Insights from Winter 2021-22 using an Acoustic Zooplankton Fish Profiler - *Ice* in the Coastal Waters of the Nunatsiavut Region of Newfoundland and Labrador, Canada

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***Abstract*—Improved understanding of the role of the ocean in moderating climate and sustaining complex food webs is required to support ocean stewardship and ocean protection goals being pursued through Indigenous-led initiatives across Canada's coastlines. The traditional territorial waters of the Nunatsiavut in the Labrador Sea contain a rich and diverse marine ecosystem regulated by a combination of physical oceanography and the presence of seasonal sea ice cover, transported southward by wind and ocean currents. The Nunatsiavut Government operates a growing research program to understand and monitor this complex biophysical system to support effective environmental management. As part of this research program, they are now in the fifth year of monitoring over-winter ocean and sea ice conditions at an offshore site near Nain, Labrador. Measurements made at this site have included water temperature, salinity, dissolved oxygen, turbidity, currents, and ice drafts and velocities. Combining these measurements to understand the ocean's role in moderating climate and complex food webs is an important step in support of Indigenous-led research initiatives and ocean stewardship across Canada's coastlines.**

The Nunatsiavut Government has collaborated with ASL Environmental Sciences to further develop environmental monitoring at this site by supporting the first-ever deployment of the new ASL instrument known as the AZFP-*ice*. The AZFP-*ice* is designed to collect high temporal and spatial resolution measurements of ice draft and simultaneous biological observations from its calibrated (±1 dB) multifrequency acoustical sensors. The AZFP-*ice* is a calibrated, scientific, singlebeam echosounder. The AZFP-*ice* uses a narrow beam 417 kHz center frequency channel to obtain ice keel depth, similar to ASL's Ice Profiling Sonar (IPS). Simultaneous biological observations are realized using three separate channels, collecting calibrated backscatter measurements at 125 kHz, 200 kHz, and 769 kHz center frequencies.

Building on ASL's experience with the Acoustic Zooplankton Fish Profiler (AZFP) sonar system, the AZFP-*ice* is designed to operate autonomously for up to 12 months at a time. The AZFP-*ice* also features an upgraded electronics package that allows up to 1 TB of data to be stored internally. Its endurance and its internal memory capacity allow for excellent temporal coverage and make the instrument well-suited for deployment in challenging environments. The (*ex situ*) factory calibration allows backscatter to be measured on an absolute scale, which facilitates downstream processing such as the so-called 'dB differencing' approach that is common in fisheries acoustics.

This paper introduces the new AZFP-*ice* and showcases its capabilities as a tool for environmental monitoring. An IPS-5 was located near the AZFP-*ice*, allowing for a comparison of the observed ice characteristics. Preliminary analysis of the data collected during an over-winter deployment from 2021 to 2022 indicates that the AZFP-*ice* facilitates sea-ice characterization. Much of the over-winter period is dominated by landfast ice, and segments of ice from break-up to ice clearing are compared from the closely spaced AZFP-*ice* and IPS-5.

During the period of landfast ice, the ice dynamics are simple as the ice responds to the thermodynamic forcing. Daylight hours are greatly reduced in the winter, but this environment does not experience 24-hour darkness, unlike high-latitude environments. While the ice may be motionless, the other AZFP-*ice* frequencies indicate that below the ice activity continues during this period of reduced daylight. In this paper, the AZFP-*ice*'s acoustical observations of the under-ice biology are presented and discussed as we review examples from this deployment. The AZFP-*ice* is shown to provide a unique combination of measurements in a single instrument, offering researchers a physical context (i.e. ice thickness) alongside biological data.

***Index Terms*—sonar, underwater acoustics, instrumentation, ice characteristics, plankton**

I. Introduction

ASL Environmental Sciences has developed a new product, the AZFP-*ice*, to assist researchers in answering complicated questions about dynamic marine environments. While a particular study may focus on the behavior and abundance of select organisms, there is most often a larger context that drives this behavior and abundance. For researchers studying fish and zooplankton in the Arctic, ice characteristics are an important part of this larger context. Recognizing the growing need

Fig. 1. Location of study site on the map, and chart image showing closer detail. A Log Ice Profiling Sonar (LogIPS), along with additional sensors, was deployed in the area of the Metocean Mooring (red dot within insert). The AZFP-*ice* mooring was approximately 500 m east of the Metocean Mooring.

for such abiotic data alongside biotic data, ASL introduces the AZFP-*ice*, designed to collect high temporal and spatial resolution measurements of ice draft and simultaneous biological observations from its calibrated (± 1 dB) multifrequency acoustical sensors.

