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A post-processing technique to remove background noise from echo integration data

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Echo integration of biological organisms with a low target strength can be difficult because of the problem of setting suitable pre-integration thresholds, and this is particularly acute with higher frequencies, such as 120 or 200 kHz, which are often used in studies of euphausiids. One solution is to integrate data without any threshold and then remove background noise during post-processing. Unthresholded, integrated data of micronekton and *Euphausia superba* collected with a SIMRAD EK500 at frequencies of 38 and 120 kHz are presented. The underlying background noise level follows a $20 \log R + 2\alpha R$ relationship, which can be scaled to the minimum volume backscatter (Sv) in each layer during a transect and then subtracted from the entire data set to remove background noise. The utility of this procedure is demonstrated by making comparisons of Sv at each frequency and investigating the effect of noise removal on the identification of targets based on the dB difference (120 kHz Sv–38 kHz Sv).

Key words: echo integration, noise removal, threshold.

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Introduction

Echo integration techniques are commonly used as a means for assessing abundance of fish (MacLennan and Simmonds, 1992) and micronekton species such as Antarctic krill (*Euphausia superba* Dana) (McClatchie *et al.*, 1994). Background noise (defined here as the signal present at the receiver output in the absence of any transmission; MacLennan and Simmonds, 1992) and reverberation from small targets (where reverberation is defined as the echoes from unwanted targets) can often be excluded from the echo integration process by the use of appropriate integration thresholds. Thus, for the stock assessment aggregations of fish with swimbladders, such as gadoids, which are strongly reflecting targets (target strength (TS) > -45 dB; MacLennan and Simmonds, 1992), a high integration threshold (for instance a -70 dB volume backscattering (Sv) integration threshold) may be quite appropriate. However, for weak scatterers, such as krill (Foote *et al.*, 1990; MacLennan and Simmonds, 1992), the selection of pre-integration threshold levels is more critical. A high threshold will eliminate all noise but may also exclude significant amounts of echo energy arising from biological targets, while a low threshold will detect low densities of targets but may also include noise, especially near the surface or in the deeper layers. The TS at 120 kHz for a 30 mm Antarctic krill is -76 dB (TS = 34.85 log (animal length in mm) − 127.45: SC-CAMLR, 1991). Even with a Sv integration threshold of -70 dB the attenuation coefficient in Antarctic waters (0.028 dB m^{-1}) results in integration of background noise below 170 m. Recent work using the difference in backscattering from targets measured at two frequencies to separate Antarctic krill from zooplankton and fish (Madureira *et al.*, 1993a, b) places additional emphasis on the selection of appropriate combinations of thresholds for both frequencies.

An alternative procedure is to collect data without any threshold (Johannesson and Mitson, 1983) and then attempt to partition the contributions of noise, reverberation, and targets during post-processing (MacLennan and Simmonds, 1992). Nunnallee (1990) describes a technique to separate background noise from reverberation by estimating the background noise through echo integration with the transmitter disabled.

In this paper we apply a post-processing TVG-based noise reduction algorithm to unthresholded data collected at 38 and 120 kHz. We then derive the echo integral due to biological targets by subtracting the

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background noise from the overall echo integral. Finally, we consider the effects of such a transformation on the derivation of dB difference between two frequencies and implications for target discrimination.

Materials and methods

Acoustic data were obtained with a calibrated SIMRAD EK500 echo-sounder operating at 38 and 120 kHz through split-beam hull-mounted transducers. The echo-sounder was operated using version 3.01 of the SIMRAD firmware. Data were collected from RRS ''James Clark Ross'' in January and February 1994 around South Georgia and the South Orkney Islands in the Atlantic sector of the Southern Ocean.

Volume backscattering (Sv) was integrated in 120 layers, each 2 m thick, at thresholds of -100 and -70 dB. The former setting, the minimum allowable using the EK500, is considered to be unthresholded data. The EK500 automatic noise thresholding mechanism was disabled.

Integrated data, layer and parameter telegrams from the echo-integrator were logged on a PC through the serial port connection. In order to obtain data values independent of the ensonified depth range, the integrated Sa data produced by the EK500 were transformed to Sv values using a standard algorithm (SIMRAD, 1993) during logging. Separate files were produced for each transect.

For each data file the minimum recorded Sv values for each depth layer at both thresholds were extracted and plotted using either GENSTAT (Payne *et al.*, 1987) or custom Application Visualization Systems (AVS) modules (Socha *et al.*, 1996). Suspect data (for instance those occurring close to the surface or bottom) were edited using other custom AVS modules.

