Breakout: Sound Speed Smörgåsbord
Multibeam Advisory Committee

RVTEC - Honolulu, HI
24 October 2023

Kevin Jerram
Paul Johnson
Vicki Ferrini
Hayley Drennon

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Sound Speed on the Ocean Mapping Community Wiki

Top 10 multibeam issues

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kjerram edited this page on Sep 8 · 8 revisions

The MAC, technicians, and colleagues encounter several common factors that limit data quality across a wide variety of platforms.

Top 10 common issues

In no particular order, here are ten common complications to consider when planning, collecting, and processing multibeam data:

1. **Inaccurate vessel offsets** (or incorrect interpretation)
   i. Data quality depends fundamentally on sensor configuration; see Dimensional Control
2. **Inadequate sound speed profiling** and/or mismatches at the transducer
   i. See Sound Speed and SmartMap
3. **Higher noise levels** due to biofouling and changes in machinery
   i. Run pre- and post-shipyard RX Noise tests to examine this
   ii. For Kongsberg systems, see the Transducer Cleaning, Fairing, and Painting Procedure
4. **Inappropriate runtime parameters**
   i. Automatic modes still need monitoring
   ii. The depth gates mean business!
5. **Infrequent calibrations**
   i. Routine patch testing can rule out some biases
6. **Interference** from other acoustic or electronic systems
   i. Is that 12 kHz bridge fathometer *really* secured?
   ii. Synchronize your scientific echosounders
7. **Sea state**, aeration, and bubble sweep along the hull
   i. Work is underway to adjust ping cycles around washdown events
   ii. Meanwhile, testing RX Noise vs. swell direction can help to identify quieter/better survey orientations for each particular vessel
   iii. Mapping is often the 'back up plan' when other work is on hold due to sea state!
8. **Waterline errors**
   i. Like other sensor offsets, this *directly affects* the reported depth
   ii. Waterline impacts refraction correction by changing the 'starting point' in the sound speed profile
   iii. The value depends on the manufacturer's conventions and **is not always equivalent to the draft**
   iv. Sound Speed Manager plots the transducer sound speed value and depth; this can be **extremely helpful** in verifying the waterline configuration

Pages 17

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Sound Speed

Edit New page

kjerram edited this page 3 weeks ago · 4 revisions

Seeking Contributors

This section is under development. If you have expertise in sound speed profiling and processing, please reach out to the admins at omcadmin@ccom.unh.edu to become a contributor today!

Overview

The sound speed environment fundamentally impacts the operation of a multibeam system. This environment is always changing, and care must be taken to sufficiently capture its variability.

Data quality depends directly on acquiring and applying correct sound speed information at the transducer (or the 'surface') and in the water column. There are no replacements for in situ measurements.

Transducer

Sound speed at the transducer face directly affects the beamforming and beamsteering capabilities of a multibeam echosounder. Most, if not all, multibeam echosounders require transducer sound speed information to enable transmission or allow acquisition. ***A fixed value should never be used during normal survey operations.***

This is typically measured directly (e.g., Reson SVP-70 probe) or calculated from temperature and salinity data (e.g., Seabird SBE45 thermosalinograph). The sensor is typically mounted in one of two configurations:

1. near the transducer to provide near-real-time sound speed at the face, or
2. in a flow-through system with an intake near the transducer.

Where possible, in situ measurement near the transducer face is preferable for quickly and accurately capturing transients in the upper surface layers. The flow-through approach may be necessary in some cases (e.g., icebreakers), at the risks of temperature changes between intake and measurement and the associated time lag, depending on layout of the intake system and speed of flow.

Increasing insulation and reducing residence times can improve the flow-through measurements. Conversely, mixing in a large-volume sea chest (especially with any outflows nearby) may delay and alter the flow-through measurement to the point that it is no longer applicable for multibeam operations.

In all cases, the intake or sensor must be exposed to the same water flowing over the transducer. This is generally not a concern with a well-mixed upper layer extending below the hull draft, but becomes important when transmitting and sampling at significantly different depths / hull locations across steep temperature and/or salinity gradients between upper surface layers.

Tips

Recommend cleaning the probe before deployment--if the probe is not measuring sound velocity accurately, it can have a cascading effect. SIS will reject the probe if the values are out of range (1400-1700m/s). The RESON SVP 70, for example, flatlines at 1350 when the probe is covered in growth! Cleaning is, of course, dependent on logistics and diver availability if the probe is not otherwise accessible.

Pages 17

Find a page...

MBES Recap…

MAC supported under NSF grant 1933720

Ocean Mapping Community Wiki

github.com/oceanmapping/community/wiki

Glossary of Terms

absorption loss	The energy lost by a propagating wave to the medium in which it is traveling.
acoustic energy	The energy carried by a sound wave.
acrosstrack	See athwartship.
active sonar	A device that makes remote measurements in a water medium by transmitting sounds and processing their echoes off remote targets.
alongtrack	Dorection parallel to a ship's keel and its direction of motion.
amplitude	The measured size of the oscillations of a wave.
analog signal	A measurement that is continuous in time.
angle of incidence	The angle at which a sound pulse strikes a medium, usually measured with respect to the perpendicular.
athwartship or **acrosstrack**	The direction that is perpendicular to a ship's keel.
attenuation	Any loss in energy of a propagating wave.
backscattering strength	The fraction of incident energy per unit area that is directed back from the ocean bottom in the direction of the projector.
bathymetry measurement	See echo sounding.
beam	Used to describe focusing of acoustic energy by a hydrophone system or of sensitivity to received acoustic energy within a narrow solid angle.
beam forming	The process of using projector arrays and hydrophone arrays to produce narrow transmit beams and receive beams.
beam pattern	A description of the focusing of transmitted or received acoustic energy within a beam as a function of angle. Also called a power pattern or directivity pattern.
beam stabilization	See motion compensation.
beam steering	The process of using time delays or phase delays to direct the beams of a hydrophone array at specific angles.
beam width or **beam solid angle**	A measurement of the size of the main lobe of a beam pattern. Measured at the half power point.

Because BDI results generate more accurate DOA information, the SEA BEAM 2100 system attempts to use them where possible. This is mostly in the non-specular regions, generally in the "outer" beams that are at large angles from the vertical (although you could imagine situations where the non-specular region would be directly below the survey ship, depending on the bottom configuration – see Figure Chapter 4 - -29). Where BDI calculations produce no results, WMT processing is used.

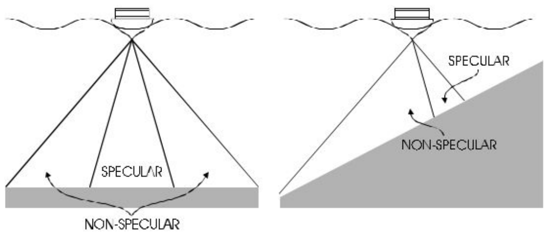


Figure Chapter 4 - -29: Specular and Non-specular Regimes with Different Sea Floors

Range Calculation and Bottom Location

...ocessing is to convert echo DOA and TOA measurements into ..., the complications introduced by the pitch of the survey vessel at ... in the velocity of sound at different ocean depths must be taken ...

...ng a single ping. At the time of transmission, the ship will have a ... the VRU system (see the "Motion Compensation" section ... "Beam Formation," in Chapter 2, that the SEA BEAM 2100 ...rrow in the alongtrack direction, but wide in the acrosstrack ...

The sound velocity profile of an area of ocean can be approximated by a set of layers, each with a different sound velocity. Sound traveling through different layers moves at different speeds. In addition, when changing from one layer to another, the direction of the sound changes. When traveling from a region of high sound velocity to one of lower sound velocity, a sound wave bends toward the vertical. When traveling from low to high speed regions, it bends away from the vertical. If you start with the launch angle and TOA of an echo, you can follow the path an the echo must have taken from the bottom, changing its angle based on the sound velocity profile (see Figure Chapter 4 - -32). Within each layer, you subtract the amount of time it would take the echo to travel through the layer at the appropriate angle (twice– once down, once back) from the TOA. Eventually, you are going to run out of time, yielding the location of the true echo. This process is called *ray tracing*. Using the location of the true echo, you can get the true depth to the echo, and the *bearing offset*– the distance between it and the position directly below the sonar. Combining the bearing angle (see Figure Chapter 4 - -31) and the navigation information of the survey ship with the bearing offset will give the exact longitude and latitude of the echo position.

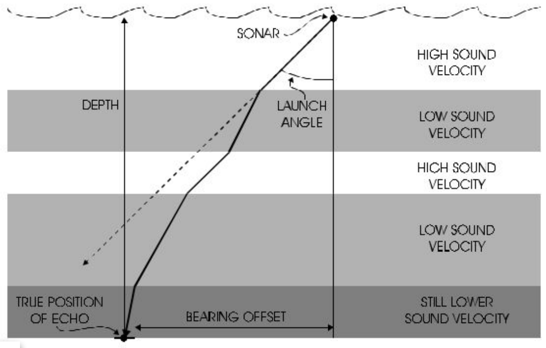


Figure Chapter 4 - -32: Ray Tracing to Find the Bottom

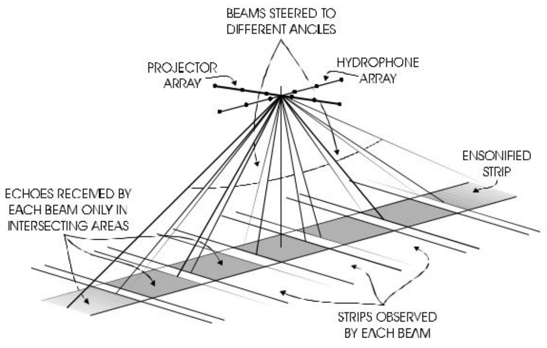


Figure Chapter 3 - -21: Mills Cross with Multiple Steered Beams

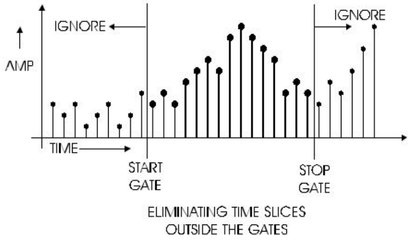


Figure Chapter 4 - -23: Eliminating Time Slices Outside the Gates

https://www3.mbari.org/data/mbsystem/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf

Positioning

Positioning topics

Helpful links

1. GPS Visualization

Resources

Below are a few helpful resources to find, manage and evaluate ocean mapping data.

Open-source data tools

1. HydrOffice - a collaborative research-to-operations framework, including Sound Speed Manager and QC Tools
2. Ocean Data Tools - tools for data acquisition, management and event logging, including OpenRVDAS, OpenVDM and Sealog
3. GMRT Tiler - compare processed data to the GMRT grid to identify issues with sound velocity, etc., and ensure suitability for archive
4. MB-SYSTEM - open source; commonly used for automated / scripted processing of data from AUVs and other vehicles

Best practices

1. Ocean Best Practices - repository for ocean science SOPs from around the world
2. IHO-IO GEBCO Cookbook - technical reference manual focused on how to build grids
3. NOAA OER Deepwater Exploration Mapping - reference for NOAA OER mapping operations on the NOAA Ship *Okeanos Explorer*
4. Australian Multibeam Guidelines 2.0 - technical reference manual focused multibeam operations

Helpful presentations and papers

1. Sonar Synchronization and Tradeoffs
2. Rolling Deck to Repository Overview - 2020 RVTEC
3. Open Vessel Data Management - 2020 RVTEC
4. Lessons Learned from a Successful Integration of the EM 304 MKII Variant Multibeam Sonar
5. Ocean Exploration in a Data-Rich World - white paper from 2022 National Ocean Exploration Forum
6. Exploring the use of Sound Speed Profiles... - 2022 Ocean Sciences
7. Calibration of Acoustic Instruments - Summarizes fundamental sonar theory and details calibration methods.
8. Multibeam Sonar Theory of Operation - a clear overview of sonar concepts (multibeam and sidescan)

Why map the ocean?

Most of this wiki focuses on *how* to map the watery 71% of our planet. Here are a few examples of *why*.

Beyond the critical role of safety of navigation, ocean mapping is important for a wide array of reasons:

1. confirming plate tectonics and ancient oceans
2. understanding ocean circulation and climate
3. studying historic tsunamis and present risks
4. managing fisheries and food sources
5. tracking sources of greenhouse gases
6. routing global submarine cables
7. catching up to maps of our moon and Mars

Multibeam Recap: **One Element, Two Elements…**

Introduction to Multibeam Sonar:
Projector and Hydrophone Systems

Multibeam Sonar Theory of Operation

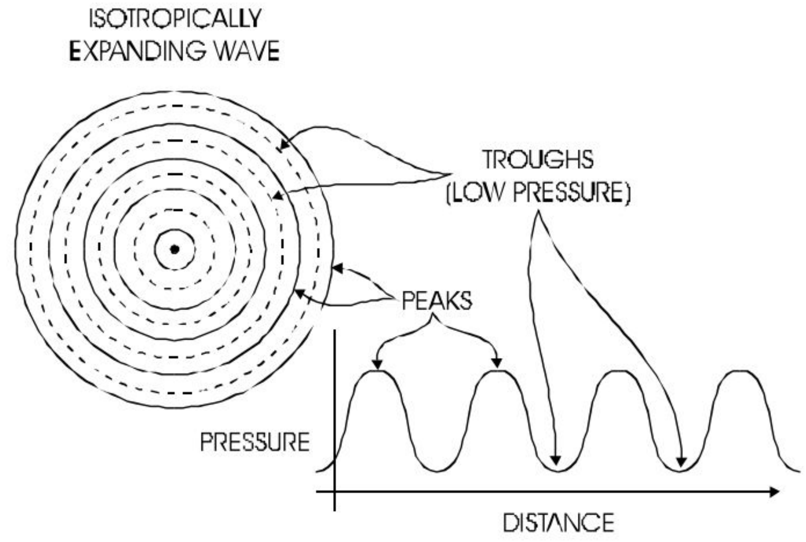


Figure Chapter 3 - -1: Isotropic Expansion

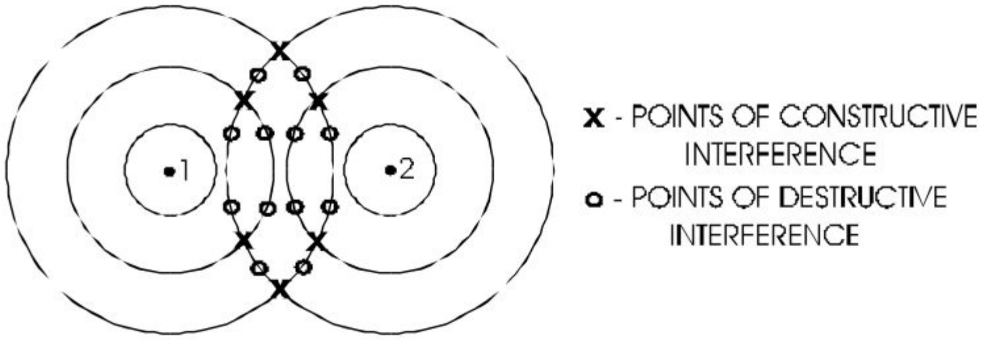


Figure Chapter 3 - -2: Constructive and Destructive Interference

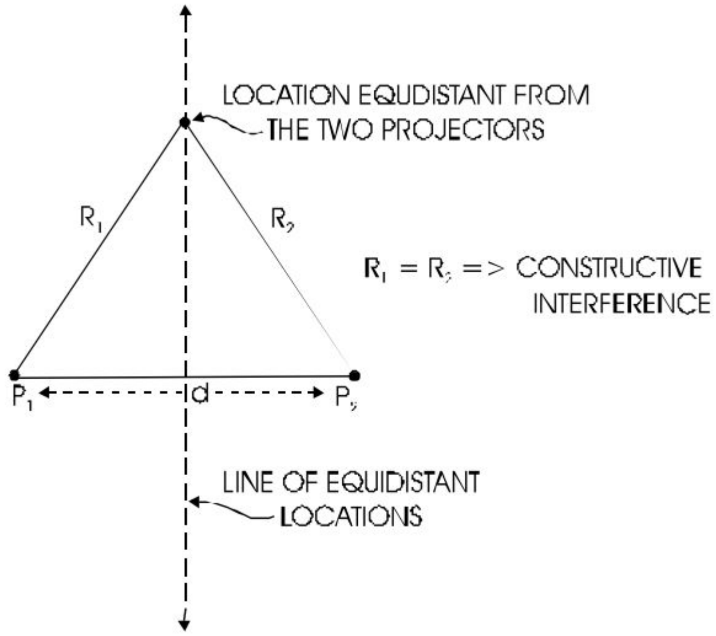


Figure Chapter 3 - -3: Positions of Constructive Interference (Example 1)

The locations of other constructive interference are less obvious, but they can be found with some simple geometry. In Figure Chapter 3 - -4, two projectors P_1 and P_2 again have a spacing d. Consider a point at a location R_1 from P_1 and R_2 from P_2. The direction to this location (labeled R_0 in the figure) intersects a line perpendicular to the spacing d with an angle θ_0. Next, assume that the point you are considering is very far away compared to the spacing of the projectors—meaning that R_1 and R_2 are much larger than d. For a typical operating environment for a sonar, this is a good approximation—projectors are spaced centimeters apart (d = cm) and the ocean floor they are ensonifying is hundreds or thousands of meters away (R_0 = 100 m to 1000 m, meaning R_0/d = 1000 to 10000). This is called the *far field* approximation, and it is necessary to keep computations simple. In this situation, the lines R_0, R_1, and R_2 are treated as parallel, and all intersecting angles θ_0, θ_1, and θ_2 as equal.

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

https://www3.mbari.org/data/mbsystem/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf

Multibeam Recap: **Three Elements, 100s of Elements…**

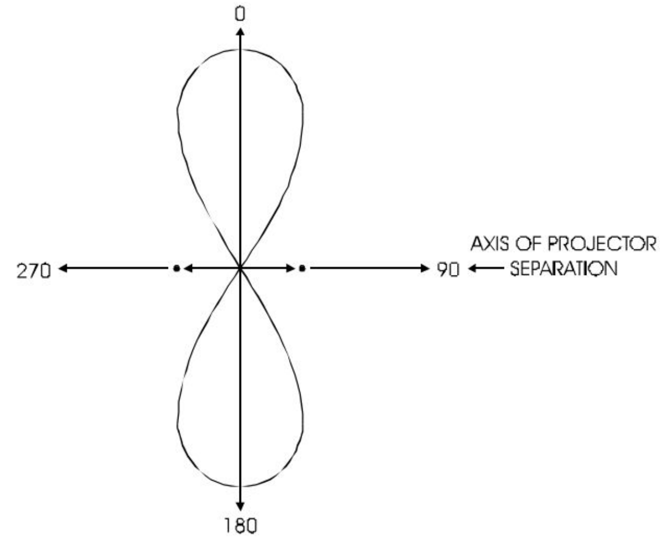
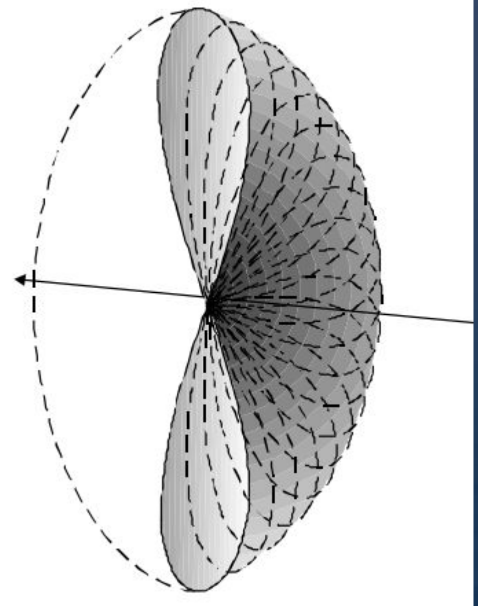


Figure Chapter 3 - -6: Beam Pattern for Two Hydrophones with Spacing λ/2



Same concept…
TX: projectors
RX: hydrophones

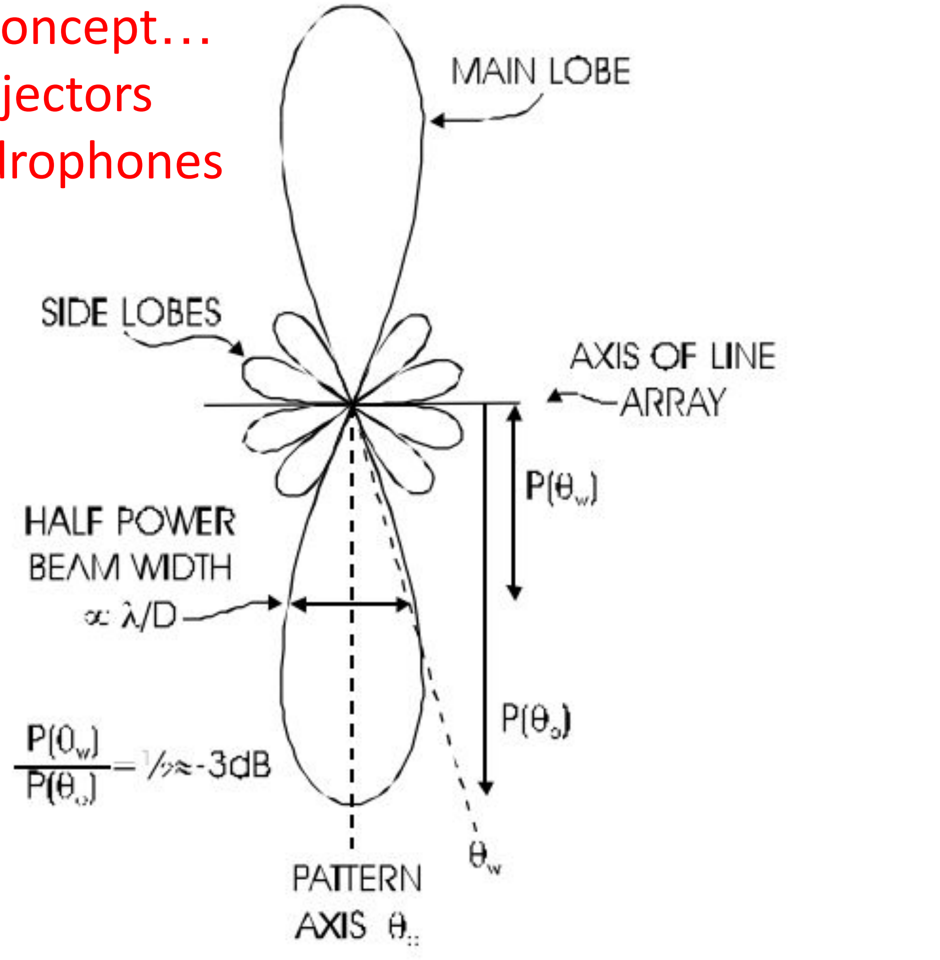
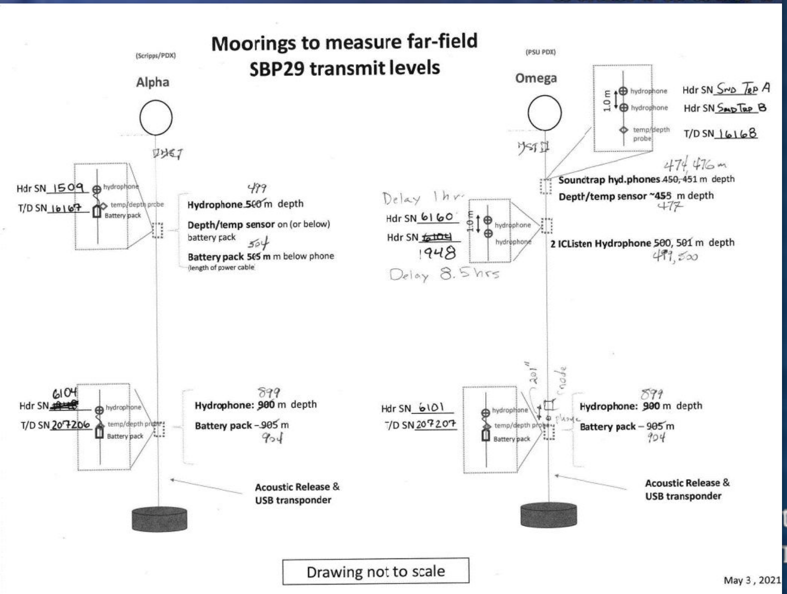


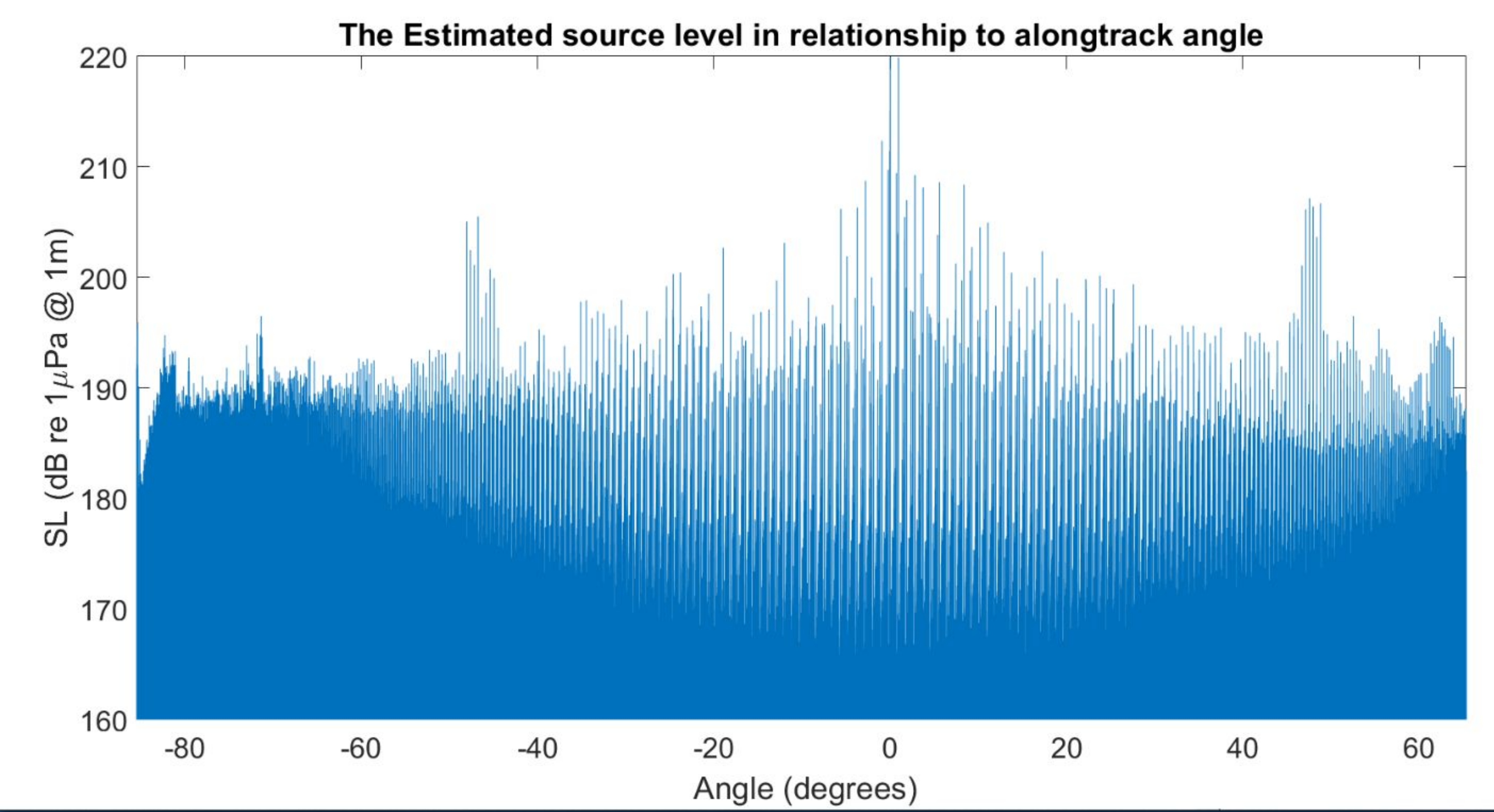
Figure Chapter 3 - -8: Beam Pattern of a Multiple-Element Line Array

