CLIMATE-DRIVEN VARIABILITY OF UNDERWATER NOISE PROPAGATION IN HORNSUND FJORD, SVALBARD

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Abstract: *Arctic fjords are particularly sensitive to climate warming due to the accelerated melt of glaciers and sea ice. The resulting meltwater delivery impacts the spatial and temporal variability of sound speed conditions. Changes in sound speed profiles modify underwater noise propagation – a key factor determining noise pollution. Moreover, the sea ice loss causes an increase in shipping traffic, which is a main source of anthropogenic noise. Here, we investigate the long-term variability of noise propagation conditions in Hornsund fjord, Svalbard. The archival CTD data collected from 2001 to 2019 along the fjord axis have been used for sound speed calculation. We used the Bellhop model to predict noise propagation in different years. The results show that the long-term variability of noise propagation in Hornsund is driven primarily by the intensity of glacier melting and shelf-fjord water exchange. Different underwater acoustic channels are identified. We also analyze and discuss the variable transmission loss of the shipping noise and its potential impact on marine mammals. As ocean warming continues, we suggest that the climate-driven changes in the propagation of anthropogenic noise will impact the noise pollution in Hornsund.*

Keywords: *underwater noise propagation, Arctic fjords, climate warming*

1. INTRODUCTION

Arctic fjords are particularly sensitive to climate warming due to the accelerating retreat of glaciers and sea ice melting (e.g., [1]). Processes of ice loss can influence the marine noise pollution in two different ways. First, the sea ice loss causes an increase in shipping traffic, which is a main source of anthropogenic noise in the fjords (e.g., [2]). Second, meltwater delivery modifies the thermohaline structure of the water column, which changes sound speed profiles (e.g., [3]). For example, in the Arctic, cold and less saline water near the surface creates an upward refracting sound speed profile (near-surface sound channel; [4]). Such changes in sound speed profiles influence underwater noise propagation, which is a key factor determining the noise pollution (e.g., [5]). Underwater noise pollution affects marine mammals, causing behavioural disturbance, hearing damage, and masking effects (e.g., [5]). For this reason, it is important to understand the impact of climate warming on underwater noise propagation in Arctic fjords.

Here, we discuss the impact of climate-driven warming on the underwater noise propagation in Hornsund fjord, Svalbard. Two contrasting years are presented to demonstrate this relationship: 2001 and 2014.

2. STUDY AREA

Hornsund is a glacierized fjord located in the southernmost part of West Spitsbergen (red box in Fig. 1). It is approximately 10 km wide and extends about 35 km [6]. Fifteen marine-terminating glaciers flow into Hornsund. Glacier meltwater runoff, resulting from the surface melting of ice, is the major freshwater input to the fjord [7]. Moreover, the fjord's mouth topography facilitates the water exchange with the West Spitsbergen Shelf, specifically water from two different currents: cold and less saline water from the Spitsbergen Polar Current and warm and more saline water from the West Spitsbergen Current (Fig. 1a) [8]. The warming of fjord waters, along with atmospheric warming, intensifies meltwater runoff and submarine glacier melting in the fjord (e.g., [1]).

