9-2006

Experiments for multibeam Backscatter Adjustments on the NOAA Ship FAIRWEATHER

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Abstract- **A series of experiments were conducted to adjust and normalize the acoustic backscatter acquired by Reson 8111 and 8160 systems. The dependency of the backscatter on the receiver gain, transmit power, pulse width and acquisition mode was analyzed. Empirical beam patterns are calculated as the difference between the backscatter measured by the sonars and the expected backscatter. Expected acoustic backscatter is estimated based on a mathematical model.**

I. Introduction

In the spring of 2005, an experiment was conducted on the NOAA Ship FAIRWEATHER around Cape Decision, Alaska. The purpose of the experiment was to understand how changes in acquisition parameters related to recorded values of backscatter, so that normalized records can be produced. The normalized records can be used in enhanced backscatter mosaics and in methods for remote seafloor characterization. Additionally, it is important to normalize the acoustic backscatter acquired by Reson 8111 (100kHz) and 8160 (50kHz) multibeam sonars during normal survey operations. The survey consisted of five experiments designed to determine the dependency of the backscatter on the main acquisition parameters, particularly the receiver gain, the transmit power and the transmit pulse-width. Additionally, we attempted to understand the relationship between the operating mode of Reson systems (*auto-gain on/off* and *TVG on/off*) and the modifications made to backscatter data before it is recorded in the output data stream. Finally we wanted to determine a methodology for implementation of backscatter processing tools in a standard ship-board processing chain, and for the extraction of the transmit beam-pattern of the sonars. The same experiments were conducted with each of the sonars.

II. Experiments

The first experiment tested backscatter dependency on the receiver gain. The bathymetry chosen for the experiment consisted of a flat area having a depth of 100m, with identifiable features and a length of 1.8km. The depth was adequate for operations with both 8111 and 8160 sonars. The sonar acquisition mode was set to *TVG on* and *auto-gain off* and the acquisition parameters of pulse-width and transmit power were fixed during the duration of the line. The gain settings were changed at about the middle of the line to allow for a before-and-after comparison of the backscatter on the same area. Six data sets were acquired on the same planned line, testing 12 combinations of gain settings (Figure 1).

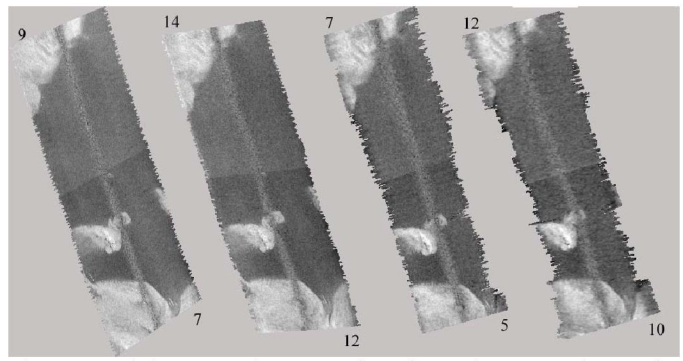

Fig. 1- Gain experiment. The four images show the backscatter mosaics with no compensation for the gain changes. The gain settings used in the experiment where 7, 9, 12 and 14 with the 8111 (two images on the left), and 5, 7, 12 and 10 with the 8160 (two images on the right).

The second experiment focused on the relationship between backscatter intensity and transmit-power. It was conducted in the same area as the first experiment. The system settings for the RESONs were: *TVG on*, *auto-gain off*, fixed pulse-width and gain, with power settings varied in the middle of the line. Four additional data sets were acquired on the same planned line, testing a total of 8 combinations of power setting (Figure 2).

