ISCRA-2025

The positioning system for Baikal-GVD

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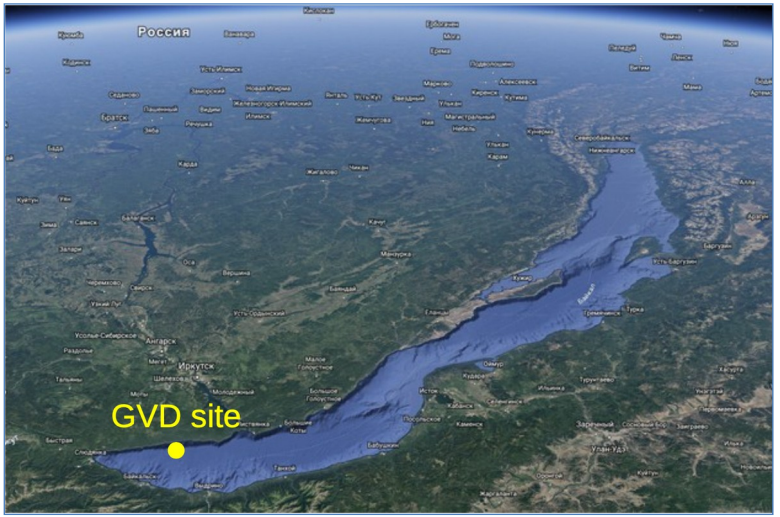
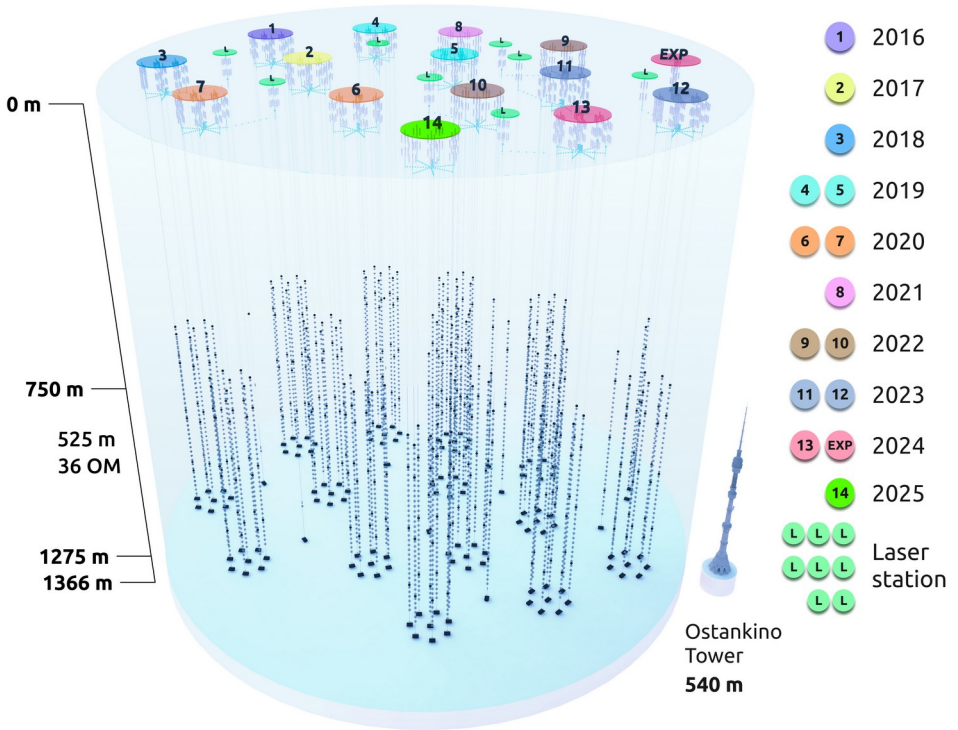
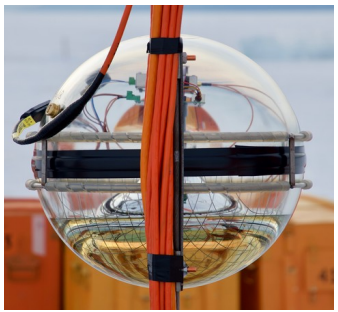
The Baikal-GVD neutrino telescope

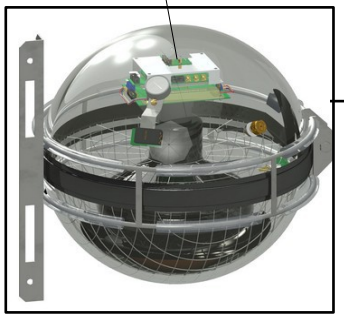


- Currently, the largest NT in Northern Hemisphere
- 15 clusters, 8-9 strings each
- 36 optical modules per string



