SOUNDSCAPE CONTRIBUTIONS OF GLACIER ICE BLOCKS – INSIGHTS FROM LABORATORY MEASUREMENTS

Philippe Blondel[a], Jaroslaw Tęgowski [b], Grant Deane[c]

[a]University of Bath; Bath (United Kingdom)
[b]University of Gdanks; Gdansk (Poland)
[b] Scripps Institution of Oceanography, La Jolla (USA)

Philippe Blondel; Department of Physics, University of Bath, Bath BA2 7AY, UK;
P.Blondel@bath.ac.uk

Abstract: *Acoustic measurements in Arctic fjords and next to marine-terminating glaciers show important contributions from glacier melting, and individual icebergs or growlers. As they melt, they release high-pressure gases and produce sounds at medium to high frequencies. Associated to fields of hundreds or thousands of melting growlers and ice blocks, they add significantly to the soundscape. A summer 2009 survey of Murchison Fjord and Hornsund Fjord (Svalbard) by Tegowski et al. (2010) show these contributions can, even in extremely calm weather (Sea State 0), be as loud as Sea State 4. To isolate individual contributions, a series of laboratory experiments have been conducted, using growlers of different sizes and freshness. In 2012, growlers collected in Svalbard and stored on R/V Horyzont II were measured a few months later in an anechoic tank at the Technical University of Gdansk in a variety of configurations, individually and in groups of colliding and scraping icebergs. A field survey in Svalbard, in summer 2014, was used to collect another series of growlers of different sizes, aspects (e.g. bubble contents, ice colours) and morphologies (from rough to rounder and partially melted). After collection, they were immediately measured in an ad hoc tank at the Polish Polar Station, until full melting of each growler. Both sets of experiments used similar setups, with high-sensitivity broadband hydrophones and high-frequency data acquisition (96-kHz sampling rates). The acoustic pressures and energies radiated over the lifetime of the growlers were measured by 0.1-second segments. Relative levels of individual transients and evolution over the lifetimes of the individual growlers, in different configurations and with different melting rates, have been measured. These two sets of measurements can then be related to large fields of melting ice blocks, and compared to field measurements, quantifying the soundscape contributions at different frequency bands, and offering insights into ice dynamics and local conditions.*

Keywords: *polar acoustics, ambient noise, Svalbard, tank experiments, glacier ice, growlers, transient emissions*

1. SOUNDCAPE CONTRIBUTIONS OF GLACIER ICE

The Arctic Ocean and surrounding regions are becoming increasingly important as global warming makes them more accessible, raising economic and political interests. Current and future changes, natural and anthropogenic, will affect the characteristics of Arctic soundscapes. The International Quiet Ocean Experiment (iqoe.org) and its working group on "Arctic acoustic environments" [1] are working toward establishing baseline soundscapes for different regions. Low-frequency acoustics of sea ice is well understood [2], for example from past programmes like SHEBA (*Surface Heat Budget of the Arctic Ocean*, www.esrl.noaa.gov/psd/arctic/sheba/) and current, multidisciplinary and large-scale activities like INTAROS (*Integrated Arctic Observing* System, www.intaros.eu). But there are still many questions about the acoustic contributions of freshwater ice, from melting glaciers and from icebergs. How their broadband acoustic emissions can be used to monitor calving has been well studied by [3-5] *inter alia*. The acoustic contributions from smaller ice blocks, from growlers to ice floes, are less well understood, but they are important to better understand ice melting processes, soundscape evolutions with time and with local environmental conditions, and contributions to air-ocean boundary transfers.

Measurements by [6], made in summer 2007 along Kongsfjord in Svalbard, clearly distinguished the higher-frequency acoustic signatures of small icebergs (up to 48 kHz) from other environmental processes, down to < 10 Hz (Fig. 1, left). More extensive surveys [7] measured broadband ambient noise (20 Hz – 24 kHz) in Hornsund and Murchison fjord in Svalbard during the summer of 2009 (Fig. 1, right). Statistical analyses of the probability density distribution of noise showed it was not normally distributed between 20 Hz–1 kHz, and could be explained by few, loud sources. Conversely, the noise above 2.5 kHz was normally distributed and consistent with a large number of distributed and superposed sources [7-8]. Similar observations in Hornsund in summer 2013 [4], associated with directional measurements, further confirmed these observations.

