IMPACTS OF ANTHROPOGENIC AND ENVIRONMENTAL FACTORS ON THE UNDERWATER SOUNDSCAPE IN FRAM STRAIT

Asuka Yamakawa[a], Hanne Sagen[a], Mohamed Babiker[a], Peter F. Worcester[b], and Birgitte Furevik[c]

[a] Nansen Environmental and Remote Sensing Center, Thormøhlens Gate 47, Bergen, NO-5006, Norway
[b] Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California, USA
[c] Norwegian Meteorological Institute, University in Bergen, Norway

Asuka Yamakawa, Environmental and Remote Sensing Center, Thormøhlens Gate 47, Bergen, NO-5006, Norway, +47 5520 5800, asuka.yamakawa@nersc.no

Abstract:
The soundscape in Fram Strait is composed of sounds from natural physical processes, marine mammal vocalizations, and anthropogenic sources, e.g., seismic airgun noise. In this paper we present analysis of time series acoustic recordings from two different locations in the central part of Fram Strait. Seismic airgun and mechanical noises were filtered out of the datasets prior to the analysis to understand variability of the natural soundscape. Time series of 18 independent natural physical variables were obtained as explanatory variables of the soundscape variability. Based on statistical analysis of the yearlong data, four out of 18 physical factors were found to be the major contributors to the natural soundscape variability [1]. In this paper, we quantify how the four physical factors influence the soundscape in summer and winter.

Keywords: *Soundscape, Fram Strait, Passive acoustic, Environmental factors*

1. INTRODUCTION

In a previous study [1], 18 natural physical factors obtained from satellite remote sensing data, in-situ data, and modelled data were used to statistically explain the soundscape variability in the Fram Strait. It was found that the wind speed, mean sea level pressure, wind sea wave height and swell wave height are the major contributors to variability in the natural component of the soundscape.

In this paper, two seasonal datasets of passive acoustic recordings for winter (January and February 2012) and summer (May to July 2012) are created. Impacts of the major factors on the natural sound variability are explained in 25 Hz frequency bands by a statistical approach. This is then used to establish baseline frequency spectra for the two seasons. The summer and winter results at the two locations are compared and discussed.

2. DATA ACQUISITION

2.1 Passive acoustic data

A multipurpose acoustic system was deployed and operated as part of the ACOBAR project in 2010 and recovered in 2012. The system consisted of three transceiver moorings (A, B and C) and one acoustic receiver mooring (D). The configuration of the moorings is shown in Fig. 1. In 2011 moorings D and A were recovered and redeployed with a modified mooring design to reduce the mechanical noise induced by the strong mooring motion. Correspondingly, passive acoustic recordings from the receiver arrays on moorings A and D are used for the soundscape analysis. Further details of the ACOBAR experiment are given in Sagen et al. 2017 [2].

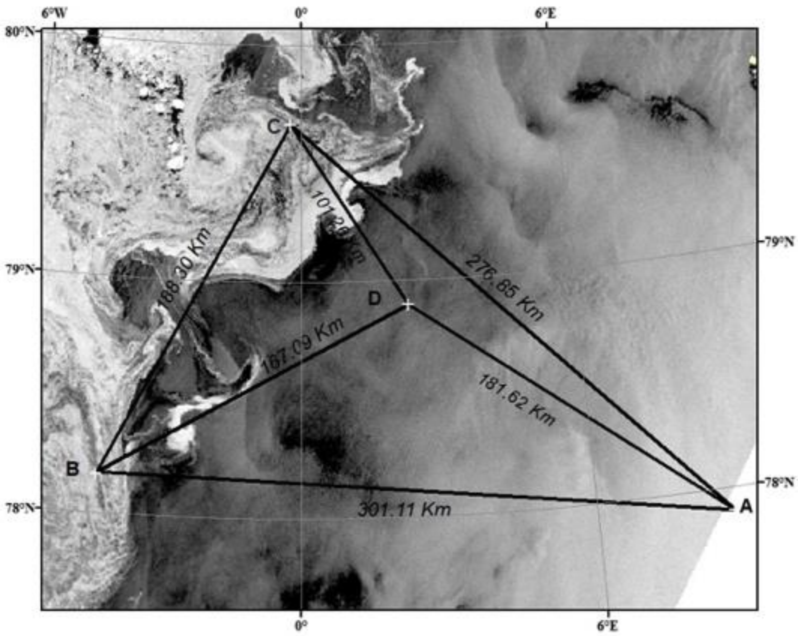

Fig.1: Positions of three transceivers, A, B and C, and one receiver mooring, D, in the ACOBAR experiment. The moorings A and D, discussed in this study, were located at 77°53.60’N, 008°44.49’E and 78°53.42’N, 002°19.42’E, respectively.

