Seasonal Variation in Underwater Noise Levels in Western Baffin Bay, Nunavut, Canada

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by

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ABSTRACT

Scharffenberg, K., Hussey, N. and Marcoux, M. 2021. Seasonal Variation in Underwater Noise Levels in Western Baffin Bay, Nunavut, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3449: v + 39 p.

Underwater noise levels in the Arctic are typically lower than the rest of the ocean, enabling acoustic signal detection over long distances. However, noise levels are expected to increase as climate driven changes result in longer periods of open water and increased anthropogenic activity. Therefore, characterization of baseline noise levels is essential to understanding the effects of environmental changes on the ecosystem. Ambient noise levels have been reported in various locations in the Arctic, but have yet to be reported in Baffin Bay, an area that is expected to see a notable increase in anthropogenic activity. To address this gap, acoustic recording units were deployed between 2014 and 2018 at five locations on the east coast of Baffin Island, Nunavut. Broadband sound pressure level (SPL) and third-octave level measurements were made for each month at each location and representative power spectral density plots were computed for October and March (generally the loudest and quietest months respectively) at each station. Linear regression models were created to examine the effect of wind speed on SPL under different sea-ice conditions. Long term spectral average plots were created to identify general patterns of marine mammal occurrence and vessel traffic. There was a high degree of seasonality, with the highest sound pressure levels recorded in September/October at all stations. In autumn, bowhead whales, narwhals, and vessel traffic were common at all stations. Wind speed had the greatest effect on SPL in the open-water months compared with ice covered months at all stations.

RÉSUMÉ

Scharffenberg, K., Hussey, N. and Marcoux, M. 2021. Seasonal Variation in Underwater Noise Levels in Western Baffin Bay, Nunavut, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3449: v + 39 p.

Les niveaux de bruit sous-marin dans l'Arctique sont généralement inférieurs au reste de l'océan, permettant une détection efficace des signaux acoustiques sur de longues distances. Cependant, les niveaux de bruit devraient augmenter à mesure que les changements climatiques entraînent de plus longues périodes d'eau libre et une activité anthropique accrue. Par conséquent, la caractérisation des niveaux de bruit de base est essentielle pour comprendre les effets des changements environnementaux sur l'écosystème. Des niveaux de bruit ambiant ont été enregistrés à divers endroits de l'Arctique, mais n'ont pas encore été publiés dans la baie de Baffin, une zone qui devrait connaître une augmentation notable de l'activité anthropique. Pour combler cette lacune, des unités d'enregistrement acoustique ont été déployées entre 2014 et 2018 à cinq endroits sur la côte est de l'île de Baffin, au Nunavut. Des mesures du niveau de pression acoustique (NPA) à large bande et en tiers d’octave ont été effectuées pour chaque mois à chaque emplacement et des diagrammes représentatifs de densité spectrale de puissance ont été calculés pour octobre et mars (généralement le mois les plus bruyant et le plus silencieux respectivement) à chaque station. Des modèles de régression linéaire ont été créés pour examiner l'effet de la vitesse du vent sur le NPA dans différentes conditions de glace de mer. Des représentations graphiques de moyennes spectrales à long terme ont été créées pour identifier les schémas généraux d'occurrence de mammifères marins et de trafic maritime. Le degré de saisonnalité était élevé, les niveaux de pression acoustique les plus élevés ayant été enregistrés en septembre / octobre dans toutes les stations. En automne, les baleines boréales, les narvals et le trafic maritime étaient courants à toutes les stations. La vitesse du vent a eu le plus grand effet sur le NPA pendant les mois en eau libre par rapport aux mois couverts de glace dans toutes les stations.

1. INTRODUCTION

The underwater soundscape is an important feature of the marine ecosystem (Duarte et al. 2021). Sound propagates very effectively underwater, and many species have developed ways to exploit this for communication and other purposes. For instance, baleen whales have developed long distance communication networks for mating and other forms of social interaction (Edds-Walton 1997), and toothed whales have developed echolocation systems (Au 1993), and communication systems which facilitate cooperative behaviour (Benoit-Bird and Au 2009) and group cohesion (Ford 1991, Yurk et al. 2002). Additionally, several fish species generate sound in certain behavioural situations including distress, combative interactions, courtship, and to maintain social status (Amorim 2006, Ladich and Fine 2006, Cott et al. 2014, Ladich 2019).

Ambient noise is the major component of the underwater soundscape. It is the background noise against which signals are discerned, and when heightened, it can affect an animal's ability to detect and interpret signals. Contributors to ambient noise can be natural, including biological (i.e., animal noises) and physical (e.g., natural seismic activity, wind, waves, rain), or anthropogenic. Seismic activity typically affects the 1-20 Hz bandwidth, changes to sea-state (associated with wind speed) influence noise levels up to 100 kHz, though the greatest impacts are typically below 10 kHz, while rainfall affects a similar bandwidth with the greatest influence in the 3 - 10 kHz range (Heindsman et al. 1955, Wenz 1962, Urick 1983, Au and Hastings 2008). Anthropogenic sources include: commercial shipping, oil and gas exploration and development (e.g., air-guns, ships, oil drilling), naval operations (e.g., sonar, military communications, and explosions), icebreaking, recreational boating and many others. Most anthropogenic noise affects the 20-1000 Hz range, with large ships impacting the 20-200 Hz bandwidth (Urick 1983, Ross 2005). Increases in anthropogenic noise can have detrimental effects on wildlife, especially marine mammals, through the masking of communication signals, which decreases the range at which these signals can be heard (Erbe and Farmer 1998, Simard et al. 2008, Clark et al. 2009). Anthropogenic noise can also cause behavioural responses, including avoidance (Richardson et al. 1985, Castellote et al. 2012), changes to the frequency and rate of calling (Lesage et al. 1999, Scheifele et al. 2005, Parks et al. 2007, Blackwell et al. 2015, 2017), and changes in respiration and dive rates (Richardson et al. 1990, Williams et al. 2014), and may result in increased stress levels (Wright et al. 2007, Rolland et al. 2012).

The Arctic typically experiences lower levels of ambient noise than the rest of the ocean due to the presence of sea ice, which isolates the marine environment from weather-related noises, and the lack of human activity in the region (Diachok and Winokur 1974, Roth et al. 2012, Insley et al. 2017). However, sea ice can contribute to heightened ambient noise levels, especially at the ice edge (Diachok and Winokur 1974) and during freeze-up and break-up (Roth et al. 2012, Kinda et al. 2013, 2015, Insley et al. 2017) due to ice fracturing and sheering, and collisions among ice blocks. The seasonal presence of sea ice means ambient noise levels in the Arctic are also highly seasonal. As climate driven changes result in longer periods of open water (Stroeve et al. 2012) and increased levels of human activity (Reeves et al. 2014, Dawson et al. 2018), ambient noise levels are expected to increase, and sound dynamics will change (e.g., the timing of ambient sounds associated with ice fracturing will change, and there will be fewer ambient sounds associated with ice cover). Characterization of baseline noise levels is essential to monitor and manage the impacts of increased noise on the marine ecosystem (Reeves et al. 2014, Merchant et al. 2016).

Ambient noise levels have been reported in various locations in the Arctic, including the Beaufort Sea (Roth et al. 2012, Kinda et al. 2013, Simard et al. 2014, Insley et al. 2017, Haver et al. 2018), Bering Sea (Stafford et al. 2018), Chukchi Sea (Roth et al. 2012, Haver et al. 2018) and Greenland Sea (Bourke and Parsons 1993, Klinck et al. 2012, Ahonen et al. 2017, Haver et al. 2017, Ozanich et al. 2017), but have yet to be reported in the Kara Sea, the Laptev Sea, or the East Siberian Sea (PAME 2019). Reports from Baffin Bay are limited to a recent comparison of sites across the Canadian Arctic (Halliday et al. 2021) which presented broad-scale summaries, but did not report detailed seasonal or monthly values. This region is expected to see a notable increase in anthropogenic noise due to accelerated industrial pressures, including the operations of a relatively new large-scale mining operation (Mary River Project of Baffinland Iron Mines Corporation), increased oil and gas exploration, expansion of fisheries, and increased shipping through the northwest passage (Reeves et al. 2014). As such, there is a pressing need to document baseline ambient noise levels in this region. Hydrophones have been deployed in Baffin Bay since 2014 to collect data on marine mammals in the region. Here, we use this data to characterize ambient noise in the region.

2. MATERIALS AND METHODS

2.1 ACOUSTIC RECORDINGS

Acoustic recording units were deployed in Autumn between 2014 and 2018 on the east coast of Baffin Island, near Scott Inlet and Qikiqtarjuaq, Nunavut, at stations G02-04, G15-01, QMM01, G05-03, and G05-04 (Figure 1). Recorders were recovered at approximately the same time the following year for servicing and data download, though in all cases the recorder stopped before the retrieval date (sometimes well before; see Table 1 for dates). In most cases, the same recording unit was redeployed at each site in subsequent years. Recorders were attached to a line connecting a subsurface float to an acoustic release attached to an anchor at depths ranging from 150m to 507m (Figure 2; Table 1). Most acoustic recordings were made with Song Meter SM2M+ Submersible Marine Recorders (Wildlife Acoustics, Maynard, MA, USA), with one SM3M (Wildlife Acoustics). Recorders were equipped with HTI 96-MIN hydrophones, (High Tech Inc, Long Beach, MA, USA) with hydrophone sensitivities ranging from -165 to -166 ± 1 dB re 1 V/µPa, and a flat frequency response between 100 Hz and > 50 kHz, decreasing to ~-175 dB re 1 V/µPa at 20 Hz. Sample rates varied between 48000 Hz and 384000 Hz (see Table 1). In most cases, two different sampling rates were used: a low frequency sample rate every hour, and a high frequency sample for a shorter duration a few times per day (e.g., 4 mins at 96000 Hz every hour, with 1 min every 6 hours recorded 384000 Hz). In this report, we present results from the low frequency sample rate; these are presented in Table 1.

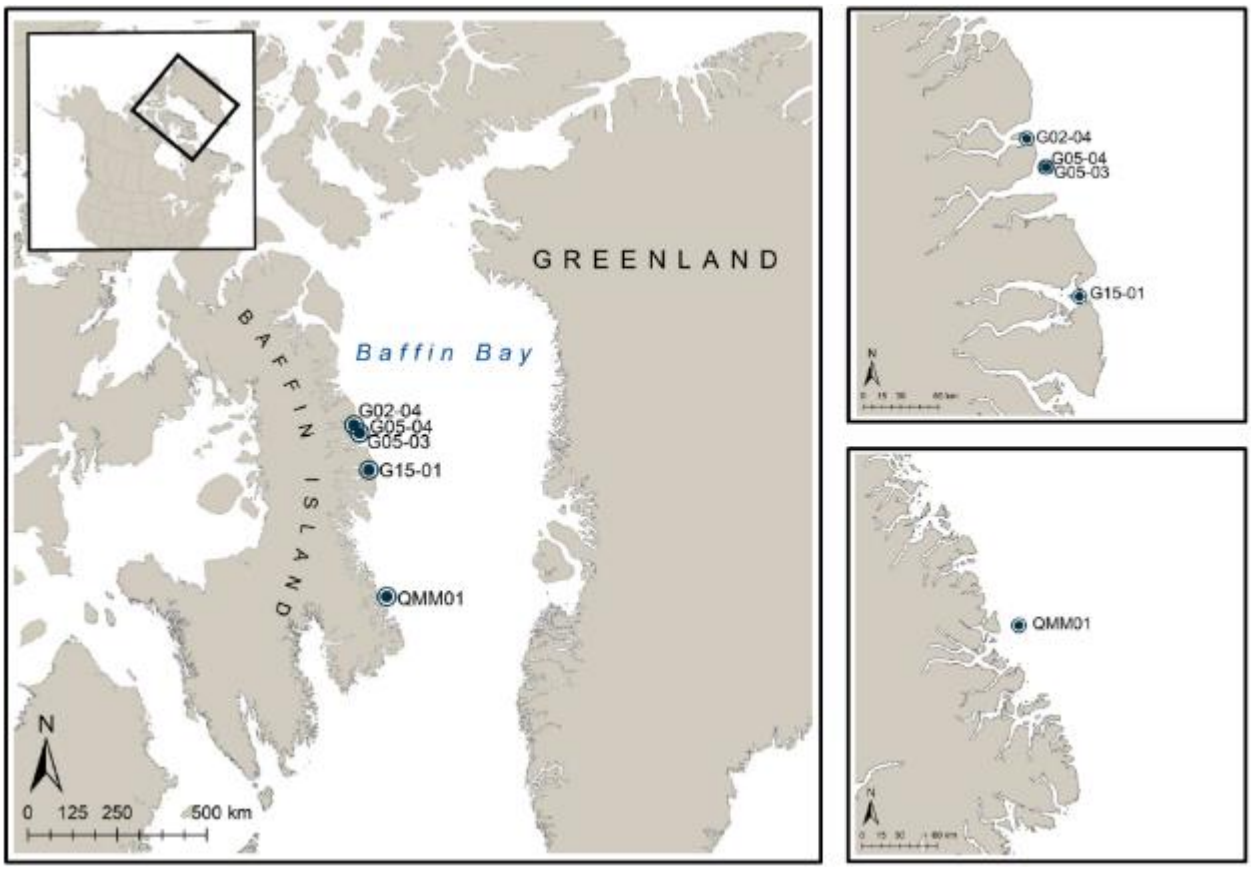

Figure 1: Map of Baffin Island showing location of 5 stations where hydrophones were deployed between 2014 and 2018.

Figure 2: Mooring configuration used in Baffin Bay deployments 2014-2018.

Table 1: Basic information about hydrophone deployments 2014/2015-2017/2018.

Station	Year	Sensor Model	Latitude	Longitude	Duty Cycle (min)	Sample Rate (Hz)	Depth (m)	Recording Start (YYYY-MM-DD)	Recording Finish (YYYY-MM-DD)
G02-04	2015/2016	SM2M+	71.12733333	-70.9772	4on/56off	96000	255	2015-09-28	2016-09-03
G02-04	2016/2017	SM2M+	71.12806667	-70.977733	4on/56off	96000	205	2016-09-13	2017-02-26
G15-01	2014/2015	SM2M+	70.3248	-68.3404167	5on/55off	48000	408	2014-09-26	2015-09-12
G15-01	2015/2016	SM2M+	70.32416667	-68.33833	5on/55off	96000	425	2015-10-07	2016-09-16
G15-01	2016/2017	SM2M+	70.324	-68.3375	4on/56off	96000	412	2016-09-25	2017-07-17
G15-01	2017/2018	SM2M+	70.325	-68.339	5on/55off	192000	414	2017-09-29	2018-03-30
QMM01	2016/2017	SM2M+	67.613	-63.447383	3on/57off	96000	150	2016-09-05	2017-04-01
QMM01	2017/2018	SM2M+	67.612333	-63.44733	5on/55off	192000	329	2017-09-27	2018-01-17
G05-03	2016/2017	SM2M+	71.01983333	-70.317833	4on/56off	96000	161	2016-09-12	2017-04-02
G05-03	2017/2018	SM2M+	71.01983333	-70.316833	5on/55off	192000	165	2017-10-04	2018-04-30
G05-04	2015/2016	SM3M	71.0245	-70.293333	7on/53off	96000	507	2015-09-30	2016-09-06

2.2 SOUND ANALYSIS

Sound pressure level (SPL) was measured using the software package PAMGuide (Merchant et al. 2015) run in MATLAB® (The MathWorks, Natick, MA, USA). The recorded acoustic signal was converted to absolute sound pressure values using the sensitivity curve of the HTI-96-MIN hydrophones, the amplification gain used, and the voltage conversion factor of its A/D convertor. All recordings appeared to use a high-pass filter at 30 Hz, so analyses were restricted to frequencies > 30 Hz, and broadband SPL measurements were restricted to > 100 Hz to match the flat portion of the hydrophone's frequency response curve. Broadband SPL was measured in the 100-1000 Hz (low), 1000-10000 Hz (mid), and 10000-48000 Hz (high) bandwidths (in 2014, G15-01 was sampled at 48000 Hz so it was not included in the high bandwidth measurements). Measurements were made using a Hann window in 1-s segments with 50% overlap averaged to 60-s resolution via the Welch method (Welch 1967). 1/3-octave band levels (TOLs) were also calculated in 1-s segments and averaged to 60-s resolution via the Welch method. TOL measurements below 100 Hz were corrected using the sensitivity curve of the HTI hydrophone provided by the manufacturer. Median SPL and TOL measurements were presented, along with boxplots indicating the spread of values for each season at each location. Additionally, power spectral densities (PSDs) were computed for the 30-1000 Hz bandwidth, using 1-s segments and averaged to 60-s resolution via the Welch method for one two-week period in October and March for each station. These months were chosen as representatives of

relatively loud, open-water conditions (October) and quiet, ice-covered conditions (March). Long term spectral average plots (LTSA) were computed for each hydrophone using the MATLAB® script Triton (Scripps Whale Acoustic Lab, San Diego, CA, USA), to average acoustic energy over 5 s intervals and 100 Hz frequency bins. LTSA spectrograms were presented using a 1920 FFT Hann window with 50% overlap to visualize sound pressure measurements. Manual scans of LTSAs and spectrograms were conducted to identify common sounds which were representative of the soundscape. Recorded sounds that were not part of the soundscape, like mooring strum and flow noise, were also noted where present. These types of sounds (especially flow noise) can artificially elevate noise levels and mask true signals; this primarily occurs in the lower frequencies (tens of Hz), but can extend to higher frequencies (hundreds of Hz) during strong currents (Strasberg 1979, Bassett et al. 2014).