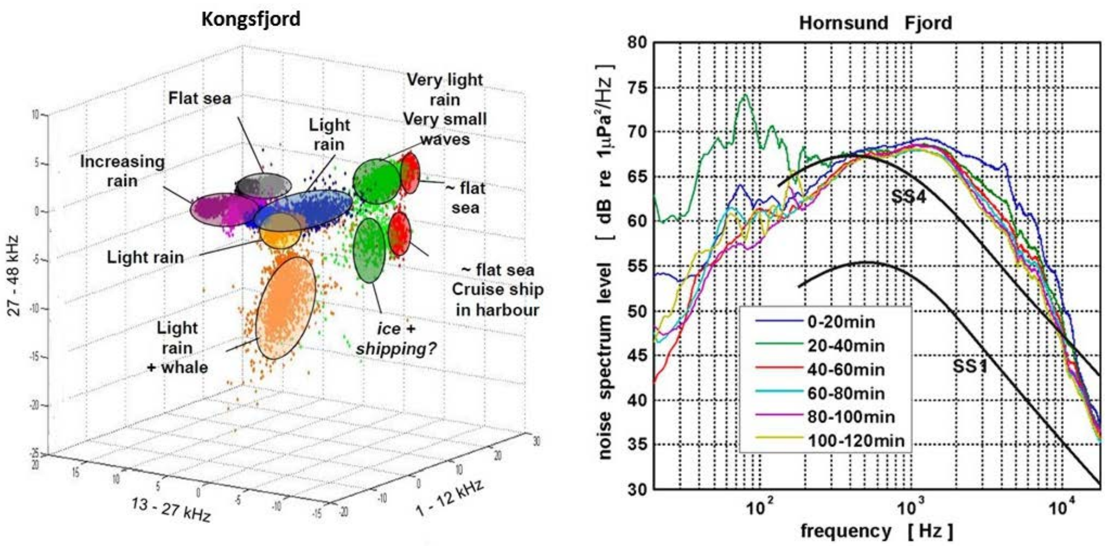

Fig.1: Left: Principal Component Analysis of broadband ambient noise measured in Kongsfjord (2009) identify different processes, each associated to specific frequency bands [6], Right: broadband measurements in other fjords show melting ice in calm seas can be as loud as Sea State 4 [7], with clear contributions above 1 kHz.

Freshwater glacier ice contains many air bubbles, formed as the snow compacted and pressurised over time. Their pressures can reach 2MPa [9], and the release of gas as the ice melts can be a noisy process. It is referred to as "Seltzer ice" by submariners (Wadhams, personal communication) and was first measured by [10]. Detailed experimental measurements of gas bubbles and comparison of acoustic signatures with high-speed photography and mathematical models have been published [11-12]. The work presented here is focusing on the long-term acoustic contributions of individual ice blocks throughout their melting. To study them in isolation from other processes (e.g. wind, waves, other ice blocks in the vicinity), we use tank measurements of single blocks, or in small groups. Logistical constraints in the collection of ice blocks in the field and tank sizes mean these studies are restricted to sub-metric sizes, called "growlers" [13]. Section 2 extends analyses by [14] of growlers in an anechoic tank, and Section 3 presents studies of freshly-collected growlers at a field station. The main observations will be synthesised in Section 4.

2. ANECHOIC TANK MEASUREMENTS OF GROWLERS

To understand the high-frequency contributions of individual growlers, ice blocks similar to those observed in the field in summer 2009 [7] were harvested by the same field team, in the same part of Hornsund Fjord, in summer 2012. The growlers were kept in cold chambers on board R/V *Horyzont II* and at the Institute of Oceanology, Polish Academy of Science in Gdansk, until the time of the experiments. Typical growlers are around 20-40 cm wide, and they show numerous gas inclusions, most often small (< 3-mm width). The melting, cracking and general interaction of these growlers with their immediate environment were investigated acoustically in an anechoic water tank at the Technical University of Gdansk.