The acoustic recordings in the ACOBAR system were made using the Simple Tomographic Acoustic Receiver (STAR) technology [2]. Each STAR had a four-element receiving array and recordings from the closest hydrophone to the controller unit in a STAR are discussed in this study. The STAR systems were programmed to record 100 s every 3 hours from 24 September 2011 to 31 July 2012.

For the analysis of mooring A, the recordings from the shallowest of the four hydrophones (reference depth 373.0 m) are used. The water depth at location A was 1431 m. Mooring D included two vertical arrays of 4 hydrophones each controlled by a STAR instrument. The upper STAR, discussed in this paper, is labeled Da and the reference depth was 263.9 m. The water depth at mooring D was 2439 m.

The hydrophone signals were amplified, bandpass filtered, and sampled using 16-bit delta-sigma converters at a 1000 Hz rate. Power spectral density (PSD) of each signal is calculated using 50 % overlapping Hanning window with a window length of 1024 samples.

2.2. External variables

To interpret the variability observed in the acoustic recordings, the following time-series of environmental data were obtained:

Distance from the mooring to the ice edge is an important factor in the marginal ice zone. Acoustic energy in the MIZ is produced by interaction between individual floes this is primarily driven by ocean swell propagating into the ice pack [3]. Mooring A was always located in the open-ocean. Satellite images from ENVISAT ASAR and ice charts produced by Norwegian Metrological Institute (MET Norway) were used to measure the distance between location D and the nearest ice edge (Fig.2). It was found that mooring D was located into the ice pack for 7.1 % of the experiment period.

Sea state, resulting from waves generated by local and distant wind systems, is important for estimating acoustic noise levels in open water. However, there are no in-situ measurements of sea state, wind or waves in this region, and therefore we use reanalysis of wind and waves from the NORA10 [4] in our analysis. NORA10 is a downscaling with the atmospheric High Resolution Limited Area Model (HIRLAM) of ERA40 and analyses (after 2002) from the European Center for Medium Range Weather Forecasts (ECMWF), forcing the Wave Model (WAM) on a 10-11 km grid. The model analyses provide a large number of parameters such as wind speed, wind north-southerly and east-westerly directions, mean sea level pressure (MSLP), air temperature, relative humidity, precipitation, significant heights of wind sea wave and swell, peak periods of wind sea wave and swell, and north-southerly and east-westerly directions of peak wind sea wave and swell. For this study, NORA10 provides time series modelled meteorological data at 77.87°N, 08.70°E and 78.86°N, 02.72°E as the external factors corresponding to moorings A and D respectively (Fig.2).

Ocean temperature is important for bio-production and therefore also for marine life in the area. Average ocean temperatures between moorings A and D have been estimated using ACOBAR acoustic tomography data to an accuracy of about 70 mC (Personal communication with Brian Dushaw, 2017)

Seismic airgun noise has a periodic signature for frequencies between 25 and 400 Hz, especially below 200 Hz. Strong seismic signals were observed from the middle of April to the middle of November at both locations, while weak seismic signals were detected from December to March (see Fig.2 in Yamakawa et al. 2016 [1]). During the winter time, seismic airgun noise was more frequently observed at mooring A than at D. Most of seismic surveys during the experiment were carried out off the west coast of central Norway and the border between the Norwegian and Barents Seas. The distances between mooring A and the locations of the seismic surveys were shorter than the distances to mooring D. This and differences in propagation conditions might cause the difference between the two moorings on seismic airgun detection during the winter.

