A revaluation of multibeam beam-steering accuracy

in the context of residual sound speed errors

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

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Jean-Guy Nistad & Patrick Westfeld

“Accurate beam steering is crucial in multibeam surveys”

oceanmapping / **community**

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.***

Technical Note

The Importance of Under-Keel Sound Velocity Sensor in Measuring Water Depth with Multibeam Echosounder

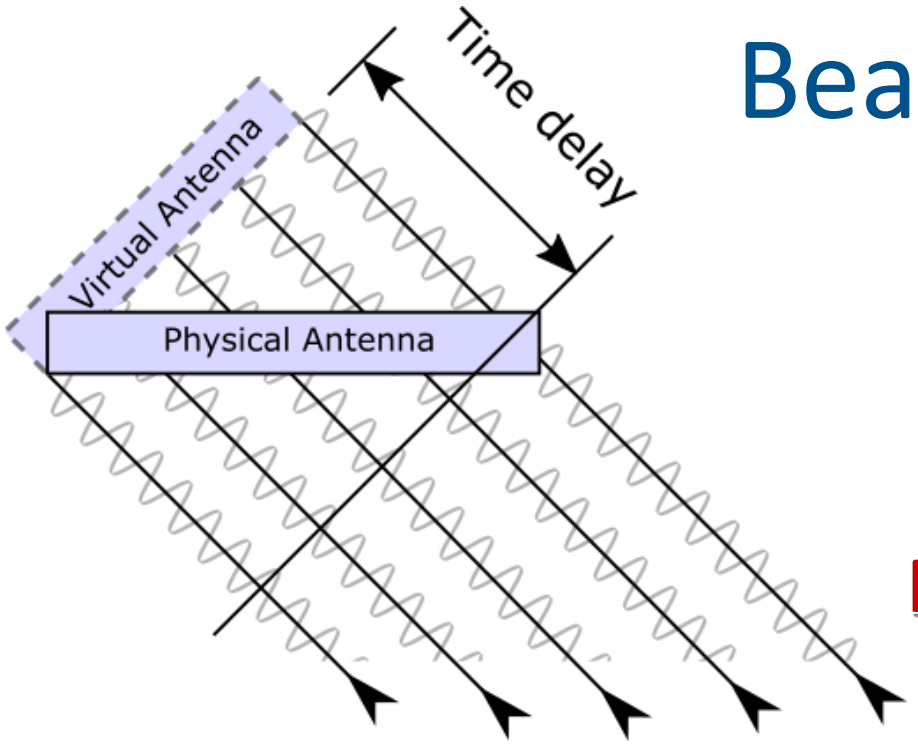
Artur Grządziel

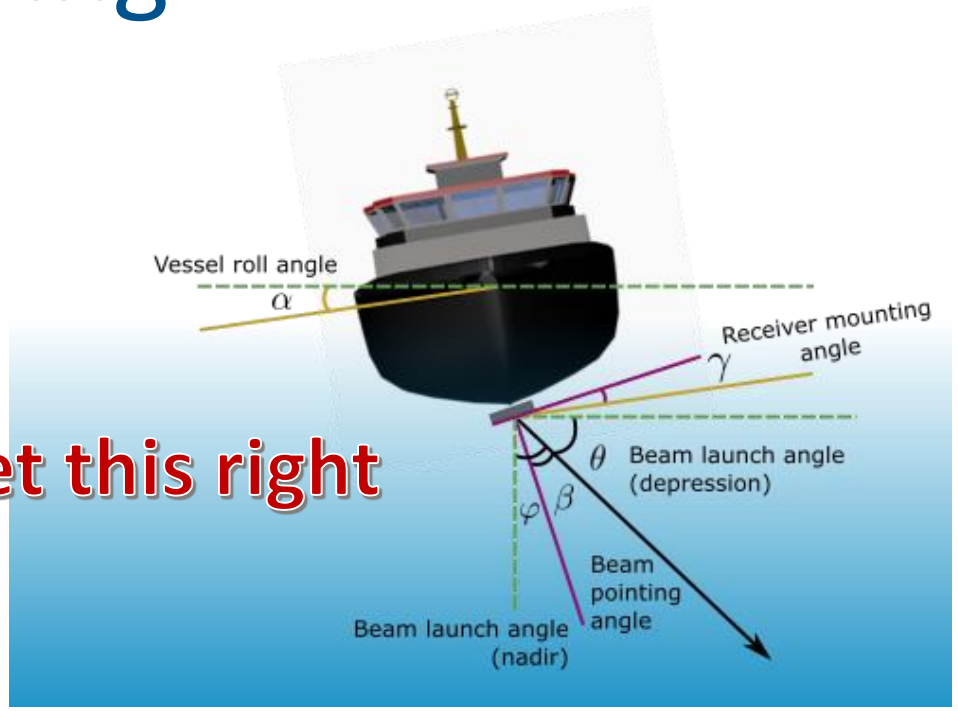
If the vessel is equipped with a surface sound speed-measuring instrument (typically installed at the head of a multibeam sonar), compare a measurement from this instrument to the results of a full sound speed profile acquired.

All discrepancies greater than 1 m/s should be noted and tracked to determine whether the instrument requires repairs or recalibration. ***NOAA FPM***

The TPU values associated with surface sound speed have a smaller range and magnitude than measured sound speed (0.2 m/s to 2 m/s) because sound speed is continually measured at the transducer. The sound speed uncertainty, therefore, is dictated by the sound speed gradient at the velocimeter’s sensor head. ***NOAA FPM***

Beam Steering

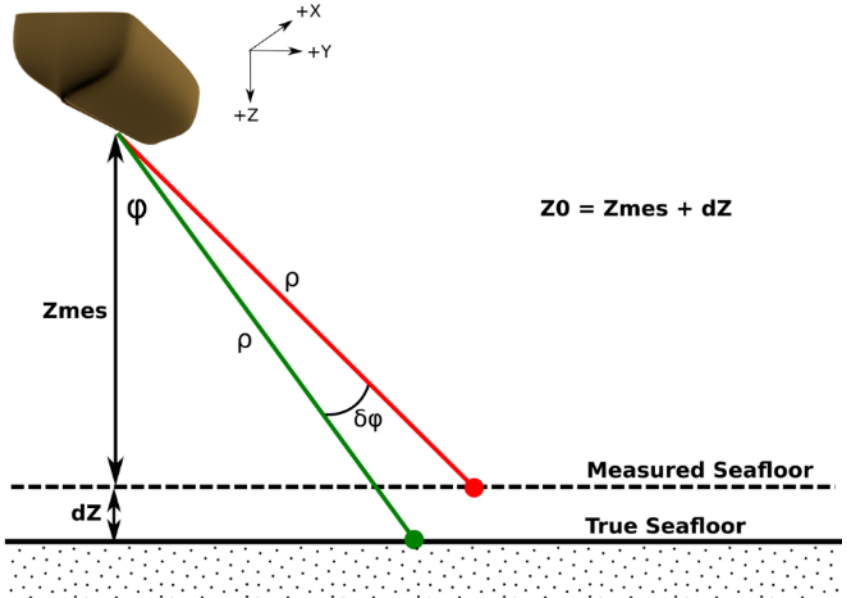




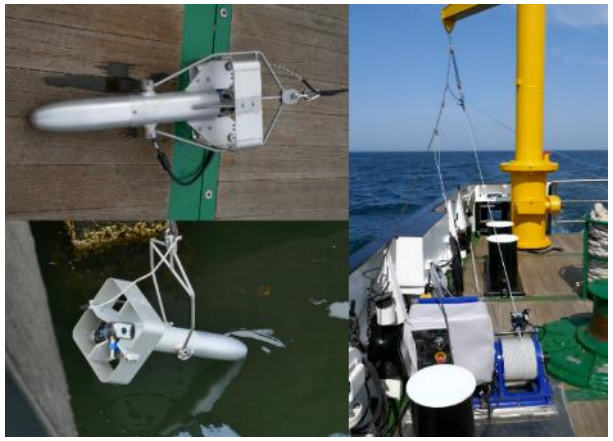
Need to get this right

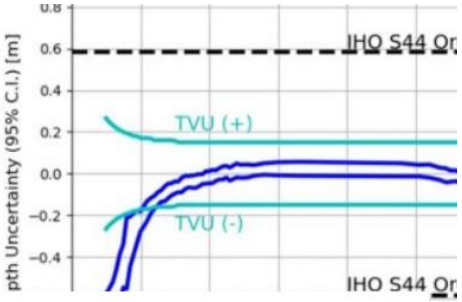
$$\varphi = \sin^{-1}\left(\frac{c_s}{c_{sss}}\sin(\beta_s)\right) - \alpha - \gamma$$

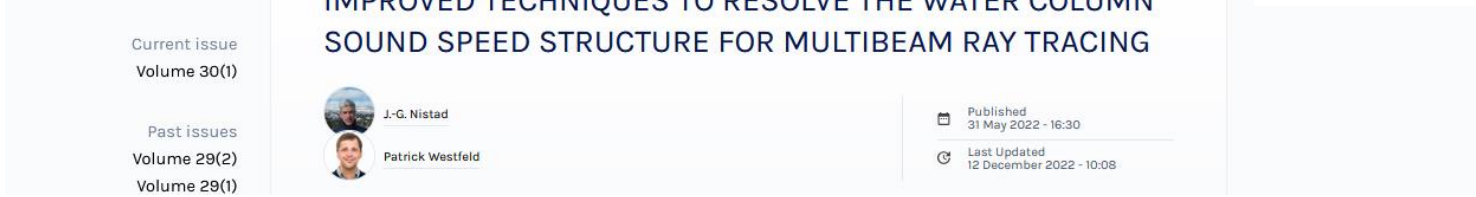
1) Adjust the design sound speed c_s to the real-time surface sound speed c_{sss} to get the beam pointing angle β.
2) Calculate φ the beam launch angle (w.r.t. nadir)



