Measuring Suspended Sediment in Sand-Bedded Rivers Using Down-looking Acoustic Doppler Current Profilers

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Abstract

The use of side-looking acoustic Doppler velocity meters (ADVMs) to estimate fluvial suspended-sediment concentrations (SSC) has become more operational by the U.S. Geological Survey in recent years; however, direct transfer of these techniques to down-looking acoustic Doppler current profilers (ADCPs) currently is not widely feasible. Key assumptions in the side-looking ADVM method related to sediment homogeneity within the acoustic measurement volume are almost never met in wide, sand-bedded rivers because SSC and particle size commonly vary with depth and location in the river cross section. The use of ADCPs to estimate SSC has been investigated by researchers, but the requirements and limitations of an operational method that could be successfully applied at many locations are not well defined. If an operational method could be developed, the use of ADCPs, which are routinely used for flow measurements, would revolutionize sediment science by providing rapid measurements of sediment flux and spatial distribution.

We collected detailed datasets in six sand-bedded rivers in the U.S. in 2016-2018, to evaluate the efficacy of using down-looking ADCPs of multiple frequencies to estimate SSC. The datasets included replicate sets of point and depth-integrated suspended-sediment samples and stationary and cross-sectional backscatter profiles using multiple ADCPs with differing frequencies. Reasonable calibrations were developed at all sites measured when calibrating to the coarse fraction (R^2 0.66 to 0.98 with slopes close to 0.1 using 1200kHz ADCPs). Calibrations to the fines fraction were problematic because acoustic backscatter response was dominated by coarse particles when present, and substantial attenuation was contributed by coarse particles at some sites. A sensitivity analysis on minimum datasets showed that good calibrations could be developed using two verticals of data collected over a range of backscatter and sediment conditions, with a minimum of three points sampled for sediment within each vertical. Overall, results to date show great promise in using ADCPs to rapidly estimate and visualize SSC with high spatial resolution, and a new beta software tool called Sediment Transect Acoustics simplifies data processing. Improvements are underway to the beta software used in processing to allow incorporation of more acoustic and sediment characteristics and to estimate SSC in areas of the river cross section unmeasured by the ADCP.

Introduction

Acoustic Doppler meters typically are used in rivers to measure water velocities and flow (Mueller and others, 2014) and are deployed in “side-looking” and “down-looking” orientations. A side-looking meter is typically fixed to the river bank and emits an acoustic pulse horizontally within the river. A down-looking meter is typically attached to a floating, tethered boat platform on the water surface or a mount on a motorized boat. A down-looking meter can be held stationary at one point for a given time or can be moved across the river, and it emits an acoustic pulse vertically into the river’s water column. The acoustic pulse bounces off particulate matter in the water and is measured by the meter as acoustic backscatter, which can be related to the amount of suspended sediment in the water after correction of the signal for losses (Wood, 2014). The use of side-looking acoustic Doppler meters to estimate fluvial suspended-sediment concentration (SSC) has become operational in recent years, providing continuous, high temporal resolution data on sediment concentration, load, and size based on a horizontal section of the flow. However, key assumptions in the operational, side-looking meter method (as described in Wood and others, 2015, and Landers and others, 2016) related to sediment homogeneity within the acoustic measurement volume are almost never valid vertically in sand-bedded rivers because SSC and particle size commonly vary with depth and location in the river cross section. As a result, operational side-looking methods are not directly transferable to a down-looking application. The use of down-looking acoustic Doppler current profilers (ADCPs) to estimate SSC has been investigated by other researchers (Gartner, 2004; Wall and others, 2006; Boldt and others, 2012; Guerrero and others, 2013; Moore and others, 2013; Latosinki and others, 2014; Boldt, 2015; Szupiany and others, 2009, 2016, 2018; Guerrero and others, 2017). Yet, an operational method, using commercially available and commonly used instrumentation over changes in sediment characteristics (particle size distribution) and hydrologic conditions is not well defined. If an operational method could be developed, the use of ADCPs would increase access to sediment data by allowing rapid and accurate measurements of suspended-sediment transport and distribution at spatial and temporal scales that are far beyond the capabilities of traditional physical samplers. Such spatial resolution of concurrent sediment, hydraulic, and fluvial geometric data has not been previously possible and can immediately address and improve our understanding, modeling, and prediction of fluvial sediment transport. In the U.S. alone, measurements of flow are made with ADCPs nearly every day at streamgages. If calibrations could be developed at even a fraction of these locations, the amount of sediment information available to the public and science communities would be greatly expanded.

