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1. Introduction

Optical Backscatter Sensors (OBS) have been deployed in the marine environment for several years. These sensors emit infra-red light pulses which scatter off suspended sediments in the water column. Backscattered light is detected by a receiver and converted to a voltage level. This paper outlines the calibration procedure to relate OBS output levels to suspended sediment concentration. Relative noise levels for different gain settings will also be investigated.

The outline of this report is as follows: Section 2 describes the sensors and the calibration facility; Section 3 gives the method; and Section 4 presents the results.

2. Apparatus

The calibration tank consists of an outer tube, an inner tube, 2 endcaps, a propeller, an electric motor with a controller, the drive mechanism and a support stand, Figure 1. The outer tube is 30 cm outside diameter (OD) by 29 cm inner diameter (ID) clear acrylic tubing 122 cm long. The endcaps are made from ultra-high molecular weight polyethylene. The bottom endcap is scalloped to channel returning sediment towards the center of the tube while the top endcap directs the flow towards the outside. An outboard motor propeller 16 cm diameter is mounted in the center of the bottom endcap. The shaft protrudes through the endcap and is sealed with a dynamic o-ring seal. The shaft rests on a small thrust bearing located in a housing which is bolted to the underside of the support structure. A toothed pulley is keyed to the shaft and is connected to a 560 W electric motor via a toothed timing belt. The motor is mounted on the support structure and the motor shaft is keyed to a second pulley. The pulleys give a 2:1 drive ratio. The motor is a variable speed (0-1750 rpm) Leeson motor with controller.

The inner tube is 18 cm OD by 17 cm ID clear plastic tubing 111 cm long. It is supported from the top endcap by two threaded rods which allow for some height adjustment. The top endcap has an opening for sample removal and sensor cable access. Three OBS sensors are attached near the top of the inner cylinder in the test section. A black vinyl sheet (matte finish) covers the inside of the test section, reducing reflected light from the sides of the cylinder. Rectangular mesh flow straighteners ($\sim$1x1.5cm), inside the inner cylinder breakup coherent vortices formed by the propeller. Two flow straighteners are positioned transverse to the flow (horizontally across the cylinder), and a third vertical mesh is placed in between them.

A small tube entering from the top of the tank is used to draw off a subsample of fluid and suspended sediment. The subsample flow rate is approximately 62 ml/s. The tube is 0.6 cm ID, giving flow speeds in the tube of 220 cm/s. This velocity is higher than the centerline velocity inside the test section (30.4 cm/s at a motor setting of 55) and it is high enough to avoid particle settling in the suction tube. The settling velocity of the larger particles (grain diameter of 500μm) is approximately 8 cm/s.

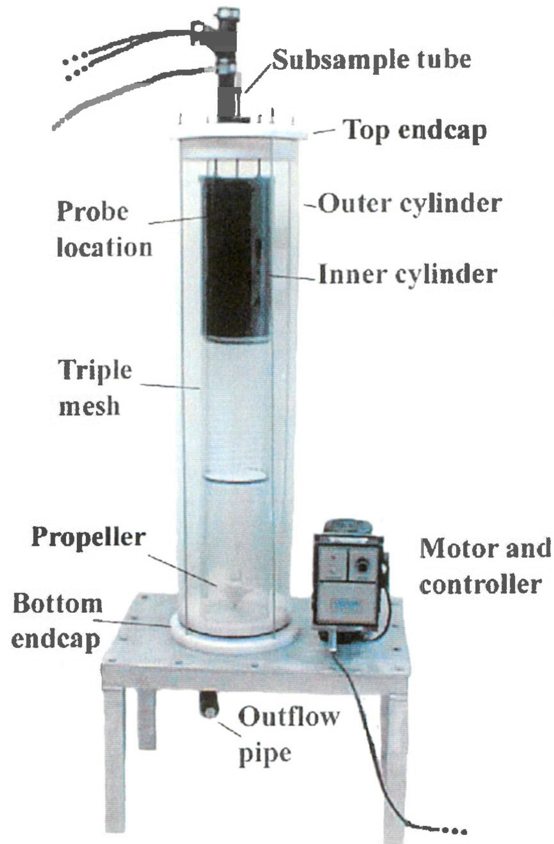

Figure 1. The calibration tank apparatus.