The Nunatsiavut Government operates a growing research program that is aimed at improving the understanding and the stewardship of their traditional territorial waters. As part of this effort, the Nunatsiavut Government collaborated with ASL to deploy multiple instruments and test a prototype AZFP-*ice* in an offshore site (shown in Fig. 1) near Nain, Labrador. This site contains a rich and diverse marine ecosystem regulated by a combination of physical oceanography and the presence of seasonal sea ice cover, transported southward by wind and ocean currents. A Log Ice Profiling Sonar (LogIPS) was deployed on a multi-sensor metocean mooring near the prototype instrument mooring. The LogIPS is similar to the traditional IPS, but uses a logarithmic amplifier. The LogIPS has been deployed alongside the IPS5 multiple times including the Beaufort Sea [5] and this site off Nain [6] and [7]. Approximately 500 m east of the LogIPS mooring was a separate mooring that contained the AZFP-*ice*.

Following this Introduction, Section II introduces the AZFP-*ice* that was used in the study. Section III details the case study, beginning with a validation of the ice profiling capabilities of the instrument (Section III-B). In Section III-C, data are presented that showcase the biological observations made by this instrument during its lengthy deployment under-ice. A discussion of the data is presented in Section IV and conclusions are presented in Section V.

II. The AZFP-*ice* Instrument

The AZFP-*ice* is a further development of the traditional AZFP that also incorporates ASL's IPS ice profiling capabilities. The main features that differentiate this instrument from its AZFP and IPS predecessors are:

- Ice profiling capability in an AZFP, building upon ASL's industry standard IPS technology.
- Increased memory capacity, allowing researchers to ping faster and collect more time series data.
- Faster interrupt response time, making it easier to wake the device from sleep or to change parameters on the fly.

Much like a traditional AZFP, the AZFP-*ice* features up to four channels and is factory calibrated using ASL's standard two-step process, described in [1]. Calibration of the ice profiling channel is optional but atypical, and it was not performed for the current deployment. Ice profiling is typically performed at a center frequency of 417 kHz, as is the case with the AZFP-*ice*.

The AZFP-*ice* is designed to provide ice information for the non ice-expert. In the deployment of this prototype, a standard strain gauge featuring 0.1% full scale accuracy was used. The IPS5, on the other hand, uses a Paroscientific pressure sensor which has an accuracy of 0.01% of full scale and is stable to 7 ppm/year. This corresponds with an accuracy drift only 0.001 dBar/year for an IPS outfitted with a standard pressure sensor. Further details of the ice profiling capabilities of the instrument are provided in Section III-B.

The AZFP-*ice* features greatly expanded memory storage compared to its predecessor. The instrument supports two SD cards, allowing for a combined storage capacity up to approximately 1 TB. This greatly increased storage capacity provides flexibility to researchers seeking to balance power and memory budgets for a multi-month study.

III. Case Study: AZFP-*ice* Deployment near Nain, Labrador

A number of factors were considered when selecting the study location. The waterways in Nain Bay and Strathcona Run, north of Paul Island, are of great interest to the community of Nain. There is an area of open water in the coastal sea ice that is caused by high currents and wind. These open-water features, commonly referred to as polynya, are known locally as 'rattles'. A rattle of particular local interest was selected. This rattle is depicted in Fig. 1, north of Paul Island. The pair of moorings (the Metocean mooring and the AZFP-*ice* mooring) were located approximately 17 km east of the rattle. Both moorings were deployed in approximately 87 m water depth, and both instruments were located at a depth of approximately 35 m. The AZFP-*ice* mooring prior to deployment is shown in Fig. 2. The moorings were deployed in October 2021 and were recovered in July 2022. The AZFP-*ice* collected data for approximately 250 days.

A. Deployment Configuration

The moorings were deployed 24 October 2021 and were recovered on 1 July 2022. The ice is landfast through part of the season, and during other parts of the season can reach speeds in excess of 50 cm/s. As the one-way -3 dB beam width of the 417 kHz transducer is 1.8°, the ensonified footprint has a diameter of 1 m at 35 m depth. In order to sample all of the overhead ice when it moves at its highest speed, ping repetition periods of at least 2 s are required. Even though the AZFP-*ice* comes from a long line of lower power upward looking

