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MONTEREY, CALIFORNIA

ARCEX23 CRYOPHONE EXPERIMENT

by

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The Arctic Exercise 2023 (ARCEX23) Cryophone Experiment was funded by ONR Code 32 (Battlespace Environments). The experiment was conducted during March 5-9 on Lake Colleen in Prudhoe Bay and on first year sea ice 180 nm north of Prudhoe Bay during March 10-11. Both environmental and acoustical data were collected with a focus on acoustical wave propagation through three media (water, ice, and air). This report documents the equipment used by the Naval Postgraduate School (NPS) during the study and details initial findings. The initial findings suggest cryophones can be used to detect signals below and above the ice, providing 360 degrees of detection. Final results will be published in future peer-reviewed scientific journals.

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ABSTRACT

The Arctic Exercise 2023 (ARCEX23) Cryophone Experiment was funded by ONR Code 32 (Battlespace Environments). The experiment was conducted during March 5-9 on Lake Colleen in Prudhoe Bay and on first year sea ice 180 nm north of Prudhoe Bay during March 10-11. Both environmental and acoustical data were collected with a focus on acoustical wave propagation through three media (water, ice, and air). This report documents the equipment used by the Naval Postgraduate School (NPS) during the study and details initial findings. The initial findings suggest cryophones can be used to detect signals below and above the ice, providing 360 degrees of detection. Final results will be published in future peer-reviewed scientific journals.

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I. INTRODUCTION

A. OVERVIEW OF THE EXPERIMENT

During Arctic Exercise 2023 (ARCEX23), NPS conducted a Cryophone field experiment funded by ONR Code 32 (Battlespace Environments). The experiment focused on expounding upon studies performed in the 1990's that utilized geophones alongside hammer drops to determine wave propagation in sea ice (Stein *et al.,*1998; Xie & Farmer, 1994). The cryophone experiment sought to expand upon these past studies, and run tests on both freshwater ice and sea ice. This study was carried out in two experimental areas. The first was on Lake Colleen, which lies within Deadhorse, Alaska directly west of the Aurora Hotel. The second area was on a sea ice floe approximately 180 nm northeast of Deadhorse airport. Lake Colleen, a freshwater lake, was determined to be nearly frozen through with about a couple feet of water at the bottom. The freshwater ice provided unique acoustical properties in comparison to sea ice. The primary pieces of equipment utilized at both sites were three NPS cryophones, each consisting of an H4N Zoom recorder, three pre-amps (PCB Piezotronics), and a three-channel accelerometer (PCB). The cryophones were frozen into the surface of the ice at strategic locations where they recorded sounds produced by the acoustic sources. Sound sources used at both sites were a ten-pound metal ball that generated an impulsive broadband signal and a coherent sound source, (the "Tactile Sound Transducer" (TST)) that generated a linear frequency modulated (LFM) chirp signal. Other equipment utilized on the sea ice floe included a conductivity, temperature and depth (CTD) sensor to obtain a sound speed profile, two acoustic record recorders (SoundTrap ST300s) on a vertical line array (VLA), light bulbs used as imploding sound sources at depth, and a ten-inch auger to drill all the necessary holes in the ice.

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II. ENVIRONMENT

A. AREAS OF STUDY DESCRIPTION

The study of sound propagation through ice is a niche and little-researched realm of acoustical studies in both fresh and saltwater ice. The environments investigated in the study were chosen to further characterize both media. The first site was Lake Colleen, a rather large freshwater lake that is ~1.8 km long and 1.6 km wide located in Prudhoe Bay near Deadhorse airport. The second site was a sea ice floe in the Beaufort Sea located ~180 nm northeast of Deadhorse, comprised of a large area of first-year ice surrounded by thicker multiyear ice.

Lake Colleen was situated directly west of the Aurora Hotel where the team stayed and bordered by the Deadhorse airport to the South, industrial sites to the Northwest and Northeast, and roads all the way around (Fig. 1).

