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Deployment of an Enhanced Ice Profiling Sonar (IPS) in Seasonally Ice-covered Coastal Waters of the Nunatsiavut Region of Labrador, Canada

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ABSTRACT

The Ice Profiling Sonar (IPS) is an example of an Upward-Looking Sonar (ULS) that provides continuous (1-2 Hz), high-resolution (1 cm vertical, ~1 m horizontal) measurement of ice draft. The IPS is typically installed on a subsurface mooring anchored to the seabed and has been used in data-logged and real-time configurations since the early 1990s. Used repeatedly over many years, the IPS has helped develop long time-series (25+ years) of Arctic ice conditions in a changing climate.

ASL has recently completed a second field test of a prototype IPS with a logarithmic detector module, the IPS5L. The IPS5L was deployed in seasonally ice-covered waters near Nain, Labrador in collaboration with the Nunatsiavut Government via a through-ice deployment from February - October 2020. The site was positioned downstream of an area which becomes ice-free through the winter due to currents and winds, locally known as a “rattle”. The measurements were made in 87 m water depth and are anticipated to provide insights into the biological activity that is fostered by the rattle, and the ice conditions around the rattle. The higher dynamic range of the IPS5L is expected to lead to the measurement of the full echo amplitude response of various acoustic targets including level ice, deformed ice, calm and rough open water, and sediment and zooplankton clouds in the water column. These features will also allow the IPS5L to characterize ice in a harbour and narrow waterway where safety of snowmobiles is important.

KEY WORDS Ice; Ice Profiling Sonar (IPS); Underwater Acoustic Profile; Logarithmic Detector

INTRODUCTION

The Ice Profiling Sonar (IPS) is a type of Upward Looking Sonar designed to acoustically measure ice draft, or the depth of ice below the sea surface. The IPS was first commercialized in 1996 and has since become one of the leading instruments for ice detection. It can make high temporal resolution (1-2s) measurements of the ice over periods in excess of a year through the use of up to 12 programmable phases which can be optimized to the expected environmental conditions and low power consumption components. Narrow acoustic beams which are 0.9° half beamwidth from the center of the beam where power is maximal to where the power reaches half the value provide high spatial resolution of about 1 m at 50 m depth. From 2007-2008, the IPS was further improved to have a better analogue to digital converter, added memory, and a better micro-processor. The additional memory also facilitated the option to store profiles of the acoustic return for select acoustic pings.

The IPS was first deployed by Dr. Melling at the Department of Fisheries and Oceans Canada to monitor sea ice (Melling and Riedel, 2005). It was commercialized in the mid-1990's to support the engineering of offshore structures off Sakhalin Island, Russia (Birch et al, 2002). The technology then started to proliferate within the scientific community with studies in the Sea of Okhotsk (Fukamachi et al 2003), Fram Strait (Hansen et al, 2011) and the Beaufort Gyre (Krishfield et al, 2014). Additionally, the IPS has been used to study ice dynamics at the Confederation Bridge in Canada (Belliveau, Hayden and Prinsenberg, 2001), compare ice characteristics across the Arctic (Mudge et al, 2013), and identify and quantify ice hazards (Fissel et al, 2014a; Fissel et al 2014b) including multiyear ice (Fissel et al, 2012).

The IPS is currently undergoing a further upgrade which will include a logarithmic detector. This new version is named the IPS5L. The use of the logarithmic detector will provide about 85 dB of dynamic range, meaning it should be possible to measure the acoustic strength of strong scatterers, such as the air-water interface at short range, as well as weak scatterers such as the ice-water interface at long range. This is not possible with the linear detector. A prototype IPS5L has been developed and by the end of this deployment had undergone three winter trial deployments. The first two of these deployments were in the Beaufort Sea, in the western Canadian Arctic, in collaboration with the Department of Fisheries and Oceans Canada. The ice regime in the coastal zone of the Beaufort Sea tends to have high ice concentrations throughout much of the ice season and is characterized by intervals of slow ice motion interspersed with brief periods of enhanced ice motion, typically induced by large-scale wind forcing.

