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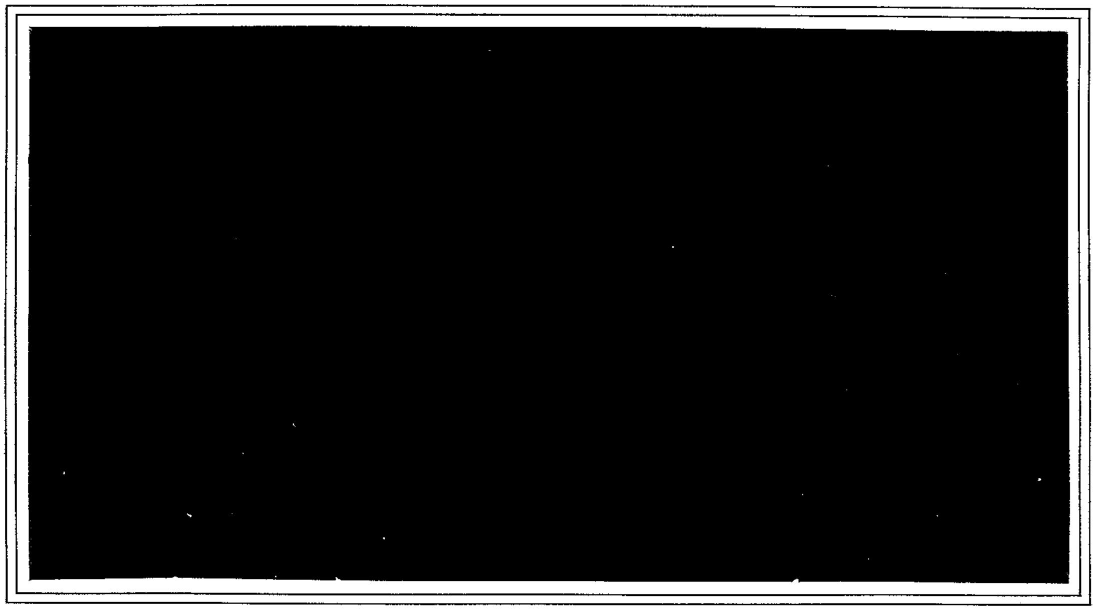

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EFFECT ON SIGNAL TO NOISE RATIO OF CLIPPING ARCTIC ACOUSTIC DATA

by

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December 1990

ABSTRACT

Arctic ambient noise is characterized by the presence of transients due to ice cracking. The present document reports the results of an investigation into the effect on signal to noise ratio (SNR) of clipping ambient noise time series to which artificial sinusoid signals had been added. Because the ambient noise contains more power at low frequencies than at high frequencies, it was deemed necessary to bandpass filter the time series before clipping. The effect of clipping on SNR was found to depend strongly on frequency. At low frequency ($f \leq 40$ Hz) the SNR was not greatly affected by clipping. At higher frequencies, however, clipping was found to improve the SNR, by as much as 5 dB.

RÉSUMÉ

Le bruit ambiant dans l'océan arctique est charactérisé par la présence de bruits transitoires dûs au craquement de la glace. Ce document rapporte les résultats d'une investigation de l'effet sur le rapport signal sur bruit d'écrêter des séries temporelles auxquelles des signaux sinusoïdaux ont été additionnés. Parce que le bruit ambiant est plus élevé aux basses fréquences qu'aux hautes, on a trouvé nécessaire de filtrer les séries temporelles avec des filtres passe-bandes avant de les écrêter. On a trouvé que l'effet de l'écrêtage sur le rapport signal sur buit dépend fortement de la fréquence du filtre passe-bande. Aux basses fréquences ($f \leq 40$ Hz) le rapport signal sur bruit n'a pas été grandement affecté par l'écrêtement. Aux plus hautes fréquences cependant, on a trouvé que l'écrêtement améliore le rapport signal sur bruit, par autant que 5 dB.

1. INTRODUCTION

1.1 Motivation

The underwater ambient noise in the Arctic in winter and spring is characterized by the presence of transients due to ice cracking events. This causes the ambient noise to be non-Gaussian and non-stationnary[1,2]. Since a sizeable portion of the noise energy is contained in the form of transients, one way to increase the signal-to-noise ratio (S/N) is to decrease selectively the energy contained in the transients. A simple way to do so is to clip the time series just above the amplitude of the background between the transients. The hope is that the loss of power due to the clipping will be greater for the noise than for the signal.