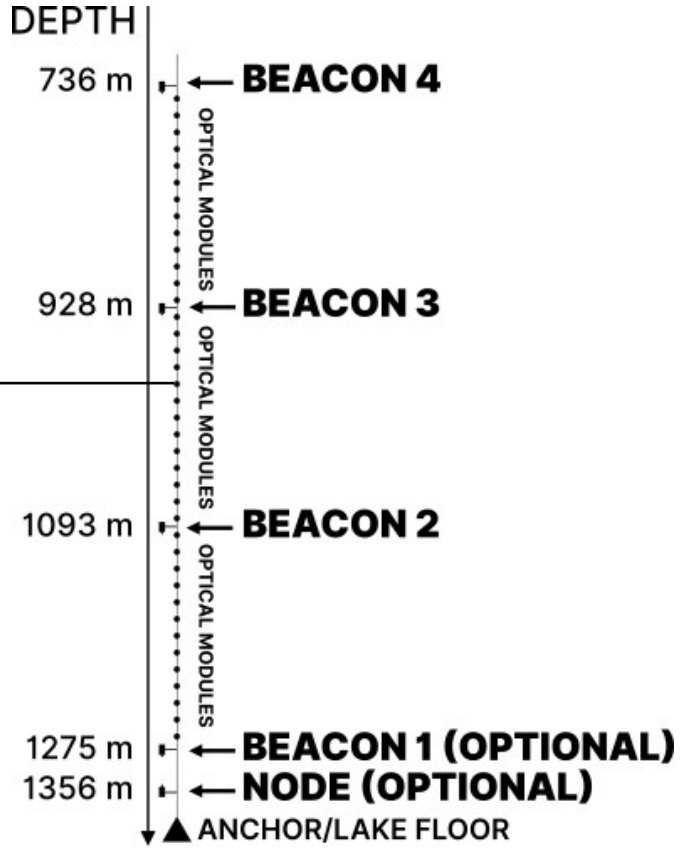
A GVD String

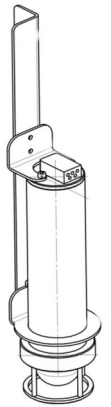




A GVD optical module

- 10 inch Hamamatsu R7081HQE PMT
- 17” (43 cm) VITROVEX glass sphere

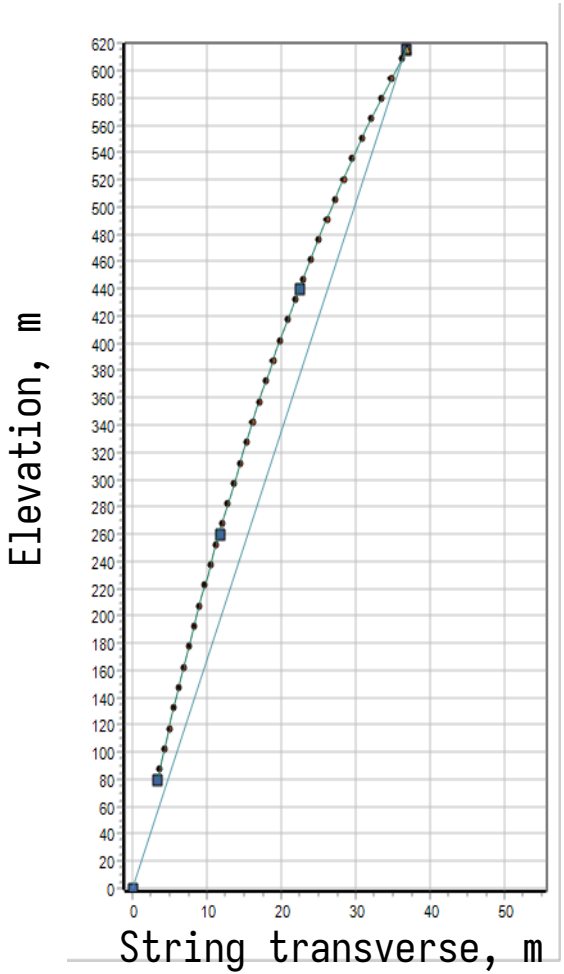


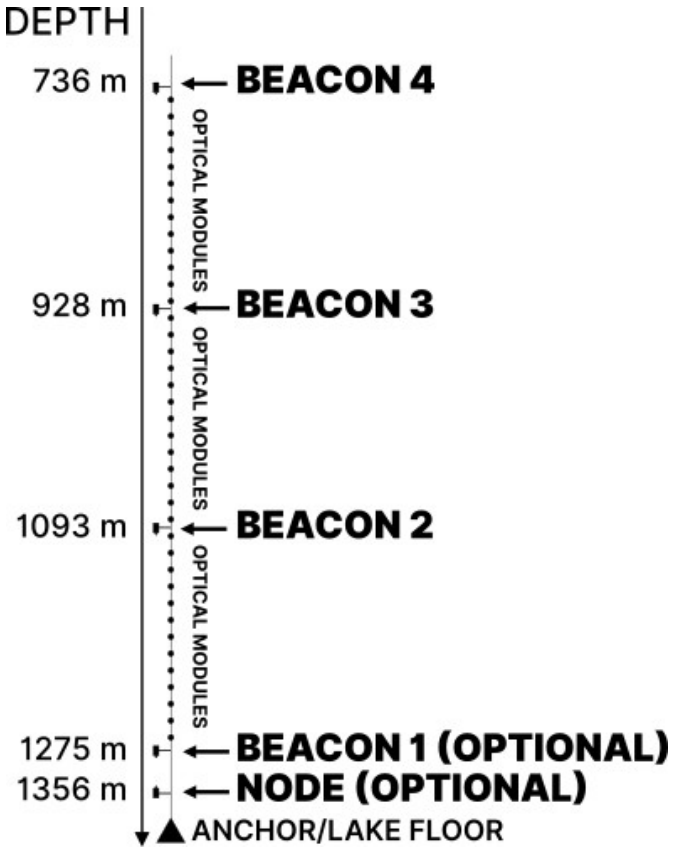


An S2CR 42/65 acoustic modem or a Latena SpiN 57

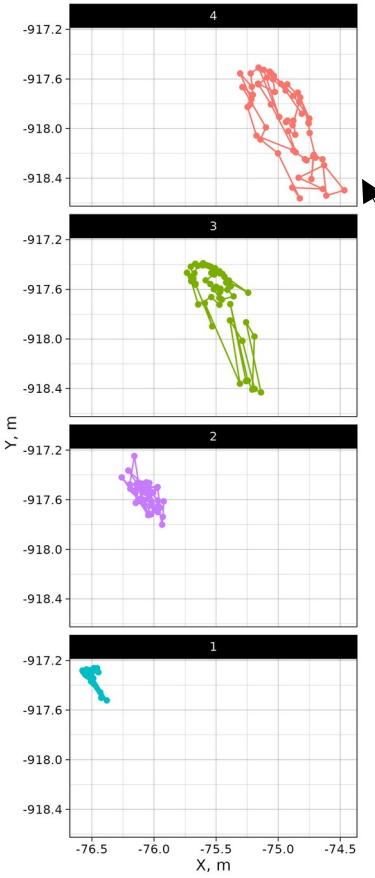
- 2-way acoustic communication
- Whole detector volume is signal transparent
- Can measure acoustic ToF between acoustic modems

A GVD String in real life





Cluster 9 String 8
July 13th-15th 2024



Can drift by 50-70 meters!

The positioning system for GVD (and HUNT!)