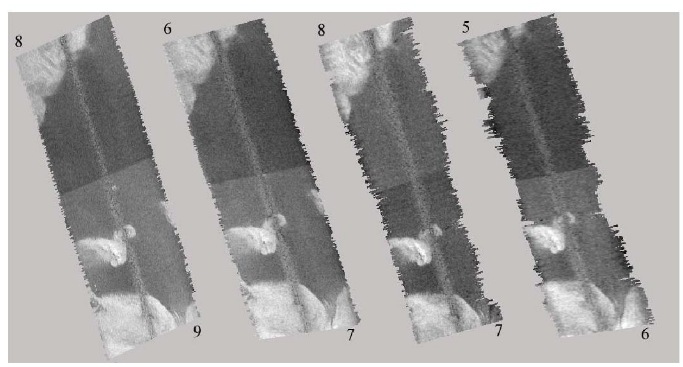

Fig. 2- Power experiment. The four images show the backscatter mosaics with no compensation for the power changes. The power settings used in the experiment where 6, 7, 8 and 9 for the 8111 (two images on the left), and 5, 6, 7 and 8 for the 8160 (two images on the right).

Also in this same area, a third experiment was conducted to test the backscatter dependency on the pulse-width. For that, the gain and power settings were fixed, *TVG on* and *auto-gain off*, and the pulse-width was changed in the middle of the line. A total of 20 combinations of pulse-widths were tested, 10 for the 8111 (Figure 3) and 10 for the 8160 (Figure 4).

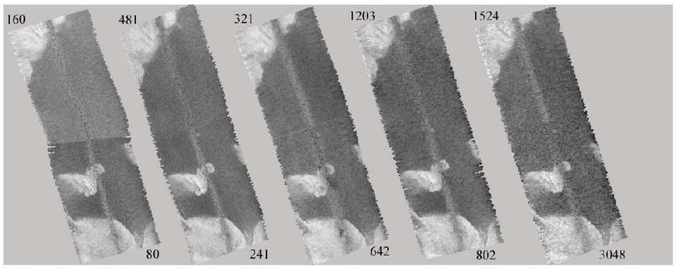

Fig. 3- 8111 pulse width experiment. The five images show the backscatter mosaics with compensation for changes in the pulse width. The pulse width settings used in the experiment where 80, 160, 241, 321, 481,642, 802, 1203, 1524 and 3048µs. Note that the applied correction was not sufficient at 80µs.

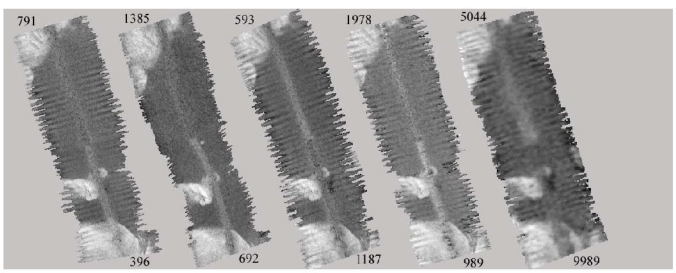

Fig. 4- 8160 pulse width experiment. The five images show the backscatter mosaics with compensation for changes in the pulse width. The pulse width settings used in the experiment where 396, 583, 692, 791, 989, 1187, 1385, 1978, 5044 and 9989µs.

The fourth experiment was designed to measure the transmit beam pattern of the sonars. Bathymetry for this experiment was flat and uniform with a depth of 100m. Two parallel survey lines were laid out with a length of 1.8km such that the outer beams of the swaths would overlap 50%. Each survey line was run in the normal and reciprocal directions for both the 8111 and 8160 systems (Figure 5). The RESONs system settings for power, gain and pulse width were optimized to produce a good return. *TVG on* and *auto-gain off* were selected.

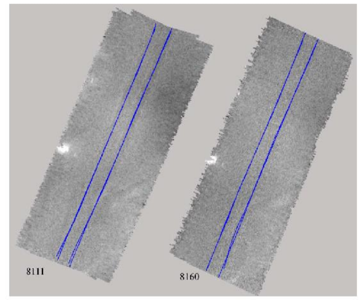

Fig. 5- Transmit beam pattern experiment. The two images are the backscatter mosaics of four overlapping lines. The left mosaic shows data from the 8111 and the right from the 8160. The blue lines show the navigation track.

