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JASA EDITORIAL

# Introduction to the special issue on ocean acoustics in the changing arctic[a)]

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**ABSTRACT:**
This paper introduces the Special Issue of *The Journal of the Acoustical Society of America* on Ocean Acoustics in the Changing Arctic. The special issue includes papers on ocean (and in one case atmospheric) acoustics. Changes in both the ice cover and ocean stratification have significant implications for acoustic propagation and ambient sound. The Arctic is not done changing, and papers in this special issue, therefore, represent a snapshot of current acoustic conditions in the Arctic.  https://doi.org/10.1121/10.0010308

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## I. INTRODUCTION

This Special Issue of *The Journal of the Acoustical Society of America* (JASA) on Ocean Acoustics in the Changing Arctic includes papers on ocean (and in one case atmospheric) acoustics. The decreases in sea ice extent and thickness (Kwok, 2018; Stroeve and Notz, 2018; Serreze and Meier, 2019), the dramatic reduction in ice that has survived more than one summer (Kwok, 2018), and the changes in ocean stratification as warmer waters enter the Arctic Ocean through the Barents Sea and the Fram and Bering Straits (Polyakov *et al.*, 2012; Timmermans *et al.*, 2014) all have significant implications for ocean acoustics (Worcester and Ballard, 2020; Worcester *et al.*, 2020). At the same time, multipurpose acoustic systems can operate below the ice to monitor the changing Arctic by recording natural and anthropogenic sounds, remotely measuring large-scale ocean temperatures, and providing undersea navigation for floats, drifters, and autonomous underwater vehicles (AUV) (Mikhalevsky *et al.*, 2015; Howe *et al.*, 2019). Acoustic systems, therefore, have a special role to play in making measurements in the ice-covered Arctic Ocean.

## II. OVERVIEW OF PAPERS

Most of the papers in this issue are on (i) ambient sound and passive acoustic monitoring and (ii) measurements and modeling of acoustic propagation in the Arctic. There is one paper each on positioning and navigation under ice, Arctic geo-acoustics, and Arctic atmospheric propagation.

### A. Ambient sound and passive acoustic monitoring

In ice covered regions, the deformation, fracturing, and breaking of ice in response to wind, currents, and thermal stresses are the prevailing sources of natural ambient sound (Mikhalevsky, 2001). In the Marginal Ice Zone (MIZ) and other areas with lower ice concentrations, the bumping and grinding of ice floes caused by wind waves and swell are also important. The disappearance of multiyear ice and the decreases in ice extent and concentration are therefore changing the character of ambient sound in the Arctic. In addition, the reduction in ice cover opens more of the Arctic to ship operations, seismic exploration, fishing, and military activities, resulting in increases in anthropogenic sound, especially during the summer. Finally, the contributions to ambient sound by marine life are also changing. Species that depend on the presence of sea ice are changing their distributions. The migratory patterns of marine mammals often follow the ice edge, and the contributions to ambient sound from marine mammal vocalizations are therefore changing in response to the changing ice cover.

The papers in this special issue report on analyses of ambient sound data recorded at a wide variety of locations in the Arctic, including the Beaufort and Chukchi Seas (including the Chukchi Shelf), Bering Sea, the Canadian Arctic Archipelago, and northwest and southeast Greenland. A final paper reports on ambient sound measurements in an ice-covered river, as an analog for ambient sound under multiyear ice.

Three of the papers report on data collected on the Chukchi Shelf and Slope using different recording systems during the 2016–2017 Shallow-Water Canada Basin Acoustic Propagation Experiment (SW-CANAPE) (Ballard and Sagers, 2021; Bonnel *et al.*, 2021; Escobar-Amado *et al.*, 2022). Ballard and Sagers (2021) report on ambient sound data in the 40 Hz to 4 kHz band analyzed using

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k-means clustering to study the relationship between ambient sound and environmental forcing (ice cover, air temperature, and wind speed). Each of the clusters was associated with a different generation process. One of the clusters was found to be associated with marine mammal vocalizations. Bonnel *et al*. (2021) report on the analysis of low-frequency ambient sound in the 250–350 Hz band. In addition to comparing the ambient sound with local ice concentration and wind speed, they also compared with ice-drift magnitude over the entire Arctic and found that propagation effects were important. Ambient sound levels dropped significantly when the Beaufort Duct, a subsurface sound-speed duct formed by relatively cold, low sound-speed Pacific Winter Water (PWW) located beneath a layer of relatively warm, high sound-speed Pacific Summer Water (PSW), called the Beaufort Lens (Litvak, 2015), and above relatively warm, high sound-speed Atlantic Water (AW), disappeared in the vicinity of the Chukchi Shelf during March 2017. The Beaufort Duct has strengthened in the western Arctic Ocean in recent years due to an increase in the influx of warm water through the Bering Strait. Finally, Escobar-Amado *et al*. (2022) report on the application of deep learning techniques, specifically convolutional neural networks, to detect and classify bearded seal vocalizations. Regions of interest were first identified using cross-correlations in time and frequency of the measured spectrograms with representative templates to detect potential vocalizations. Convolutional neural networks were then used to validate and classify the signals in the regions of interest, reducing the number of false positives.