1 meter positioning error for an optical module produces a 4.5 ns timing error

Achieving 2ns resolution means positioning optical modules with <40cm precision

Optimal precision: 25 cm (PMT diameter)

Hydroacoustic network (APS)

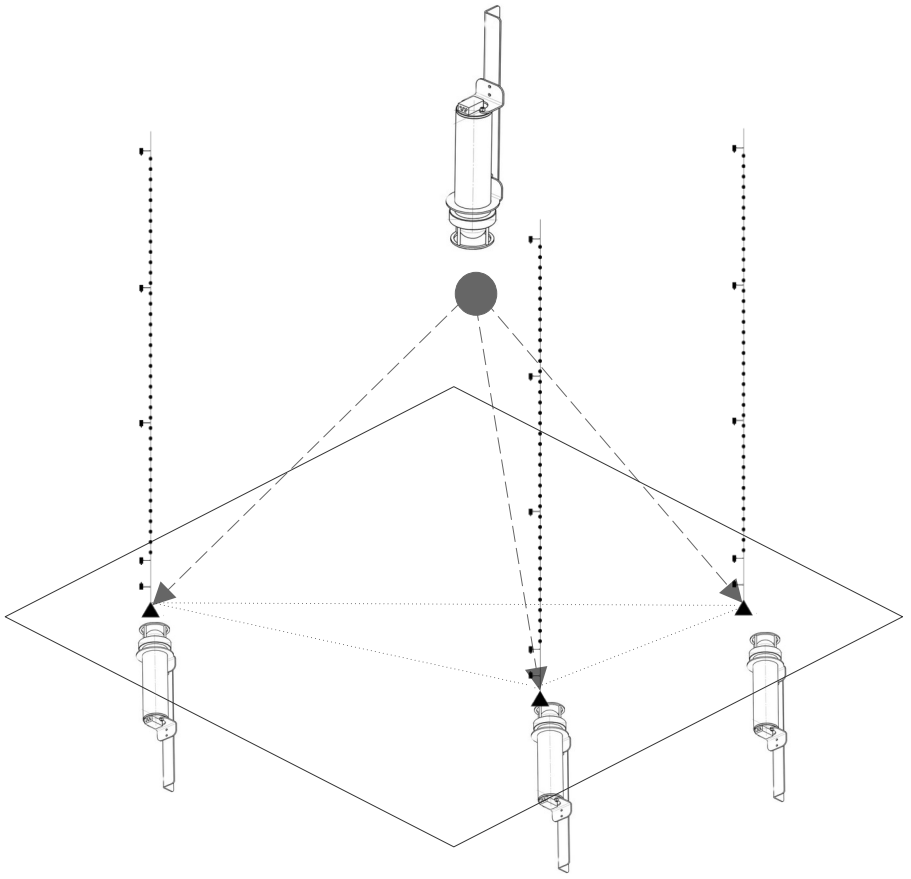
- Very precise (~ 1cm error)
- Uses acoustic modems mounted along the optical modules and at the lakebed
- Currently large interval between measurements (tens of minutes)

Inertial positioning (IPS)

- Less precise (10-20 cm error, up to 1m).
- Uses inertial sensors mounted in optical modules.
- Interval between measurements ~ 2 minutes.