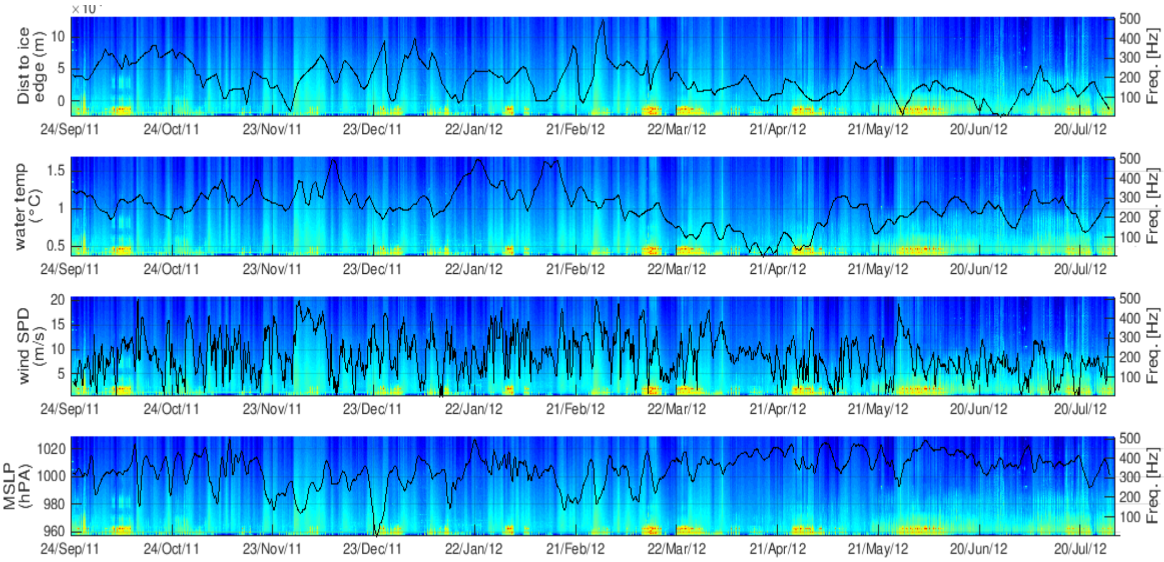

Fig.2: Spectrogram of the acoustic recordings from the Da overlain from top to bottom by the nearest distance from the ice edge (positive is out in the open ocean), temperature from the ACOBAR tomographic data, wind speed from the NORA model, and mean sea level pressure (MSLP). Yellow colour is 100 and dark blue is 50 dB re 1µPa^2 Hz^{-1}

Mechanical noise associated with the vertical displacement of the hydrophone due to flow past the moorings contaminates the recordings below 60 Hz [1]. Strong effects of mechanical noise were observed when the vertical displacements of the hydrophones were larger than 5.0 and 2.5meters for A and Da, respectively. Numbers of the recordings with the displacements lower than the thresholds are 1730 (A) and 1233 (Da).

3. STATISTICAL APPROACH

Multivariate analysis is used to analyze the relationships between more than one statistical variable at a time. Multiple linear regression analysis (MLR) [5], which is one of the multivariate analysis approaches, is applied in this study to explain the acoustic variability with environmental factors as predictors. Linear statistical models such as MLR are relatively easily interpreted, because they provide results for a simple linear combination of the explanatory variables.

Suppose there are p explanatory and one response variables, $(x_{i1}, x_{i2},\cdots,x_{ip}, y_i)$, $i=1,\cdots, n$, are given. Here n represents a number of samples. A linear model of MLR is defined by

$$y_i = b_0 + b_1 x_{i1} + b_1 x_{i1} + \ldots + b_p\, x_{ip}\ , \tag{1}$$

where b_0 and $b_1,\cdots, b_p$ are a constant term and partial regression coefficients, respectively. The objective of MLR is to compute a combination of $b_0, b_1,\cdots, b_p$ so as to minimize the sum of the square errors between observations (y_i) and expected values($\hat{y}_i$) as:

$$\text{Min.} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2\ . \tag{2}$$

4. RESULTS

The method described above is applied on acoustic recordings from A and Da made during the winter (January and February 2012) and summer (May to July 2012). Seismic airgun noise and mechanical noise are excluded from the four datasets by manual detection of seismic airgun noise and by setting a threshold for the vertical displacement of the hydrophones. The numbers of the recordings included for A and Da are 260 and 281 for the winter and 97 and 52 for the summer, respectively. The acoustic recordings are analysed in successive 25 Hz frequency bands using MLR with the four major factors identified in [1] as the explanatory variables (wind speed, MSLP, wind sea wave height and swell wave height). The impacts of the each explanatory variable on the variability of the acoustic energy in each frequency band are computed. The baseline frequency spectrum is defined by subtracting the sum of the variability of each of the four major factors from the mean noise level. In other words, the mean frequency spectrum corresponds to the baseline and the impact of the four physical variables.

In Fig.3, the resulting baseline frequency spectrum and contribution from each variable are shown for Da and A for winter and summer. The blue part corresponds to the baseline frequency spectrum, the green corresponds to the effect of swell, the yellow indicates the impact of wind sea wave height, the orange represents the effect of MSLP, and the red corresponds to wind speed. After adding all the effects, the top line in each figure represents the mean noise level at each frequency.