Stafford *et al*. (2022) report on year-round passive acoustic monitoring of sounds produced by marine mammals on the Chukchi Plateau (75.1° N, 168.0° W). They analyzed year-long data sets for 2009, 2012, and 2014–2020 for the presence of vocalizations from Arctic species, including bowhead and beluga whales, bearded seals, and walrus. Their data provide evidence of change in the far north of the Pacific Arctic where Arctic endemic bowhead whales are heard into December, ribbon seals have expanded their distribution northwards, and subarctic killer whales are being heard further north and with increasing regularity. Although the Chukchi Plateau region currently remains largely ice-covered for nearly nine months of the year, expansion of subarctic species into the high North can be expected to change biodiversity if sea ice continues to decline there.

Chen and Schmidt (2020) report on data collected in the deep Beaufort Sea during the U. S. Navy Ice Exercise in the Arctic Ocean during March 2016 (ICEX-16). The Beaufort Duct was prominent during ICEX-16 and altered the level and vertical directionality of the ambient sound, creating a noise notch at low grazing angles. Thode *et al*. (2021) is the final paper in this issue to report on ambient sound measurements in the Beaufort Sea and specifically on the Beaufort Shelf. These data were acquired using bottom-mounted vector sensors to provide information on the horizontal directionality of the ambient sound. The data were acquired seasonally from late summer to early autumn when little or no ice was present. Ambient sound was found to have high directionality at lower sound levels, arriving at angles between 0° and 30° from true north. This was thought to be due to the dominance of wind-driven sources of noise along an east-west coastline.

McKenna *et al*. (2021) report on measurements made near St. Lawrence Island in the Bering Sea from mid-2015 to mid-2016 as well as (for a shorter period) near Bering Strait. This paper combines the acoustic data with information on various potential sound sources, including ice concentration, wind speed, tidal flow, shipping (i.e., AIS-transmitting vessels), and marine mammal vocalizations, using a generalized additive model to identify dominant features of the soundscape and compare their relative contributions. Wind, ice coverage, and tides were found to be the main contributors to received sound levels across all octave bands near St. Lawrence Island.

Two papers report on ambient sound measurements in the Canadian Arctic Archipelago (Cook *et al*., 2022; Sweeney *et al*., 2022). Cook *et al*. (2022) report on real-time ambient sound observations made by the cable-connected Barrow Strait Real-time Observatory (BSRTO) near Gascoyne Inlet, Nunavut, from September 2018 to August 2019. Contemporaneous data on surface currents and ice draft obtained by the BSRTO were used in the analysis of the ambient sound data. Sweeney *et al*. (2022) interpret ambient sound data obtained along a shipping route in Milne Inlet in Northern Baffin Island considering the hearing sensitivity as a function of frequency of the marine mammal species in the area (M-weighting) to assess the likely perceived sound pressure levels associated with ore carrier transits. Auditory weighting functions were found to significantly affect the potential perception of shipping noise. Narwhals, for example, were unlikely to clearly perceive shipping noise unless a ship was within 3 km and ambient sound levels were low.

Two papers report on measurements in Greenland (Podolskiy *et al*., 2022; Mattmüller *et al*., 2022). Podolskiy *et al*. (2022) report on measurements of the sounds generated by an iceberg calving event from the marine-terminating Bowdoin Glacier in northwest Greenland. An ocean bottom seismometer was deployed about 640 m in front of the calving front. The potential for acoustic impacts on marine mammals in the fjord was evaluated using the M-weightings for Medium Frequency cetaceans (MF-cetaceans) and *Phocid pinnepeds*, suggesting that the high cumulative sound exposure level (SEL) may lead to the onset of Permanent Threshold Shift (PTS) for narwhals and seals within a few hundred to a few thousand meters of the calving event. Mattmüller *et al*. (2022) assess the seasonal presence of vocalizing marine mammals off Tasiilaq, Southeast Greenland, using three years of passive acoustic recordings at one site and one year of recordings at a second site approximately 30 km distant.

Finally, Sheng *et al*. (2021) measured under-ice ambient sound in the Mudan River in northeast China and argue that the study of under-ice noise in fresh-water rivers can be used as an analog to simulate the sounds generated by multiyear ice in the Arctic.

### B. Ocean acoustic propagation: Measurements and modeling

The Canada Basin has experienced some of the greatest changes in ice cover and ocean stratification in the Arctic Ocean (McLaughlin *et al.*, 2011). The decrease in ice extent and thickness, the disappearance of multiyear ice, and the appearance and strengthening of the Beaufort Duct have dramatically affected sound propagation in the Canada Basin and Beaufort Sea. Most of the papers in this section report on measurements and/or modeling of acoustic propagation or on measurements of the sound-speed field in this region. The remaining two papers report on propagation in a fjord and on an Arctic shelf.