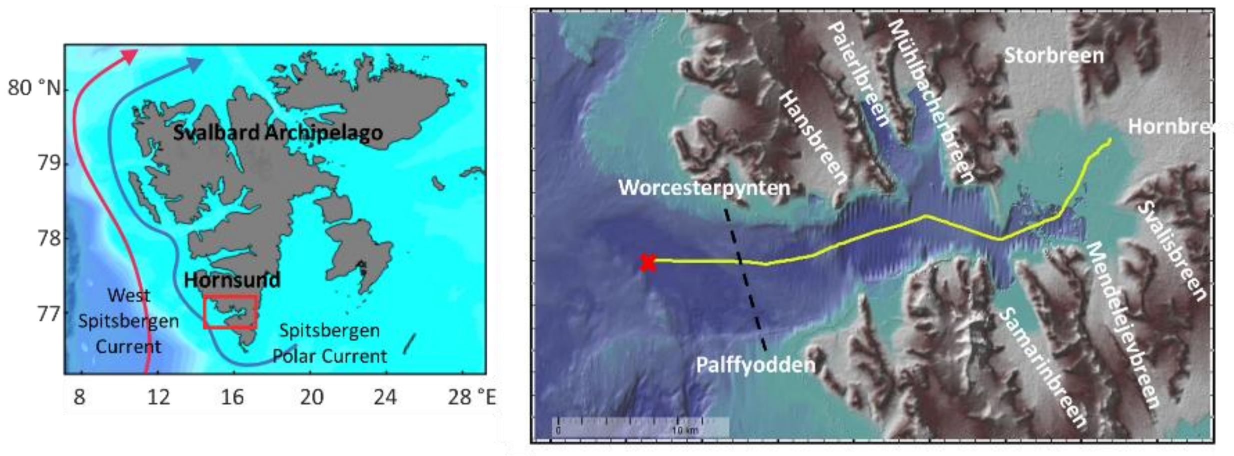

Fig.1: The study area. (a) Svalbard archipelago, the location of Hornsund fjord (red box) and main currents (adopted after Nilsen et al. [9]). (b) Detailed map of Hornsund fjord with positions of the CTD transect (yellow line). The red cross indicates the position of the passenger ship in modelling of noise transmission loss.

In Hornsund, summer is the main shipping season. The ship traffic is dominated by passenger ships, the number of which continuous to grow [10]. The increasing ship traffic certainly results in higher noise levels in the fjord that potentially impact the marine life. Hornsund is home to several cetaceans species [11]. In this study, we limit our analysis to the arctic endemic beluga whale (*Delphinapterus leucas*) and the summer resident minke whale (*Balaenoptera acutorostrata*), both of which are sensitive to shipping noise [12].

3. METHODS

3.1 Sound speed calculation

The CTD data, collected along the fjord axis in late July of 2001 (138 stations) and 2014 (82 stations), were used for sound speed calculation (Fig. 1b). For this purpose, we used Chen and Millero formula adopted by UNESCO [13].

3.2 Transmission loss and received noise level calculation

The beam tracing Bellhop model was used to calculate transmission losses in the study area [14, 15]. Incoherent transmission loss calculations were performed using the Gaussian ray bundle approximation based on the sound speed calculation in 2001 and 2014. The vertical and horizontal resolution of the model were $\lambda/4$ and λ, respectively, where λ is the sound wavelength. The number of beams was set to 28400, with the emitting angles ranging from -80 to 80 degrees with respect to the sea surface. The Thorpe equation was used for the frequency-dependent attenuation in seawater. The homogeneous silt sediment was considered for Hornsund [16]. The seafloor's sound speed and density were set to 1570 m/s and 1.6 g/cm^3, respectively [17]. The frequency-dependent seafloor attenuation was set to 0.1 dB/m/kHz [18]. Bathymetry data for the model were provided by the Norwegian Hydrographic Service. We assumed a flat sea surface. The passenger ship was considered as the noise source located 2 m below the sea surface in the fjord’s mouth (Fig. 1b, red cross). We considered one harmonic component of frequency spectrum of the ship noise at 1 kHz.

The sonar equation was applied to calculate the received noise level (RL) at receiver depth of 5 m below the sea surface along the fjord (see Eq. 1), using 152 dB re 1µPa as the ship's source level (SL) at 1 kHz [19], and transmission loss (TL) calculated from the beam tracing Bellhop model.

$$RL = SL - TL \quad (1)$$

Studying the possible impact of the shipping noise on marine mammals required the consideration of hearing thresholds: 95 dB re 1µPa and 80 dB re 1µPa for belugas and minke whales, respectively [20, 21].The visualizations of the results were done using the MATLAB software (Version 2020b).

4. RESULTS AND DISCUSSION

4.1 Variability of near-surface sound channels in Hornsund

Fig. 2 illustrates two contrasting scenarios of sound speed profiles in Hornsund. In 2001, the barely visible near-surface sound channel was observed only in the easternmost part of the fjord (pink rectangle in Fig. 2a). In contrast, in 2014, more prominent near-surface sound channel developed along the entire fjord (pink rectangle in Fig. 2b).

The fact that Hornsund is a glacierized fjord is crucial, particularly because cold and fresh glacier meltwater forms a near-surface sound channel in Hornsund during the warmer summer periods, which was demonstrated in Vidanamesthrige et al. [22]. Accordingly, the lack of a prominent near-surface sound channel in 2001 could be due to reduced glacier meltwater input, likely caused by the cold water flowing from the Spitsbergen Polar Current into the fjord and the relatively low air temperature in that year [8, 23]. Meanwhile, it was shown in Vidanamesthrige et al. [22] that in 2014 long and prominent near-surface sound channel was formed as a result of intense glacier meltwater that was almost certainly caused by the inflow of warm water from the West Spitsbergen Current (WSC) into the fjord in combination with atmospheric warming [8, 22].