To investigate short, impulsive sounds (which were not well represented with 60-s resolution measurements), SPL was also calculated to a 0.5-s resolution for the low, mid, and high bandwidths for examples of the following conditions: 1) silent conditions, 2) ice cracking, 3) ice and wind, 4) ice shedding, 5) seismic operations, 6) vessel passing, 7) bowhead presence, and 8) narwhal presence. Spectrograms were made for each of these conditions using PAMGuide. Spectrograms were made with varying time and frequency resolutions, depending on the content being displayed, because of the trade-off between smearing in the time or frequency domain. Where presented, spectrogram parameters are provided in the figure caption.

2.3 EFFECT OF WIND

To examine the effect of wind speed on SPL under different sea-ice conditions, we conducted linear regression of mean wind speed on 2-day averaged SPLs for the low, mid, and high bands in the open water months (September-October) and ice-covered months (February-March). Wind speed data were obtained from climate stations at Qikiqtarjuaq (for QMM01) and Clyde River (for G02-04, G05-03, G05-04, G15-01) maintained and monitored by the Department of Environment and Climate Change Canada (downloaded from http://climate.weather.gc.ca/). Using 2-day averages allowed us to measure the effects of broader regional wind patterns rather than local, short-term variation, given that weather stations were distant from the hydrophones. The Qikiqtarjuaq weather station was ~25km from QMM01, and the Clyde River weather station was ~45km, 60km, and 84km from G05-03/04, G02-04, and G15-01, respectively. Regression models were conducted in R (package *stats*; function *lm*, R Core Team 2016).

3. RESULTS AND DISCUSSION

3.1 RECORDING QUALITY

In general, recording quality was good, with some limitations imposed by the noise-floor and self-noise (noise generated by the recorder). The noise floor of the instrument was a limiting factor at high frequencies, so the lowest sound levels at these frequencies are probably lower than actually measured. This is common in many underwater recording systems at frequencies above 20 kHz (Merchant et al. 2015). TOL plots demonstrated this was the case at these frequencies even during the loudest months (see overlap of minimum and median values in Figure 3Figure 7). In the quietest months, overlap with the noise floor was present in lower frequencies as well. In previous Arctic studies, instrument noise floor has been a limitation in

winter months, even when recorders were equipped with low-noise hydrophones (e.g., Insley et al. 2017). Electronic noise is present on most PSD plots (Figure 8Figure 12) but was most evident on the SM3M unit (G05-04; Figure 8), especially during the winter months, when ambient noise was lowest. Self-noise for this unit is present on PSD plots as prominent peaks occurring at 25 Hz intervals. One of the authors (K. Scharffenberg) has observed this same electronic noise in other SM3M units (equipped with HTI 96-MIN hydrophones) deployed elsewhere in the Arctic (DFO unpublished data). In noisier months, this self-noise was mostly masked by ambient noise, but the hydrophone was nonetheless removed from subsequent analysis. Self-noise was present on the other hydrophones during the quietest months, with major peaks at 41, 120, 376, and 751 Hz (Figure 9Figure 12). Artificial signals, like vibrations, mooring strum, and flow noise, were rarely observed in LTSAs and spectrograms. Most of these signals, especially flow noise, were probably minimized by the 30 Hz high-pass filter. SPL measurements for G05-03 during the 2017/2018 deployment were anomalously low, suggesting an error occurred during recording or during programming. As such, this hydrophone was also excluded from analysis.

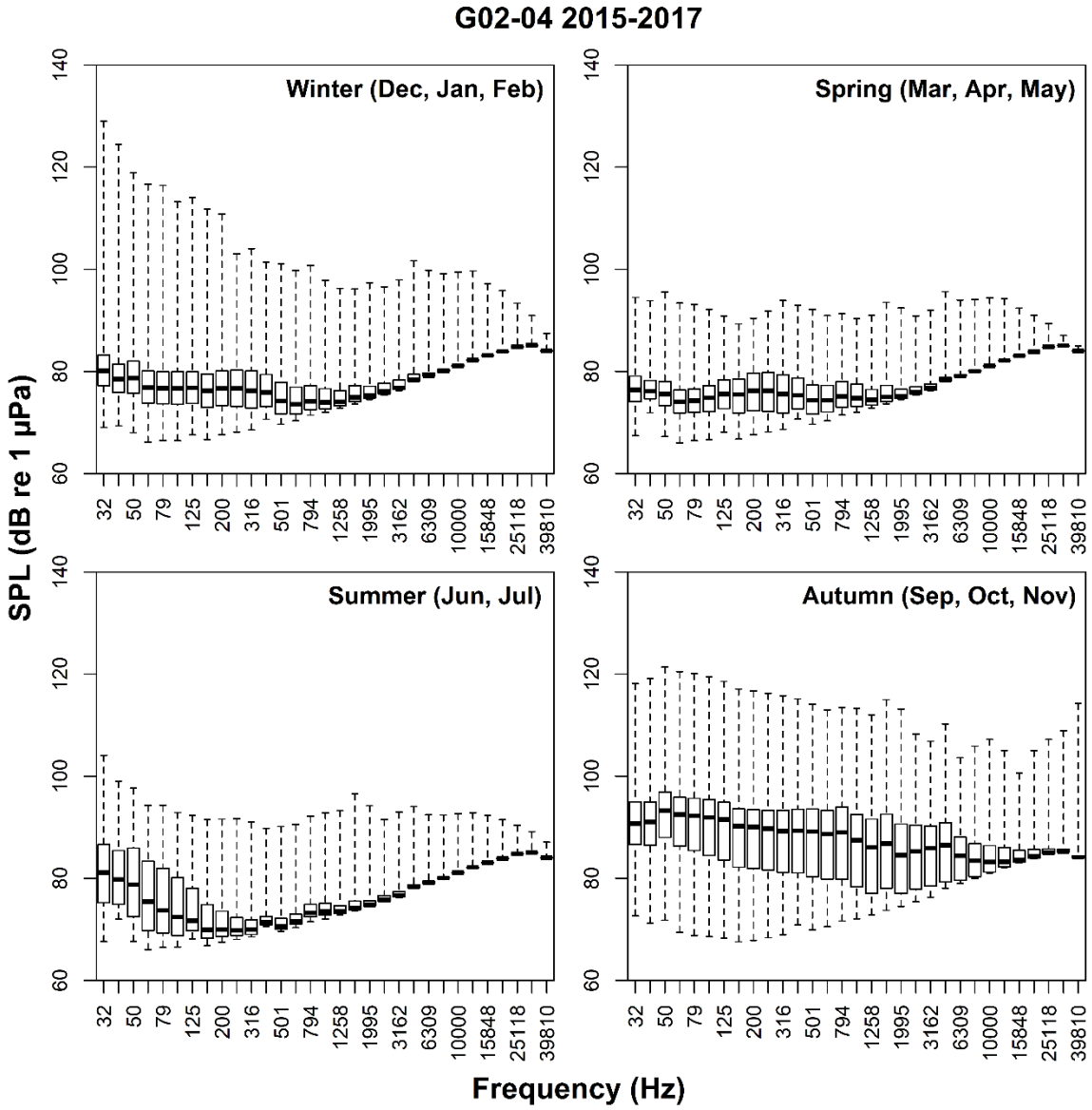

Figure 3: TOL measurements at the G02-04 station. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded sound pressure level (SPL) for each month. Note the range in higher frequencies is limited by the noise floor of the SM2M hydrophone.

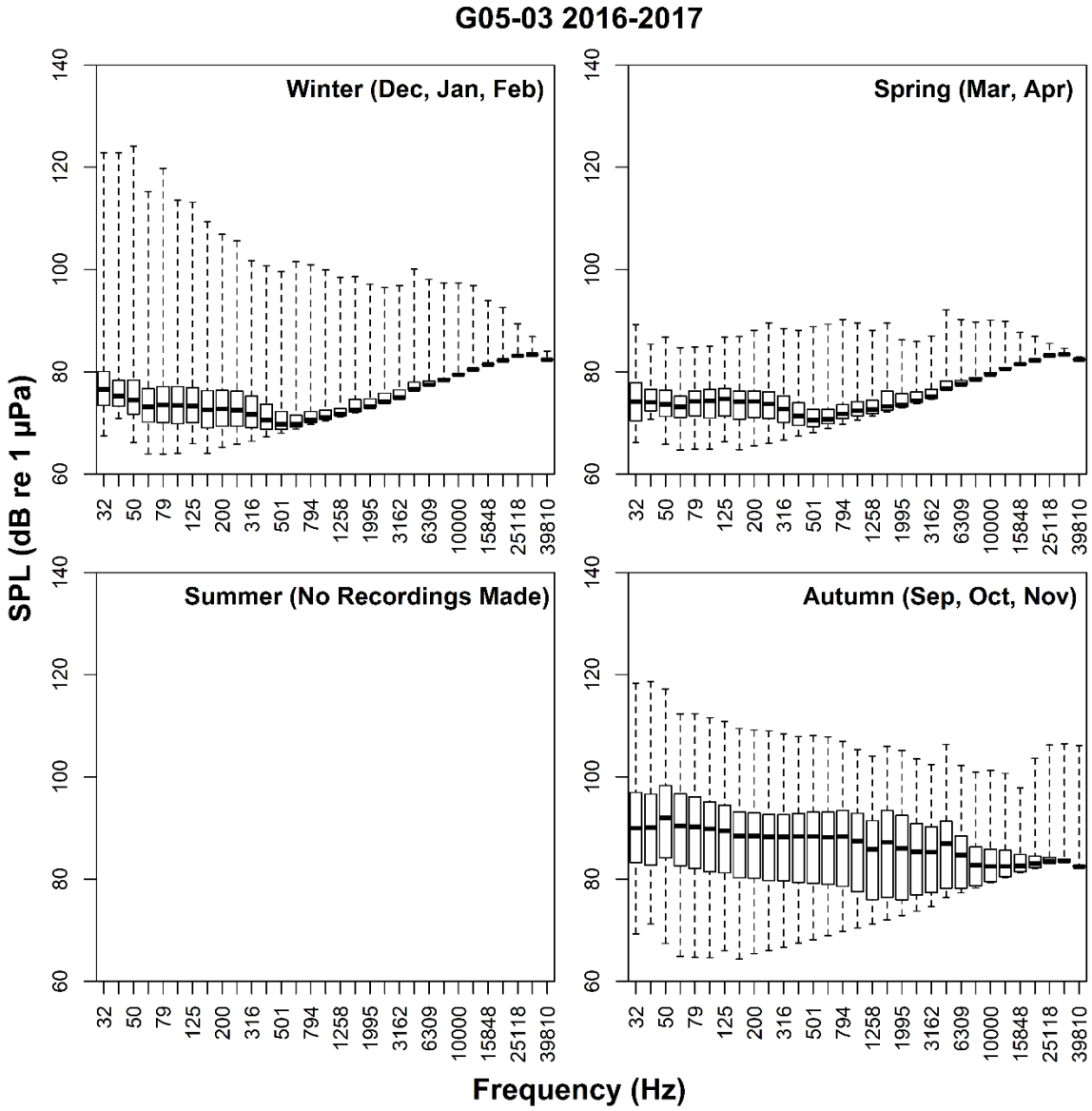

Figure 4: TOL measurements at the G05-03 station. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded sound pressure level (SPL) for each month. Note the range in higher frequencies is limited by the noise floor of the SM2M hydrophone. The acoustic recording unit stopped recording in April of the two years of deployment, therefore summer data was not available.

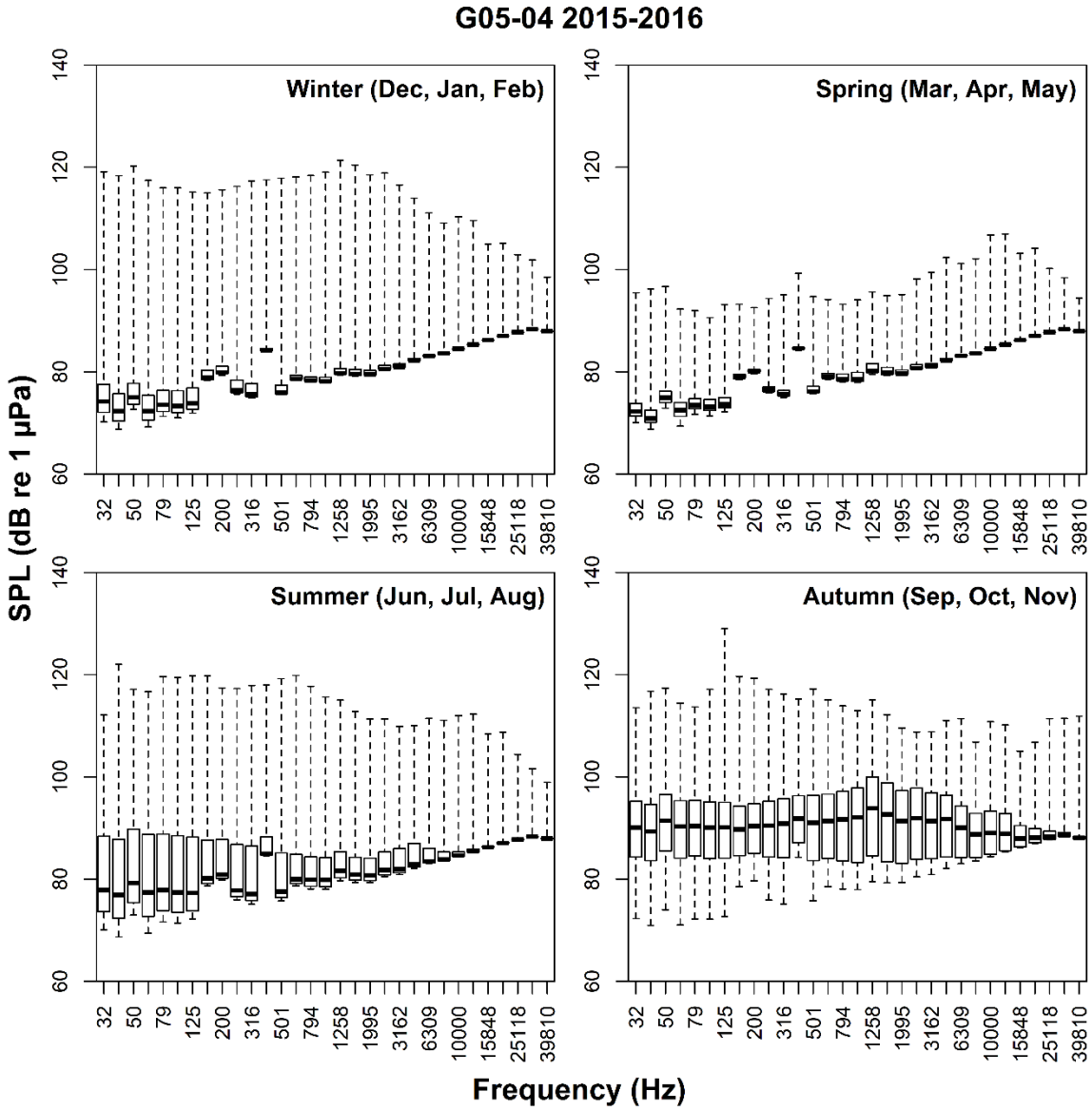

Figure 5: TOL measurements at the G05-04 station. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded sound pressure level (SPL) for each month. Note the range in higher frequencies is limited by the noise floor of the SM3M hydrophone. Also note electronic noise spikes in the winter, spring, and summer at 158, 200, and 398 Hz.

