Estimation of wave induced sediment resuspension using an ADV

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Introduction

Ship induced waves has manifold impacts on the hydromorphological and ecological condition of rivers, especially in the littoral zone [1, 2]. In this study, the sediment resuspending effect of the prevailing hydrodynamic conditions is investigated, by means of acoustic field measurement techniques. The backscatter intensity (BSI) logs of and acoustic Doppler velocimeter (ADV) are calibrated for the estimation of suspended sediment concentrations (SSC) through a two-step indirect methodology, using synchronous measurements with a calibrated acoustic turbidimeter (LISST-ABS). The calibrated ADV is then used to analyze interactions between suspended sediment concentrations and wave related currents.

Study sites

The study sites are in a side arm of the Hungarian section of the Danube (Fig. 1), where 2/3 if the total discharge is flowing ($Q_{mean} \approx 1400$ m^3 s^{-1}), consequently, it is used for navigation purposes. A series of isokinetic point integrating samplings and ABS measurements were performed between 01.2019 – 11.2019. in the area of Sződliget, which formed the basis of the calibration of the ABS device [3]. In the area of Horány, one-day field campaigns were performed, with synchronous ADV and ABS measurements at the riverbank [2], to investigate the prevailing hydrodynamic conditions and sediment resuspension characteristics induced by ship waves. The ADV and the ABS sampled the same water volume, which was then used for the indirect calibration of the ADV backscatter intensity time series.

Figure 1 Study sites

ABS calibration

The collected water bottle samples were analyzed in laboratory conditions to determine mass concentrations [3]. The comparison of uncalibrated ABS values and reference concentrations showed the expected linear fit (Fig. 2). In order to use the calibration equation for further analyses, the assumption was made, that sediment characteristics do not changes notably between the two study sites due to their relative closeness (5 km).

ADV BSI calibration

Using the ABS calibration equation, SSC time series were generated and used to calibrate ADV backscatter intensities for the estimation of SSC based on the so-called sonar equation (see e.g. [4]). The two free variables of the exponential equation were derived via regression analysis resulting in a very good fit of $r^2 = 0.96$ (Fig. 3).

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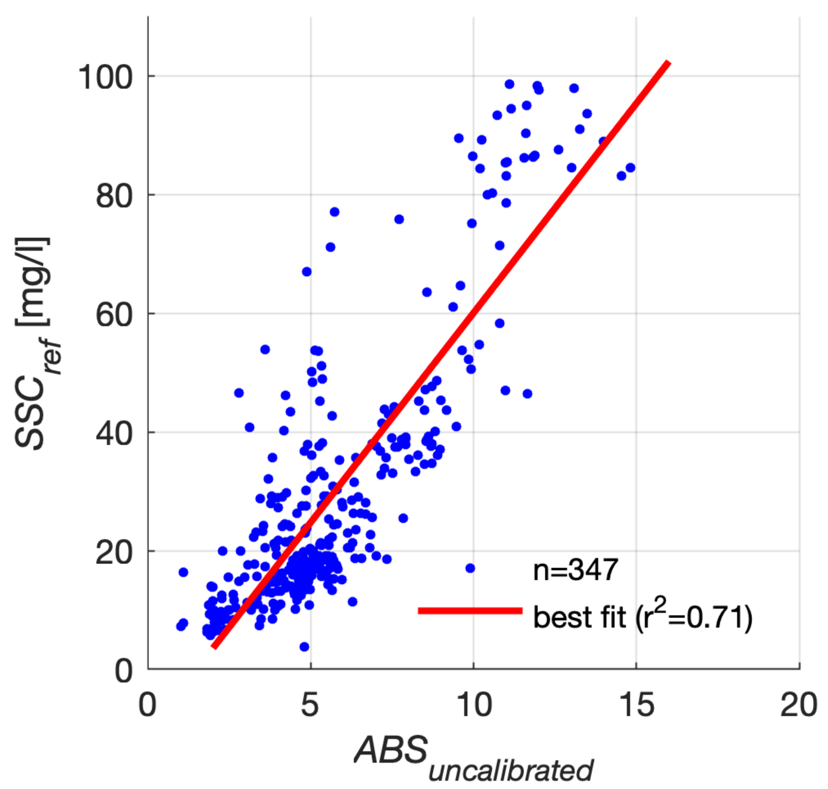