Background noise, amplified during time-varied-gain (TVG) compensation in the echo-sounder, can be described by a curve of the form $20 \log R + 20\alpha R + offset$ where R = depth (m), α = attenuation coefficient (set during data collection at 0.01 and 0.028 dB m^{-1} for 38 and 120 kHz, respectively), and *offset* = dB value analogous to an intercept in a regression. This noise curve was adjusted to fit the Sv minima curve from the transect in several ways. Firstly, while fixing α at the level used during data collection, the most appropriate value of the *offset* was determined by using least squares analysis. Secondly, the depth at which a particular background noise level was detected was used as a point through which to force the noise curve (see Nunnallee, 1990). Thirdly, curves were fitted using AVS custom modules which either automatically derived the best TVG-based fit over the entire depth range, or a limited depth range set by the user, or allowed for user manipulation of α and *offset* (Socha *et al.*, 1996). Data were subsequently noise corrected by subtracting, in the arithmetic domain, the appropriate values derived from the noise curve from all Sv values in the data file.

Results

Unthresholded (-100 dB), integrated 120 kHz data (Fig. 1) from a transect across the shelf of the South Orkney Islands show discrete, dense targets with integrated Sv values between -60 and -45 dB, which are characteristic of swarms of Antarctic krill (Everson, 1982; Miller and Hampton, 1989). Outside these swarms the background Sv is relatively constant for a given depth but increases with depth due to the effect of TVG amplification (Fig. 1a). Minimum background levels of ~ -90 dB in the upper 50 m increase to -70 dB at a depth of $\sim$175 m. In Figure 2 the fitted noise curve ($\alpha = 0.028$ dB m^{-1}, *offset* = -125.0) is plotted with minimum and maximum Sv for each depth within the transect. The fitted noise curve follows the minimum Sv curve well, apart from near the surface and at 100–150 m. Surface noise levels are likely to be higher than those predicted with a TVG-based compensation due to aeration and turbulence effects which cause reverberation. The step-like function in the minimum Sv between 100 and 150 m occurs because with SIMRAD firmware (v3.01) the serial port outputs only integer values for Sa between 1 and 9, resulting in an apparent 3 dB jump in Sv between Sa values of 1 and 2. Similar noise compensations have been carried out for 38 kHz data where values of $\alpha = 0.01$ dB m^{-1}, *offset* = -139.4 were obtained.

The effect of subtracting the noise from the unthresholded data can be seen in Figure 1b. Although some banding due to the step-like function described above is evident, much of the original depth-related increase in noise has been removed. Structure at 200–250 m, originally very close to the background noise level, is now visible. Background Sv values appear much more constant through the water column, varying in this case between -90 and -75 dB even at 250 m. In contrast, uncompensated background values may be as much as 25 dB higher at 250 m (compare Fig. 1a and b).

The effect of this noise reduction algorithm on calculation of the Sv difference between 120 kHz and 38 kHz was explored in a simple simulation. Krill backscatter data were created by making all 120 kHz Sv data points either -65 or -70 dB, while corresponding 38 kHz Sv values were 7 dB lower. Simulated noise was then calculated from the noise curve using α and *offset* values shown above. Finally, overall Sv for each depth was obtained by summing the arithmetic contribution of noise and krill. The proportional contribution of noise to the overall Sv rises with increasing depth because of TVG amplification. In addition, the noise amplification increases at different rates because of the different values of α used for the two frequencies, and so there is a shift