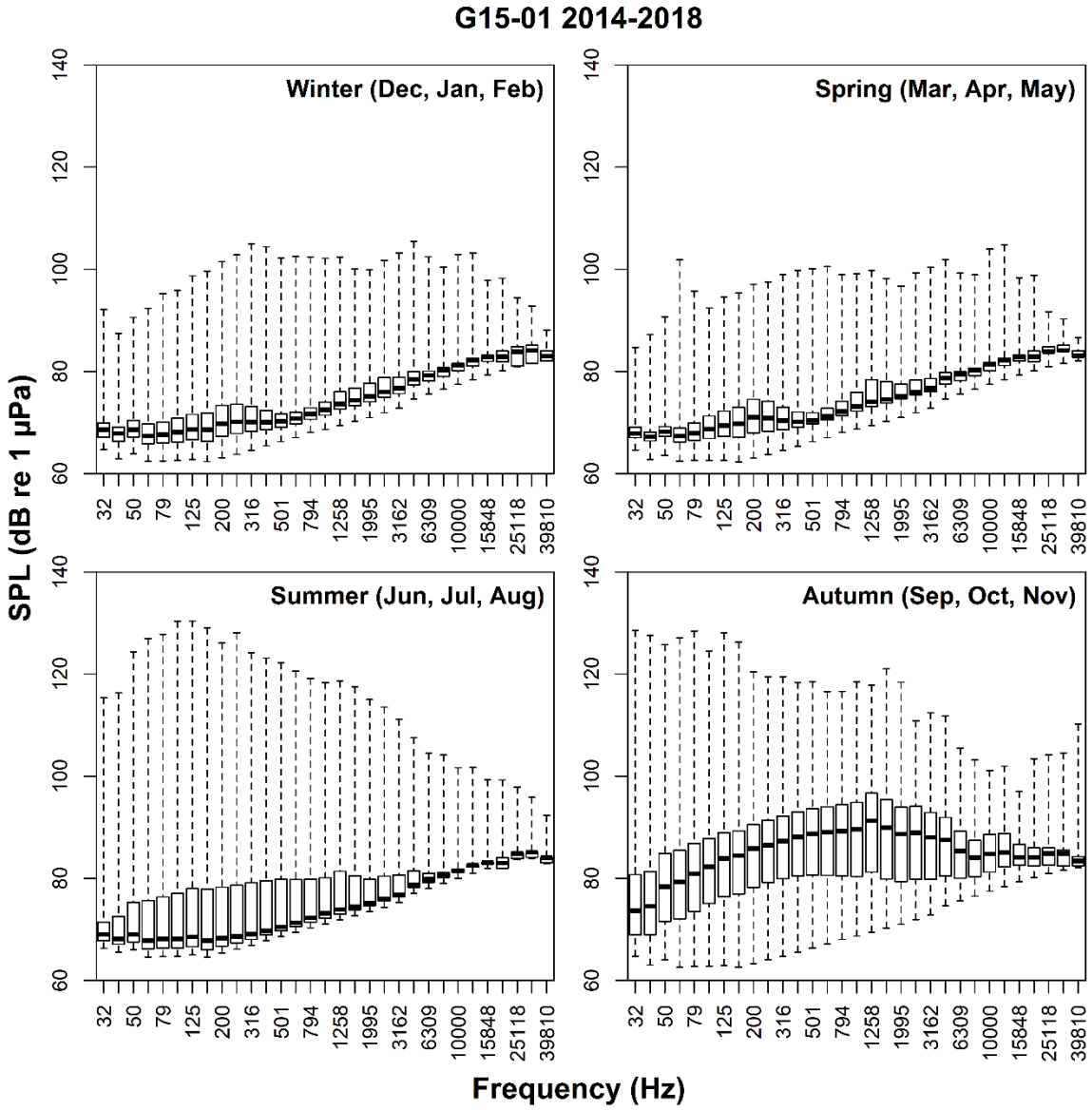

Figure 6: TOL measurements at the G15-01 station. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded sound pressure level (SPL) for each month. Note the range in higher frequencies is limited by the noise floor of the SM2M hydrophone.

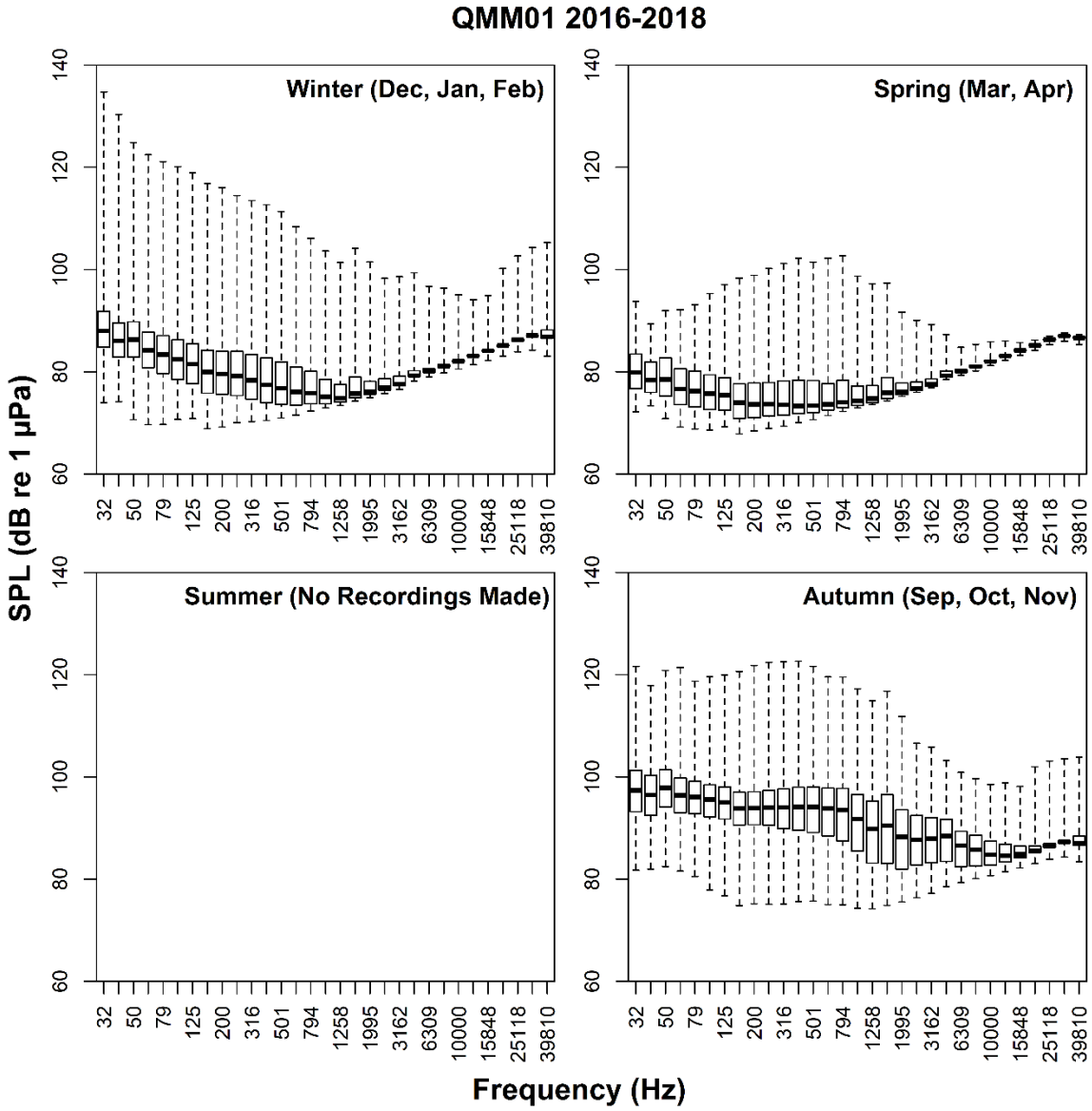

Figure 7: TOL measurements at the QMM01 station. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded sound pressure level (SPL) for each month. Note the range in higher frequencies is limited by the noise floor of the SM2M hydrophone. The acoustic recording unit stopped recordning in April 2017 and January 2018, therefore, summer data was not available.

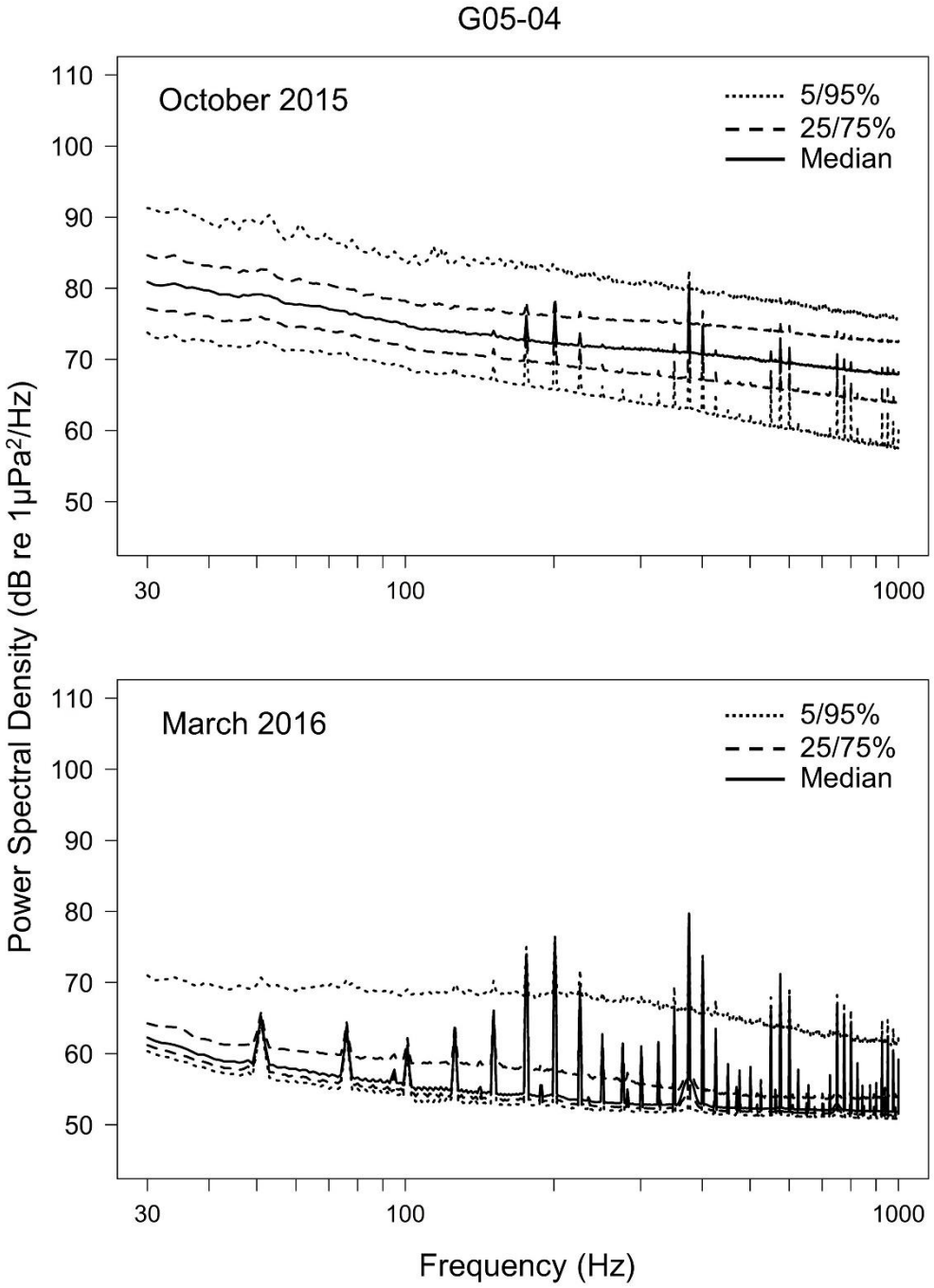

Figure 8: Power spectral density plots for a two-week period in October 2015 and March 2016 at the G05-04 station. Electronic noise appears as prominent peaks at 25 Hz intervals, beginning at 50 Hz.

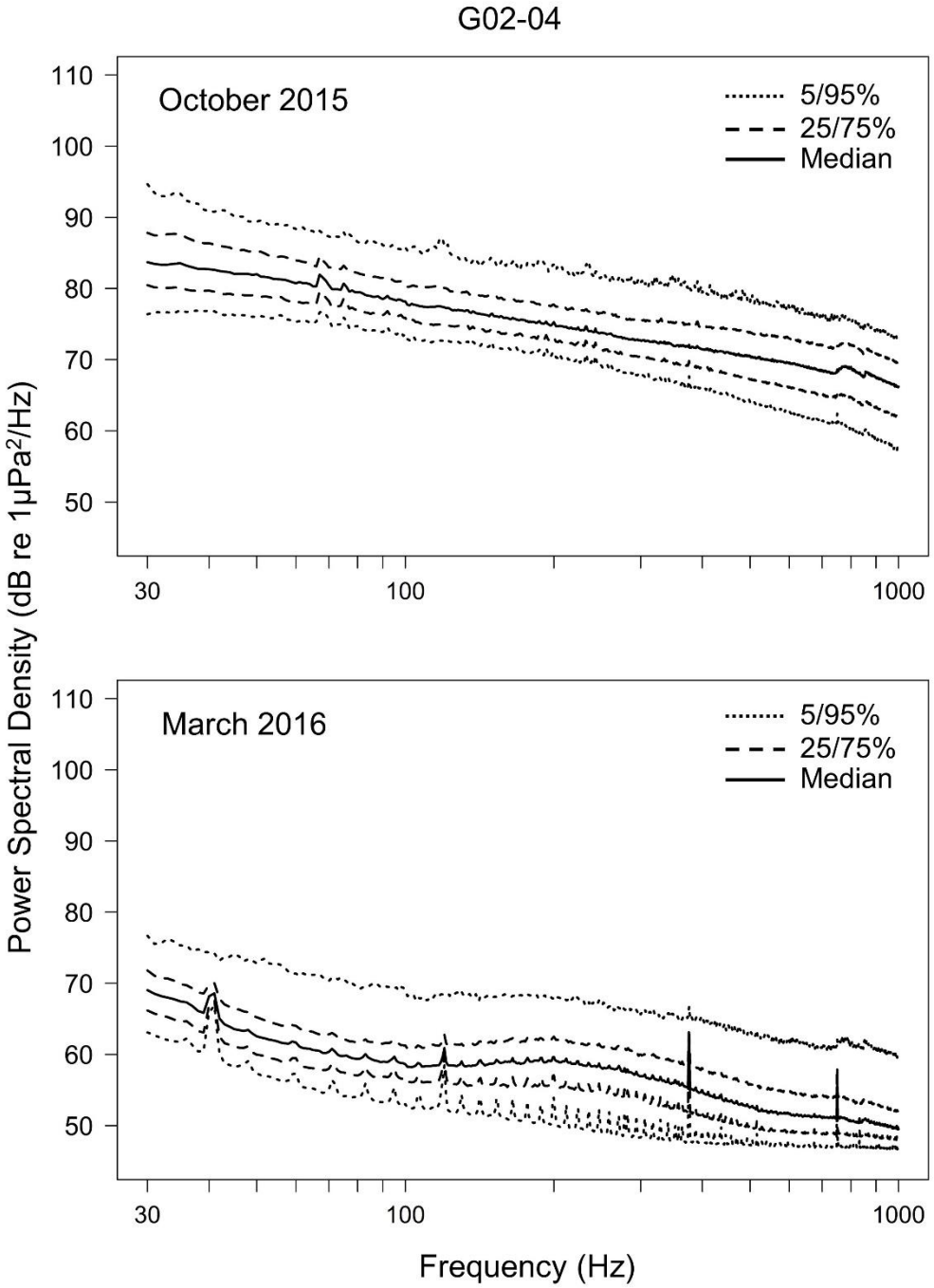

Figure 9: Power spectral density plots for a two-week period in October 2015 and March 2016 at the G02-04 station. Prominent spikes in March are due to electronic noise generated by the hydrophone.