Figure 2 Calibration of the LISST-ABS

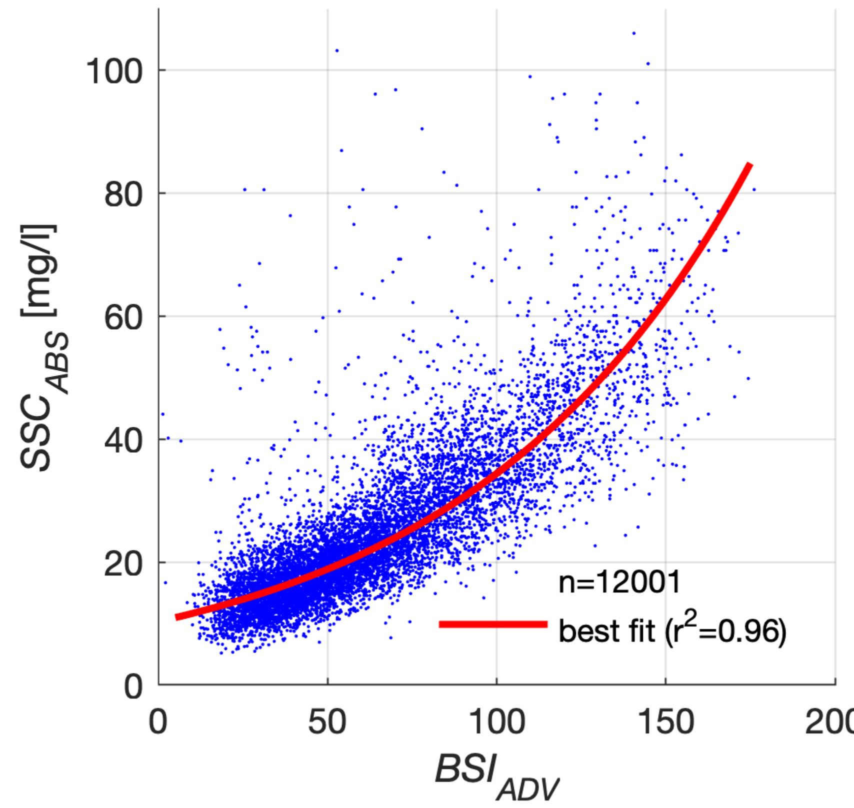

Figure 3 Calibration of ADV backscatter intensities

Wave velocity decomposition

A frequency-based velocity decomposition was performed in order to individually analyze the temporal evolution of i) low frequency ($f < 0.033$ Hz), primary waves (drawdown and surge) and ii) the secondary waves ($f > 0.033$ Hz). Low-frequency components are separated using a steep low-pass filter, while secondary components are calculated by subtracting the former from the original time series ensuring that the sums of the decomposed time series are identical to the original, measured data (Fig. 4).

