Adapting Multi-Frequency Echo-sounders for Operation on Autonomous Vehicles

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***Abstract*— Low-power, internally-recording multi-frequency echo sounders can acquire continuous profiles of echoes throughout the water column over long periods of time, thus providing a low-cost method to study the behavior and abundance of fish and zooplankton in the ocean. Ocean gliders are growing in importance as components of ocean observing systems, extending measurements of physical oceanography beyond those possible with moorings and expensive oceanographic research vessels. Payloads are typically composed of conductivity, temperature and pressure along with optical measures of chlorophyll reflectance and dissolved organics. The small size and low power consumption of such echo sounders now makes it practical to install them in gliders, providing the means to simultaneously measure biological metrics through the water column over extended areas and linking physical properties and primary productivity to higher trophic levels such as zooplankton and fish.**

We have recently installed single-beam echo-sounders with up to four acoustic frequencies in gliders. The echo-sounder (ASL Environmental Sciences' AZFP) was designed as an autonomous, moored instrument, and several modifications, mechanical, electronic and software were required to adapt it to installation and operation in gliders. The existing lower-frequency transducers were too large and heavy for the glider; their size was reduced by increasing the beam-width, and the housings were redesigned to reduce weight and improve their profile to reduce drag. The transducer housings are designed to be mounted at an angle on the vehicle body so that they are aimed vertically down during the dive phase. Several modifications were also made to the electronics chassis and shrouds to reduce weight, and the power connection was altered to operate from the vehicle battery rather than its own dedicated supply. Examples of these design alterations will be discussed. The instrument operating software was modified to allow communication and control from the vehicle, although data storage remained in the AZFP itself. In the initial case, a 200 kHz, single-beam echo-sounder was integrated and calibrated in a Slocum Webb electric ocean glider. Calibration and controlled field tests demonstrated reasonable signal-to-noise ratio, allowing for detection of plankton and fishes to greater than 75m range. The noise background was higher than that found when the AZFP is used as an autonomous unit, so improvements to noise isolation in the glider should be able to improve the signal to noise ratio in future. A data analysis workflow was developed that estimates glider position and orientation underwater to correct for depth and range of targets. Trial missions in the eastern Gulf of Mexico traveled over a submerged pipeline and a rocky reef. Acoustic backscatter signals attributed to mid-water plankton layers were co-located with oceanographic features and peaks in chlorophyll. Schools of pelagic and demersal fishes were detected and mapped over charted seafloor features.

To date, three multiple frequency versions have been built and integrated into Slocum Webb G2 gliders. Several 3-frequency AZFP (38, 70 and 125 kHz) will be used to assess the spatial and temporal distribution of krill biomass in the Antarctic. Several 4-frequency instruments (125, 200, 455 and 769 kHz) have been built to study whales. A glider with a 3-frequency AZFP (38, 125 and 200 kHz) combination was deployed in Terra Nova Bay (western Ross Sea) and mapped the vertical and horizontal distribution and abundance of zooplankton and pelagic silverfish. Future developments will be aimed at adapting the AZFP to other autonomous vehicles and to reducing the effects of the vehicle's internal noise environment. Ultimately, this glider-based acoustic technology will pave the way for cost-effective, automated examination of food webs and ecosystems in regions throughout the global ocean.

I. INTRODUCTION

Low-power, internally-recording multi-frequency echo sounders can acquire continuous profiles of echoes throughout the water column over long periods of time, thus providing a low-cost method to study the behavior and abundance of fish and zooplankton in the ocean. Ocean gliders are growing in importance as components of ocean observing systems, providing high-resolution data that extend measurements of physical oceanography beyond those possible with moorings and expensive oceanographic research vessels. Payloads are typically composed of conductivity, temperature and pressure instruments, along with optical instruments that measure chlorophyll fluorescence and dissolved organics, and dissolved oxygen sensors. The small size and low power consumption of recently engineered echo sounders now make it practical to install them in gliders, providing the means to simultaneously measure biological metrics through the water column over extended areas and linking physical properties and primary productivity to higher trophic levels such as zooplankton and fish. We have recently installed single-beam echo-sounders with up to four acoustic frequencies in gliders. The Acoustic Zooplankton Fish Profiler (AZFP) echo-sounder (ASL Environmental Sciences) was designed as an autonomous, moored instrument, and a number of modifications, mechanical, electronic and software were required to adapt it to installation and operation in gliders.