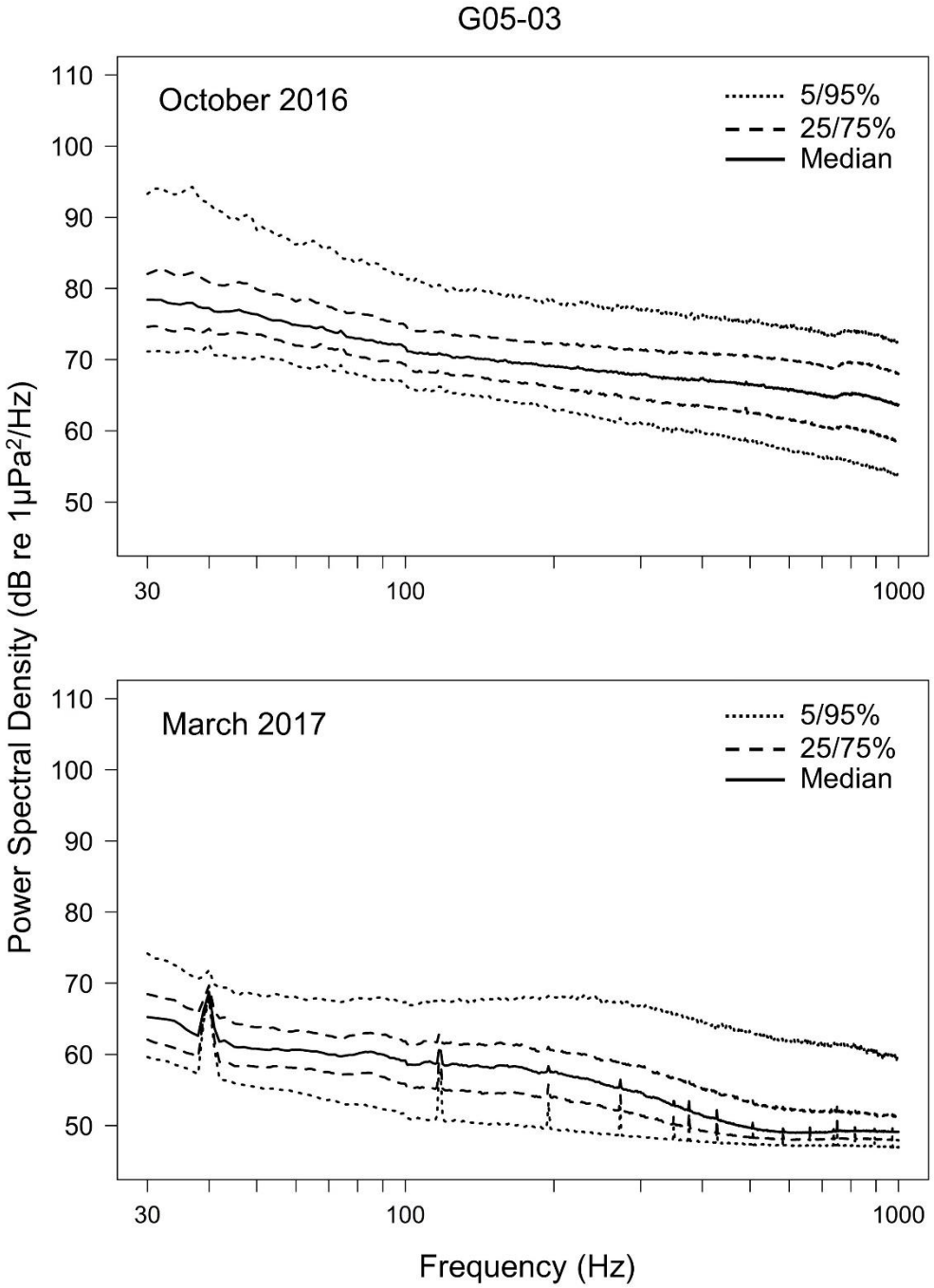

Figure 10: Power spectral density plots for a two-week period in October 2016 and March 2017 at the G05-03 station. Prominent spikes in March are due to electronic noise generated by the hydrophone.

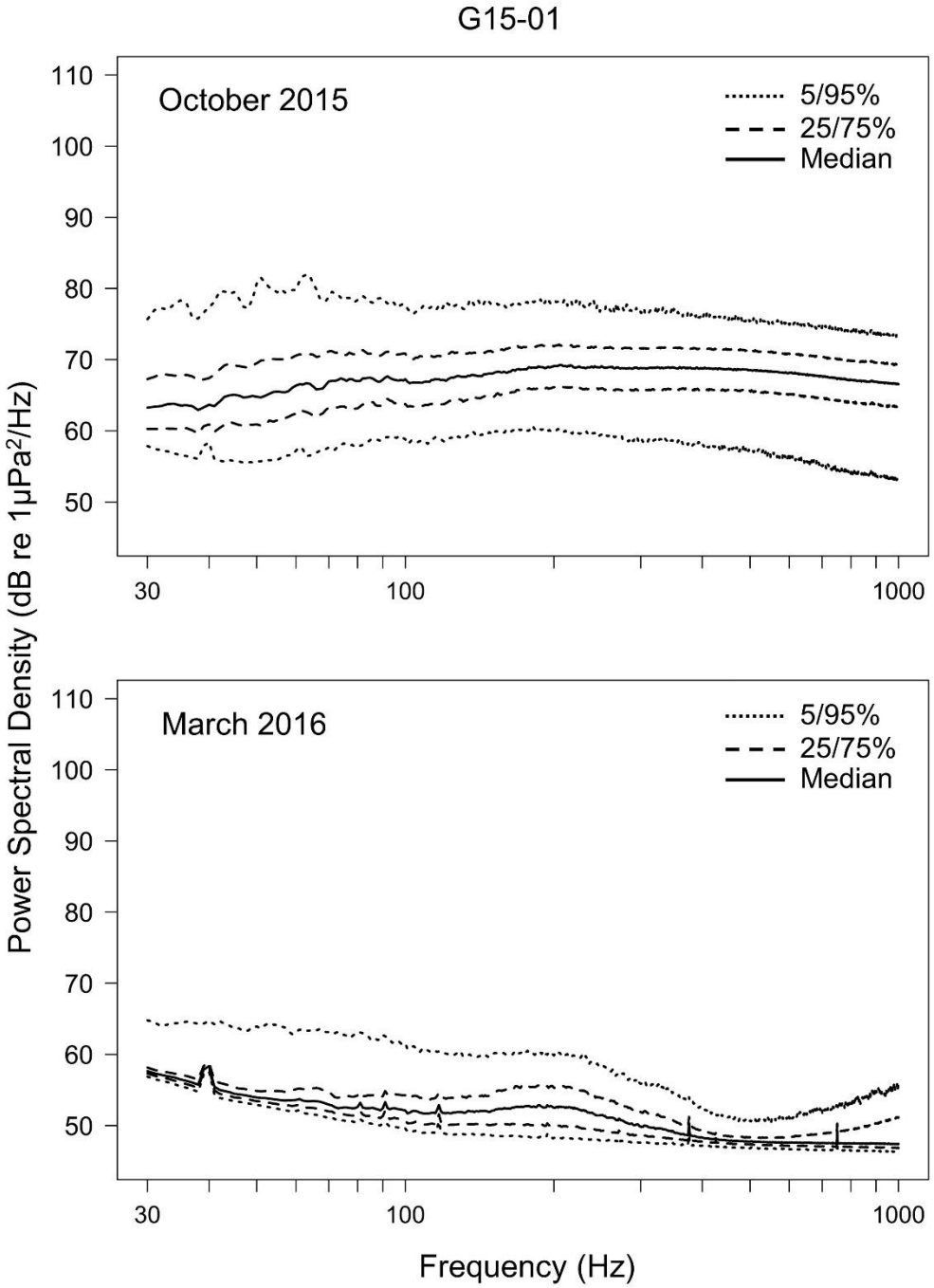

Figure 11: Power spectral density plots for a two-week period in October 2015 and March 2016 at the G15-01 station. Prominent spikes in March are due to electronic noise generated by the hydrophone.

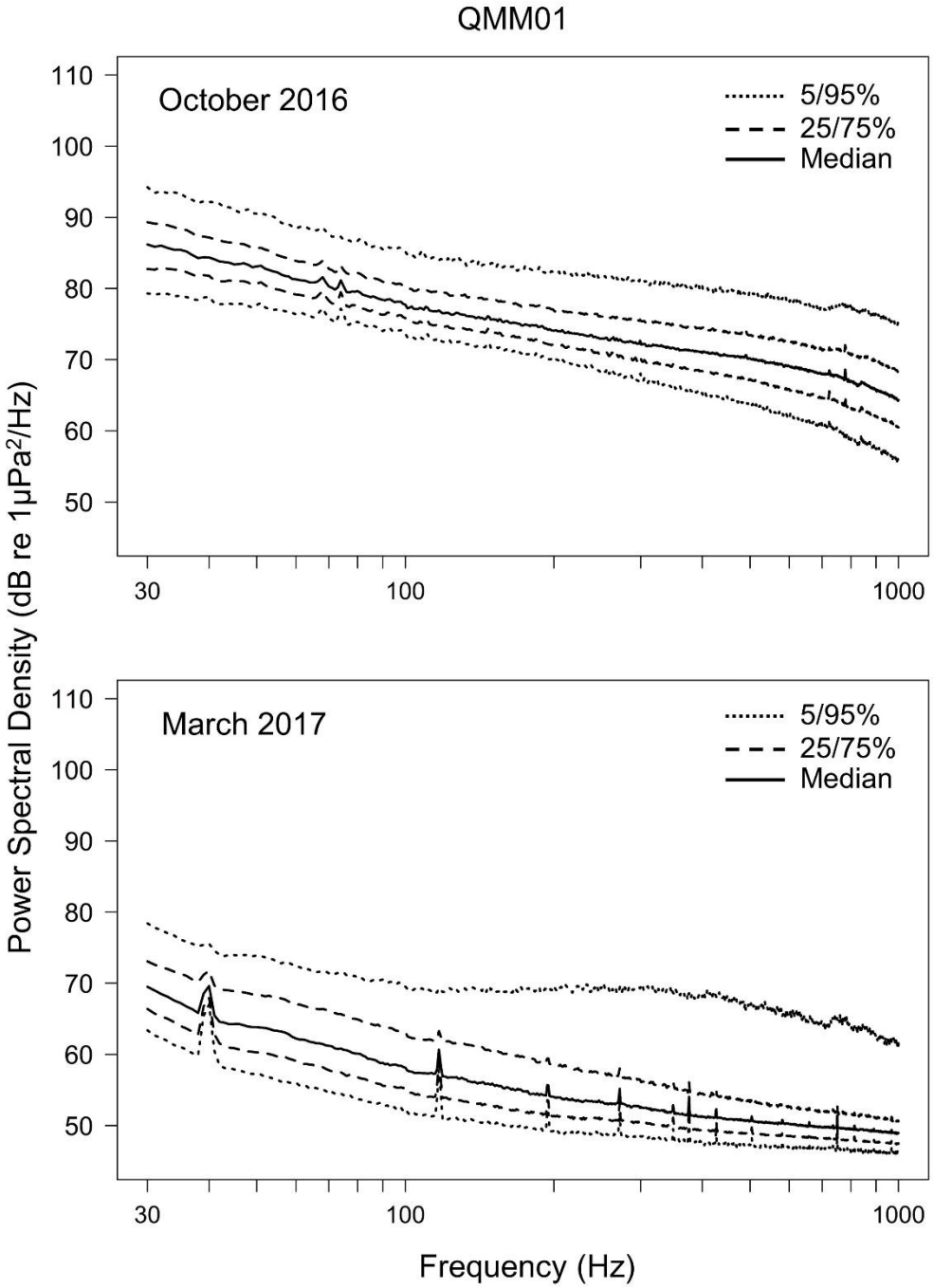

Figure 12: Power spectral density plots for a two-week period in October 2016 and March 2017 at the QMM01 station. Prominent spikes in March are due to electronic noise generated by the hydrophone.

3.2 SEASONAL PATTERNS

The highest sound pressure levels in all frequency bands were recorded in September/October at all stations, with increased SPL measurements at all exceedance levels (Figure 13Figure 16).

November and August also had elevated SPL measurements compared with the rest of the year, the magnitude of which was likely controlled by the timing of break-up and freeze-up. SPL increases were greatest in the low- and mid-frequency bandwidths. For example, at the G02-04 site, between March and October, median SPL measurements raised ~20 dB in the low, ~11 dB in the mid and only ~2 dB in the high bandwidth (Figure 13). This comparatively small increase in SPL in the high frequency band is due in part to the lack of noise in that frequency band throughout the year and in part to limitations imposed by the noise floor of the system. PSD plots in October were generally similar among hydrophones, with median values between ~78-84 dB at 30 Hz, decreasing to ~67-70 dB at 1000 Hz. G15-01 was the exception, with median PSD starting at ~63 dB at 30 Hz and increasing to ~66 dB at 1000 Hz (Figure 8Figure 12). Autumn noise levels in the low-frequency band were slightly higher than those reported for a similar bandwidth during the loudest months in Sachs Harbour (Insley et al. 2017). However, median TOLs at 50, 63, 125, 250, and 500 Hz during September/October were lower than those reported in the loudest seasons in Fram Strait and similar to those reported in the quietest seasons (Figure 3Figure 7; Ahonen et al. 2017).

In autumn, LTSAs and spectrogram analysis revealed that bowhead moans and songs, narwhal whistles and clicks, vessel traffic, and some unidentified strong impulse sounds were common at all stations (Figure 17Figure 25). Impulse sounds most closely resembled the sounds of sheering glaciers or calving icebergs. A preliminary investigation into sea ice concentration did not reveal any ice in the area during many of these recordings; however, icebergs are common in the area at the time and are the most likely explanation (N. Hussey pers. comm). These did not occur at periodic intervals, were often followed by an echo several seconds later, and did not occur in the winter/spring (Figure 18Figure 19). Impulse sounds at periodic intervals, indicative of seismic ships, were present in some files but were rare (Figure 20). Vessel noise was commonly identified (Figure 21) but was often distant. Bowhead moans and songs were common throughout the autumn and early winter (Figure 22Figure 23). Narwhal clicks were clearly identifiable in LTSAs (even when LTSAs spanned several months; Figure 17) and spectrograms (Figure 24 and Figure 25) and caused increases in maximum TOL measurements at frequencies > 15 kHz in the autumn (Figure 3Figure 7).

60-s averaging limited the impact of impulsive sounds on measurements overall, so higher resolution measurements averaged to 0.5-s measurements were made for a few representative examples to depict their contribution to the soundscape (Figure 19Figure 28). For example, impulsive noises during an ice sheering event raised SPL above the median measurement by ~27 dB in the low frequency band, ~16 dB in the mid frequency band, and ~1 dB in the high frequency band (Figure 19).

