UNDERWATER AMBIENT NOISE OF GLACIERS ON SVALBARD AS INDICATOR OF DYNAMIC PROCESSES IN THE ARCTIC

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1 INTRODUCTION

The noise generated by marine-terminating glaciers allows for the quantification of melting processes in the Arctic and is a good indicator of rapid climate processes. Detection and joint analysis of hydro-acoustic and seismic signals from a glacier on Svalbard will provide a new and valuable method to predict the effects of climate change on the Earth's environment. Underwater acoustic measurements are complementary to existing techniques in that they can monitor areas not accessible by ship or satellite, and they offer the potential for long time-series measurements using inexpensive technology. Although remote sensing data deliver an excellent overview about the extent of ice cover in the entire Arctic Ocean, there is still a need for studying and monitoring local processes that will improve our understanding of ice-shield disintegration. The measurements of ambient noise in the Arctic have a long history [1-4], but the literature of this subject is not very extensive.

In August 2009, an Arctic expedition on board R/V Horyzont II from Gdynia Maritime University (Poland) studied two significantly different Spitsbergen fjords. The Hornsund fjord is surrounded by mountains and melting glaciers, which are especially frequent in the inner part – Brepollen. The Murchison fjord, located in the northern part of Spitsbergen, is devoid of glaciers but full of floating ice floes. Such experimental circumstances allowed for the comparison of ambient sea noise in two completely different Arctic environments. During the measurement campaign, the weather was calm, with no wind, rain or breaking waves, but there were fast currents of water flowing from glaciers in the Hornsund and tidal currents in the Murchison fjord. Both fjords were empty of vessels during the noise measurements (R/V Horyzont II was anchored more than 10 km away). These particularly “clean” experimental conditions provided noise recordings dominated by melting and calving glaciers, melting icebergs and growlers in the Hornsund fjord, and by melting and colliding ice floes in the Murchison fjord.

2 EXPERIMENT METHODOLOGY

Ambient noise measurements were conducted from a rubber boat drifting freely through the fjords. All measurements were made using an omnidirectional broadband hydrophone ITC-6050C, which was deployed at the depth of ~18 m with an attached 4-kg weight 2 meters below the transducer. Ambient noise in the frequency range 20Hz–24kHz was recorded using a 16-bit Sony DAT TCD-D8 portable recorder with a 48-kHz sampling frequency. The sensitivity of the hydrophone is nearly flat in the measurement range and equal to -157 dB re 1V/μPa. The DAT recorder gain was set to 19 dB. At the beginning and end of each recording session (around 2 hours in duration), one minute of electronically-generated, white-noise signal with known parameters was recorded for calibration purposes. GPS positions were recorded every several minutes to track the boat drift induced by strong currents. Video and photographic images were taken to document environmental conditions.

3 DATA PROCESSING

The main goal of the data processing so far has been to characterize noise sources through the study of spectral, wavelet and other statistical features of the noise, with a particular emphasis on cracking and melting glaciers. Prior applications of spectral parameter analyses have shown their advantages in laboratory studies of noise generated by breaking waves [5] and in algorithms of anthropogenic noise detection and phenomena associated with atmospheric precipitation [6].

All spectral parameters (spectral moments of different orders, the mean frequency of the noise process and its spectral width, skewness and kurtosis) were computed for 1 second time spans in frequency range of 20 Hz –18 kHz (the upper limit being set by a weak slope in the white noise spectrum at higher frequencies, which was observed in the calibration signal). Moreover, the noise signal was filtered and analysed in 29 1/3rd–octave frequency bands with centre frequencies $f_{central}$ = {25, 31.5,...,16,000} Hz.

The next group of parameters were wavelet transformation coefficients and related wavelet energies. The wavelet energy content was computed using the 10-channel dyadic decomposition (scale $a=2^j$, $j=1,..,10$) with a 3rd–order Coiflet wavelet.

The last group of statistical parameters were the standard deviation, kurtosis and skewness. Chosen parameters – mean frequency, spectral width and wavelet energies were the input to the self-organized Kohonen's neural network algorithm with a learning set containing 25% of the input data. The result of clusterization was established for 3 classes depicting different sources of ambient noise.