II. AZFP ECHO SOUNDER

The AZFP was originally designed as an autonomous moored instrument. It contains up to 4 acoustic channels; the available frequencies and their parameters are summarized in Table 1. Each channel is a calibrated single-beam, narrow band sonar. The maximum ping rate is 1 Hz overall, with transmissions being sequential from the highest frequency to the lowest; pinging can be either continuous, or in bursts (see Figure 1). The sampling range, digitization rate and pulse width (up to 1000 µsec maximum) are independently selectable by channel. There are 32 gigabyte of storage available on CompactFlash. The instrument has a wide dynamic range logarithmic receiver with an instantaneous dynamic range of over 80 dB which allows operation without a time-varying gain. For the moored version, the transmitter has a separate regulated battery to maintain a constant source level, and the standard 200 A-Hr receiver battery allows 150 days operation pinging 4 frequencies at 0.5 Hz to 100 m range. The source level and receiver sensitivity are calibrated using a reference hydrophone (± 1dB accuracy) and calibrated source at 1 m range, and then verified with a reference target sphere in a larger tank at 3.5 m range.

III. ADAPTATION TO GLIDERS

To date, versions of the AZFP have only been installed in the Teledyne-Webb Slocum glider, so the adaptations described here are for that case, although they would be largely applicable to other glider platforms. Several modifications, mechanical, electronic and software, were required to adapt the AZFP to operation in the glider. The existing low-frequency transducers were too large and heavy; their size was reduced by increasing the beamwidth; the effect on the AZFP characteristics is summarized in Table II

Table 1 AZFP SPECIFICATIONS

f (kHz)	SL (dB)	Receiver Dynamic Range (dB)	Minimum Detectable Sv @ 50m (dB)	Nominal Full -3dB beamwidth (°)	Maximum Sidelobe (dB)
38	208	90	-101	12	-15
67.5	205	87	-95	10	-15
125	210	89	-98	8	-18
200	210	88	-91	8	-20
455	210	80	-71	7	-20
769	210	80	-48	7	-22
1250	211	80	n/a	7	-16
2000	212	75	n/a	7	-19

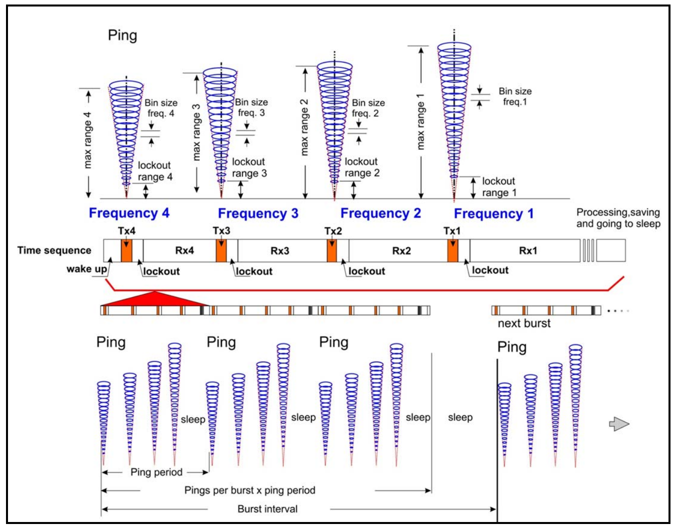

Figure 1 AZFP sampling

TABLE II. AZFP SPECIFICATIONS (GLIDER VERSION)

f (kHz)	SL (dB)	Receiver Dynamic Range (dB)	Minimum Detectable Sv @ 50m (dB)	Nominal Full -3dB beamwidth (°)	Maximum Sidelobe (dB)
38	196	90	-83	27	-20
67.5	201	87	-89	17	-20
125	210	89	-98	8	-18
200	210	88	-91	8	-20
455	210	80	-71	7	-20
769	210	80	-48	7	-22

The housings for all frequencies were redesigned to reduce weight and improve their profile to reduce drag, as they mount on the outside of the glider hull. Figure 2 shows examples of the transducer housings used for the 38, 125 and 200 kHz instrument. The transducer housings are designed to be mounted at an angle (22.5°) on the vehicle hull so that they are aimed vertically down during the dive phase.

Figure 2 38 kHz transducer and 125/200 kHz transducer

The electronics chassis and shrouds were modified to reduce size and weight so that they would fit into the science bay; Figure 3a shows a 200 kHz transducer and electronics package, mounted in the science bay. The electronics package occupies approximately half of the available space.