Table Chapter 3 - -1: Main Lobe Width Comparisons

	Beamwidth	
Array Elements	Unshaded	Chebyshev (-35 dB)
20	5.1°	6.8°
40	2.5°	3.3°
48	2.1°	2.8°
80	1.3°	1.6°
96	1.1°	1.4°

Example: R/V *Sally Ride* EM124 TX Characterization





Multibeam Recap: **Beamsteering**

$$A = d \times \sin\theta \qquad (3.7)$$

$$B = 2d \times \sin\theta$$

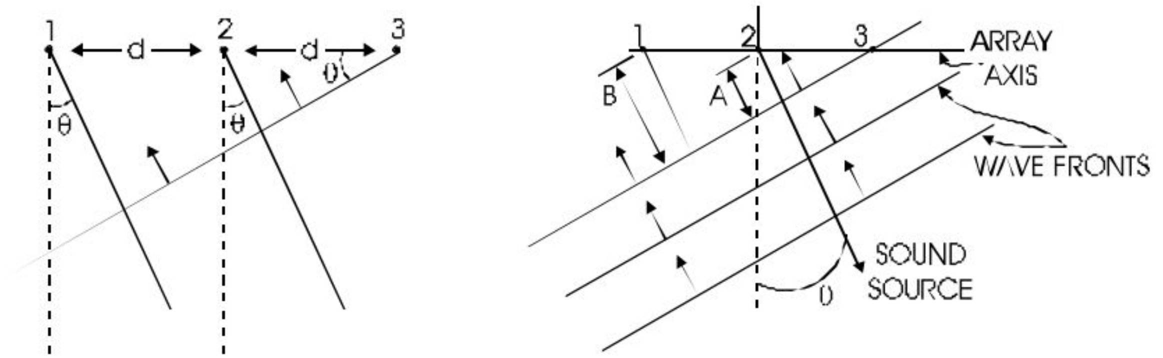


Figure Chapter 3 - -16: Wavefronts Striking a Hydrophone Array from a Source at Angle θ

The extra times required for the wave front to reach each hydrophone are given by the distances divided by the local sound speed c:

$$T_2 \text{ (time to hydrophone 2)} = A / c = (d \sin\theta) / c \qquad (3.8)$$

$$T_1 \text{ (time to hydrophone 1)} = B / c = (2d \sin\theta) / c$$

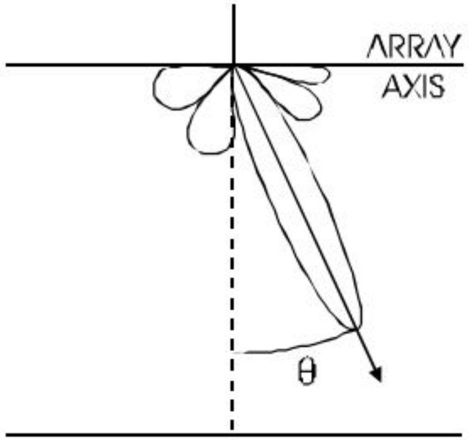
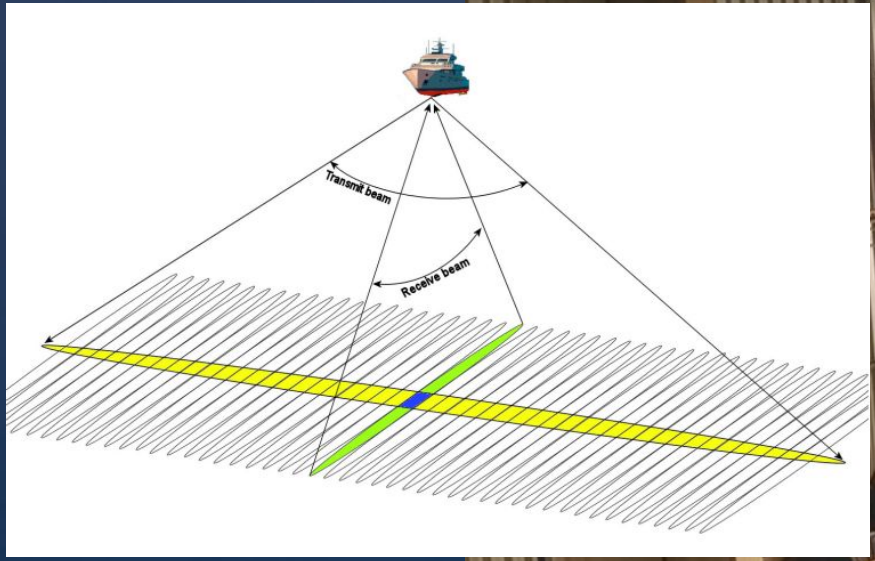


Figure Chapter 3 - -17: Main Lobe Shifted to Angle θ by Introducing a Time Delay

Note that in steering a hydrophone array to be sensitive to a particular angle, nothing about the array itself is changed—only the interpretation of the data it records is altered. By changing the data processing, the same array can be steered to observe any of a large range of angles. In fact, using the same recorded data from the elements of the hydrophone array, different data processing can be used to examine the sounds coming from different angles *simultaneously*. In this way, a hydrophone array can be used to examine the echoes from a single ping at many different locations.

Multibeam Recap: **Mill's Cross**



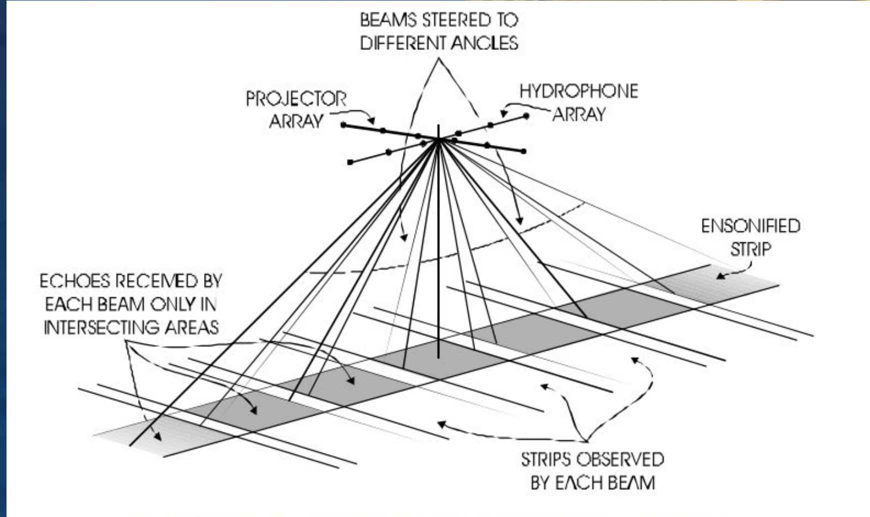
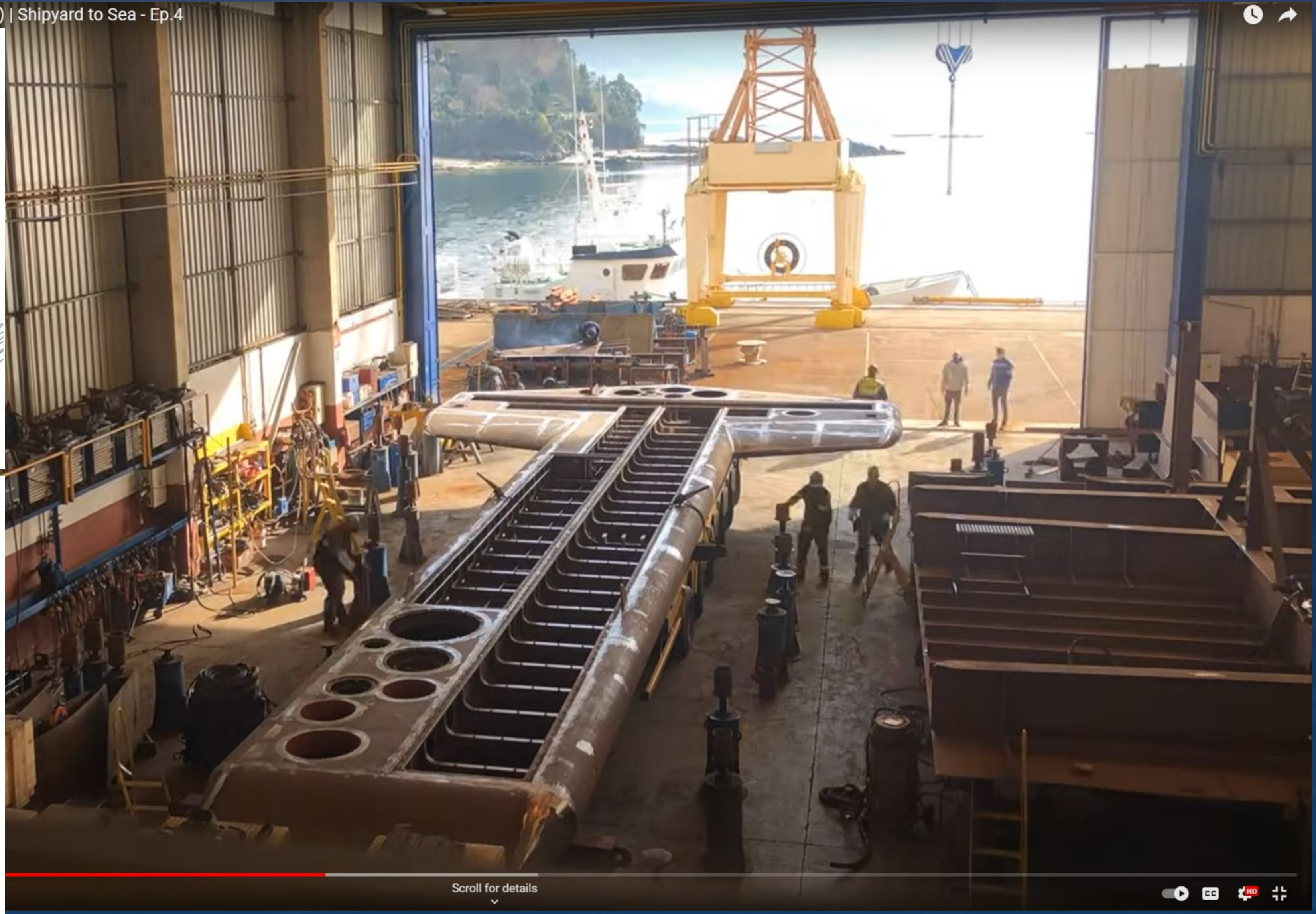


Figure Chapter 3 - -21: Mills Cross with Multiple Steered Beams



Physical Principles of Multibeam Sonar for Mapping of the Seafloor, DeSanto and Sandwell (2022)
Schmidt Ocean Institute (https://www.youtube.com/watch?v=6GambgOUlnA)

Multibeam Recap: **'Surface' (Transducer) Sound Speed**

Beamforming and beamsteering depend on…

a. Element spacing in the array (proprietary)
b. Wavelength (λ = c/f) at the transducer during TX/RX

…and enable ALL TX and RX stabilization processes…

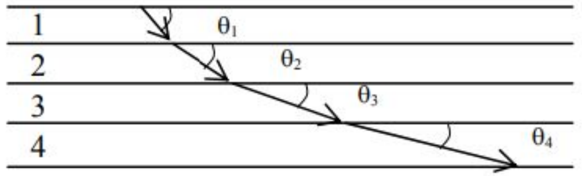
a. TX: roll, pitch, yaw stabilization → alongtrack sounding density
b. RX: roll stabilization and beam spacing → acrosstrack sounding density

…which control 'launch' angles for refraction correction to the sounding!

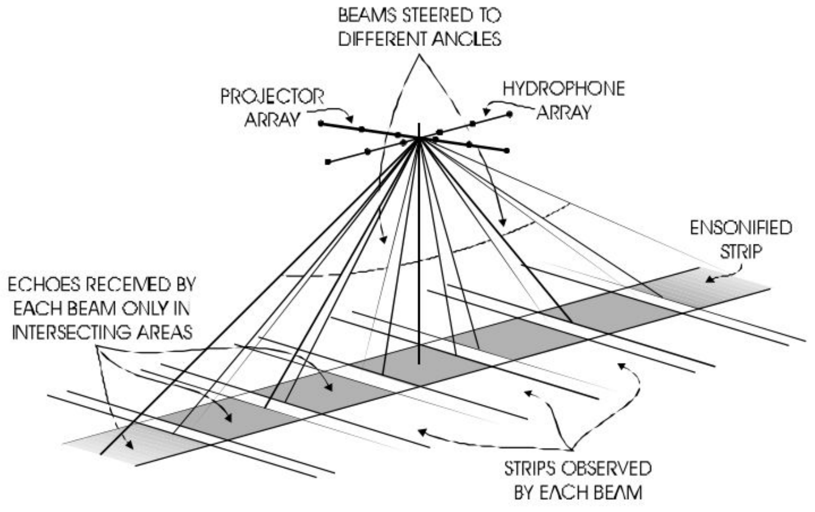
Multibeam Recap: **Refraction Correction**

$$\frac{\cos(\theta_1)}{c_1} = \frac{\cos(\theta_2)}{c_2} = \frac{\cos(\theta_3)}{c_3} = ... = \frac{\cos(\theta_n)}{c_n} = \text{constant}$$

Snell's Law (1621)



where $c_1 < c_2 < c_3 < c_4$ and $\theta_1 > \theta_2 > \theta_3 > \theta_4$



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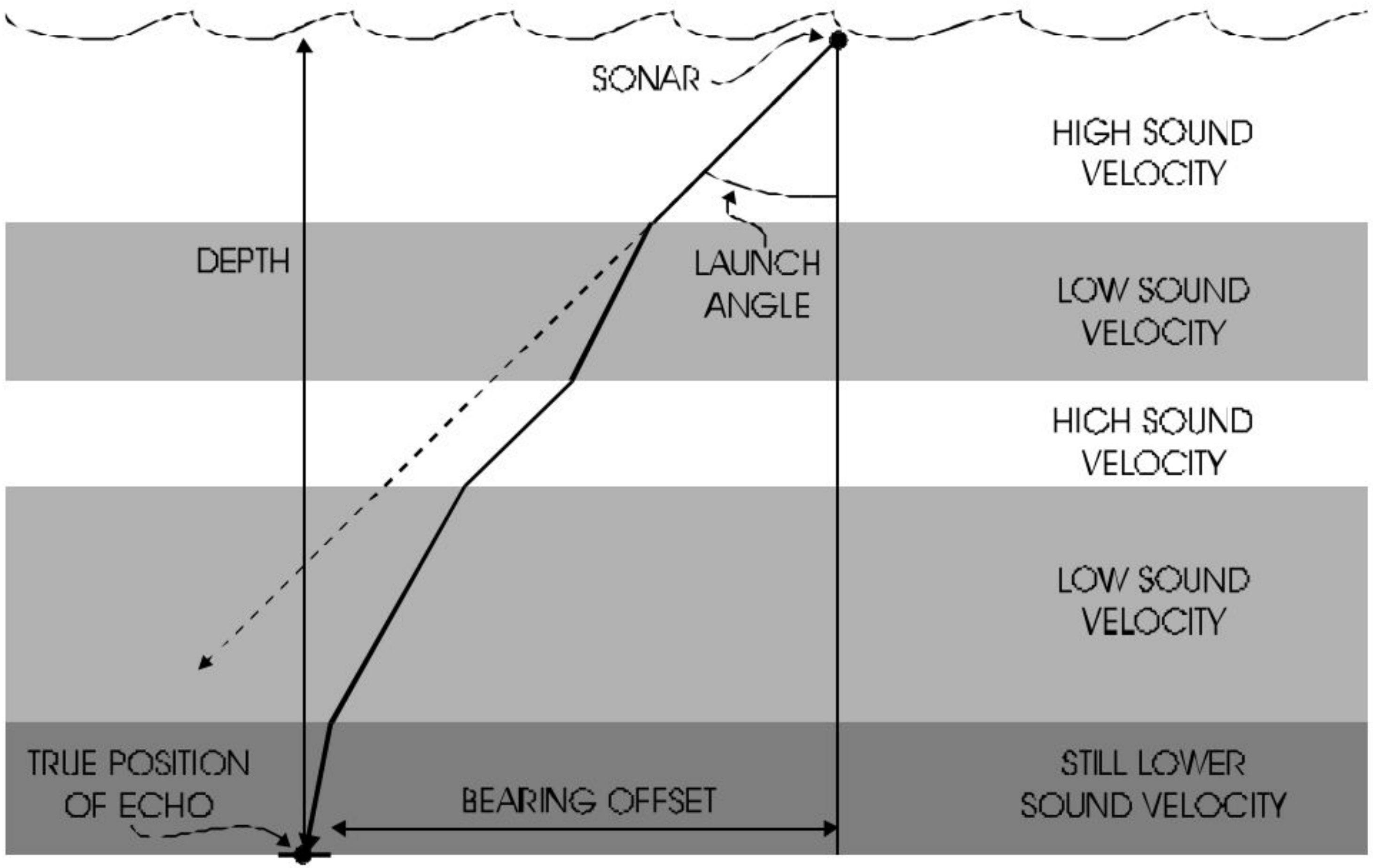

Figure Chapter 4 - -32: Ray Tracing to Find the Bottom

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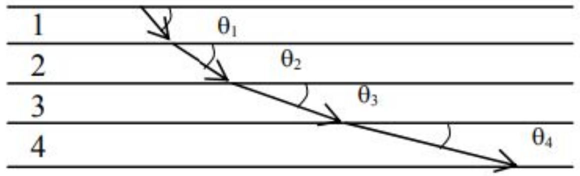
https://www3.mbari.org/data/mbsystem/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf
https://ccom.unh.edu/sites/default/files/publications/cordero-ms-2018.pdf

Multibeam Recap: **Refraction Correction**

$$\frac{\cos(\theta_1)}{c_1} = \frac{\cos(\theta_2)}{c_2} = \frac{\cos(\theta_3)}{c_3} = \dots = \frac{\cos(\theta_n)}{c_n} = \text{constant}$$

Ibn Sahl (984)!!!



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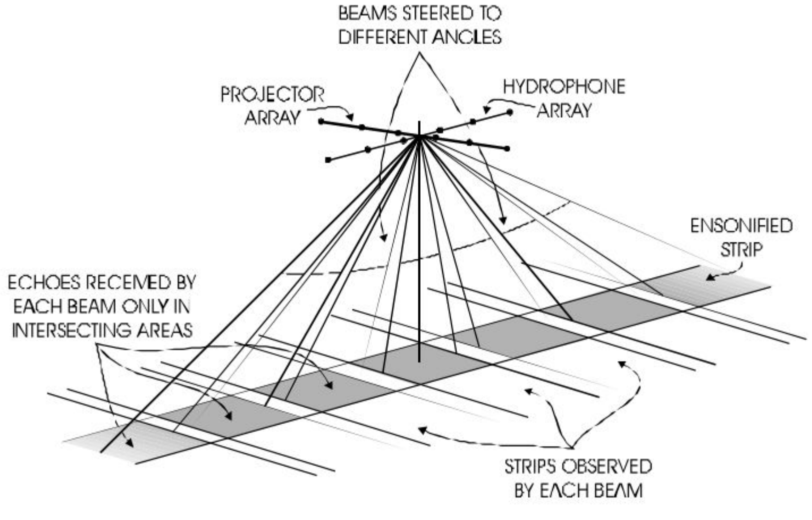

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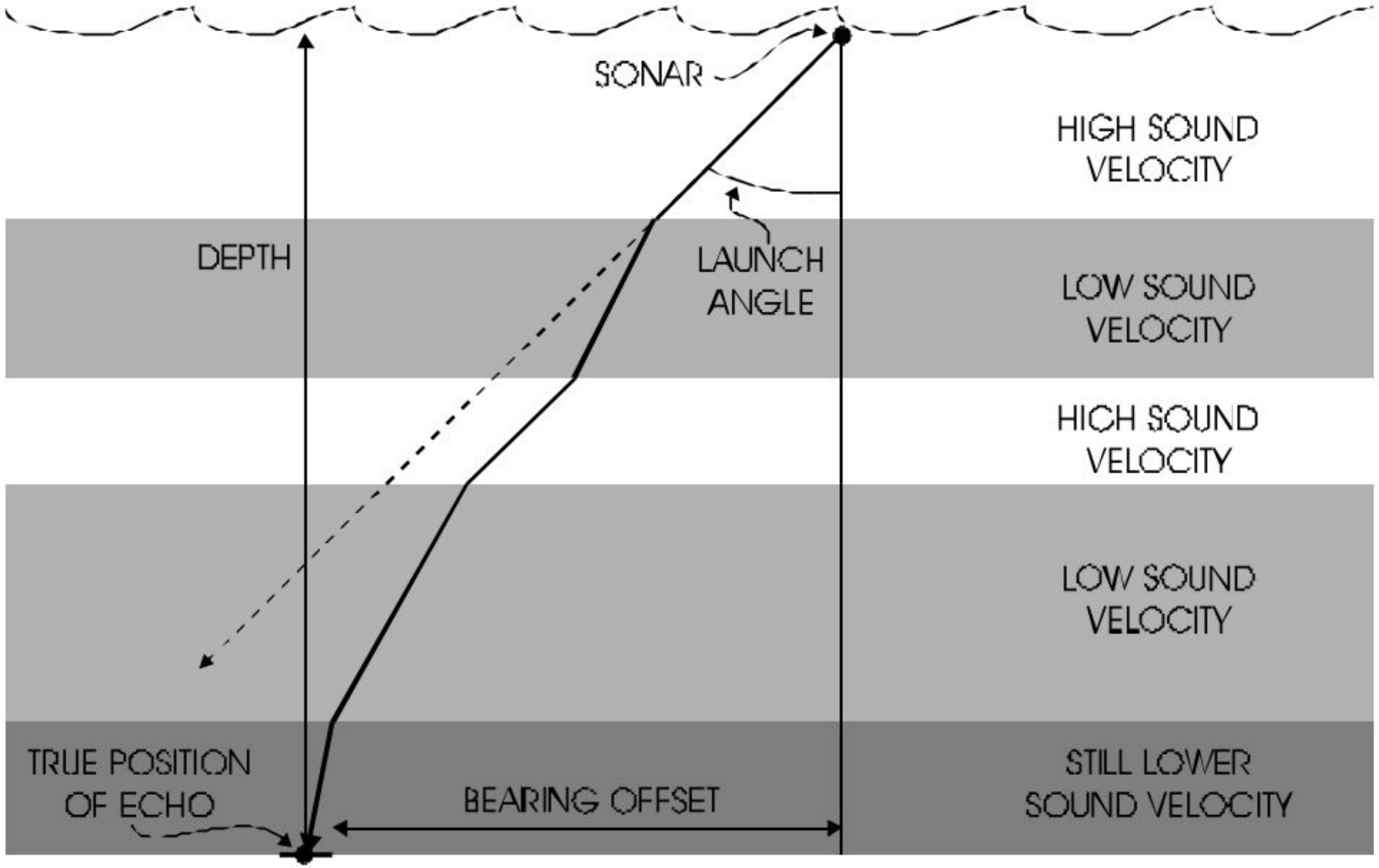

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https://ccom.unh.edu/sites/default/files/publications/cordero-ms-2018.pdf

Multibeam Recap: **Range Calculation**

The sound velocity profile of an area of ocean can be approximated by a set of layers, each with a different sound velocity. Sound traveling through different layers moves at different speeds. In addition, when changing from one layer to another, the direction of the sound changes. When traveling from a region of high sound velocity to one of lower sound velocity, a sound wave bends toward the vertical. When traveling from low to high speed regions, it bends away from the vertical. If you start with the launch angle and TOA of an echo, you can follow the path an the echo must have taken from the bottom, changing its angle based on the sound velocity profile (see Figure Chapter 4 - -32). Within each layer, you subtract the amount of time it would take the echo to travel through the layer at the appropriate angle (twice—once down, once back) from the TOA. Eventually, you are going to run out of time, yielding the location of the true echo. This process is called *ray tracing*. Using the location of the true echo, you can get the true depth to the echo, and the *bearing offset*—the distance between it and the position directly below the sonar. Combining the bearing angle (see Figure Chapter 4 - -31) and the navigation information of the survey ship with the bearing offset will give the exact longitude and latitude of the echo position.