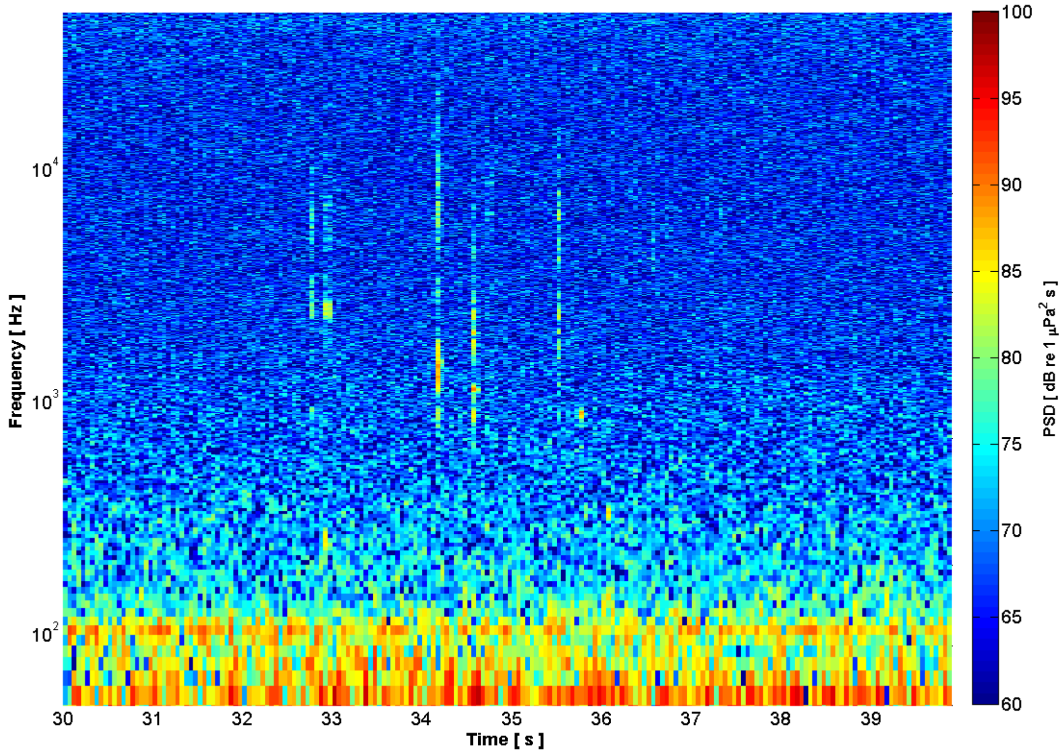

Fig.2: Typical spectrogram extract of a melting growler, showing strong transient events with high frequencies (> 1 kHz) and very short durations (< 0.1 second) [14].

Measurements with several hydrophones included a Brüel and Kjaer omnidirectional B&K-8103 hydrophone (effective bandwidth 0.1 Hz to 180 kHz, receiving sensitivity –211dB re 1V/µPa), plugged into a 1:1-gain signal preconditioner and connected to a B&K Heterodyne Signal Amplifier type 2010, with a 30-dB gain. Received voltages were sampled at 96 kS/s and 24-bit resolution, using a USB-4431 data acquisition card from National Instruments. The files were in LabVIEW's proprietary format TDMS, then converted to CSV (Comma-Separated Values) and 24-bit WAV files. Still photography and video were used to further document these experiments, fully detailed in [14].

All growlers (initially at sub-freezing temperatures) were measured until full melting, often lasting several hours. This process was characterised with very short acoustic emissions, audible over a range of frequencies, defined as "transients" and visually associated to escaping bubbles [14]. Typical spectrograms (Fig. 2) show constant background noise below 100 Hz, associated to the melting process, and very short emissions with high-frequency signatures extending to 40 kHz. Using analysis windows of 0.08 s (2^{13} samples at the sampling frequency used), these transients are defined on the basis of their Sound Pressure Level (SPL) being significantly larger than the surrounding 10-second segments. Frequency distributions were compared for segments with and without transients (Fig. 3). In this particular example, they showed broad peaks at 500 – 700 Hz, 800 – 900 Hz. Above 1 kHz, the segments with no transients are undistinguishable from the background noise, but those with transients show sharp peaks at 1 – 2 kHz, 2.5 kHz, up to 10 kHz.