Motivation



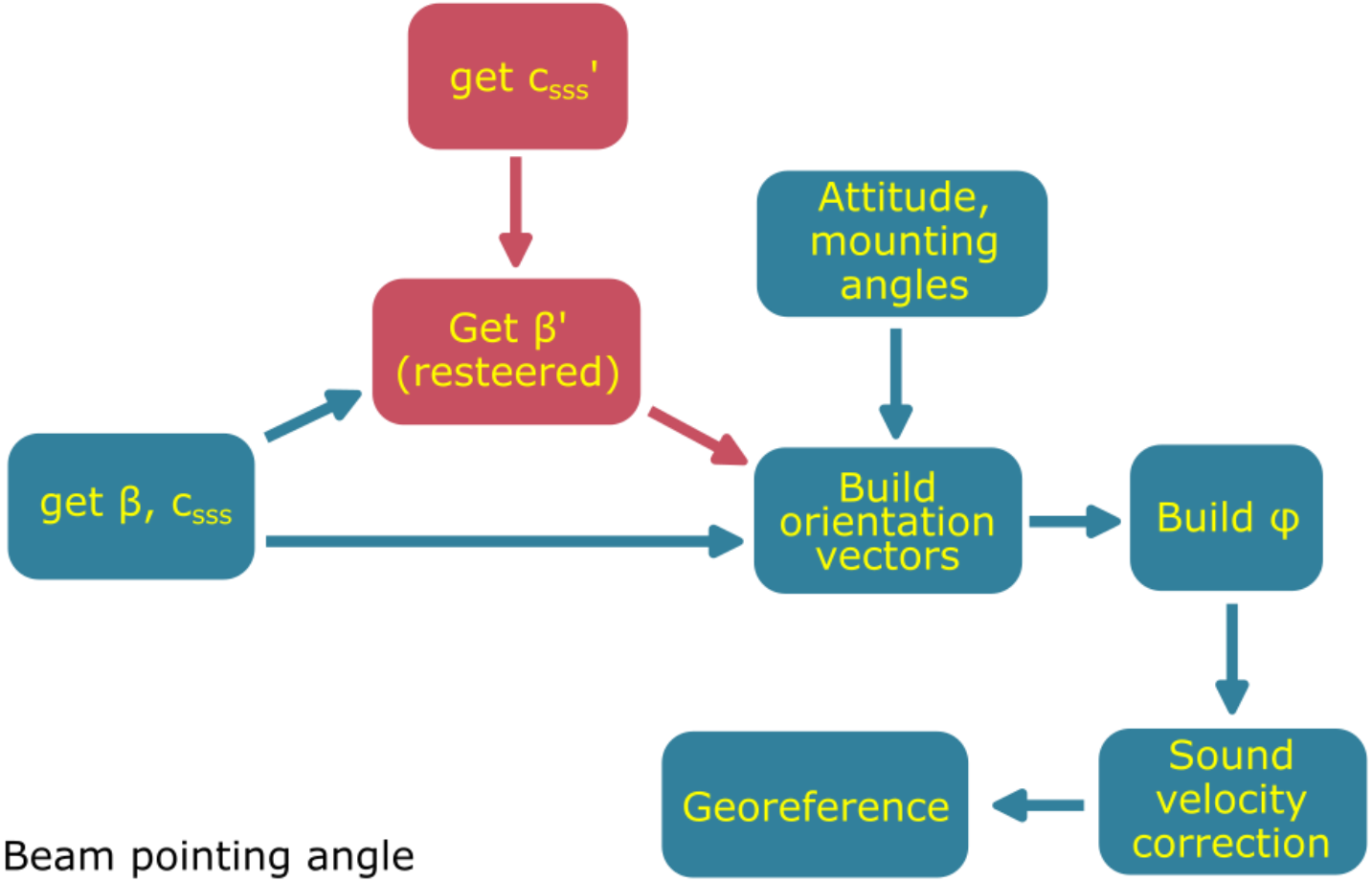




Could a residual depth bias present even with the use of an MVP be related to a surface sound speed error?

Method

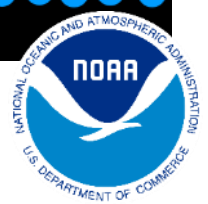
Measurement redundancy by setting up a second surface sound speed probe



β - Beam pointing angle
c_{sss} - original surface sound speed
β' - Resteered beam pointing angle
c_{sss}' - new surface sound speed
φ - Beam launch angle (w.r.t. nadir)

Material

KLUSTER



python™ + xarray + dask + Zarr

High-level programming language

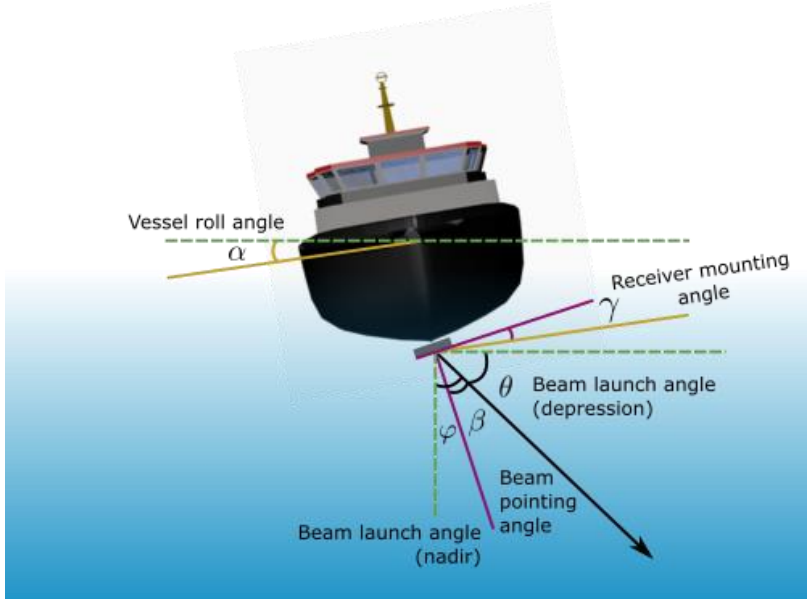
Multi-dimensional labeled structured arrays

Parallel and cloud computing

Archiving and compression of multi-dimensional arrays into chunks

Research Contributions

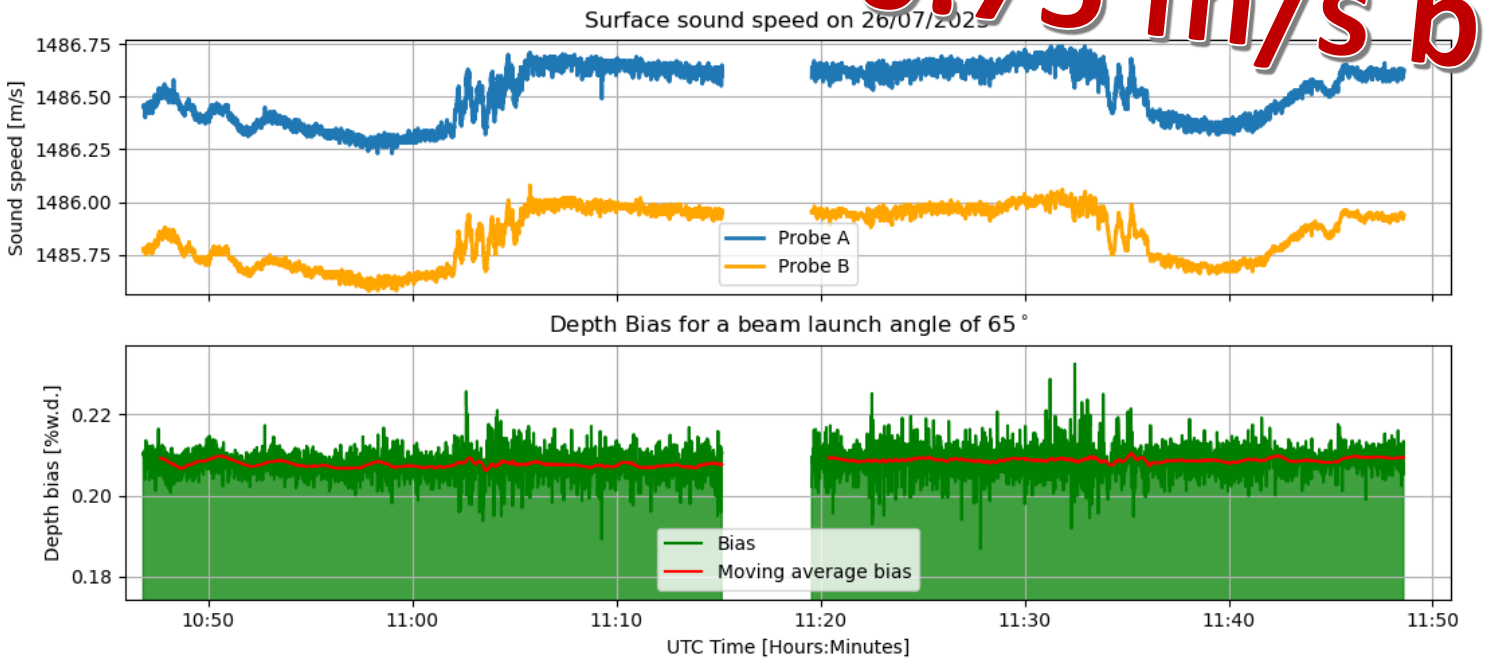
1. What is the error signature of a surface sound speed error in an operational context?
2. How significant is a surface sound speed error in proportion to the overall sound speed error?
3. What to do when there is a strong mismatch between the surface sound speed and the sound speed profiles?



