Calibrations of Optical and Acoustic Sensors for Coastal Protection and Restoration Research

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Abstract

The transport of sediment in the coastal zone and continental shelf is highly impacted by fluvial and oceanographic dynamics. In Louisiana, the Mississippi River delivers a bulk of water, sediment, and nutrient to the coast. Sediment is the foundation to build land and suspended sediment concentration (SSC) tracks the delivery, deposition, and erosion of sediment. On a more applicable scale, variables such as SSC can be used to calculate sediment transport flux, an important parameter for projects such as sediment diversion and barrier island restoration. In order to rely on suspended sediment concentration (SSC) as continuous data, lab experiments are needed to establish the relationship between turbidity and SSC. Factors such as sensor type (optical or acoustic) and grain size (coarse or fine) can greatly impact the estimated SSC.

In this study, fine-grained sediment was collected from multiple sites in coastal Louisiana and used to calibrate both optical backscatter (OBS) and acoustic backscatter (ABS) sensors to establish the relationship between sensor type and accuracy of the SSC estimation. Results indicated that the OBS-3A sensor's turbidity data were more correlated with the SSC than the OBS-5+'s data. Possible explanations for this could be due to differences between the instruments' measuring ranges and their sensitivity to various grain sizes. This technology development has a broad impact to the studies of sediment delivery, transport, and deposition in multiple types of coastal protection and restoration projects.

Introduction

In coastal Louisiana, the reality of land loss has created the necessity for protection and restoration projects at both local and regional scales. Many of these projects aim to build land by delivering sediment into strategic locations using a variety of methods. One such proposed method is a series of sediment diversions that will transport sediment where it is needed by diverting it away from major river channels. However, the plans for these sediment diversions contain many uncertain variables during the process of numerical modelling. For example, suspended sediment concentration (SSC) is an essential, yet uncertain parameter that helps track the sediment budget and flux of different coastal environments. The success of the proposed sediment diversions relies heavily on the accuracy of variables such as SSC and the methodology used to estimate it.

Much research has been done on the topic of SSC calibration (Merten et al. 2014, Thorne and Hanes, 2002). Many of these methods rely on the use of turbidity sensors, which in turn are used to estimate levels of SSC. However, these turbidity sensors need to be calibrated using known values of SSC in order to produce calibration curves that most accurately reflect the relationship between turbidity and SSC. Only then can an acceptable estimate of SSC be taken in the field. The two most used types of turbidity sensors for this purpose are optical backscatter (OBS) sensors and acoustic backscatter (ABS) sensors. While OBS sensors use light to detect the amount of backscatter (Downing 2006), ABS sensors use different frequencies of acoustic pulses to determine backscatter throughout a column of water (Thorne and Hanes, 2002).

Although these sensors are currently being deployed and used to track turbidity and SSC, the best methodological practices are still unknown. For example, it has been proven that factors such as grain size and the type of sensor used can affect the accuracy of turbidity sensors (Downing 2006). Currently, there is no accepted methodology for the calibration of these turbidity sensors that takes into account the different grain size distributions and levels of SSC found across the Louisiana coast. This research aims to clarify these practices by using sediment from different coastal environments to calibrate two OBS sensors and one ABS sensor in a laboratory environment. Afterward, the best methodology can be deduced that considers which type of sensor is best for any given environment.

Methods

In order to establish calibration curves between turbidity and SSC, a laboratory calibration must be performed for the turbidity sensors. Three sensors were used for this study, namely the Campbell Scientific OBS-3A®, the Campbell Scientific OBS-5+®, and the AQUA*scat*® 1000R ABS sensor.

OBS-3A and OBS-5+ Sensors

The OBS sensors both record turbidity by measuring backscatter, or reflection, of light from suspended solids in water. Some key differences between the OBS-3A and the OBS 5+ sensors include the source of the emitted light and the range of SSC in which the sensor can operate with confidence. While OBS-3A uses an infrared light source, OBS 5+ uses a laser diode source. Additionally, the OBS-3A is accurate in concentrations of up to 5000 mg/L, while the OBS 5+ is accurate up to 50,000 mg/L in muddy environments (Downing 2006).

Fig. 1. OBS 3-A sensor (Right) and OBS 5+ Sensor (Left)

ABS Sensor

The ABS sensor used acoustic pulses sent via transducers to measure turbidity throughout a water column. This SONAR technique used acoustic backscatter to estimate turbidity. Grain size and texture is known to affect the accuracy of the sensor's readings (Thorne and Hanes, 2002).