SPLs were generally lowest at all stations in all frequency bands in December through July, though QMM01, the southern-most mooring, had higher December measurements than other locations, likely relating to later freeze-up (Figure 13 - Figure 16). PSD plots in March varied slightly among hydrophones. At G02-04, G05-03, and QMM01, median PSD decreased from ~64-70 dB at 30 Hz to ~50-52 dB at 1000 Hz, whereas at G15-01, PSD varied less with frequency, dropping from ~58 dB to ~50 dB (Figure 8 - Figure 12). However, the median value at G15-01 appeared closer to the noise floor than other hydrophones. Median 50, 63, 125, 250, and 500 Hz TOLs during the ice-covered months were lower than those recorded during the quietest seasons in Fram Strait (Figure 3Figure 7; Ahonen et al. 2017). Broadband SPL measurements in the low-frequency bandwidth were higher than those reported in the winter in

Sachs Harbour (Insley et al. 2017), although this is likely due to limitations imposed by the noise floor.

The main source of noise during the ice covered months was intermittent ice cracking (Figure 26) and creaking (

Figure 27). Vessel sounds were rare and bowhead and narwhal calls were absent. Bearded seal calls and walrus knocks were also common, but often distant and negligible in SPL measurements.

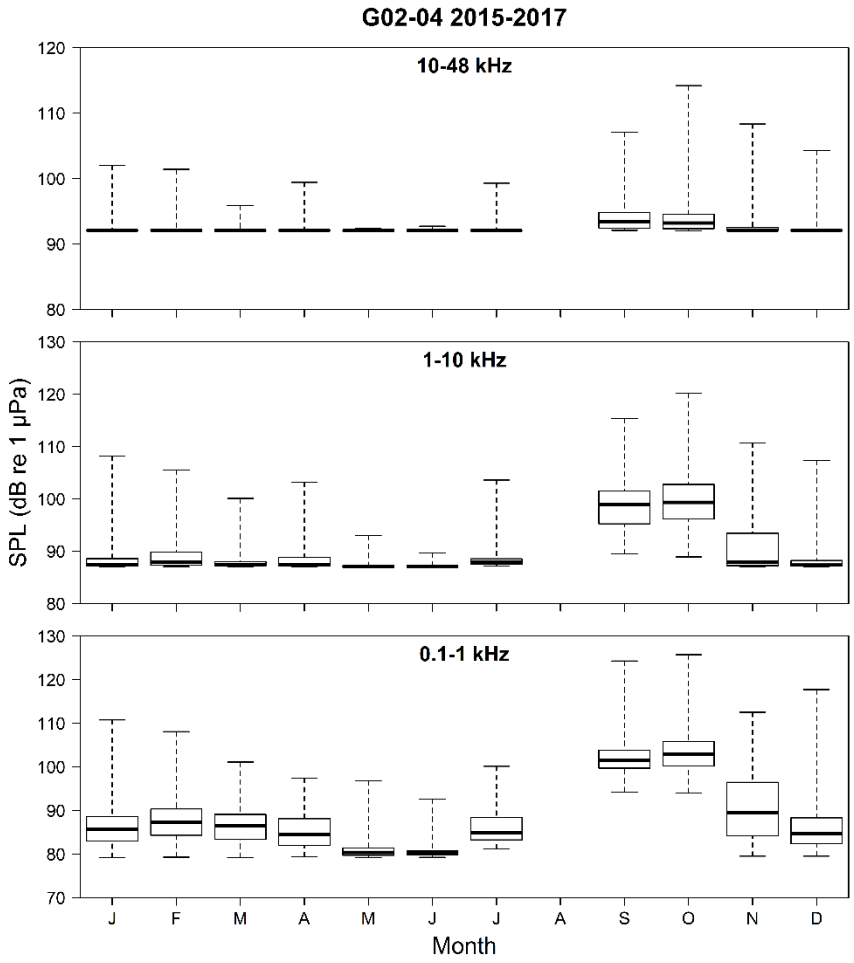

Figure 13: Boxplots showing the spread of broadband sound pressure level (SPL) measurements at G02-04 by month from September 2015 to February 2017. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded SPL for each month.

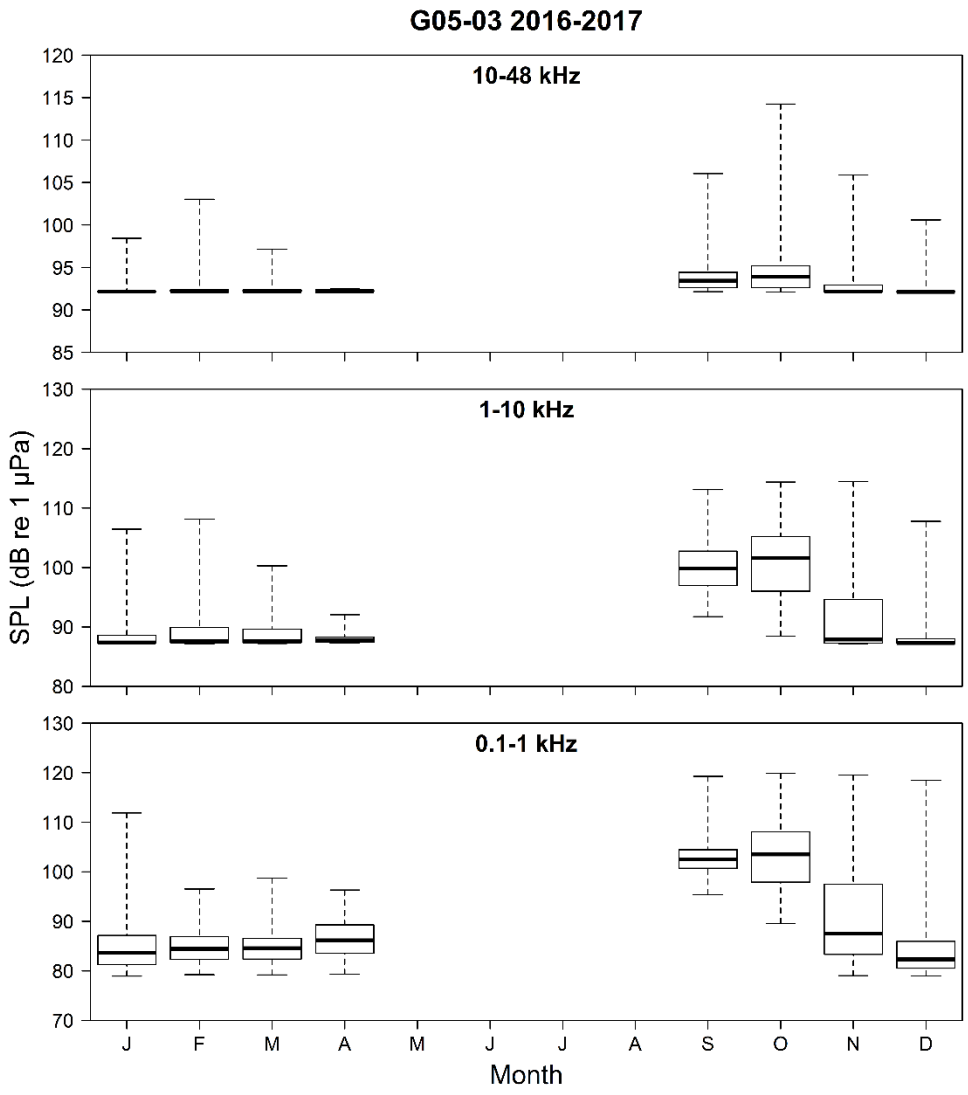

Figure 14: Boxplots showing the spread of broadband sound pressure level (SPL) measurements at G05/03 September 2016 to April 2017. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded SPL for each month.

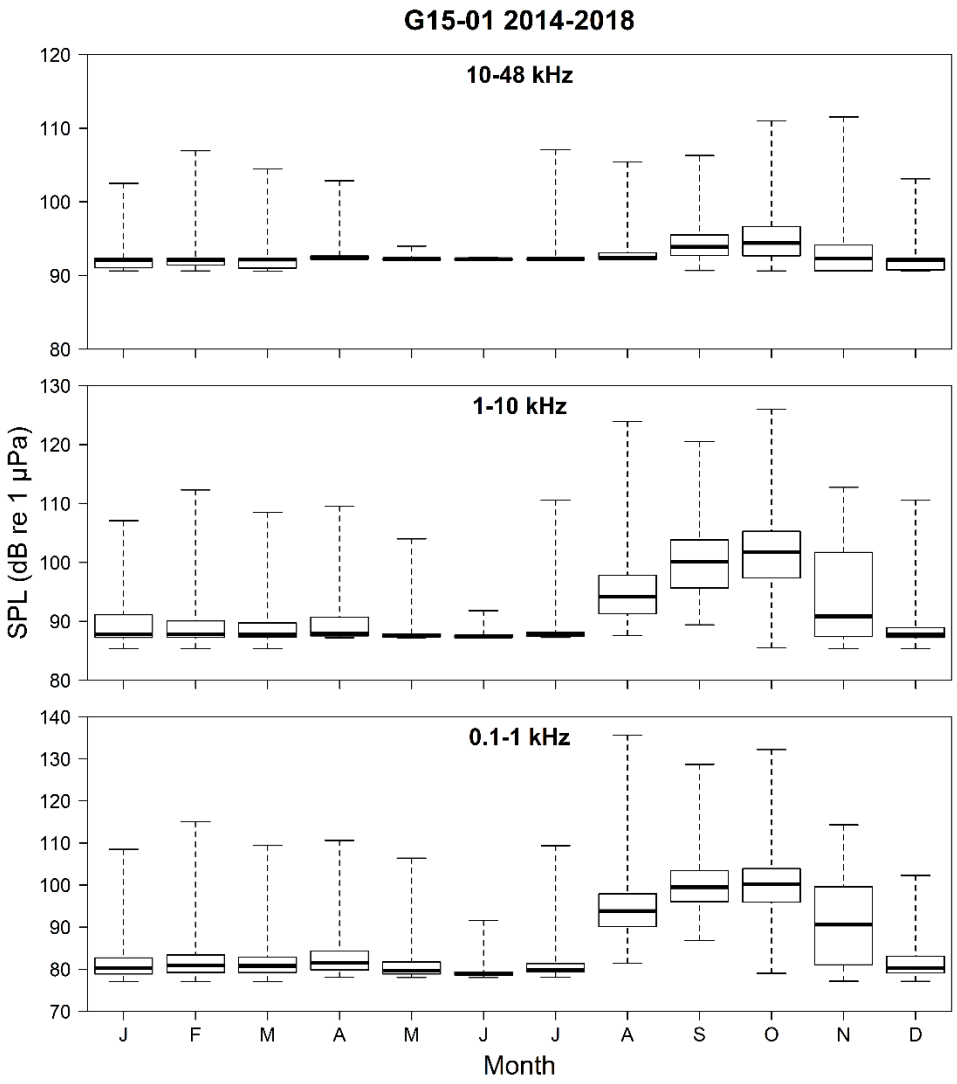

Figure 15: Boxplots showing the spread of broadband sound pressure level (SPL) measurements at G15-01 by month from September 2014 to March 2018.The high frequency bandwidth (10-48 kHz) is from September 2015 to March 2018 only (the first deployment only recorded to 24 kHz). The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded SPL for each month.

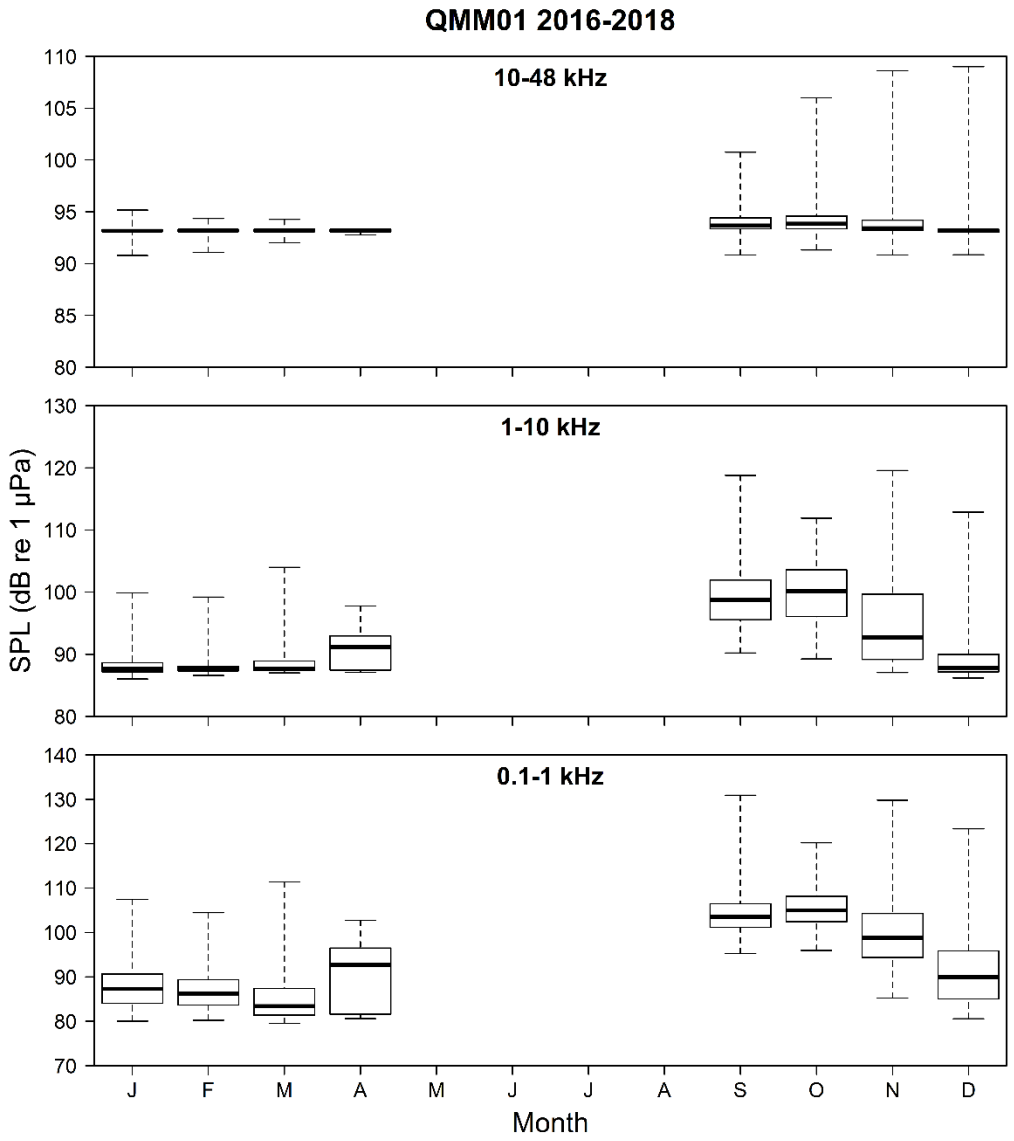

Figure 16: Boxplots showing the spread of broadband sound pressure level (SPL) measurements at QMM01 by month from September 2016 to January 2018. No data were available for May-August. The boundary of the box represents the first and third quartiles, the line inside the box is the median. Whiskers extend to the maximum and minimum recorded SPL for each month.