Surface sound speed error signature

Comparing two surface sound speed probes

	Probe A	Probe B
Accuracy [m/s]	**± 0.02**	**± 0.05**



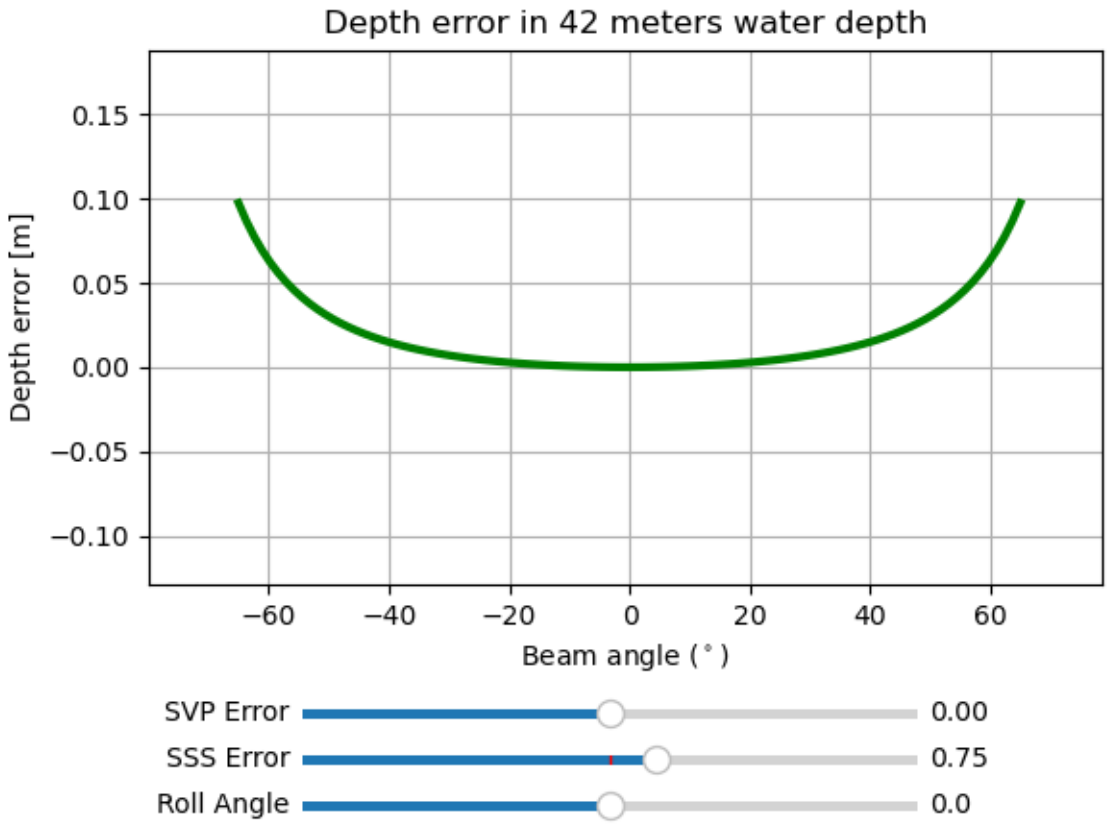
~0.75 m/s bias

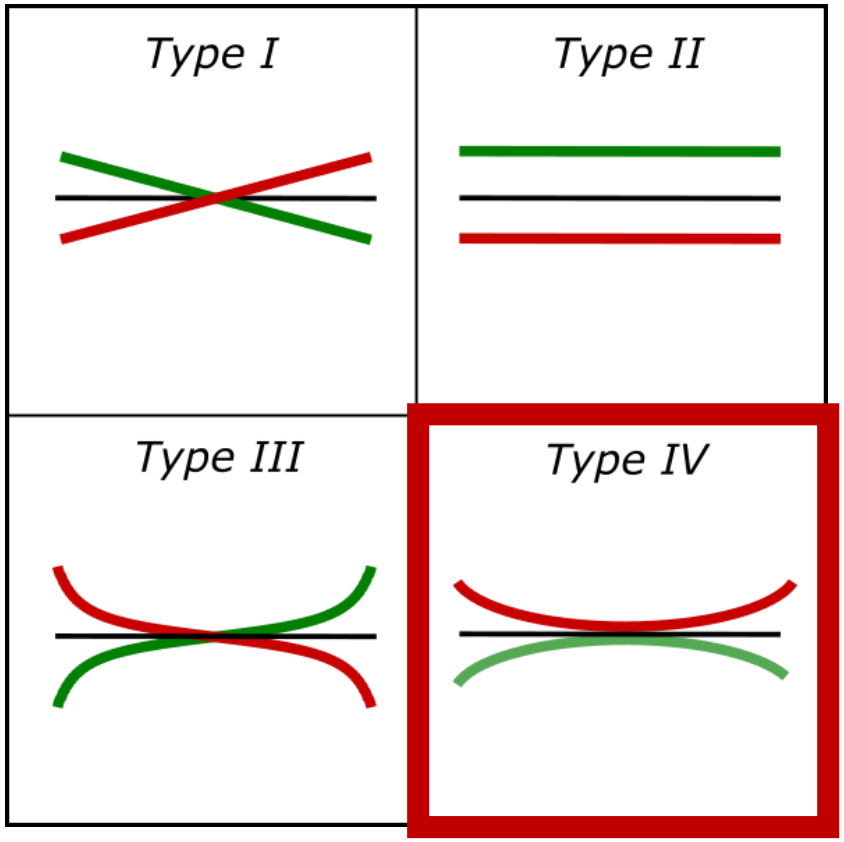
or 0.21 %w.d. at 65°

- ✓ Different manufacturers
- ✓ Newly calibrated
- ✓ Installed according to manufacture recommendations

Surface sound speed error signature

Modeling the surface sound speed error

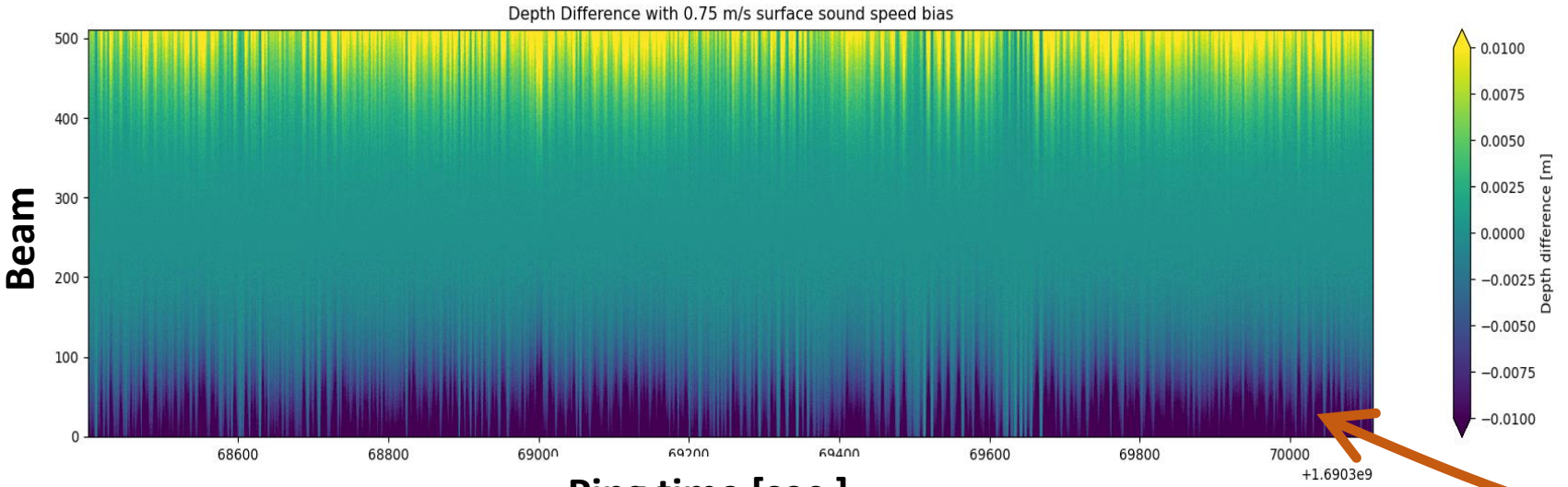


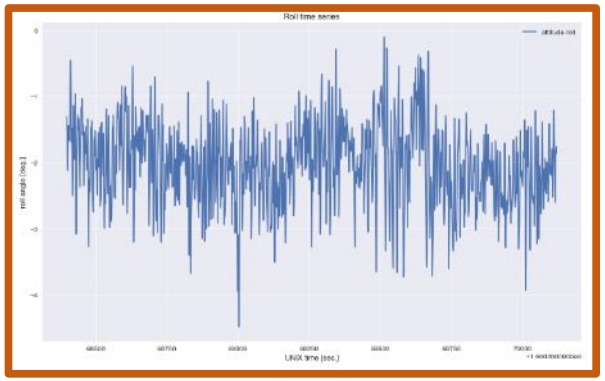


$$dz = z * \frac{\Delta c_{sss}}{c_{sss}} * \tan(\varphi)\,[\tan(\varphi) - \tan(\varphi - \alpha - \gamma)]$$

