Proposal Title: **In-situ bedload measurements using MBES and ADCPs**

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Introduction

Knowledge of sediment dynamics is of great importance for practical purposes such as monitoring and investigation of river morphology, habitat restoration, and dredging operations. While the measurement of suspended load is currently an active area of research for optical and acoustic technologies, bedload measurement has not experienced a similar progress (Abraham et al, 2011). This call for research is a timely opportunity to translate a proof-of-concept methodology successfully tested in the laboratory (Muste et al., 2016) to field conditions. The technique, labelled Acoustic Mapping Velocimetry (AMV), estimates bedload rates in river with bedforms using acoustic maps and image velocimetry processing protocols. The time-sequenced acoustic maps are acquired with multi-beam echosounders (MBES) or Acoustic Current Doppler Profilers (ADCP) surveys repeated over time to capture the progression of the bedform movement in cross-sectional swaths. Subsequently, two-dimensional (2D) velocity distributions associated with the bedform migration are obtained by applying particle image velocimetry algorithms on the above-obtained maps. The bedload transport rates over the whole surveyed area are obtained from the acoustic and velocity maps in conjunction with analytical bedload formulations. Bedload rating curves at specific river locations can also be determined if AMV measurements are obtained for a range of flows. An additional benefit of AMV is that it is capable to quantify bedform movement in areas of scouring or deposition.

The availability of accurate estimates of bulk sediment transport rates and cumulative river bedload are critically relevant for monitoring multiple river functions as well as for assessment of its environmental health. Moreover, given that ADCPs and MBES's are efficient and safe to operate, the bedload rate estimation in river cross sections as well as along reaches can be obtained with minimal effort, in a fraction of the time required by the conventional bedload measurement technologies. The potential of AMV implementation using MBES' and/or ADCPs is highly relevant for the FISP mission in that it promotes innovative methods for sediment transport estimation in surface waters (FISP, 2019).

Background

The Acoustic Mapping Velocimetry (AMV) method determines bedload transport rates using the following sequence (see also Figure 1): (a) sounding of river beds with multi-beam acoustic instruments, (b) repeating cross-sectional bathymetry surveys at time intervals commensurate with the movement of the bedforms, (c) producing acoustic maps of the surveyed areas, (d) applying image velocimetry concepts to the successive acoustic maps to produce velocity distributions associated with the bedform movement, and, (e) estimating bedload transport rates over the mapped area using the above-determined bedform geometry and velocity fields in conjunction with conventional analytical relationships.

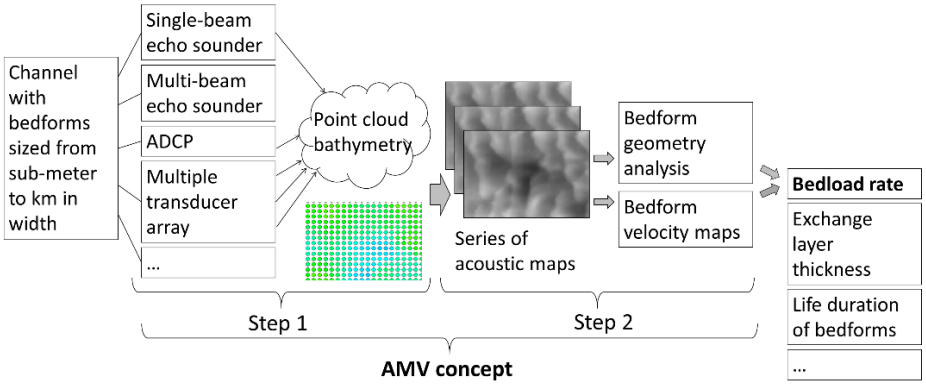


Figure 1. Schematic of the AMV concept (Muste et al., 2016)

The ***3D acoustic maps*** can be created using different instruments depending on the desired result accuracy. For field studies, single beam ecoshounders, MBES, or ADCPs can all be used for acquiring the maps (Muste et al., 2012). While the idea of determining bedload transport using the change in bedform geometry during a known time period (without estimation of bedform velocities) has been previously tested by Abraham et al. (2011), quantifying velocities associated with individual bedforms via image velocimetry protocols applied to acoustic maps is novel (Muste et al., 2016). This distinct AMV feature empowers the method with capabilities to characterize bedform dynamics in the 2D space.