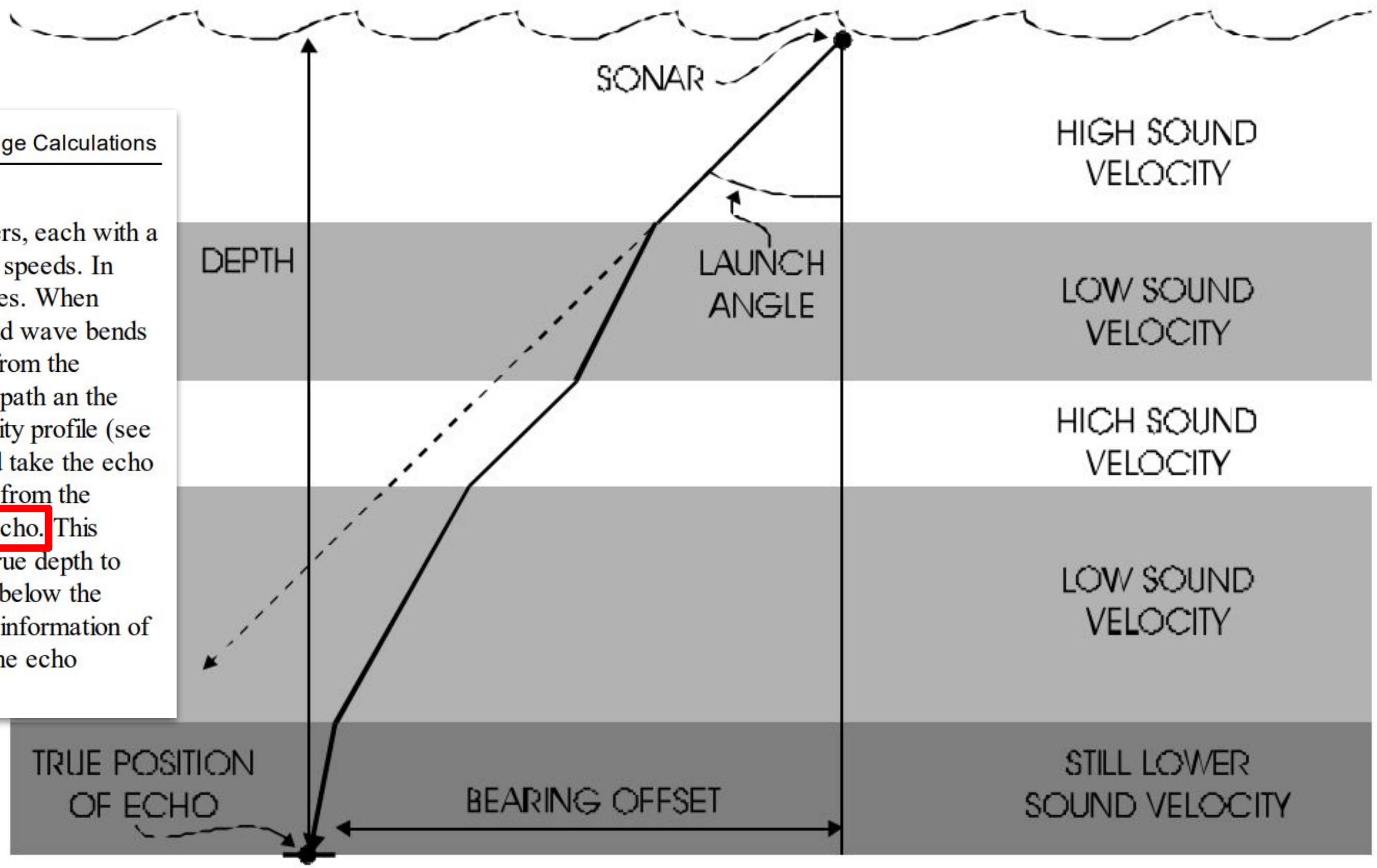
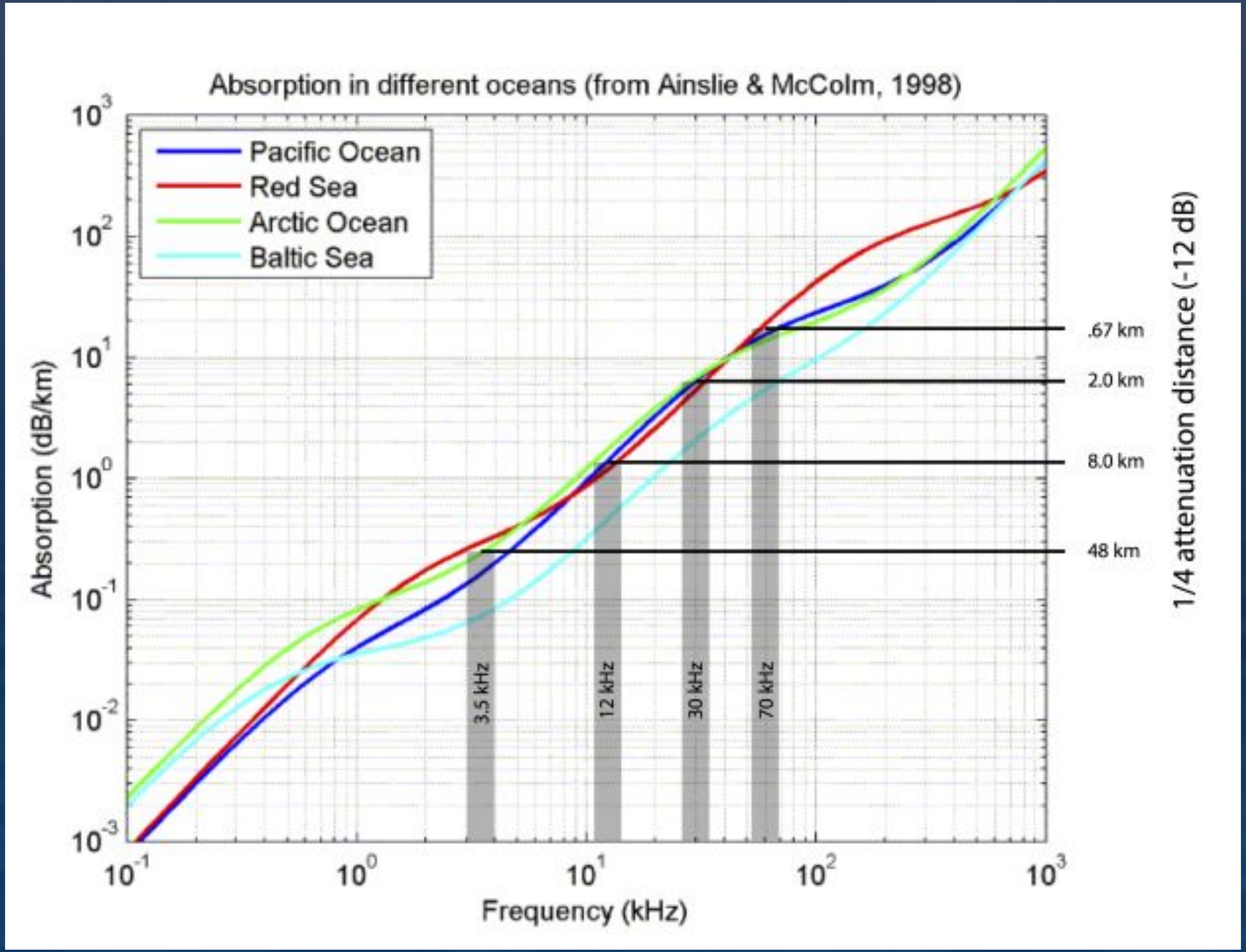


Figure Chapter 4 - -32: Ray Tracing to Find the Bottom

Multibeam Recap: **Absorption**



Physical Principles of Multibeam Sonar for Mapping of the Seafloor, DeSanto and Sandwell (2022)

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

Multibeam Recap: **Sound Speed Profile**

Range calculation for each beam depends on travel time along the ray path…

a. Cumulative travel time along a ray path ⟶ sum of travel time within SSP layers

…which depends on 'launch angles' into the water column…

a. Transformation from array reference ⟶ ship reference ⟶ global reference

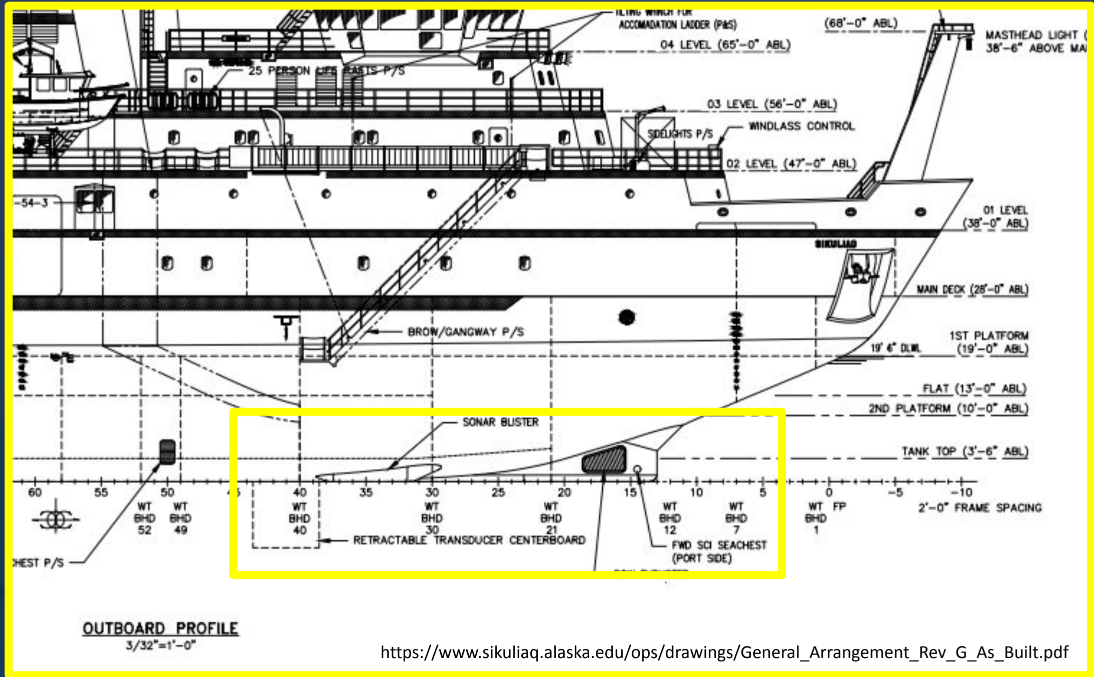
…and refraction correction along the ray path to the seafloor.

a. Final horizontal and vertical positioning (and uncertainty) of the sounding!

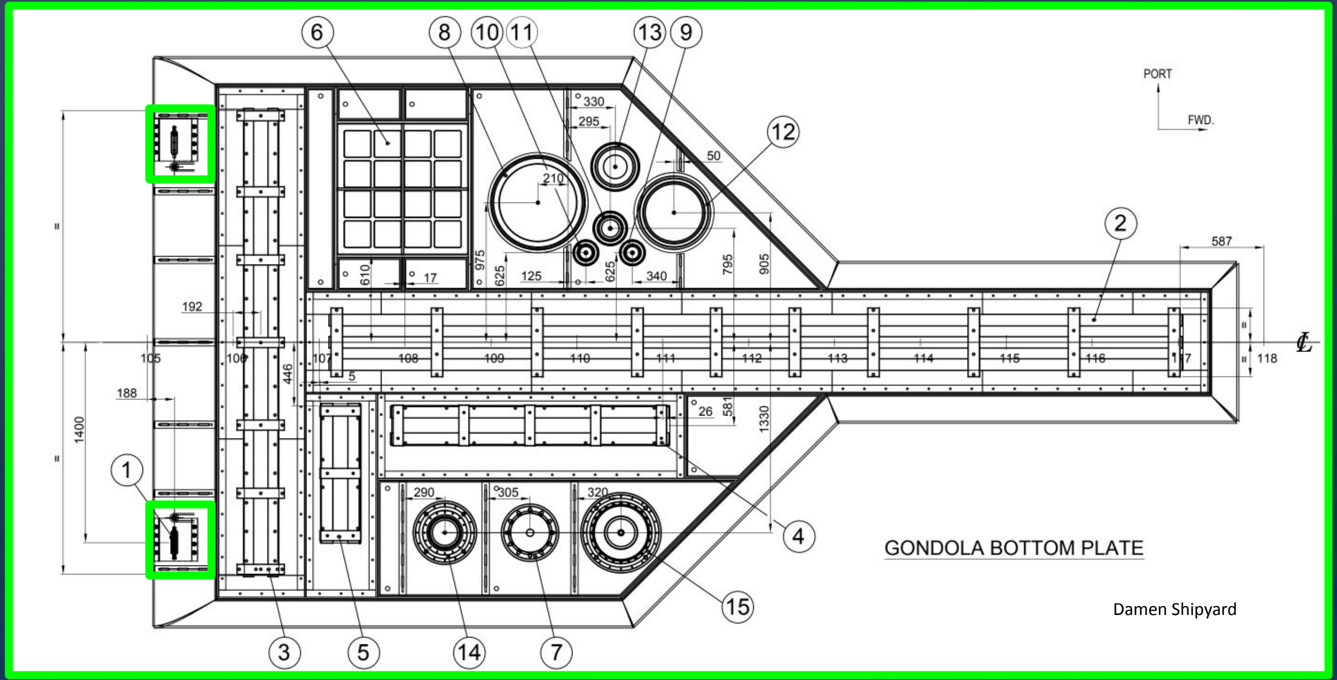
Common setups and tradeoffs

MAC supported under NSF grant 1933720

Setups and Tradeoffs: Surface Sound Speed



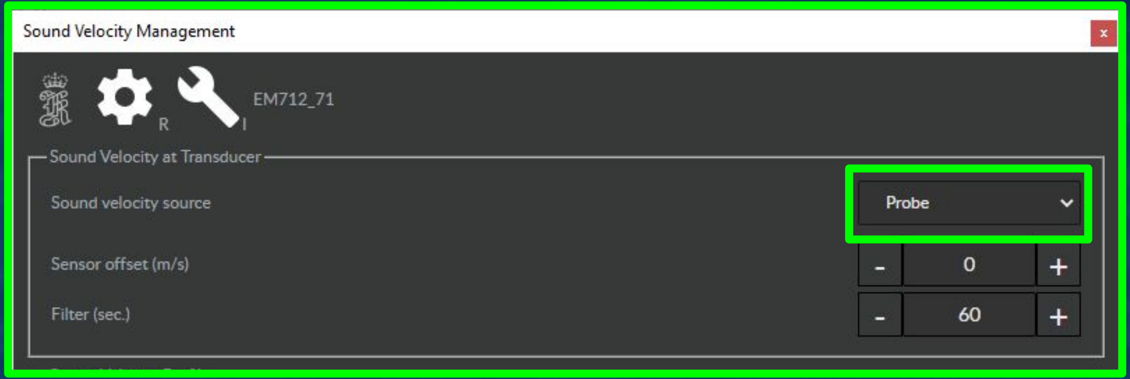
https://www.sikuliaq.alaska.edu/ops/drawings/General_Arrangement_Rev_G_As_Built.pdf



Damen Shipyard

Flow-Through / Not Near Arrays
(May be necessary, e.g., ice windows!)
Pros:
- Accessible for sensor maintenance

Cons:
- Conditions at intake ≠ array faces
- Latency (if cutting through gradients)



***In Situ* Near Arrays**
Pros:
- Closest to conditions at array faces
- Negligible latency or Z difference
- Standard for shallow water systems

Cons:
- Biofouling; difficult to access/swap

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Setups and Tradeoffs: Surface Sound Speed

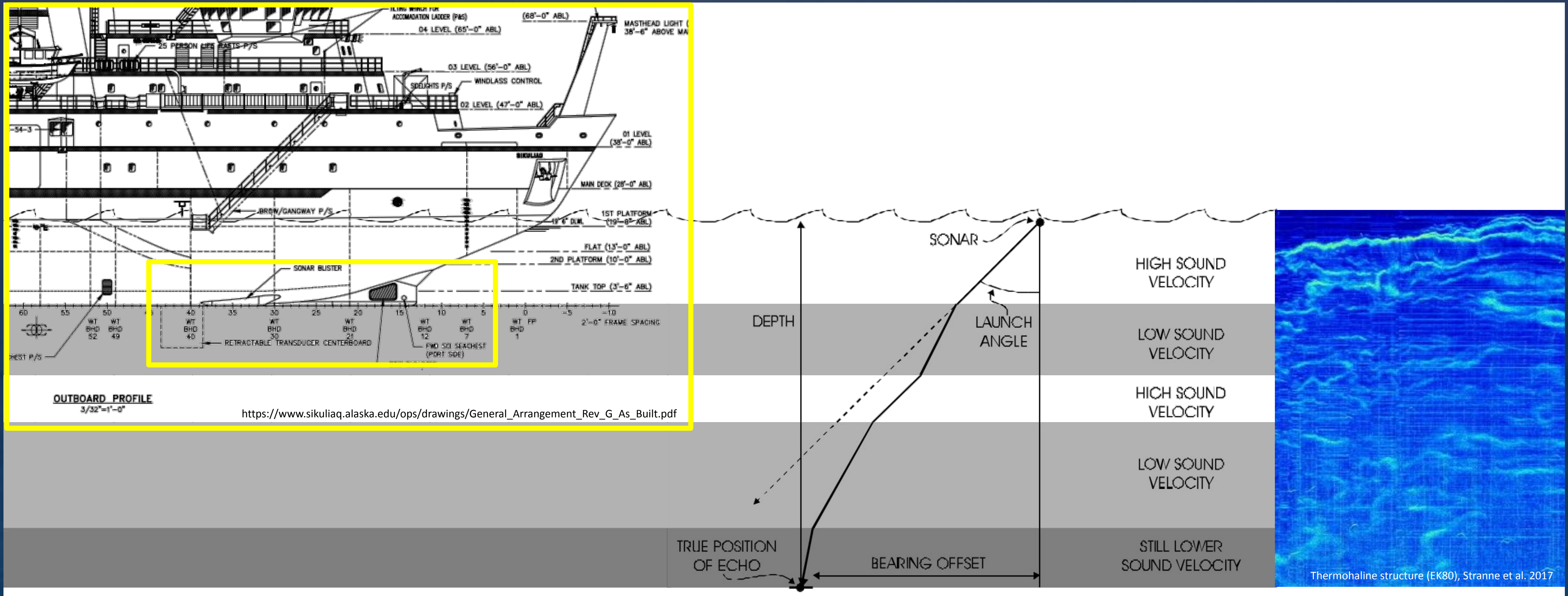

Figure Chapter 4 - -32: Ray Tracing to Find the Bottom

Setups and Tradeoffs: Sound Speed Profiles

Sound Speed Profile Method	XBT	XSV	XCTD	CTD	SV Profiler	Underway CTD	Underway SV	Moving Vessel Profiler
Env. Impact	**Expendable**			**Reusable**				
Ship Operations	Underway			Stationary	Stationary	Underway	Underway	Underway
Data (+Depth)	Temp.	SV	C, T	C, T	SV	C, T	SV	SV (C, T)
Depth source	Est. fall rate (2% depth errors noted[1])			Measured	Measured	Measured	Measured	Measured
Additional data needed for SSP	Salinity profile	None	None	None	None	None	None	None
Additional data needed for BS	Salinity profile	Salinity profile	None	None	Salinity	None	Salinity profile	Salinity profile if not collected
Deployment	Hand launcher, Auto-launcher			Winch				
Advantages	No need to stop (time/cost savings), broad user base, simple deployment			"Gold standard", ROV sources	Lower cost than CTD	No need to stop the vessel, potentially high-frequency casts		
Downsides	Waste	Waste, cost	Waste, cost, failure rate	Cost, stationary, low-freq. casts, calibrations	Stationary, low-freq. casts	Cost, sensitivity of winch/wire underway, limited user base, calibrations		

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[1] *Comparison of the fall rate and structure of recent T-7 XBT…* by Kizu, Sukigara, and Hanawa 2011

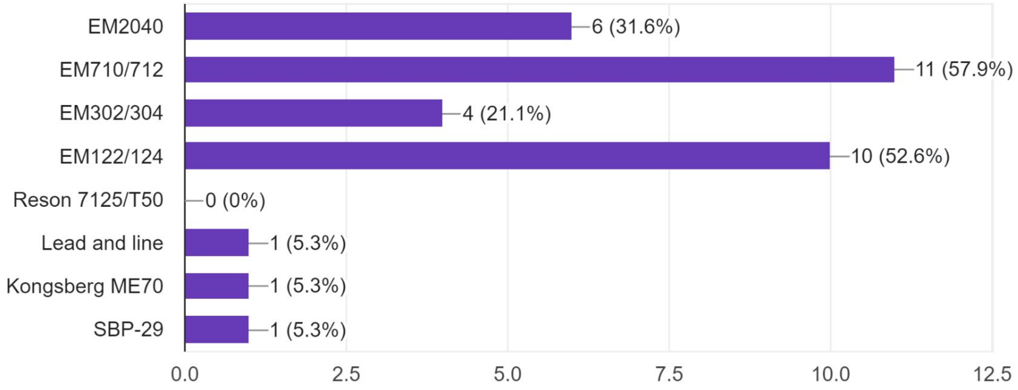
Survey Results

MAC supported under NSF grant 1933720

Survey Results: **Surface Sound Speed (Primary)**

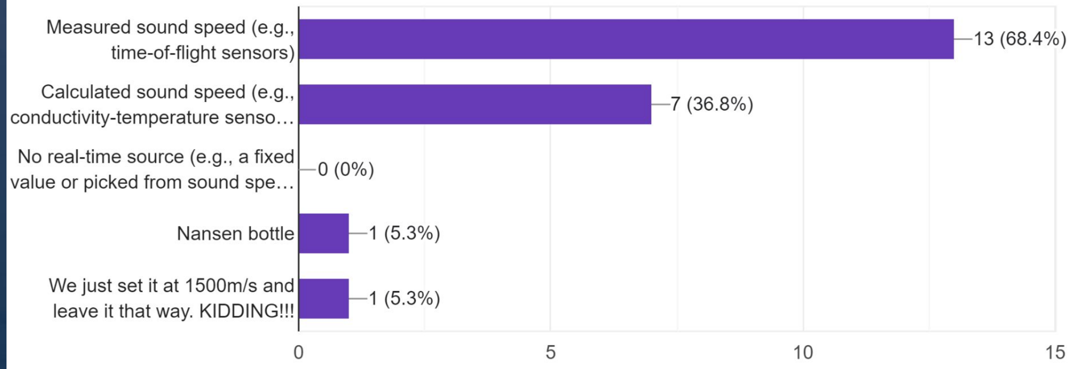
Which multibeam systems are available on your vessel?

19 responses



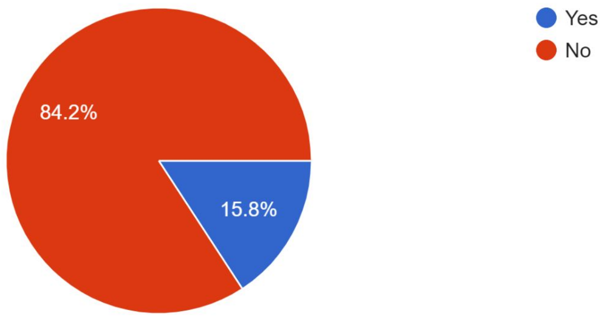
What kind of 'surface' (transducer) sound speed sensor is installed as the primary source for the multibeam mapping system(s)?

19 responses



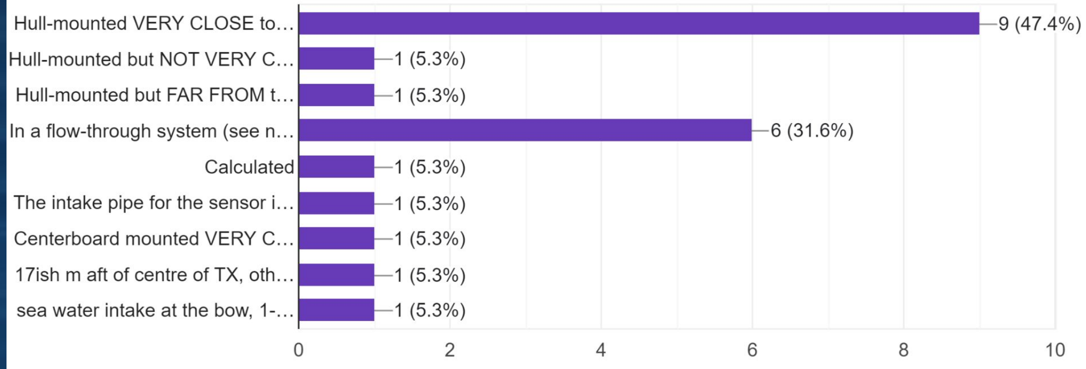
Are the multibeam transducers installed behind ice windows?

19 responses



Where is the primary surface sound speed sensor installed on your vessel? A rough estimate or description is OK!

19 responses



Survey Results: **Surface Sound Speed (Backups)**

If known, what are the brand and model of the **primary** surface sound speed sensor?

18 responses

RESON SVP 70	AML Oceanographic, Micro-X
Valeport miniSVS	valeport minisvs
Temp (SBE38) & Salinity (SBE45) / AML Sound Velocity Probe	Valeport MiniSVS
Teledyne Reson SVP-70	Valeport Thru-Hull SVS
AML 3-RT	SBE 3S temperature sensor and SBE 45 TSG
Reson SV-70	Seabird SBE-45 (TSG)
Reson SVP-70 (launches), Valeport Thru-hull SVS (ship)	Valeport Modus SVS
Reson SVP-70	Valeport thru hull SVS
Seabird SBE 45	SBE45 and SBE48.

Are there any **backup / spare** surface sound speed sources for multibeam operation?

If so, how do they differ from the primary sensor configuration?

18 responses

- Flow through system
- We typically run a pair of miniSVS sensors
- We measure surface temp from 5 sources (2x SBE38, 2x SBE45, IR pyrometer), salinity from 2x SBE45, only one AML SVP in flooded drop keel.
- Each multibeam has its' own SVP-70 and they are in close proximity to each other, so the other system can act as a spare. We also carry spare SVP-70s onboard and ship divers could swap them out. Lastly, worst case our flow through SBE-45 could stand in as surface sound speed.
- Yes, we could use the thermosalinograph data for sound speed. We had at one point built the script for that and saved it in the archives somewhere. It seems to us less ideal for a myriad of reasons, so we keep a spare AML onboard.

…Lots of TSG backups! :)

- No real-time source (picked from XBT sound speed profiles)
- see above and calculation from flowthrough system (in prog)
- Dual MiniSVS sensors. Swappable from surface.
- Yes, TSG/SBE43 calculated via Flow through system
- Primary and secondary TSG

Survey Results: **Surface Sound Speed (Challenges)**

Do you have any specific concerns or challenges with your surface sound speed system?

17 responses

Marine growth is always a challenge. Bubbles on the face of the sound speed transducer cause erratic readings. The hull mounted SVP-70 does not have a long lifespan, maybe 2-3 years. Customer service to have the sensors calibrated can be challenging.

Our setup is an intake which opens to a short pipe run to a chest with the sensor, then a pump down stream of that pulling water up and out an overboard pipe. How much could bio fouling in the chest be impacting results if at all. How can one tell if the sensor is putting out bad data? if its say 1m/s off. Do they fail that way? or would it be so wildly off that it would become obvious right away?

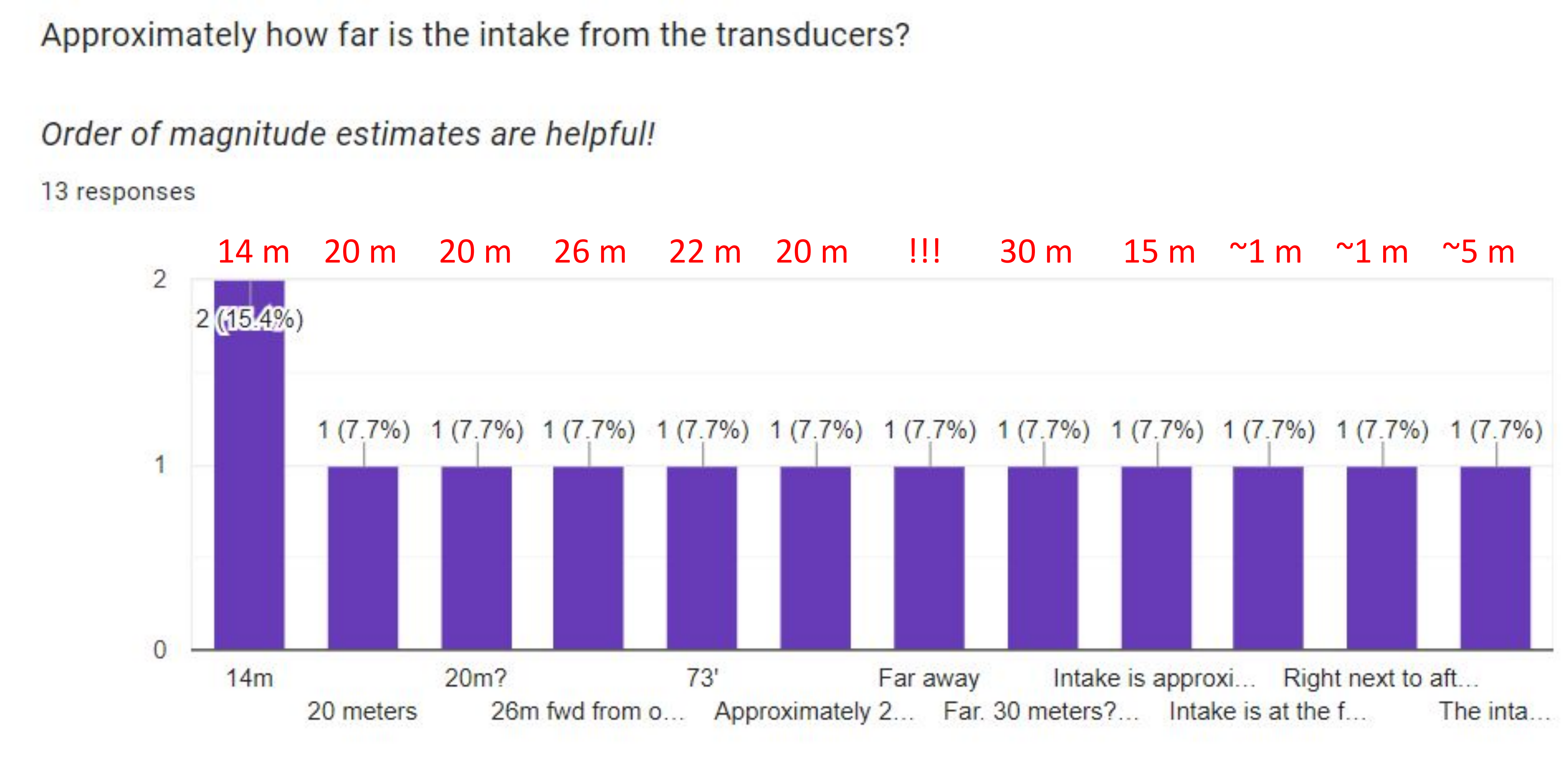
I would prefer to have a thru-hull SV probe. When the hull-mounted probe has failures, it is sooooo much drama (technically speaking). Both my time with the ship and the overall life of the ship are waning, so I do not see it as a likely modification.