The sea ice floe was identified by United States National Ice Center (NIC) analysts who worked deftly with aircraft pilots to locate an ideal ice floe for this experiment (Fig. 2). The ice floe was ideal in that it was comprised of multiyear ice and first-year ice with a sufficiently large, flat expanse to land Twin Otter aircraft. Besides the NPS research team, there were several other research teams performing their own unique studies. Due to the flatness and ease with which snow could be cleared to gain access to the ice surface, the experiment was tested alongside the runway. Two Twin Otter aircraft were utilized to fly to the sea ice, one operated by the Royal Canadian Air Force (RCAF) and the other operated by Ken Borek Air (Fig. 3). The first-year ice section of the ice floe was roughly two meters thick and 1.5 km by 1.5 km.

Figure 1: Google Earth image of Lake Colleen, the site for all freshwater ice experiments. Aurora Hotel, Deadhorse airport, and two industrial sites are located east, south, northeast and northwest, respectively.

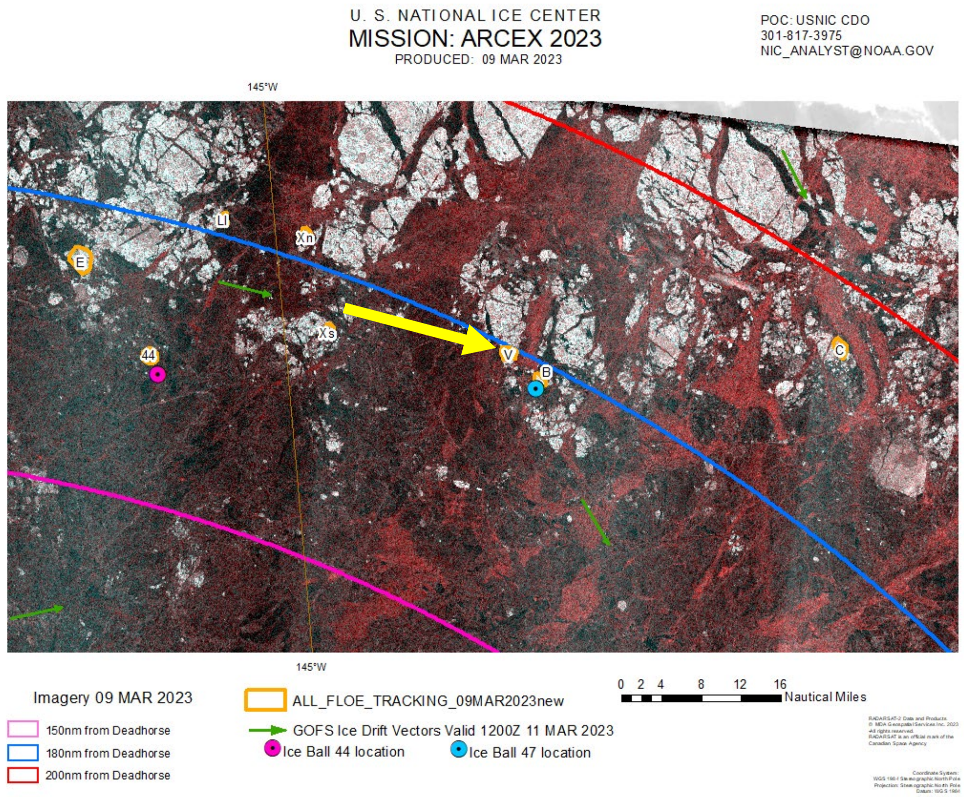

Figure 2: Location of sea ice floe on which the experiment was conducted, indicated by the arrow and letter "V". The ice floe was located ~180 nm northeast of Deadhorse airport.

Figure 3: Twin Otter aircraft flown by the Royal Canadian Air Force (background) and Kenn Borek Air (foregroud) on the sea ice at ice floe V.