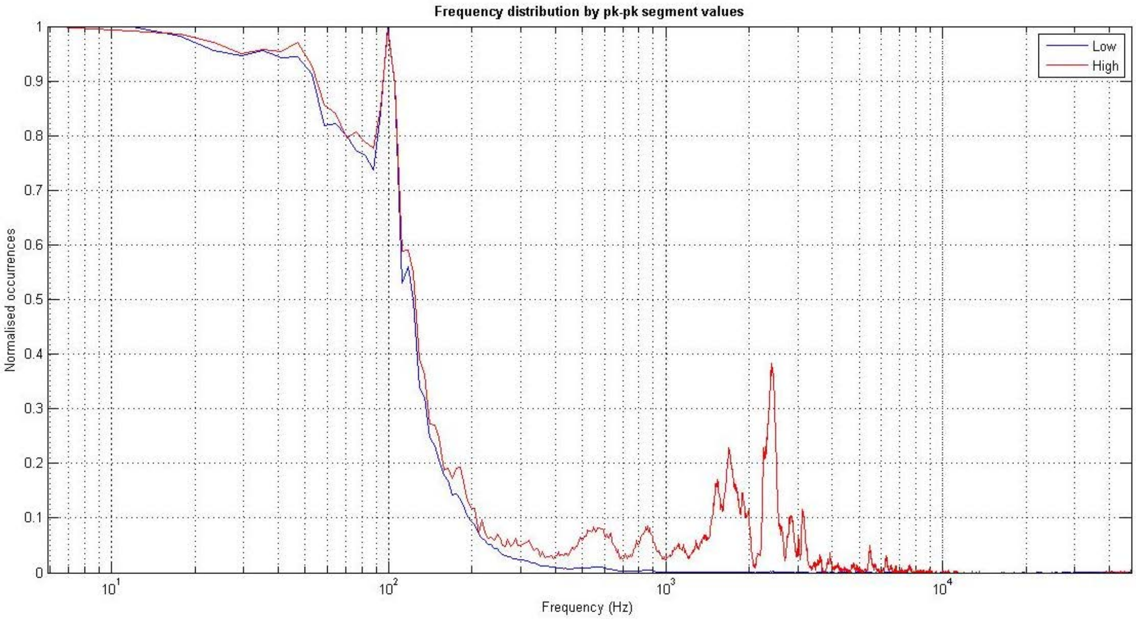

Fig.3: Compared frequency distributions of background segments (blue) and high-SPL transients (red) for the full melting of one single growler. See text for details. From [14].

How do acoustic emissions evolve as a single growler melts? As there will be less ice volume, they should obviously decrease in numbers and in intensities, but the increasing exposure of more gas bubbles might lead to more frequent emissions. As they melt, the shape of growlers will change their centre of gravity and they will capsize, each time with a different energy (based on the shape of the growler at that stage, and on its volume), adding acoustic contributions at lower frequencies. Broadband measurements to full melting (Fig. 4) show RMS mean and percentile probability densities of the same growler, with clear contributions at higher frequencies (> 1 kHz). Measurements over all 0.1-second segments, with a 50% overlap, were arbitrarily separated between third-octave bands below 1 kHz and above: the higher frequencies are in average 8 – 9 dB louder, with frequent peaks up to 14 dB for some of these 0.1-second segments (meaning short, loud sounds with higher frequencies).