Ballard *et al.* (2020), Duda *et al.* (2021), and Baggeroer and Collis (2022) report on measurements of transmission loss. Ballard *et al.* (2020) report on broadband, long-range propagation from moored sources in the Canada Basin with center frequencies around 250 Hz to a receiver on the Chukchi Shelf during the 2016–2017 SW-CANAPE experiment. They focused on the loudest arrival in the receptions, which was associated with propagation in the Beaufort Duct. The duct weakened significantly over the slope and shelf in the winter and spring, however, resulting in decreases in the received levels that exceeded 60 dB because the sound was no longer trapped in the duct and interacted with the ice-covered surface. Duda *et al.* (2021) interpret the received levels at a different receiver on the Chukchi Shelf during the 2016–2017 SW-CANAPE experiment using a surface-forced ocean circulation model with ice cover. The PSW in the model is strained and filamentary, affecting the Beaufort Duct and acoustic propagation. Finally, Baggeroer and Collis (2022) interpret transmission loss measurements in the deep Beaufort Sea during the U. S. Navy Ice Exercise in March 2018 (ICEX-18) in terms of acoustic modal propagation. Transmissions at frequencies from 100 to 550 Hz from a source suspended from the ice were recorded on a towed array receiver on a U.S. Navy submarine transiting away from the ice camp out to a maximum range of approximately 100 km. The Beaufort Duct was present throughout the experiment. For a given acoustic mode to be fully trapped in the duct, the acoustic frequency must be greater than a critical frequency that increases with mode number. The situation is complicated in this case by the presence of a second, surface duct, however.

Kucukosmanoglu *et al.* (2021) and Kucukosmanoglu *et al.* (2022) report on observations made during the 2016–2017 deep water CANAPE experiment. Kucukosmanoglu *et al.* (2021) describe the sound-speed fluctuations in the Canada Basin, characterizing variability due to eddies, internal waves, near-inertial waves, and spice. Kucukosmanoglu *et al.* (2022) investigate sea-surface scattering using 11.0–12.5 kHz transmissions from the bottom-mounted acoustic transponders used to determine the positions of the CANAPE moorings as they moved in response to ocean currents. The receivers on the moorings recorded both the direct and single-bounce surface-reflected acoustic paths. The surface-reflected arrivals were using in an opportunistic effort to infer the changing ice characteristics.

The final two papers in this section report on propagation under special conditions that occur in the Arctic. Zeh *et al.* (2022) compare measurements and modeling of transmission loss on direct and surface-reflected paths at 11 kHz in a fjord covered with floating ice fragments from a marine-terminating glacier. Petnikov *et al.* (2022) study the effects of the spatial variability of bottom parameters on low-frequency acoustic propagation on a shallow Arctic shelf based on measurements of the sound-speed field in the seafloor from a three-dimensional (3-D) seismic survey in the Kara Sea.

### C. Positioning and navigation

A long-baseline (LBL) positioning system using one-way travel times from an AUV to acoustic transceivers suspended below the ice in the Beaufort Sea was used to navigate the AUV during the U. S. Navy Ice Exercise 2020 (ICEX-20) in March 2020 (Bhatt *et al.*, 2022). The presence of the Beaufort Duct significantly complicated the operation of the LBL system. Bhatt *et al.* (2022) describe real-time, ray-based prediction methods to improve the estimates of the effective sound speeds for the paths between the AUV and the receivers suspended below the ice, achieving accuracies of a few meters.

### D. Arctic geo-acoustics

Chotiros *et al.* (2021) analyze bottom-interacting acoustic receptions at 900 Hz from the 2013 UNDER-ICE transmission experiment in the Fram Strait between Greenland and Svalbard. The seabed was determined to consist of a thin (4.8 m) surficial layer over a sediment half-space based on the acoustic receptions combined with other available data on the seabed.

### E. Atmospheric propagation

Both the ocean and the atmosphere in the Arctic are changing in response to increasing greenhouse gases. The final paper in this special issue is on acoustic propagation in the atmosphere (Wilson *et al.*, 2022). A two-dimensional (2-D), wide-angle parabolic equation that includes the effects of high wind speeds was used to compute infrasound propagation out to ranges of about 200 km for a variety of atmospheric conditions specific to the Arctic.

## III. CONCLUSION

The Arctic is not done changing. Stroeve and Notz (2018) estimated that the Arctic Ocean will become ice free in the months of August and September in roughly 20 years based on the observed correlation between anthropogenic $CO_2$ emissions and sea-ice extent if the emission rate continues unchanged. There is of course considerable uncertainty in when the Arctic Ocean will in fact become ice free in summer, but sea-ice extent is continuing to decline. The decrease will cause further changes in acoustic propagation as well as increased anthropogenic activities in the Arctic. The ocean stratification can also be expected to continue to change as warm water enters the Arctic Ocean through the Barents Sea and the Fram and Bering Straits. In addition, the increase in open water as the sea ice extent decreases and the more frequent occurrence of open leads and polynyas in summer will lead to increased solar heating of the Arctic Ocean. The papers in this special issue, therefore, only represent a snapshot of current acoustic conditions in the Arctic Ocean. Ongoing research will be needed to understand the effects on ocean acoustics as the Arctic continues to evolve.

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