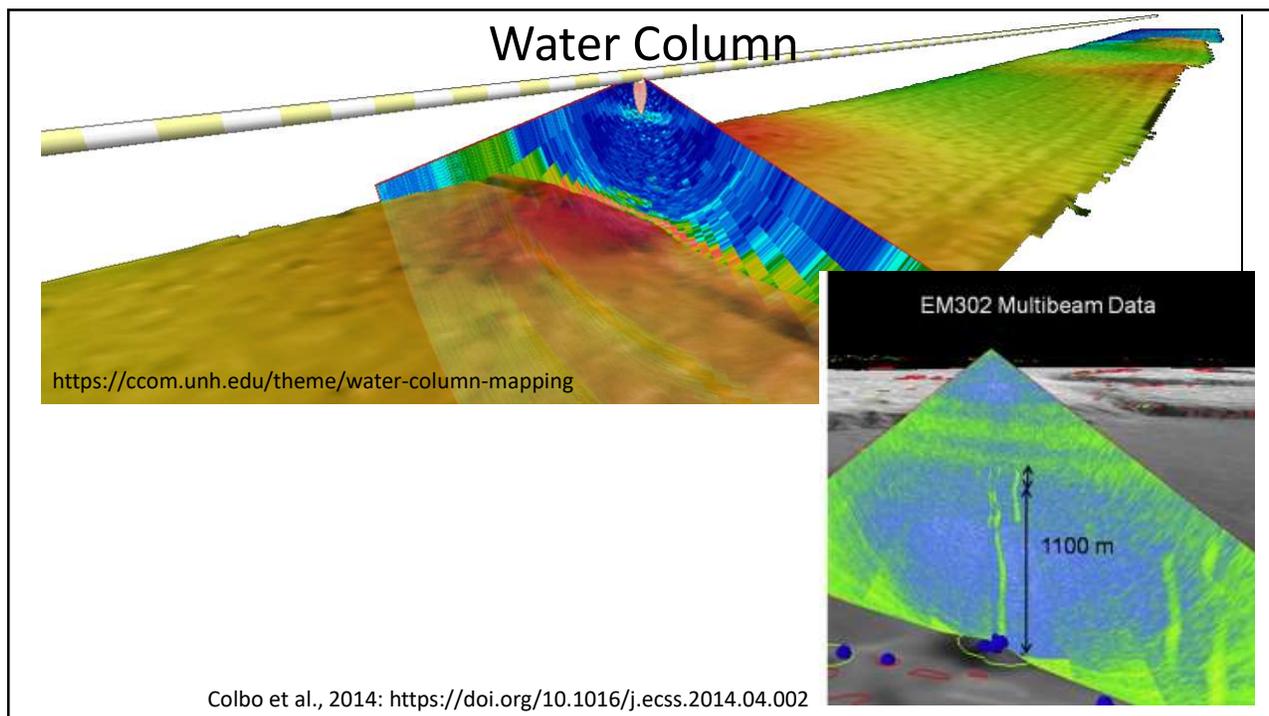
Credit: Glenn Johnson & Associates (GJA)



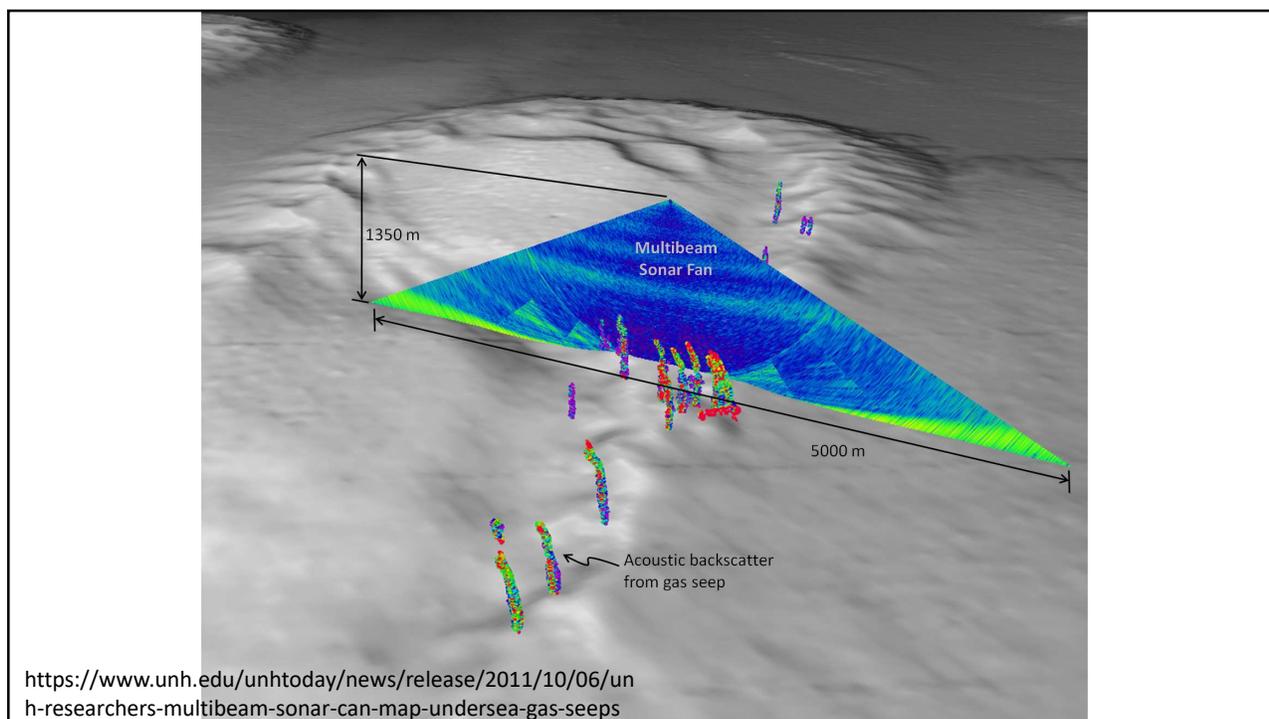
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Applications

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Hydrographic Organizations

- International Hydrographic Organization
- United States
 - NOAA's Office of Coast Survey (US EEZ)
 - US Army Corps of Engineers (US Inland Waters)

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Hydrographic Private Industry

- Fugro
- Woolpert (eTrac)
- NV5
- Terrasond
- JOA Surveys
- David Evans & Associates
- Others...

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Resources

- NOAA Office of Coast Survey
 - Field Procedures Manual
 - Data (modern and historic)
 - Coast Pilot
- NOAA National Geodetic Survey
 - Data (modern and historic)
- PASDA
 - Imagery
 - Lidar
- Local
 - E.g., "Thirty Lakes in the Vicinity of Wyoming Valley" by Charles B. Reif

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Data Sources

- PASDA
- NOAA's Bathymetric Data Viewer
- NOAA's Digital Coast
- USGS 3DEP

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Questions & Discussion

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Overall Summary

- Almost all inland applications in PA probably require single-beam
 - Aim for most cost-effective and simply to integrate option with your equipment and workflows
 - 200 kHz (single) frequency is likely all you need
 - Try to use reasonable sound speed values
- Water level/vertical datums are key
- UAS-based bathymetric could be force multiplier, particularly for streams, but expensive for smaller companies

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Contact Information

LinkedIn: Matt Sharr
email: matthew.sharr@gmail.com

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References

- Penn State SUR 421
- Oregon State CEE 561
- NOAA Office of Coast Survey

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