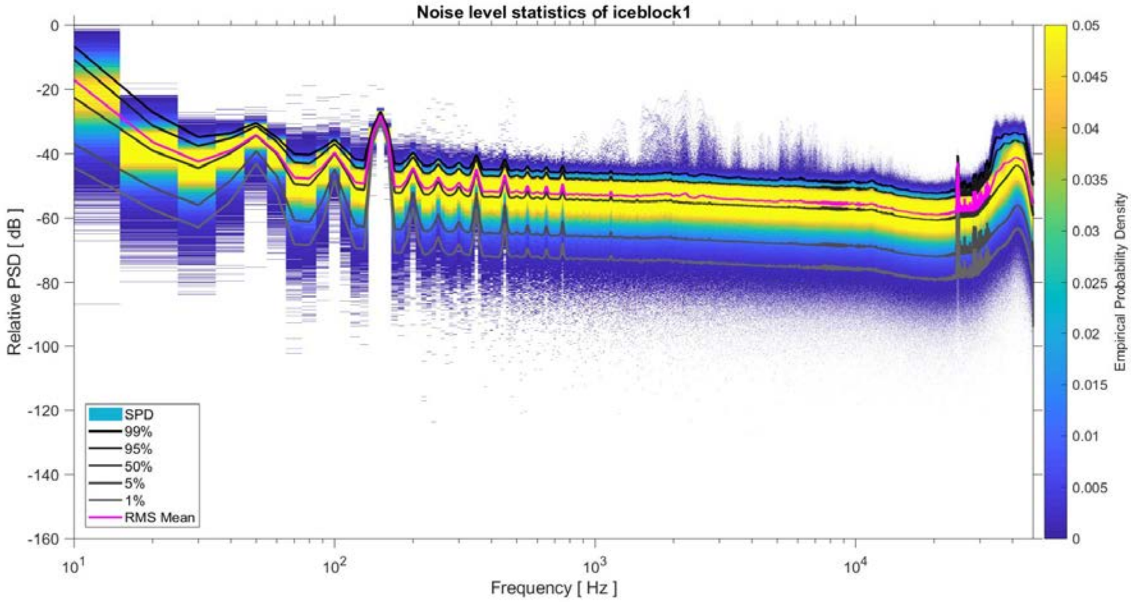

Fig.4: Probability Spectral Density for a fully melting growler, calculated with PAMGuide [15] over 0.1-s segments, overlapping by 50%, with strong high-frequency contributions.

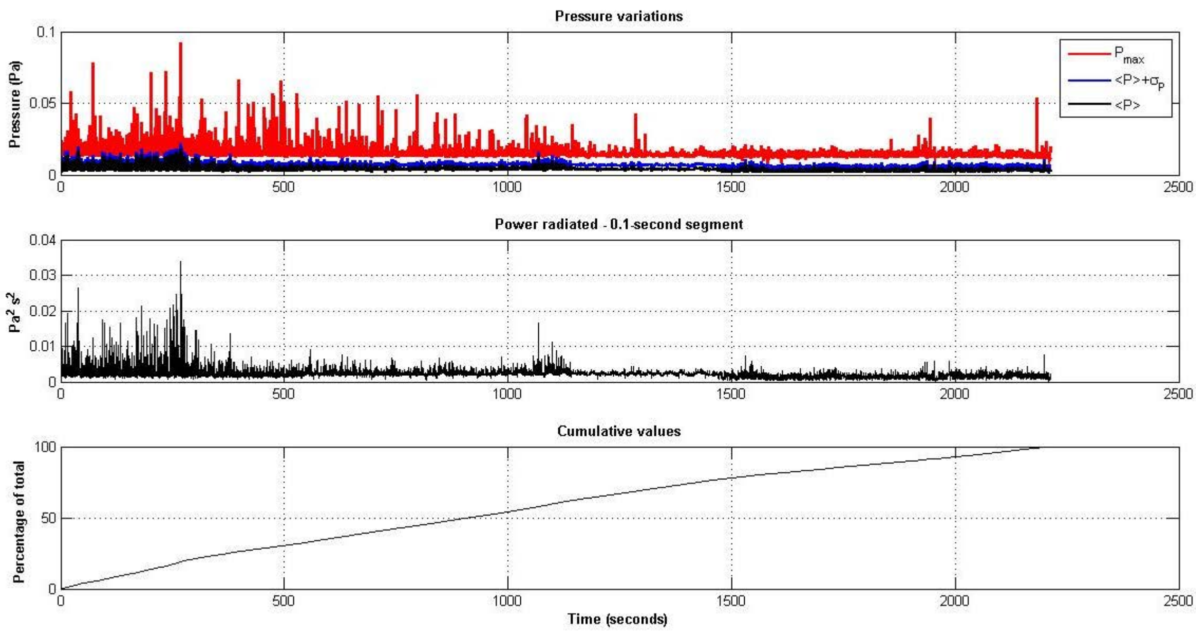

Fig.5: Variations in pressure (mean pressure within each 0.1-second segment, mean pressure and standard deviation and maximum instantaneous pressure recorded within the segment) and acoustic power radiated for the full melting of a single growler.