4 RESULTS

Our hypothesis that different sources dominate the ambient noise in both experiment locations – the Hornsund and the Murchison fjord – is supported by the observation of distinct differences in the shape and level of the noise spectra (Fig.1). Noise Spectrum Levels (NSLs) were calculated from 1-second time segments and averaged over 20 minute periods, demonstrating the most visible differences at the low frequency ranges, especially below 300 Hz.
A comparison of spectra for the Hornsund fjord (Fig.1a) shows that a wide local maximum in the noise power between approximately 300 Hz and 2 kHz. At frequencies greater than ~2 kHz, the spectral slopes dramatically decrease down to -30 dB/decade. Assuming that noise radiated by the glacier terminus dominates the spectrum below 10 kHz, the rapid roll-off can be explained as a consequence of higher acoustic attenuation in the fjord waveguide for these higher frequencies. We also observe consecutive spectral levels to decrease for mid and high frequencies, with this trend being especially clear during the first 40 minutes of the experiment as the boat drifted away from glacier wall. In contrast to the high frequency behaviour, we observe a distinct increase of NSL of up to 17 dB at 80 Hz with comparison to NSLs at the relatively quiet conditions during the 20- to 40-minute time period. This increase in noise level was the result of an energetic calving event observed at the Stor glacier wall.

A very different noise environment is observed in the Murchison fjord (Fig.1b), particularly in the low frequency band. At frequencies below 40 Hz, we observed an increase in spectral level relative to that seen in Hornsund. As the Murchison fjord is wider than Hornsund, and more strongly coupled to the ocean, we are attributing this increase to distant oceanic sources. Local maxima in the spectra can be seen in the frequency range of 70–200 Hz and these can probably be interpreted as the result of frequent collisions and disintegrations of ice floes in this area. Generally, the NSLs are about 4–5 dB lower at frequencies above 1 kHz in comparison to the Brepollen area. In turn, at frequencies near about ~5–6 kHz a change in spectral slope can be seen, which is a result of a weak increase of the noise spectrum levels for higher frequencies. This effect can be explained by the enormous number of gas bubbles released from ice floes during their collision, disintegration and melting (accordingly with [7] and [4], resonance frequencies of 5-18 kHz correspond to bubbles

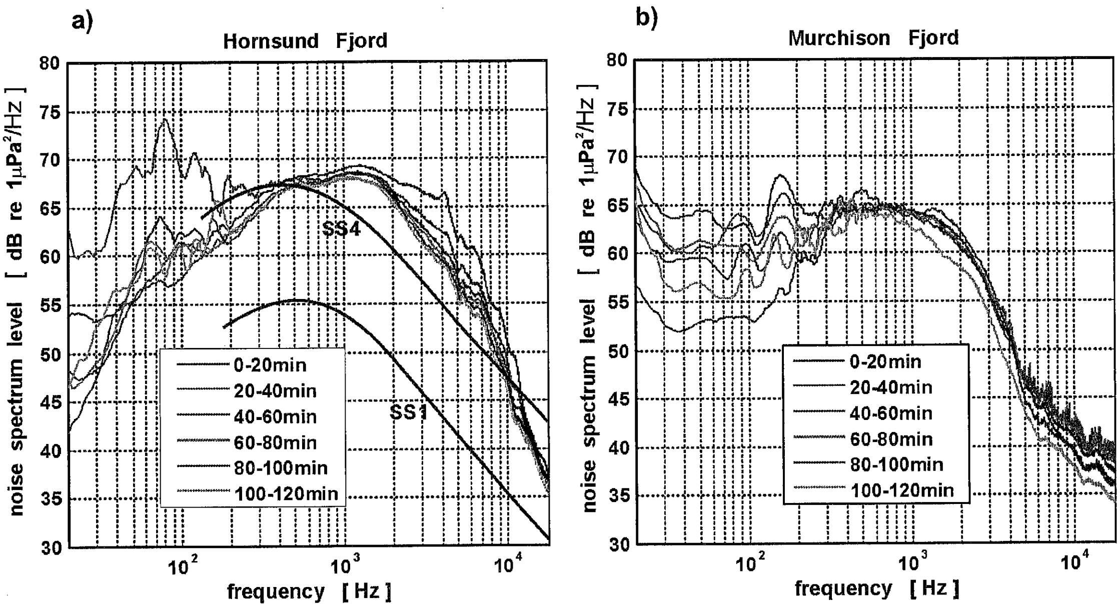

Fig.1 Noise spectrum levels [dB re 1μPa^2/Hz] averaged in 20-minutes time periods recorded in the Hornsund fjord at the Brepollen area close to the Stor glacier (a) and in the Murchison fjord (b). The black curves SS1 and SS4 are typical noise spectra observed in open water at for Sea States 1 and 4 Beaufort, respectively (from [8]).

with radii 0.15–0.55 mm). One of the main goals of the experiment was the detection of physical processes related to acoustical events originating from glacier ice cracks resulting from thermal or mechanical stress. To achieve this goal, we created a classification algorithm based on spectral and wavelet parameters as input to a neural network clustering algorithm. Proposed algorithm has demonstrated the feasibility of detecting and classifying cracking and calving glacier events. Further studies will help elucidate the relationship between features in the ambient noise and the underlying physical processes taking place in the melting Arctic ice environment.

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