In 2020, there was an opportunity to collaborate with the Nunatsiavut Government to deploy an IPS5L off the coast of Nain, Labrador. The deployment was east of an area which becomes ice-free through the winter due to currents and winds, locally known as a "rattle". The combination of data measured by the IPS, which includes acoustic profiles of the water column, are anticipated to provide novel insights into the ice regime near this dynamic site.

ACOUSTIC MEASUREMENT OF ICE

The IPS is deployed in an upward-looking configuration, either at the seabed or in the water column, and measures the underside of the sea-ice by emitting short pulses of sound energy. The IPS provides a high spatial resolution (1 cm vertical, ~1 m horizontal) data. The instrument can be outfitted with up to 16 GB of memory. It records the profiles of the acoustic returns for a subset of the acoustic measurements. All the profiles are processed to identify acoustic targets, and up to five targets can be stored for every acoustic pulse. By measuring the time from emitting the acoustic pulse to detection of its return, the IPS calculates a range to the underside of the ice. Subtracting this range from the water level as measured by the highly accurate and highly stable ParoScientific pressure sensor gives a measure of the ice draft. Acoustic pulse rates of 1-2 seconds and pressure/tilt measurements taken every 3-30 s are recorded through the low power consumption electronics of the IPS.

DEVELOPMENT OF THE IPS5L

In 2013 design work began to incorporate a logarithmic detector in the IPS. With the traditional IPS, both the highly reflective air-water interface as well as the ice-water interface can have receive-amplitudes at the maximum measurable value. The use of the log detector opens the possibility of bringing all types of targets out of saturation and possibly allowing targets to be categorized based on their acoustic amplitude. The first steps were to simulate the IPS5L performance using measured data collected with the IPS5 (Chave et al., 2014). A prototype was developed and initially tested in Saanich Inlet, B.C,. Canada during 2014, and then in 2015 it was deployed for an over-winter test in the Western Arctic (Ross et al., 2017). Bugs from the 2015 deployment were identified and successfully worked out before deploying it again in 2017 for another over-winter test. In this paper, we present an update on the 2017 Arctic deployment field tests along with preliminary results of the field measurements made near Nain, Labrador during 2020. The series of events in the development of the LogIPS is summarized in Figure 1.

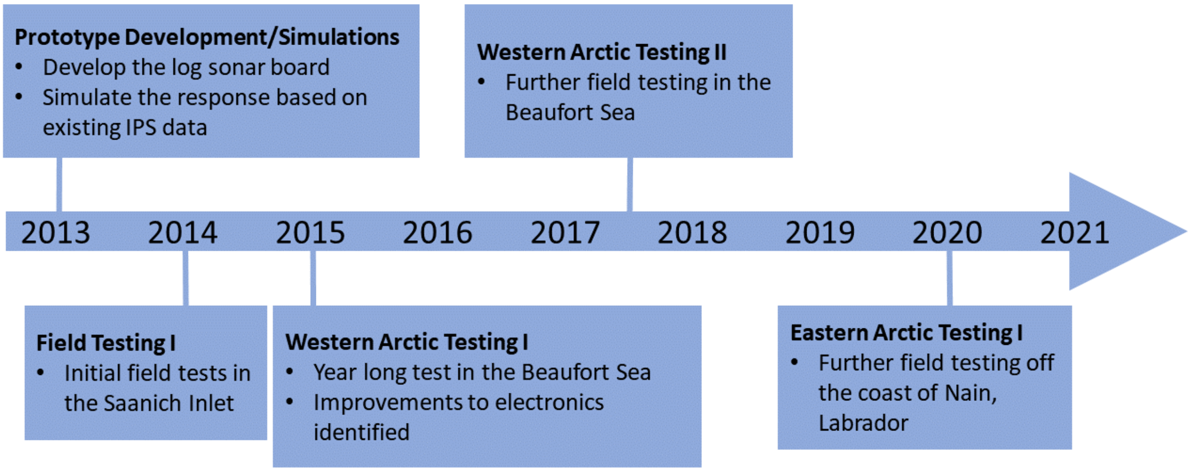

Figure 1. The development and testing timeline of the IPS5L.