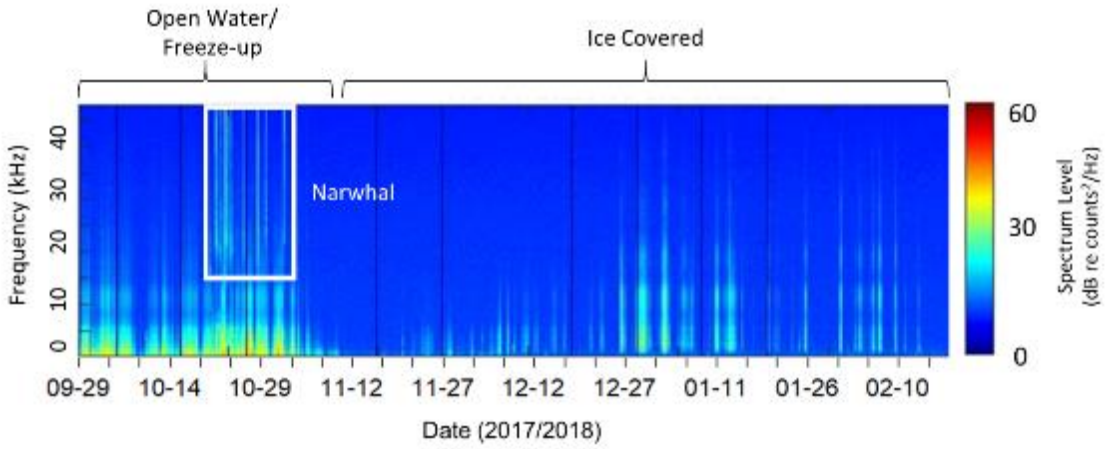

Figure 17: Long term spectral average plot for late September to early February 2017/2018 at the G15-01 station showing seasonal differences in noise levels. Narwhal clicks are easily identifiable even at long timescales.

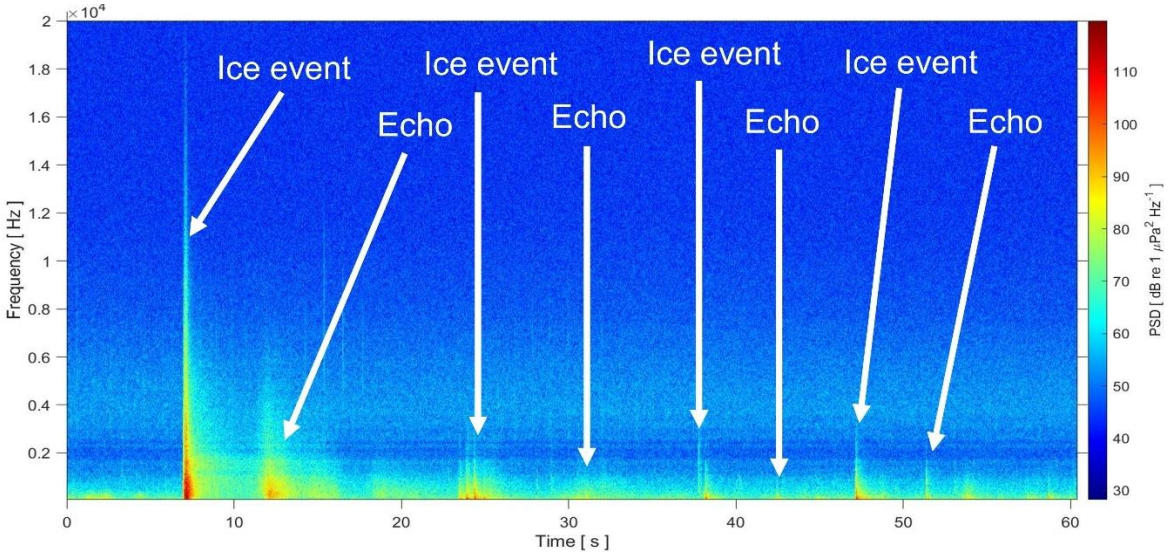

Figure 18: Spectrogram showing strong, likely ice related, impulse sounds at the G02-04 station, recorded 30-09-2015. Spectrogram was made with a 4096-point Hann window with 50% overlap, providing a frequency resolution of 23.4 Hz and time resolution of 21.3 ms.

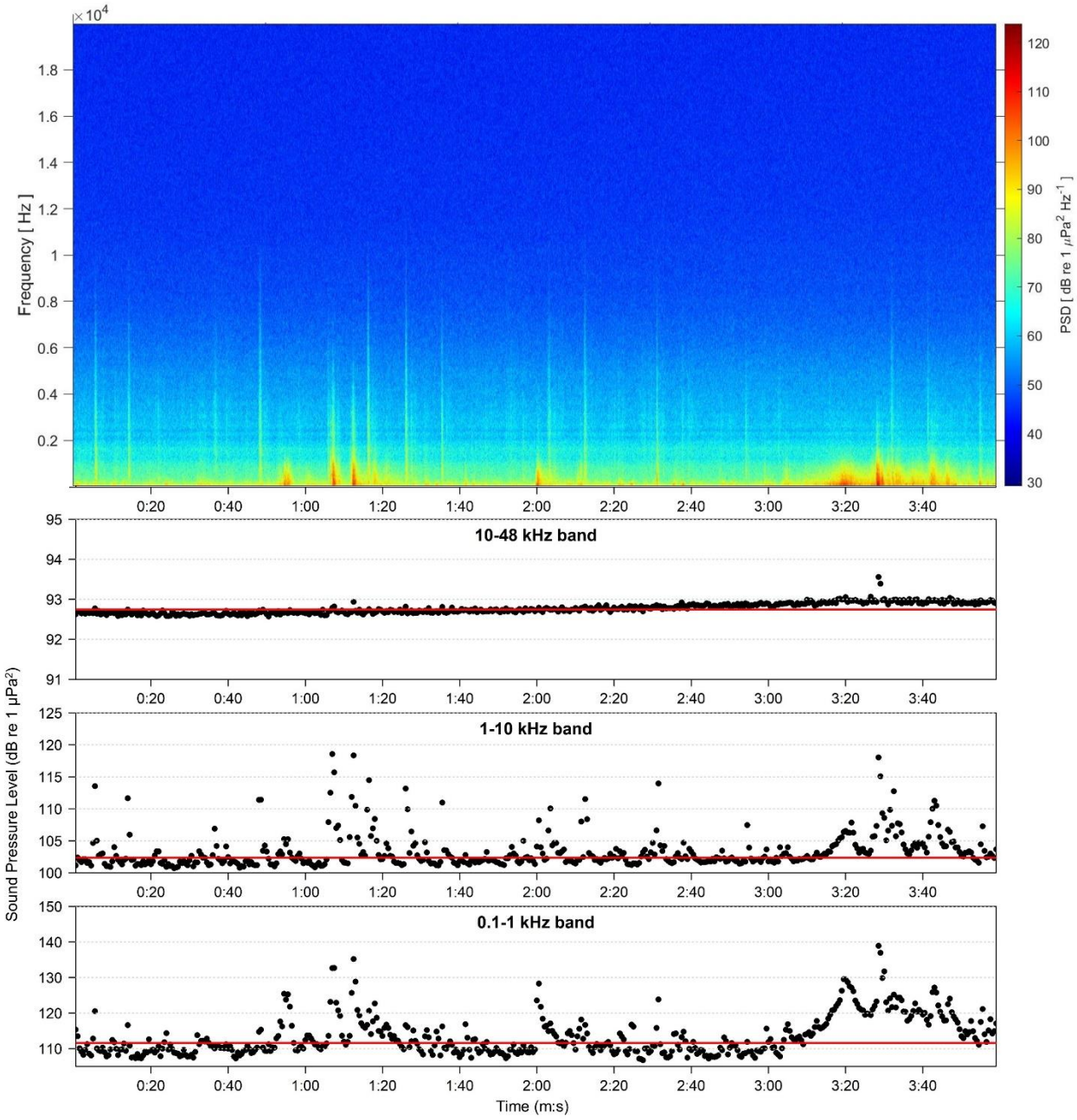

Figure 19: Ice events recorded 02-10-2015 at G02-04. Top: spectrogram made with a 2048-point Hann window with 50% overlap, providing a frequency resolution of 46.9 Hz and time resolution of 10.7 ms. Bottom: 0.5-s sound pressure levels for the low-, mid-, and high-frequency bands (as indicated), with median lines in red.

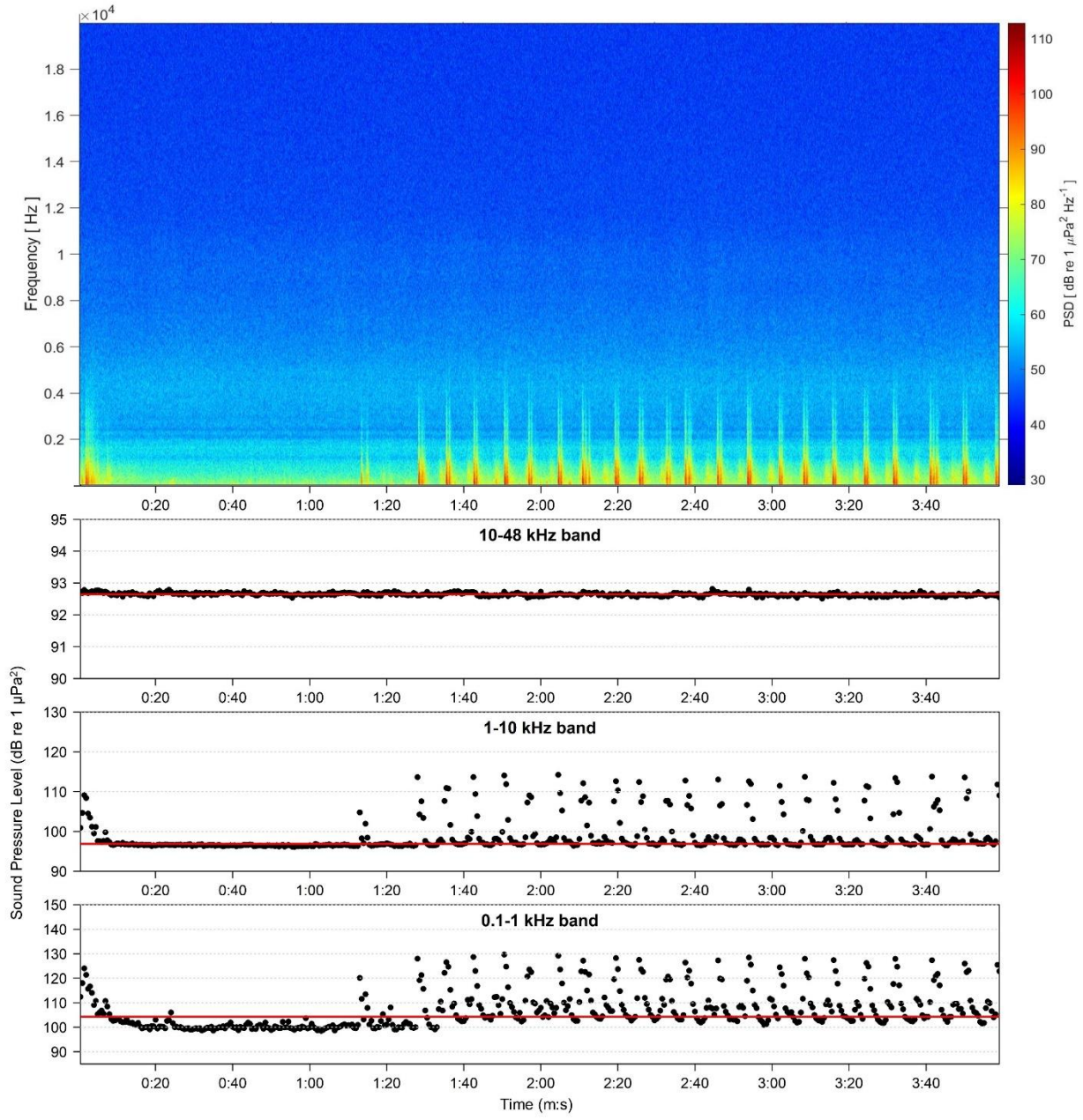

Figure 20: Seismic ship recorded 13-10-2015 at G02-04. Top: spectrogram made with a 2048-point Hann window with 50% overlap, providing a frequency resolution of 46.9 Hz and time resolution of 10.7 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

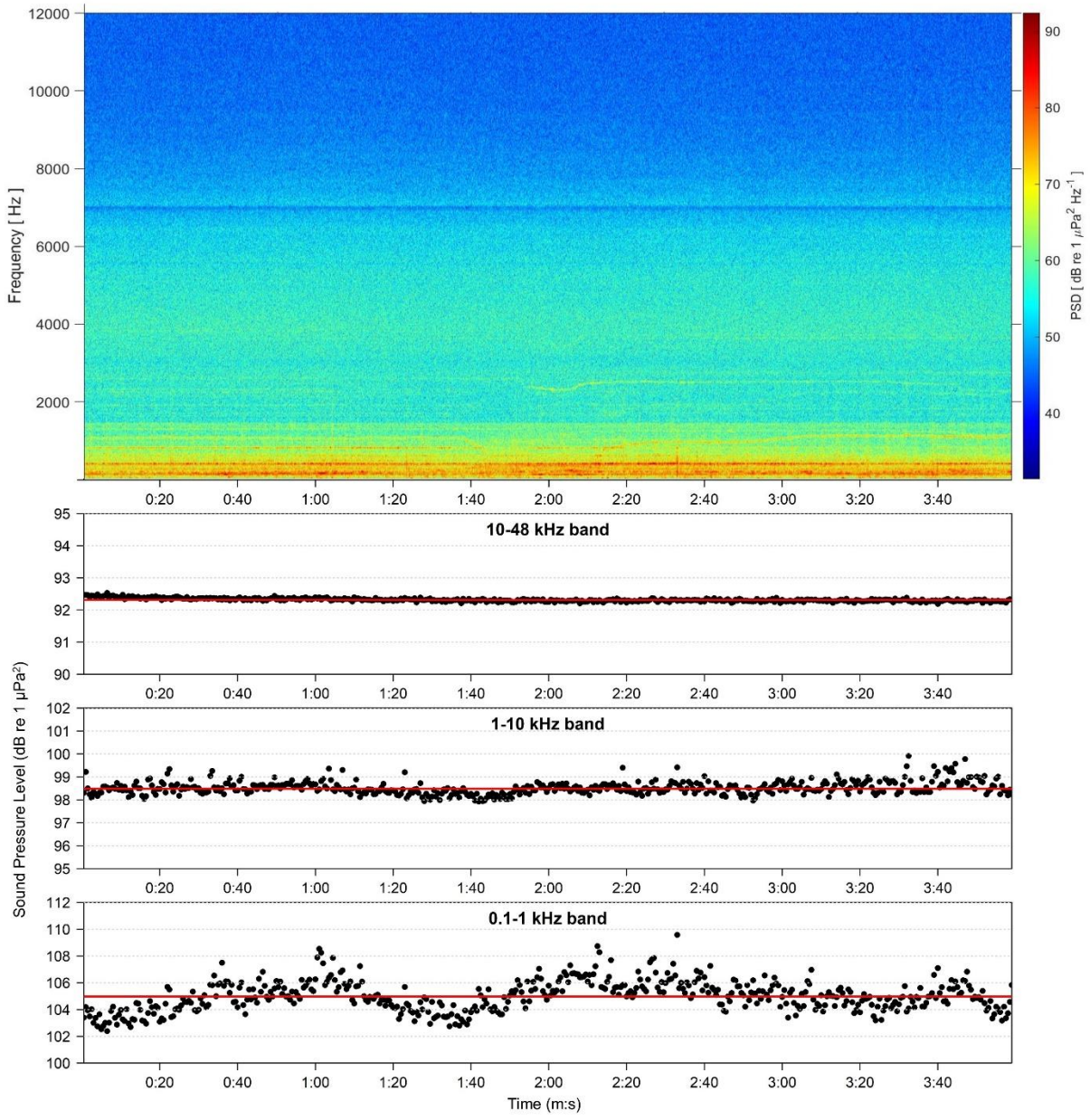

Figure 21: Vessel passing recorded 01-09-2016 at G15-01. Top: spectrogram made with a 4096-point Hann window with 50% overlap, providing a frequency resolution of 23.4 Hz and time resolution of 21.3 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