3. Calibration Method

Preparations for calibration involved de-airing the water and preparing filters. The tank was filled with de-ionized water and de-aired using a 1/2 Hp vacuum for approximately 2 hours, until bubbles were no longer visible in the tank. De-

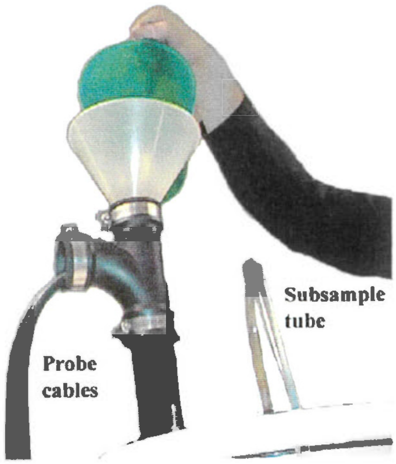

Figure 2. Additional de-aired water was added as the subsample was withdrawn.

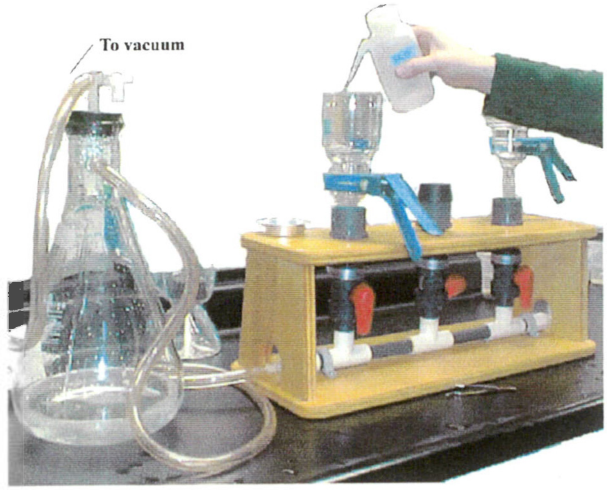

Figure 3. Millipore filtering system.

aired water was also prepared as additional water must be added as subsamples are withdrawn throughout the procedure.

The filled tank was left overnight to allow the water to equilibrate to room temperature. The next day the sensors were placed in the test section, ~ 26 cm from the top of the inner cylinder, and then the tank was completely filled. Any bubbles remaining in the tank were removed by tilting the tank and allowing the bubbles to escape via the cable access hole.

Care was taken to avoid light contamination from adjacent sensors. The data collection software, OBSshow, was designed to power all heads, so only one head was plugged in at a time. Sample rates were set to 5 Hz, and 1 minute of data was collected.

The first run was done without any sediment in the tank to assess noise levels. Noise may be introduced by bubbles, ambient light and/or electronic noise. Each sensor sequentially recorded 1 minute of data, and then 2 subsamples were drawn off. During sub-sampling, a tube was lowered to the height of the sample volume, and two ~450 ml subsamples were withdrawn while water was replaced in the tank via the cable access hole, Figure 2.

Subsequent runs followed a similar procedure. Measured amounts of sand were added to a small amount of water and were introduced through the cable access hole. The motor was turned on and allowed to come to equilibrium (~ 2 minutes), then 1 minute of data was recorded sequentially from each head, followed by collection of 2 subsamples. In total, 6 to 7 sand increments were added to the tank. For most cases, each sand addition doubled the total amount of sand in the tank. Smaller increments were used for the highest gain setting as maximum concentration is quite low, and doubling quickly saturates the signal.

Two sands were used: commercially available well-sorted, highly spherical quartz sand from a source in Ottawa, Illinois; and grab sample sand from 30 m water depth on Sable Island Bank. The median diameters were *160 μm* and *443 μm* respectively.

