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Comparison between optical and acoustical estimation of suspended sediment concentration: Field study from a muddy coast

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ABSTRACT

The aim of this study is to evaluate the ability of a 1.5 MHz Pulse-coherent Acoustic Doppler Profiler (PCADP) to measure suspended sediment concentration (SSC) in a muddy environment where SSC varies over several orders of magnitude. Two seasonal deployments were conducted south of the Atchafalaya–Vermilion Bay system along the Louisiana coast, USA. During a low discharge period of the Atchafalaya River, acoustical estimates of SSC were in good agreement with OBSs deployed. The second deployment was conducted during a high discharge period of the Atchafalaya River. The passage of a cold front across the coast resulted in a rapid advection of the river plume to the study area. High sensitivity of the OBS to fine-grained suspended sediments led to high values from the OBS readings. On the other hand, the PCADP barely sensed the transportation of fine-grained sediments and significantly responded to the combined wave and current shear stress close to sea bed. To reduce the influence of temporal variation of grain size distribution, acoustical backscatter measurements were calibrated over a time span of a few hours. The resulting SSC estimates from the time-adaptive calibration of the PCADPs were in good agreement with data from OBS sensors.

1. Introduction

The use of optical or acoustic devices, rather than direct water sampling, for estimating suspended sediment concentration (SSC) has several advantages including continuous sampling for a long period of time, simultaneous measurements with flow velocity, less disturbance to the current profile and less labor. Optical Backscatter Sensor (OBS) is one of the well-known types of optical instruments which has been extensively used to provide an indirect estimate of SSC in different marine environments (Sternberg et al., 1986; Beach and Sternberg, 1988; Wright et al., 1991; Kineke and Sternberg, 1992; You, 2005). An OBS consists of a laser or an infrared light source, and a photodetector to convert the backscattered light into photocurrent (Downing, 2006). It is important to note that the sampling domain of an OBS is around 20 cm^3 close to sensor, and SSC estimates from an OBS may be regarded as point measurements (Hoitink and Hoekstra, 2005). In addition, the number of optical devices employed in a water column is limited to avoid disturbing the current profile. Several factors can affect the OBS readings, including particle size, composition, dissolved light absorbing matters, bubbles, and biological fouling (Downing, 2006).

Acoustic profilers are nonintrusive instruments which were originally designed to measure the velocity profile (Gordon, 1989; Firing and Gordon, 1990) and later used for estimating the directional wave spectrum (Terray et al., 1999; Strong et al., 2000; Work, 2008). Several studies also investigated the potential use of backscattered echo of an Acoustic Doppler Current Profiler (ADCP) to estimate SSC (Allison et al., 2000; Thorne and Hanes, 2002; Gartner, 2004; Hoitink and Hoekstra, 2005; Defendi et al., 2010; Guerrero et al., 2011). An ADCP is far less sensitive to biological fouling (Gartner, 2004), and is able to provide the SSC estimates over its profiling range. However, the intensity of backscatter echo is a complex function of suspended sediment size, shape, and type. Presence of bubbles may lead to inaccurate results and finally, depending on the frequency of the instrument, a limited range of particle sizes are detectable.

The objective of this study is to compare the acoustical and optical measurements of suspended sediments in the field condition and close to the sea bed, in which particle size and SSC are highly dynamic over the time span of a few days. In order to have a high resolution profile close to sea bottom, the ADCP should be used in the pulse coherent mode, and there are only few studies

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that have compared the SSC from a Pulse-Coherent Acoustic Doppler Profiler (PCADP) with OBS data (e.g. Bai et al., 2009; Ha et al., 2011). Therefore the results of this study increase our understandings from the applicability of pulse coherent acoustic instruments for estimating SSC. Moreover, an acoustical device needs calibration before it can provide a realistic SSC estimate. In this study, two OBSs were placed in the profiling range of a PCADP to provide at least one independent dataset for instrument comparison. The deployment locations were selected in such a way that SSC could vary several orders of magnitudes, and the extended period of deployment would provide a realistic comparison between PCADP and OBS sensors.

2. Study site

The Atchafalaya–Vermilion Bay system is the largest estuary along the Louisiana coast, receiving 15–30% of total flow of Mississippi River and nearly 50% of its sediment load through the Atchafalaya River (Mossa and Roberts, 1990; Allison et al., 2000). The average sediment load of Atchafalaya River is estimated as 84 million tons per year based on the measurements at Simmesport station, LA (160 km north of Marsh Island in Fig. 1). Sand particles form ~17% of suspended sediment load (Allison et al., 2000) and the mean particle diameter is 2–7 μm (Wells and Kemp, 1981; Sheremet et al., 2005). The bay is 2–3 m deep and predominantly blanketed by a thick layer of mud. There are several scattered relict sand shoals on the low gradient shelf south of Atchafalaya outlet channel (e.g. Tiger and Trinity Shoals shown in Fig. 1). Away from sand shoals and reefs, the mean particle diameter is the same as particles in the river plume.