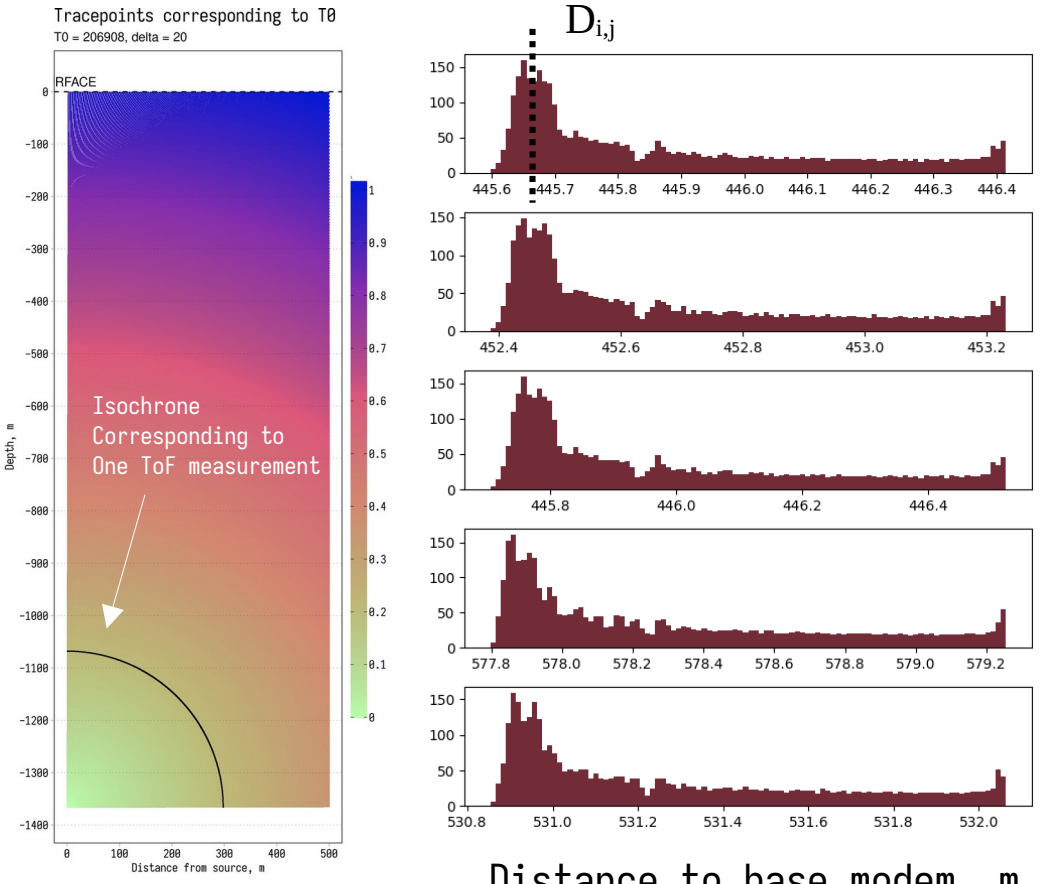
The acoustic positioning system: DAQ

- Precise GPS coordinates for anchor mounted modems are measured annualy during a winter expedition.
- Anchor mounted modems are considred fixed in place and form a **lakebed base antenna**.
- Time-of-flight (ToF) measurements from modems mounted along optical modules to the lakebed antenna are used to reconstruct their coordinates.



The acoustic positioning system: table method

Step 1: convert ToF to average distance to base modems



Step 2: Prefit in spatial domain using average distances

$$RSS_d(\vec{x_i}) = \sqrt{\sum_j (D_{i,j} - \left\|\vec{x_i} - \vec{B_j}\right\|)^2}$$