III. EQUIPMENT

A. CRYOPHONE

The cryophone was first developed during Ice Exercise 2020 (ICEX20) and improved upon for this experiment. Within the cryophones were three primary pieces of equipment: a PCB triaxial accelerometer, three PCB pre-amps, and a Zoom H4N recorder. (Fig. 4) The accelerometer was attached to a metal plate at the bottom of the cryophone, allowing better coupling to the ice. While each piece of equipment held internal batteries, a couple of external battery options were engineered to further withstand the test of time in cold temperatures. The first was an entirely external system outside of the cryophone (Fig. 5). The second was an internal system comprised of a six cell AA battery pack that proved to be much more manageable. Without the external power systems, the Zoom H4N would only last approximately 11.5 hours on brand new batteries. On external battery power, the systems could last for over 24 hours. The limiting factor with the cryophone was the memory capacity of the Zoom recorders. The 32 Gb SD card reached its full capacity after about 25 hours. The 9-volt batteries within the PCB pre-amps were sufficient to last over 24 hours.

Figure 4: (left) Zoomed view of cryophone comprised of a PCB triaxial accelerometer, three PCB pre-amps, and a Zoom H4N recorder. (right) Cryophone frozen into Lake Colleen.

Figure 5: Cryophone and external battery capsule frozen into Lake Colleen.

B. SOURCES

Two types of sources were used for the experiment: a coherent source and an impact source. The coherent sources consisted of a Dayton Audio Sound Exciter Transducer and an Electro-Voice UW-30 pool speaker. The team nicknamed the devices the “TST.” Both of the sources were controlled by an external box that held an Apple iPod, an amplifier and a battery. A hole was cut out of the corner of the box to connect to the speakers on the outside (Fig. 5). The Dayton TST was the primary speaker utilized as the Electro-Voice TST was determined to be faulty. A ten-pound ball was used to generate a mechanical, impulsive signal in the ice when dropped from waist height to impact the snow-cleared ice.

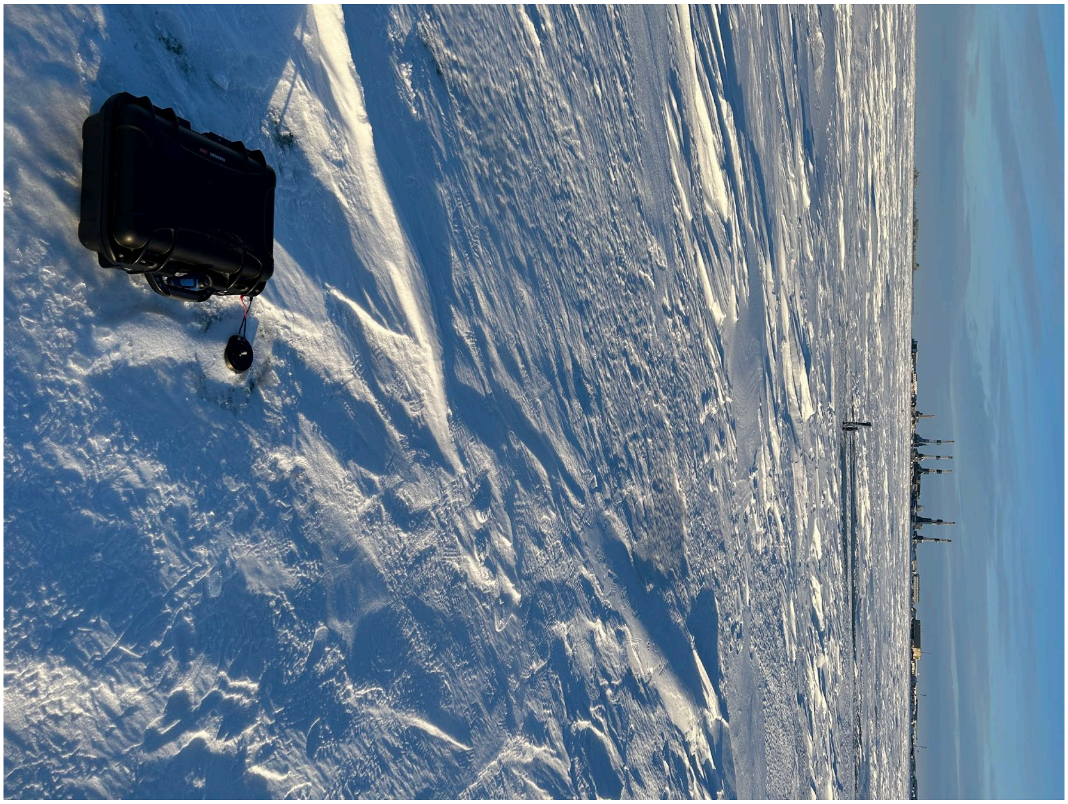

Figure 6: Dayton "Tactile Sound Transducer (TST)" sound source and external power box consisting of an iPod, amplifier and battery located on Lake Colleen with a cryophone located 25 meters away.