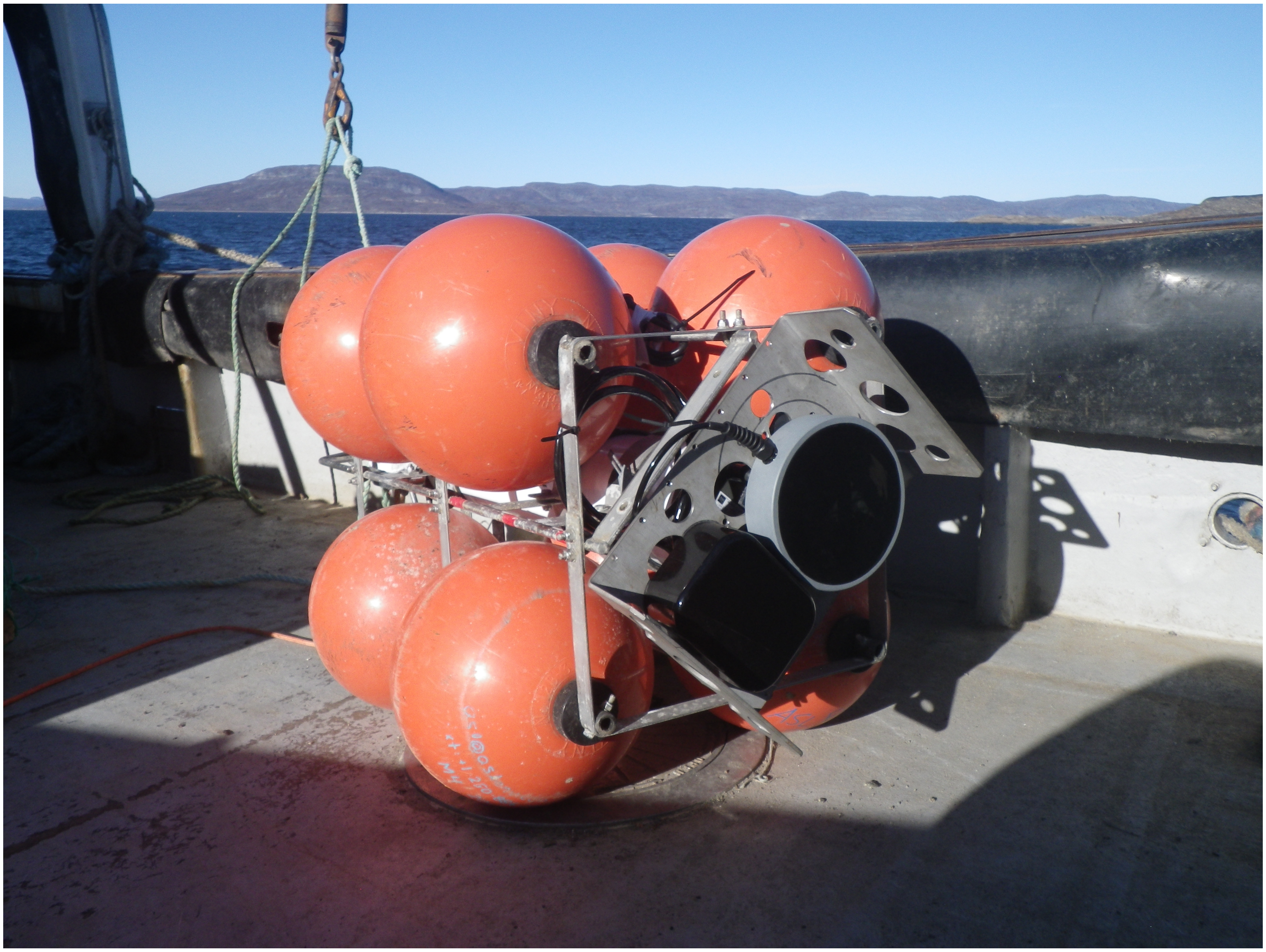

Fig. 2. AZFP-*ice* mooring immediately before deployment. A standard pressure housing was mounted inside the dual cage mooring frame. Two transducer housings are visible, a rectangular black housing (containing the 125 kHz, 200 kHz, and 769 kHz elements) and a large circular housing that contains the narrow beam 417 kHz ice profiling element.

sonars, it is not possible to sample all of the transducers at this high rate.

Over the course of the deployment, the instrument collected a total of 247 GB of data. This represents nearly ten times the storage capacity of previous-generation instruments. The expanded memory capacity of the AZFP-*ice* allowed for significantly more data collection, translating into higher temporal resolution for the time series.

During the deployment, the instrument was configured to continuously profile the ice cover and also to periodically collect data focused on the under-ice biology. The AZFP-*ice* may be programmed in a number of 'phases' such that it exhibits different behavior at different times. In this case the instrument was programmed with two data collection phases (Table I). The first phase enabled only the 417 kHz channel, used a ping repetition rate of 1 s (i.e. ping every second), and lasted for 17 minutes. The second phase enabled all channels, used a ping repetition rate of 1 s, and lasted for 3 minutes. Following the end of the second phase, the instrument would repeat this two-phase sequence until recovery, approximately 250 days after deployment.

Table I shows that many of the features of the LogIPS have been retained in the AZFP-*ice*, including the narrow beam-width and the short pulse length. Whereas the narrow beam-width comes through the transducer design and ensures that the recorded returns are from a narrow cone in space, the pulse length is a user selectable parameter set during the programming. Though not tabulated here, the user can also select the digitization rate. The 417 kHz transducer was sampled at 64 kS/s, the same as happens in an IPS, whereas the other frequencies were sampled at 40 kS/s. The 64 kS/s sample rate yields a vertical resolution of about 1 cm in the acoustic profiles.

B. Comparison: AZFP-ice and LogIPS

Ice drafts were calculated for the Log IPS and for the AZFP-*ice*. There was one major distinction in how this calculation

TABLE I

PARAMETERS FOR EACH PHASE, WITH A PING PERIOD OF ONE SECOND FOR PHASES 1 AND 2. THE SENSOR SAMPLE RATE IS DIFFERENT FROM THE PING RATE AND REFERS TO THE SAMPLING OF TILT, TEMPERATURE AND PRESSURE.