In a first stage, the probable displacements of recognizable bedform patterns embedded in a pair of images are estimated using a statistical approach based on pattern matching applied to image intensity distribution in the images (Adrian, 1991). Displacements are successively estimated over the entire imaged area with small interrogation areas (IA) illustrated in Figure 2. The similarity index for patterns enclosed in an IA is calculated within a larger Search Area (SA) selected in the subsequent image (Fujita et al., 1998). The selection of IA and SA is guided by heuristic rules of thumb (e.g., Adrian, 1991) complemented by trial-and-error tests for every new application. ***Velocity fields associated with the bedforms*** are produced by dividing the estimated displacements by the time between successive maps.

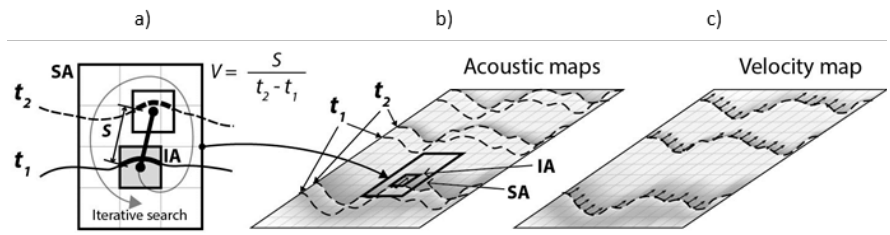


Figure 2. Velocimetry process: a) processing parameters; b) pattern matching in successive maps; c) results of the image velocimetry (Muste et al., 2016)

Given that the details of the ***bedload rate estimation algorithm*** are fully described in Muste et al. (2016), we replicate herein only essential information for evaluation of the concept of the AMV technique. In a first step, the area acoustically mapped with MBES swaths or ADCP transects is split into longitudinal strips as described in (Abraham et al., 2010). The volumetric bedload transport rate per unit width (q_b) is estimated with Simons et al. (1965) formula (derived from Exner, 1925):

$$q_b = (1 - p)V_D\Lambda/2 \qquad (1)$$

where p = porosity of the river bed, V_D is the bedform velocity, and Λ is the bedform height. The characteristic bedform height, Λ, is estimated from longitudinal profiles set along the centerline of the strips used for bedload estimation. Bedform characteristics (wavelength and height) for each strip are calculated by averaging them along the survey lines. Equation (1) assumes a steady uniform flow and bedforms in an equilibrium regime. The mass of the bedload material transported by the stream can be estimated by multiplying q_b by the density of the sediment. The cross-sectional bedload transport is obtained by integrating q_b across the river width. Given its 2D estimation nature, AMV can also be applied to determine bedform dynamics around structures (scour-deposition). This capability is not available for mapping techniques using the change of bedform geometry along a line.

The ***AMV proof-of-concept and validation tests*** obtained so far are from laboratory experiments entailing three different flows with natural sand moving exclusively as bedload (Muste et al., 2016). A sample view of the mapped bedforms for one of the experiments is provided in Figure 3a for illustration purposes. The mapping was made by scanning the flume width with a linear array of 32 sensors spaced at 1" apart. No more than five consecutive maps were acquired (keeping the time for scanning strictly the same) for any given flow rate. Results of the application of the image velocimetry procedure applied to the migrating bedforms are shown in Figure 3b where the 2-dimensional velocity distributions superposed on the color-coded map of velocity intensity (as iso-contours) are determined using a pair of images from an experimental run. Applying equation (1) in conjunction with the bedform velocities obtained from image velocimetry and the bedform height determined from the acoustic maps we firstly obtained bedload rates along the sections shown in Figure 3b. Subsequently the total bedload across the flume was obtained by integration across the flume width. The total AMV bedload estimates for the three laboratory tests compared well with the direct physical samples acquired with the sand trap as illustrated in Figure 3c. The AMV measurement protocols used in laboratory need to be verified and adjusted for field conditions.