Thru-Hull is not flush with hull, so it sticks out ~1ft. Which has resulted in fishing gear entanglement and damage.

Distance from the intake temperature sensor to the TSG

Concerns: Location compared to transducers, measurement is calculated, not real-time, Technical challenges: potential to be airbound during flow

Survey Results: **Flow-Through Locations**



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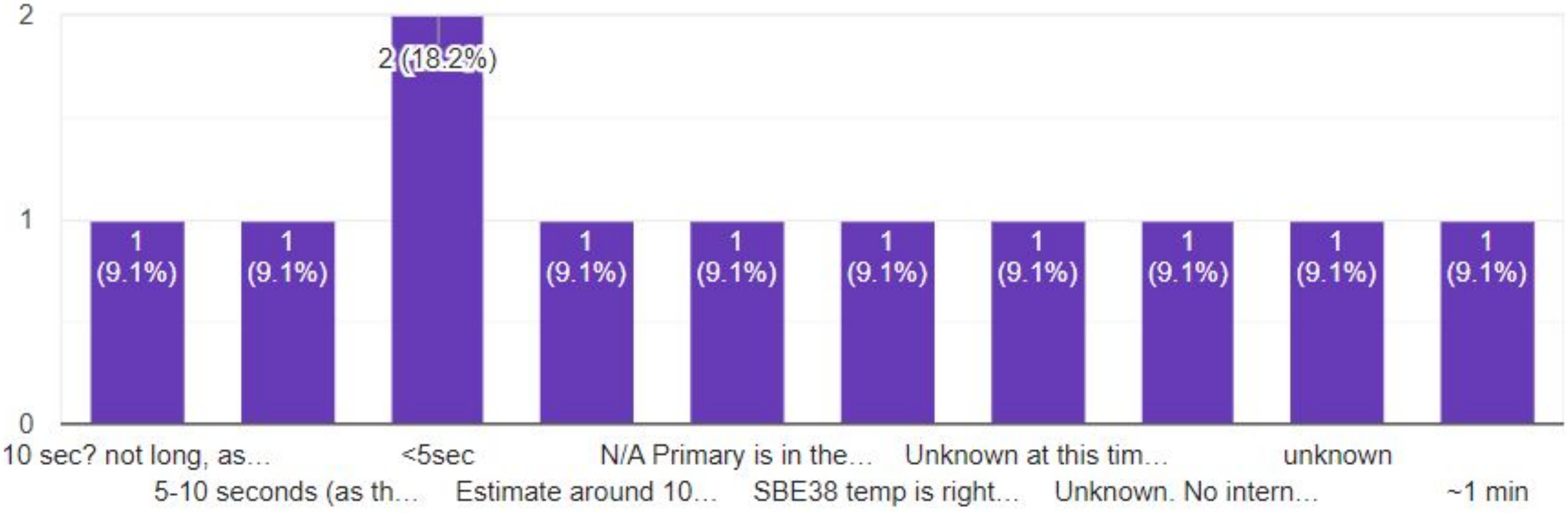
Survey Results: **Flow-Through Times**

Approximately how long does it take for water to flow from the intake to the primary surface sound speed sensor during typical mapping operations?

Order of magnitude estimates are helpful!

11 responses 10 s 5-10 s <5 s 10 MIN. {--------------------Uncertain---------------------} ~1 MIN



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Survey Results: **Flow-Through Temperatures**

Is it possible to monitor temperature changes between the intake and the surface sound speed sensor?

Have differences been noted between temperatures at the intake and surface sound speed sensor?

If so, how large are these differences?

13 responses

Yes, we always monitor the warming effect through the vessel by taking the delta between intake and main lab sensors. On Sikuliaq, warming can range between 0.2-0.4 degrees C depending on how cold the source water is.

Yes, we monitor both sensors against each other on a 4-hour display plot. Minimal differences have been identified due to the water warming NGT .2 degrees C while transiting from intake to TSG. This makes the TSG SV reading slightly offset from the SV probe (usually NGT 1m/s).

While it is not possible to monitor temperature changes between the two sensors, we do daily checks to compare the sound speed being reported by each sensor. Generally, they agree within 0.5m/s.

YES! We have the 38 for intake temp and have a correction method identified. TBD of actual temp deltas but the shipyard spec requires no greater than 2 degree C temp change. We've joked about how to test that (like 90 degree day on 90 degree gulf water probably isn't a valid test).

typically <1* C

Yes it is possible to monitor between intake and where our wet wall is. For calculated SVS currently between 0.5-2 degrees depending on where sensors are in the wet wall and the intake. our surface(actually keel) SVS does not have a T sensor. Our intake only has T sensors, the salinity sensor is in our wet wall.

Yes. Yes there are small differences (but still noticeable) between the SBE48 close to intake and the sbe45 at the flow through wall.

Yes, 1-2° C between 3S and TSG

1 °C → ~4.5 m/s

Source: rbr-global.com/speed-of-sound-in-water

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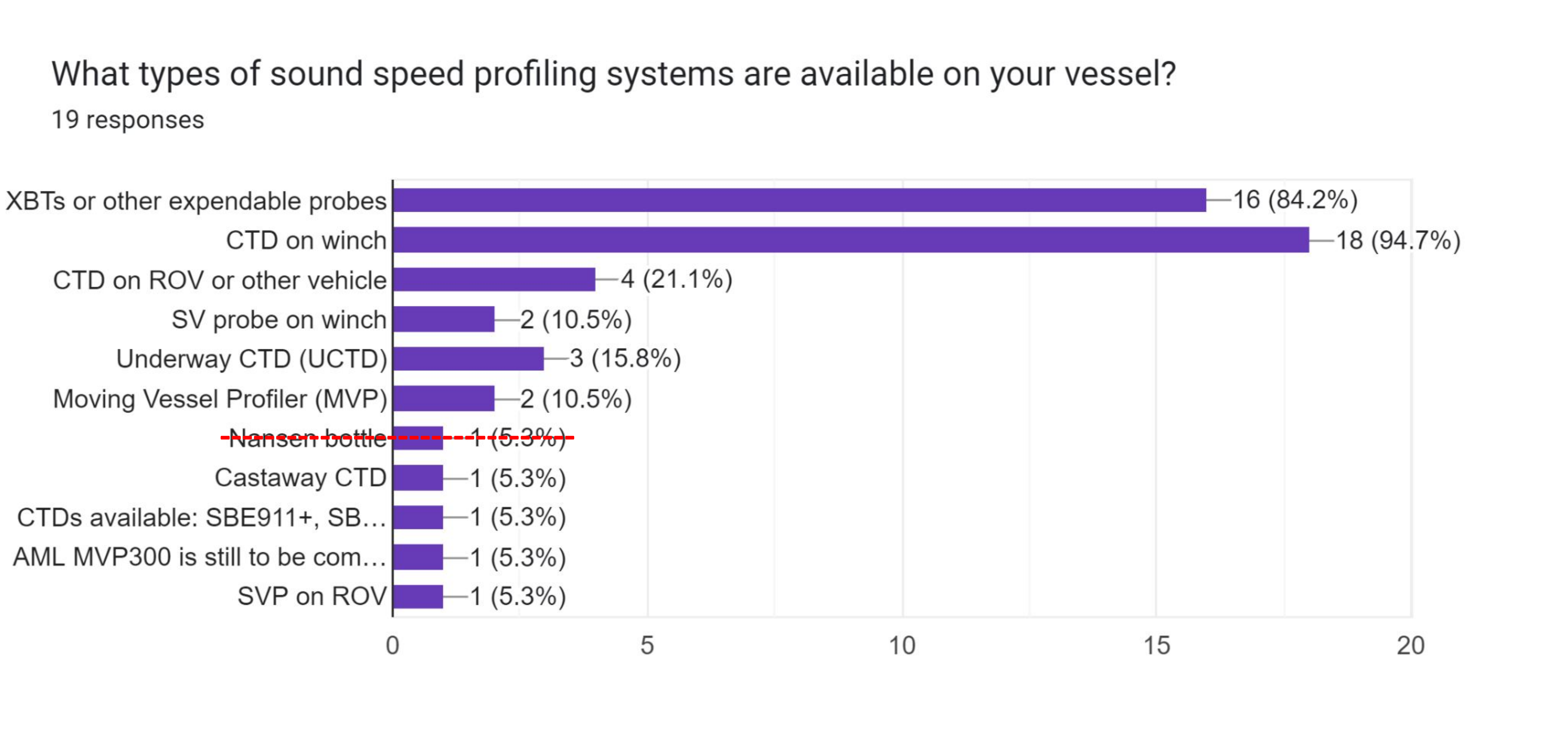
Survey Results: **Sound Speed Profiling**



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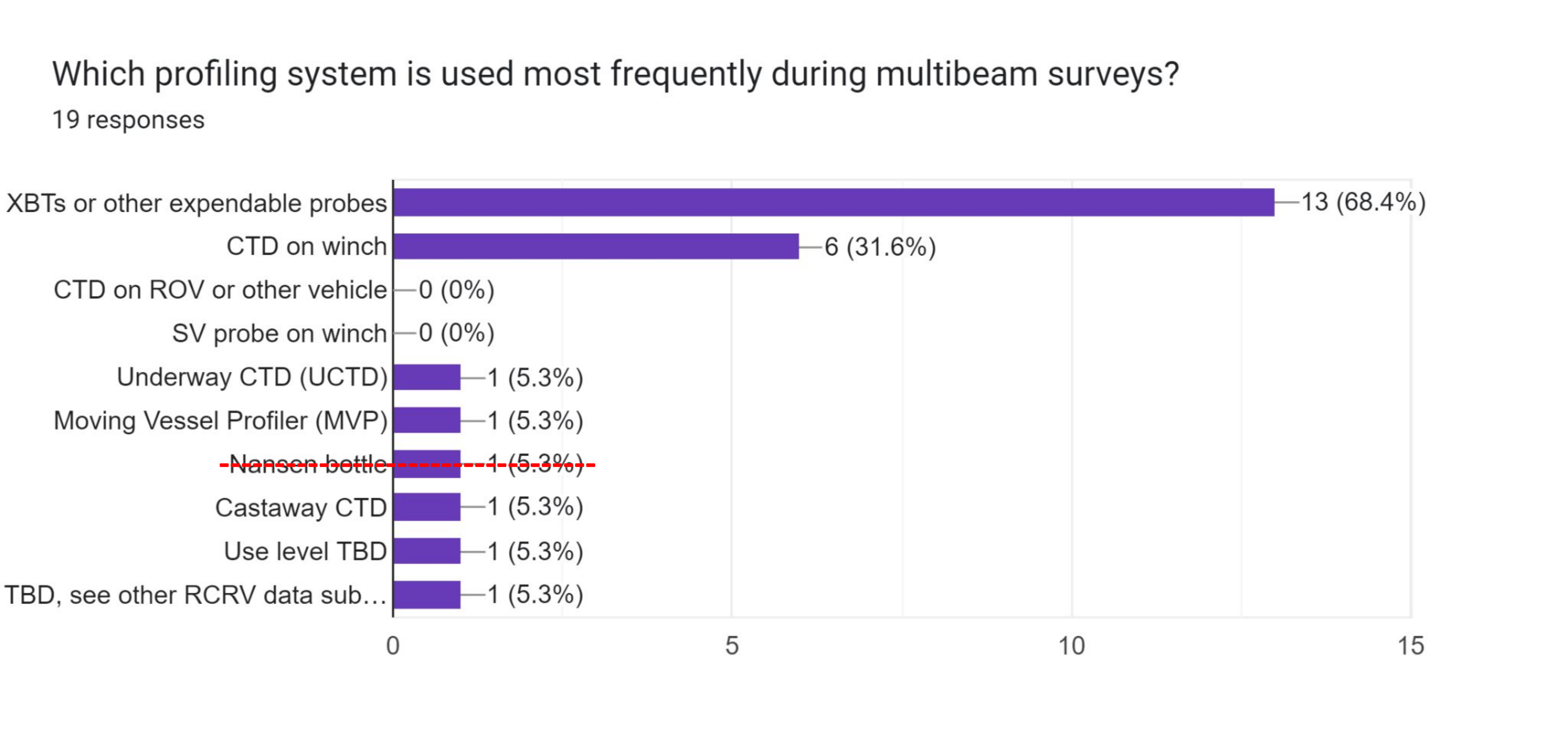
Survey Results: **Sound Speed Profiling**



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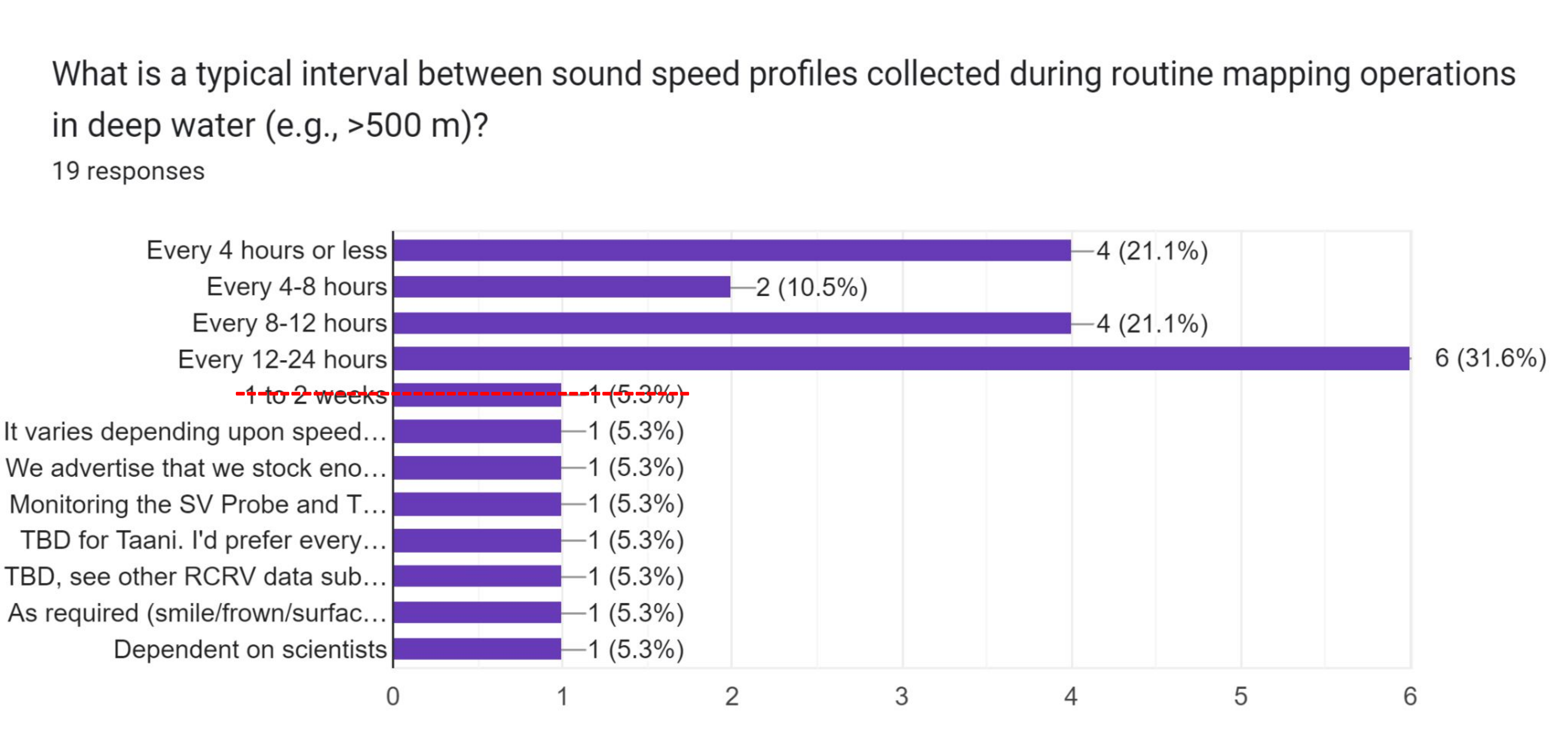
Survey Results: **Sound Speed Profiling**



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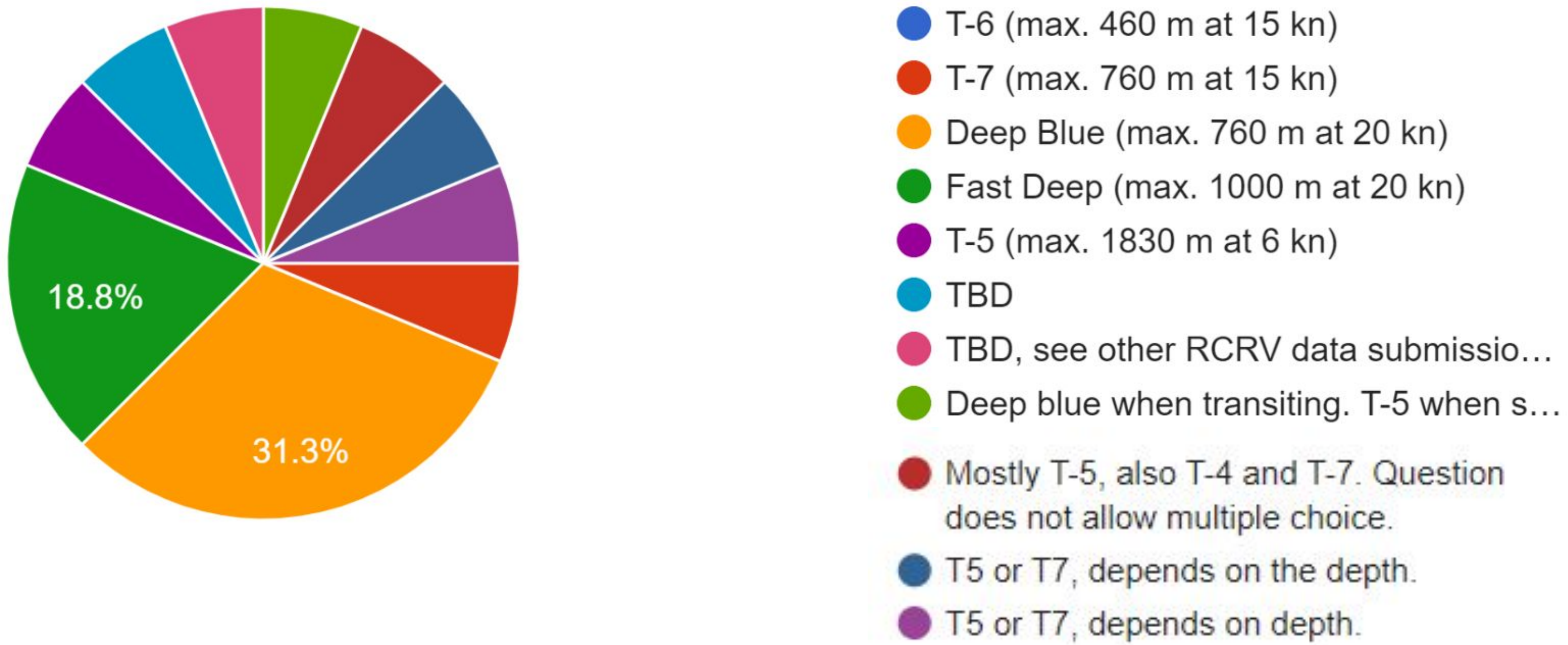
Survey Results: **Sound Speed Profiling**

If your vessel uses XBTs, which probe model(s) is/are commonly used?

16 responses



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Survey Results: **Sound Speed Profiling**

Is Sound Speed Manager used during typical multibeam mapping operations on board your vessel? (https://www.hydroffice.org/soundspeed/)

19 responses

Survey Results: **Sound Speed Profiling**

Do you have any specific concerns or challenges with your sound speed profiling system?

15 responses

We would rather not litter the seabed, but there is no alternative, other than stopping the ship, or buying an expensive system such as the MVP.

I am interested in a rapid-cast CTD underway profiling system if Sikuliaq ends up being scheduled to transit to Chile for Antarctic ops. Something like an MVP.

New versions of sound speed manager have been quite finicky. A fair amount of bugs to deal with.

Each individual underway profiling system brings several qualities, but also several caveats. If someone wants to go into business making an underway system that nullifies those caveats, I will gladly direct government money towards you.

The MVP has a large safety buffer (4.6m) to where it thinks the "bottom" is. When working in shallow water, we often cannot completely capture the thermocline which leads to persistent refraction in the data.

Not at this time for the EM2040 with measured surface sound speed, though we are very much seeking an alternative to using XBT's for speedy vertical profiling (speedier than CTD cast).

Survey Results: **Other Feedback**

Thank you for sharing your sound speed setup!

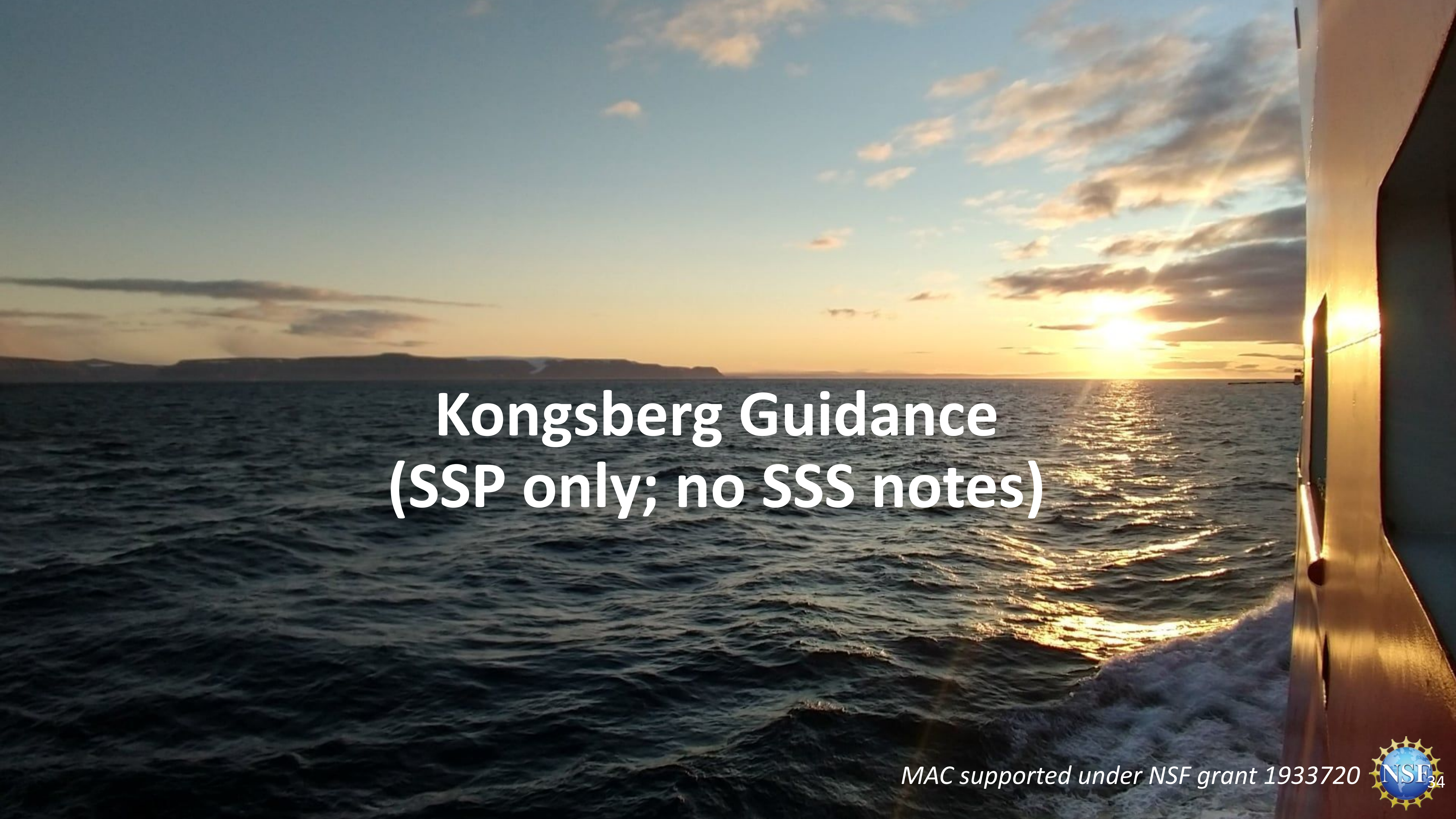
Are there any other comments or concerns you'd like to pass along?

8 responses

We had previously used a Valeport Thru-hull SVS but found this sensor, due to the cage surrounding the fixed reflector, trapped sargassum. Partly a consequence of where we operate, but makes sound speed measurements difficult.

Is anyone else using AML products? Other manufacturers for SVP? Is there a push toward UNOLS standard instrument for this data?

Maybe address the location option for TOF sensors for the vessels with gondolas. Retractable is above the system. If located on the gondola, it's hard to service.