Phase	Freq-uencies (kHz)	Pulse Length (μs)	Beam Width (Degrees)	Sensor Sample Rate (s)	Phase Duration (min)
1	417	68	1.8	10	17
2	769	500	7	10	3
	417	68	1.8		
	200	500	8		
	125	500	8		
3 Repeat					

was done. Traditionally, the IPS has done all of the target detection of ice on-board in real-time and saves the resulting range. In the IPS5 and LogIPS, up to 5 target candidates could be stored per ping. For select pings, the profiles from which the targets were identified could be stored. Readers wishing to learn more about the on-board target detection methods employed by the LogIPS are referred to [8].

In the AZFP-*ice*, the expanded memory allows the profiles for all of the pings across all of the transducers to be stored. Storage of the ping profiles allows the target detection to be done in post processing. A benefit of moving the ice detection to post processing is that the requirement to commit to detection thresholds before deployment is obviated. The output of this step is the equivalent to the range data of the Ice Profiling Sonar.

Pressure, range, instrument tilt and atmospheric pressure are required in order to calculate ice draft. Atmospheric pressure data from the Environment Canada meteorological station at the Nain Airport were used in this calculation. Readers wanting to learn more about this calculation are referred to [2], [3], and [4]. Following the calculation of draft for each instrument, histograms of all the ice drafts were created. Fig. 3 illustrates the two distributions: AZFP-*ice* in blue and LogIPS in red. Note that we have made no effort to eliminate waves in making this comparison, thus negative drafts are included in the distributions. These distributions for the entire season show consistency that is reasonably expected for two instruments, using different pressure sensors, and located 500 m apart.

Before proceeding to the profile data and the insights they can give into biology and the interactions between the biology and the ice, we leave the reader with an example in Fig. 4 of one of the larger ice keels observed during the 2021-22 field season at this site.

C. Under-ice Observations

In this Section, data are presented that were collected during Phase 2 of the instrument's phase cycle. The second phase enabled all channels, used a ping repetition rate of 1 s, and lasted for 3 minutes. This phase reoccurred every 20 minutes throughout the deployment.

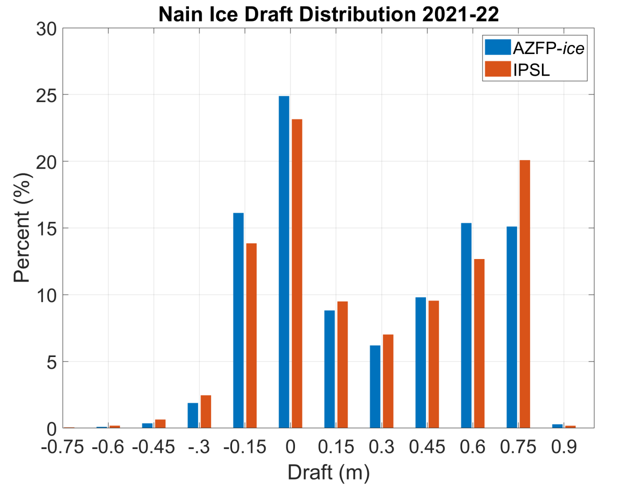

Fig. 3. Empirical histogram of ice draft for the AZFP-*ice* (blue) and the LogIPS (red). All targets (including open water and waves) were binned into 15 cm bins. The vertical axis shows the percentage of all targets that fall into each bin.

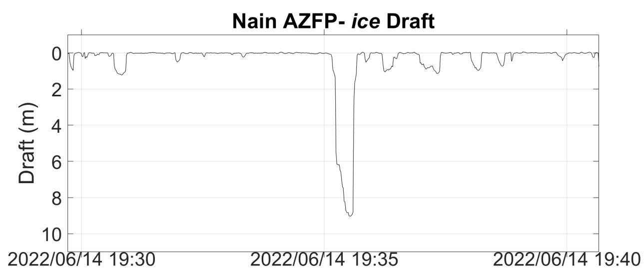

Fig. 4. One of the largest keels as observed by the AZFP-*ice*

Figure 5 shows 1 week of data, collected between March 14 and March 21, 2022. The figure contains five subplots, the top four subplots corresponding to volume backscatter data (Sv) at each of the four instrument channels, and the lowest subplot corresponding to solar elevation angle [11] shown by the red curve. On the solar elevation angle subplot, the transition between civil twilight [12] and night is shown by the dashed line at a solar elevation angle of -6 degrees. The top subplot shows the Sv data collected at 125 kHz, the second plot presents the 200 kHz data, and the third and fourth plots present the 417 kHz and 769 kHz data, respectively. Figs. 5-8 follow this same subplot arrangement.