Table 1 Equipment list in each cryophone and Source

Cryophone	Equipment	Serial Number
C1	PCB Accelerometer PCB Pre Amp PCB Pre Amp PCB Pre Amp	3369 00039497 00039511 00039495

	Zoom H4N Recorder	C41105371
C2	PCB Accelerometer PCB Pre Amp PCB Pre Amp PCB Pre Amp Zoom H4N Recorder	3368 00039574 00039575 00039563 C41113978
C3	PCB Accelerometer PCB Pre Amp PCB Pre Amp PCB Pre Amp Zoom H4N Recorder	3375 00039496 00039494 00039493 C41113979
Source Box	Equipment	Serial Number
	Lepal Amplifier Battery iPod Electro-Voice Speaker Dayton Exciter	LP1601S N/A N/A UW30 22012 HDN-8

C. VLA AND CTD

A Vertical Line Array (VLA) was constructed to acquire acoustical data at two depths in the water column. The VLA line consisted of 200 meters of line with one SoundTrap ST300 at the bottom and a second SoundTrap ST300 125 meters above the bottom of the line. Between both SoundTraps there were four light bulbs tied to the line to acquire impulse data when they imploded due to pressure. To have an accurate understanding of the environment, an RBR Brevio CTD was utilized. A list of the equipment can be seen in Table 2.

Table 2 Hydrophone and CTD Equipment

Equipment	Serial Number
CTD	205304
SoundTrap (ST300)	6222
SoundTrap (ST300)	6235

IV. EXPERIMENT

The experiment was conducted during 5-11 March, 2023 and consisted of two sites: Lake Colleen and a sea ice floe in the southern Beaufort Sea. All equipment on Lake Colleen was deployed approximately at the center of the lake and on first-year ice on the sea ice floe. Lake Colleen tests were designed to study the acoustical properties of freshwater ice and to perfect the cryophone system. On the sea ice floe, the study was multi-faceted. First, a better understanding of wave propagation characteristics in sea ice was sought, with the use of mechanically impulsive and coherent sound sources. Second, the sound propagation through three media (water, ice, and air) was observed and analyzed. The equipment used in the sea ice test on 11-March consisted of a VLA, three cryophones in a 75m line, a coherent source and an impact source (Fig. 7).

Fig. 8 shows the waveform (top) and spectrogram (bottom) of the in-ice signals generated by dropping the 10-pound lead ball on a small aluminum place on the ice and observed by the cryophones placed at ranges of 25, 50 and 75 meters from the source. Signals generated by the TST were also observed at all three cryophones, demonstrating the feasibility of remote ice property inference via acoustic signals generated by an autonomous, battery-powered coherent source.

The use of light bulbs, which implode under pressure at depth, make excellent low cost and environmentally friendly sound sources (Heard *et al*., 1997). The impulsive signals generated by light bulb implosions were detected by ear above the ice, by the cryophone array on top of the ice floe (Fig. 9) and by the two hydrophones in the water. These signals further demonstrated that waterborne acoustic signals couple to the ice sheet and can be detected by the cryophones. Future studies will focus on the use of EMATTS as mobile sources that will transmit signals from greater distances (~10 km). Future work will also investigate the use of signals from lightbulb implosions to characterize the seabed and under-ice rough surface properties.

During a flyover by the RCAF plane, the two SoundTrap hydrophones clearly captured the broadband signal 150 m below the ice (Fig. 10). Additionally, the closest point of approach and Doppler-shifted signals were captured by the cryophones on the surface, suggesting ice-mounted cryophones may be used to detect and track aircraft in addition to underwater and in-ice acoustic signals. Future studies seek to create a cross domain vs. 360-degree acoustical view of the environment with the use of a single ice-imbedded instrument.

The field log for the experiment can be found in Table 3.