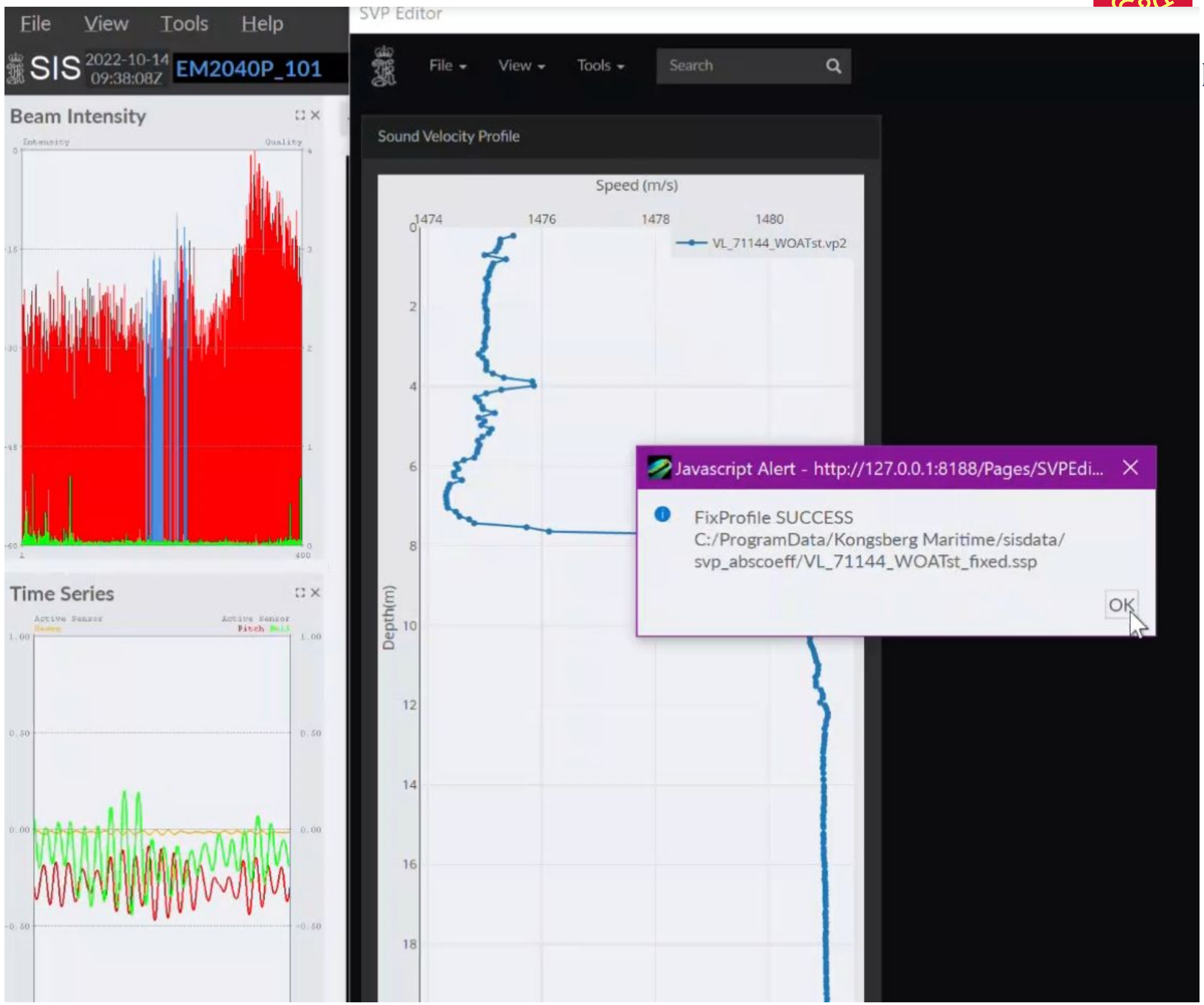


Kongsberg Guidance (SSP only; no SSS notes)

MAC supported under NSF grant 1933720

Use SVP Editor in SIS

- Create a filter profile to read any format directly
  - *.csv, CTD profiles, *.asvp, etc.
- WOA setup
  - Download temperature and salinity data from WOA
  - Extend profiles with WOA



Adapted from FEMME 2023 workshop by Colleen Peters, Kongsberg Discovery

ASVP vs. SSP Formats

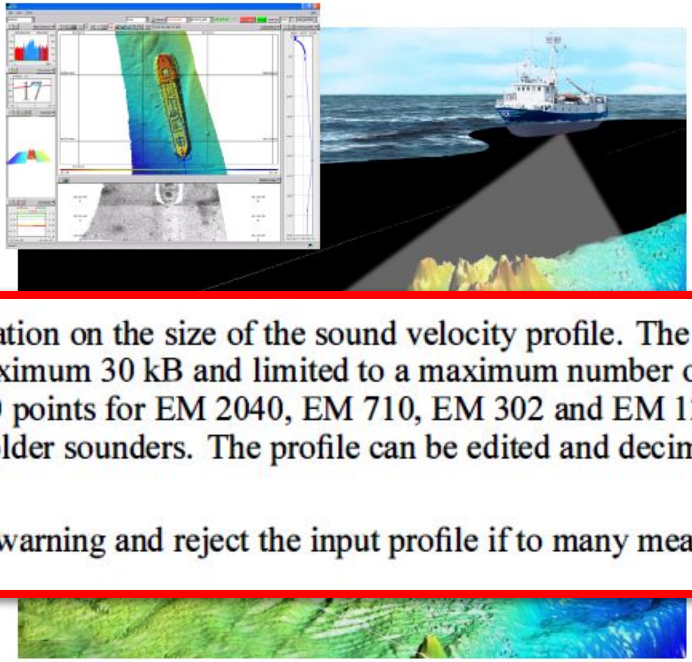
KONGSBERG

- **SSP recommended over asvp** to preserve data, particularly for CTD where there is more information than just depth and sv (e.g., XBTs)
  - QuickGuideSSP.pdf found in: C:\Program Files\Kongsberg Maritime\EMSystem\Doc\SIS
- Have to update the filter if you change anything about the data output
  - If using CTDs with rotating sensors, recommend setting up a "SVP" output (e.g., from SBE data processing) for consistency

Kongsberg Notes: SSP Quickstart Guide

Quick Guide KONGSBERG

Kongsberg Maritime
SSP format



There is a limitation on the size of the sound velocity profile. The file used by the PU must be maximum 30 kB and limited to a maximum number of depth points. Maximum 1000 points for EM 2040, EM 710, EM 302 and EM 122. Maximum 570 points for older sounders. The profile can be edited and decimated in the SIS SVP editor.

SIS will give a warning and reject the input profile if to many measurements.

Generation of SSP datagrams

The SSP format is Kongsberg Maritime proprietary and predates the SIS44 and SIS55 developments. The SSP format is described at the end of this document.
A vital requirement for SSP datagrams received by SIS is that they are fault free, - this is particularly important for the SSP datagrams to be used immediately. As a guideline for the generation of fault free datagrams the following check list is prepared:

1 Profile must contain at least two samples (measurements)

datagram must be resent!

2 UTC time of acquisition, legal range: 000000-235959
3 Day of acquisition, legal range 1—31
4 Month of acquisition, legal range: 1—12
5 Year of acquisition, legal range: 0000—9999
6 Number of samples contained in datagram must correspond to set "Number of measurements" in the datagram header part.
7 Datagram header and end must be correct otherwise datagram is disposed of,
- the end of datagram delimiter, \CRLF, is essential.
Note that each sample must be terminated by the CRLF delimiter.
Note that all commas are necessary also when a field is optional and empty.

might fix in SVP Editor…

8 Sound velocity in m/s, legal range: 1400.00—1700.00
9 Depth in m, legal range: 0.00—12000.00.
Pressure in MPa, legal range: 0.0000—150.0000
10 Profile must be extended upwards to 0.00m and downwards to 12000.00m (giving two samples!).
11 No multiple similar depths, - depths must be minimum 1cm apart.
12 Depths must be increasing.
13 Number of allowed samples in profile depends on KM echo sounder type:
New generation of echo sounders, max 1000 samples (i.e. EM122, EM302, EM304, EM710, EM712, EM2040, EM2040C...).
(Older echo sounders, max 570 samples.)
14 Temperature in deg C, legal range: -5.00—45.00
15 Salinity in ppt, legal range 0.00—45.00
Conductivity in S/m, Legal range 0.000—7.000 (Note S/m units!)
16 Checksum is optional, except for S00, but checksum calculation is always encouraged!

C:\Program Files\Kongsberg Maritime\EMSystem\Doc\SIS

Sound Speed Manager (SSM)

KONGSBERG

- Transmit to SIS = good, preserves all fields
- Export to .ASVP = no CTD absorption

Note: SSP filenames are not stored in .kmall

- Asked HydrOffice to implement SSP format as an output option
- Configuration steps updated in SSM 2023.0.5: https://www.hydroffice.org/manuals/soundspeed/stable/user_manual_setup_sis_v5.html#sis-v5-settings
- **Need to ensure that the DDIST is ENABLED in Tools > Parameter Setup > Logging in SIS 5**
  - *Now set to be enabled by default in SIS 5.12.1*

Sound Speed Manager

MAC supported under NSF grant 1933720

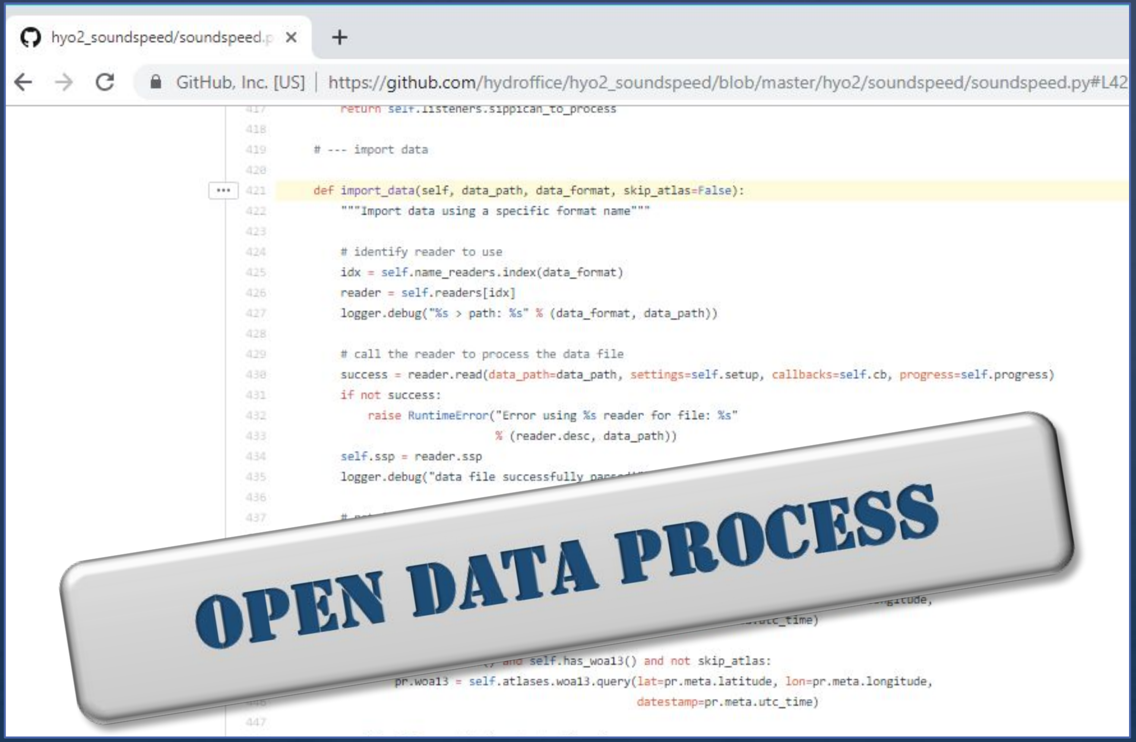
Sound Speed Manager

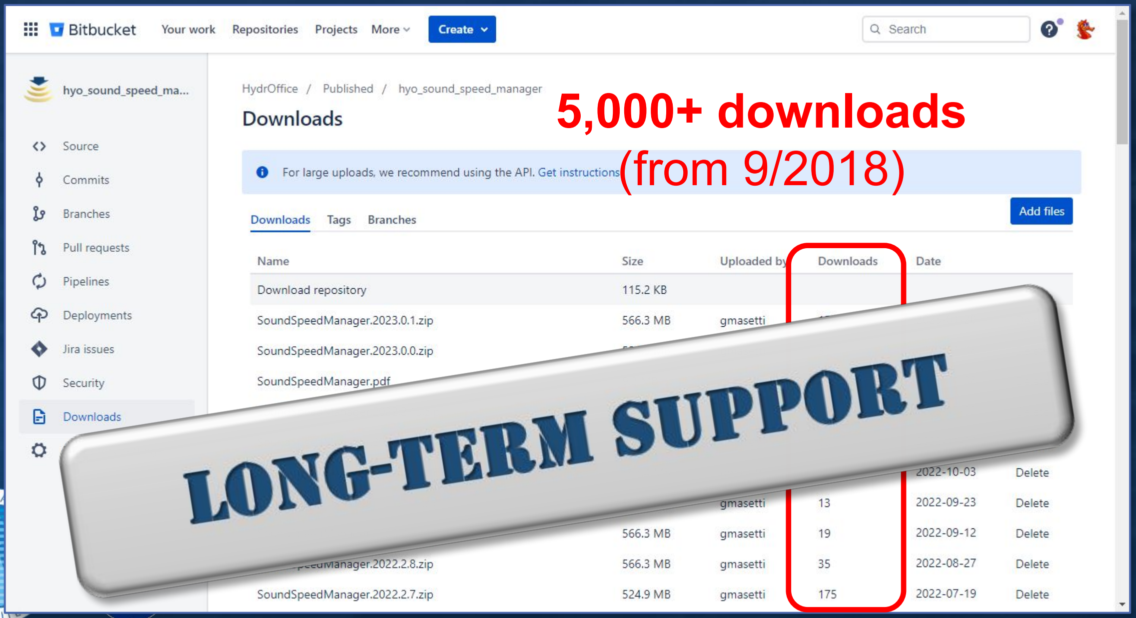
A **ready-to-go** and **free** solution to ease the **management of sound speed profiles** for ocean mapping

hydroffice.org

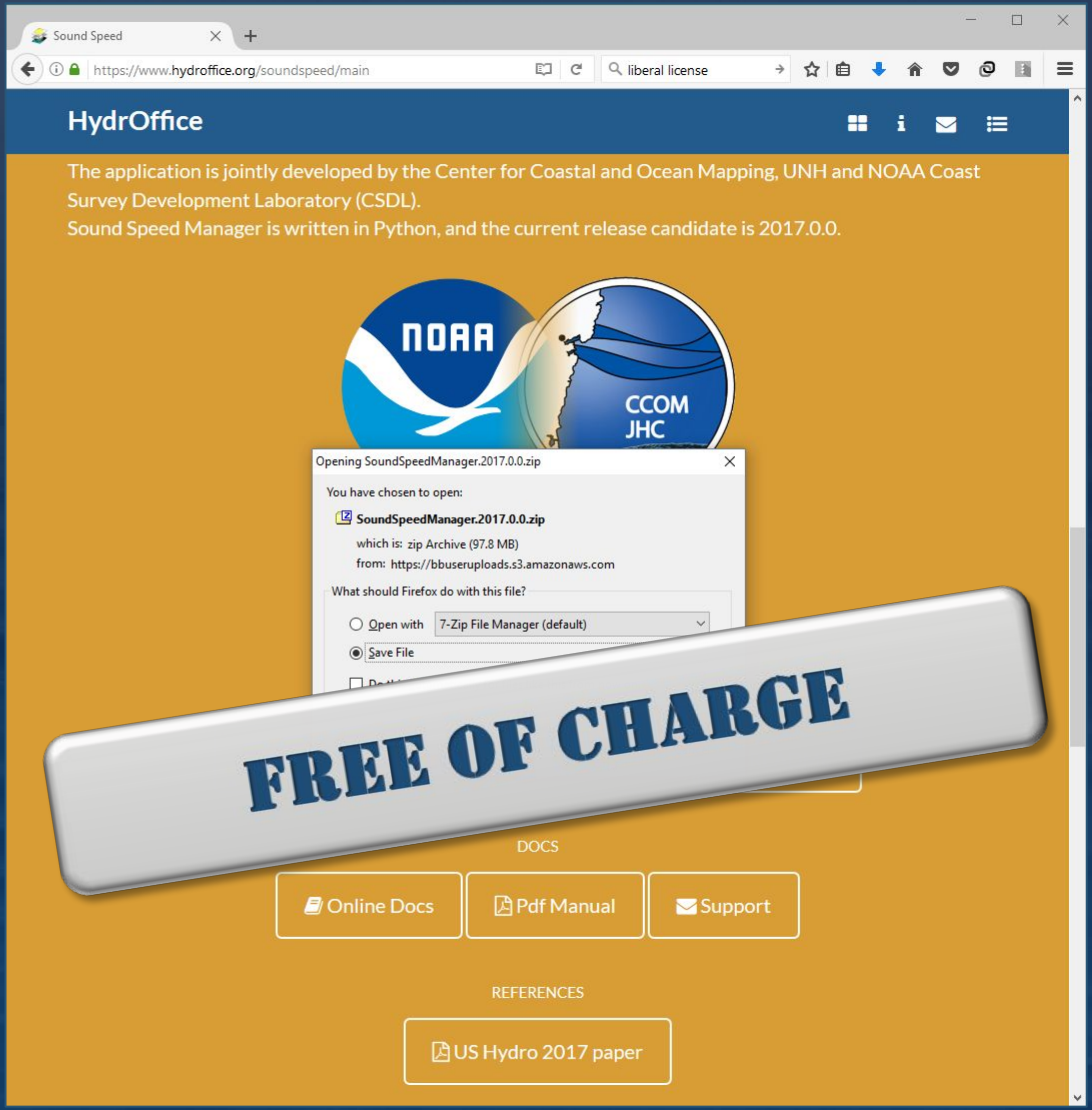
Ref.: Masetti, G. et al., *Sound Speed Manager: An open-source application to manage sound speed profiles*, International Hydrographic Review, vol. 17, pp. 31-40, 2017.

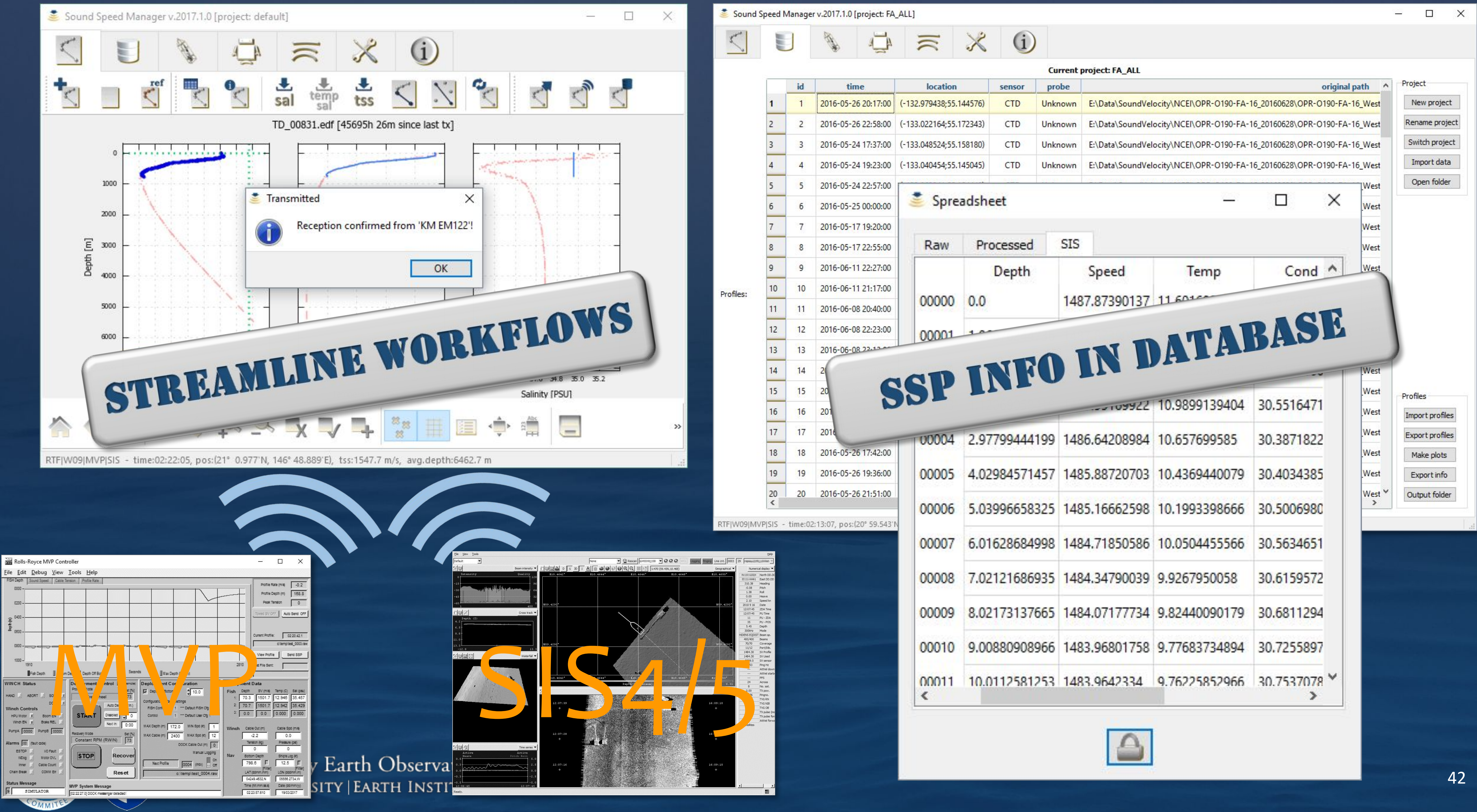
NOAA OCS POCs:
- Barry Gallagher
- Chen Zhang





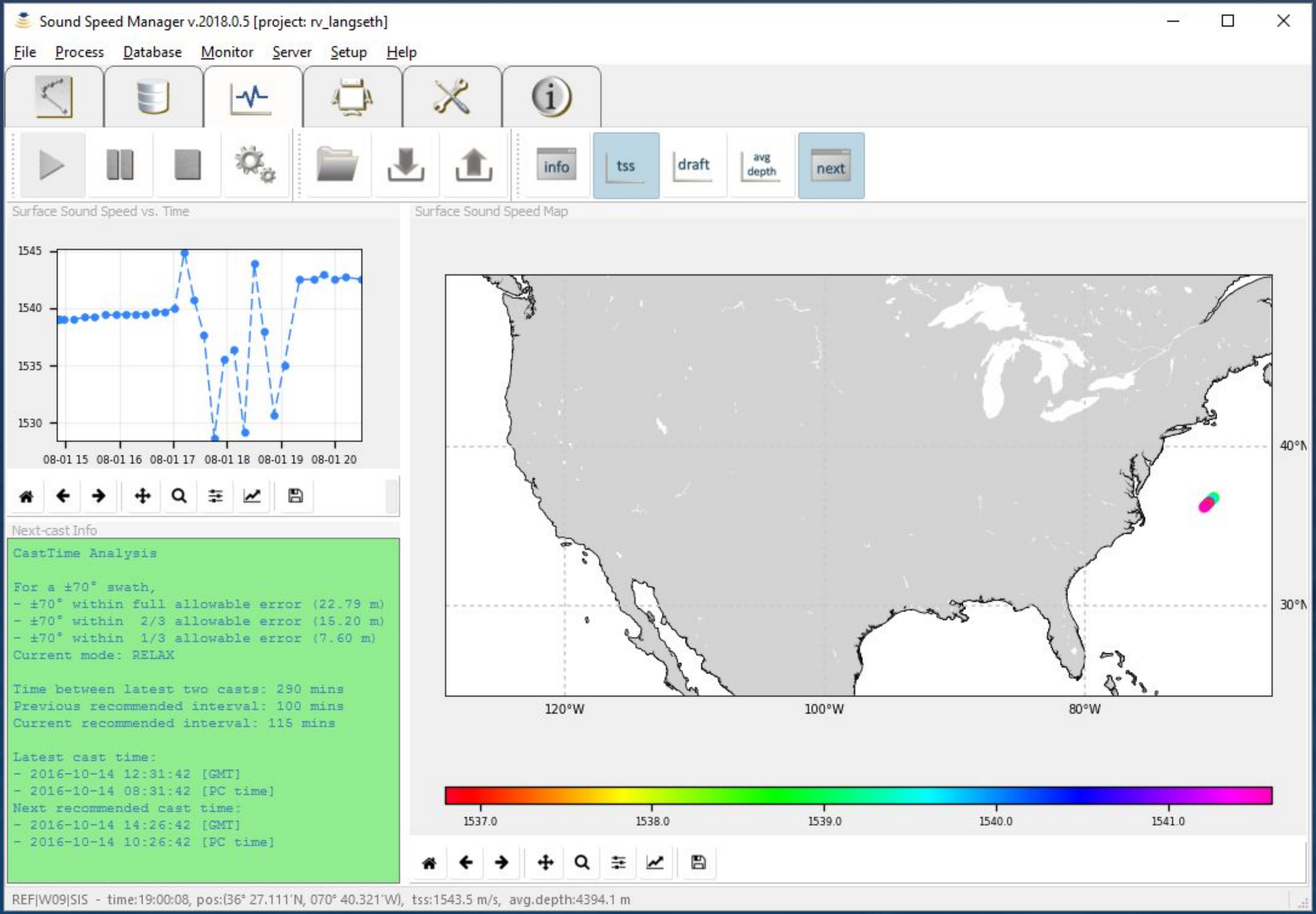
5,000+ downloads
(from 9/2018)

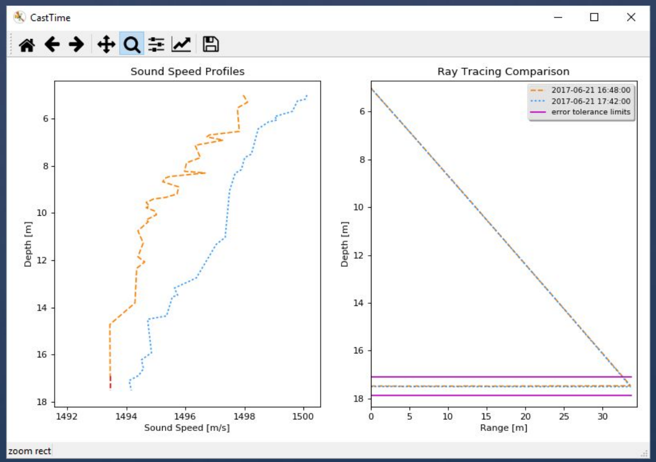


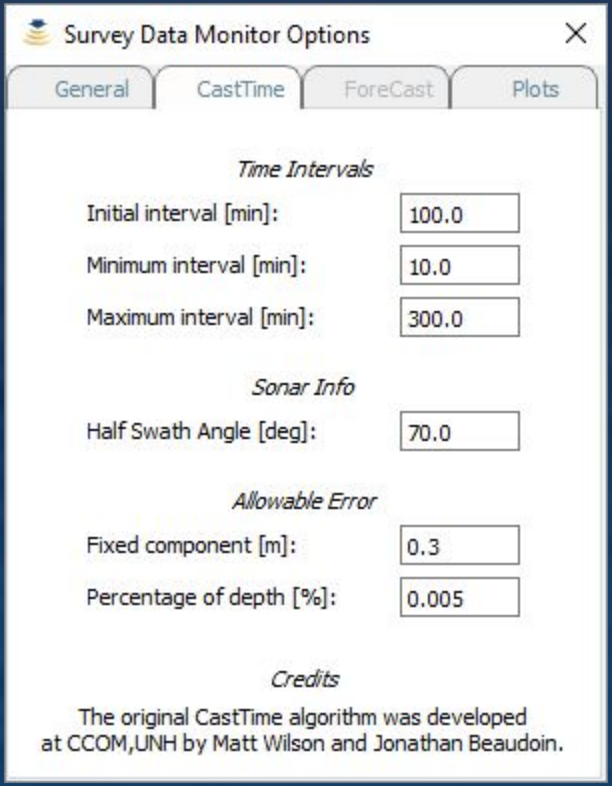

Sound Speed Manager v.2017.1.0 [project: default]
TD_00831.edf [45695h 26m since last tx]
Transmitted
Reception confirmed from 'KM EM122'!
OK
Depth [m]
Salinity [PSU]
RTF|W09|MVP|SIS - time:02:22:05, pos:(21° 0.977'N, 146° 48.889'E), tss:1547.7 m/s, avg.depth:6462.7 m
STREAMLINE WORKFLOWS
Sound Speed Manager v.2017.1.0 [project: FA_ALL]
Current project: FA_ALL
Profiles:
Project
New project
Rename project
Switch project
Import data
Open folder
Profiles
Import profiles
Export profiles
Make plots
Export info
Output folder
Spreadsheet
Raw
Processed
SIS
Depth
Speed
Temp
Cond
SSP INFO IN DATABASE
Rolls-Royce MVP Controller
MVP
SIS4/5

Flexible Import → Conversion → Extension → Export

Survey Data Monitor and CastTime







https://www.hydroffice.org/manuals/soundspeed/stable/user_manual_how_to_use_3_data_monitor.html