$\mathbf{B}_i$ – coordinates of i-th base modem

Step 3: Calculate effective speed of sound per ToF measurement

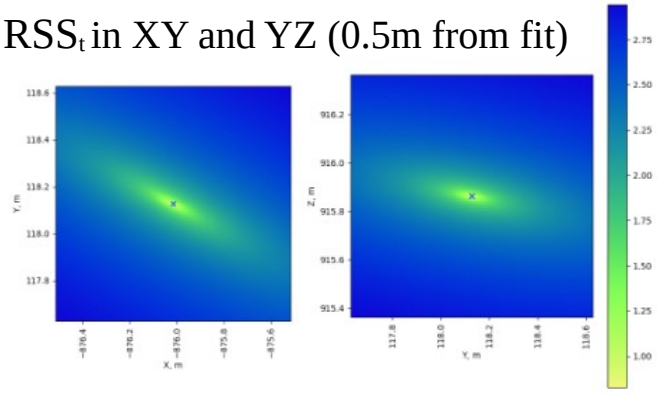
$$c_i = D_{prefit,i}/t_{prefit,i}$$

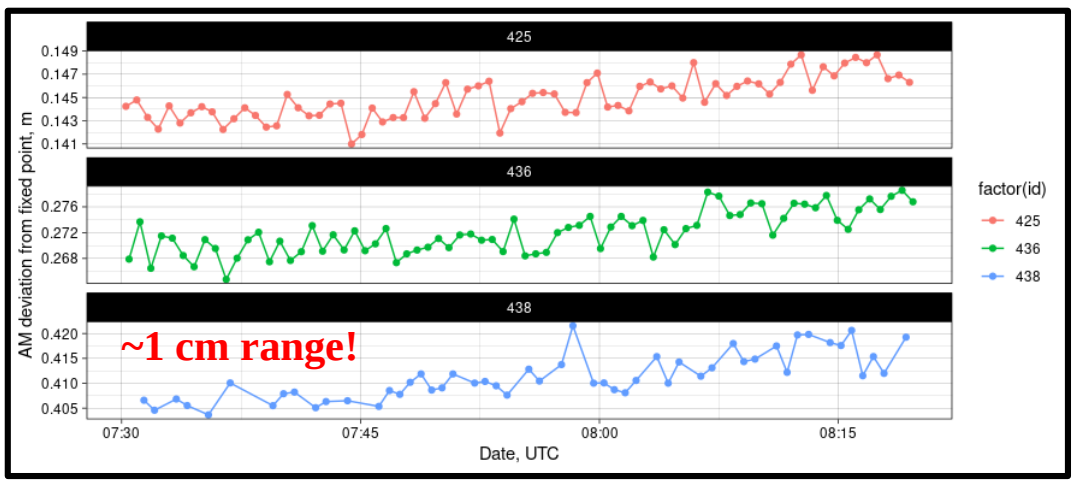
Step 4: Fit in time domain using effective c_i

$$RSS_t(\bar{x}) = \sqrt{\sum(\frac{1}{c_i}||\bar{x} - \bar{B}_i|| - t_i)^2}$$

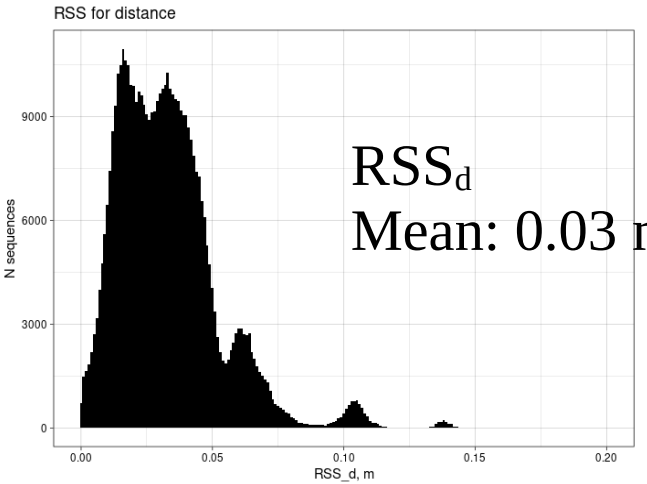
The acoustic positioning system (results)

RSS_t in XY and YZ (0.5m from fit)