Calibration Method

Implementing the calibration method for relating down-looking ADCP data to SSC requires an understanding of how acoustic pulses passing through a water-sediment mixture will scatter and attenuate as a function of fluid, sediment, and acoustic instrument characteristics (as described in Thorne and others, 1991; Landers and others, 2016). Various researchers (Gartner, 2004; Moore and others, 2013; Latosinski, 2014; Boldt and others, 2015; Szupiany and others, 2016, 2018) have presented an empirical sediment surrogate approach involving the need to adjust acoustic backscatter data obtained from an ADCP to isolate the attenuation (rate of absorption of the signal with distance from the instrument) and backscatter characteristics of sediment. The basic approach in many of these studies involves collecting a series of stationary profiles using an ADCP, collecting concurrent or near-concurrent sediment samples at multiple points in each profile, and developing a calibration between the ADCP data (corrected for losses) and the sediment sample results. The ADCP data undergo a conversion from raw backscatter to sediment corrected backscatter using the following equation (Gartner, 2004):

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

where:

SCB is the sediment corrected backscatter (dB),
RB is the raw backscatter data or echo intensity recorded by the instrument (counts),
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 and others, 1995),
R is the range or distance along the beam (m),
α_w is the sound absorption coefficient due to water viscosity (dB/m) (Schulkin and Marsh, 1962), and
α_s is the sediment attenuation coefficient (dB/m).

The first three terms on the right side of equation (1) are commonly referred to as the water corrected backscatter (WCB). The sediment attenuation coefficient can be determined through knowledge of sediment characteristics and theoretical assumptions (most notably the hybrid Urick-Sheng-Hay method described in Wright and others, 2010; Landers and others, 2016) or through actual measurements of the slope of the WCB profile. The latter approach for determining sediment attenuation is common in the side-looking acoustic method (Wright and others, 2010; Landers and others, 2016), but may not be appropriate in a down-looking application because of the previously mentioned variations in particle size and concentrations with depth. Latosinki and others (2014) and Szupiany and others (2018) present a method for addressing the attenuation contributed separately by fines (particles < 63 μm) and coarse (particles >= 63 μm) sediment and use of theoretical assumptions appropriate for particle sizes in transport. This method was incorporated into the processing of datasets described in this paper as a modification of equation (1):

$$SCB = K_c * RB + 20 * \log_{10}(\psi R) + 2\,\alpha_w R + 2(\alpha_{sS} + \alpha_{sF})R \qquad (2)$$

where:

α_{sS} is the sediment attenuation coefficient from coarse sediment,
α_{sF} is the sediment attenuation coefficient from fine sediment, and
other variables are as previously defined.

Some researchers (Topping and others, 2007; Wright and others, 2010; Landers and others, 2016) have noted that the backscatter response (WCB or SCB) often correlates well with the coarse fraction in transport, and the sediment attenuation coefficient often correlated with the fines fraction in transport. However, both coarse and fines can contribute to attenuation from sediment, hence the desire to separate the attenuation coefficients for coarse and fines in eq. (2) to investigate the effect of each fraction.

In sediment surrogate applications, Moore and others (2013) and Topping and Wright (2016) note the need for describing a sediment particle size distribution as the distribution by number of particles (hereafter called the number distribution), rather than the distribution by volume of particles (hereafter called the volume distribution), which is the typical distribution obtained from a laboratory analysis. Thus, the particle size distribution data collected in this study were converted to number distributions to better represent the true scattering cross section of the particle according to theory (Thorne and Meral, 2008). The median sediment diameters for the fines and coarse fractions were then used to determine sediment attenuation.

Field Data Collection

We collected six datasets in sand-bedded rivers in the U.S. in 2016-2018 (Table 1) to advance our understanding of the factors influencing successful use of down-looking ADCPs to estimate SSC and load. With a few exceptions, the data collection efforts consisted of:

- Stationary acoustic backscatter and velocity profiles using ADCPs of various makes, models, and frequencies, all referenced to differential GPS (Figure 1, level 1). This paper focuses on results obtained from 600kHz and 1200kHz Teledyne RD Instruments Rio Grande ADCPs (any reference to trade names does not imply endorsement by the U.S. Government), which were used at all sites. Acoustic cell size was set to 0.5 m for the 600kHz ADCPs and 0.25 m for the 1200 kHz ADCPs for consistency across sites.
- Point sediment samples from multiple locations in the cross section, typically collected using a P-6 sampler (Figure 1, level 1). Point samples were typically collected within five verticals in the cross section, selected using the Equal Discharge Increment (EDI) method described in Edwards and Glysson (1999), and within five depths within each vertical (0.2-depth (D), 0.4-D, 0.6-D, 0.8-D, and 0.9-D). At many sites, three replicate sets of samples were collected at each point sample location.
- Moving-boat discharge measurements before and after sample collection using ADCPs of various frequencies, typically 600kHz and 1200kHz Teledyne RD Instruments Rio Grande ADCPs, following procedures in Mueller and others (2014) (Figure 1, level 2).
- Cross-sectional- and depth-integrated (EDI method) sediment samples collected to validate estimates produced by acoustic calibrations (Figure 1, level 3). If EDI samples could not be collected, one set of the point sediment samples was used to validate estimates produced by acoustic calibrations.