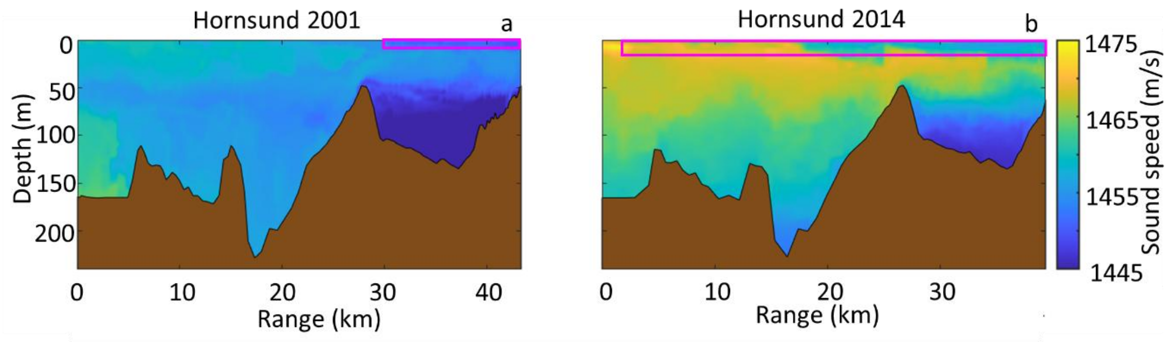

Fig. 2: Sound speed profiles (a and b) along Hornsund in 2001 (left panel) and 2014 (right panel). Pink rectangles indicate the near-surface sound channels.

4.2 Variability of the shipping noise level in Hornsund and its potential consequences

Fig. 3 illustrates the received noise level of the passenger ship along the Hornsund fjord. In 2014, the ship noise level was higher near the surface compared to 2001 (Fig. 3). This higher level resulted from the lower transmission loss due to the more prominent long near-surface sound channel in 2014 (see Fig. 2).

Consequently, in 2014, the ship noise exceeded the hearing threshold of the beluga whale (black dashed line) up to 5 km from the ship, while in 2001 this range was almost two times smaller (~3 km). Moreover, for minke whales, ship noise exceeded their hearing threshold (green dashed line) up to ~23 km from the ship in 2014, which was a larger noise detection range than in 2001 (~17 km). These findings suggest that the prominent near-surface sound channel in 2014 contributed to expanding the ship noise detection range for both species. Consequently, ship noise impact on both species could be higher that year.

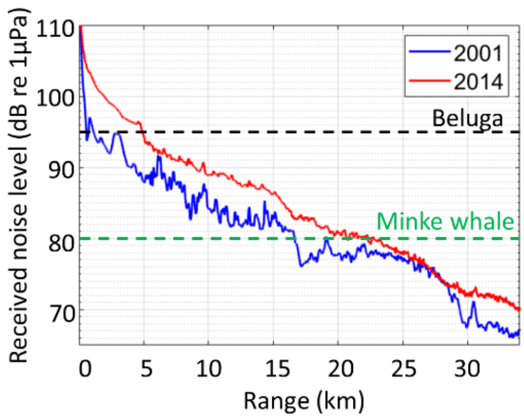

Fig. 3: Range-dependent, received levels of the underwater noise produced at 1 kHz by a passenger ship in Hornsund in 2001 (blue) and 2014 (red). The source and receiver depths were set to 2 and 5 m, respectively. The black and green dashed lines indicate the hearing threshold levels at 1 kHz for the beluga and minke whales, respectively.

5. CONCLUSIONS

The climate-driven variability of near-surface sound channels in Hornsund was evidenced by the lack of a channel in 2001 and its pronounced presence in warmer 2014 year. A more prominent long near-surface sound channel in 2014 resulted in reduced sound transmission loss, leading to increased ship noise level in the fjord compared to 2001. Therefore, the ship noise detection ranges for Beluga and Minke whales were increased near the surface in 2014. The results demonstrate that climate-driven warming of Hornsund can make beluga and minke whales more sensitive to the shipping noise.

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