Subsampled volumes were recorded and siphoned down to 100ml. The remaining sediment/water mixture was filtered using Whatman filter paper, or if the sand mass was less than ~ 2g, a Millipore 0.6 μm filter (Type BD) was used, Figure 3. Filters and subsampled sediments were dried in an oven (60 °C) overnight to remove moisture. The weight of the sediment was determined from the total mass of the subsample minus the mass of the tray and filter. Care must be taken to avoid the effects of moisture, particularly with the larger Whatman paper filters. Filter papers were pre-weighed, after drying in the oven overnight to remove moisture.

4. Results

4.1. Gain Setting 100X

All OBS sensors were calibrated at the highest gain setting, 100X. Figure 4a shows that the measured output counts versus estimated suspended sediment concentrations were similar for all sensors. The slopes of the loglog fits ranged from 1.03 to 1.2 (as indicated in the figure), close to the ex-

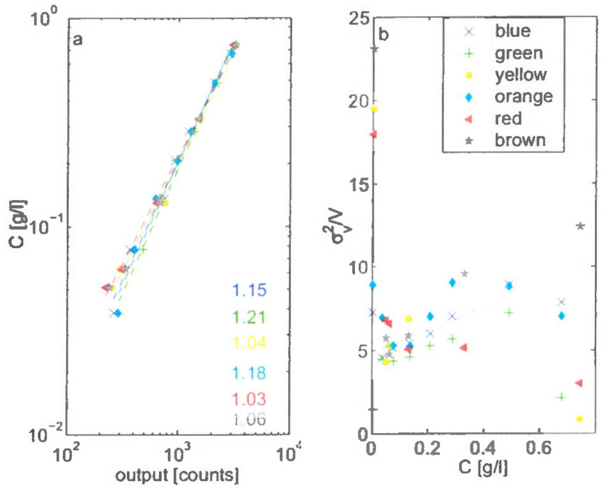

Figure 4. Gain Setting 100X, Ottawa sand. a) OBS output versus the estimated concentration. Dashed lines are loglog fits. b) Relative variance as a function of concentration. The straight line fit (dashed line) excludes the first and last points for each sensor.

pected value of 1. Higher slopes were associated with higher noise levels for the zero run, suggesting noise from bubbles, or electronic noise at low signal to noise ratios. Linear fits between OBS output and estimated suspended sediment concentration are given in Tables 1 and 2. All linear fits had high regression correlation coefficients.

Noise may also be introduced by incomplete mixing in the tank. *Downing and Beach* [1989] found the variance of the output voltage normalized by the mean voltage was linearly related to the suspended sediment concentration. Present observations, Figure 4b, shows that although the absolute signal variance increased with suspended sediment concentration, the relative variation showed only a small increase. Large noise values were observed for the zero-run, where occasional bubbles or particles likely increased the variance. The lowest relative noise was for the highest concentration, where the sensor was close to saturation and the signal was likely clipped, thereby reducing the variance.

Sensor	100X		20X		5X		0X	
	M	*b*	*M*	*b*	*M*	*b*	*M*	*b*
Blue	2.41	-2.2	12.6	5.3	-	-	-	-
Green	2.32	-2.7	10.4	0.9	-	-	-	-
Yellow	2.32	-2.1	10.3	4.8	-	-	-	-
Orange	2.34	-1.8	-	-	45.1	0.6	-	-
Red	2.41	-1.7	-	-	-	-	259	-61
Brown	2.36	-1.9	-	-	48.8	10	-	-

Table 1. Slope, *M*, and intercept, *b*, for linear fits (C=1e-4**M* *counts +1e-2**b*) of OBS output to estimated suspended sediment concentration using Ottawa foundry sand.

Sensor	20X	
	M	*b*
Blue	15.1	-17
Green	11.6	-20
Yellow	11.8	-14
Orange	13.7	-0.2
Red	16.5	-2.7
Brown	20.1	1.9

Table 2. Slopes and intercepts for linear fits (C=1e-4**M* *counts + 1e-2**b*) of output to suspended sediment concentration for SIB sand.