Sediment samples were analyzed for concentration, coarse/fine break (percent finer than 0.0625 mm), and particle size distribution. Individual point samples were analyzed for particle size distribution in both coarse and fines fractions if sufficient sediment mass was available. In some cases, samples had to be composited to obtain enough mass for analysis.

At several sites, the following additional data were collected:

- Diagnostic tests with ADCPs to measure background noise with and without the other ADCP pinging.
- Point measurements of turbidity and acoustic backscatter (Sequoia Scientific LISST-ABS) at all point sample locations.
- Bed material samples at one or all EDI stations or verticals.

Table 1. Research sites and datasets collected to evaluate use of down-looking ADCPs for estimating suspended sediment [USGS, U.S. Geological Survey; EDI, equal discharge increment method]

River site	Nearest USGS streamgage number	Drainage area at nearest USGS gage (mi^2)	Date of data collection	Discharge (ft^3/s)	Number of point samples collected	Number of sets of cross section EDI samples collected
Missouri River at St. Charles, MO	06935965	524,000	July 20, 2016	95,300	75	0
Sacramento River at Freeport, CA	11447650	Indeterminate	May 3, 2017	69,100	75	2
Illinois River at Florence, IL	05586300	26,870	May 23, 2017	69,300	60	2
Missouri River at Nebraska City, NE	06807000	410,000	May 25, 2017	75,000	55	2
St. Joseph River at Napier Ave. at St. Joseph, MI	04102080	4,260	February 23, 2018	24,600	50	0
Cowlitz River at Castle Rock, WA	14243000	2,238	March 5, 2018	7,920	32	2

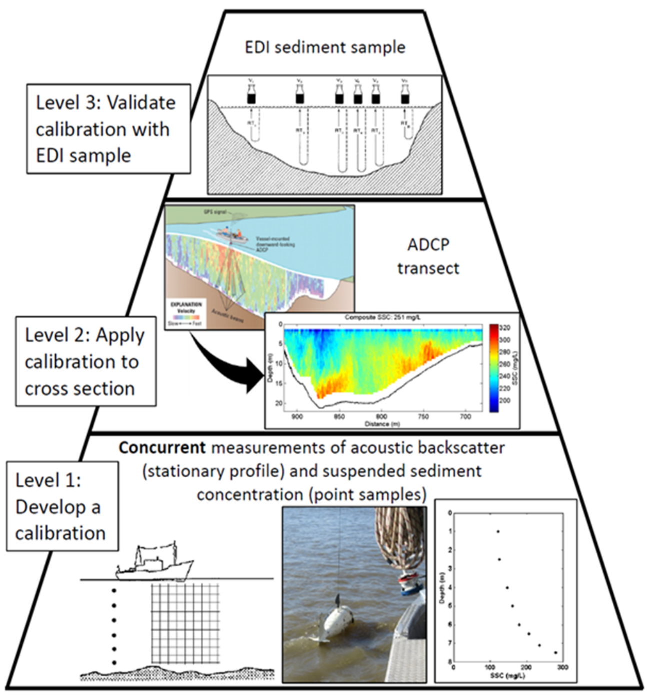

Figure 1. Basic procedure and data collection requirements to estimate suspended sediment using down-looking ADCPs using the Sediment Transect Acoustics software

Software Used for Developing Calibrations

Datasets collected at sites in Table 1 were processed in the Sediment Transect Acoustics (STA) software, beta version 4.0, written in Matlab and described in Boldt and others (2012), Boldt (2015), and at https://water.usgs.gov/osw/SALT/discrete_methods.html. STA is not yet available for public release. STA temporally and spatially matches the nearest SCB value in a vertical ADCP backscatter profile to a point sample SSC. Given the different acoustic response from fine and coarse fractions of particles, STA can perform linear regression between the matched values to develop a calibration for fine (SSC_f), coarse (SSC_c), or total (SSC_t) sediment concentration of the form:

$$\log_{10} SSC_f \textit{ or } \log_{10} SSC_c \textit{ or } \log_{10} SSC_t = a * SCB + b \qquad (3)$$

where a is the slope and b is the y-intercept. The theoretical value for the slope, a, is 0.1, but testing to date has shown variability in this slope among sites and acoustic instruments (Wright and others, 2010; Landers and others, 2016).