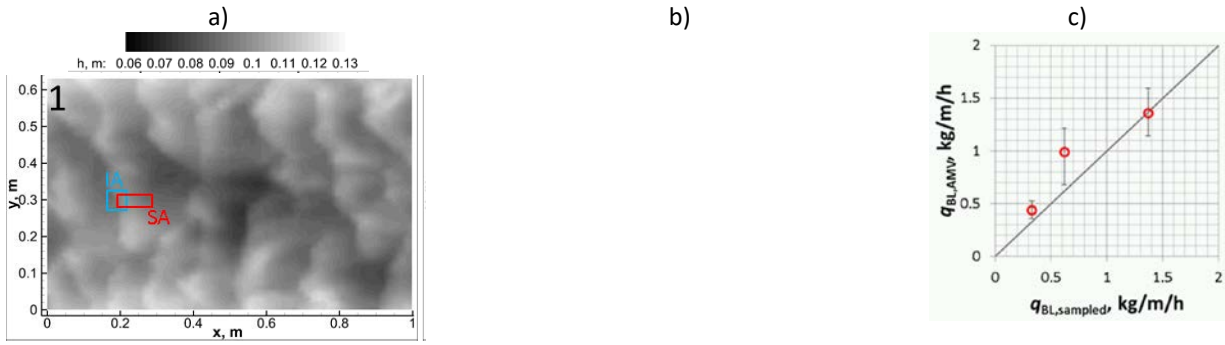


Figure 3. Laboratory validation of AMV (Muste et al., 2016): a) gray-level acoustic maps of the bedforms in the flume cross section; b) 2D bedform velocities; c) comparisons of AMV bedload estimates with physical sampling

Unresolved issues: The above-described AMV proof of concept and validation experiments were conducted in laboratory conditions taking great care to establish uniform equilibrium flows with a quasi-2D bedform geometry, while operating the instruments following strict measurement protocols in an easy to control environment. There are multiple concerns associated with translating the AMV technique from lab to field conditions that require special attention. Among them are the following: a) to attain adequate resolution of the acoustic maps (widely different for data collected with MBES and ADCPs), b) to design navigation strategies for acquiring suitable acoustic maps, c) to estimate the time for surveying individual acoustic maps and the time between successive mappings, d) to estimate the bedform velocity and beadload rates for bedforms of considerably larger spatial non-homogeneous and diverse bedform geometries and orientations. The above concerns require development of specific guidelines for AMV implementation in conjunction with MBES and ADCPs surveys. Finally, the initial end-to-end AMV processing was done with a piece-meal approach and considerable data manipulations; this process needs to be streamlined and optimized to attain the needs for practical monitoring in rivers. All of the above concerns will be addressed through a phased research that is described next.

Purpose and Scope

The primary contribution of the proposed research is the AMV implementation for measurements in natural streams where, excepting ISSDOT method, the current bedload measurement technologies are of questionable accuracy irrespective of their type (bottom tracking with ADCPs or direct sampling with bedload probes). The proposed research is timely as it takes advantage of the increased usage of the MBES and ADCPs (often bundled together). The addition of the AMV for bedload estimation enables coupling of the sediment transport dynamics with that of water in the column leading to additional inferences on these complex flows. Especially relevant for this purpose is the use of AMV with ADCP measurements as the flow and sediment dynamics can be quantified with just one instrument deployment. The possibility to apply AMV to in-situ measurements can potentially transform the way the bedload measurements are currently made with far reaching benefits for conventional monitoring (e.g., evaluation of the natural bedload regime or effectiveness of training structures) and customized geomorphological studies (e.g., assessment of habitat suitability, river stability, validation of numerical models). So far, these type of measurements were only possible in the laboratory conditions.

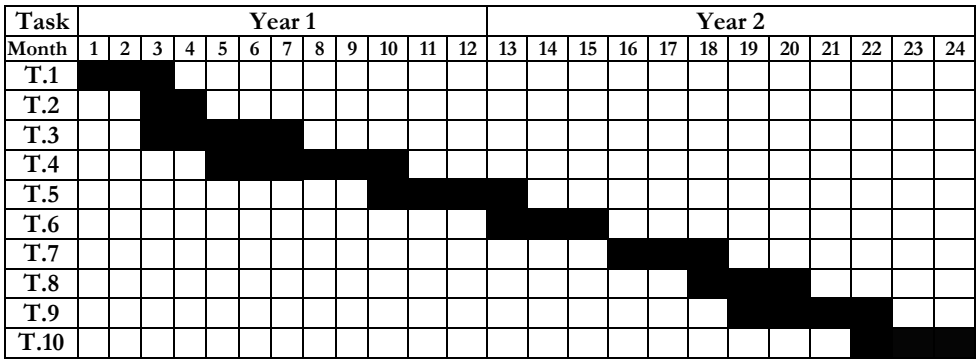
Collaborators' role: **D. Abraham** is the initiator of the Integrated Section Surface Difference Over Time version 2 (ISSDOTv2) method that estimates bedload transport rates based on the rate of change in bedform geometry (Abraham et al., 2011). When applied to rivers, the ISSDOTv2 has used acoustic maps acquired with a multibeam-echo sounder (no tests with ADCPs were conducted so far). Using the database of time-sequenced bathymetric sets acquired in large rivers (Abraham et al., 2018), the AMV performance will be compared with that of the ISSDOTv2 method applied at several sites (**K. Jones)**. **D. Wagner** has extensive experience in assembling bathymetry maps by combining ADCP with MBES measurements (Mueller et al., 2013; Wagner, 2018; Wagner and Whaling, 2018; Wagner, 2018; Wagner and Lee, 2017; Wagner and Lee, 2017). D. Wagner and **A. Whaling** will assist with the development of field guidance for implementation of the AMV for various stream and flow conditions. Their involvement is critically important in tailoring the ADCP data collection protocols suitable for AMV purposes.