Measured on March 27th 2023



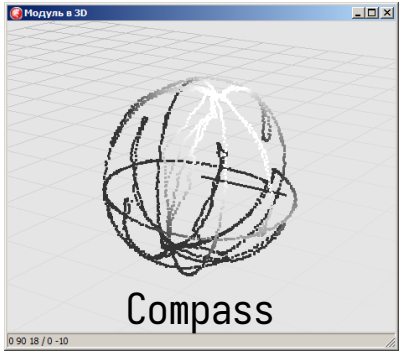
RSS_d
Mean: 0.03 m

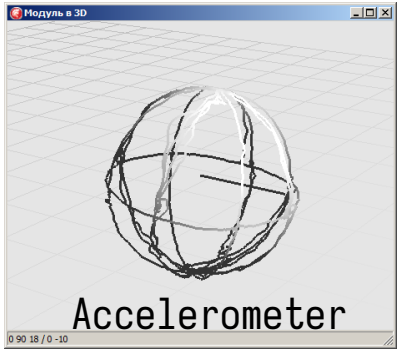
RSS_t
Mean: 2.87 s^{-6}

Season 2024

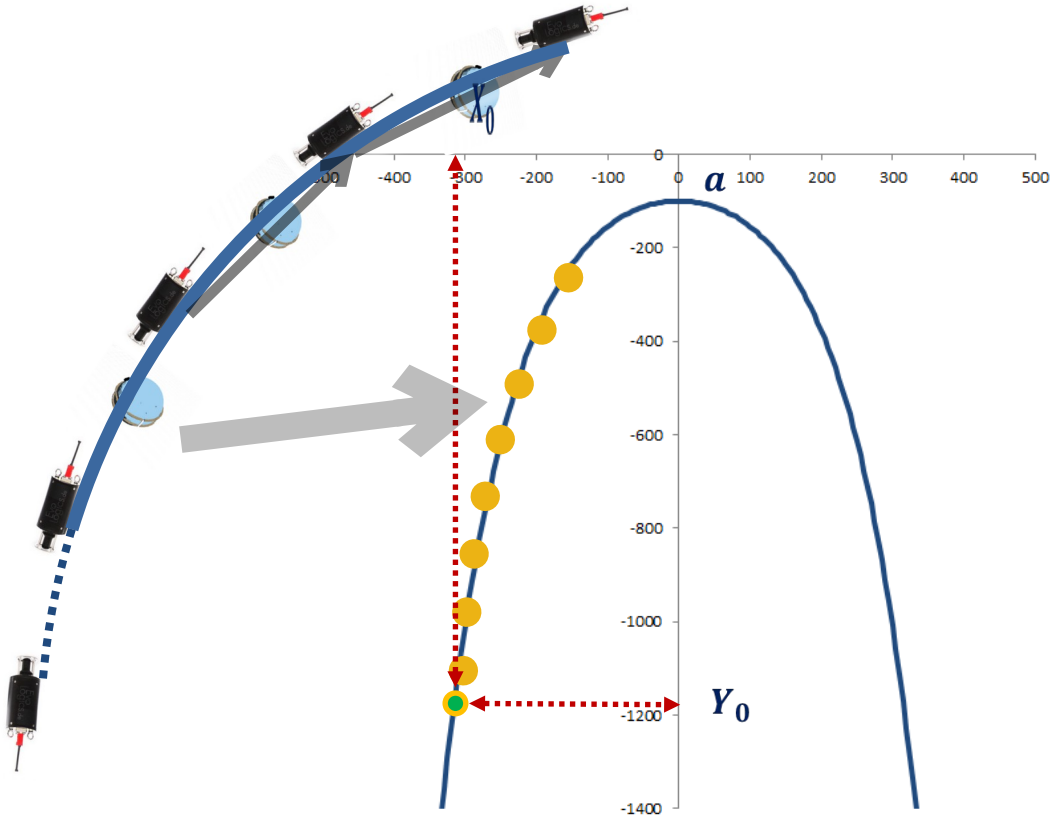
The inertial positioning system

- APS data used to calibrate IPS sensors on optical modules.
- IPS measurements are used to fit OM positions to a catenary.
- Once the catenary is obtained, acoustic modem coordinates can be inferred from the string layout and appended to APS data.



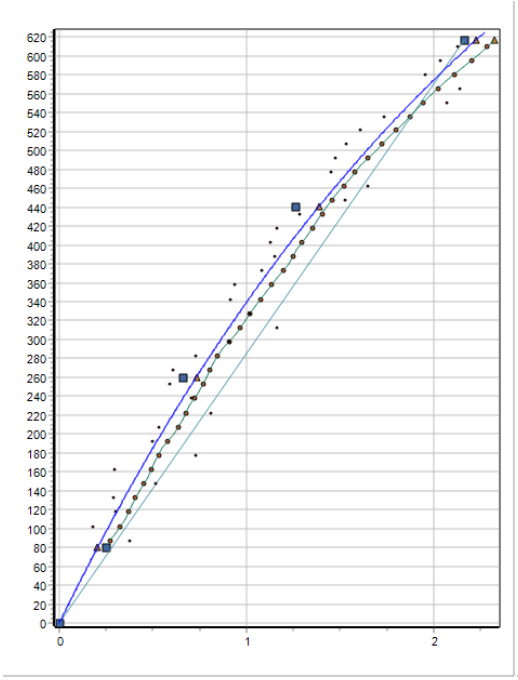


Lab IPS sensor calibration measurements

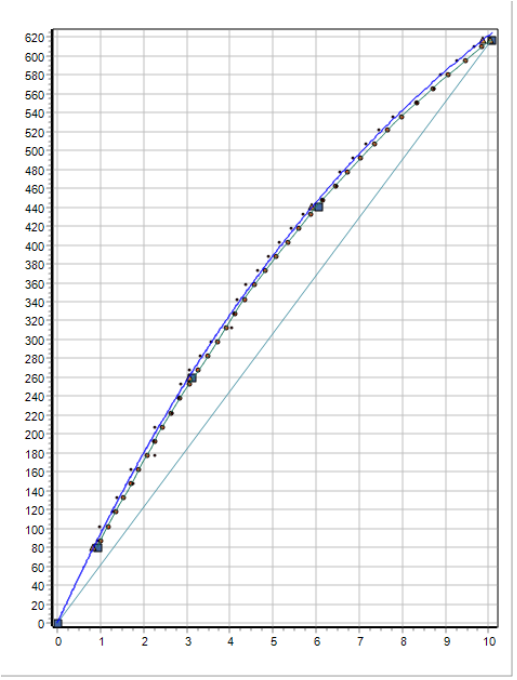


$$y = \frac{a}{2}\left(e^{x/a} + e^{-x/a}\right) = a * ch\left(\frac{x}{a}\right)$$