In Fig. 5 a diel vertical migration signal (DVM) is evident at 125 kHz and 200 kHz. The 417 kHz channel was primarily used for ice profiling, and the 769 kHz channel is heavily influenced by seawater absorption that limits its effective range with weak scatterers. All channels observe the surface at a range of approximately 35 m. The DVM signal appears strongest on March 16 and 17, and appears to grow weaker on March 18 and 19. The migrating organisms are presumed to dive below the depth of the instrument during daylight hours, explaining the absence of these targets during the day and sudden reappearance at night.

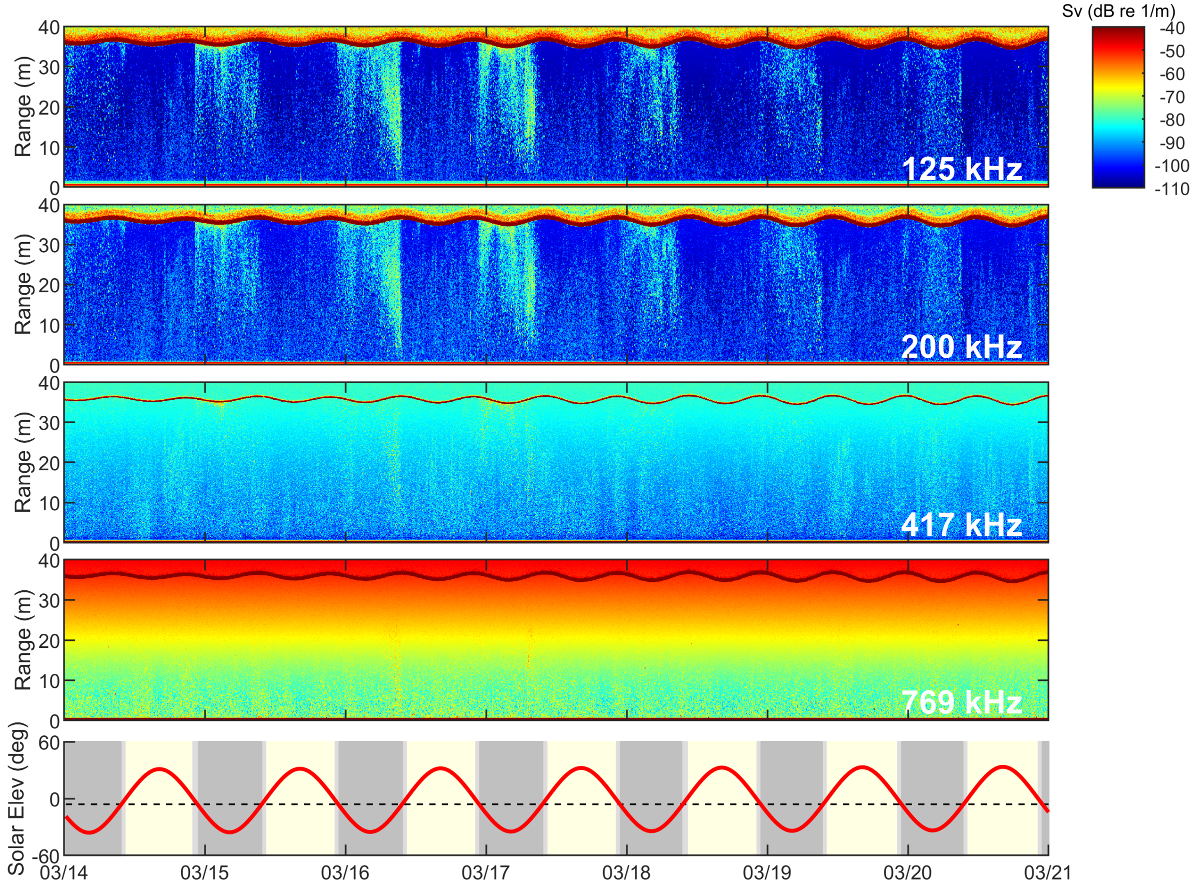

Fig. 5. AZFP-*ice* data from March 14-21 2022. The top four subplots show the volume backscatter (Sv) values recorded by the upward-looking instrument on each of its four channels. The lowest subplot shows the solar elevation angle (red curve) near the deployment site. The dashed horizontal line corresponds to a solar elevation angle of -6 degrees, corresponding with the transition between civil twilight and night. The solar elevation plot features shading that corresponds with daytime (light yellow), nighttime (grey), and twilight (light grey).

Ten days later, this DVM signal is significantly weaker. Fig. 6 presents the data collected between March 24 and March 31, 2022. During this time the DVM signal is still present and most visible on the 125 kHz and 200 kHz channels, but the intensity of this signal is diminished.

Between April 8 and April 15 2022, the DVM signal has returned as shown in Fig. 7. The 125 kHz and 200 kHz plots show a strong DVM signal in the 25 m of water immediately below the ice. This DVM signal is now stronger than the preceding plots from March, and its extent is sharply defined.

In contrast to the data from March and April, where the study site was ice-covered, the data from July show strong scattering that is distributed within the water column. Fig. 8 presents data collected between July 7 and July 14, 2022. There is a DVM signal present, but the scatterers display significantly different behavior compared to March and April. Whereas during the winter months these targets would not linger in the upper water column during the daytime, in July the visible portion of the water column is largely occupied. The scattering is strong enough that a DVM signal is clearly visible on the 417 kHz channel and even on the 769 kHz channel despite the significant seawater absorption.