Fig. 2. ABS Sensor

Sediment samples from two different locations along the Louisiana coast were used in the calibration of the sensors. The OBS sensors were calibrated using sediment from the Wax Lake delta, while the ABS sensor was calibrated using sediment from the Raccoon Island dredge pit. (Fig. 3). These locations were chosen because they represent different parts of the Louisiana coast; the first being a young, muddy delta and the second being a sandy underwater dredge pit.

Fig. 3. Sediment sample sites

The sensors were calibrated using a sediment mixing chamber (Fig. 4).

Fig. 4. Calibration Chamber

The sensor being tested was fastened to a steel bar apparatus and lowered into the water (Fig. 5). The calibration chamber was filled halfway with clear tap water. While the chamber water was being mixed by the bottom propeller, fifteen mL of sediment slurry was added. After waiting one minute, the turbidity data was collected for approximately one minute using the appropriate data logger on a nearby laptop. Forty mL of slurry was then transferred to a beaker. The beakers were all dried in an oven and weighed. The final mass was the actual sediment weight, which was then used to calculate actual SSC.

Fig. 5. Calibration apparatus

Results and Discussion

Calibration curves for the different turbidity sensors were created by plotting the relationship between known values of SSC, taken during the calibration, and the turbidity values recorded by the sensors at that time. Turbidity values were measured in ND counts for the OBS sensors. In order to assess which sensor was more suitable, the R^2 value (coefficient of determination) was used. Higher values of R^2 indicate that the data is a better fit to the regression, and so would be more reliable as a calibration curve for SSC.

OBS Sensor Calibration

The calibration of the OBS-3A sensor used 14 samples as opposed to the 17 samples in the OBS 5+ calibration. This was due to the 3A sensor maxing out after 14 steps in the calibration, meaning that the accuracy of the sensor began to decrease because of its limitations in water with a very high SSC. Because the OBS 5+ sensor is less limited in measuring turbidity in highly concentrated water, more calibration samples were taken. Calibration ended after the SSC reached about 7000 mg/L, which is more than what the OBS-3A sensor could accurately measure and consistent with the instrument’s known capabilities.

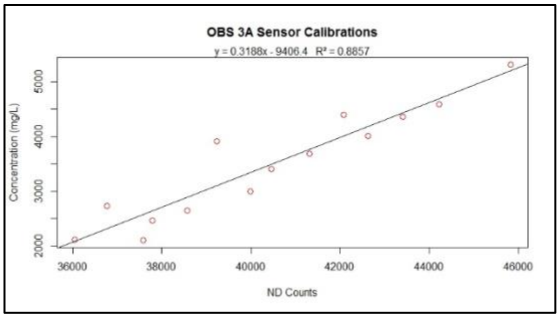

Fig. 6. Calibration curve for OBS-3A

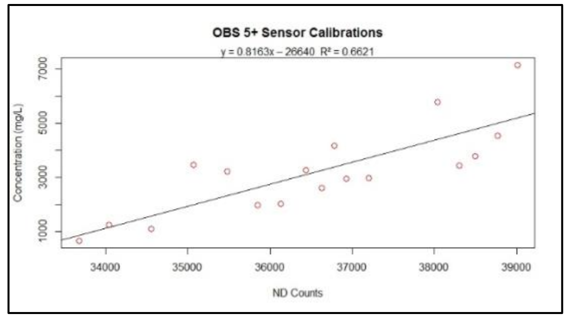

Fig. 7. Calibration curve for OBS 5+

Although the OBS 5+ showed that it could measure turbidity in situations of higher SSC, the higher R^2 term of the OBS-3A indicates that its calibration is more reliable in environments with sediment concentrations of less than 5000 mg/L.

ABS Sensor Calibrations

The calibration of the ABS sensor was done at two different elevations in the mixing chamber; one at 29 cm below the sensor's transducers and one at 57 cm below the sensor's transducers. Data gathered from the sensor, as well as the sampled SSC, was used to create a calibration curve for each elevation level within the chamber. Once collected, the SONAR data was organized by frequency of the acoustic signal used. These calibrations used the 4 MHz signal data because its turbidity patterns were the most discernible. A range of 5 cm was used for each of the sampling elevations to increase the accuracy of the signal data.