The last experiment tested the four possible combinations of different acquisition modes: *auto-gain on/off* and *TVG on/off.* Suitable bathymetry was chosen to be a sloping area with identifiable features with depths ranging from 40 to 100m and a length of approximately 2.5km (Figure 6).

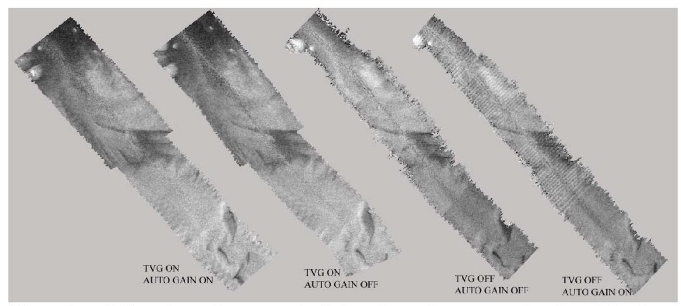

Fig. 6 - Mosaic of corrected backscatter acquired with four different acquisition modes. The top part of the images is the deepest area of the survey.

III. Results

The acoustic backscatter data were analyzed using a processing scheme developed at the CCOM-JHC [1]. For experiments 1, 2 and 3, the average backscatter was calculated inside two small adjacent reference boxes, with areas of approximately 40x40m, located before and after the point where acquisition parameters were changed (Figure 7). In average, there was a measured change of 0.94dB per gain step with a standard deviation of 0.06dB (Table 1); and 3.23dB per power step with a standard deviation of 0.06dB (Table 2).

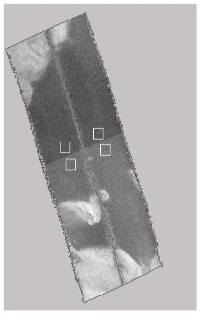

Figure 7 – One acquisition parameter is changed in the middle of the line. Four measurements of average backscatter are done (white boxes) for port and starboard, before and after the parameter change.

Sonar	G_1	μ_1	σ_1	G_2	μ_2	σ_2	Δ
8111	7	91.62	0.95	9	93.29	0.90	0.84
8111	7	90.89	0.84	9	92.70	1.01	0.91
8111	12	86.51	0.89	14	88.41	0.80	0.95
8111	12	87.48	0.92	14	89.51	0.96	1.02
8160	5	80.95	1.03	7	82.74	0.88	0.89
8160	5	81.29	0.89	7	83.39	0.93	1.05
8160	12	77.13	0.97	10	78.95	0.73	0.91
8160	12	77.04	0.83	10	78.99	1.03	0.97

Table 1 – Gain experiment. G_1 and G_2 are the gain settings and μ_1, σ_1, and σ_2 are the average and the standard deviation of the backscatter in dB of the samples before and after the gain change. Δ is the net change in the backscatter (μ_2-μ_1).

Sonar	P_1	μ_1	σ_1	P_2	μ_2	σ_2	Δ
8111	8	87.80	1.03	9	91.16	0.91	3.36
8111	8	87.37	0.95	9	90.25	0.90	2.88
8111	6	87.76	0.93	7	91.00	0.87	3.24
8111	6	89.24	1.07	7	92.14	0.87	2.90
8160	7	78.72	0.95	8	82.07	1.01	3.35
8160	7	78.20	0.84	8	81.51	0.99	3.31
8160	5	78.78	0.73	6	81.99	0.74	3.21
8160	5	78.53	1.01	6	82.02	0.79	3.49

Table 2 – Power experiment. P_1 and P_2 are the power settings and μ_1, σ_1, μ_2 and σ_2 are the average and the standard deviation of the backscatter in dB for the samples before and after the power change. Δ is the net change in the backscatter (μ_2-μ_1).