After the calibration was developed at each site, it was applied to a moving boat ADCP discharge measurement made before or after the stationary profile data collection to obtain an estimate for SSC for each bin of acoustic data comprising the measured cross section using the following transformation of eq (3):

$$SSC_f \textit{ or } SSC_c \textit{ or } SSC_t = 10^{(a*SCB + b)} \qquad (4)$$

If the option is selected in STA to calibrate to SSC_f or SSC_c, a cross-sectional estimate of SSC_t is still reported by adding the calibration estimates (SSC_f or SSC_c) to the average sample value of the fraction not included in the calibration (SSC_f or SSC_c). For example, if a calibration is developed to SSC_c, the reported cross-sectional estimate of SSC_t is the summed calibration estimates of SSC_c plus the average SSC_f from the samples used in the calibration.

The method employed within STA for the analysis described in this paper did not report suspended sediment in areas unmeasured by the ADCP, including the ADCP draft and transducer blanking distance near the water surface, sidelobe interference zone near the bed, and shallow areas near banks.

Substantial enhancements have been made to STA as part of this research effort since initial presentation in Boldt and others (2012). The new interface (Figure 2) allows for loading up to five verticals of ADCP and sediment sample data per cross section. The new interface also allows for:

- Entry of different sediment characteristics (sediment density and median sediment diameter, or separate characterization of attenuation) for the coarse and fines fractions.
- Use of individual or combinations of ADCP beams and their accompanying echo intensity scale factors.
- Ability to obtain a calibration or apply an already-developed calibration to another ADCP-measured cross section.
- Ability to separately characterize sediment attenuation from the coarse and fines fractions.
- Visualization of the box coefficient, sediment load, ADCP echo intensity, velocity and SCB distribution in the cross section, in addition to SSC.