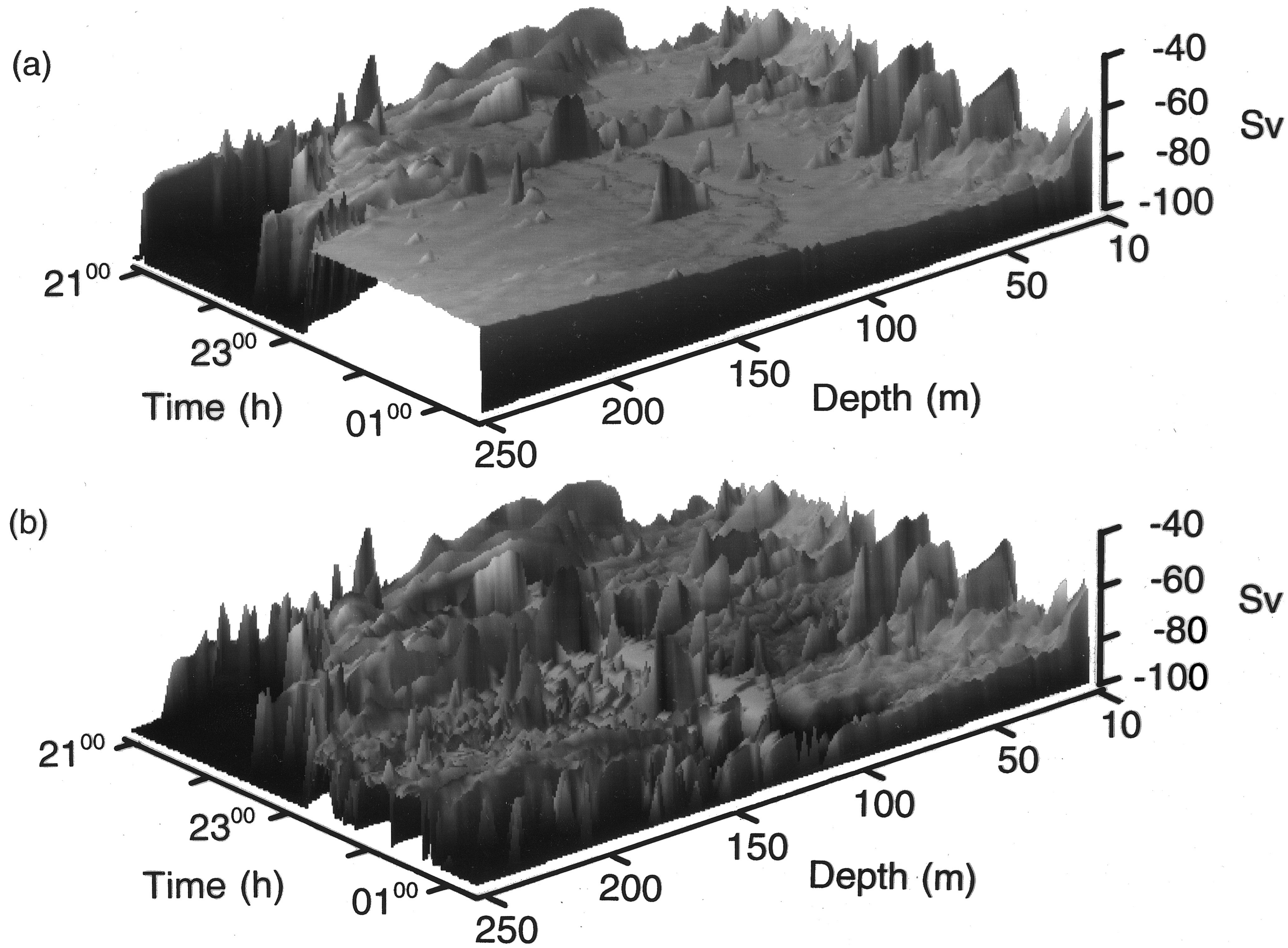

Figure 1. Plots of integrated, unthresholded 120 kHz data collected during a transect across the South Orkney Islands shelf: (a) data prior to application of noise reduction algorithm, (b) data after noise reduction algorithm (20 log R + 2αR + *offset*; α = 0.028 and *offset* = − 125) has been applied. Note that the hole in background noise at the beginning of the transect is due to the passage of the ship over shallow water.

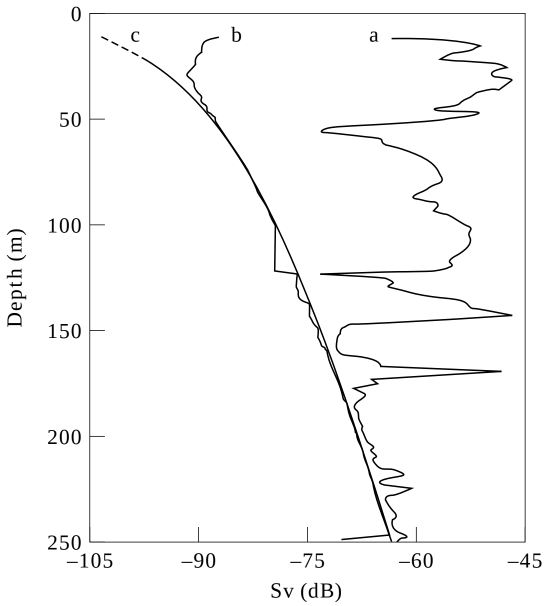

Figure 2. (a) Maximum and (b) minimum Sv values for 120 kHz unthresholded, integrated data from transect across the South Orkney Islands shelf. (c) Noise reduction algorithm (20 log R + 2αR + *offset*) fitted with α = 0.028 and *offset* = − 125.