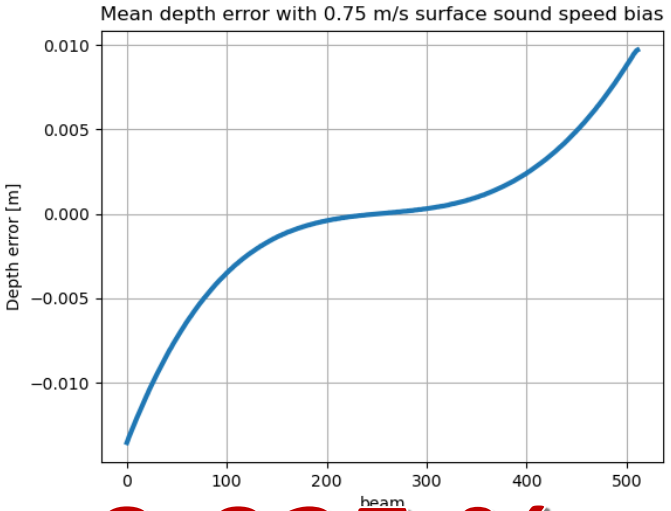
Surface sound speed error signature

Depth bias when re-steering with a 0.75 m/s surface sound speed bias

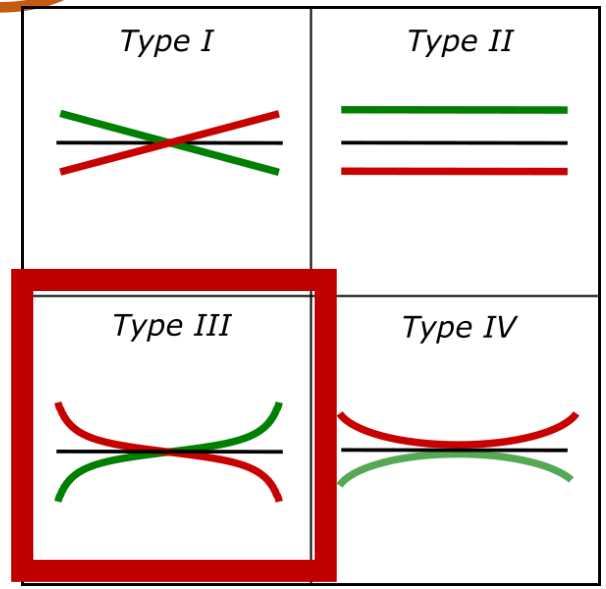




Roll signature



Mean plot <u>given ray-tracing with the same sound speed profiles</u>

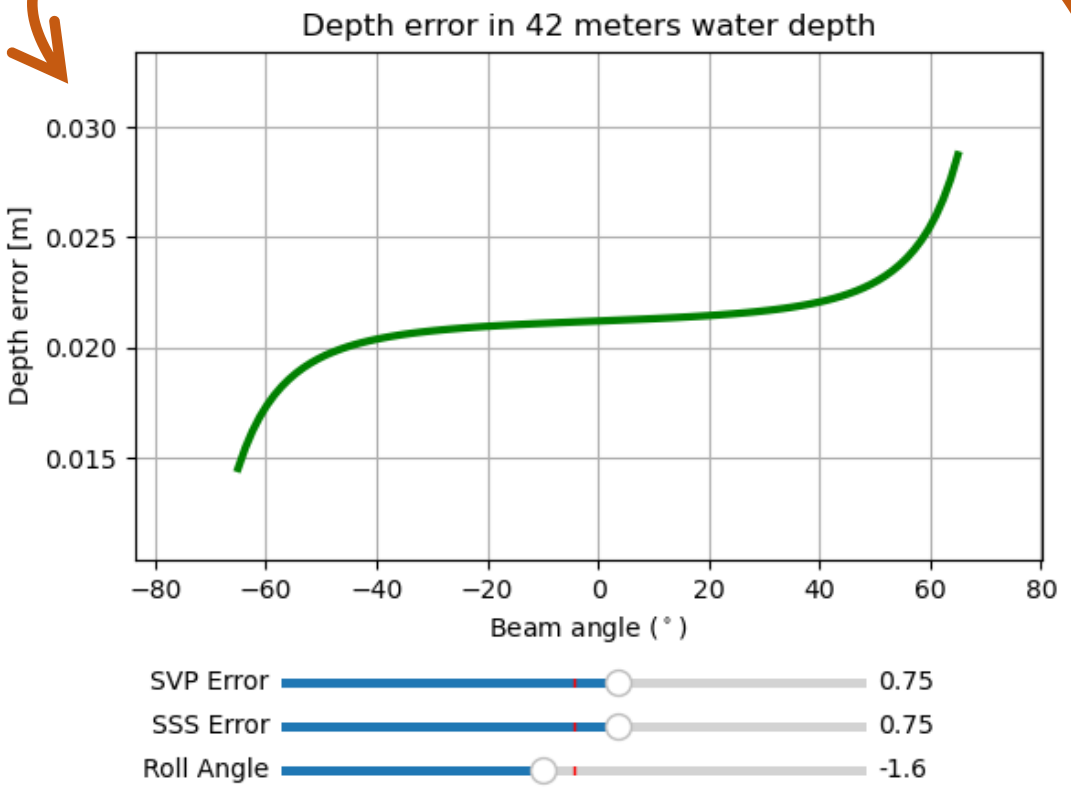


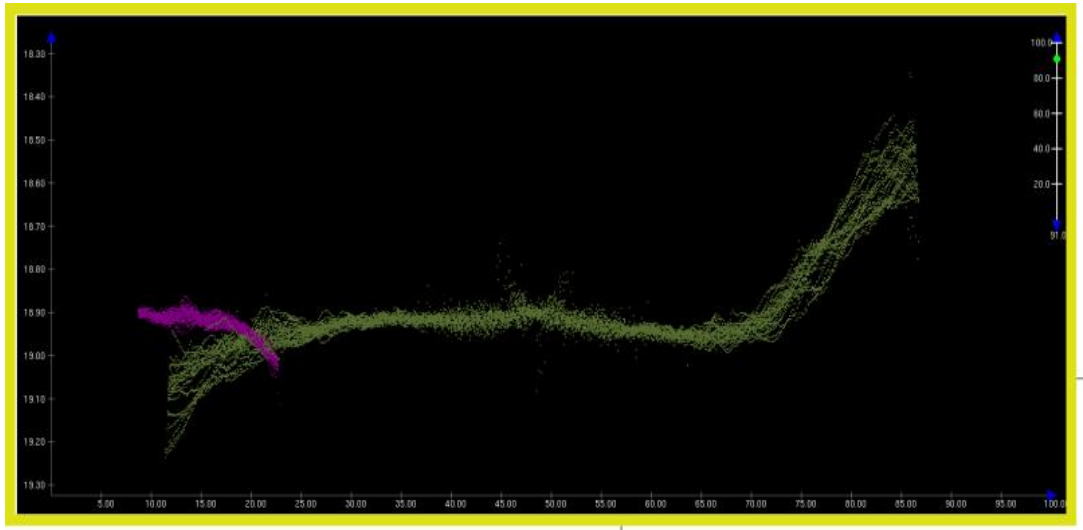
< 0.025 %w.d. at 65°

Surface sound speed error signature

Modeling the surface sound speed error

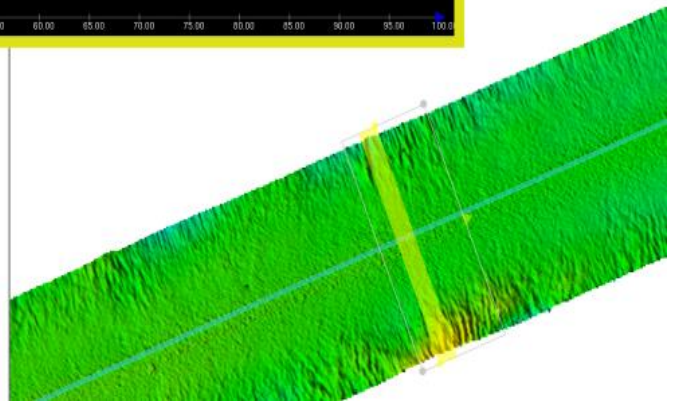
Amplitudes don't match





Presence of type III error signature in survey 1122102.

Survey line 20210716_093617 between times 09:39:25 and 09:39:28

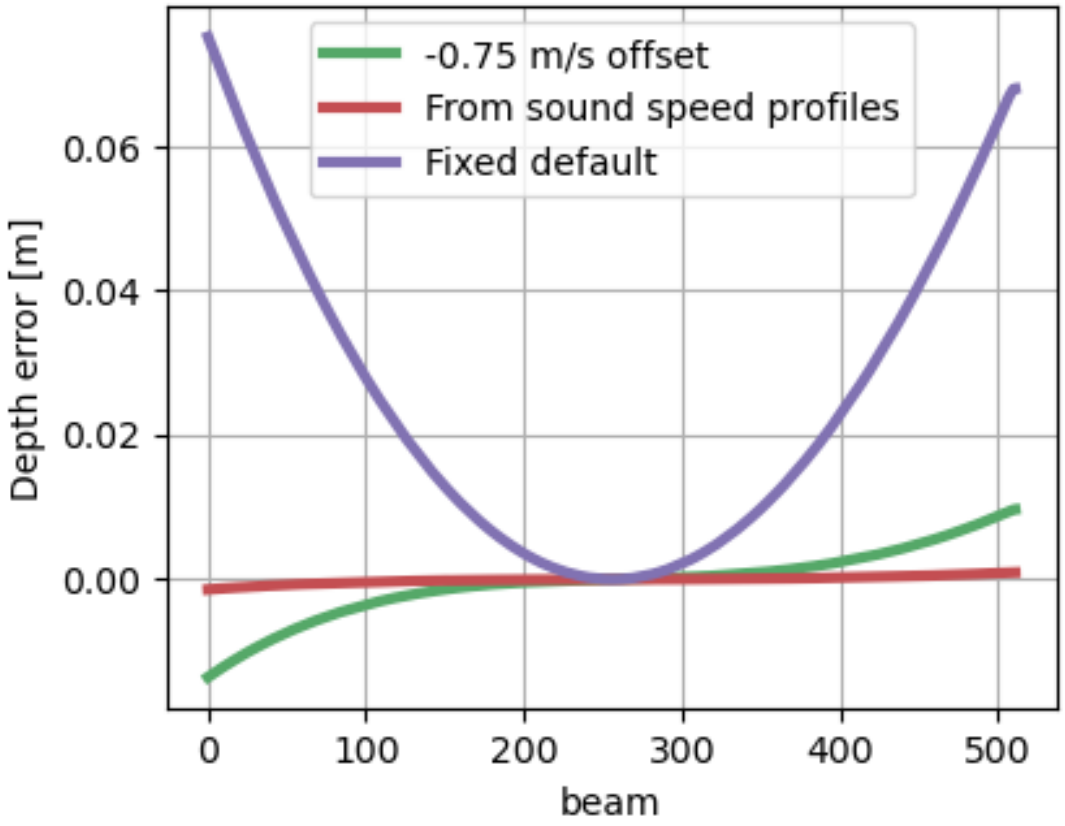


$$\alpha + \gamma = 1.64°$$

$$dz = z * \frac{\Delta c_{sss}}{c_{sss}} * \tan(\varphi)\,[\tan(\varphi) - \tan(\varphi - \alpha - \gamma)]$$

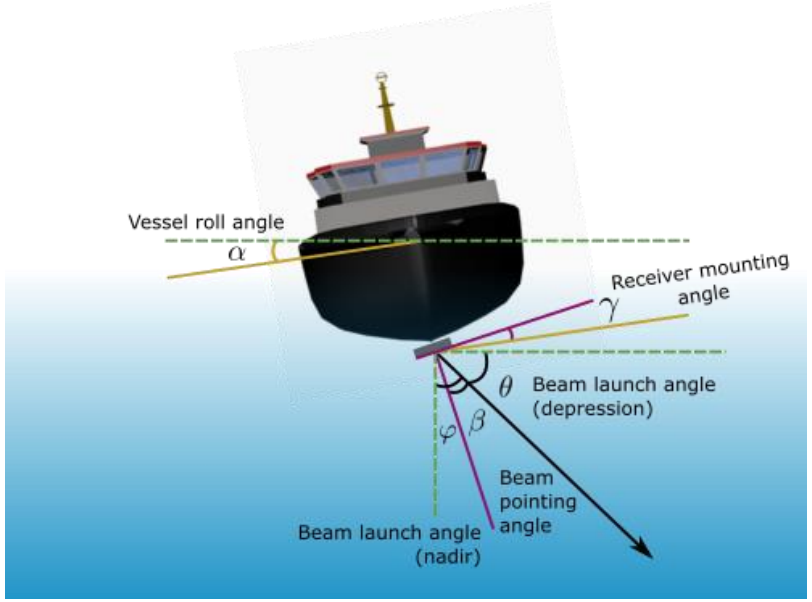
Surface sound speed error signature

Several other operational scenarios



Research Contributions

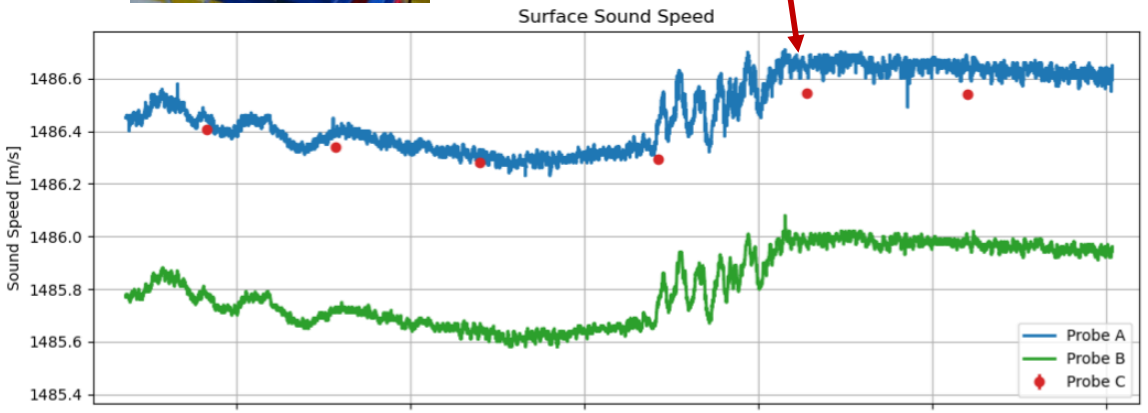
1. What is the error signature of a surface sound speed error in an operational context?
2. How significant is a surface sound speed error in proportion to the overall sound speed error?
3. What to do when there is a strong mismatch between the surface sound speed and the sound speed profiles?