TESTING IN THE EASTERN CANADIAN ARCTIC NEAR NAIN, LABRADOR

The ice regime in the Eastern Arctic near Nain, Labrador is expected to be considerably different than the ice regime of the Beaufort Sea. The Labrador Current conveys ice along the rugged Labrador coast toward the Atlantic. The Nunatsiavut Government became interested in becoming a partner in evaluating the IPS5L as the region also has areas of sea ice cover which reliably open up throughout the winter, and often host rapid ocean currents. These open-water features, commonly referred to as polynya, are known locally as “rattles”. A rattle of particular local interest was selected, and the mooring was deployed approximately 17 km east of the rattle in a local depression in the bathymetry (Figure 2).

The IPS5L was programmed to record acoustic targets at 2 Hz, pressure and tilt data every 5 seconds, and acoustic profiles every 15 seconds. The instrument was deployed through a hole in the ice on 15 February 2020. The 16 GB card installed in the unit provided ample memory to store the results of the 263-day deployment which concluded on 27 October 2020.

Figure 2. IPS5L tests in 2020 were conducted in the Eastern Canadian Arctic in Nunatsiavut administered waters near Nain, Labrador, Canada.

OBSERVED FEATURES

The selected site proved beneficial because it afforded a local bathymetric minimum which protected the instrument from ice impacts. The measurements indicated a dynamic environment with a variety of conditions being encountered above the instrument. Open water, waves, flat level ice and moderate size keels were measured (Figure 3). Keels up to 13 m draft were observed during the deployment.

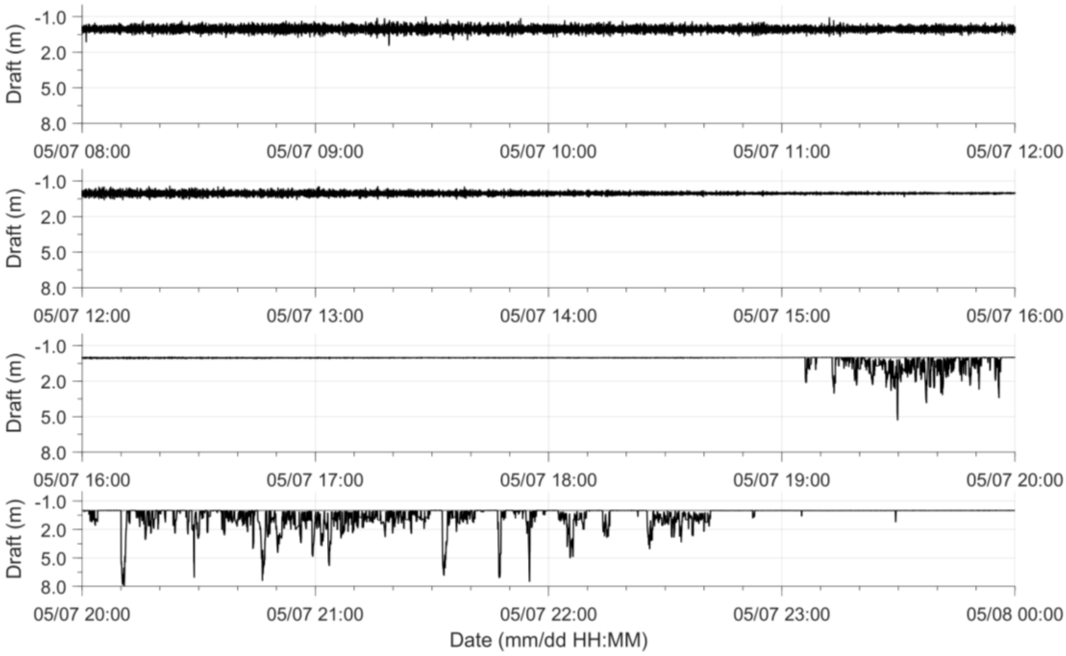

Figure 3. The IPS5L encountered open water, waves, level ice, and moderately deformed ice.