in the apparent dB difference with depth. The size of this apparent shift depends on the contribution of noise to the overall Sv. This is illustrated using the signal-to-noise ratio (SNR), calculated as overall 120 kHz Sv–120 kHz noise (dB). At high SNR the effect of noise on the dB difference is negligible and the dB difference remains at 7 dB (Fig. 3, where SNR > 20 dB). However, at low SNR, the contribution of noise to the overall Sv rises and the apparent dB difference between 120 kHz Sv and 38 kHz Sv increases from the original 7 dB up to nearly 13 dB (Fig. 3). Therefore, TVG-based noise amplification has the potential to change the observed dB difference at low SNR ratios. This in turn will have serious consequences for studies which utilize dB difference as an aid to target identification.

The effect of noise reduction on the dB difference was then investigated using the 120 kHz field data illustrated in Figure 1a and b, together with the 38 kHz data collected concurrently (Fig. 4). The differing amounts of noise reduction applied at the two frequencies is clearly seen, with a substantially greater reduction occurring in the 120 kHz data (Fig. 4a). The effect of this difference in noise reduction on the calculation of dB difference is shown in Figure 5. At a high SNR the contribution of noise is minimal and the dB difference is the same whether the data are noise-processed or not. However, as the SNR falls below 10 dB, the increasing differential contribution of noise in 120 and 38 kHz data means that the dB difference produced from noise-reduced data is less than that produced by noise-included data. The relationship observed in the field data follows that of the simulation data (Fig. 3) down to a SNR of approximately 2.5 dB, but below that level the dB differences from noise-removed and noise-included data become extremely variable (Fig. 5).

Discussion

The technique described here is applicable to all frequencies and overall depth ranges; the benefits, however, will be greater at higher frequencies and at greater depths where the TVG compensation is larger. The technique allows dB differences to be calculated and applied to signals closer to the background noise level than would otherwise be possible. This is important given the increasing interest in characterization of zooplankton across a range of sizes and TS values. Madureira *et al.* (1993a) used post-processing thresholds in the discrimination of Antarctic krill and other scatterers. However, in their case, a single threshold for each frequency was applied

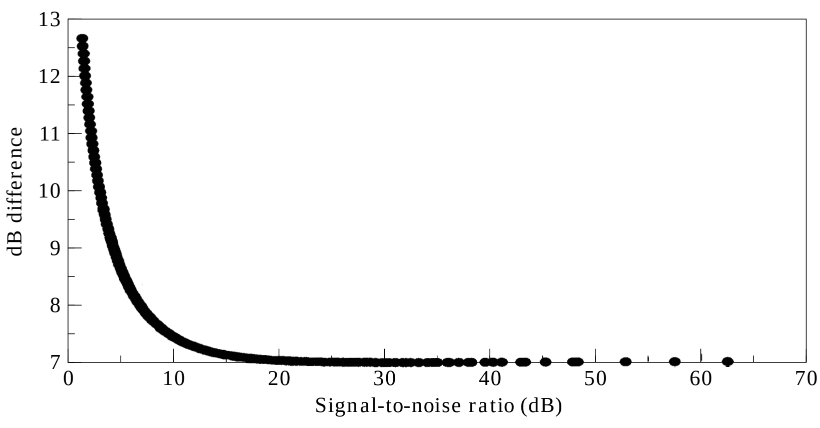

Figure 3. Simulation of the effect of change in signal-to-noise ratio (SNR dB) on a nominal dB difference of 7 dB for targets with Sv = − 65 and − 70 dB at 120 kHz.