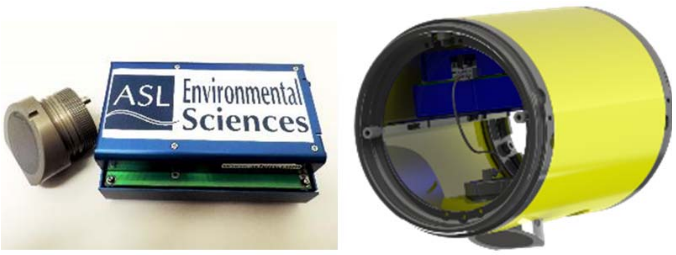

Figure 3a 200 kHz echo-sounder and transducer, mounted in the Slocum science bay.

Figure 3b shows the adaptation for the 4-frequency 125, 200, 455 and 769 kHz. The housing has been enlarged to accept 4 transducer elements. To reduce the possibility of entanglement in fishing line, etc. and improve hydrodynamic performance, we have included a fairing to fit around the housing. Fairings can be machined out of neutrally buoyant plastics or out of syntactic foam to add buoyancy to the glider.

The power connection was altered to operate from the vehicle battery and the instrument serial port was connected to the glider processor for control. The latter required modifications to the instrument's operating firmware. Data storage remained in the AZFP itself.

The firmware for the original autonomous moored instrument was designed for multi-phase deployments allowing for different deployment parameters at different time intervals or phases. The parameters where programed via a PC-based software package over RS232 communications with binary packets imbedding data structures containing the parameters. To simplify the programming of the AZFP for gliders or other third-party equipment, a set of text-based commands were developed. The commands allow the programming and operation of a one phase deployment of the AZFP by sending commands to the AZFP over the serial port. In this mode of operation, the AZFP can be programmed to send out a short status string on every ping to the glider to confirm that data is being collected by the AZFP.

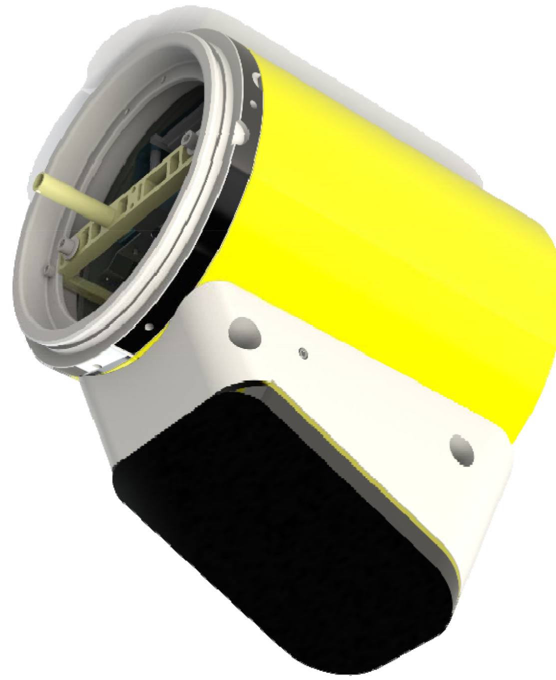

Figure 3b 4-frequency 125, 200, 455 and 769 kHz transducer with fairing

An optional feature was added to allow the glider to enable or disable data acquisition using a Digital Input Output (DIO) line during operation. This option requires the physical connection of a DIO line from the glider to the AZFP. During data acquisition the AZFP conserves power by shutting down powered resources after each ping. An external clock wakes the AZFP from the low power mode every second to continue data acquisition, collect data and then shutdown again. This shutdown conserves power but shuts down RS232 communications to the glider. The DIO feature allows the glider to control data acquisition without having to communicate with the AZFP over the RS232 port. Setting the DIO pauses the AZFP's data acquisition. When the DIO is cleared, data acquisition resumes. This allows the glider to collect data at the appropriate times which is normally when it is diving. When this feature is not used the glider must initiate communications with the AZFP during the periods the AZFP comes out of the low power mode to enable or disable data acquisition.

IV. Example Results

In the initial case, a 200 kHz, single-beam echo-sounder was integrated and calibrated in a Slocum Webb glider. Calibration and controlled field tests demonstrated reasonable signal-to-noise ratio, allowing for detection of plankton and fishes to greater than 75m range. The noise background was higher than that found when the AZFP is used as an autonomous unit, so improvements to noise isolation in the glider should be able to improve the signal to noise ratio in future.