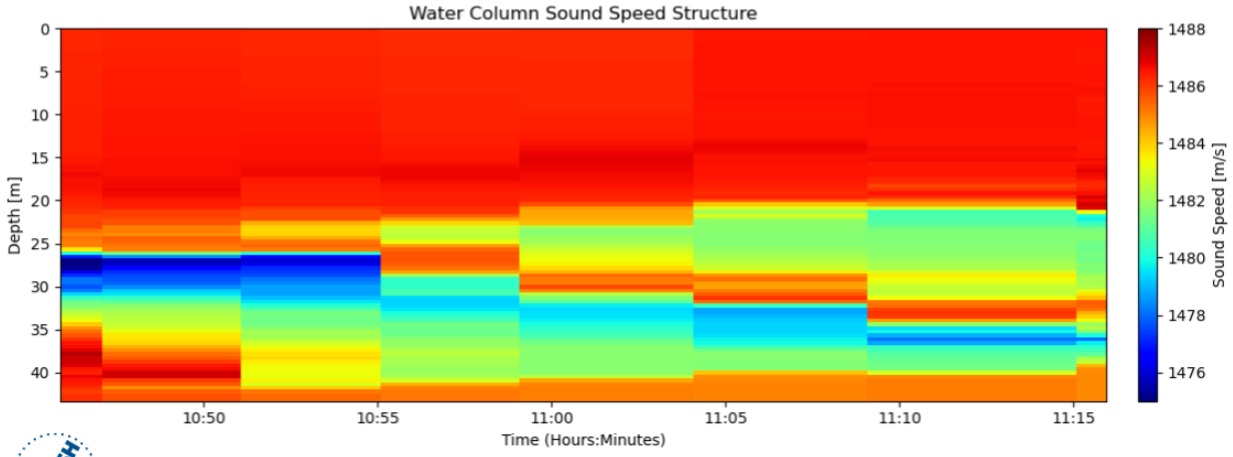


Surface sound speed error in proportion

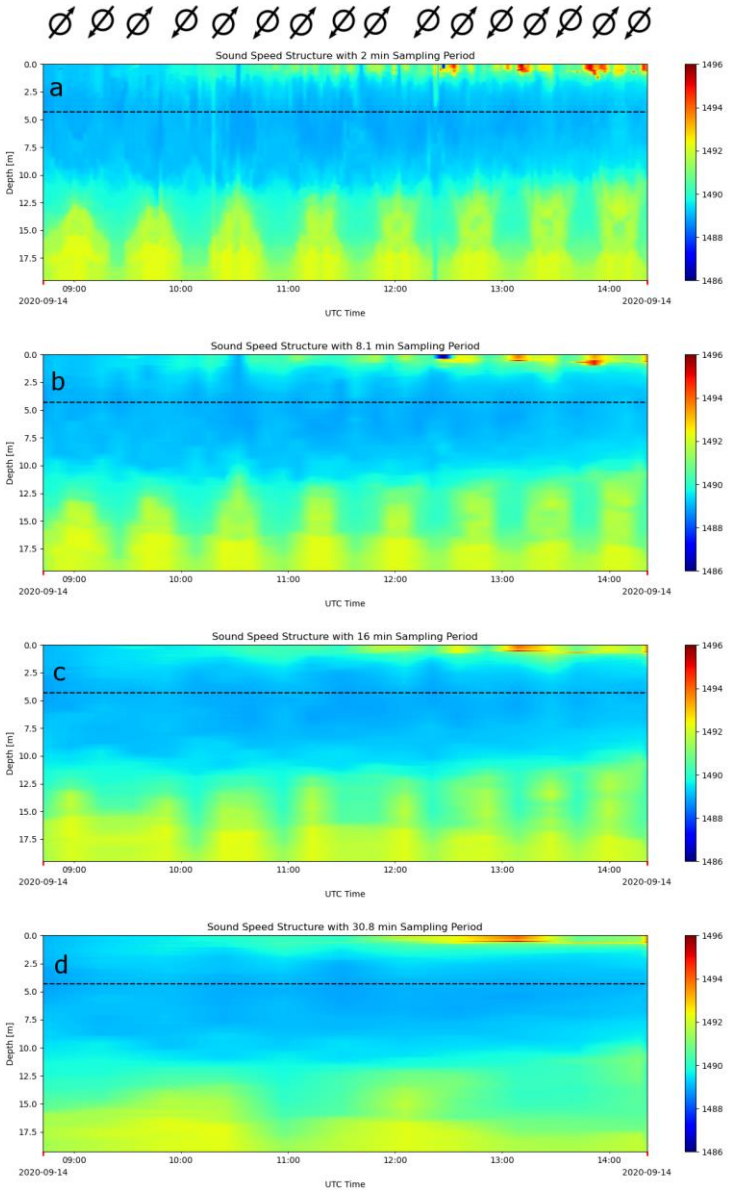
Compared to a ray-tracing error

MVP 30 (Probe C) tracking Probe A





We can do an exercise of subsampling the water column.



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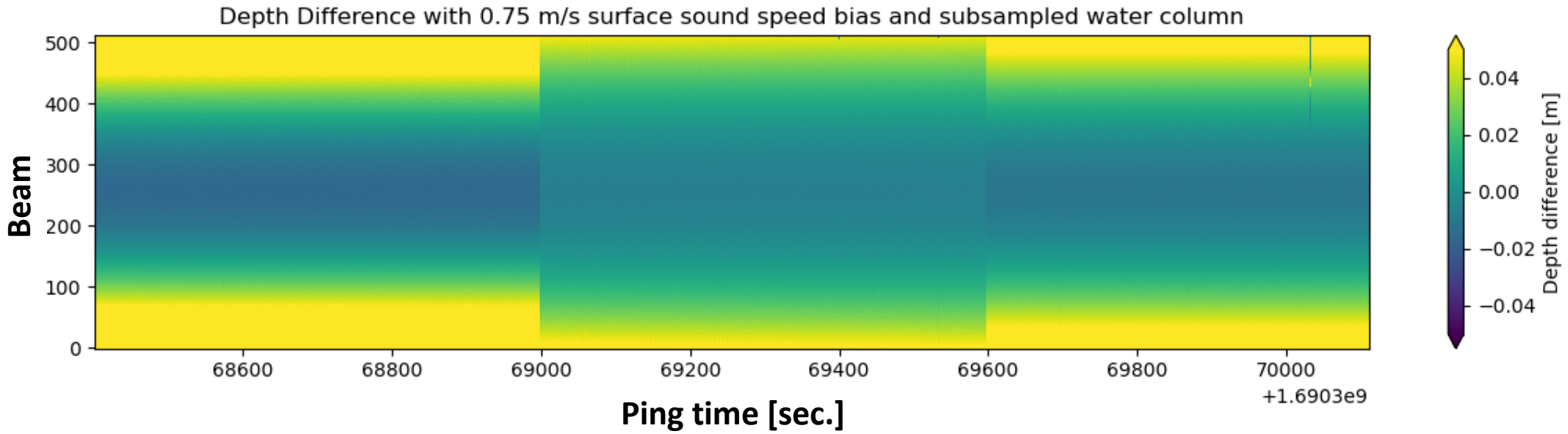
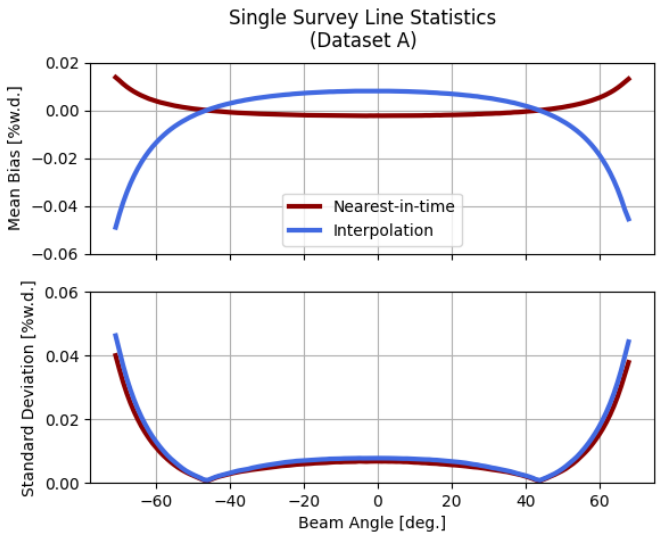
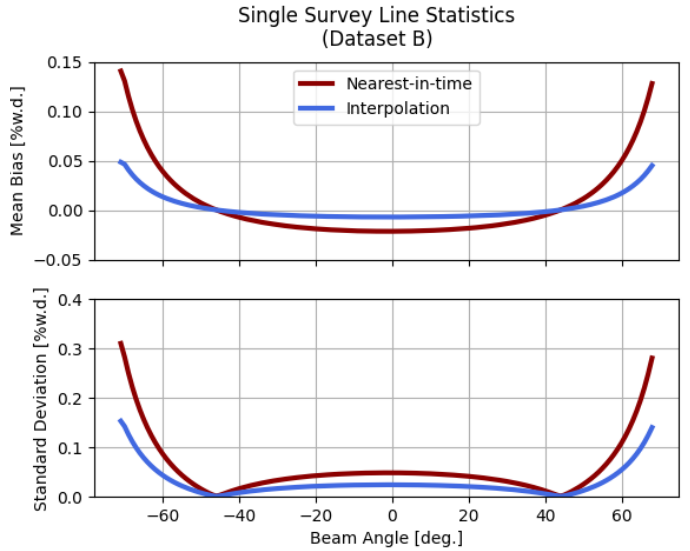
Surface sound speed error in proportion