ACOUSTIC BACKSCATTER DISTRIBUTIONS

The IPS5Lwas recovered in late October 2020. One of the first objectives was to assess whether the log amplifier was successfully bringing all target types out of saturation. Figure 4 presents primarily ice data which is recorded from February to June in red, and the full data set from February to late October, in blue, which includes the data shown in red plus the mostly open water encountered following June. The full data set shows none of the target types are in saturation as the histogram of acoustic returns for the full dataset fades off prior to the 65,536-count limit of the 16-bit A/D converter. The higher amplitude returns are primarily measured in the open water season from the air-water interface which is a strong acoustic target.

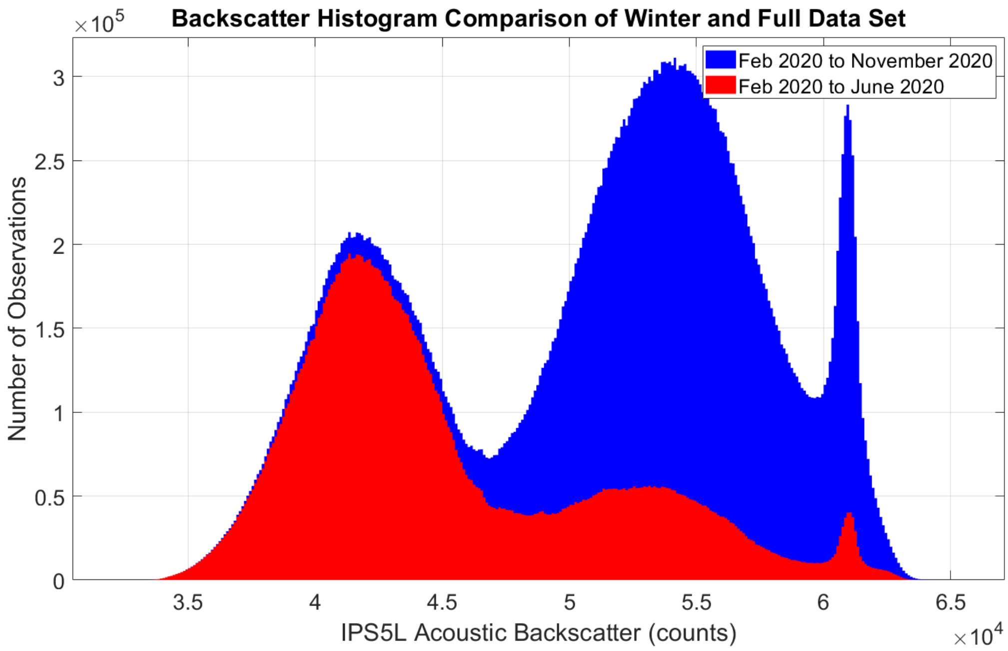

Figure 4. Comparison of two acoustic backscatter amplitude histograms.

It is instructive to revert to the previous Beaufort Sea trials of the IPS5L as there has been time to fully analyze this data and categorize the acoustic targets. The histograms of acoustic amplitude for the different target categories are interesting, especially in the context of these new measurements from Nain. The various types of sea ice showed a peak at smaller amplitudes than open water in the Beaufort Sea data as well (Figure 5). Unlike the data from the Beaufort Sea, however, the Labrador data shows 3 peaks, probably related to 3 populations within the data. The initial hypothesis is that the narrow peak at the highest amplitudes is due to flat open water; however, additional analysis is required to quantitatively confirm this hypothesis.