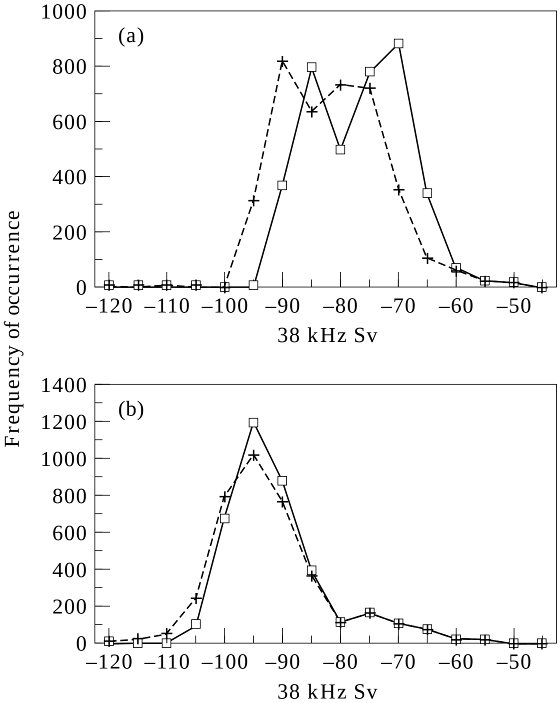

Figure 4. Effect of the noise reduction algorithm on Sv values for (a) 120 kHz data and (b) 38 kHz data from transect across the South Orkney Islands shelf. □ with solid line indicates Sv values when noise included; + with broken line indicates Sv values when noise removed.

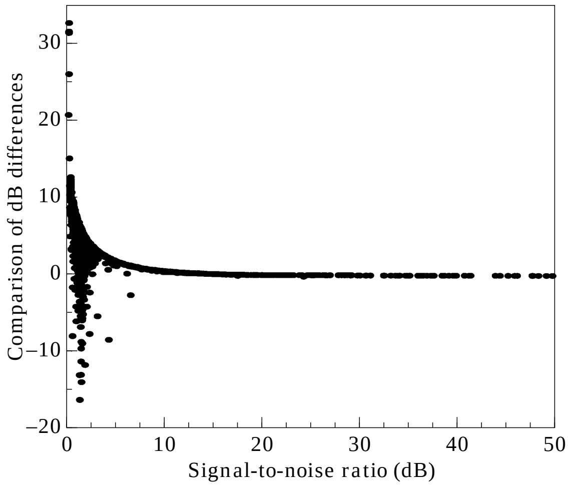

Figure 5. Plot of [dB difference (120 kHz Sv − 38 kHz Sv) with noise included] minus [dB difference (120 kHz Sv − 38 kHz Sv) with noise removed] against the signal-to-noise ratio (overall SNR at 120 kHz). Data from transect across the South Orkney Islands shelf.

down through the water column (− 78 and − 76 dB for 38 and 120 kHz, respectively). It is likely that the high thresholds necessary to eliminate noise from deeper targets will exclude useful data that are well above the noise level at shallow depths. Madureira *et al.* (1993a) distinguished between three types of target. The dB differences for their types I and III are sufficiently close (3 to 9 dB and − 3 to 1 dB) that distortions in the dB difference reported in our study could shift targets from one category to another, resulting in errors in target classification and hence in biomass estimation. We suggest that, using the technique outlined here, it is possible to make valid dB difference estimates for targets that are greater than 2.5 dB above the background noise level.

Nunnallee's (1990) techniques to monitor noise (with the transducer set to receive only) separately from the total echo integral are the only way of providing true measurements of ambient noise. In contrast, our technique assumes that within a given period there will be some depth intervals where there are effectively no targets. This is more likely when integration layers and periods are small (2 m deep and 1 min in duration for the data analysed here).

Our technique allows noise to be monitored during each transect and localized changes, which could be due to bathymetry, bottom type, weather, ship's speed, or system changes, can be seen and investigated. Post-processing to remove this noise is advantageous because the user has complete control over the process. Thus, the horizontal distance over which the Sv minima curve is calculated can be altered as appropriate. For example, the effect of bathymetry on noise levels can be examined by splitting up transects into separate on-shelf and off-shelf components. Alternatively, the same noise removal curve may be used from transect to transect so that all data in the survey can be considered comparable.

In the present study we show the utility of a post-processing TVG-based noise-removal algorithm. Such an algorithm can be applied easily to any data through simple statistical packages as well as more sophisticated acoustic analysis systems. However, it has not been possible to demonstrate that the dB difference characteristic of a particular type of target (for instance krill or copepods) is increasingly distorted with depth and that the noise reduction algorithm corrects this distortion. Such a confirmation requires more net hauls directed at weak targets covering a significant depth range. It is hoped that such information will become available to provide a complete field validation of the technique.

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