1.2 Preview

In this study, we investigate the effect of clipping ambient noise time series to which artificial signals had been added. The intention is to see if noise due to transients can be selectively removed to provide an improved signal-to-noise ratio. The signals consisted of sinusoids at octave intervals between 10 and 1280 Hz. Because the underwater ambient noise in the Arctic has a "pink spectrum", i.e. the power at low frequency is much higher than at high frequency, it was deemed necessary to bandpass filter the time series before performing clipping.

In the following sections, we describe the technique used to determine the clipping threshold, then examine the effects of clipping for three different noise samples both with and without prefiltering.

2. METHOD

2.1 Threshold level

Since ice-cracking transients typically have amplitudes that are significantly larger than the amplitude of the background noise[3], the optimum threshold level is that amplitude below which most of the background between the transients lies. This observation that the transients have large amplitudes also indicates that considering only the local peaks within a time series should provide sufficient separation of the transients from the background. Thus, in this study, we deal primarily with the probability distribution function (p.d.f.) of the local peaks in the time series rather than the p.d.f. of all the samples in the time series.

One would hope than the p.d.f. of peaks will be multimodal, where each mode corresponds to the p.d.f. of a different process. For example, the p.d.f. might be bimodal, one mode corresponding to the p.d.f. of the background noise between transients, and the other one corresponding to the p.d.f. of the transients themselves. If such was the case, the optimum threshold to choose would be at the minimum occurring between the two maxima in the p.d.f.[4].

Unfortunately, the p.d.f. of Arctic ambient noise proved to be unimodal in all cases considered to date. The p.d.f. of both transients and background overlap enough to prevent the formation of a minimum between the two distribution functions. One must therefore rely on some other criterion to decide on the threshold level at which to apply the clipping.

The criterion used for choosing the clipping level in this study is based on the comparison of the measured p.d.f. with the p.d.f. that would be expected if there were no transients present. The threshold is chosen to be the amplitude at which the two distributions start to differ significantly. The expected p.d.f. is derived from a random Gaussian time series, since Nielsen and Thomas[1] found that the background between transients exhibited Gaussian statistics. This is to be expected, since the background between detectable transients is made of a great number of overlapping weaker transients. The central limit theorem predicts that the statistics of such a time series should be Gaussian.

The expected p.d.f. of the peaks contained within a Gaussian time series can be calculated explicitly. The probability $S_G(p_O)$ that there is a peak in the absolute value of the noise-only time series at an amplitude p_O is given by

$$S_G(p_o) = G(p_o)\int_0^{p_o} G(p)dp \int_0^{p_o} G(p)dp \qquad (1)$$

where $G(p)$ is the Gaussian distribution function. It is simply the probability of having a value p_O at a given point with points of lower amplitude both preceeding and following. The integral is related to the error function

$$\mathrm{erf}(p_o) \equiv \int_{-\infty}^{p_o} G(p)dp \qquad (2)$$

Using the symmetry of the Gaussian function:

$$\int_0^{p_o} G(p)dp = \int_{-\infty}^{p_o} G(p)dp - \int_{-\infty}^{0} G(p)dp$$

$$= \mathrm{erf}(p_o) - ½ \qquad (3)$$

Therefore

$$S_G(p_o) = G(p_o)[\mathrm{erf}(p_o) - ½]^2 \qquad (4)$$

That function is plotted in Fig. 1, along with the histogram H of the amplitude peak distribution of a 70-Hz highpassed noise sample, after having rescaled S_G so that its peak coincides with that of H. The amplitude at which H/S_G=2.0 is about 0.25 Volts, so this level was chosen as the threshold for clipping the sample from which H was constructed. The good fit of S_G to H for V≤0.15 Volts supports the choice of a Gaussian distribution for the transient-free periods of the time series.

2.2 Signal

Continuous wave signals were added to the ambient noise samples at every octave between 10 Hz and 1260 Hz. The amplitude of the signal was adjusted so that its power level within a 1-Hz-wide bin was about the same as the ambient noise power level at each frequency. The total power of the signal was therefore negligible relative to the total power of the ambient noise.