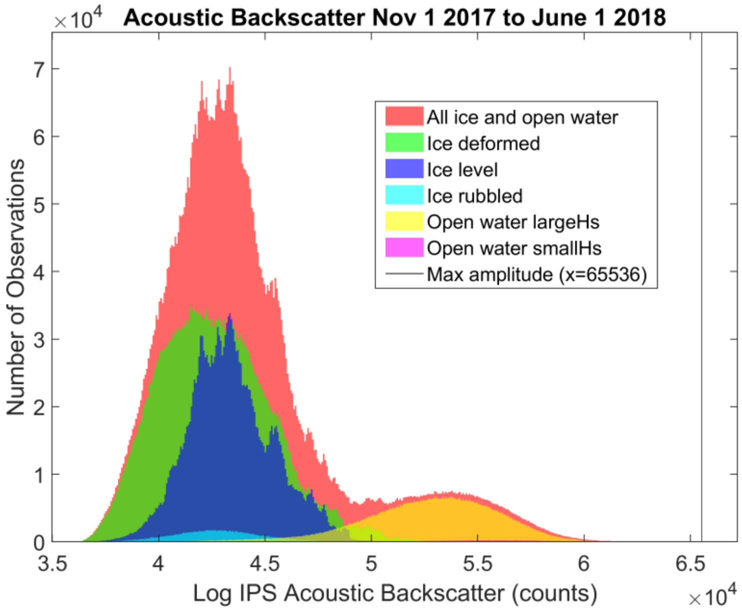

Figure 5. Acoustic backscatter histograms for different target types for data from the Beaufort Sea 2017 deployment.

DISTRIBUTION OF ACOUSTIC TARGETS

The IPS can store the range and amplitude of up to 5 targets, or peaks in the profile of backscatter versus range. The backscatter amplitudes which have been presented so far correspond to the amplitudes of the first peak as ranked by persistence. Further details about the target detection algorithm are provided in Chave et al., (2014).

There were modifications spawned from the 2015 Beaufort Sea overwinter trials in relation to the pulse length and filtering of the emitted sound and the preamplification of the received sound in the IPS5L electronics. The need for this modification was due to the acoustic amplitudes from open water not being pulled out of saturation. At the time, Ross et al., (2016) noted a much larger number of ensembles which contained five targets compared to a deployment of a standard IPS deployed at the same site in the preceding year. In the 2017 Beaufort Sea deployment this pattern was no longer observed, and this change was thought to be related to the changes made to the instrument electronics. Examination of the 2020 Nain data is consistent with a small number of five target solutions and no significant deviation from the distribution in the number of targets as compared to those observed by a standard IPS are detected (Figure 6).