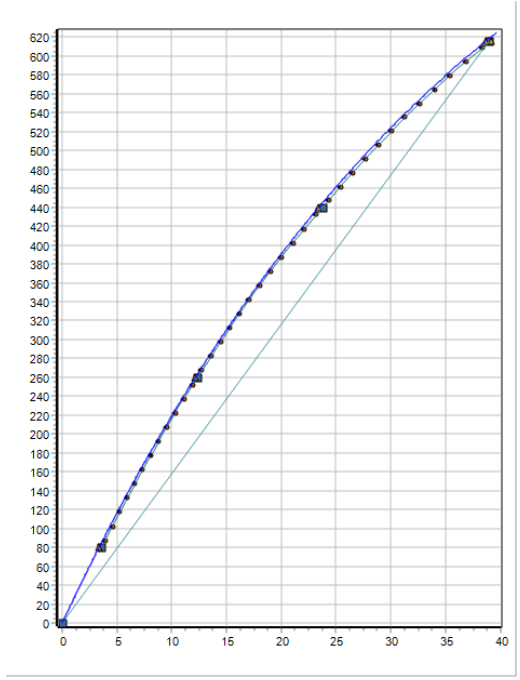
APS vs IPS measurements



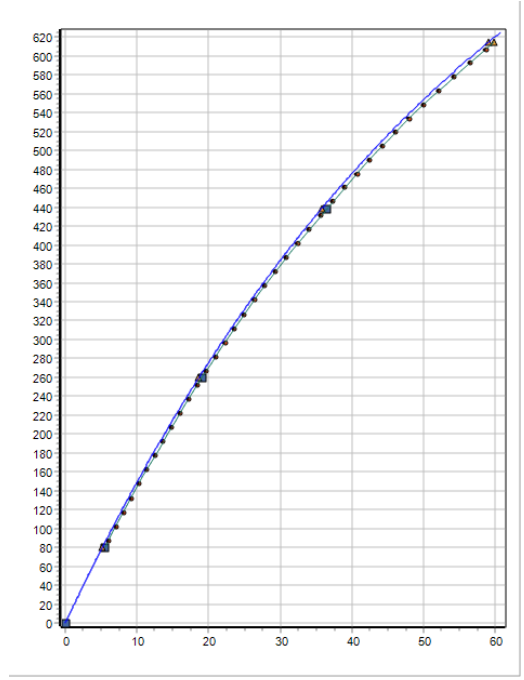
2м



10м

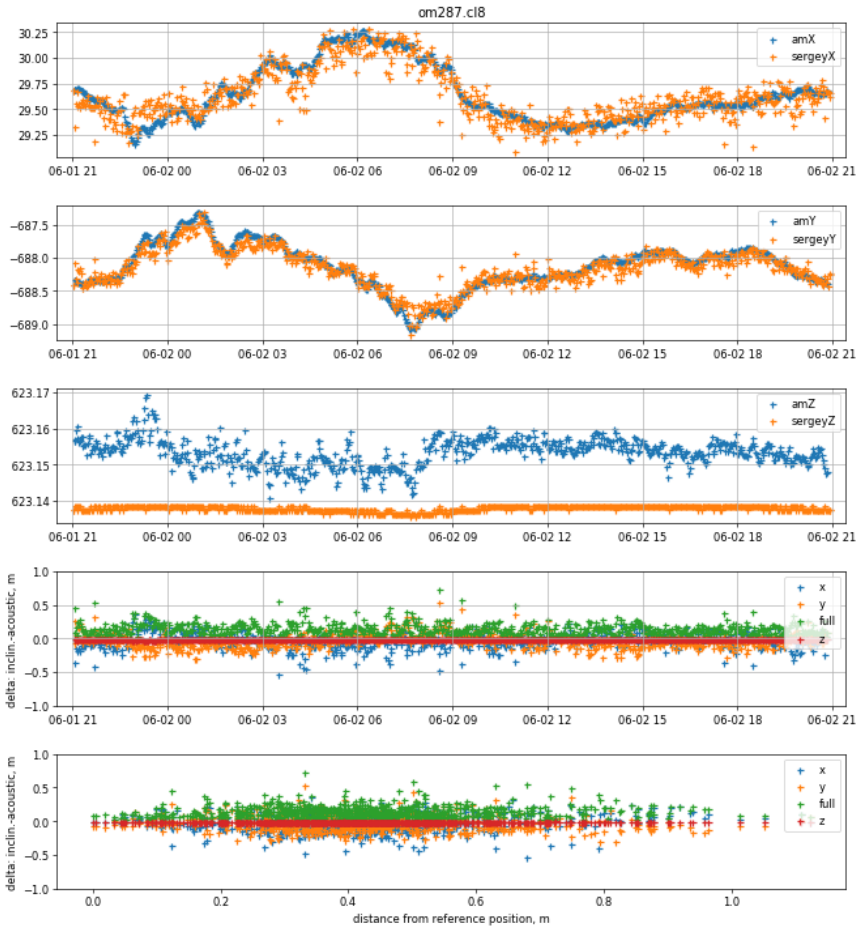


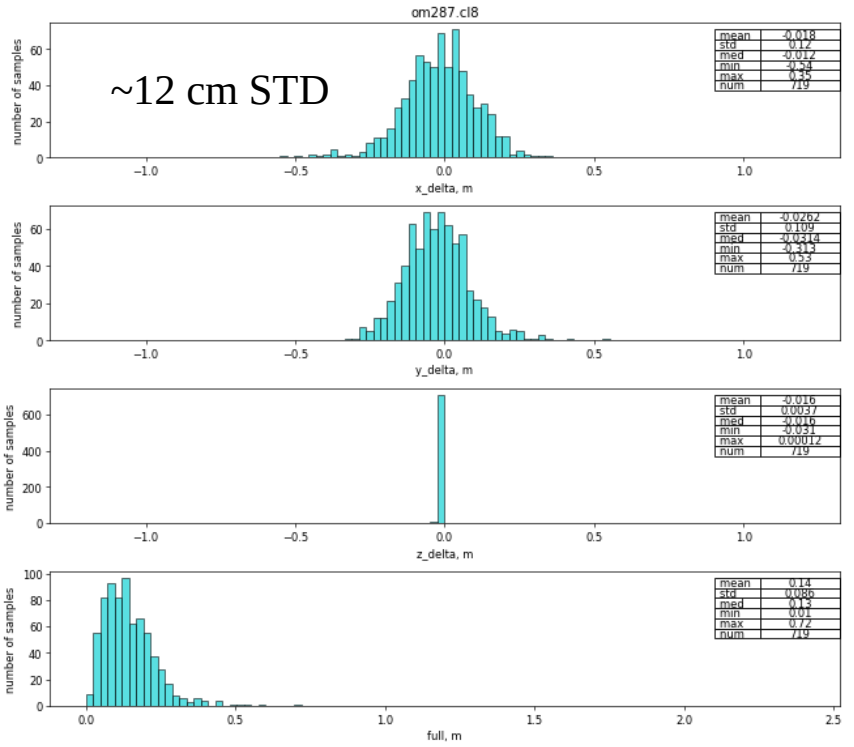
40м



60м

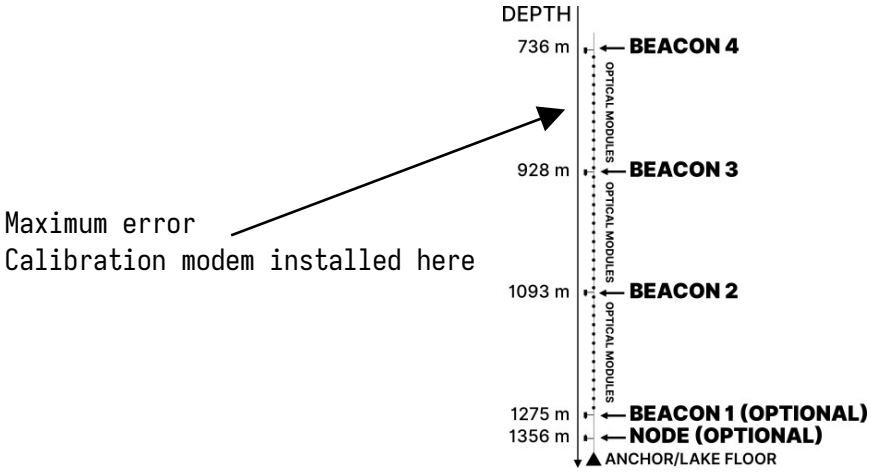
Combining data

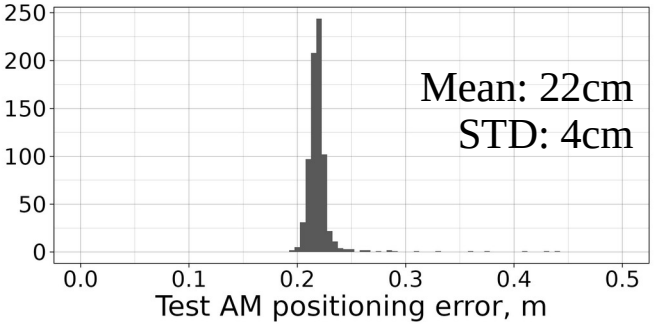




OM positioning precision check

- We interpolate OM positions from modem coordinates assuming piecewise-linear string structure
- In this approach the error is not constant along the string and is maximized in the center of the top section
- We have installed an AM in this position on cluster 3 to compare direct measurements with interpolated expectation



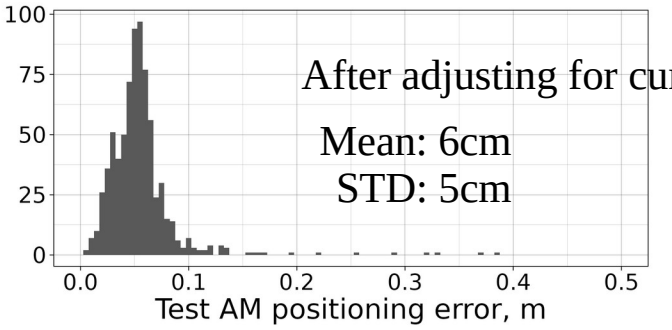


July-October 2024

Conclusion

- A new, hybrid positioning system has been developed for Baikal-GVD: from data acquisition to coordinate reconstruction
- Acoustic positioning system yields a ~1cm precision using a tabulated approach
- IPS system provides a rapid, if less precise, coordinate estimate.
- The final OM positioning error is ~20 cm, comparable to PMT diameter, as expected.

Backup



July-October 2024