IV. Discussion

The under-ice data in Figs. 5-7 shows significant variability, both from day to day and from week to week. A quantitative analysis of these biological data has not yet been performed. A qualitative analysis is provided here, leading into research questions that result from these data.

Interestingly, the DVM is sharply defined in Fig. 5 yet is nearly absent in Fig. 6. Approximately 1 week later, the DVM signal returns as shown in Fig. 7. In contrast to Fig. 6 the migrations shown in April are characterized by increased intensity (i.e. increased Sv values), and the organisms involved in these migrations occupy an increased portion of the water column above the instrument. It is unknown which factors influence this changing behavior while the organisms remain under land-fast ice. The nearest known solar irradiance measurements were collected at a weather station approximately 300 km away from the study site, but such measurements may not be representative of irradiance at the study site.

In March and in April, civil twilight appears strongly related to diel vertical migration timing. This is not unexpected, as

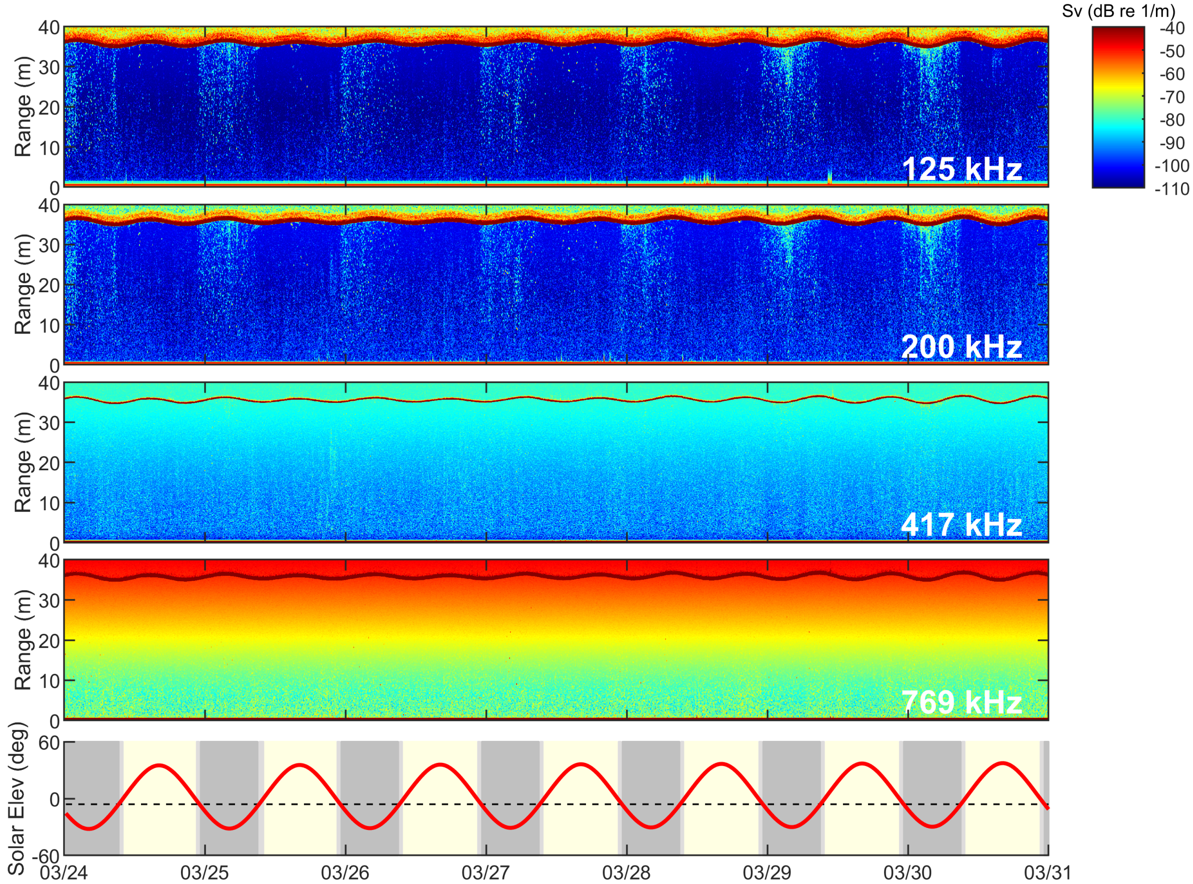

Fig. 6. AZFP-*ice* data from March 24-31 2022. The top four subplots show the volume backscatter (Sv) values recorded by the upward-looking instrument on each of its four channels. The lowest subplot shows the solar elevation angle near the deployment site. The dashed horizontal line corresponds to a solar elevation angle of -6 degrees, corresponding with the transition between civil twilight and night. The solar elevation plot features shading that corresponds with daytime (light yellow), nighttime (grey), and twilight (light grey).

previous studies have explored this relationship and found significant correlation between civil twilight and migration timing [9], [10]. The absence of water column scatterers during daytime hours is attributed to the altitude of the instrument on the mooring. The full water column is approximately 80 m deep, and the instrument is located roughly 35 m below the surface. It is therefore presumed that the scatterers simply dive deeper than the instrument during the daytime.