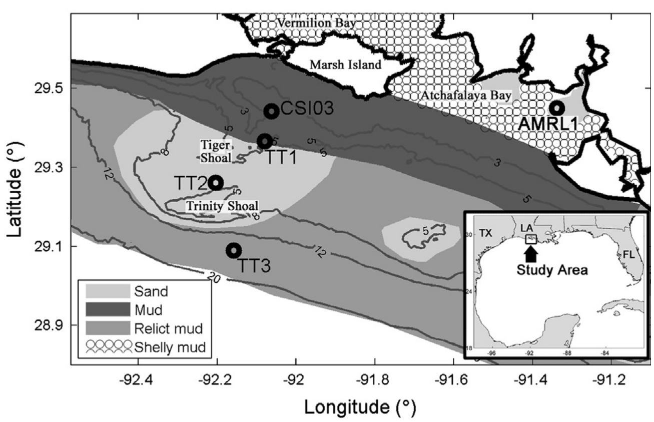

Fig. 1. The study area: Atchafalaya Bay and the surrounding shelf. The location of deployment sites at the Tiger and Trinity Shoals, CSI03 and AMRL1 stations are also shown. The shadings represent a qualitative extension of various sediment types onto the Atchafalaya shelf, modified from Neill and Allison (2005).

The tides are diurnal and the mean tidal range is less than 0.5 m, forcing tidal currents with an average speed of nearly 0.1 m/s, landward of 10 m isobaths (Wells and Roberts, 1980; Walker and Hammack, 2000), and waves are the dominant force for local resuspension of sediments (Jaramillo et al., 2009).

The turbid sediment plume exiting the Atchafalaya bay system is advected to the west along the Louisiana coast (Wells and Kemp, 1981) due to a sustained westerly low frequency circulation of Texas–Louisiana shelf during non-summer months (Cochrane and Kelly, 1986). This sediment plume is confined to water depths of less than 10 m in fair weather conditions (Kineke et al., 2006). During the passage of a cold front over the Atchafalaya Shelf, which occurs every 4–7 days in winter/spring seasons, the wind direction changes clock-wise from pre-frontal southeast direction to south, west, and eventually to north. Westerly winds disrupt the westward movement of the river plume and Ekman transport contributes to extending the sediment plume farther to the south. The pre-frontal water level set-up along the Atchafalaya Bay would also be released once the front passed through the region (Feng and Li, 2010). Northerly wind during the cold fronts results in a rapid offshore transport of sediment-laden river plume (Walker and Hammack, 2000) and the low salinity area can extend up to 50 km offshore (Allison et al., 2000).

Based on the data from a transect south of Marsh Island (see Fig. 1), Allison et al., (2000) reported that during early stages of a frontal passage, the SSC across the entire water column can exceed 1 g/l in water depths smaller than 5 m. After a few hours of wind speed weakening, accumulation of sediments close to the bed would form a fluid mud with concentration higher than 25 g/l. High concentrations of suspended sediments close to the bottom were also reported during the passages of winter storms, from a station along the seaward margin of the Atchafalaya subaqueous delta (approximately 60 km to the east of station TT2 in Fig. 1) and further westward of the delta front (approximately 20 km to the east of station TT1 in Fig. 1) by Jaramillo et al. (2009).

In this study, a transect across the Tiger and Trinity Shoal complex was identified based on the bathymetry and general orientation of the shoal complex. Three locations were selected for seasonal deployment of instrument tripods, which included acoustical and optical instruments for recording waves, sediment concentration, and current profiles. The stations were designated as TT1, TT2 and TT3 in Fig. 1. Inshore of station TT1, a permanent observation station, noted as CSI03 in Fig. 1, provided the

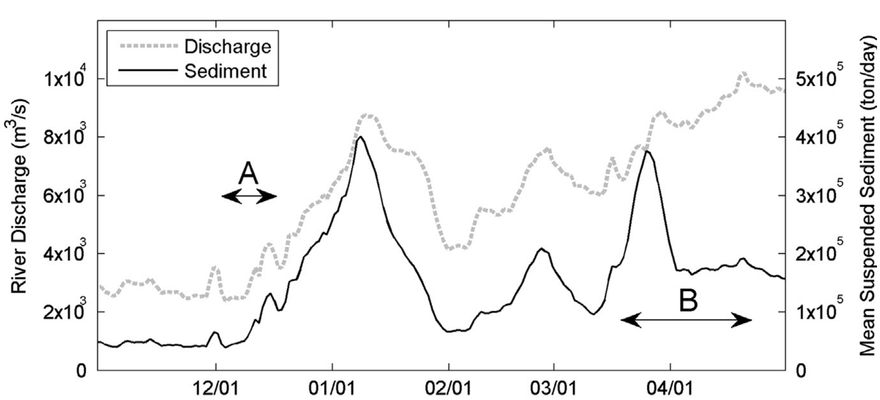

Fig. 2. Daily mean discharge of Atchafalaya River and its mean suspended sediment load, measured at Simmesport, LA (Data courtesy USGS). The time period of experiments A and B are shown by double arrows.