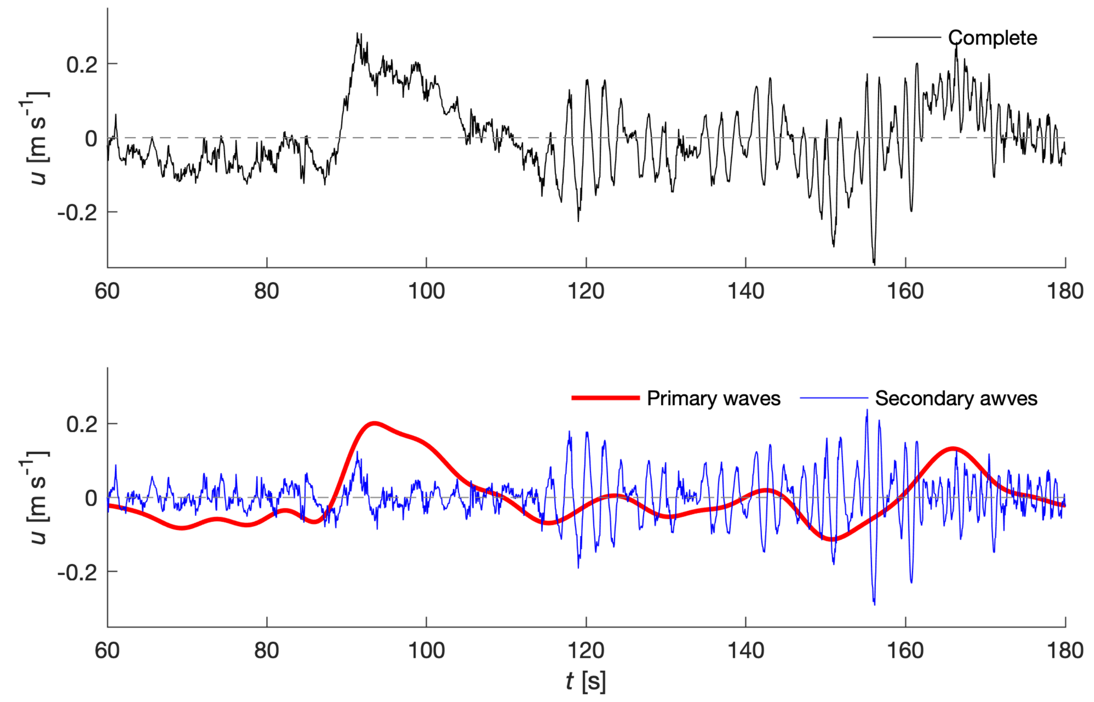

Figure 4 Wave velocity decomposition

Results

The accuracy of the proposed ADV BSI calibration equation was tested through comparing estimated values (SSC_{ADV}) with meausred (also indirectly determined) suspended sediment concentrations (SSC_{ABS}). Comparison of time series for a wave measurement campaign is presented on Fig. 5, where reasonably good agreement is observed. The rapid concentration increases as well as the gradual settlings are observed in both time series, indicating the sediment resuspending effect of ship waves during the measurement period. While the general accuracy of the esitmation concentrations is considered adequate in a large time scale, it is noted, that short term (seconds) extremes are often underestimated by the ADV results.

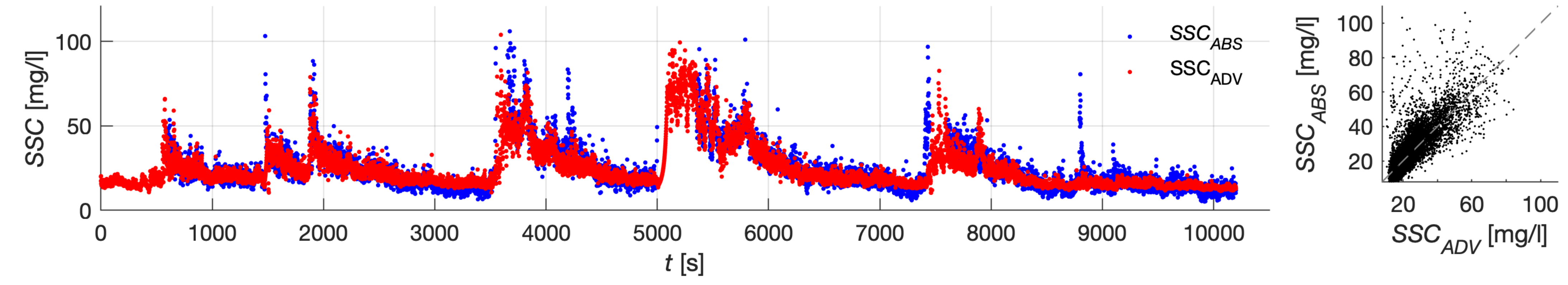

Figure 5 Comparison of estimated suspended sediment concentrations (SSC_{ADV}) with the measured time series (SSC_{ABS})

The initial jump in secondary wave velocity magnitudes and thus kinetic energies is followed by the increase of SSCs, highlighting the sediment resuspending effect of ship waves (Fig. 6b). While the magnitude of primary and secondary wave velocities are in the same order of magnitude, their contribution to lateral sediment fluxes (cumulative integral of instantaneous sediment transport rates) is very different – primary waves determine the lateral advection of resuspended fine sediments, underlining the relevance of these low frequency components. Results emphasize the spatial complexity of wave related sediment transport phenomena and call for spatially more extensive field measurements, as well as numerical modeling based investigations.