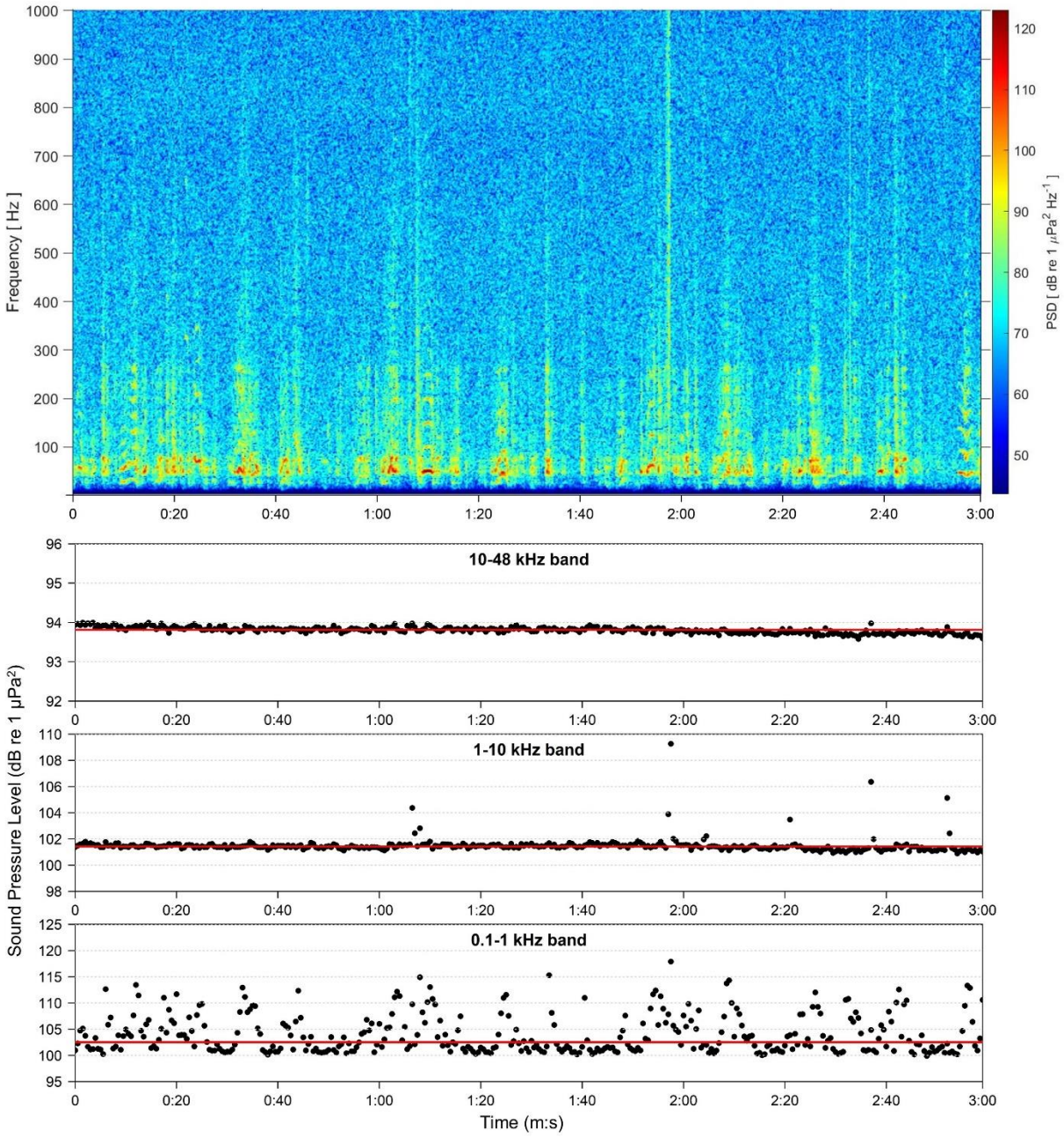

Figure 22: Bowhead moans recorded 17-09-2016 at G05-03. Top: spectrogram made with a 48000-point Hann window with 50% overlap, providing a frequency resolution of 4 Hz and time resolution of 0.125 s. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

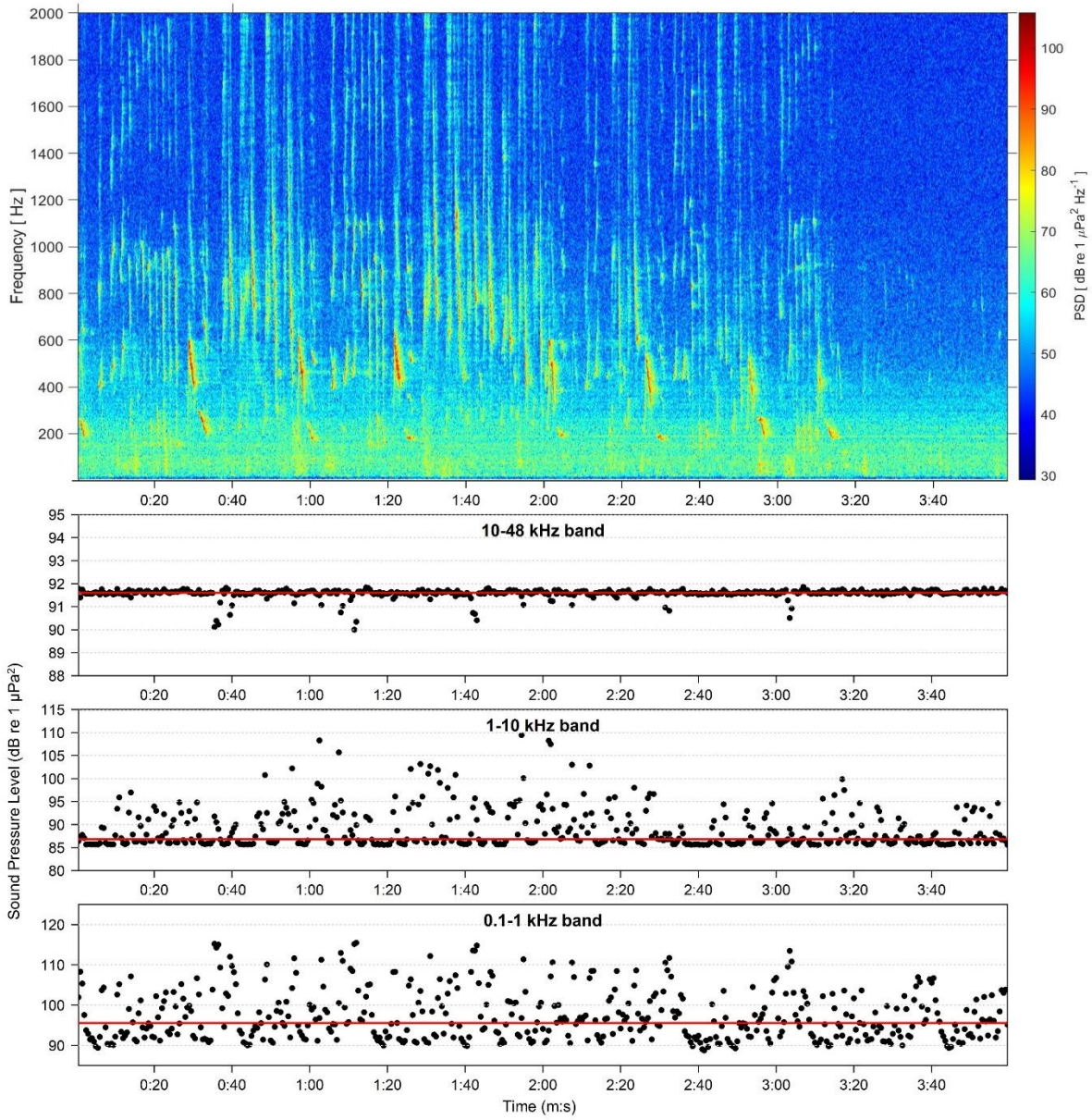

Figure 23: Bowhead songs recorded 10-11-2017 at QMM01. Top: spectrogram made with a 48000-point Hann window with 50% overlap, providing a frequency resolution of 4 Hz and time resolution of 0.125 s. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

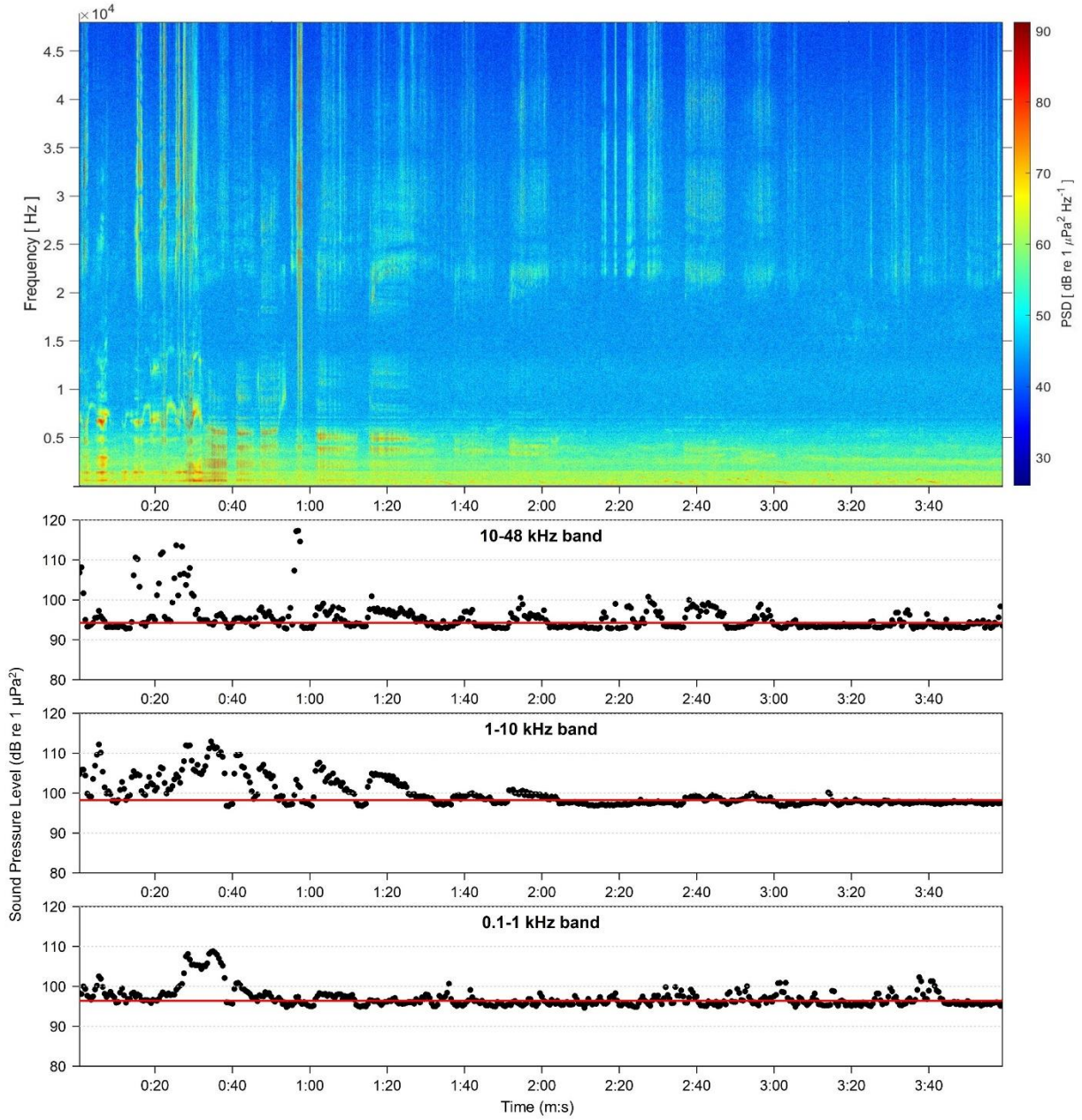

Figure 24: Narwhal vocalizations and clicks recorded 04-11-2015 at G15-01. Top: spectrogram made with a 8192-point Hann window with 50% overlap, providing a frequency resolution of 11.7 Hz and time resolution of 42.7 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

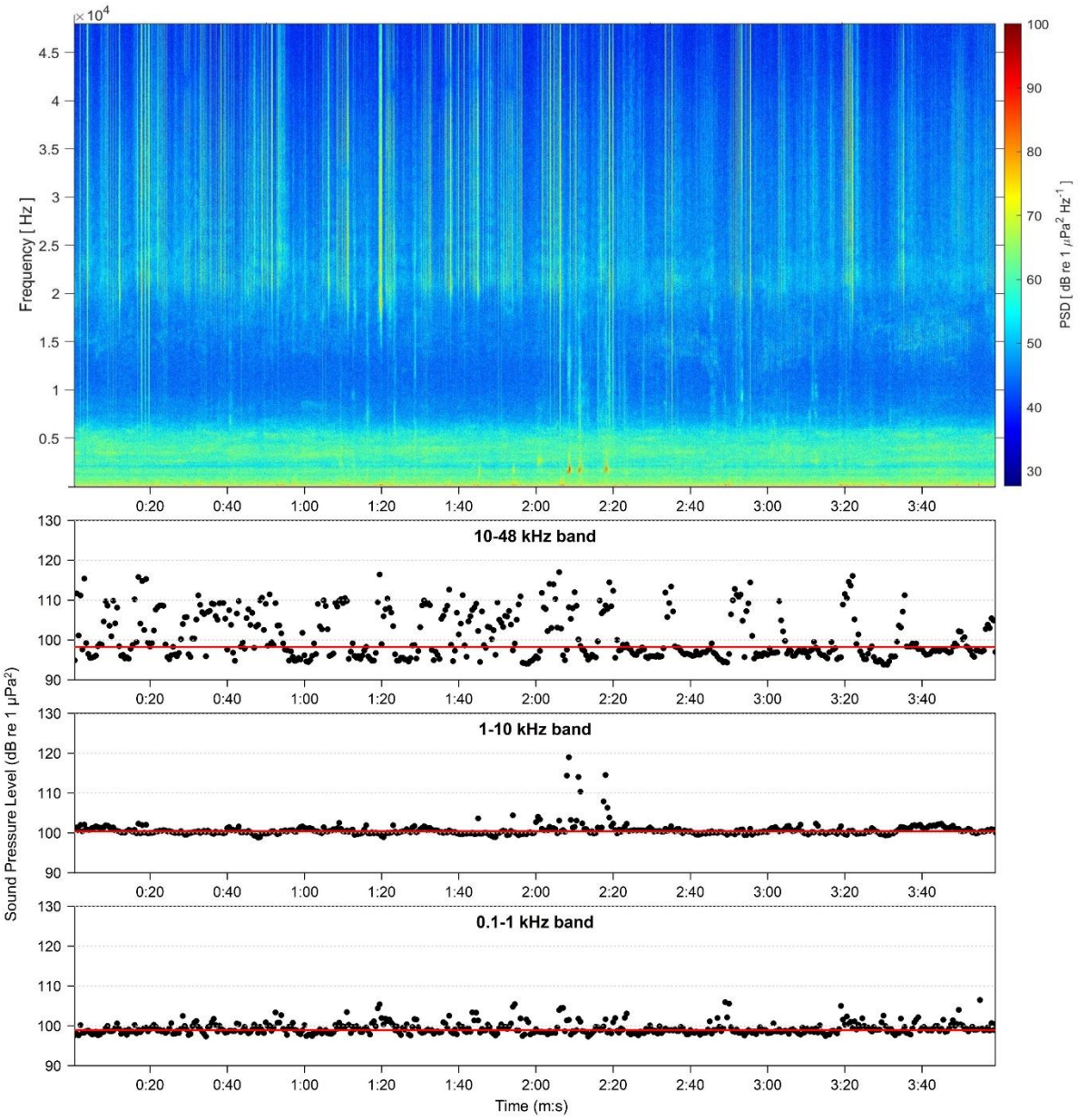

Figure 25: Narwhal clicks recorded 21-10-2015 at G02-04. Top: spectrogram made with a 8192-point Hann window with 50% overlap, providing a frequency resolution of 11.7 Hz and time resolution of 42.7 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