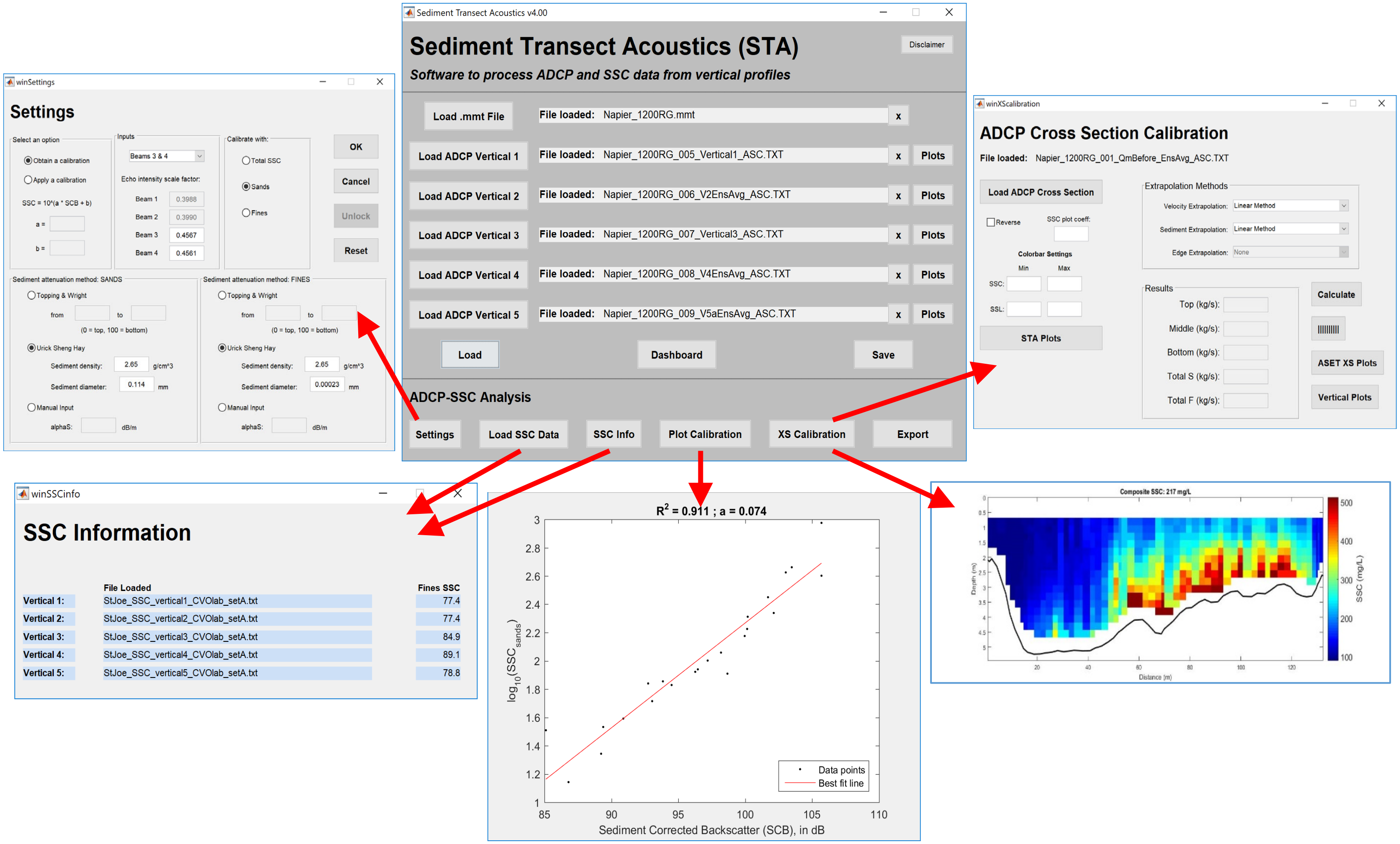

Figure 2. Main software elements of Sediment Transect Acoustics software (beta version 4.0) and calibration results from the St. Joseph River at Napier Ave. at St. Joseph, Michigan

Summary of Calibrations

Reasonable calibrations (R^2 0.66 to 0.98) and rating slopes close to 0.1 (expected from theory (Landers and others, 2016)) were developed for the coarse fraction (SSC_c >= 63 μm) at all sites over a wide range of sediment conditions (i.e. particle size and coarse/fine concentration ratios). The best calibrations were found with the 1200kHz ADCP compared to the 600kHz ADCP (Table 2). The best calibrations also were obtained at sites with relatively high coarse concentrations and stable sediment distributions during the sampling campaign (such as those in the St. Joseph River at Napier Ave. at St. Joseph (Figure 2) and Missouri River at St. Charles (Figure 3)). The comparisons between STA-estimated SSC_t and sampled SSC from the validation EDI samples also were good; the average percent difference among all sites between validation samples and STA estimates was -16.5 and -20.0 percent for the 1200kHz and 600kHz ADCPs, respectively. The negative percent differences were expected because the selected processing methods in STA do not yet report SSC in the unmeasured areas of the cross section and would therefore be less than the validation EDI sample. STA estimates of SSC_t were less than validation sample SSC in all cases except the Missouri River at Nebraska City (Table 2). Flow and sediment transport were especially turbulent at the Missouri River at Nebraska City, as demonstrated by the "banding" and non-uniform appearance in sediment distribution in the cross-sectional estimate of SSC (Figure 4). The range of SSC in sediment samples collected in the Missouri River at Nebraska City was large (451 mg/L to 838 mg/L) at individual EDI validation sample verticals and within replicates, suggesting that sediment transport conditions were highly variable during the research campaign.

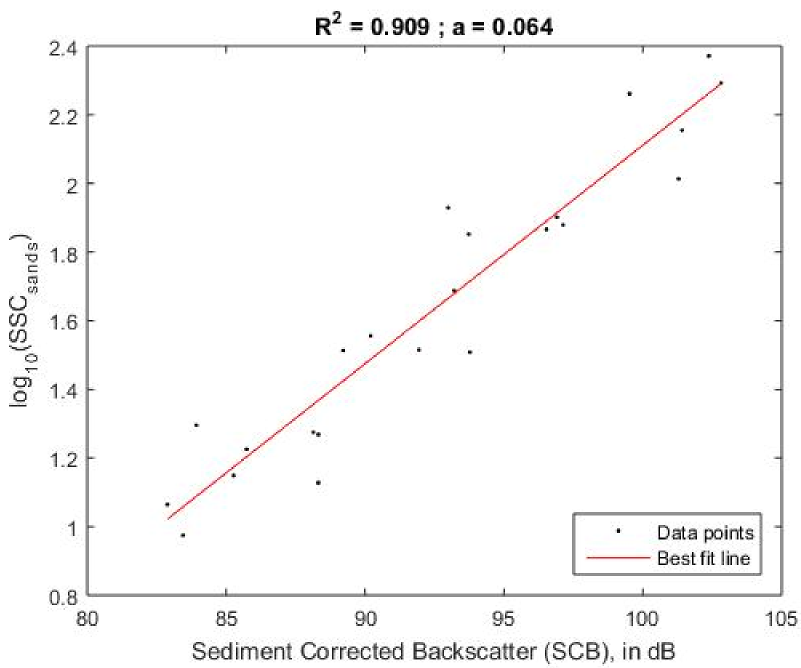

Figure 3. Calibration developed for coarse fraction concentration for the Missouri River at St. Charles, MO, July 20, 2016

Table 2. Research sites and calibration results from the Sediment Transect Acoustics software when processing data from all available verticals and calibrating to the coarse fraction [EDI, equal discharge increment method; SSC, suspended-sediment concentration; SSC_t, total suspended-sediment concentration; D50, median particle size diameter; kHz, kilohertz; ADCP, acoustic Doppler current profiler; STA, Sediment Transect Acoustics software; R^2, coefficient of determination; N/A, not applicable]