Broadband pressures from the moment the growlers were put in the water to their full melting show regular variations, decreasing in amplitudes and frequencies of occurrence as melting progresses (Fig. 5). Fig. 5 (top) shows the mean pressure within each 0.1-second segment (in black), its variation with the local standard deviation (in blue), and the maximum instantaneous pressures (red). Fig 5 (middle) shows the power radiated within each 0.1-segment segment, and its cumulative variation (Fig. 5, bottom). The power radiated is more important at the onset of melting and steadily increases to full melting. Similar results are seen for the other growlers analysed in this series of experiments.

3. TANK MEASUREMENTS OF FRESH GROWLERS

The measurements presented in Section 2 were supplemented in summer 2014 with the direct measurement of fresh growlers collected in Hornsund Fjord, Svalbard. Field conditions varied from day to day, with recent glacier melting episodes producing large numbers of growlers (Fig. 6, left). These growlers come in all shapes and sizes. The ones selected for analyses (Fig. 6, right) were of similar sizes (approx. 30 cm wide, 25 cm high and 20 cm long), with surface temperatures of –2°C. They exhibited different bubble densities, estimated visually, and different colours (i.e. different origins within the original glacier). Bubbles sizes close to the surface of each growler varied between a few millimetres and below, with irregular shapes. All growler samples were measured to full melting in cold water (external temperature), in a small tank at the field station nearby, within 20 minutes of collection.

Acoustic measurements were conducted again with a B&K 8103 hydrophone. Signals were amplified with a Parnell precision amplifier, using a constant 80-dB gain and bandpass filtering from 100 Hz to 100 kHz. The signals were sampled at 96 kHz with 24-bit precision, using a NI-USB 4431 card controlled with LabVIEW. Later processing was done with Matlab. Concurrent video was usually limited to the most intense melting (within the first 30 minutes), due to HD card size, and it was complemented with log of visual observations. Melting times varied significantly, typically up to 2 hours, and was not correlated with their volumes. They were determined visually and acoustically (no change in ambient noise). A dozen growlers and smaller ice blocks were analysed, and the background noise was small enough not to be an issue. A batch of similar growlers (same sizes, same apparent bubble densities) were set apart to measure the influence of warmer waters (i.e. faster melting).

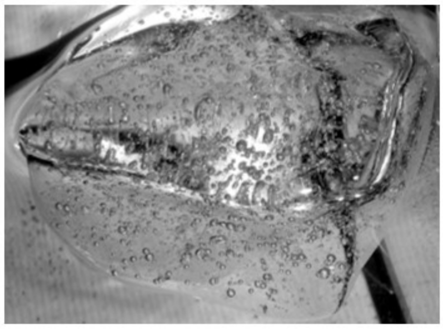

Fig.6. Left: field conditions in Hornsund, on a particular day. Growlers come in all shapes and sizes. Right: growler analysed in Fig. 7. Both images were contrast-enhanced to better show relevant features.

Pressure variations and total acoustic power radiated were again measured in 0.1-second segments for each growler (Fig. 7). The amplitudes and the total power radiated by the time of full melting varied with apparent bubble densities, but still within the same order of magnitude. 90% of this total power was radiated between 55% and 90% of the normalised melting times, with no discernible trend between types of growlers. The total acoustic power radiated between the time a fresh ice block was put in the tank and the time it had totally melted was exponentially correlated with the time to full melting.

There are many loud transients (Fig. 7) and similar analyses to Section 2 were conducted. They cannot be presented fully here, but one key result is how much they contribute to the soundscapes. They were conservatively defined here as segments contributing more than 3 σ of the mean acoustic energy radiated. Although few in number (0.1-0.3% of all 0.1-s segments), these loud transients contribute 10% – 56% of the total acoustic energy radiated by each growler before full melting. They decrease steadily in numbers until melting is 50% complete, and near-final melting (90% of total time) sees a sudden increase in loud transients.