For the pulse-width experiment (Table 3), the backscatter was corrected for receiver gain, transmit-power and for the area of insonification. The area of insonification is calculated based on the pulse-width, the range, along-track and across-track beam widths, sound speed, and angle of incidence [3]. For short pulse-widths (80 to 200μs) the applied correction was not adequate, and the corrected backscatter increased monotonically with the pulse width (Figure 8). For long pulse-widths (200 to 3000μs), the applied corrections was sufficient, and the corrected backscatter stayed around approx. -24 dB for the 8111 and approx. -29 dB for the 8160. For pulse-widths longer than 3000μs the corrected backscatter showed a non-linear behavior with the pulse-width, decreasing slightly for the longer pulses.

8111			8160		
PW	μ	σ	PW	μ	σ
80	-28.67	1.47	396	-28.54	0.97
160	-25.29	1.44	593	-29.52	0.98
241	-23.82	0.96	692	-28.74	0.91
321	-25.25	0.94	791	-27.87	1.11
481	-23.74	1.10	989	-28.98	1.04
642	-24.56	1.10	1187	-29.04	1.28
802	-23.36	1.09	1385	-28.70	1.09
1203	-23.56	1.10	1978	-28.95	1.37
1524	-24.41	1.31	5044	-30.43	0.94
3048	-24.71	1.65	9989	-30.13	0.93

Table 3 – Pulse width experiment. PW is the pulse width in μs. The measurements μ and σ are the average and the standard deviation of the corrected backscatter in dB of the port and starboard samples.

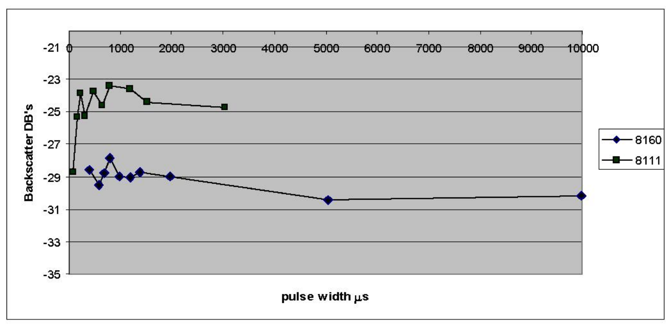

Fig. 8 – Corrected backscatter measurements for different pulse-widths.

Empirical beam patterns were calculated as the difference between the measured and the expected backscatter for all grazing angles in angle increments of 1 degree. Measured backscatter was calculated as the average backscatter angular response of all acquisition lines in experiment 4. Expected acoustic backscatter was calculated based on a mathematical model [2] and assuming a seafloor consisting of fine sand, grain size ϕ=2.5, and frequencies of 50kHz for the 8160 and 100kHz for the 8111. Before calculating the beam pattern, an angle independent offset of 60dB was subtracted from the measured backscatter. This offset is the difference in mean backscatter values, averaged over grazing angles from 30^0 to 60^0, for both measured and expected backscatter angular responses. The extracted beam pattern for the 8111 is flat from nadir to grazing angles of approximately 50 degrees, and then drops ~4dB on the outer beams (Figure 9) . In contrast, the extracted beam pattern for the 8160 shows a drop of ~5dB at nadir, increases to the reference level near grazing angles of ~75 degrees, and then drops ~10dB for the outer beams (Figure 10). There is no major difference in the extracted beam pattern for the port and starboard sides.

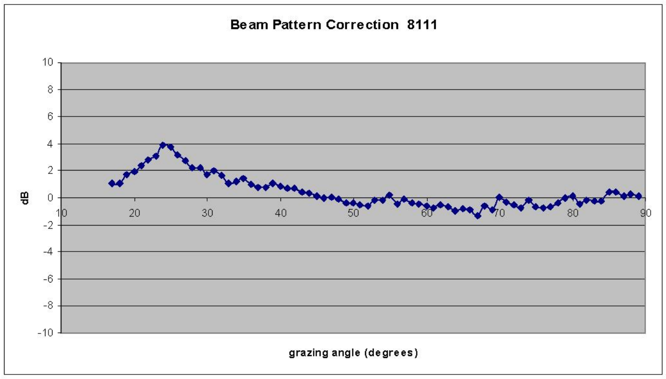

Fig. 9 – 8111 empirical compensation table for beam pattern correction.