Technical Requirements: The proposed research will be carried out in a logical sequence as indicated in the table below. Specified in the table are the research tasks to be funded by FISP (last column).

Task	Description	Charge	FISP$
T.1	Development of specifications for acquiring acoustic maps suitable for AMV using MBES (includes setting of tradeoffs between data collection time and map resolution)	**Muste**	
		Postdoc	x
T.2	Development of data acquisition protocols with consideration of non-homogeneity of bedform dynamics in natural streams	**Muste**	
		Postdoc	x
T.3	Optimization of the analytical algorithms for bedload rate estimation (includes conversion of acoustic maps to grey-level scale, automated algorithms for determination of bedform geometry, and testing of various bedload rates algorithms)	**Muste**	
		Postdoc	x
T.4	Production of the end-to-end software package for AMV field implementation	**Postdoc**	x
T.5	Testing the AMV with datasets of time-sequenced bathymetric sets acquired with MBES (includes validation with ISSDOTv2 as reference)	**Abraham**	
		Postdoc	x
T.6	Development of specifications for acquiring acoustic maps suitable for AMV using ADCPs (includes establishment of tradeoffs between data collection time and required map resolution)	**Wagner**	
		Postdoc	x
T.7	Acquisition of time-sequenced bathymetric datasets with ADCPs	**Wagner**	x
T.8	Testing the AMV with datasets of time-sequenced bathymetric sets acquired with ADCPs	**Postdoc**	x
T.9	Validation of AMV with MBES and ADCP collected at the same site	**Wagner**	
		Postdoc	x
T.10	Report writing and preparation of knowledge-transfer materials	**Muste**	
		Postdoc	x

Deliverables: Final report documenting the AMV-associated protocols for field implementation using MBES and ADCP measurements. Additional data and materials as requested by FISP will also be issued.

Timeline: The proposed research timeline follows closely the development tasks as illustrated below:



Budget: We request $30,000 per phase, $60,000 total for this two-phase project, as follows: ***Labor*** – We request $17,288 (salary+fringe) for a 29% effort Post-Doctoral researcher in Phase 1 and 12% effort in Phase 2. ***Travel*** – We request $2,384 in each project phase to support travel costs of trips to each data collection site (two trips per phase). Estimated costs per trip include Airfare from Cedar Rapids, IA ($500), 3 nights lodging ($392), per diem ($165), and rental car ($135). ***Professional Services***: In Phase 2, we request $10,000 for USGS to acquire ADCP data for Tasks T.6, T.7, and T.9. ***Facilities & Administrative Indirect Costs*** are calculated at the University of Iowa federally negotiated rate of 52.5% of modified total direct costs (MTDC). We calculate indirect costs of $10,328 on a MTDC base of $19,672. ***Cost share*** – Dr. Marian Muste will contribute approximately 2% effort per project phase at a total estimated cost including salary, fringe and indirects of $5,710 for Phase 1 and $5,905 for Phase 2.

Unique Qualifications: The proposal team is uniquely qualified to take on the proposed research as it entails the creators of the two tested techniques (AMV and ISSDOTv2). These techniques have been vetted through peer-reviewed publications and partially tested (Baranya et al., 2016). The team has access to data and instrumentation to support the proposed research tasks. All three institutions are known for high-level technical expertise and capacity to partially support the involvement of the PIs in this research.

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