River site	Validation EDI sample SSC, average of sets if applicable (mg/L)	Percent fines	Coarse D50 (μm); volume distribution (number distribution)	Fines D50 (μm); volume distribution number distribution)	Results with 1200kHz ADCP (calibration to coarse)			Results with 600kHz ADCP (calibration to coarse)		
					STA-estimated SSC_t (mg/L)	STA calibration R^2	STA calib-ration slope	STA-estimated SSC_t (mg/L)	STA calibration R^2	STA calib-ration slope
Missouri River at St. Charles, MO	348	77	159 (90)	2[a] (1)	279	0.91	0.06	280	0.78	0.06
Sacramento River at Freeport, CA	96	43	204 (76)	11.5 (0.61)	68	0.82	0.06	67	0.81	0.06
Illinois River at Florence, IL	78	81	154 (120)	4.1 (0.18)	67	0.66	0.08	59	0.44	0.05
Missouri River at Nebraska City, NE	691	69	169 (104)	11.4 (0.21)	710	0.82	0.09	744	0.48	0.05
St. Joseph River at Napier Ave. at St. Joseph, MI	292	46	253 (114)	12.1 (0.23)	217	0.91	0.08	193	0.80	0.07
Cowlitz River at Castle Rock, WA	15	32	150[b] (150)	4[b] (4)	13	0.98	0.09	N/A[c]	N/A[c]	N/A[c]

[a]Over 50 percent of the distribution of the fines fraction was smaller than 2 μm, the smallest particle size category reported during analysis; input 2 μm as the fines D50.
[b]Did not perform detailed particle size analysis on this dataset; used assumed D50 values based on data from similar sites and historical data.
[c]600kHz ADCP data not collected at this site.

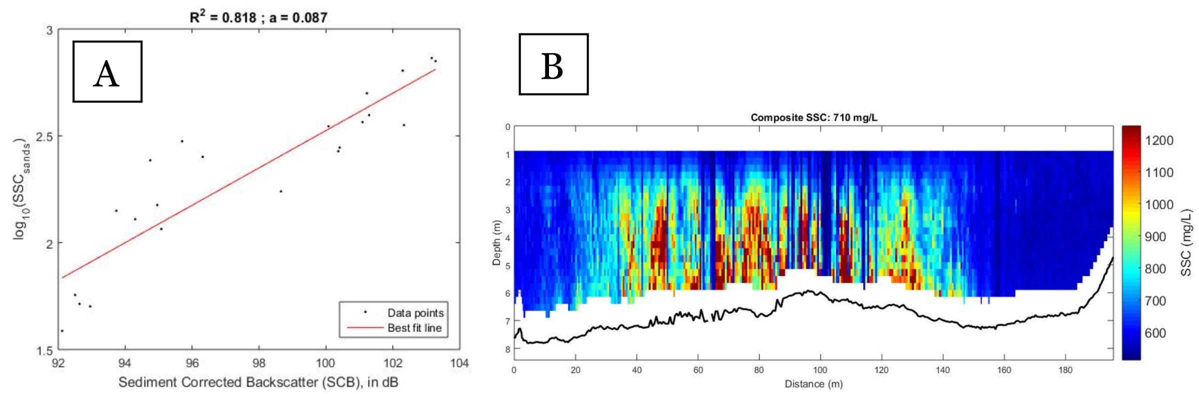

Figure 4. Calibration developed for SSC_c (A) and cross section estimates of SSC_t (B) for the Missouri River at Nebraska City, NE, May 25, 2017, showing banding and non-uniform appearance in sediment distribution

Overall, calibrations developed for SSC_c were good but were typically not adequate when calibrating to SSC_f or SSC_t. Other researchers have noted similar issues (Topping and others, 2007; Wright and others, 2010; Moore and others, 2013; Szupiany and others, 2018) indicating backscatter from coarse particles dominates the acoustic response and calibration when coarse particles are present. Additionally, some of the datasets showed that attenuation can also be dominated by coarse particles even when substantial fines are present. One example is the Sacramento River dataset (Figure 5), which showed that the backscatter in each bin is dominated by the coarse particle sizes, as expected. The sediment size contributing to attenuation, however, varied by depth in the water column and was often medium and coarse-sized sands. Figure 5A shows the particle sizes contributing to bin backscatter (top) and bin attenuation (bottom) for the point sample collected at vertical 2-0.9D near the bed. Figure 5B shows the same graphs for the point sample collected at vertical 1-0.2D near the water surface. The sample at vertical 2-0.9D contained about four times higher coarse fraction concentration and twice as high of a coarse fraction D50 than the sample at vertical 1-0.2D. This dataset shows that coarse particles can contribute a substantial amount of attenuation and that, overall, separating the acoustic response to the fines fraction in an attempt to quantify fines concentration, in the presence of coarse particles, can be problematic. As a result, the calibrations developed and presented in Table 2 were calibrations on SSC_c, but as previously mentioned, SSC_t is calculated for the cross section by adding the average fines concentrations from the point samples to the SSC_c calculated by the calibration equation. Issues associated with this approach are discussed under the Limitations section. Moore and others (2013) present an approach for estimating SSC_f using measurements of attenuation at three acoustic frequencies. This approach is not integrated in the current version of STA but may be investigated in the future.