In June, the ice cover at the study site broke up. By July, the study site was ice-free. The corresponding data shown in Fig. 8 show that nearly all of the water column above the instrument is occupied. This behavior points toward opportunistic feeding behavior, observed at other high-latitude environments in the polar summer. A DVM signal is still evident, although it is less pronounced than in March or April. Targets are observed moving closer to the surface shortly after the sun reached its apex each day, in contrast to the behavior seen in March and April. This behavior is unexpected, even in high-latitude environments where migratory behavior is understood to be more complex [13]. The cause of this behavior is not immediately clear, and warrants further investigation.

V. Conclusion

The AZFP-*ice* completed a multi-month deployment that lasted approximately 250 days, spanning periods of varying ice cover. During the course of the deployment the instrument collected a total of 247 GB of data, greatly improving upon the temporal resolution that was possible with previous instruments. The incorporation of ice profiling capabilities into the instrument proved valuable, allowing for biological observations to be made within the context of varying ice cover.

The draft time-series calculated from the AZFP-*ice* were qualitatively similar to the Log IPS, and unique features such as some of the largest ice keels were identified in both time-series. Comparison of the ice draft empirical histograms calculated for each time-series revealed consistency, validating the ability of the AZFP-*ice* to measure ice draft.

Diel vertical migration patterns were seen to be dynamic, showing high week-to-week variability during the period of landfast ice. Following ice breakup, DVM patterns were seen to be multifaceted. During the period between July 7 and July 15 2022, migrations appeared to begin shortly after the sun