Can be proportionally comparable



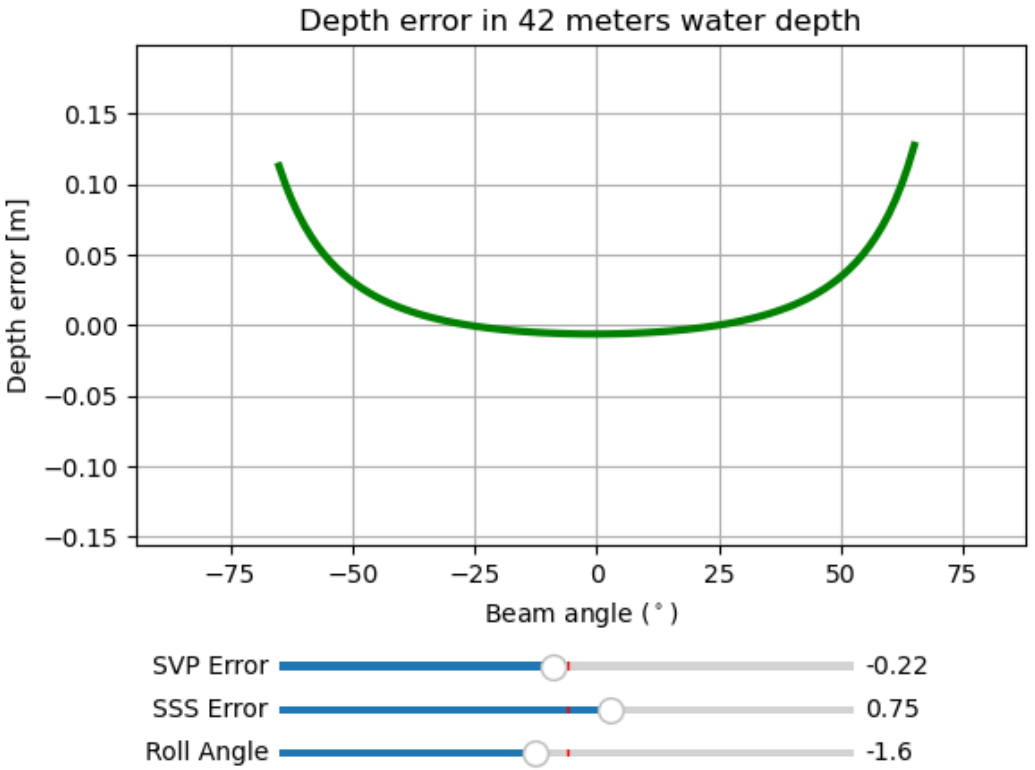


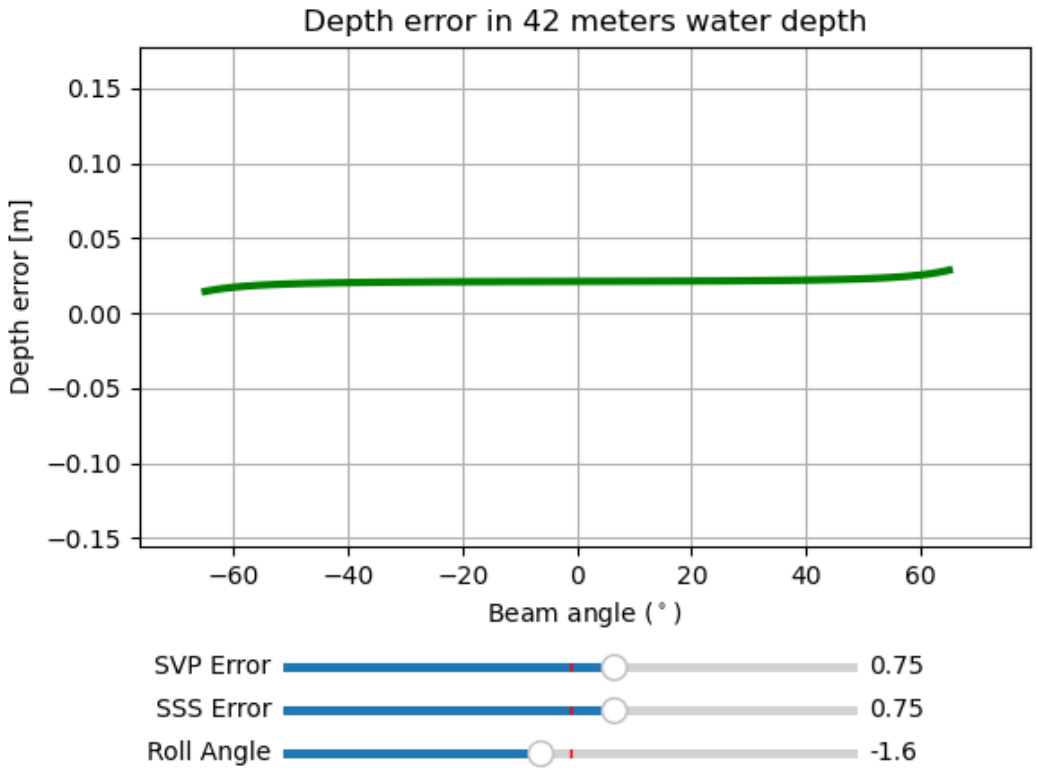


Previous work has shown that anything in the range between 0.02% w.d. and 0.15% w.d. is possible

Surface sound speed error in proportion

May also have a canceling effect





$$dz = z * \frac{\Delta c_{mean}}{c_{mean}} * [1 - \tan(\varphi)^2]$$

Research Contributions

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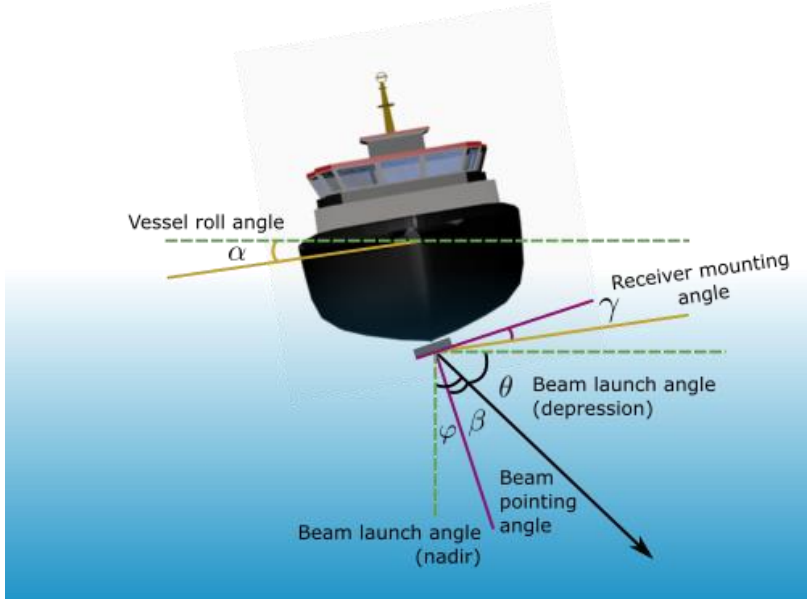
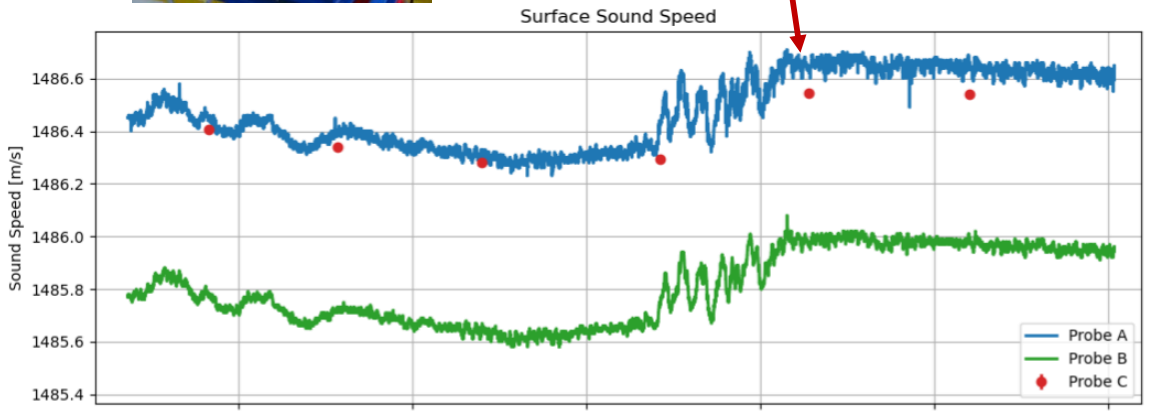
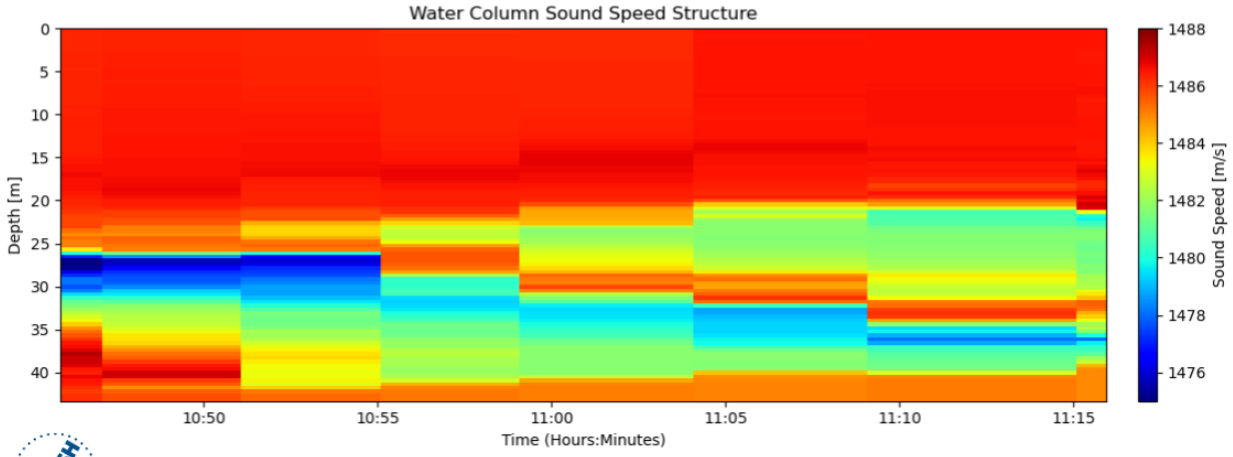


Mismatch

Case of a strong surface sound speed gradient

MVP 30 (Probe C) tracking Probe A





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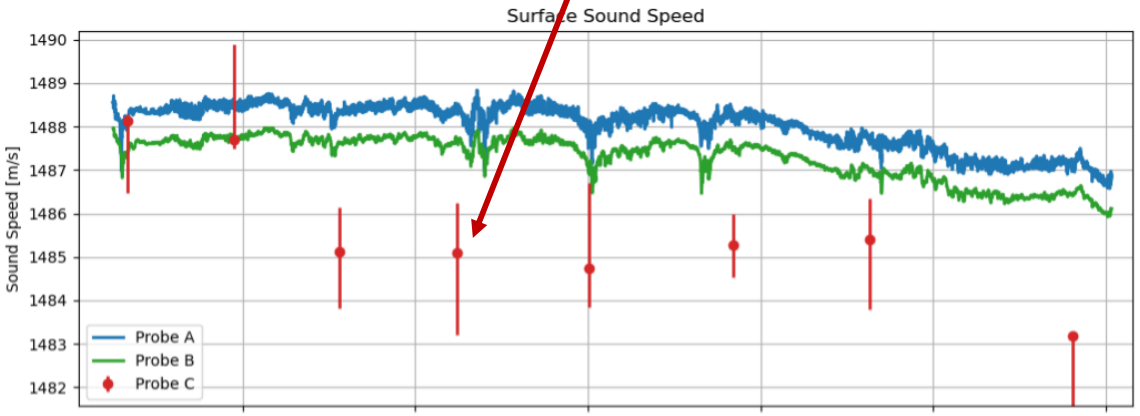
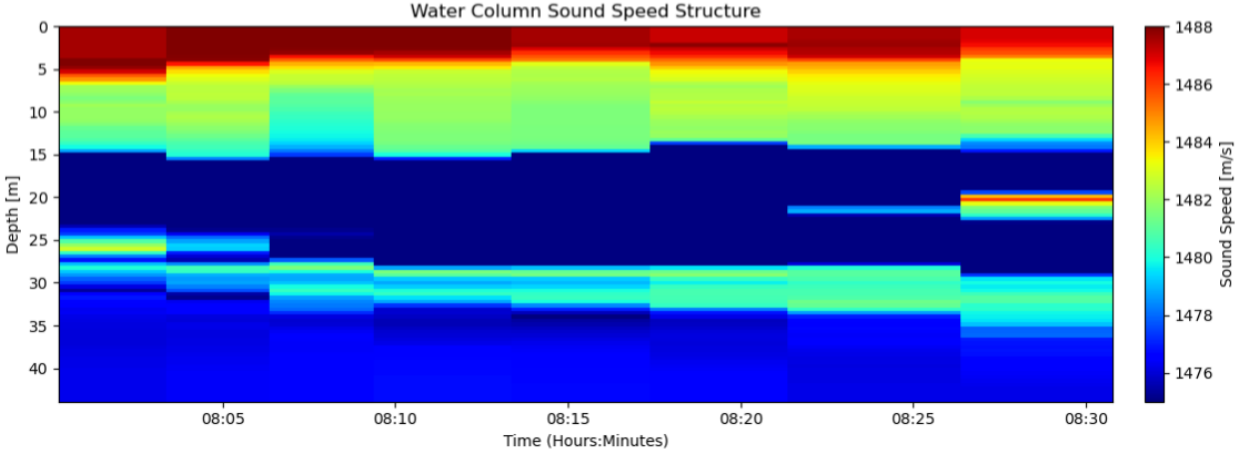
MVP 30 (Probe C) tracking neither