Figure 7: March 10th: Sea ice floe experiment. VLA (foreground, deployed through a hole under the orange reel), and Cryophone 1, 2, and 3 at 25, 50 and 75 m from VLA hole.

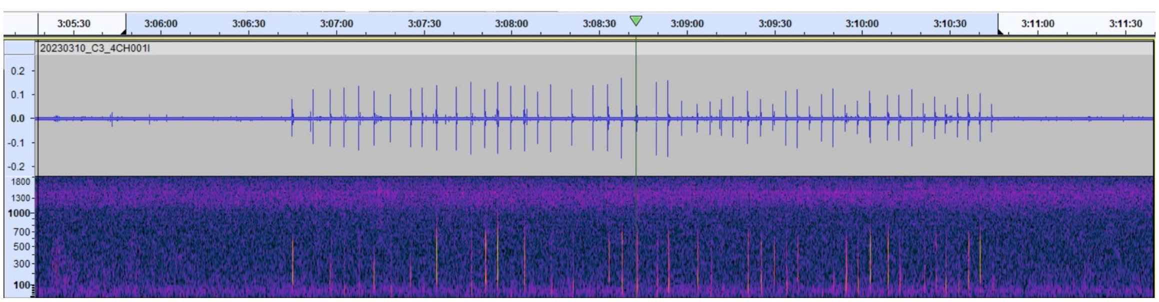

Figure 8: 10-March: Waveform and spectrogram of ball drops on an aluminum plate as received on Cryophone 3 (75 meters away). X-axis is in hours: minutes: seconds. Units for waveform amplitude and spectrogram frequency on the y-axes are in dB and Hz, respectively.)

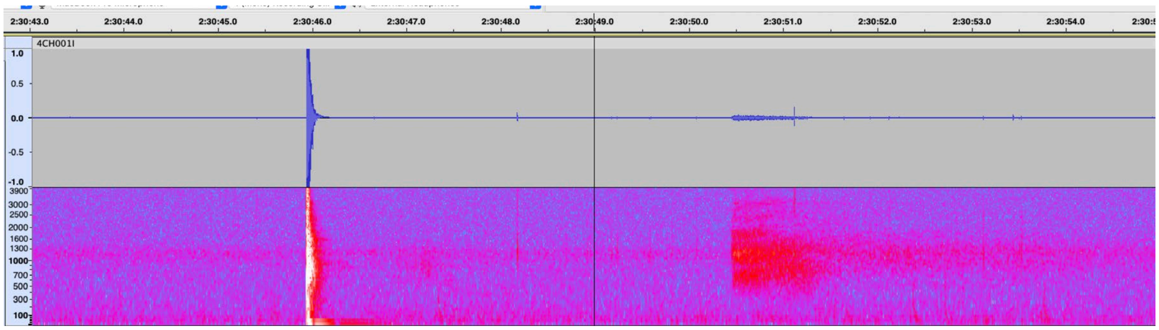
Figure 9: 10-March Waveform and spectrogram of light bulb implosions recorded at Cryophone 3. The first signal at 2:30:46 is direct path and the second signal at ~2:30:50 is the bottom bounce return. X-axis is in hours: minutes: seconds. Waveform and spectrograms y-axes are in dB and Hz, respectively.