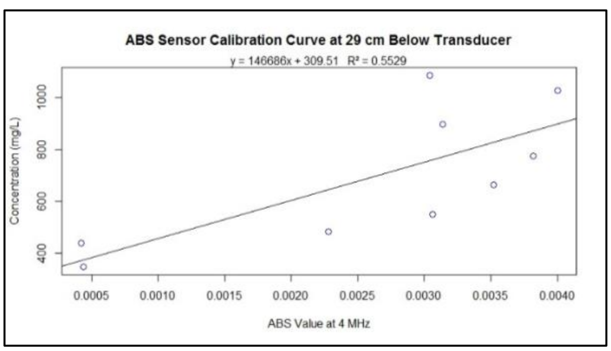

Fig. 8. Calibration curve for ABS sensor

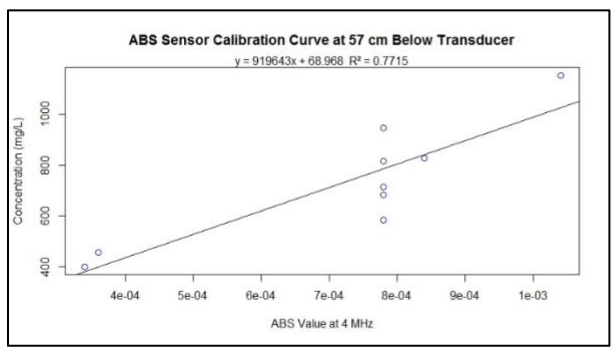

Fig. 9. Calibration curve for ABS sensor

Compared with the OBS sensor calibrations, the ABS sensor calibrations had lower R^2 values. This difference could be attributed to the known sensitivity of the instrument to grain size, as well as to microbubbles in the water that contributed to overall background backscatter signals (Thorne and Hanes, 2002).

Comparing OBS Sensors

The higher R squared term for the OBS-3A sensor translates to an overall higher agreement between the OBS output data and the known values for SSC, as compared to the OBS 5+ sensor. This indicates that it is more reliable for estimating SSC in muddy environments such as Wax Lake delta. An ANOVA test was conducted to compare the results between the calibrations in order to understand whether this difference was significant. An ANOVA test was chosen in order to compare the variance observed within both calibration curves. The resulting p-value ($P<0.00218$) concluded that these calibration curves are indeed significantly different.

The results from the ANOVA test indicate that the choice of which turbidity sensor to use for SSC measurement, specifically which OBS sensor, will significantly affect the outcome of the SSC estimation. Possible explanations for this could include the fact that each sensor performs differently under different concentrations of suspended sediment and distributions of grain size.

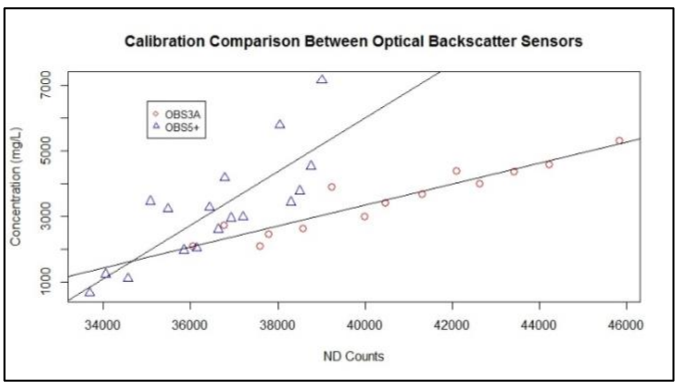

Fig. 10. OBS-3A and OBS 5+ Calibration Comparison

SSC Results

The resulting calibration curves were applied to field turbidity data collected at Mike Island in the Wax Lake delta to create a time series of SSC values. The OBS-3A (Fig. 11) and OBS 5+ (Fig. 12) sensors were used to measure turbidity in the fall of 2014.