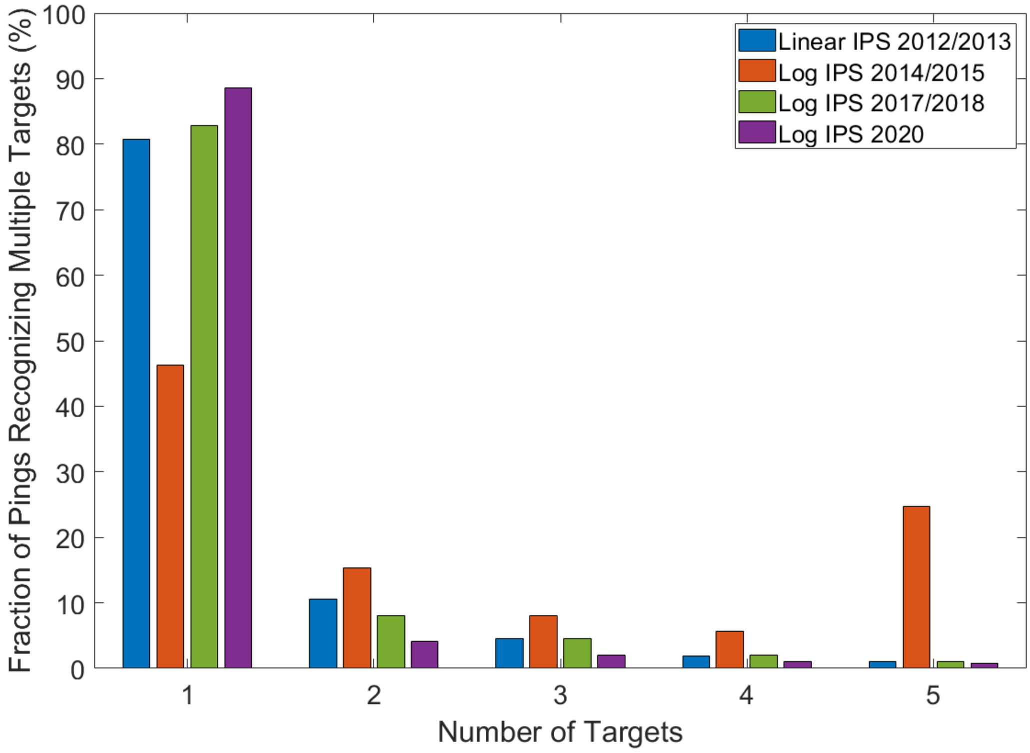

Figure 6. Histogram of the relative number of targets for each of the test datasets. The relative occurrence decreases as number of targets increases, except for the 2014 case where the IPS5L required subsequent modifications to some of its electronics.

ACOUSTIC PROFILES

In this section, three examples of the acoustic profiles that were measured in the 2020 deployment are examined further. In scanning through the data for examples to select, it quickly became apparent that, even though there were similarities with the ice features of the Beaufort Sea, there were features which set this dataset apart.