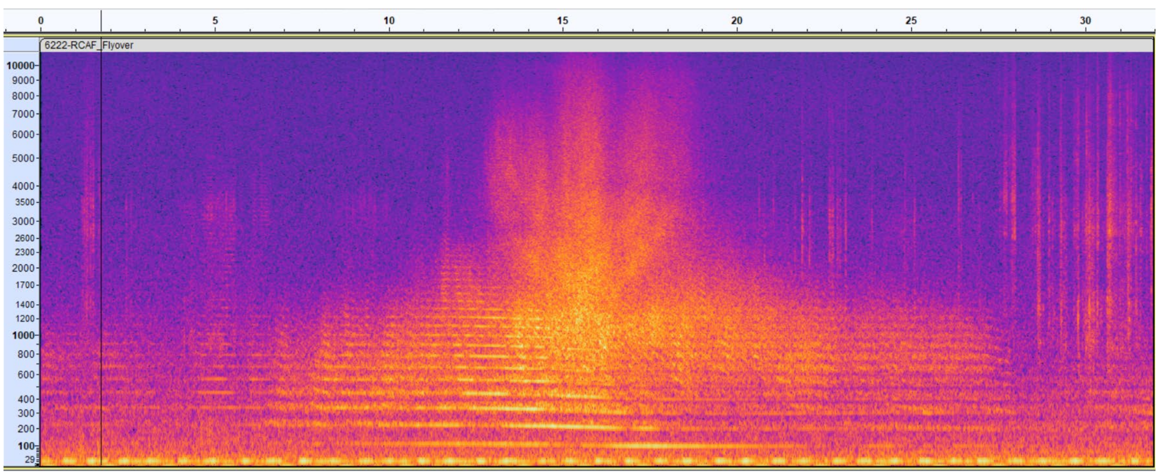
Figure 10: Spectrogram of 10-March 1RCAF plane flying over the VLA as heard from the SoundTrap at 150 meters of depth. Y-axis is in Hz and the X-axis is in seconds.

Table 3 Field log

AKST-9	UTC	Log Entry

3-MAR-23		Lake Colleen
~1253	2153	Cryophone 1 (C1) frozen into ice on lake Colleen.
1256	2156	Spiral footsteps around the cryophone.
1258	2158	Spiral stops.
1259	2159	Second, larger, spiral footsteps begin.
1300	2200	Second spiral ends.
1301	2201	Third spiral footsteps begin.
1303	2203	Third spiral ends.
1308	2208	Ball drops on north transect begin.
~1320	2220	Ball drops on west transect begin.
1410	2310	Dayton TST signal started on north transect of cryophone (~5 meters away)
1415	2315	Dayton TST signal started on west transect of cryophone (~5 meters away)

4-MAR-23		Lake Colleen
1053	1953	Cryophones installed in a line (C1-250m-C2-250m-C3) south to north at 250 meters apart.
1055	1955	50 ball drops at 28 m from C1.
1106	2006	50 ball drops at 98 m from the C1.
1506	0006	Dayton audio TST frozen into ice at 28 m from C1.
1604	0104	TST volume turned up.
1715	0215	Dayton TST switched out for Electro-Voice TST. Electro-Voice TST not performing optimally. TSTs recovered. Cryophones left to capture ambient noise in lake ice.
1800	0300	Cryophones recovered.

5-MAR-23		Lake Colleen
1700	0200	Cryophones installed in a line (C2-125m-C3-125m-C1) south to north, 125 meters apart.
1720	0220	Ball drops in a line parallel to the line of cryophones to test for triangulation. Cryophones left out overnight.

6-MAR-23		Lake Colleen
0920	1820	Cryophones checked on. C3 was dead. C3 recovered. C1 was moved into place of C3. Cryophones now at 0 and 125 meters (C2-125m-C1).
0943	1843	50 ball drops at 20.3 meters from C2.
0952	1852	Dayton TST frozen into place and activated.
1300	2200	Last two cryophones recovered. TST left in place but deactivated.
1730	0230	C1 and C2 deployed at 0 and 125 meters south to north. (C1-125m-C2)
1745	0245	TST reactivated.
1800	0300	C3 deployed 125 m west C1. Cryophones are now in a triangular formation.
1805	0305	50 ball drops 20 meters south of C1.

7-MAR-23		Lake Colleen
~0900	1800	C1 and C2 recovered. C3 left out to test 24 hour durability.

~1700	0200	C1 and C2 deployed in a westerly tract at 25 and 50 meters from the TST (TST-25m-C1-25m-C2). C3 recovered. 50 ball drops 25 meters from C1. C1 and C2 left overnight.

8-MAR-23		**Lake Colleen**
0900	1800	Recovered C1, C2 and the iPod to update the sound file. Completely iced in (encapsulated) the Electro-Voice TST.
1330	2130	C1 and C2 placed at 25 and 50 meters west of TST (TST-25m-C1-25m-C2). IPod connected and transmitting signal.
1530	0030	Cryophones recovered. Electro-Voice TST recovered.