Trial missions in the eastern Gulf of Mexico traveled over a submerged pipeline and a rocky reef (Figure 4). The glider transect was aligned with a natural gas pipeline, with an extension to the continental shelf edge. The AZFP was active during the dive phase, and in sleep mode during ascent (Figure 5). The pulse width was set to 150 μsec to optimize vertical resolution, and the ping rate to 1 Hz. At that rate, the slow speed of the glider ensured multiple pings per target if the targets themselves were not moving too quickly.

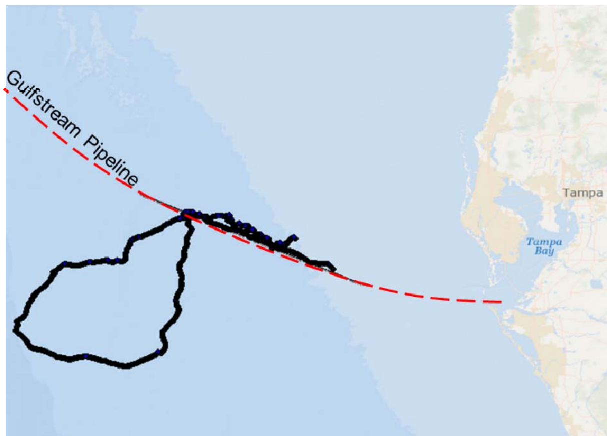

Figure 4 Example glider mission path near Tampa, FL.

The raw echo sounder data were corrected for the glider position and orientation; figure 6 shows an example of raw and depth and orientation-corrected data. Acoustic backscatter signals attributed to mid-water plankton layers were co-located with oceanographic features and peaks in chlorophyll. Schools of pelagic and demersal fishes were detected and mapped over charted seafloor features. Figure 7 shows some examples, and a plot along the track of acoustic volume backscatter, interpreted as relative biomass.

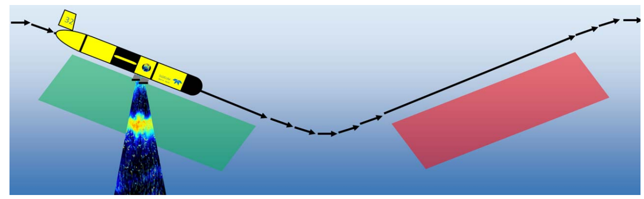

Figure 6 Schematic of glider AZFP operating in situ. Acoustic data are collected only on the downcast where transducer faces vertically down