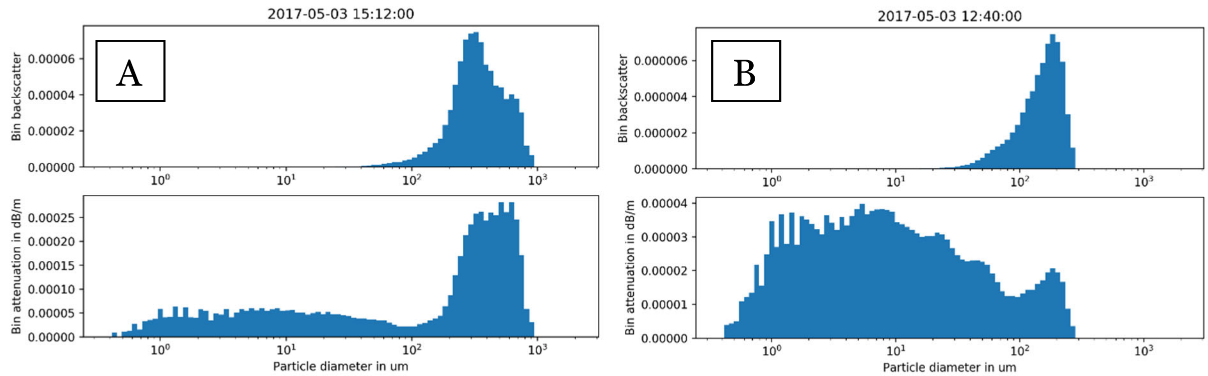

Figure 5. Graphs showing comparative contribution of sediment particle sizes on bin backscatter (top) and bin attenuation (bottom) for point sediment samples collected from (A) vertical number 2, 0.9-depth and (B) vertical number 1, 0.2-depth at the Sacramento River at Freeport, CA, May 3, 2017

Preliminary Testing on Minimum Datasets

STA was used to test various scenarios at each research site to evaluate sensitivity of calibrations and reasonable minimum datasets for estimating SSC. These scenarios included:

- the use of select verticals and combinations of verticals.
- the use of a reduced number of points collected in the water column.
- the use of different echo intensity scale factors for ADCP beams.
- the use of data from different combinations of ADCP beams (1, 2, 3, and 4).

The resulting calibrations and estimates of cross section SSC were compared to those obtained from the full dataset of five verticals and 25 sediment sampling points, using ADCP beams 3 and 4 (upstream and downstream, respectively) and manufacturer-supplied echo intensity scale factors.

The results of testing select verticals and combinations of verticals showed that selection of a minimum of two verticals, one in a more quiescent zone and one in a more turbulent, dynamic zone, together representing a wide range of sediment transport and backscatter conditions for the cross section, appears to produce calibrations that are reasonably close to those developed with data from all five verticals. Statistical comparisons of calibrations based on the full versus reduced datasets, using an analysis of covariance (ANCOVA) test, are planned to confirm initial observations.

Selection of three points within each vertical (0.4-D, 0.6-D, 0.8-D) appears to produce better calibrations than those using all available points. Data collected at 0.2-D showed unusual patterns and scatter at some sites, particularly for the 600kHz ADCP datasets, perhaps due to larger than expected near-field zones or turbulence introduced by the boat. Samples collected at 0.9-D were often within the sidelobe interference zone of both ADCPs so were not used in calibrations but could be used to validate bottom SSC estimates extrapolated by the STA software (see Plans for Future Work section).

The calibration results presented in Table 2 were based on the use of data from only ADCP beams 3 and 4. When testing sensitivity to which ADCP beam(s) is used in the calibration and associated beam echo intensity scale factors, the greatest sensitivity on results appears to be on beam used rather than the actual scale factors. Though this continues to be tested, a best practice might be to use the average of all four ADCP beams to reduce the effect of individual beam variation.