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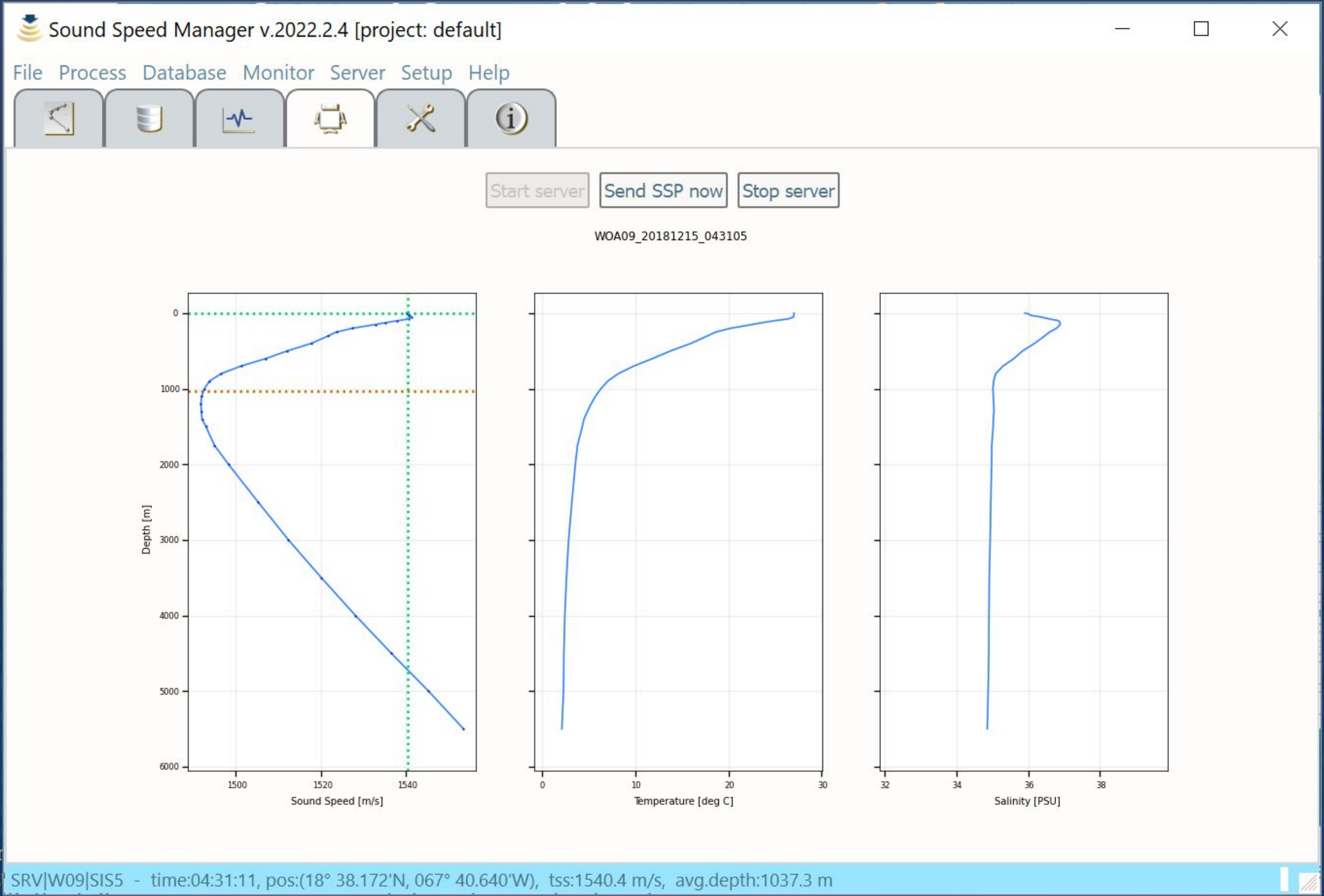
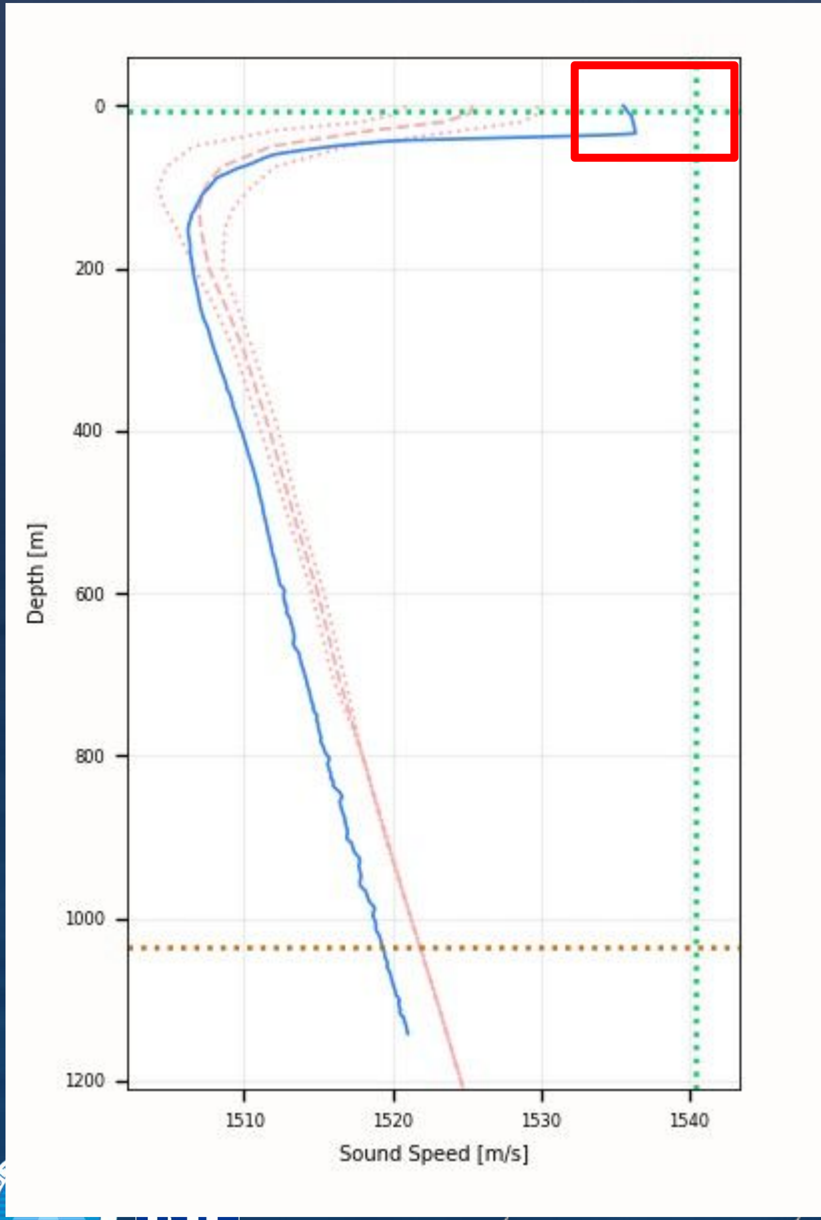
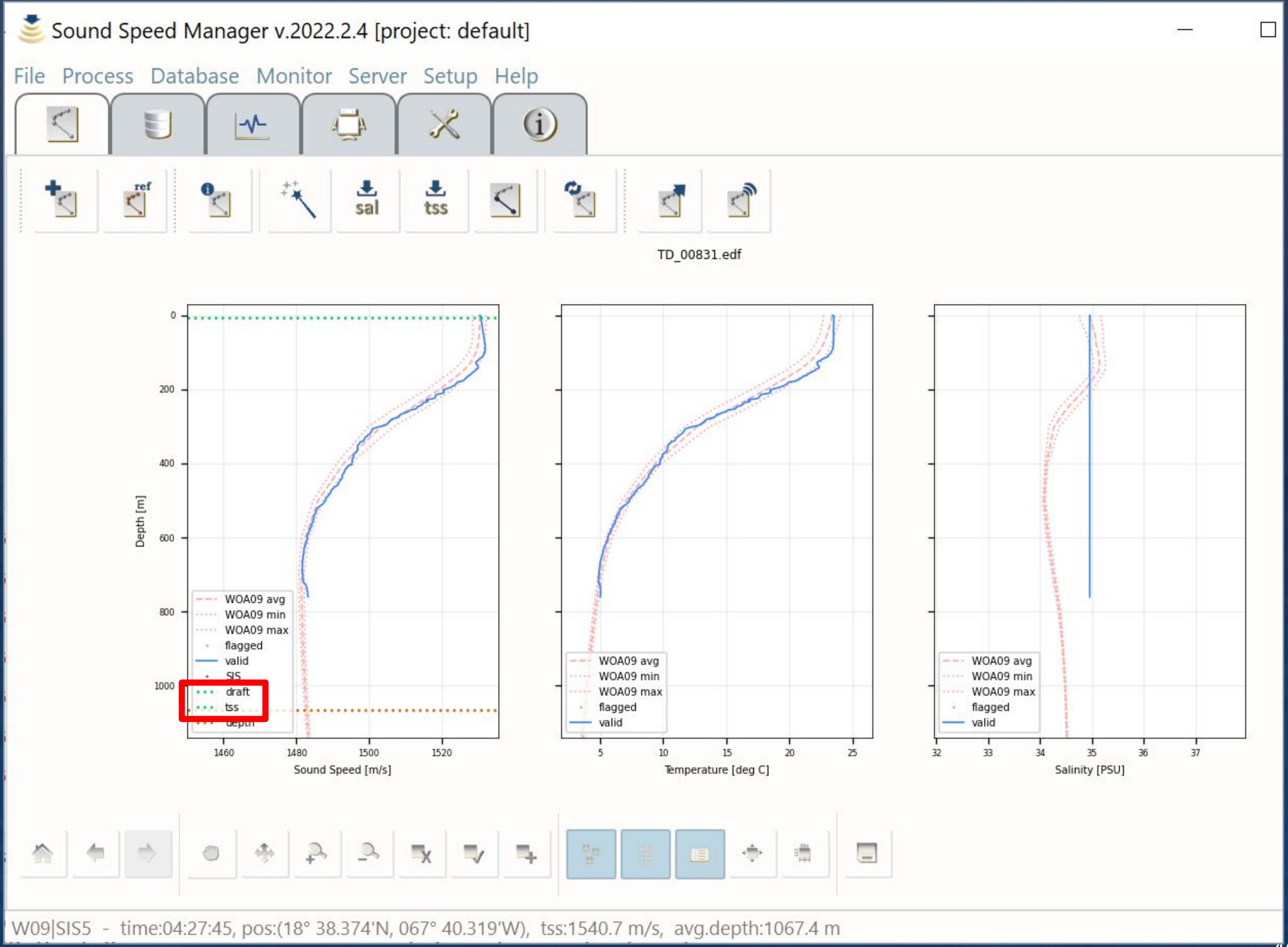
Server Mode for Transit Mapping