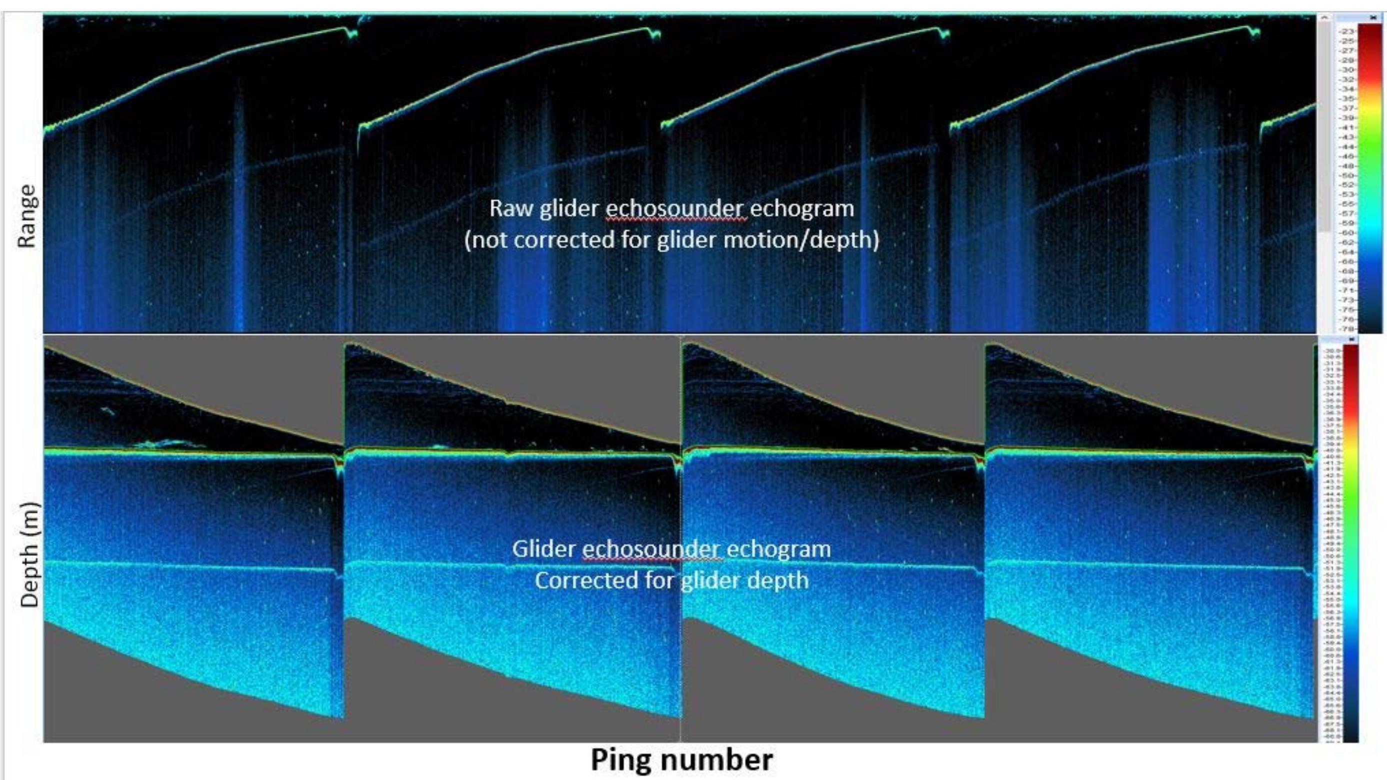

Figure 5 Echo sounder data before and after correction for glider depth and orientation.

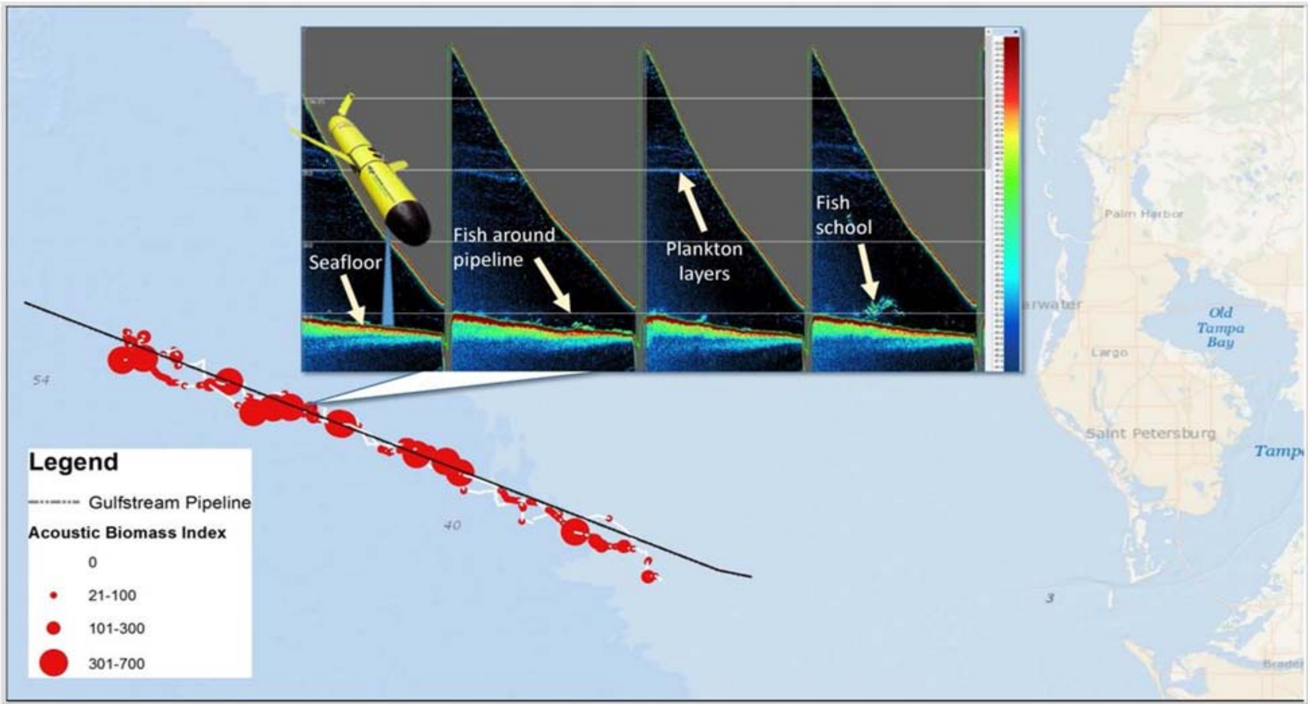

Figure 7 Example echograms form test track, and acoustic volume backscatter interpreted as relative biomass.