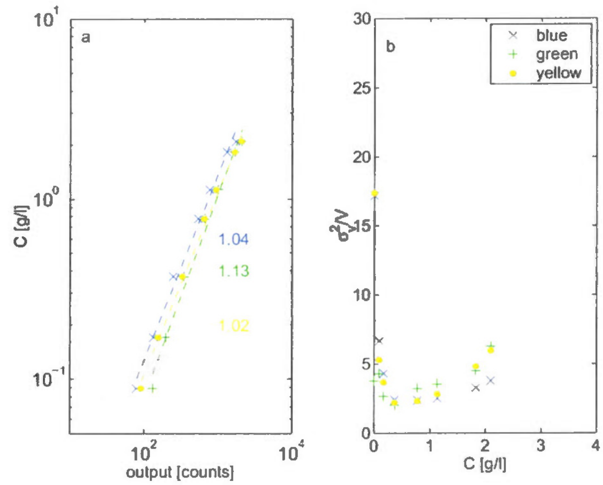

Figure 5. Gain Setting 20X, Ottawa sand. a) OBS output versus the estimated concentration. Dashed lines are loglog fits. b) Relative variance as a function of concentration.

4.2. Gain Setting 20X

The calibration procedure was repeated at a gain setting of 20X. The slope of output to estimated concentration was again found to be linear, Figure 5a, and was approximately 5 times higher than the 100X case, Table 1. The observed relative variance was similar for the 3 heads, and lower than the previous case. A minimum in relative variance was observed at the fourth subsample, at a concentration of 0.35 g/l. Noise levels increased with increasing concentration above this point.

Using the same gain setting, Sable Island Bank (SIB) sand had a higher response and higher variance, Figure 6.

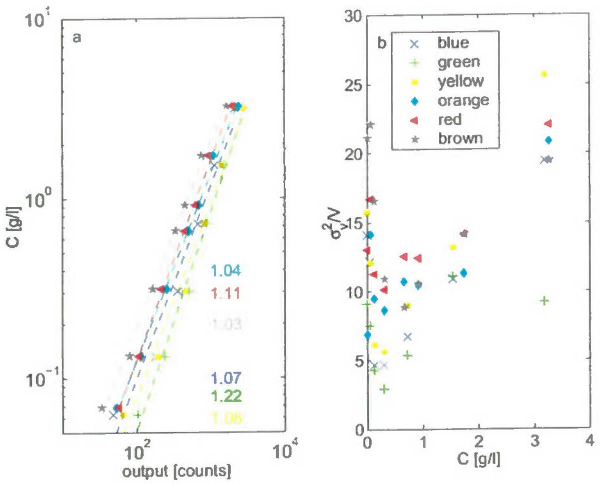

Figure 6. Gain Setting 20X, SIB sand. a) OBS output versus the estimated concentration. Dashed lines are loglog fits. b) Relative variance as a function of concentration.

The higher variance is likely caused by the larger grain size distribution in the natural sand. Relative noise levels increase linearly for the higher concentrations. Linear fits of concentration vs counts, Table 2 had slightly steeper slopes for the natural sand as compared to foundry sand.

4.3. Gain Setting 5X

Two sensors were calibrated with a gain setting of 5X. A linear slope is found for both sensors, and again a minimum in noise is found in the relative variance as a function of concentration, Figure 7. It is interesting to note that the relative noise levels were different for the two sensors for this gain setting only.

4.4. Gain Setting 0X

A linear slope was observed for the sensor with a gain setting of 0X, Figure 8, but the full range of this sensor was not covered. The maximum sensor output was ~ 600, only about 20% of the saturation value. The relative noise over this range decreased with increasing concentration, even though the maximum suspended sediment concentration approached ~ 15 g/l.

Plotting all of the above results together, Figure 9 shows clear separation between the different gain settings. The 0x gain setting has a higher slope than expected, if the values at low concentrations are included.