In the top panel of

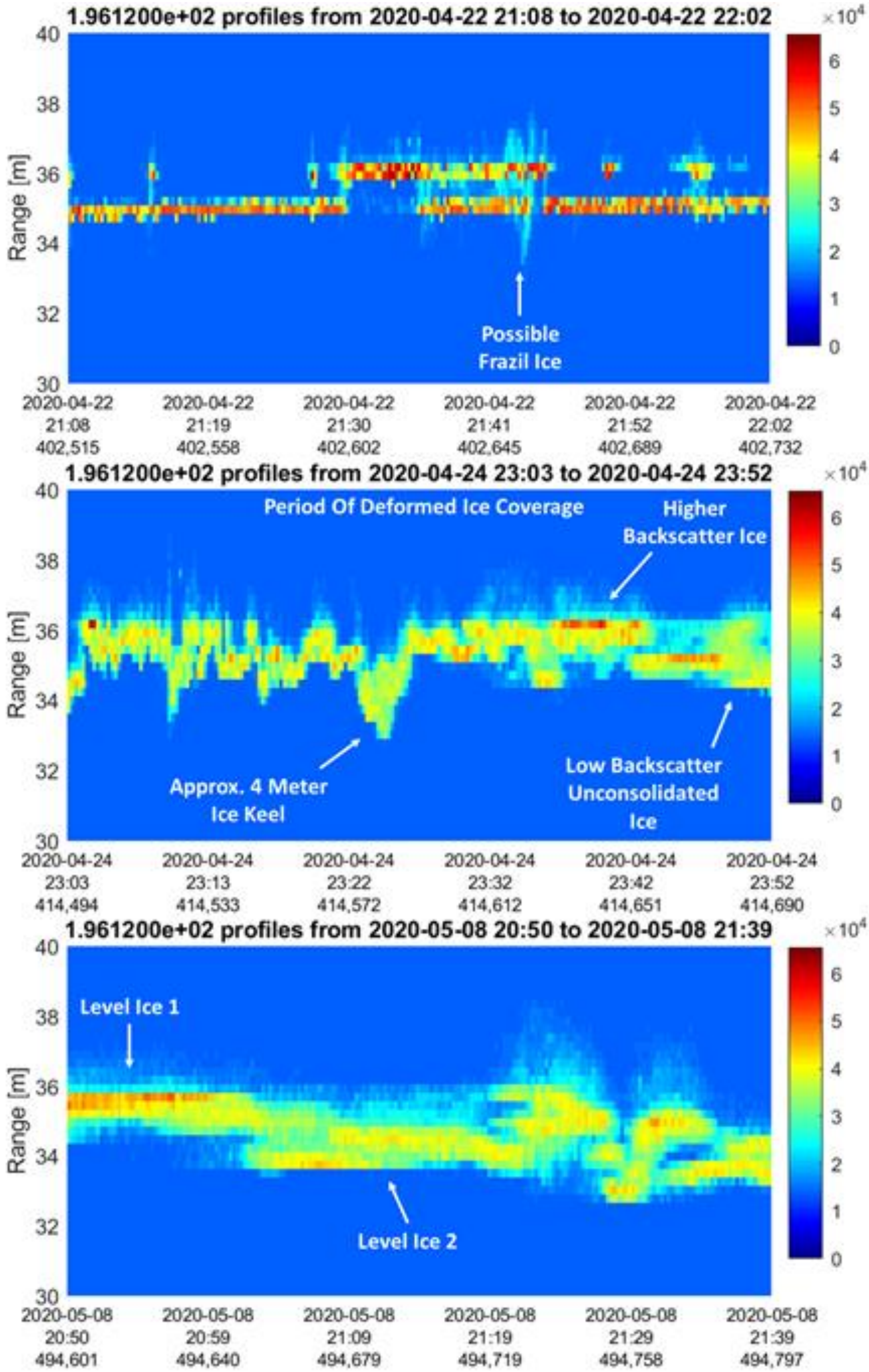

Figure 7, the IPS5L detects a 2-layer system. The IPS5L pressure sensor indicates the water level is around the upper layer at 36 m range, suggesting open water, or thin ice, and therefore the lower layer is probably the base of thicker ice.

A particularly intriguing finding is that around 21:40, the instrument detects enhanced backscatter at the air-water interface. Our initial interpretation is that the instrument may be observing frazil ice; however, the meteorological data from the Nain Airport does not show conditions favourable for frazil ice at this time; the air-temperatures are near 0°C, and the winds are easterly at 8 m/s. It is possible that the local air temperatures in the offshore close to the ice are colder than at the airport, and the winds are forcing enough sensible heat loss from the water to allow frazil ice to form.