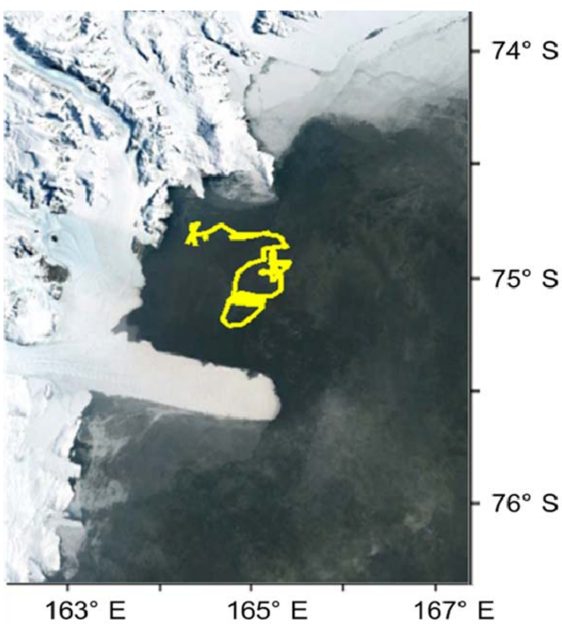

Figure 8 Map of glider AZFP deployment in Terra Nova Bay, Ross Sea. Glider was deployed on Jan. 9, 2018 and recovered Feb. 1, 2018. Net tows and mid-water trawls were conducted in close proximity to the glider and examined for species composition, abundance, and size in order to ground truth glider AZFP data.

Another Slocum glider with a 3-frequency AZFP (38, 125 and 200 kHz) combination was deployed in Terra Nova Bay (western Ross Sea, Antarctica) to map the vertical and horizontal distribution and abundance of zooplankton and pelagic Antarctic Silverfish. The AZFP glider was deployed in the Terra Nova Bay polynya on January 9, 2018 (Fig. 8). During the deployment, net tows (1m ring net) and mid-water trawls with the Isaacs Kidd Midwater Trawl (IKMT) were conducted to ground truth the glider AZFP and ship EK60-based acoustic measurements. The glider was recovered on February 1, 2018 after a 23-day, 366 km mission.

Unfavorable weather conditions at glider deployment prevented an in situ calibration, so a post-deployment calibration was conducted in a seawater tank at the NOAA SWFSC facility that resulted in minimal dB offsets (Figure 9; Table III).

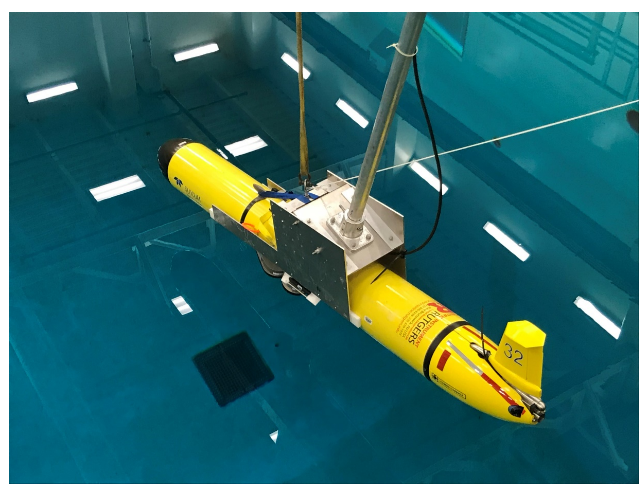

Figure 9. AZFP glider calibration in seawater tank.