Comparing summer and winter for mooring D (Figs.3a, 3b), the mean noise levels at 25 Hz are around 80 dB in both cases. In the winter, the four major environmental factors contribute to increase the noise level by up to 10 dB. The mean frequency spectrum in the winter is generally higher (up to 5 dB at the highest frequency) than in the summer, while the baseline frequency spectra are more similar at the frequencies above 150 Hz. The figures show that the impact of wind speed is higher in winter than summer at all frequencies. The impact of wind speed increases with frequency for both seasons.

Fig.3c and 3d represent the results in summer and winter for mooring A. The mean frequency spectrum in the winter is up to 8 dB higher than for the summer. The two figures show that wind speed impacts on soundscape variability in the winter more than the summer at all frequencies. The effects of the major factors except for wind speed were not observed in the summer. Comparing the two locations, the impacts of the four physical factors at location D is stronger than location A.

5. CONCLUSIONS

Acoustic recordings from two different locations in Fram Strait have been analysed using multiple linear regression analysis. Seismic airgun noise and mechanical noise were removed from the analysis. The impacts of the four major environmental factors on the variability of the natural noise components were quantified. From the mean frequency spectrum, the baseline frequency spectrum was established by subtracting the contributions from the four major explanatory variables. The analysis has been carried out for summer and winter data, showing much stronger wind speed dependency in the winter.

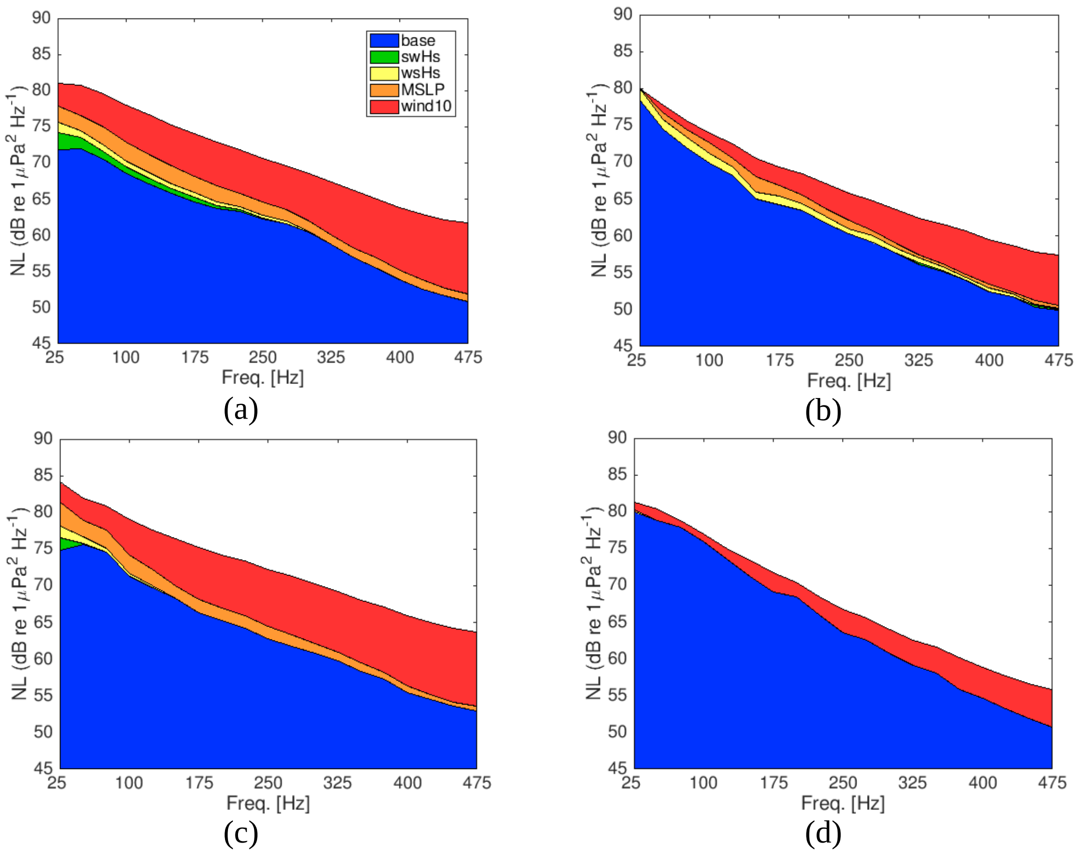

Fig.3: Impacts of the major environmental factors on noise variability and the noise baseline. (a) Winter for Da, (b) Summer for Da, (c) Winter for A, (d) Summer for A

6. ACKNOWLEDGEMENTS

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