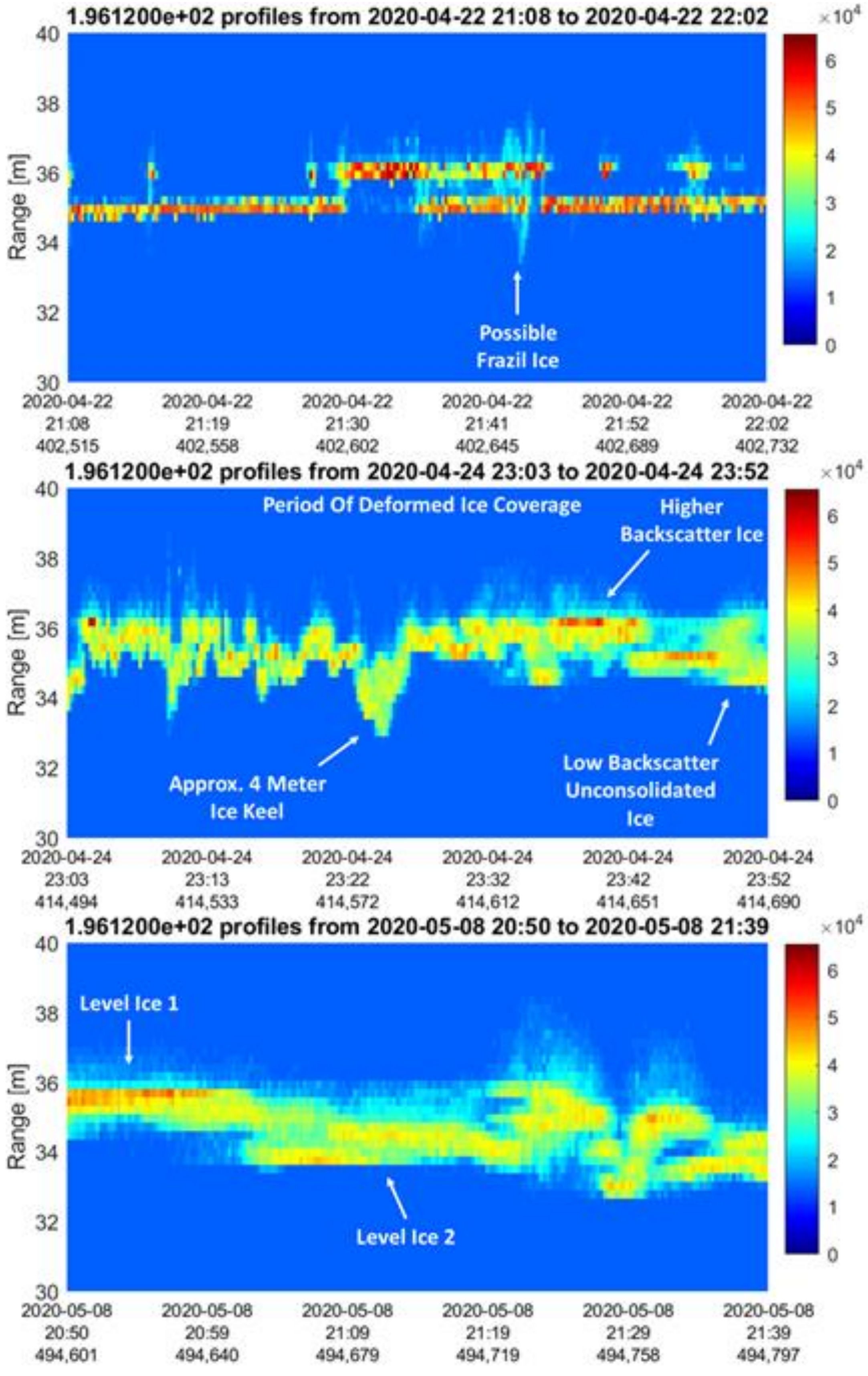

Figure 7. Profile returns from slow moving ice/water on 22 April 2020 (upper panel), deformed ice on 24 April 2020 (middle panel), and level ice on 08 May 2020 (bottom panel).

The middle panel shows deformed ice with drafts up to nearly 4 m. The profile data shows regions of low backscatter unconsolidated ice and sections of higher backscatter ice, which represents a very interesting contrast in ice observations over a short period of time.

The bottom panel shows a period of level ice. This profile also shows a multi-layer system, but probably because of the ice type, the amplitudes are reduced compared to the example in the top panel. Additionally, the large dynamic range appears to allow the IPS5L to peer short distances into the ice in conditions like those of the bottom panel.

SUMMARY AND CONCLUSIONS

The deployment near Nain, Labrador has provided an opportunity to test the IPS5L in a new ice regime. The recovery of the instrument was completed last year in this remote location despite the added difficulties of the ongoing COVID-19 global pandemic over the last year. These circumstances have delayed our retrieval and analysis of the data, but the brief examination presented in this paper shows a promising, rich dataset.

We can report that the large dynamic range of the IPS5L was able to pull all acoustic targets detected out of saturation. Early analysis suggests that the acoustic backscatter amplitude may yield information about the target type however, the distribution of acoustic backscatter is intriguing as it has an additional peak which was not observed in any of the Western Arctic trials in 2015 or 2017. The distribution of the number of targets continues to be like that of a regular IPS following the modifications of the electronics after the first western Arctic over-winter trials.

The profile data promises additional insights into the ice characteristics and suggests a complex ice regime. Further analysis is presently planned and will be underway in the future.

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