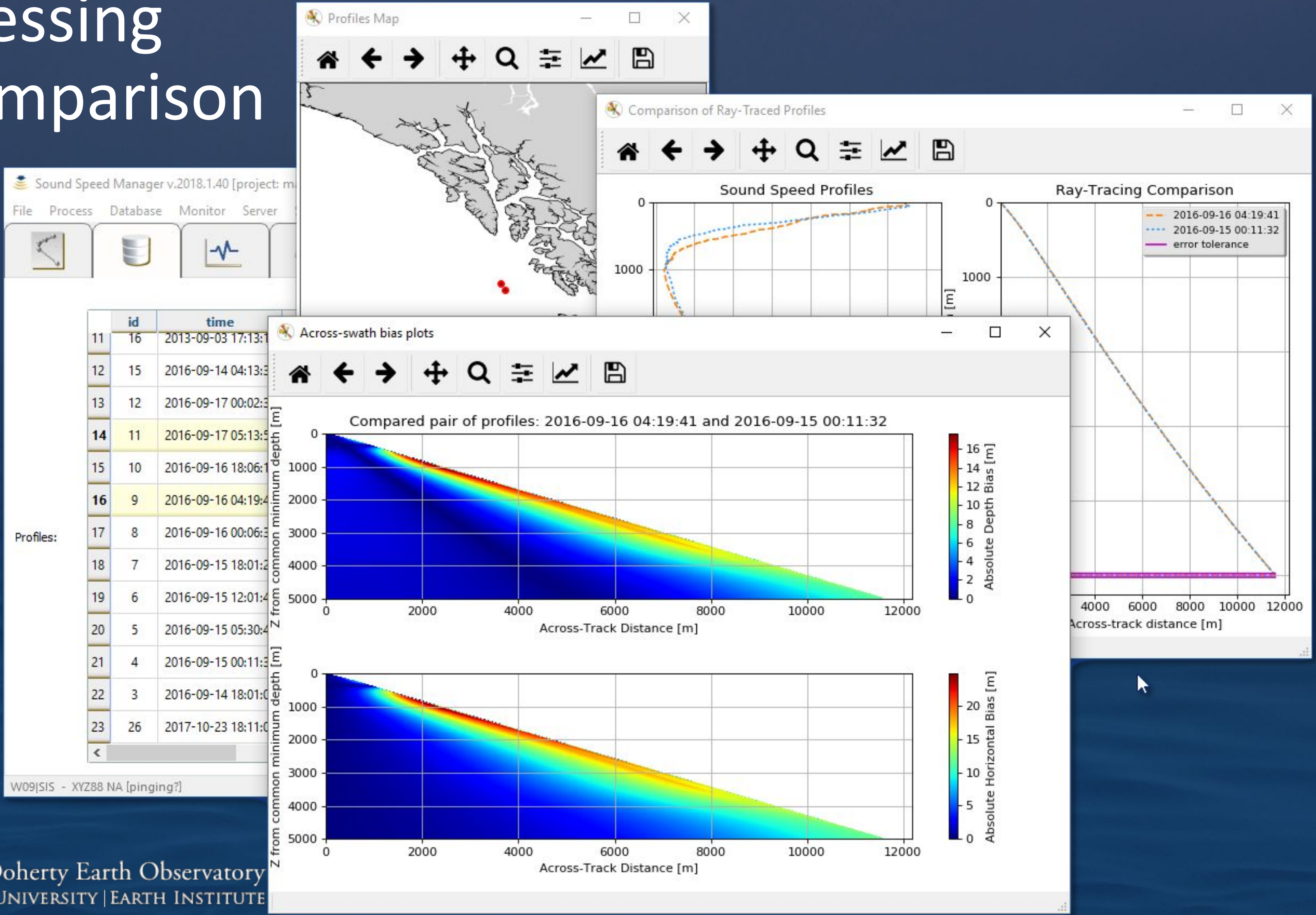


Other Data Checks…

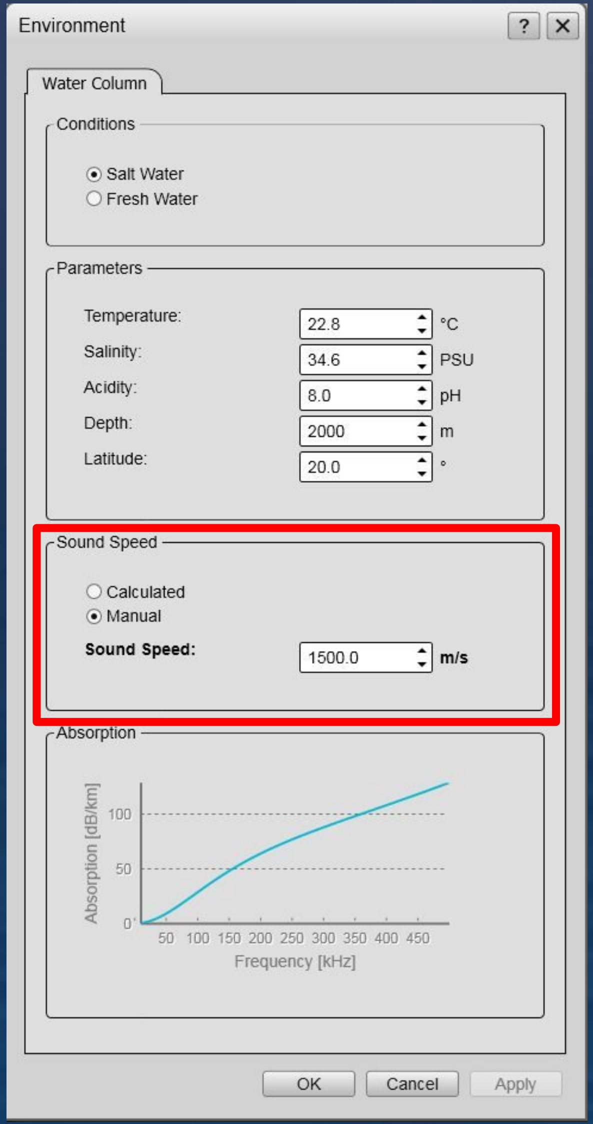


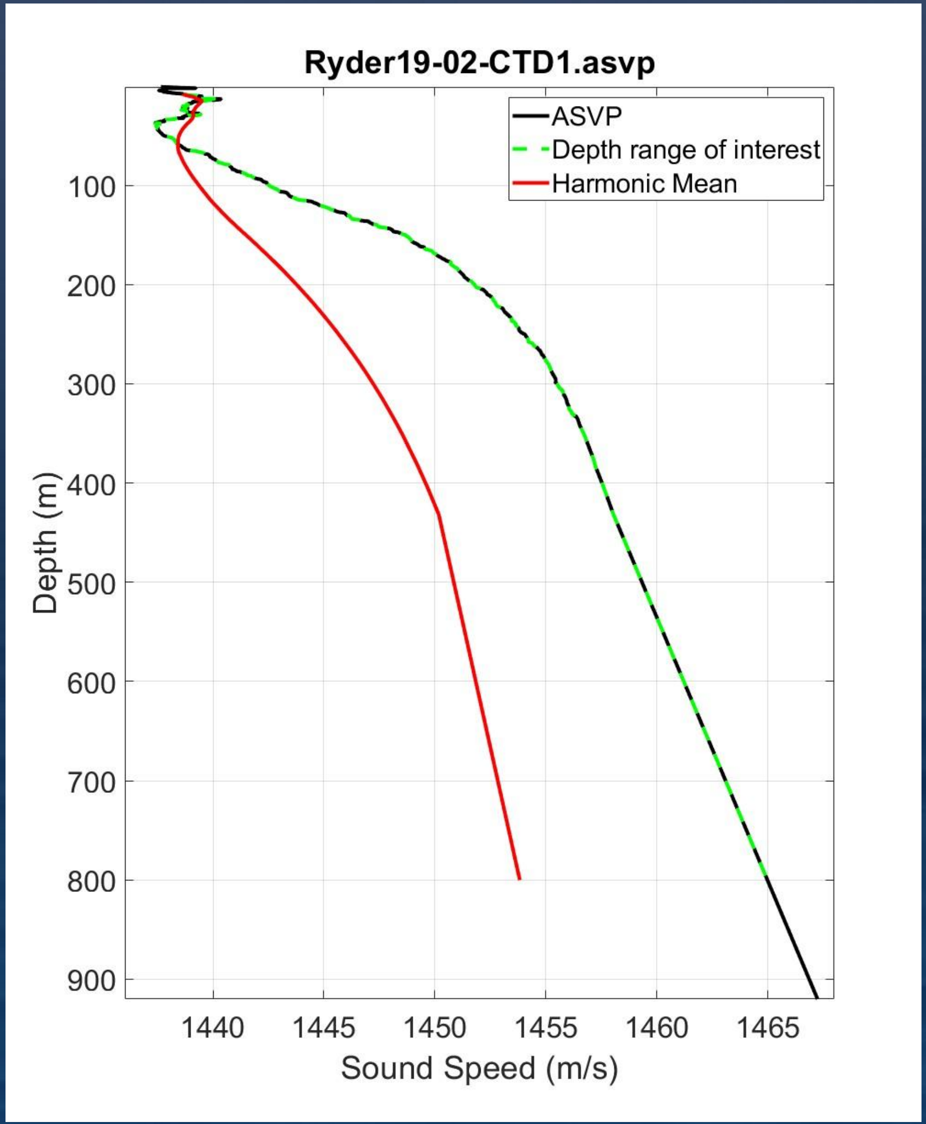


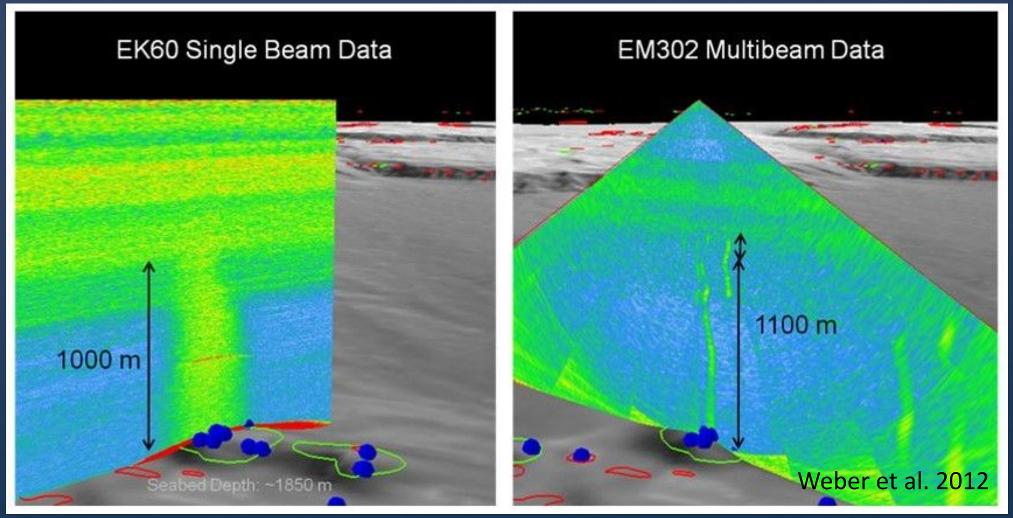
Post-Processing Profile Comparison

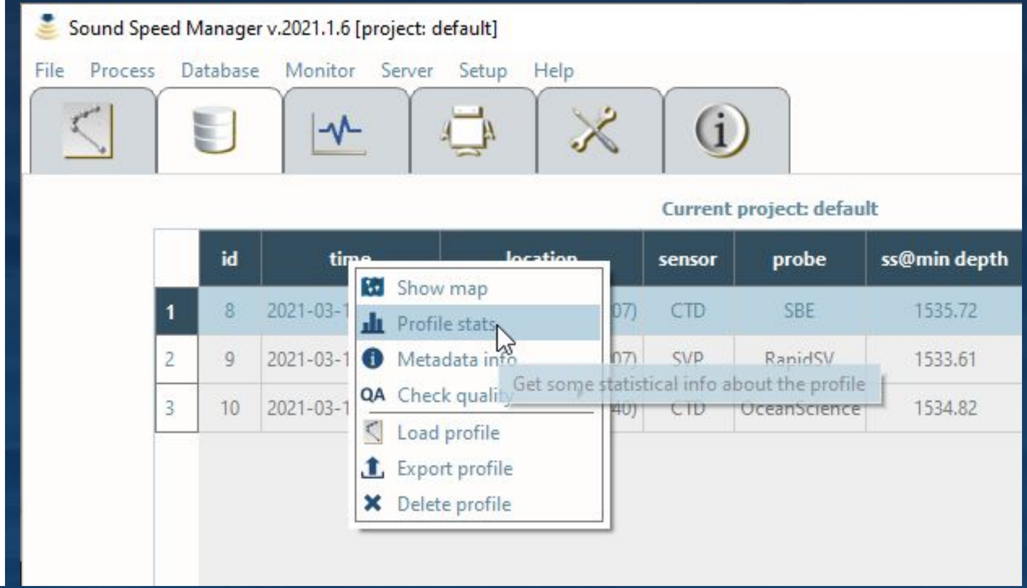


Harmonic Mean Sound Speed for EK, SBP, USBL…

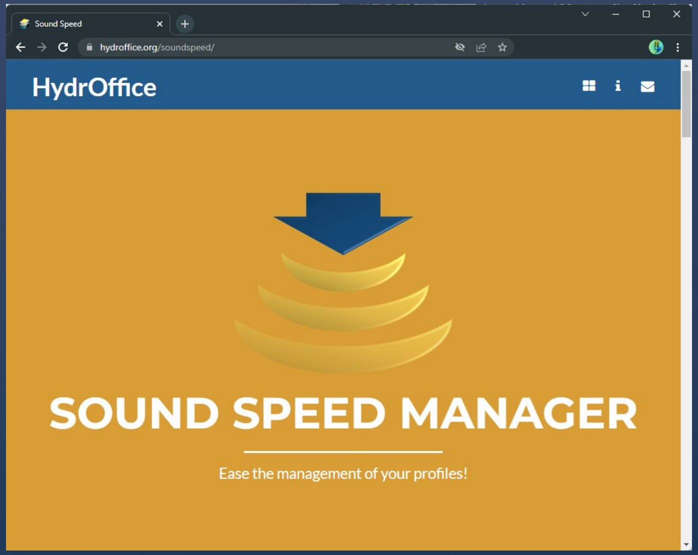








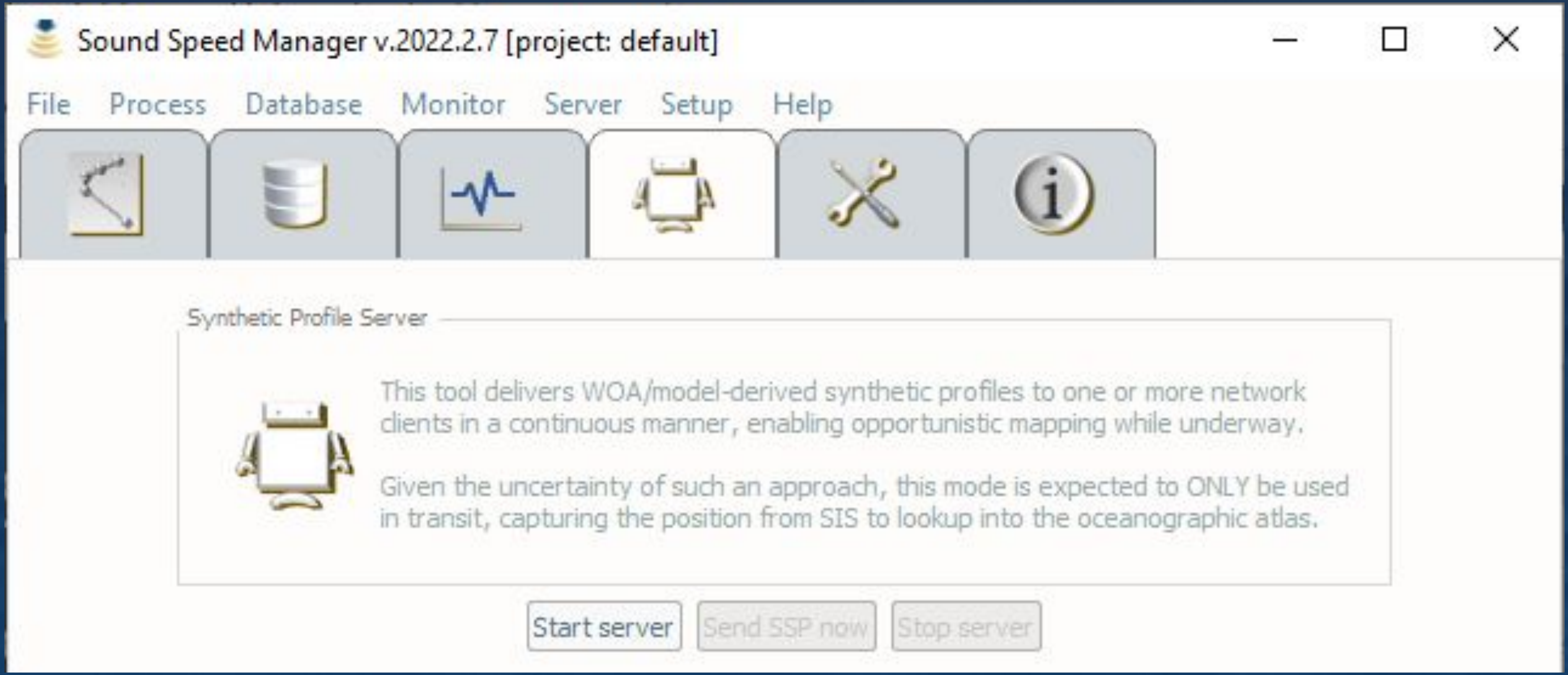
Transit Mapping: **Resources**

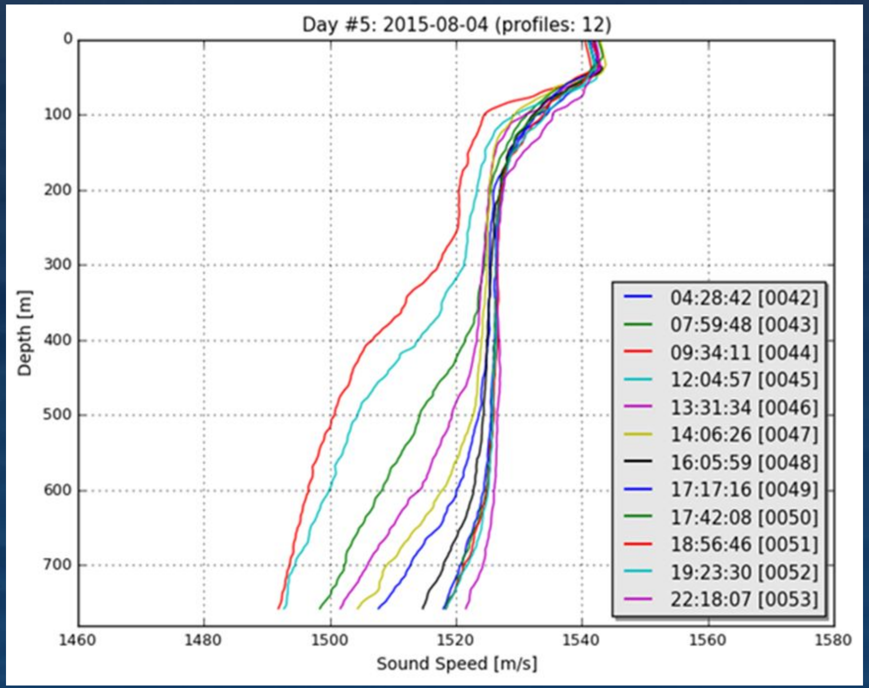


Sound Speed Manager **Synthetic Profile Server**

Updates SIS with World Ocean Atlas profiles

Not a replacement for XBTs/CTDs





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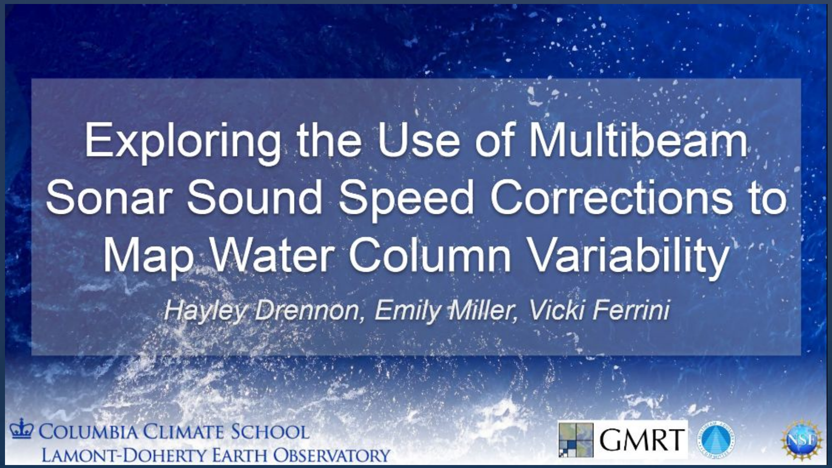
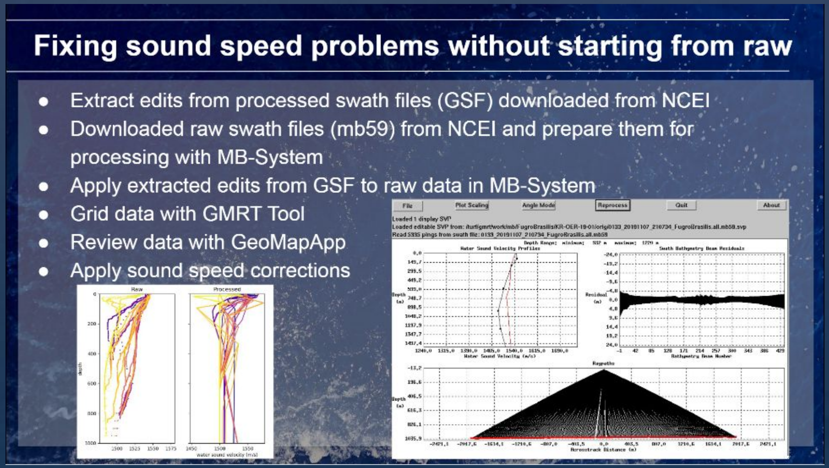
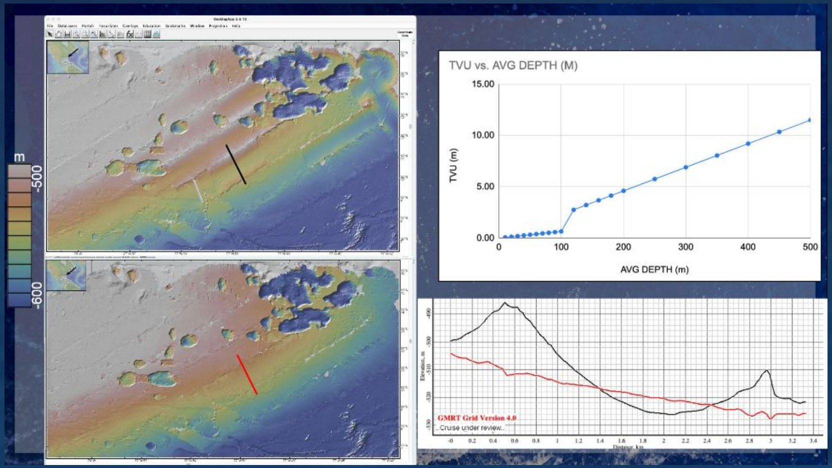
https://www.hydroffice.org/soundspeed

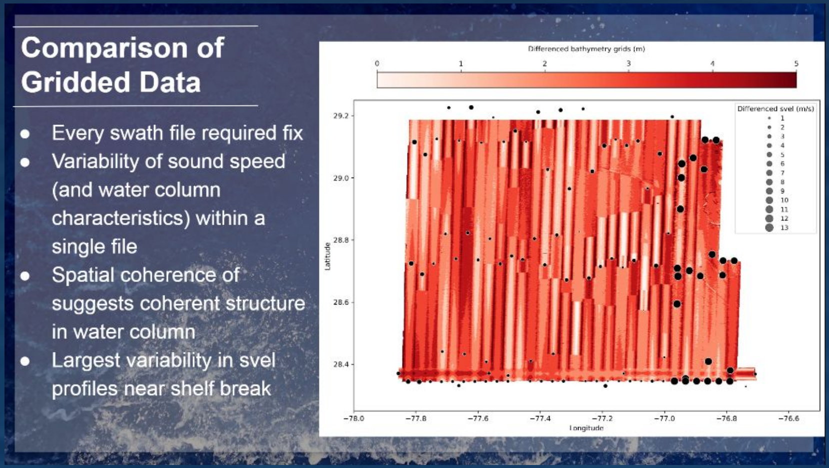
Ocean Mapping Community Wiki

github.com/oceanmapping/community/wiki









https://github.com/oceanmapping/community/blob/main/Drennon_OSM2022.pdf

Positioning

Positioning topics

Helpful links

1. GPS Visualization

Resources

Below are a few helpful resources to find, manage and evaluate ocean mapping data.

Open-source data tools

1. HydrOffice - a collaborative research-to-operations framework, including Sound Speed Manager and QC Tools
2. Ocean Data Tools - tools for data acquisition, management and event logging, including OpenRVDAS, OpenVDM and Sealog
3. GMRT Tiler - compare processed data to the GMRT grid to identify issues with sound velocity, etc., and ensure suitability for archive
4. MB-SYSTEM - open source; commonly used for automated / scripted processing of data from AUVs and other vehicles

Best practices

1. Ocean Best Practices - repository for ocean science SOPs from around the world
2. IHO-IO GEBCO Cookbook - technical reference manual focused on how to build grids
3. NOAA OER Deepwater Exploration Mapping - reference for NOAA OER mapping operations on the NOAA Ship *Okeanos Explorer*
4. Australian Multibeam Guidelines 2.0 - technical reference manual focused multibeam operations

Helpful presentations and papers

1. Sonar Synchronization and Tradeoffs
2. Rolling Deck to Repository Overview - 2020 RVTEC
3. Open Vessel Data Management - 2020 RVTEC
4. Lessons Learned from a Successful Integration of the EM 304 MKII Variant Multibeam Sonar
5. Ocean Exploration in a Data-Rich World - white paper from 2022 National Ocean Exploration Forum
6. Exploring the use of Sound Speed Profiles... - 2022 Ocean Sciences
7. Calibration of Acoustic Instruments - summarizes fundamental sonar theory and details calibration methods.
8. Multibeam Sonar Theory of Operation - a clear overview of sonar concepts (multibeam and sidescan)

Why map the ocean?

Most of this wiki focuses on *how* to map the watery 71% of our planet. Here are a few examples of *why*.

Beyond the critical role of safety of navigation, ocean mapping is important for a wide array of reasons:

1. confirming plate tectonics and ancient oceans
2. understanding ocean circulation and climate
3. studying historic tsunamis and present risks
4. managing fisheries and food sources
5. tracking sources of greenhouse gases
6. routing global submarine cables
7. catching up to maps of our moon and Mars

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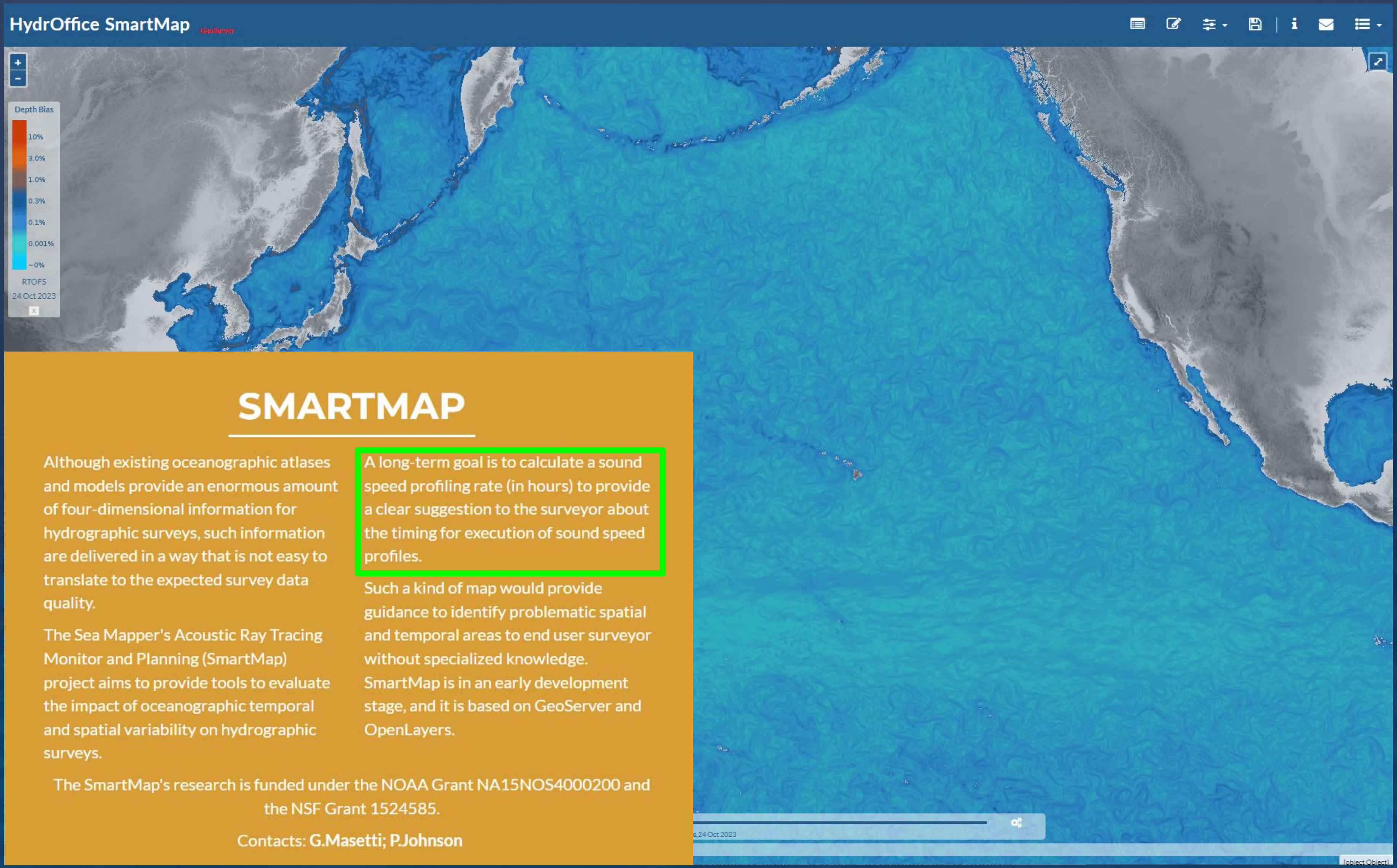
SmartMap

MAC supported under NSF grant 1933720

Survey Planning: **SmartMap**



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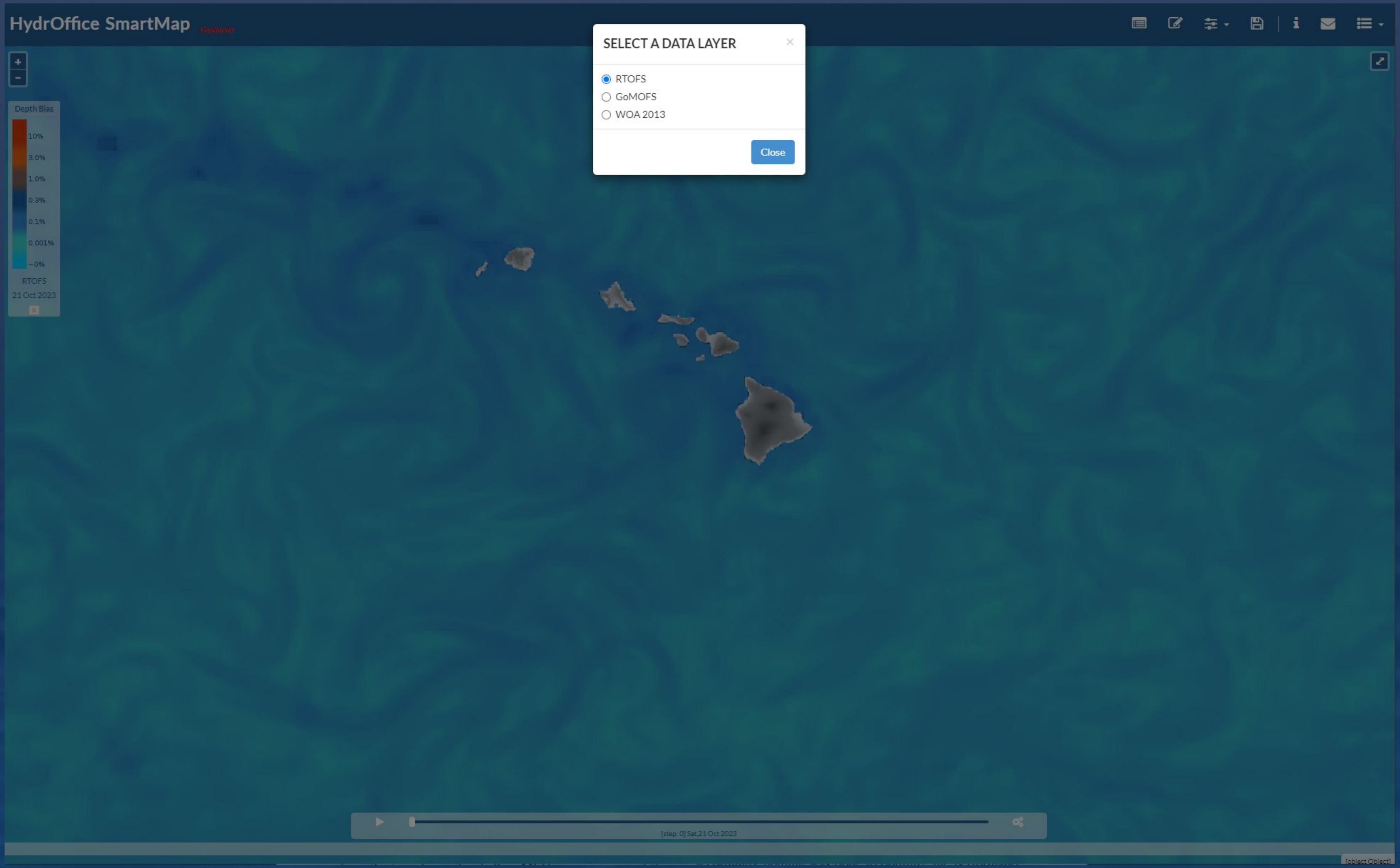
https://www.hydroffice.org/smartmap

Survey Planning: **SmartMap**



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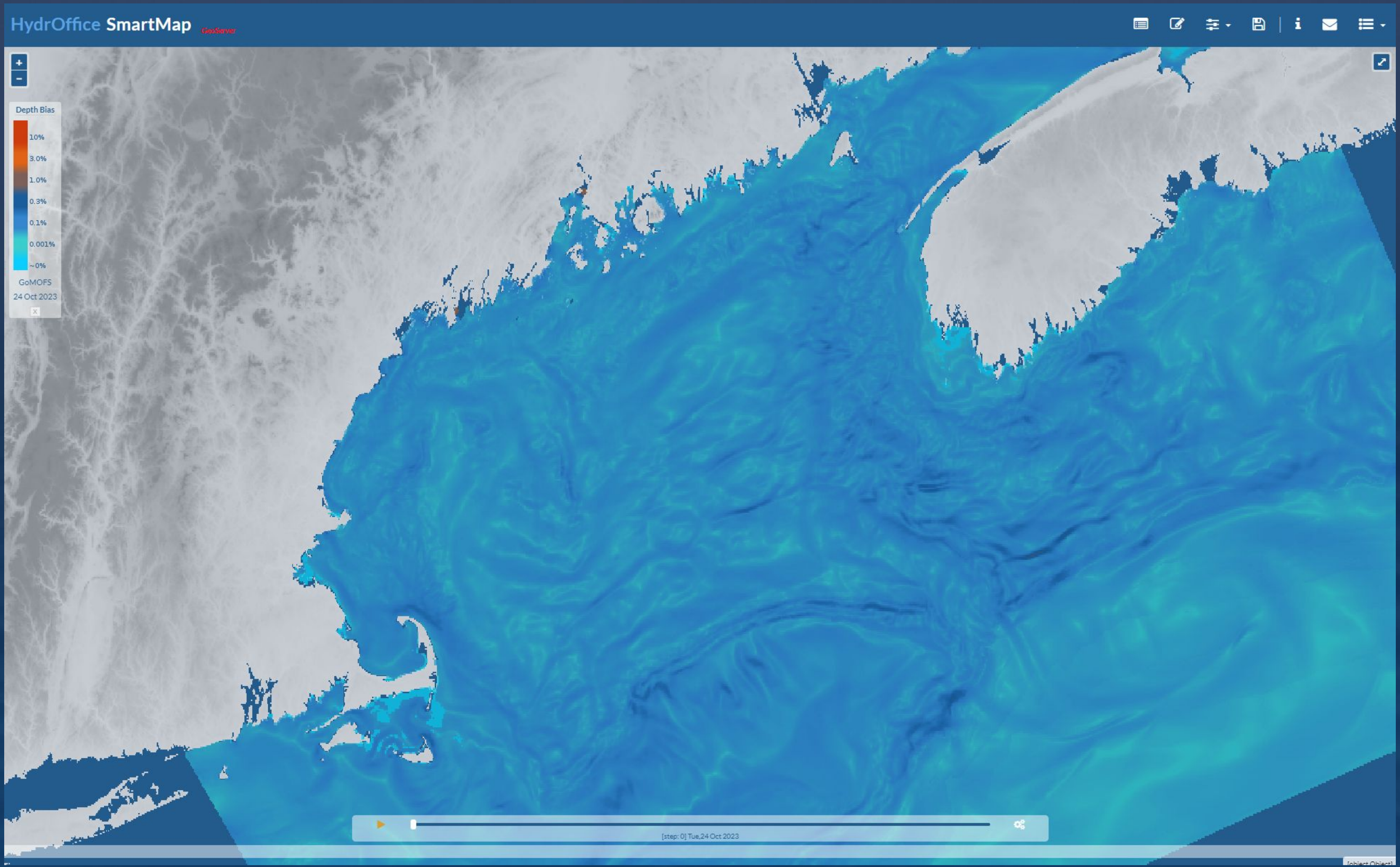

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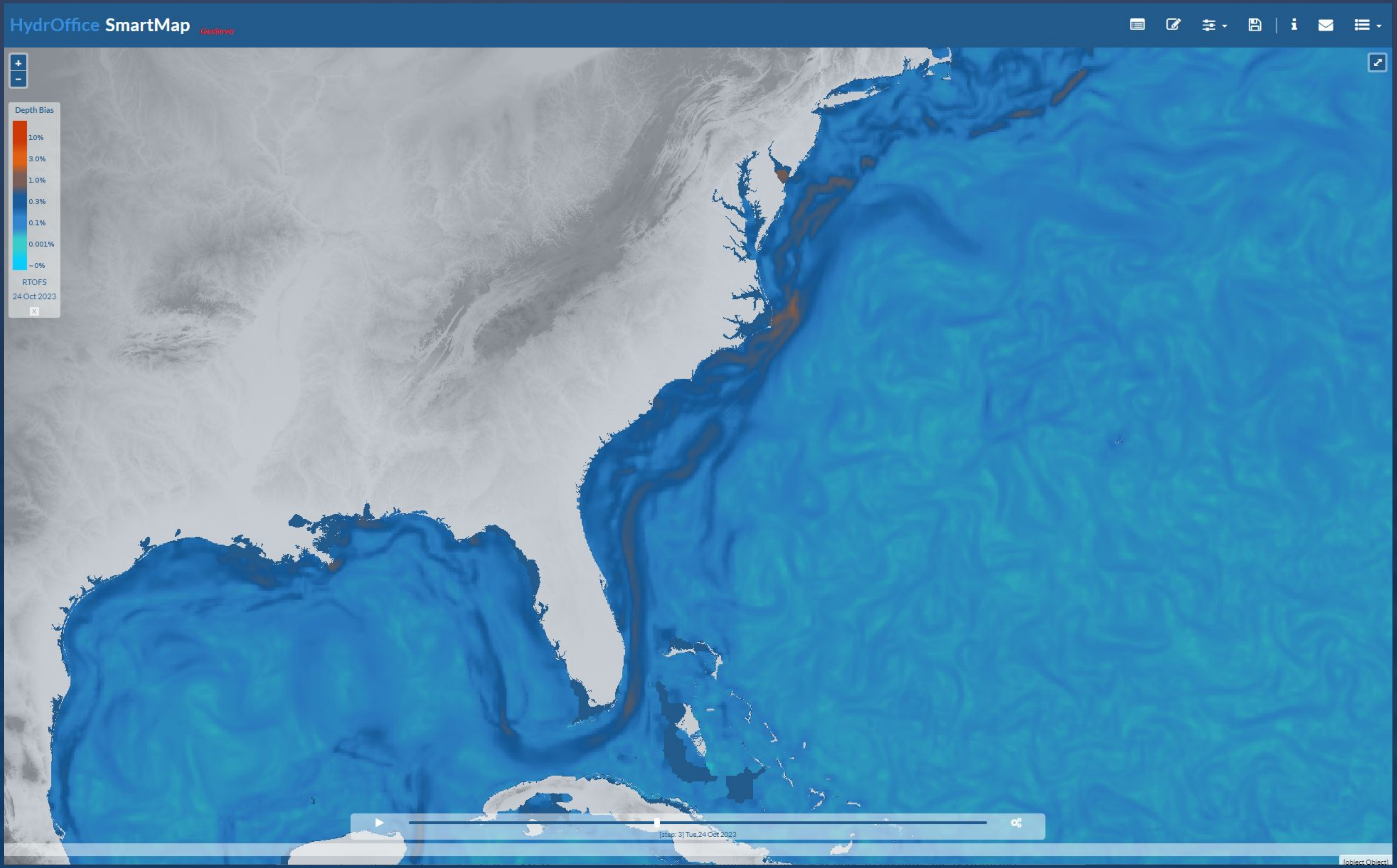
Survey Planning: **SmartMap**