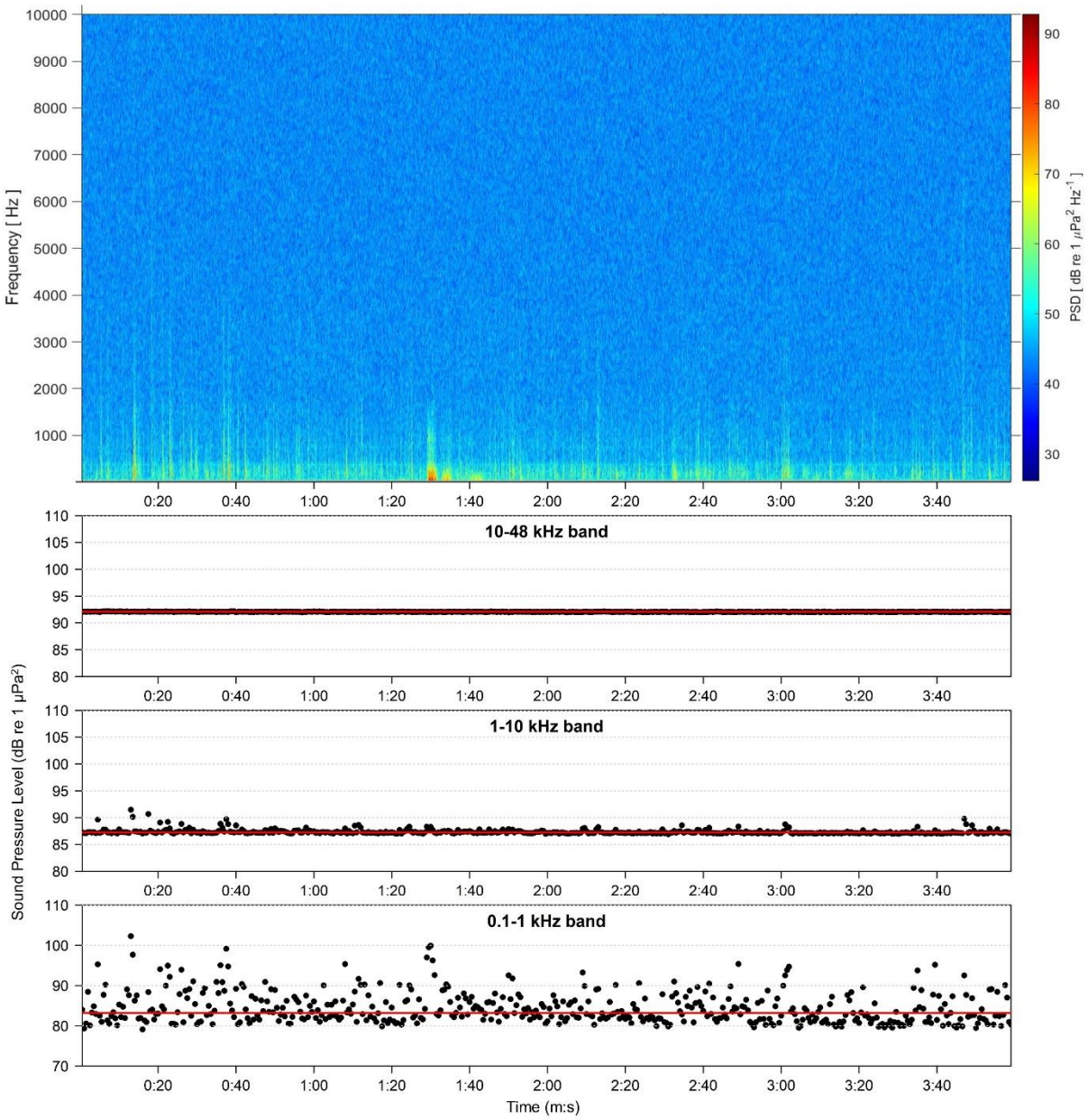

Figure 26: Ice cracking recorded 03-15-2016 at G02-04. Top: spectrogram made with a 2048-point Hann window with 50% overlap, providing a frequency resolution of 46.9 Hz and time resolution of 10.7 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

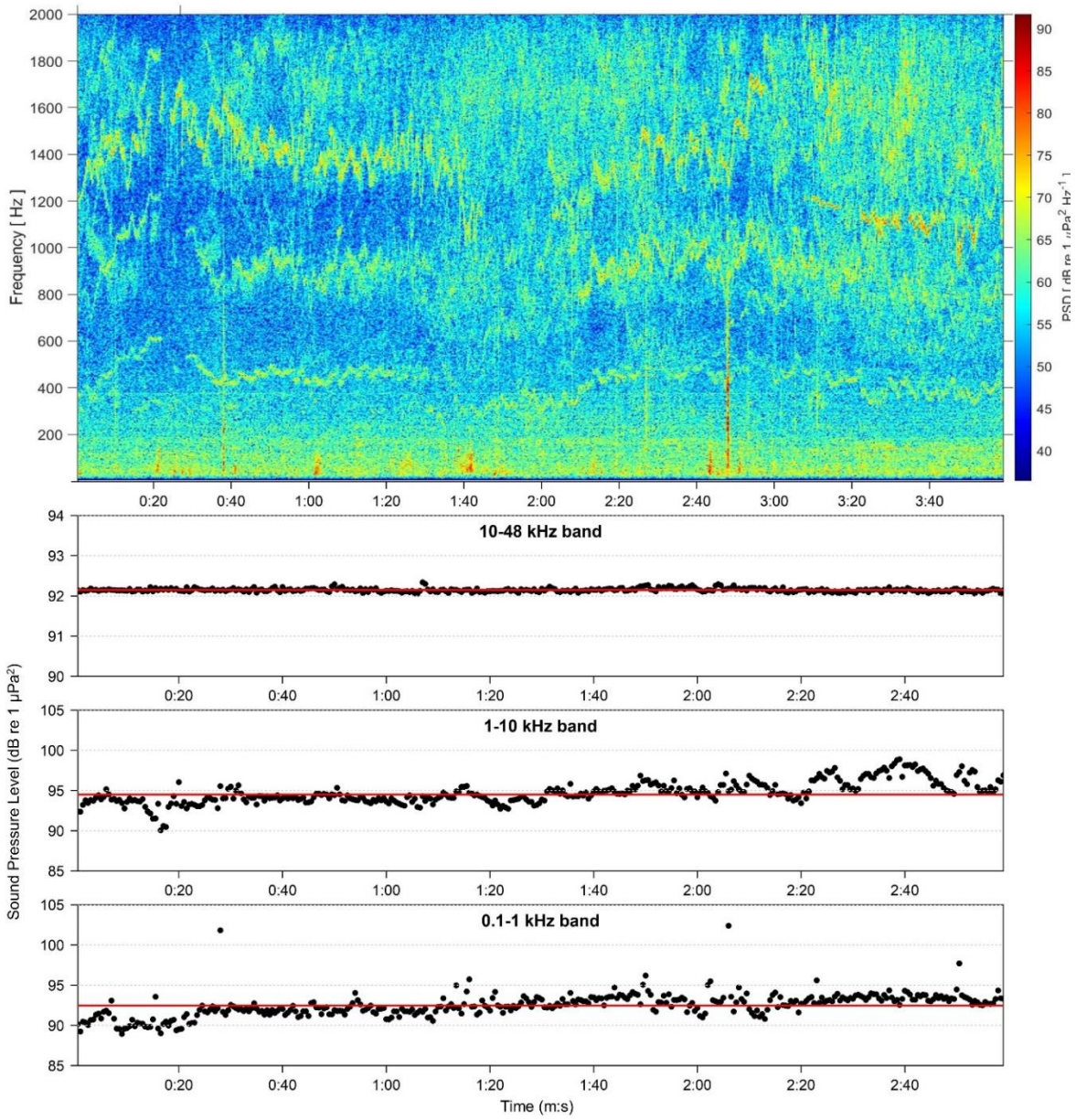

Figure 27: Ice creaking and wind recorded 10-11-2015 at G02-04. Top: spectrogram made with a 48000-point Hann window with 50% overlap, providing a frequency resolution of 2 Hz and time resolution of 0.25 s. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

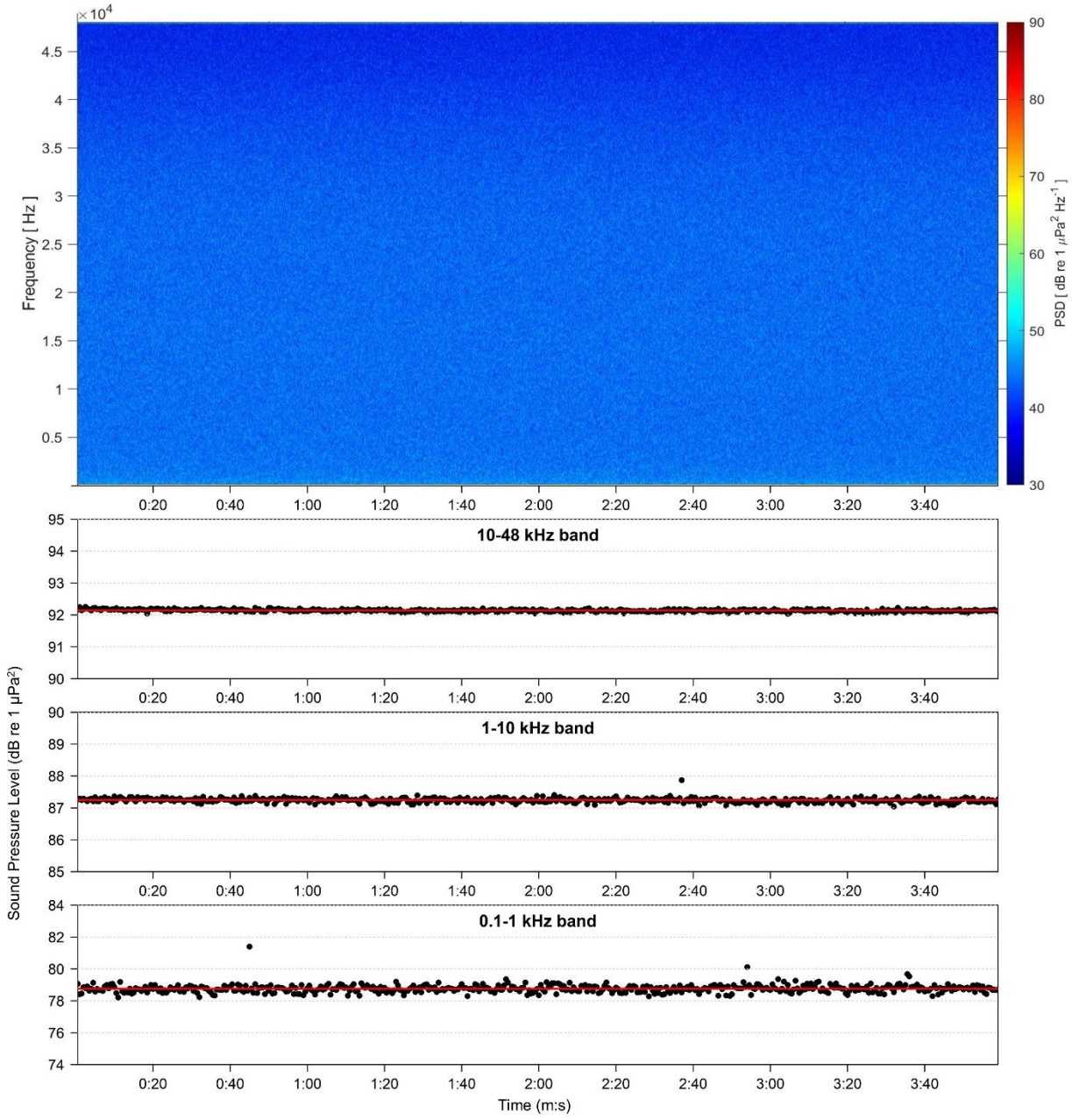

Figure 28: Quiet conditions recorded 15-12-2015 at G15-01. Top: spectrogram made with a 2048-point Hann window with 50% overlap, providing a frequency resolution of 46.9 Hz and time resolution of 10.7 ms. Bottom: 0.5-s sound pressure levels for the low, mid-, and high-frequency bands (as indicated), with median lines in red.

3.3 EFFECT OF WIND

Wind speed had the greatest effect on SPL in the open-water months (September-October) compared with ice covered months (February-March) at all stations as indicated by a steeper slope and generally higher R^2 values (Table 2). Slope values in the low frequency band ranged from 0.28 to 0.50 dB re 1 µPa/km/h in the open water season and were mostly non-significant (or small) in the ice-covered season. Slope values were similar for the mid frequency bands, but lower for the high frequency band. The relationship between SPL and wind speed seasonally moderated by ice cover is a common feature in the Arctic (Roth et al. 2012, Insley et al. 2017). The range in slope values in open water was similar to that found in the literature (e.g., Roth et al. 2012: 0.28 dB re 1 µPa/km/h; Insley et al. 2017: 0.40 to 0.43 dB re 1 µPa/km/h; Halliday et al. 2021: 0.37 dB re 1 µPa/km/h). It is important to highlight that while the weather stations used in the analysis were the closest available, they were still quite far from the moorings. Local weather patterns can vary drastically; winds measured at the weather stations were not likely to be ideal representations of wind conditions above the mooring, which may have resulted in lower R^2 values.

*Table 2: The effect of wind speed on SPLs in three frequency bands during the open-water (Sept-Oct) and ice-covered (Feb-Mar) season at 4 stations in Baffin Bay. * significant at p = 0.05, ** significant at p=0.01.*

Station	Month	Bandwidth	Slope	Std. Error	R^2
G02-04	Sep-Oct	100-1000	0.28**	0.06	0.33
		1000-10000	0.24**	0.04	0.39
		10000-48000	0.06**	0.02	0.17
	Feb-Mar	100-1000	0.002	0.04	<0.01
		1000-10000	0.03	0.03	0.03
		10000-48000	0.007	0.05	0.05
G05-03	Sep-Oct	100-1000	0.37**	0.07	0.43
		1000-10000	0.28**	0.08	0.25
		10000-48000	0.08	0.05	0.07
	Feb-Mar	100-1000	-0.03	0.04	0.01
		1000-10000	0.10**	0.03	0.17
		10000-48000	0.03	0.02	0.05
G15-01	Sep-Oct	100-1000	0.35**	0.06	0.28
		1000-10000	0.34**	0.06	0.28
		10000-48000	0.18**	0.04	0.3
	Feb-Mar	100-1000	0.007	0.04	0.0004
		1000-10000	0.16**	0.003	0.26
		10000-48000	0.05**	0.009	0.44

Station	Month	Bandwidth	Slope	Std. Error	R^2
QMM01	Sep-Oct	100-1000	0.50**	0.07	0.58
		1000-10000	0.60**	0.07	0.65
		10000-48000	0.08*	0.04	0.09
	Feb-Mar	100-1000	-0.08	0.14	0.02
		1000-10000	0.05	0.02	0.13
		10000-48000	0.01*	0.004	0.22

4. CONCLUSION

Characterization of baseline noise levels is essential to understanding the effects of climate change on the Arctic ecosystem. Here we attempted to use data collected over several years to characterize ambient noise in a region (western Baffin Bay) for which very limited data exist. We documented clear differences in sound pressure levels between the open-water and ice-covered months, similar to other studies in the Arctic (Diachok and Winokur 1974, Roth et al. 2012, Insley et al. 2017). Recordings in late-September to November were plentiful and provide useful information which can be compared with future recordings as climate driven changes affect the region. Limitations of the recording units restricted some information during the ice-covered and summer months. In particular, values reported for the ice-covered months are likely over-estimates of the actual values due to the noise-floor of the hydrophone. The use of low-noise hydrophones would likely reveal lower estimates, but even these may be higher than the actual values (e.g., Insley et al. 2017). Planning deployment scenarios in the Arctic is challenging, because most acoustic recorder manufacturers do not consider low temperatures in their power consumption estimates. In our study, only a few recorders lasted until the summer months, so data during these months are still limited. As anthropogenic activity will likely increase the most during the summer, baseline noise levels for these months are important. As such, future deployment plans should consider reducing the number of recordings made during the winter months to conserve power for the summer.

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