FROM MOBILE ADCP TO HIGH-RESOLUTION SSC:
A CROSS-SECTION CALIBRATION TOOL

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INTRODUCTION

Sediment is a major cause of stream impairment, and improved sediment monitoring is a crucial need. Point samples of suspended-sediment concentration (SSC) are often not enough to provide an understanding to answer critical questions in a changing environment. As technology has improved, there now exists the opportunity to obtain discrete measurements of SSC and flux while providing a spatial scale unmatched by any other device.

Acoustic instruments are ubiquitous in the U.S. Geological Survey (USGS) for making streamflow measurements but when calibrated with physical sediment samples, they may be used for sediment measurements as well. The acoustic backscatter measured by an acoustic Doppler current profiler (ADCP) has long been known to correlate well with suspended sediment, but until recently, it has mainly been qualitative in nature. This new method using acoustic surrogates has great potential to leverage the routine data collection to provide calibrated, quantitative measures of SSC which hold promise to be more accurate, complete, and cost efficient than other methods.

This extended abstract presents a method for the measurement of high spatial and temporal resolution SSC using a down-looking, mobile ADCP from discrete cross-sections. The high-resolution scales of sediment data are a primary advantage and a vast improvement over other discrete methods for measuring SSC. Although acoustic surrogate technology using continuous, fixed-deployment ADCPs (side-looking) is proven, the same methods cannot be used with down-looking ADCPs due to the fact that the SSC and particle-size distribution variation in the vertical profile violates theory and complicates assumptions.

A software tool was developed to assist in using acoustic backscatter from a down-looking, mobile ADCP as a surrogate for SSC. This tool has a simple graphical user interface that loads the data, assists in the calibration procedure, and provides data visualization and output options. This tool is designed to improve ongoing efforts to monitor and predict resource responses to a changing environment. Because ADCPs are used routinely for streamflow measurements, using acoustic backscatter from ADCPs as a surrogate for SSC has the potential to revolutionize sediment measurements by providing rapid measurements of sediment flux and distribution at spatial and temporal scales that are far beyond the capabilities of traditional physical samplers.

CALIBRATION METHOD

The conversion from echo intensity, also known as raw backscatter (RB, in counts), to sediment-corrected backscatter (SCB, in dB) uses the following equation (Gartner, 2004):

$$SCB = K_c * RB + 20 * \log_{10}(\psi R) + 2\alpha_w R + 2\alpha_s R \tag{1}$$

where K_c is the instrument- and beam-specific echo intensity scale factor (dB/count), ψ is the non-dimensional function describing the non-spherical spreading of the backscattered signal in the near field (Downing et al., 1995), R is the range or distance along the beam (m), α_w is the sound absorption coefficient (dB/m) (Schulkin and Marsh, 1962), and α_s is the sediment attenuation coefficient (dB/m) (Wright et al., 2010; Landers, 2010). In Eq. (1), the first term converts the raw backscatter from counts to decibels, the second term corrects for beam spreading, the third term corrects for water absorption, and the fourth term corrects for sediment attenuation.

The sediment attenuation coefficient can either be measured using the slope of the water-corrected backscatter (WCB) profile (Wright et al., 2010) or computed using knowledge of the suspended-sediment characteristics. The first method assumes uniform SSC over the range from which the slope is obtained. Vertical SSC profiles usually are not uniform with depth, but the upper portion of the SSC profile may be nearly uniform, and this assumption may be acceptable in certain environments. The second method requires analysis of the density and particle-size distribution of the sediment, but its application to a real-world environment is complex to say the least. Both of these sediment attenuation estimation methods are the subject of ongoing research.

The SCB to SSC calibration method relies on concurrent measurements of ADCP acoustic backscatter and suspended-sediment concentration at points throughout the water column at one or more stationary, vertical locations [Figure 1(A–B)]. The acoustic backscatter data from a stationary ADCP profile are time-averaged over the period during which the suspended-sediment point samples were collected. The calibration procedure requires that each physical sediment sample is temporally and spatially matched to a SCB value [Equation (1)]. A linear regression between the matched values is determined such that

$$\log_{10} SSC = a * SCB + b \tag{2}$$

where a is the slope and b is the y-intercept [Figure 1(C)]. Once the slope and intercept values have been determined for the calibration data (stationary verticals), any sequential ADCP data (e.g., transects or cross-sections) can be converted to SSC using the following equation:
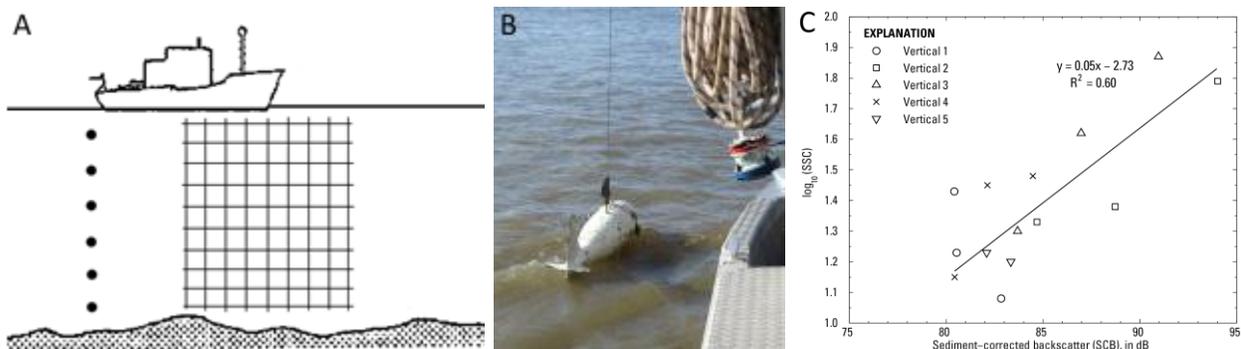
$$SSC = 10^{(a*SCB+b)} \tag{3}$$