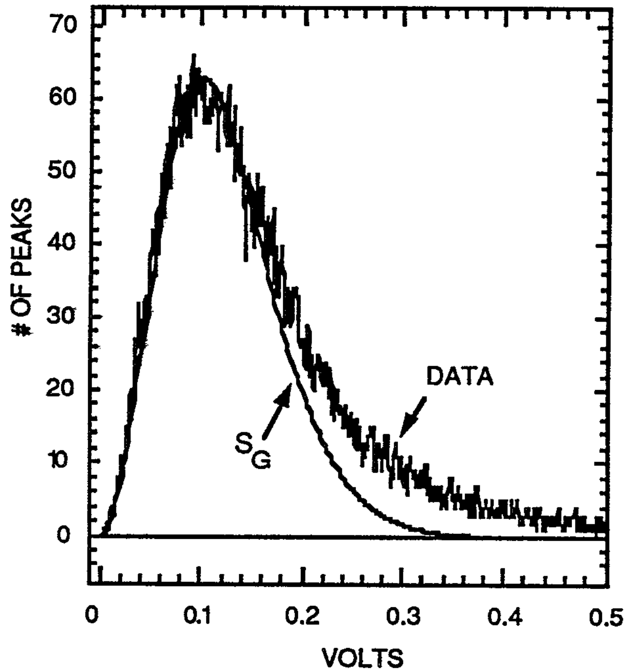

FIG. 1. Probability distribution function for the amplitude of the peaks in a Gaussian time series (S_G) and measured histogram of the amplitude of peaks in a sample of ambient noise highpass filtered at 70 Hz.

2.3 Filtering

As was mentioned earlier, Arctic ambient noise contains much more energy at low frequency than at high frequency (see Fig. 2). If one was to clip the unprocessed time series, one would be affecting the low frequencies disproportionaly to the high frequencies. Because of this, it is necessary to filter the time series with passband filters before attempting to clip them. In order to test this hypothesis, clipping was performed on both filtered and unfiltered time series. The filters used for the present study were 1-octave wide IIR filters.

2.4 Ambient noise samples

Three ambient noise samples, which will be referred to as A, B, and C, were used for the present clipping study. The three samples had been collected during the month of April 1987 as part of the ICESHELF 87 exercise on the pack ice of the Arctic ocean. The samples were chosen because each represents one of the three types of ambient noise encountered during the ICESHELF 87 exercise, as determined by listening to the recordings, and comparing their spectral levels. Sample A was taken during a "quiet" period of the ambient noise, when noise levels were very low. However, some transients could still be heard above the background. Sample B was recorded during a period of intense thermal ice cracking, characterized by a high number of audible transients, and the presence of a "hump" in the ambient noise spectrum from 40 to 2000 Hz (Fig. 2). Sample C was taken during a period of lead formation in the region the experiment took place. The noise levels were much higher at that time than before or after the lead formation. The ambient noise sounded like distant thunder.

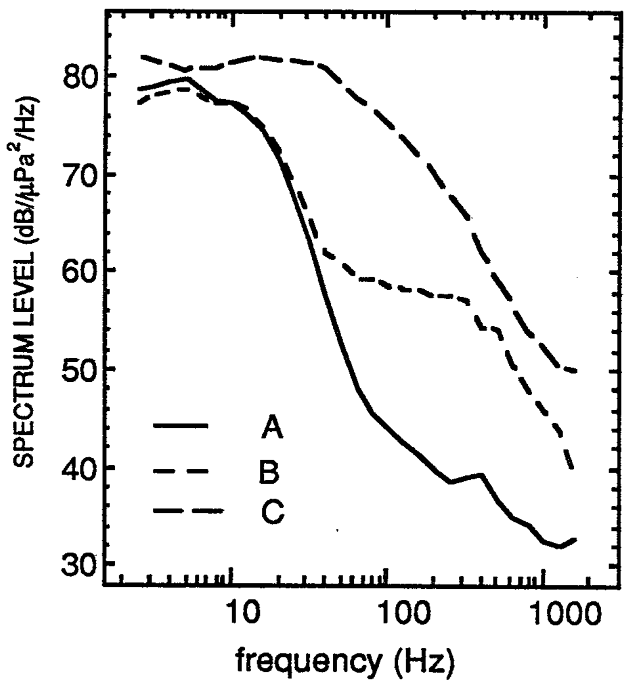

FIG.. 2. Noise spectrum level for the three ambient noise samples used for the present study. Sample A corresponds to a very quiet period, sample B contains thermal ice cracking, while sample C corresponds to a period of loud ambient noise caused by nearby lead formation.