9-MAR-23		**Sea Ice (GPS Coordinates: 72.78041, -143.52389)**
1230	2130	Flight departs for Sea Ice.
1400	2300	Flight lands on Sea Ice.
~1430	2330	Hole drilled into sea ice. CTD cast.
1550	0050	C1 deployed.
1607	0107	Dayton TST frozen into ice @ 100 meters from cryophone. Began transmitting.
1613	0113	TST stopped and removed from ice.
1619	0119	TST frozen into ice @ 200 meters from cryophone. Began transmitting.
1625	0125	TST stopped and removed from ice.
1635	0135	Cryophone removed from Ice.
1650	0150	Flight departs sea ice.

10-MAR-23		**Sea Ice (GPS Coordinates: 72.70944, -143.46263)**
~1030	1930	Flight departs for the sea ice.
~1210	2110	Flight lands on sea ice.
~1220	2120	Hole drilled into ice. Three cryophones deployed at 25, 50, and 75 meters from the hole (Hole-25m-C1-25m-C2-25m-C3).
1226	2126	VLA with two SoundTraps and light bulbs deployed down the hole. Three Light bulb impulses detected.
1235	2135	RCAF plane took off next to sensors.
1237	2137	RCAF flew over sensors.
1238	2138	RCAF flew by (not over).
1253	2153	50 ball drops on ice 2 meters in front of hole, 23 meters from the C1.
1301	2201	50 ball drops on metal plate. (same location)
1310	2210	Dayton TST frozen into ice. (same location). Recordings begin.
1326	2226	TST stopped and removed.
1350	2250	TST frozen into ice at 25 meters from hole (50 meters from C1.) Recordings begin.
~1420	2320	VLA pulled up. Reloaded light bulbs onto line. Line redeployed to 200 meters depth.
~1500	0000	VLA, cryophones, and TST recovered.
~1515	0015	Flight departs the ice.

V. LESSONS LEARNED

Throughout the experiment the team was constantly learning new and more efficient ways to conduct tests at ARCEX23 and future tests in Ice Exercise 2024 (ICEX24). Lessons learned are listed in Table 4.

Table 4: Lessons Learned

Item	Lessons Learned
Ball Drops	• Be slow and deliberate. Ensure that there is a pause of a couple seconds between each ball drop with no movement on the ice. • Use ball drops for longer ranges (walking on the snow is more suitable for shorter range tests)
Cryophones	• Install LEDs onto cryophones for ease of identification in daytime and at night. • Ensure cryophones are calibrated to obtain proper attenuation. • Sync the cryophones to GPS time to check for clock drift.
Cryophone Placement	• Allow time for the water to freeze around the cryophones for better coupling to the ice. • Wait at least 10-15 minutes for the water to completely freeze or the cryophone will pick up the sounds of the ice hardening around it.
H4N Zoom Recorders	• Log the start time of each zoom recorder. The Zoom recorders are not stamped with a real time of day, only duration of recording. • Ensure the SD cards are reformatted before every use to ensure the Zoom recorder is properly writing to it.

Wiring	• Handle wiring with care, they become brittle in the extreme cold. • Acquire winterized wiring for future experiments.
TST	• Due to vibrations from the TST it will slowly break up the coupling of the ice surrounding it. • Attach the TST to a metal plate to prevent vibrations from breaking the ice.
Coherent Signal	• Schedule the signals to be more regular. A five second break between each signal is too long.
Batteries	• Do not use Li-ion batteries with embedded electronics to power Cryophones. Embedded electronics cause electronic noise that the cryophones can pick up. Use external Li AA battery packs instead. • Bring more batteries for future experiments.
Hydrophones	• Deploy pressure sensors with each hydrophone to know their exact depths. • Sync the hydrophones to GPS time to check for clock drift.
Light bulbs	• Ensure there is no movement for a few minutes after the implosion so that the signal can successfully complete all propagation paths (i.e. Bottom Bounce) without being contaminated by surface noise.
Miscellaneous	• Bring a small garden trowel for ease of digging in snow/ice. • Ensure goggles worn by team are of "arctic grade". (Fogging was a prevalent problem.)

	• Bring large backpacks to transport cryophones/gear more easily.

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