Figure 1 (A) Schematic showing physical sediment samples (points) and stationary ADCP profile time-series (grid). (B) Photo of suspended-sediment sampler and ADCP. (C) Example of linear regression between suspended-sediment concentration (SSC) and sediment-corrected backscatter (SCB).

RESULTS

Although a single vertical can be used to develop a calibration, research to date indicates that a more robust calibration results from using multiple verticals. A convenient method is to use the verticals associated with an equal-discharge-increment (EDI) suspended-sediment sample. This method consists of taking several point samples of suspended sediment throughout the water column in addition to the standard depth-integrated sample at each EDI vertical. The point samples are used to develop the calibration, and the EDI-computed SSC provides a standard measurement of suspended-sediment concentration with which to validate the composite value output by the software tool. An example of a calibrated cross-section is shown in Figure 2. The color contours represent the suspended-sediment concentration. A composite SSC value is reported for the cross-section which may be validated with an EDI composite or other reference measurement of suspended-sediment. When combined with ADCP velocity data, the sediment flux throughout the cross-section can be computed. The software tool provides all of these data visualization options, and additional information about the tool can be found at the USGS Sediment Acoustics webpage (http://water.usgs.gov/osw/SALT/).
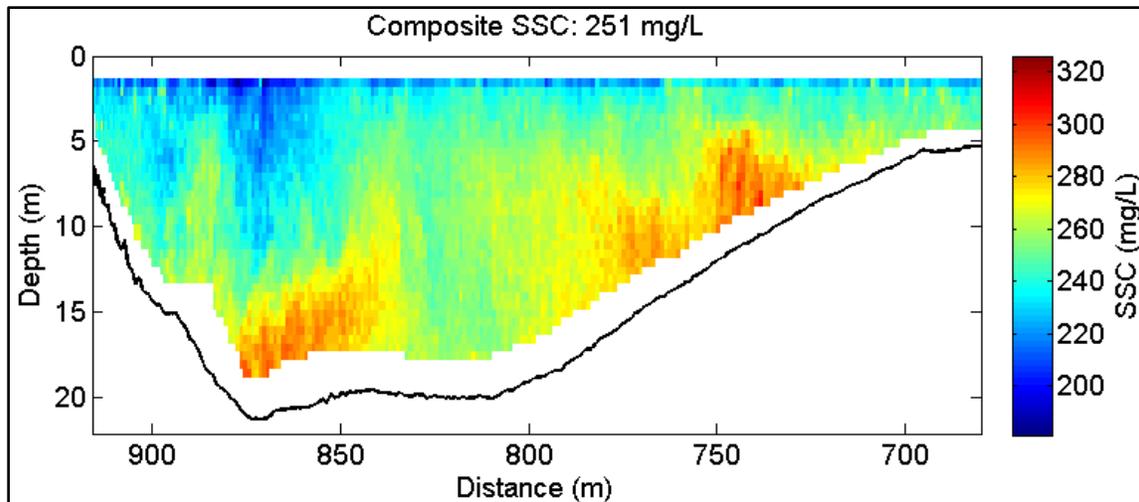
Figure 2 Calibrated cross-section showing color contours of suspended-sediment concentration.

The primary benefit of this method is the vast improvement in spatial scale. Side-looking ADCP deployments are best for continuous monitoring of suspended-sediment, but repeat cross-sections with a down-looking ADCP provide spatial and temporal scales unmatched by any other device. The main limitation of this calibration procedure is that each calibration is specific to the instrument (frequency and beam scale factors) and the particle-size distribution at each site. Changing sediment conditions cause a previous calibration to be invalid due to the complex relationship between sediment characteristics and acoustic backscatter. There is ongoing work to determine how transferable a calibration is over small changes in particle-size distribution for a single site. Another limitation is that this method only applies to measurements of suspended sediment, not bedload measurements. Because the data come from an ADCP, there exist the unmeasured areas on the top and bottom due to the blanking distance and side-lobe interference, respectively; although, estimation algorithms are under development.

SUMMARY

A calibration procedure is presented for converting ADCP acoustic backscatter data to suspended-sediment concentration, which is especially powerful when applied to a full channel cross-section. The calibration method relies on concurrent measurements of ADCP acoustic backscatter and suspended-sediment concentration at points throughout the water column at one or more stationary, vertical locations, and a software tool was developed to standardize and expedite the calibration process. As a result, it is possible to provide rapid measurements of sediment flux and distribution at spatial and temporal scales that are far beyond the capabilities of traditional physical samplers.

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