Each sample was 260 seconds long, and had been sampled at a 5 kHz rate. The hydrophone was 55 meters below the sea surface, and the water depth was 500 meters.

3. RESULTS

The gains in S/N due to clipping of the filtered data are shown in Table I. The gains in S/N due to clipping for the unfiltered data of all eight frequencies used are shown in Table II.

The most salient feature of Tables I and II is that the gains are in general higher for the high frequency bands than for the low frequency ones. This is true for all three samples of the filtered set and for the unfiltered analysis of noise sample A. Also, gains are lower for the unfiltered samples than those for the filtered samples.

Important and systematic differences are apparent in the effect of clipping for the three different ambient noise samples used. The gains are higher at all frequencies for sample A than the other two samples. Gains are also slightly better for sample B than sample C, except at 10 and 20 Hz for unfiltered data. Gains can sometimes be negative, especially when clipping unfiltered times series B and C. In other words, the S/N suffered a loss after clipping for those frequency and samples with negative gains.

TABLE I: *Gains in signal-to-noise ratio due to clipping octave-filtered time series for all three samples used.*

Midfrequency of octave band (Hz)	A	File B (dB)	C
10	0.0	0.0	-0.1
20	2.5	-0.1	-0.1
40	1.0	0.1	0.1
80	3.3	1.5	1.0
160	4.6	1.8	0.8
320	5.0	0.8	1.1
640	3.0	2.1	0.9
1280	3.5	2.6	0.6

TABLE II *Gains in signal-to-noise ratio due to clipping unfiltered time series for all three samples used.*

Midfrequency of octave band (Hz)	A	File B (dB)	C
10	0.0	-0.1	0.0
20	0.1	-0.3	0.1
40	0.4	0.2	-0.1
80	0.8	0.6	-0.2
160	1.4	0.0	-0.5
320	2.3	0.0	-0.6
640	1.7	-0.1	-1.1
1280	1.3	-0.4	-1.0

4. DISCUSSION

The frequency dependence of the gains due to clipping arises from the fact that low frequency Arctic ambient noise contains a much smaller proportion of its energy in the form of transients than higher frequency ambient noise. This was demonstrated by Zakarauskas, Parfitt and Thorleifson[3] who directly extracted transients from octave-filtered time series. Their results demonstrated that transients may constitute as little of 10% of the power of Arctic ambient noise at 10 Hz, but can contribute as much as 95% at 320 Hz. The high frequency transients are also a lot more salient than their low frequency counterparts.

Intuitively, clipping should be most effective at removing noise from well-isolated high-power transients. Since these conditions occur more frequently at high frequencies than at low frequencies, clipping will be more effective at increasing S/N at high frequencies. One can use a similar argument to explain the higher gains found with noise sample A. In that case, the background noise was low level, so any identifiable transients would be expected to be both well isolated and significantly above the background, thereby satisfying both requirements for a high gain from clipping. In cases B and C, on the other hand, the noise backgrounds were higher and the transients more frequent, so that clipping would be less effective.

Since transients are broadband events, one is lead to wonder why they appear to contribute more of the relative power at high frequency than at low frequency. An explanation may come from the nature of propagation loss as a function of frequency. Ice-covered waters have a notorious low-pass effect on acoustic propagation, supposedly due to the scattering of acoustic waves off the underice roughness and the excitation of elastic modes in the ice. This means that, for a given listening site, a larger area contributes sources to the ambient noise at low frequency than at high frequency. If the frequency is high enough, and the contributing area small enough, the transients may be detected individually. On the other hand, when the contributing area is very large, as it is at low frequencies, there are so many transient sources that they overlap in time, and, in effect, start to merge with the background.

Finally, the SNR suffers a loss when clipping unfiltered time series, because clipping affects mostly the low frequency peaks while introducing high frequency noise at the clipped edges. Low frequency peaks are more affected because they have higher amplitude than the peaks at high frequencies. Clipping introduces high frequency noise because of the squared edges of the clipped peaks.

5. CONCLUSIONS

In general, clipping proved not to be useful for the low frequencies, but at 80 Hz and above, clipping is certainly an effective and simple way to improve the signal-to-noise ratio in Arctic underwater data. The filtering and clipping stages can be easily implemented in hardware before the digitizing stage of a recording system. One must remember that the acoustic data *must* be band-pass or high-pass filtered before proceeding with clipping. Gains can even be negative (i.e. losses in S/N occur) when clipping non-filtered time series.

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