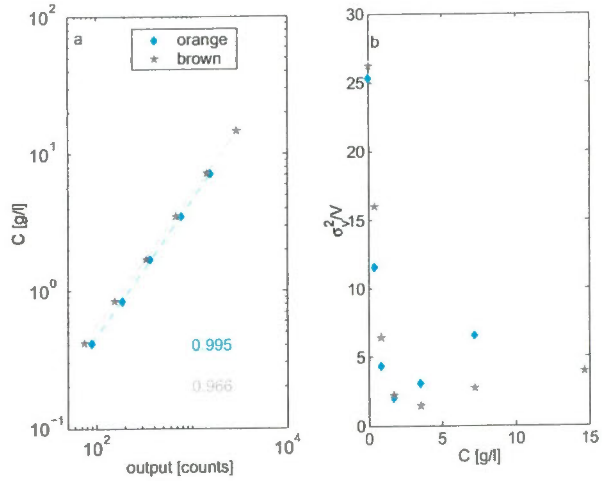

Figure 7. Gain Setting 5X, Ottawa sand. a) OBS output versus the estimated concentration. Dashed lines are loglog fits. b) Relative variance as a function of concentration.

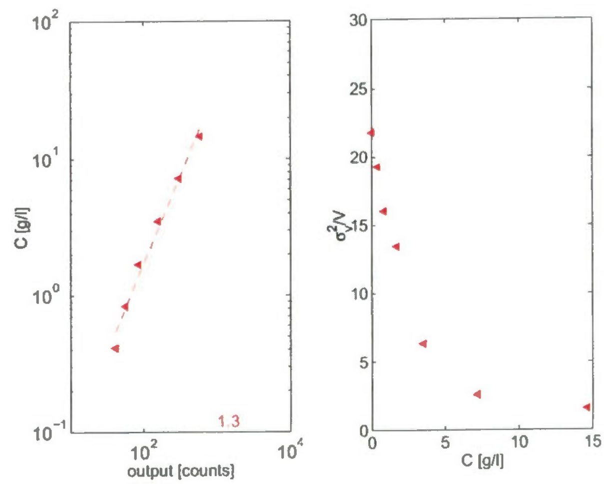

Figure 8. Gain Setting 0X, Ottawa sand. a) OBS output versus the estimated concentration. Dashed lines are loglog fits. b) Relative variance as a function of concentration.

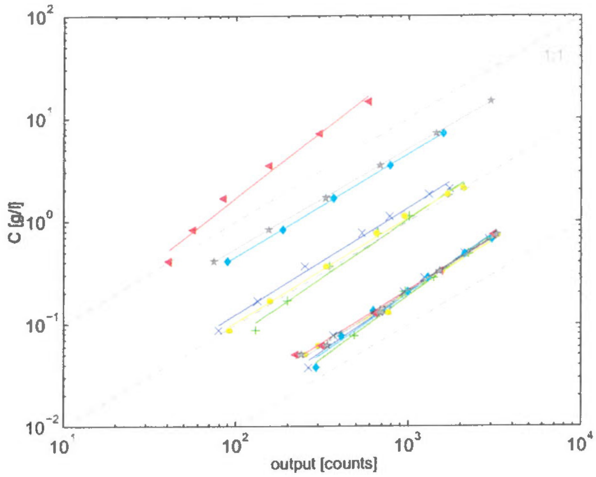

Figure 9. All Ottawa sand observations.

5. Improvement Possibilities

During subsampling, water was replaced in the tank through the cable hole. However it was difficult to match the rate of withdrawal. Pouring in the water too quickly caused an overflow, and a slower rate allowed air bubbles to enter the tank. The addition of a reservoir should be considered.

6. Conclusions

Optical Backscatter sensors were calibrated in a closed circulation tank with natural and foundry sand. Measured output was compared to sub-sampled concentration levels for 4 gain settings. Relative noise levels have a minimum in the mid-range. At low concentrations the signal to noise ratios is small. At high concentrations the noise increases, consistent with observations by *Downing and Beach* [1989].

References

Downing, J. P., and R. A. Beach, Laboratory apparatus for calibrating optical suspended solids sensors, *Mar. Geol.*, *86*, 243–249, 1989.

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