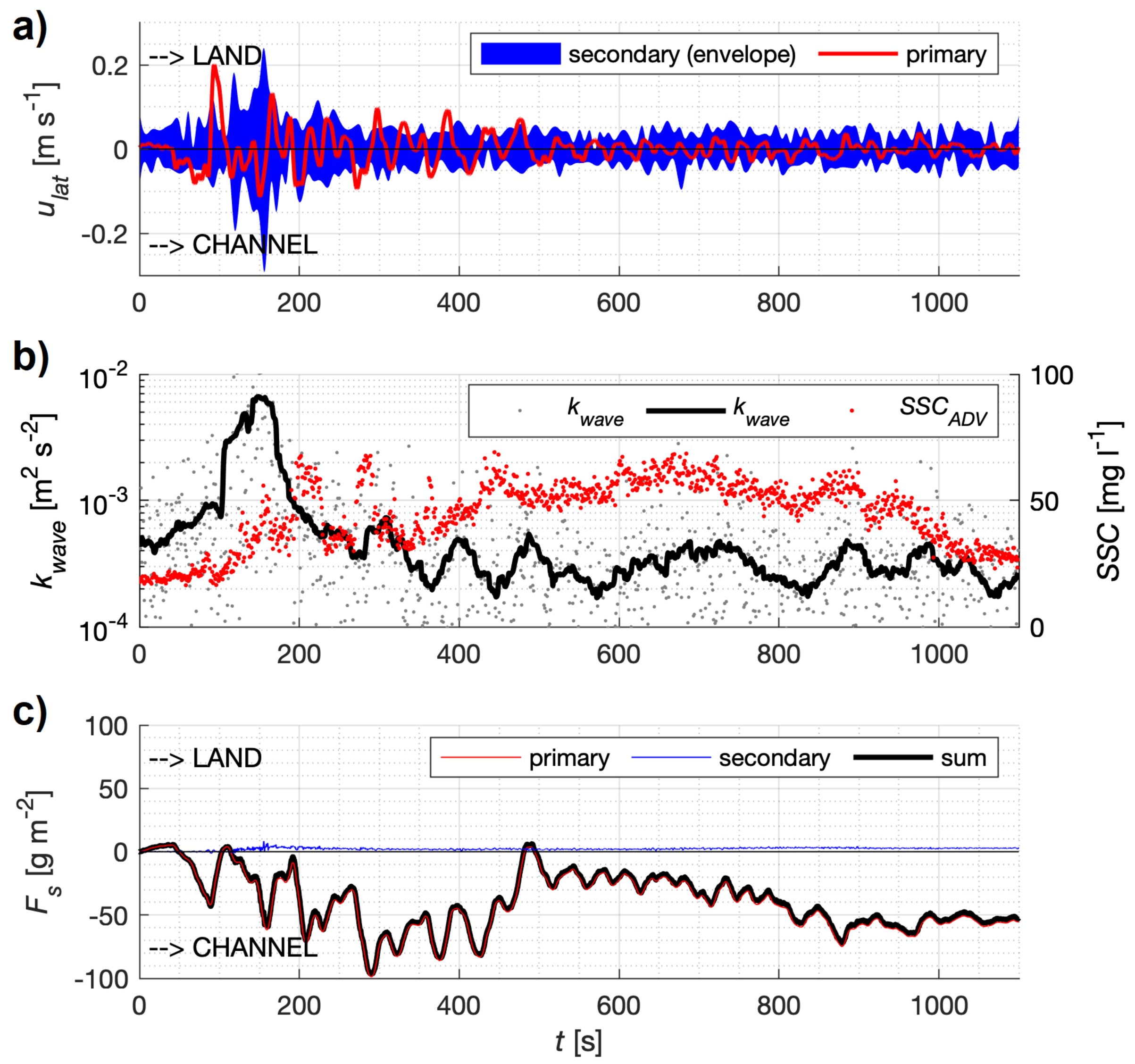

Figure 6 ADV-based velocity and sediment transport for a cruise ship. a) decomposed, lateral velocity time series; b) secondary wave kinetic energy and SSC time series; c) lateral sediment fluxes.

References

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