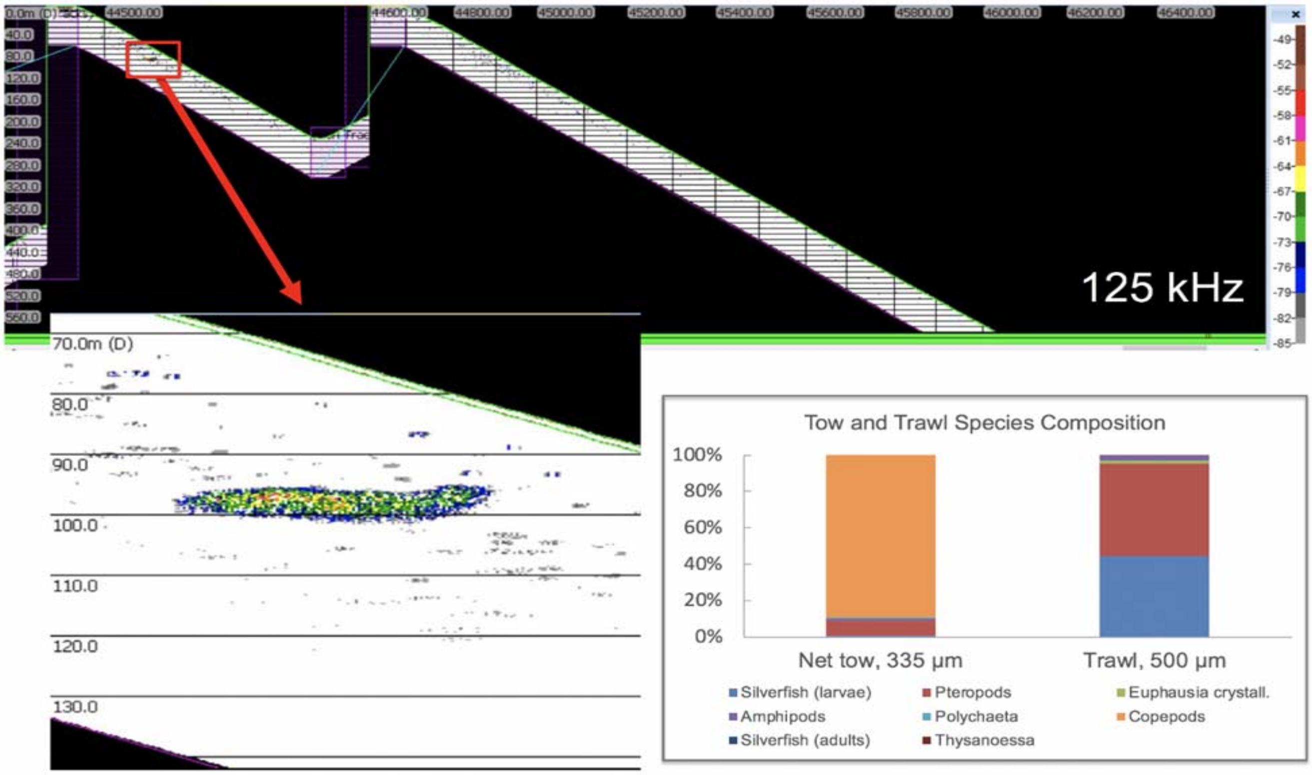

Figure 10. Echogram sample of 125 kHz transducer data from glider AZFP deployment in Terra Nova Bay compared to species composition determined from a simultaneous net tow and trawl.

TABLE III. AZFP calibration parameters and offsets. Sensor was in tank of seawater at a salinity of 33.08, temperature of 20.3°C, and pressure of 0.21 atm

Frequency (kHz)	Sphere type (size)	Depth of sphere (m)	Offset (dB)
38	Tungsten carbide (33.2mm)	4.5	-1.08
125	Tungsten carbide (33.2mm)	8.5	+1.27
200	Tungsten carbide (38.1mm)	4.5	+1.40

One data example (Figure 10) depicts a concentration of organisms at a depth where high abundances of post-larval silverfish, pteropods, and copepods were collected in the targeted tow and trawl. Further acoustic analysis for this deployment is ongoing.

V. CONCLUSIONS

Future developments will be aimed at reducing the effects of the vehicle's internal noise environment, improving the accuracy of the glider's positioning while underwater, and adapting the AZFP to other autonomous vehicles. A further goal will be to develop on-board processing and a set of metrics to decimate the data to the extent that it can be relayed to shore during the glider deployment in real-time, which would then allow the glider's mission to be adapted to examine biological features of interest as they are encountered. Ultimately, this glider-based acoustic technology will pave the way for cost-effective, automated examination of food webs and ecosystems in regions throughout the global ocean.