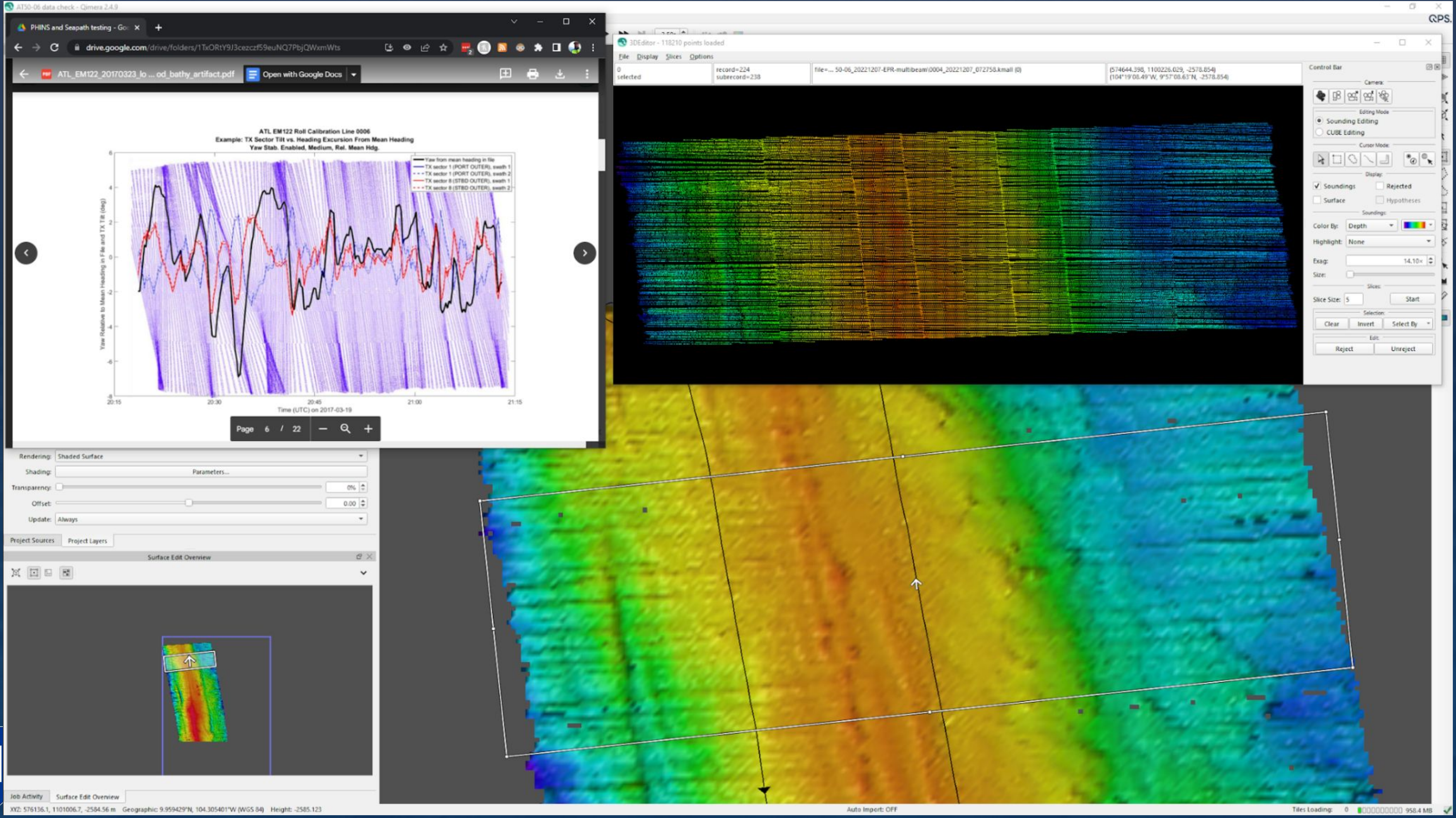
https://www.hydroffice.org/smartmap

(Unsolved) Environmental Impacts

MAC supported under NSF grant 1933720

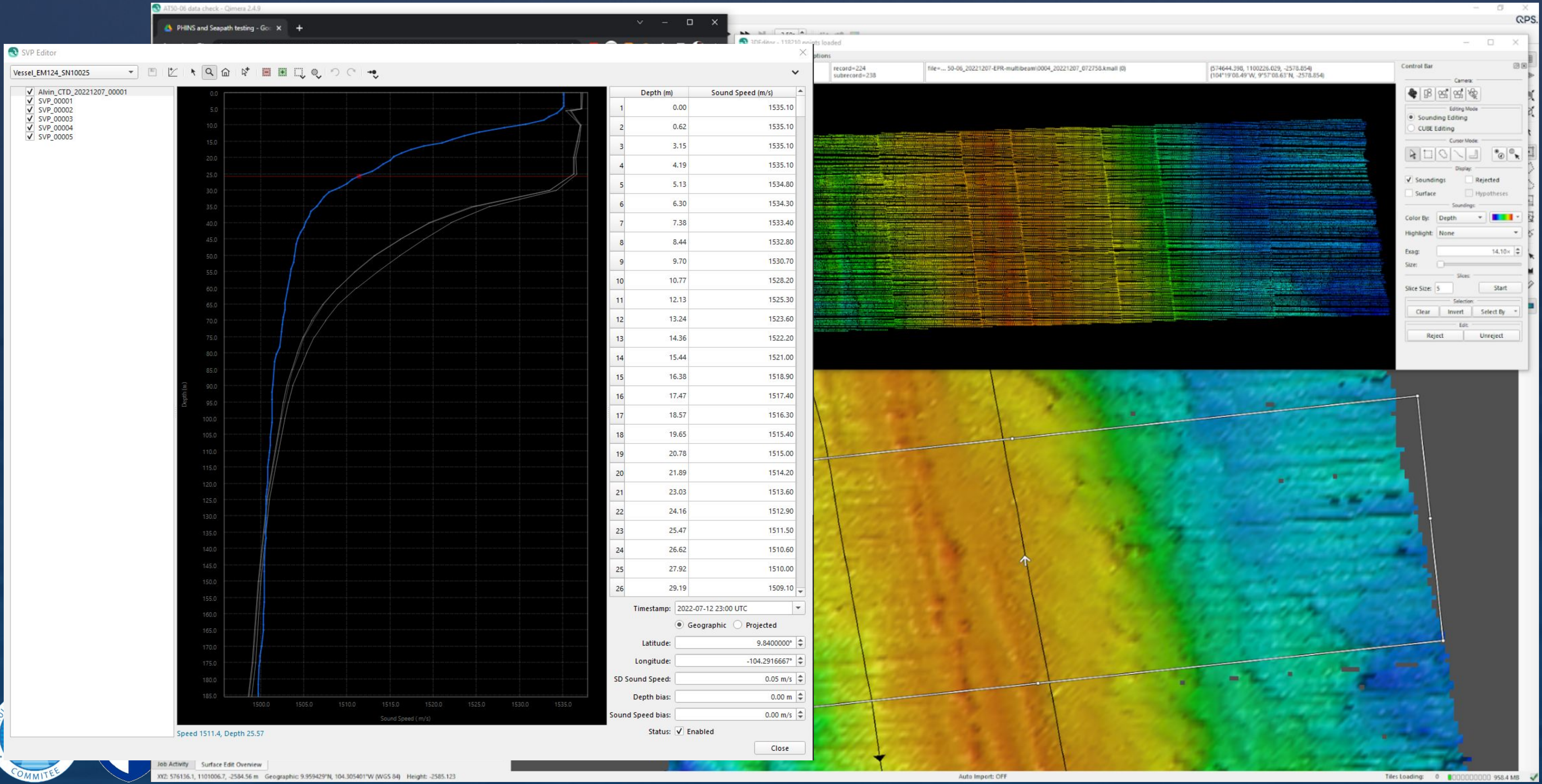
Examples from the Field: Swath Wobbles

1. EM124 swath artifacts noticed on East Pacific Rise where data has historically looked OK



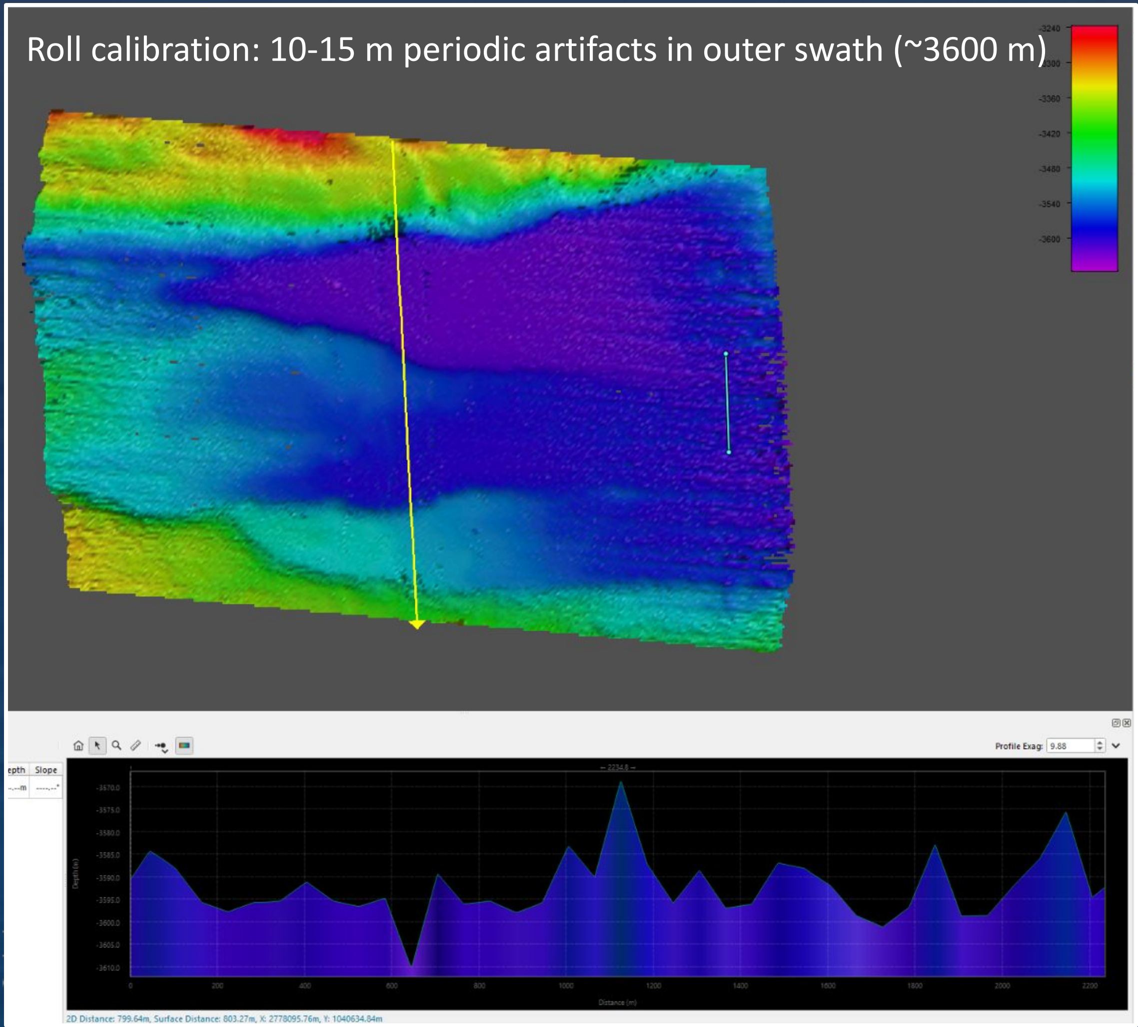
Examples from the Field: Swath Wobbles

1. EM124 swath artifacts noticed on East Pacific Rise where data has historically looked OK

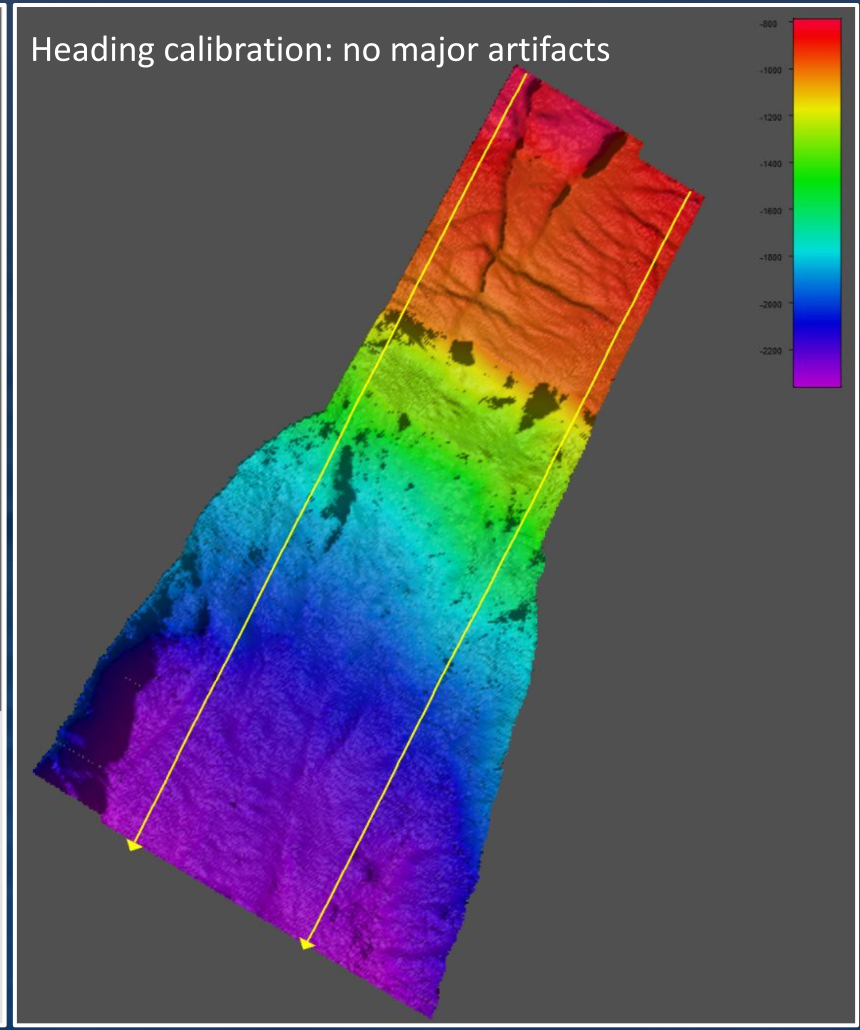


Examples from the Field: Swath Wobbles

1. Multibeam systems up to date with total geometry review, calibrations, noise testing
2. ‘Wobbles’ in some data (left) but not all (right) during calibration



Roll calibration: 10-15 m periodic artifacts in outer swath (~3600 m)

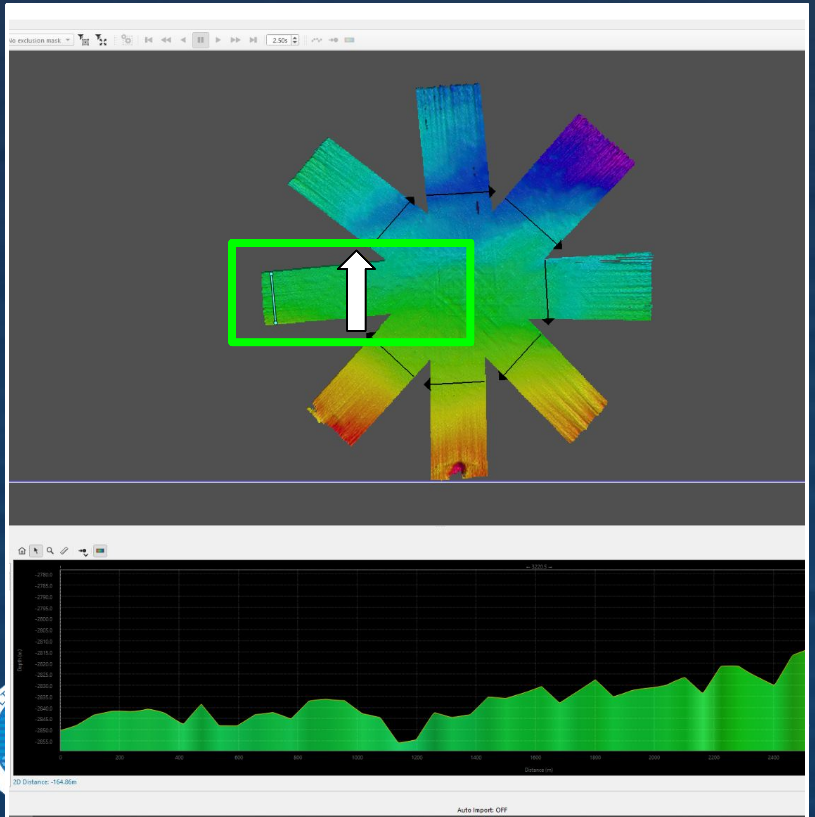


Heading calibration: no major artifacts

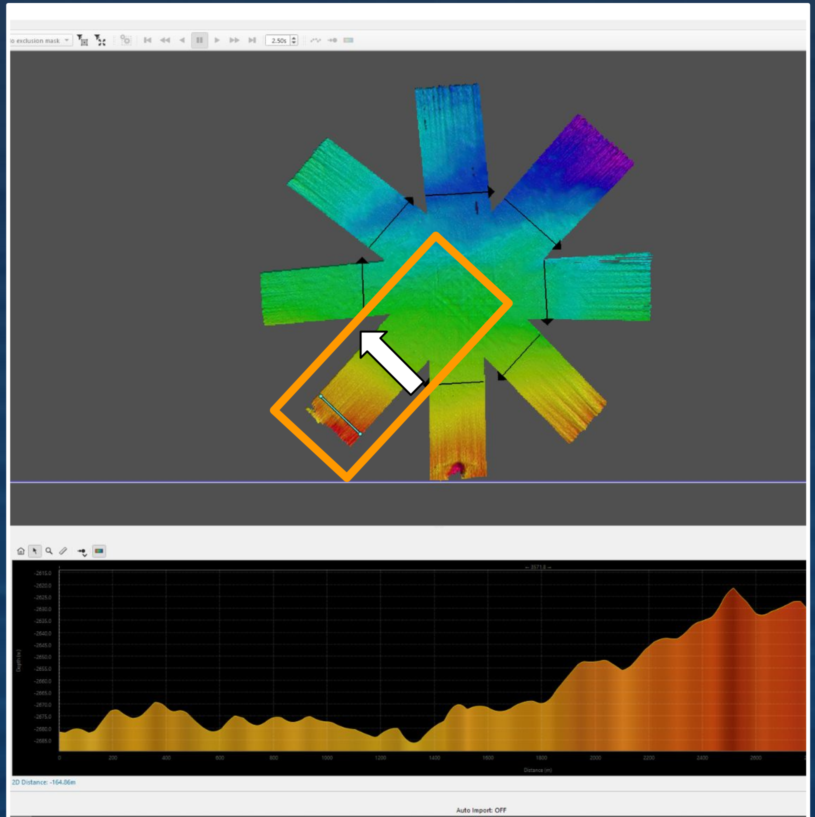
Examples from the Field: Swath Wobbles

1. Mapping ‘octagon’ with 10-15 minutes on eight headings (2650-2850 m)
2. Changes in swath behavior with orientation to potential internal wave field
3. Consistent attitude (1-3° roll and pitch) and surface sound speed on all headings

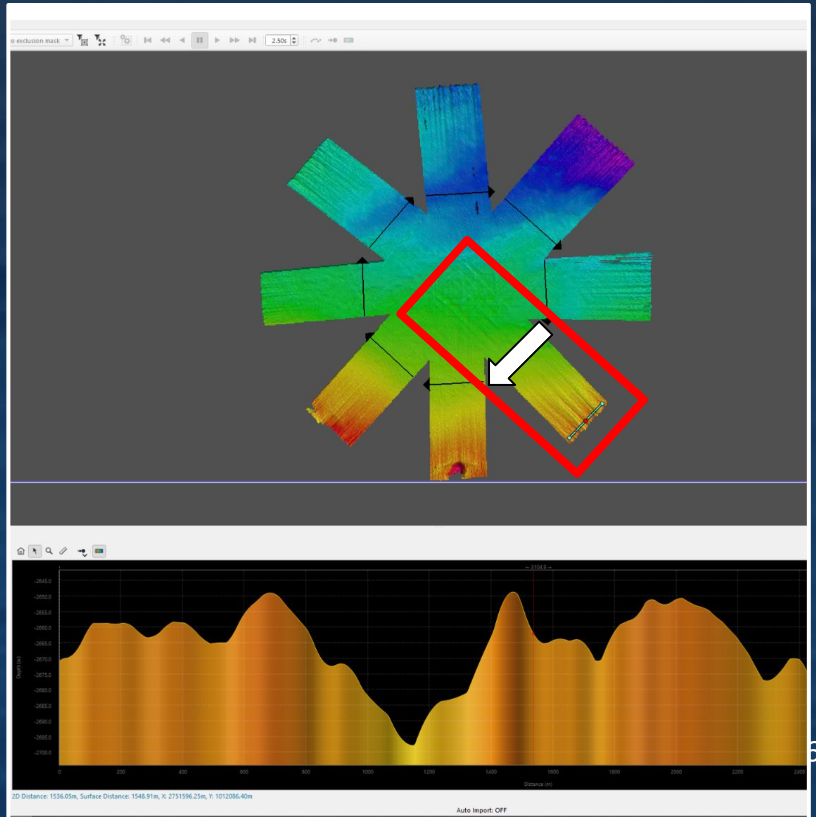
‘Best’ case: ~5 m ripples (N)



‘Middle’ case: ~20 m waves (NW)

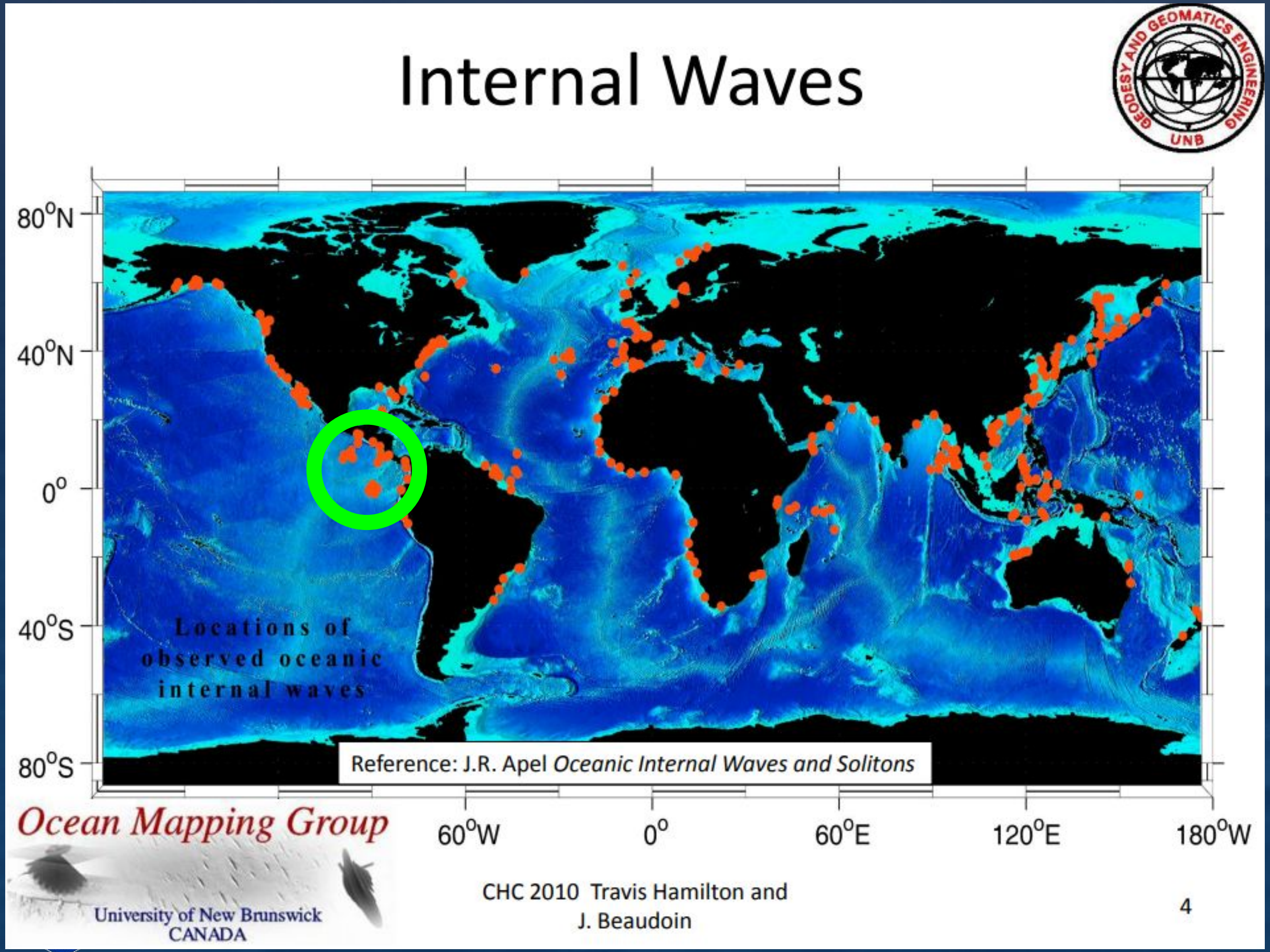


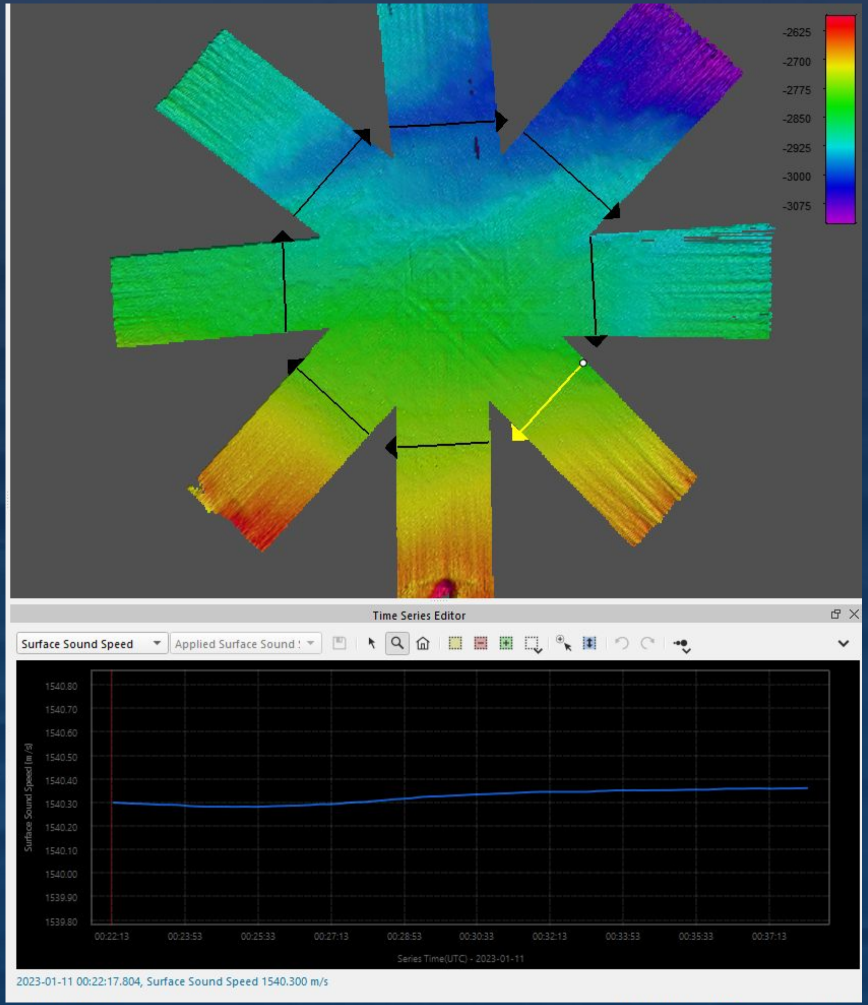
‘Worst’ case: ~50 m wobbles (SW)



Examples from the Field: Swath Wobbles

1. Oceanography: Internal waves?
2. Flow-through TSG: Intake depth? Temperature change? Lag time?





Future Work: MLD tracking and similar efforts

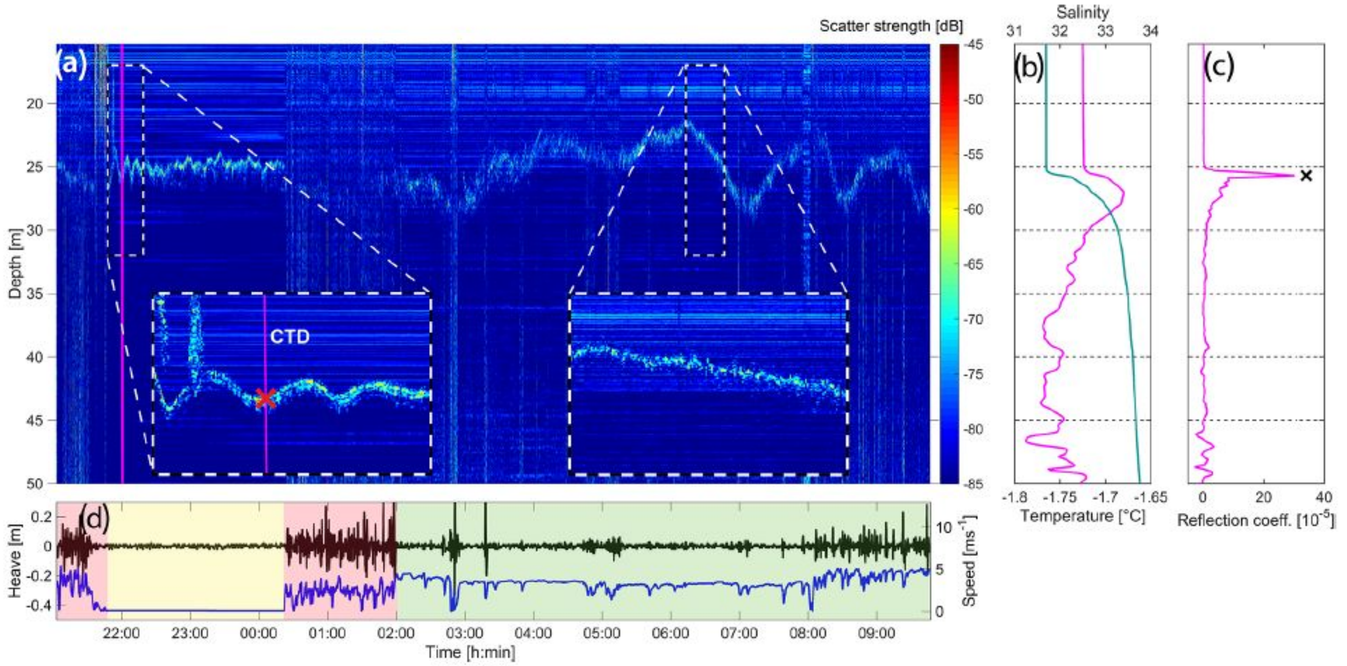


Figure 2. Continuous tracking of MLD in the central Arctic Ocean over a 117 km cruise track. Data were acquired 12–13 September 2016 at 14.5° E, 86.1° N. **(a)** EK80 echogram (2 ms pulse length) with magnified insets (dashed boxes) showing the MLD while drifting (left) and while steaming (right). **(b)** CTD profiles showing temperature (magenta) and salinity (cyan). **(c)** Reflection coefficients derived from CTD data (magenta) and from scatter strength; black cross represents the observed scatter strength of −65 dB at this depth extracted from the left inset in **(a)**. **(d)** Heave (black), speed over ground (blue), and time periods corresponding to ice breaking (red), steaming (green), and drifting (yellow). Vertical magenta lines in **(a)** show the position of the CTD. The red cross in **(a)** (left inset) marks the depth of the reflection coefficient spike in **(c)**. Note that the ability to detect MLD acoustically is severely reduced while breaking ice.

Table 1. Success and failure rates of acoustic detection of MLD when present in CTD data.

Category of detection	SWERUS-C3	AO2016	Total[a]
MLD present in CTD profile	69	22	91
MLD in CTD and in EK80 (success)	48 (70 %)	21 (95 %)	69 (76 %)
MLD in CTD but not in EK80 (failure)	21[b] (30 %)	1 (5 %)	22 (24 %)

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