Current Limitations of Method

As previously mentioned, calibrations developed for SSC_c were good but typically not adequate when calibrating to SSC_f or SSC_t. The inability to develop a calibration specifically for SSC_f presents a limitation of the method: particularly the ability to apply the calibration to another time period and get an estimate of SSC_t without having to collect a sediment sample. We are currently testing various approaches for obtaining a better estimate of SSC_f, including using the Topping and Wright (2007) and Landers and others (2016) side-looking approach by calculating sediment attenuation using only a small portion of the water column near the top (where little to no coarse particles are present) or the Moore and others (2013) approach of multi-frequency acoustic inversion. Until an operational, computational approach can be developed to estimate SSC_f, users of the methods described in this paper might collect a single vertical or grab sample, analyzed for concentration and percent fines. This approach is less labor intensive than taking a full EDI sample and may supply the information needed for the fines fraction. The datasets collected for this research effort were examined to evaluate the variability in the fines fraction of sediment concentrations in all point samples and verticals to assess whether a single vertical, grab, or point sample could be collected to adequately represent the fines fraction. For all sites, the coefficient of variation (CV, standard deviation divided by the mean) for fines concentration ranged from 2 to 17 percent among all point samples collected at a site, meaning variability was relatively low. CV was 10 percent or less for four out of the six sites. In comparison, CV for coarse concentrations ranged from 41 to 121 percent over all sites. We will continue to work on an approach for developing a calibration for fines, but in the meantime, collecting a single vertical (preferred) or grab/point sample in a well-mixed location may be adequate for representing the fines at sites similar to those tested.

Plans for Future Work

Researchers from the Littoral National University in Argentina have developed another software program, Acoustic Sediment Estimation Toolbox (ASET), described in Dominguez and others (in review). Methods in ASET are further described in Szupiany and others (2016; 2018) and allow for characterization of noise or undesired portions of the received signal as well as uncertainties in other terms; characteristics of the acoustic signal such as transmit power and transmit length; and a form factor representing sediment characteristics. ASET also computes estimates of sediment transport in the top and bottom unmeasured areas of the ADCP profile and cross section using different methods. The point sediment samples collected at the 0.9-D locations will be used to validate the estimates in the bottom unmeasured areas. Selected elements of ASET were incorporated into STA beta version 4.0 but additional coding and testing are needed to allow estimation of total SSC and to compare with results described in this paper. Once integrated and tested, the joined software will allow broader and more complete evaluations of these and future datasets compared to the evaluations described in this paper.

The seasonal and site-specific dependence of ADCP-based calibrations for estimating suspended sediment has been reported as a major challenge in advancement of the method (Latosinski and others, 2014). We also plan to conduct a series of tests to apply calibrations developed on the dates in Table 2 to other time periods where cross-section, moving boat ADCP measurements have been made and validation sediment samples have been collected. This exercise will assess whether calibrations hold over different flow and sediment transport conditions. If calibrations hold over different conditions, they could be applied to any ADCP measurement (made before or after the calibration field campaign) to get a rapid estimate of SSC and suspended-sediment load (SSL) when no other sediment data are available. Additionally, we plan to apply calibrations developed at one location on a river reach to another nearby location, on the same river, to determine if calibrations could be used to accurately "map" and quantify sediment distribution in a river reach. Development of calibrations that hold over time and space and produce reasonable estimates of SSC and SSL would greatly expand the amount of sediment information available to the public and science communities and allow reporting of sediment data on demand during times when samples cannot be collected due to logistical or safety considerations.

Conclusions

The use of down-looking ADCPs to estimate SSC and SSL showed great promise at the six U.S. river sites selected. Best results were found when using data from the 1200kHz ADCPs (R^2 0.66 to 0.98, calibration slopes 0.06 to 0.09) and by calibrating to the coarse fraction of suspended sediment. Estimates of total SSC were determined by adding sampled fines concentration to the calibration-estimated coarse concentration for a site. Obtaining a calibration for fines proved problematic for all sites because of the difficulty separating backscatter and attenuation for fines in the presence of any coarse particles. STA-estimated SSC was less than validation sample SSC at all sites except one, which was expected because the methods selected for data processing in STA do not yet extrapolate SSC at the top, bottom, and edges of the river cross section where data are not reported by the ADCP. Preliminary testing on minimum datasets showed that calibrations resulting from data collected at a minimum of two verticals over a wide range of backscatter conditions, and at a minimum of three points within each vertical (0.4-D, 0.6-D, 0.8-D), are needed to produce reasonable calibrations and cross section estimates of SSC. Additional work is needed to evaluate the validity of the calibrations when applied to ADCP cross section measurements made at other times, under different sediment transport conditions, and other locations within a river reach. Additionally, work is underway to fully incorporate features in the ASET software into the STA software to allow characterization of additional variables in the acoustic data correction process and to allow extrapolation of SSC estimates in unmeasured areas. The use of down-looking ADCPs to rapidly estimate suspended-sediment concentrations and loads, while leveraging other uses of the instruments for flow measurement, has applicability for sand-bedded rivers over a wide range of sediment transport and river conditions.

Disclaimer

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