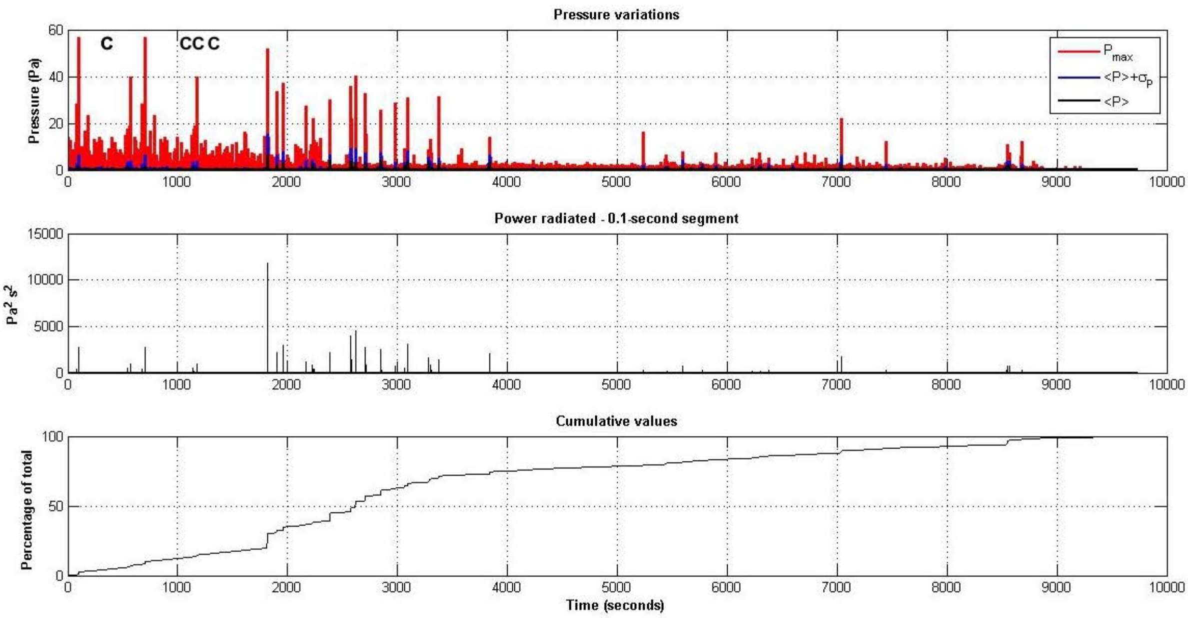

Fig.4: Acoustic emissions from a fresh growler until total melting ("C" indicates capsizing events recorded on video, available for the first 1,800 seconds).

4. DISCUSSION - CONCLUSIONS

Field measurements [6-8,11] show contributions of glacier ice and ice blocks (from floes to growlers to icebergs) include significant high-frequency components, above 1 kHz and up to 30 kHz. To better constrain the relative importance of individual growlers, we have measured their total melting in controlled conditions. Section 2 used growlers collected in a fjord, stored in cold conditions and measured in an anechoic tank several months later. Section 3 used growlers collected in the same fjord, and measured immediately afterwards in a standard tank. Growlers were selected with similar sizes but with variations in colours (i.e. originating depths within the glacier, and therefore bubble pressures) and in apparent bubble densities (as seen from the surface of the growlers).

Both series of experiments confirm the large amount of acoustic transients, with Sound Pressure Levels larger than the baseline, lasting < 0.1 second and with high-frequency components. These transients occur 0.1 – 0.3% of the time to full melting, but contribute up to 56% of the total energy radiated by each growler. They decrease steadily until melting is 50% complete, and reoccur in larger numbers in the final stages of melting.

Detailed analyses of the frequency content of each transient, and how it varies with stages of melting and the nature of the growler (volume, colour, bubble density) is on-going. They will be supplemented with other studies of how bubble pressures and shapes affect the acoustic signatures of the bubbles. These results will help quantify the contributions of growlers and fields of growlers to the changing Arctic soundscapes.

5. ACKNOWLEDGEMENTS

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