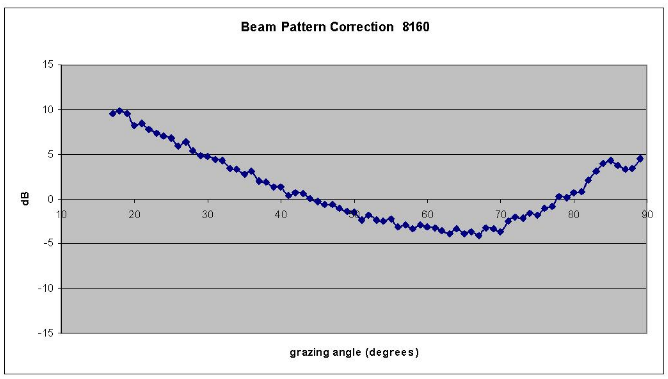

Fig. 10 – 8160 empirical compensation table for beam pattern correction.

Finally, the last experiment showed that the *auto-gain* mode does not affect significantly the backscatter, other than the 0.94 dB per step change in the gain. On the other hand, the *TVG off* mode requires extra adjustment for the spreading law and for attenuation in the water column. Even after applying these adjustments, the backscatter in this mode appears to be affected by more than a 2dB per step of gain, but in a non-linear way. The combination *TVG off* and *auto-gain on* is unstable and causes frequent changes in the gain setting (Figure 6). As a result, the mosaic shows artifacts in the form of stripes. In *TVG off* mode, a non-linearity is also present in the dependency on the power and pulse-width. The use of this mode was limited to very shallow waters (less than 70m). Figure 6 shows clearly that with the *TVG off* mode the system did not cover the complete range at the deepest part of the survey.

IV. Conclusions

The results of these experiments have been used in the assembly of adjusted backscatter mosaics. Based on the acquired data, recommendations have been made for RESON system settings and acquisition procedures where the acoustic backscatter is an important outcome of the survey. For instance, the *TVG off* mode should be avoided, as it compromises the dynamic range of the logged date, and yields non-linear behavior and saturation in the backscatter. The *auto gain* mode should be preferred, as changes in gain and power are easily compensated. To avoid saturation, the gain should always be kept above 1 and below 14, when using *auto gain* mode. This is accomplished by increasing the transmit power when the gain in too high, and decreasing the power when the gain is too low. Very long and very short pulse widths should be avoided, as they also result in non-linear behavior in the backscatter and, in the case of long pulse, reduce the sonar resolution. The proposed methodology for empirical beam pattern extraction can be used to convert the backscatter acquired by different sonars to a common reference level (normalization), provided that a common survey area is chosen as a calibration site.

Acknowledgment

We would like to express our appreciation to the captain and crew of the NOAA ship Fairweather for their dedication and enthusiasm in the conduct of this experiment, and particularly for making available survey time with the launches and ship along with expert coxswains and survey technicians. This work was support by NOAA grant # NA05NOS4001153.

References

[1] Fonseca, L. and Calder B. ,"Geocoder: and Efficient Backscatter Map Constructor ", *Proceedings of the U.S. Hydrographic 2005*, San Diego, CA, 2005.

[2] Williams, K., "An effective density fluid model for acoustic propagation in sediments derived from Biot theory," *The Journal of the Acoustical Society of America.*, vol. 110, No. 5, pp. 2276-2281, 2001

[3] Hellequin, L, Boucher, J and Lurton, X., "Processing of high-frequency multibeam echo sounder data for seafloor characterization", *IEEE Journal of Oceanic Engineering*, vol. 28, No. 1, January 2003.