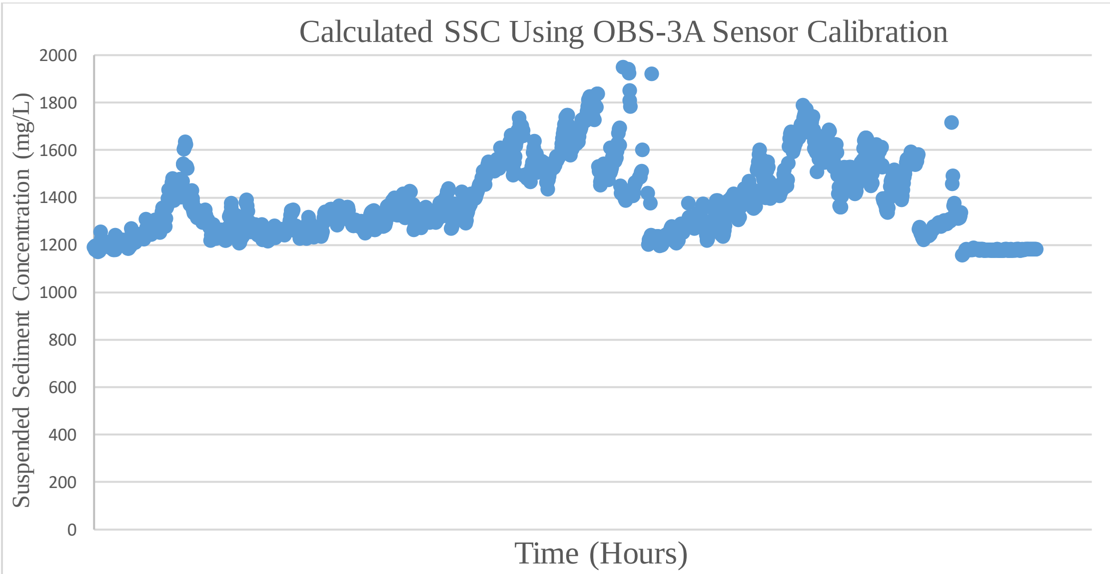

Fig. 11. Time series values of SSC for Mike Island in August-October 2014

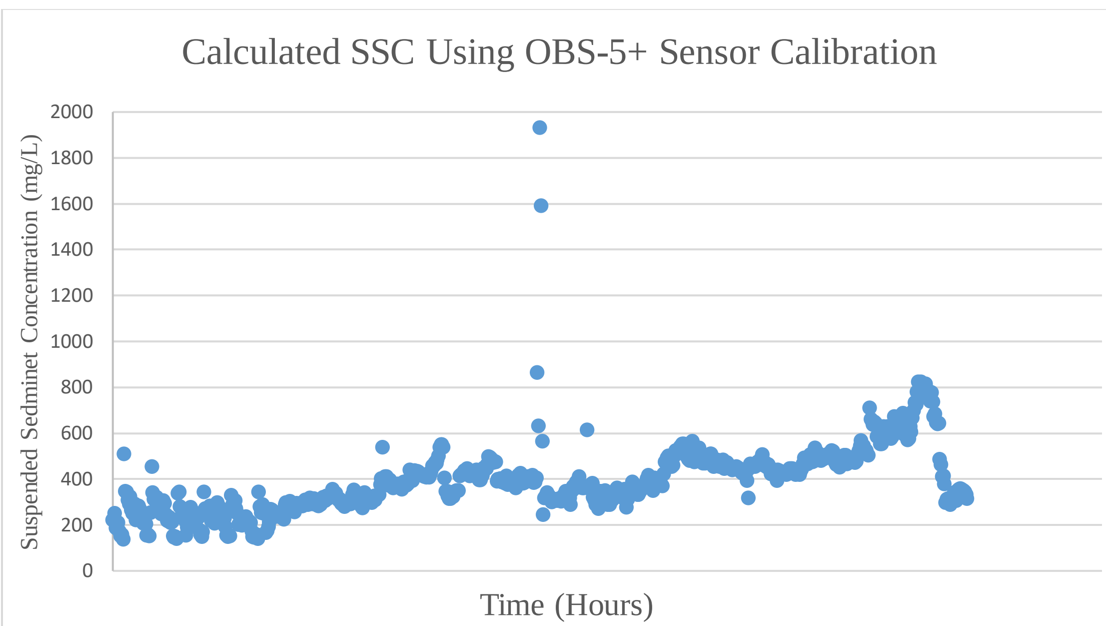

Fig. 12. Time series values of SSC for Mike Island in August-October 2014

Conclusions

The accuracy of SSC estimation using turbidity data relies heavily on the calibration of turbidity sensors and the methodology used in the calibration process. Using both OBS and ABS sensors broadens the opportunities for sediment research, while at the same time reinforcing the notion that a consistent methodology is needed to reduce uncertainty. This uncertainty can be attributed to the grain size of the sediment used during calibration and the limitations of the sensors themselves. For example, while the OBS-3A sensor calibration outperformed the OBS 5+ calibration, it was limited in high concentrations of suspended sediment. Additionally, the decision of which sensor to use would most likely have an impact on the final SSC estimation, as validated by the ANOVA test. As for the ABS sensor, the most viable method of ABS calibration was using the lower elevation when constructing a calibration for coarser-grained sediment. Further research is needed to explain this occurrence.

References

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