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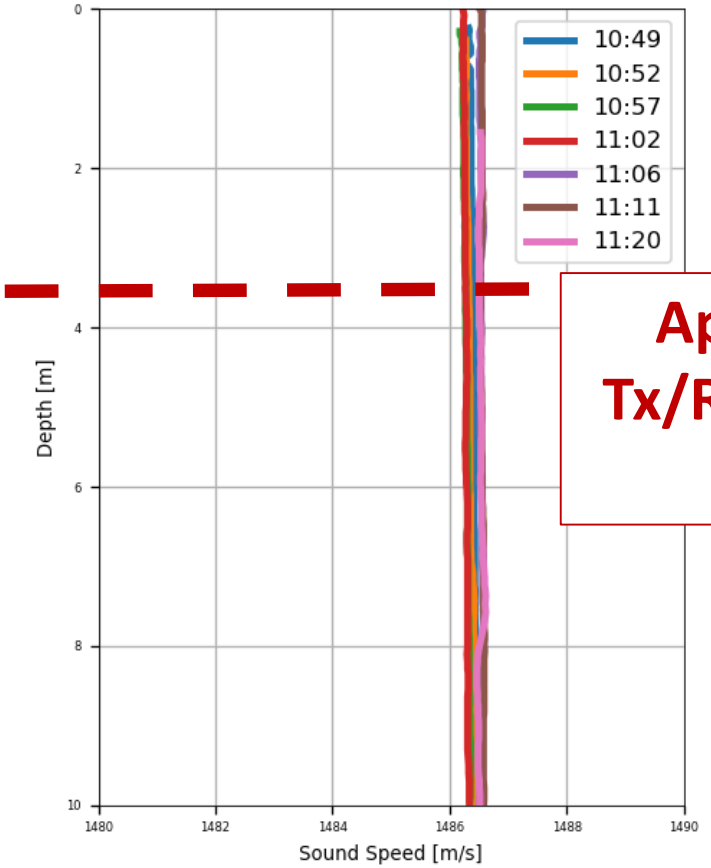
Mismatch

Case of a strong surface sound speed gradient

Surveying in a well mixed upper layer



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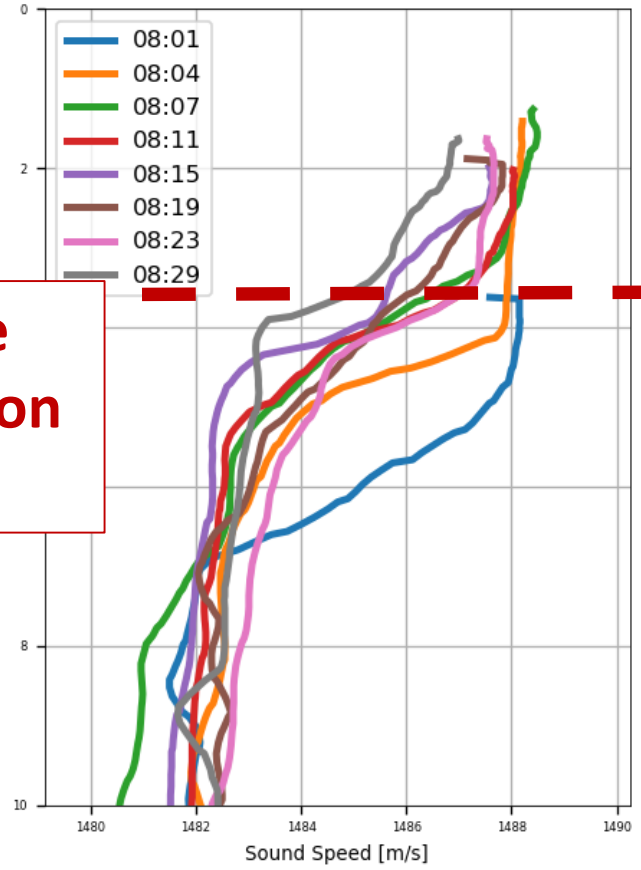
Approximate Tx/Rx immersion depth

Surveying in a strong sound speed gradient



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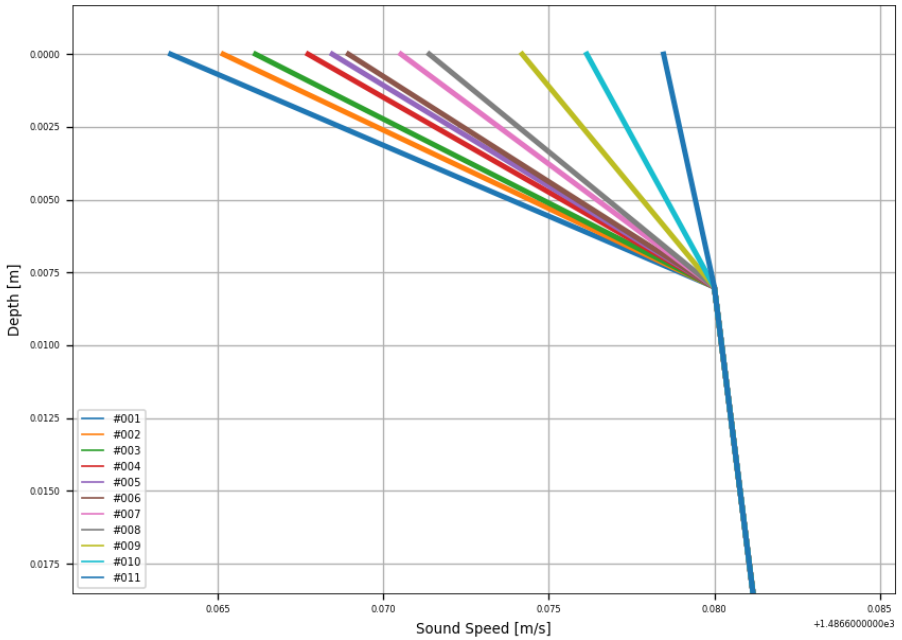
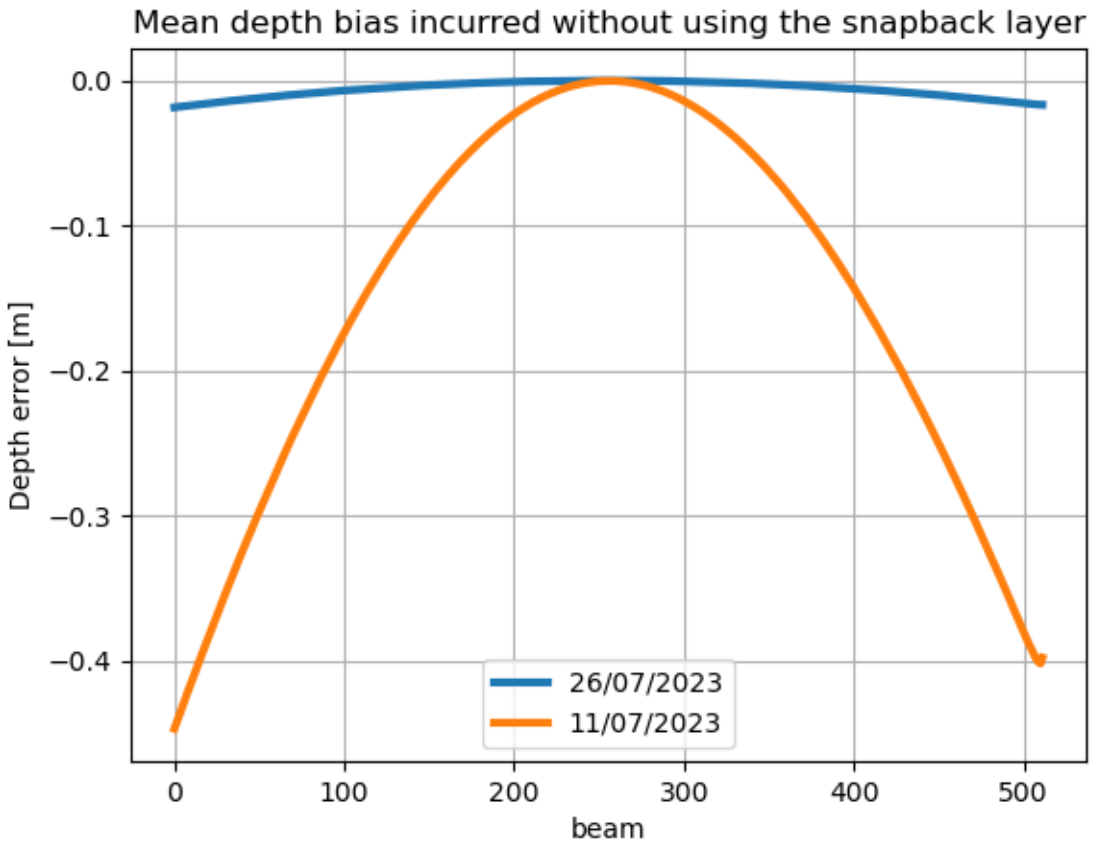
Mismatch

The snapback layer

For each ping, each SSP used in ray-tracing is “snapped back” to the surface sound speed value