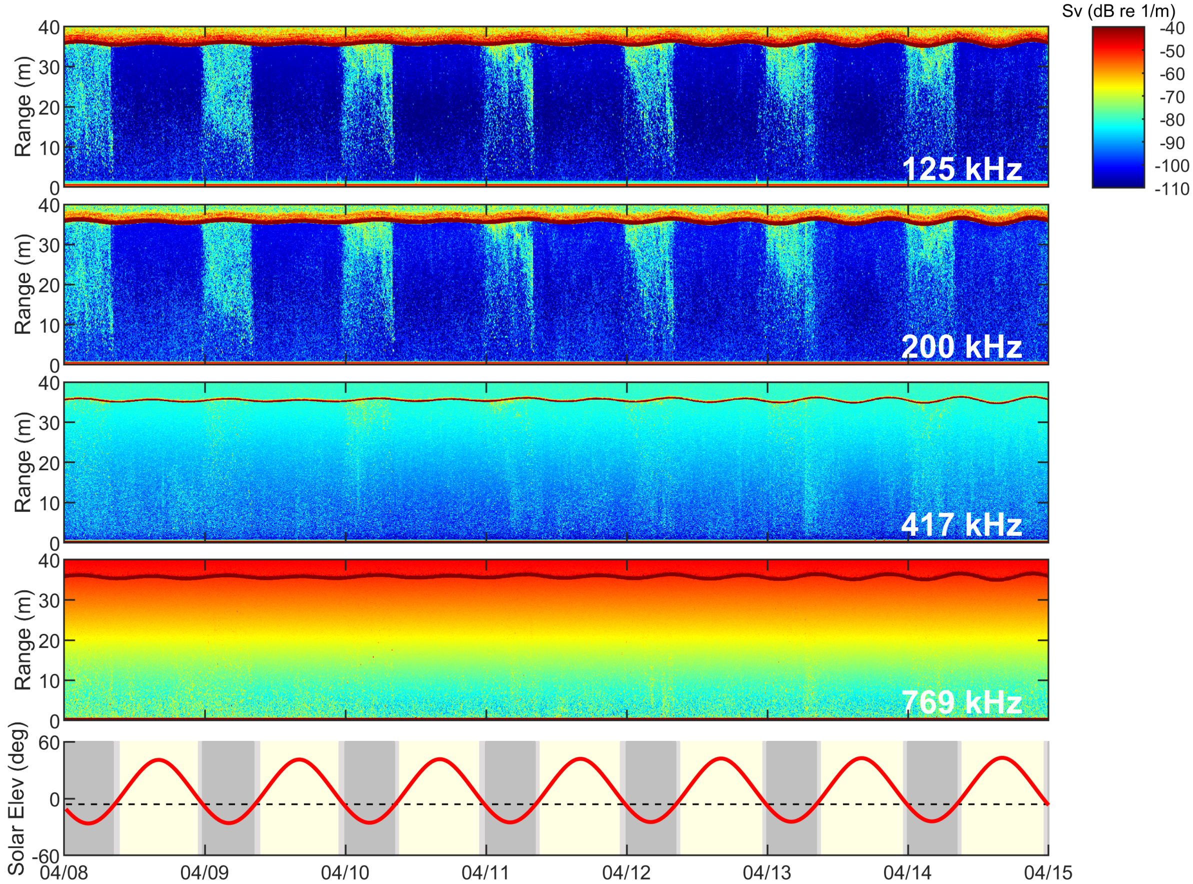

Fig. 7. AZFP-*ice* data from April 8 to 15 2022. The top four subplots show the volume backscatter (Sv) values recorded by the upward-looking instrument on each of its four channels. The lowest subplot shows the solar elevation angle near the deployment site. The dashed horizontal line corresponds to a solar elevation angle of -6 degrees, corresponding with the transition between civil twilight and night. The solar elevation plot features shading that corresponds with daytime (light yellow), nighttime (grey), and twilight (light grey).

reached its apex, in contrast to a typical DVM that would begin around the onset of civil twilight. The cause of this behavior is not understood. Future studies may benefit from the use of a long-endurance light meter attached to the mooring.

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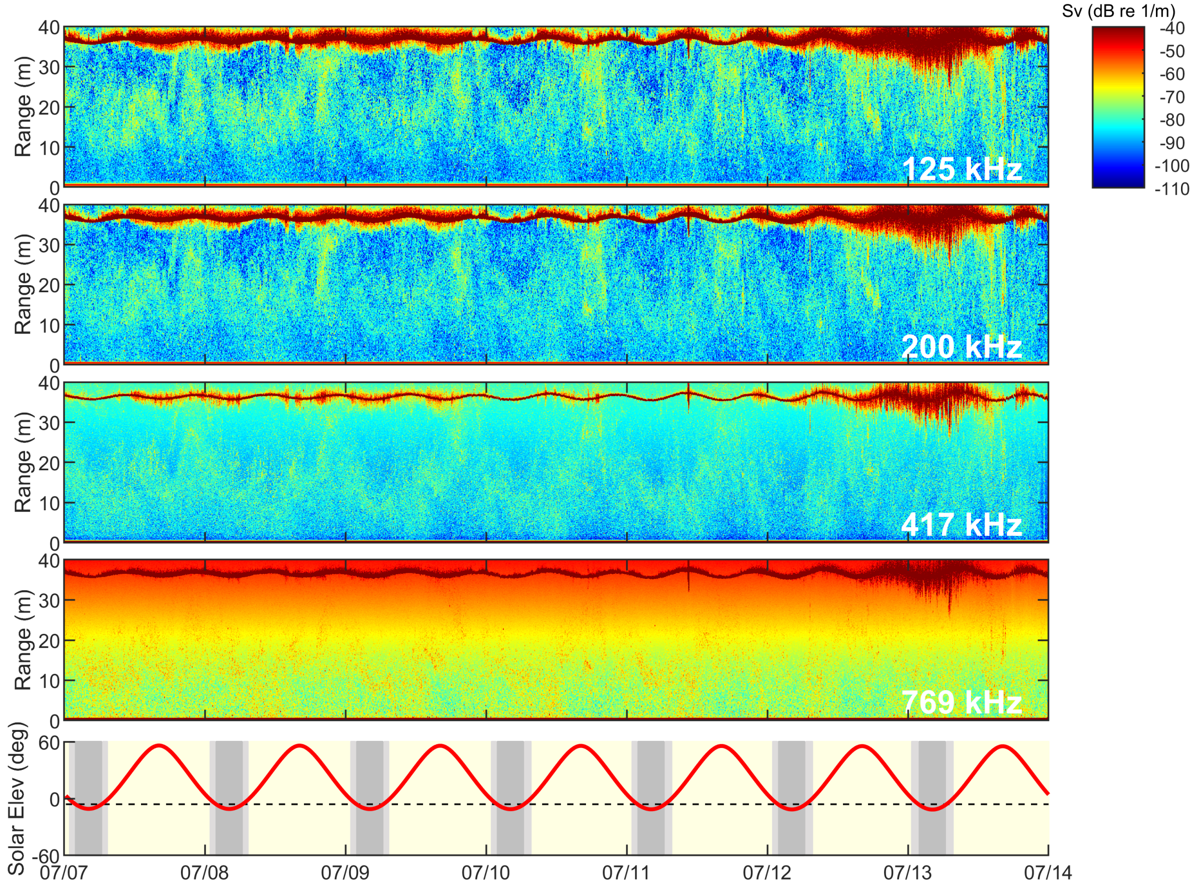

Fig. 8. AZFP-*ice* data from July 7 to 14 2022. The top four subplots show the volume backscatter (Sv) values recorded by the upward-looking instrument on each of its four channels. The lowest subplot shows the solar elevation angle near the deployment site. The dashed horizontal line corresponds to a solar elevation angle of -6 degrees, corresponding with the transition between civil twilight and night. The solar elevation plot features shading that corresponds with daytime (light yellow), nighttime (grey), and twilight (light grey).

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