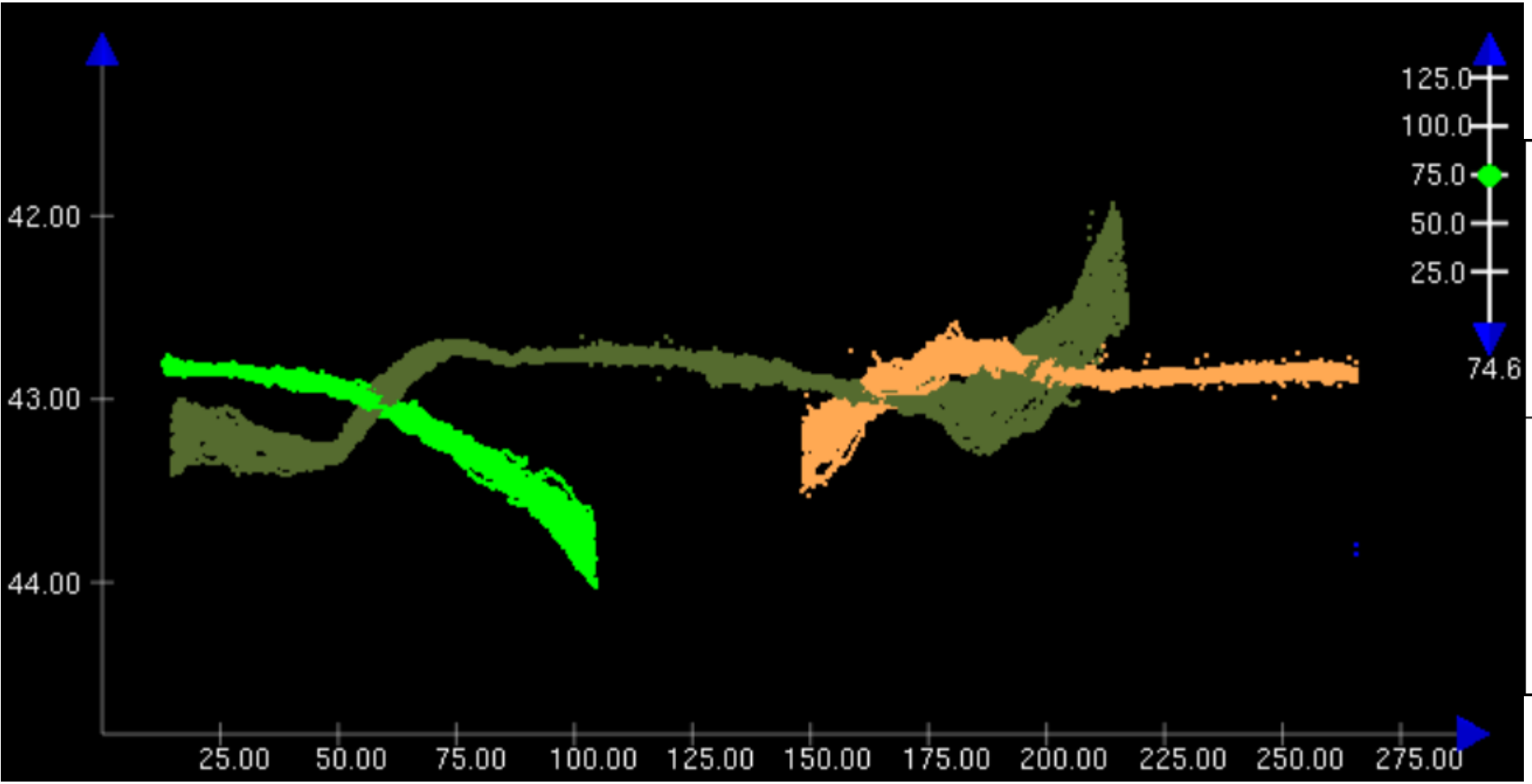


Conclusion

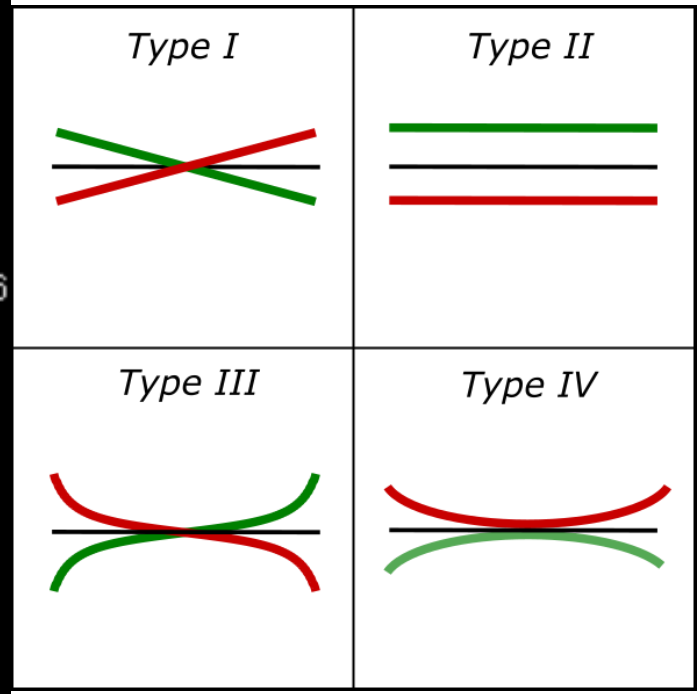
- **Proportionally speaking, if the surface sound speed error is just biased, it will have a lesser impact on the total sound speed error.**
- **Both the surface sound speed error and the sound speed error in the water column can contribute equally to the total sound speed error.**
- **Preserving the transition between surface sound speed and sound speed in the water column is important even under strong mismatch situations.**

Outlook

What type of error is this?

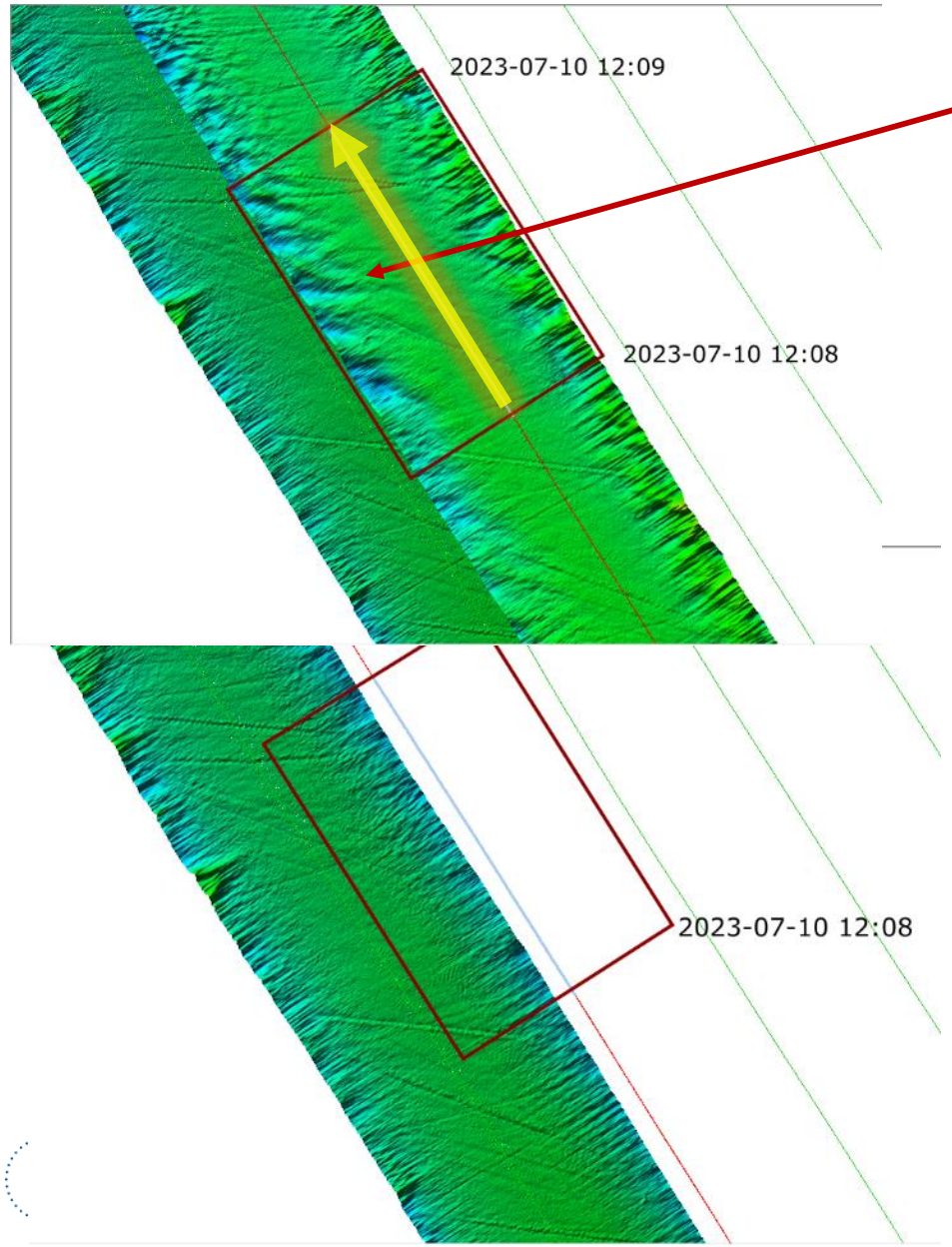


?

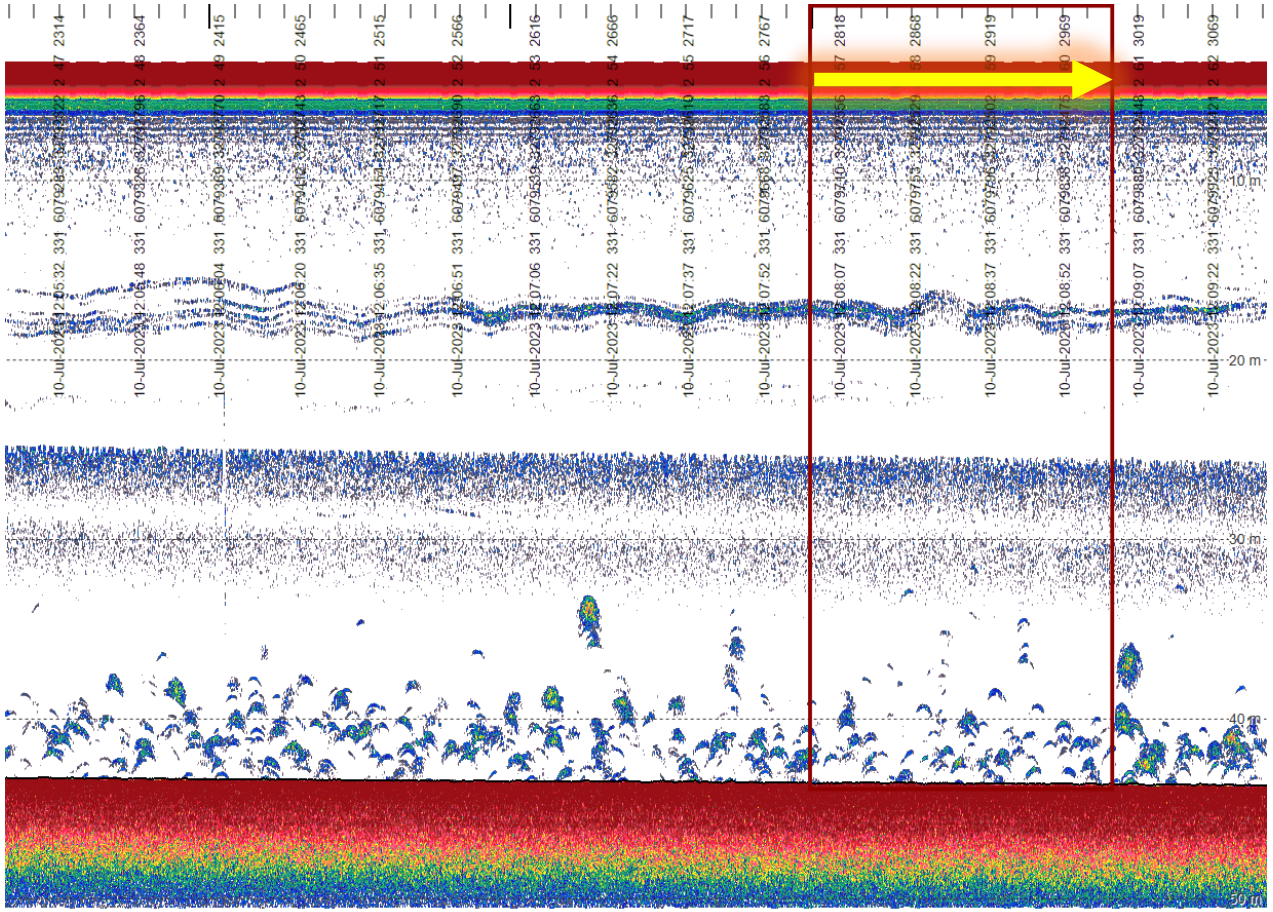


Outlook

False bottom relief imprinted on survey line



Evidence of oscillating thermocline in EA440 singlebeam echogram



Outlook

- **Our simplifying assumptions (e.g. horizontal stratification, 2D raytracing) fail in the presence of complex and short lived oceanographic phenomena (e.g. internal waves), which cannot be sampled by current sound speed instrumentation. BUT, these short lived oceanographic phenomena are observable and should be captured by other means.**

Questions?

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