Continental Shelf Research 148 (2017) 37–43

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Characterisation of the suspended particulate matter in a stratified estuarine environment employing complementary techniques

Luis P. Thomas[a,*], Beatriz M. Marino[a], Ricardo N. Szupiany[b], Marcos N. Gallo[c]

[a] GFGA, Centro de Investigaciones en Física e Ingeniería del Centro de la Prov. Buenos Aires, CONICET-UNCPBA, Tandil, Argentina
[b] Facultad de Ingeniería y Ciencias Hídricas, Universidad Nacional del Litoral, Santa Fe, Argentina
[c] Lab. Dinâmica de Sedimentos Coesivos, Área Engenharia Costeira e Oceanográfica, Universidade Federal do Rio de Janeiro, Brazil

ARTICLE INFO

Keywords:
Suspended particle matter
Estuaries
Field studies
Two-ADCP method
LISST-25X
Flocs

ABSTRACT

The ability to predict the sediment and nutrient circulation within estuarine waters is of significant economic and ecological importance. In these complex systems, flocculation is a dynamically active process that is directly affected by the prevalent environmental conditions. Consequently, the floc properties continuously change, which greatly complicates the characterisation of the suspended particle matter (SPM). In the present study, three different techniques are combined in a stratified estuary under quiet weather conditions and with a low river discharge to search for a solution to this problem. The challenge is to obtain the concentration, size and flux of suspended elements through selected cross-sections using the method based on the simultaneous backscatter records of 1200 and 600 kHz ADCPs, isokinetic sampling data and LISST-25X measurements. The two-ADCP method is highly effective for determining the SPM size distributions in a non-intrusive way. The isokinetic sampling and the LISST-25X diffractometer offer point measurements at specific depths, which are especially useful for calibrating the ADCP backscatter intensity as a function of the SPM concentration and size, and providing complementary information on the sites where acoustic records are not available. Limitations and potentials of the techniques applied are discussed.

1. Introduction

Estuarine systems are complex environments that show seasonal and spatial variations in water temperature and salinity, as well as in concentrations and sizes of suspended particulate matter (SPM). In brackish waters, suspended particles rarely exist in their primary state; instead, they are typically found as aggregated and heterogeneous assemblages of mineral and organic material. The texture, size and density of the particles are largely controlled by flocculation, which acts as one of the principal factors determining the transport and deposition of suspended matter in estuaries (Chen et al., 2005). Therefore, the flocculation mechanisms control the fate of SPM and of all contaminants associated with the particulate phase, including bacteria, viruses and chemical and metallic contaminants (Verney et al., 2009). The high spatial and temporal variability of suspended sediment and its associated components, in conjunction with the typically low flow velocities, generate different engineering and environmental challenges in these particular systems. Consequently, since measurements of SPM concentration and size are needed to study the distribution patterns and the associated deposition-erosion processes, interest has increased in the characterisation and quantification of the estuarine transport of SPM. The main challenge is to select, a priori, the appropriate method before determining the suspended matter characteristics.

Common measurement techniques include gravimetric analysis, the use of optical instruments (Downing, 2006) and acoustic sensing (Thorne and Hanes, 2002), or a combination thereof. The gravimetric technique involves the direct measurement of the particle concentration; however, all sampling procedures are usually time-consuming, expensive and intrusive, have limited spatial and temporal resolution and require considerable training and practice. Of greater concern in estuaries, the handling and analysis of samples may alter the flocs. Therefore, the characterisation of SPM that is prone to form flocs essentially requires in situ measurements, so methodologies based on samplings and laboratory analysis (such as those usual in fluvial environments) are not appropriate. In the last decades, indirect sampling methods have been developed to provide size and concentration of the SPM. These methods are based on turbidity (bulk optics), acoustic backscatter principles, laser diffraction, pressure differences, and digital imaging and holography (Gray and Gartner, 2009; Anderson et al., 2010; Gray and Landers, 2013; Talapatra et al., 2013; Agrawal and

* Corresponding author.
E-mail addresses: lthomas@exa.unicen.edu.ar (L.P. Thomas), bmarino@exa.unicen.edu.ar (B.M. Marino), rszupian@fich1.unl.edu.ar (R.N. Szupiany), marcosgallo@oceanica.ufrj.br (M.N. Gallo).

http://dx.doi.org/10.1016/j.csr.2017.08.024
Received 2 November 2016; Received in revised form 24 August 2017; Accepted 28 August 2017
Available online 22 September 2017

Hanes, 2015).

Acoustic Doppler current profilers (ADCPs) are increasingly being used to provide water velocity distribution (Szupiany et al., 2012) and bathymetry (Duncker et al., 2015), but they are also appreciated as tools for the indirect determination of the distribution of the SPM concentration using the strength of the backscattered acoustic signal (Deines, 1999; Moore et al., 2013; Latosinski et al., 2014; Venditti et al., 2016, among others). The usefulness of this application arises from its practicality for acquiring high spatial-temporal resolution information in a non-intrusive, continuous and simultaneous manner through the whole water column. This method typically relies on taking a large number of water samples and building an empirical relationship between the mass concentration of SPM and the acoustic backscatter intensity, and it entails different assumptions regarding sediment heterogeneity in the ensonified volume (e.g., particle-size distribution and spatial concentration gradient) (Guerrero et al., 2016). However, this approach provides little or no information about the degree of sediment flocculation (MacDonald et al., 2013; Vincent and MacDonald, 2015). Another disadvantage is that the intensity of the backscatter signal depends on the characteristics of the instrument and the suspended elements (e.g. concentration, size and type of particles; content of organic matter; dissolved solids) present in the water column (Guerrero et al., 2011). This condition is a problem in estuarine systems where flocculation processes are intense and control the SPM dynamics (e.g. size and density spectra), as these are key information for the inversion of the backscatter signal and the ultimate SPM concentration calculation.

The most advanced multi-frequency technique incorporates the effect of grain size on the scattering process and provides both the concentration distribution of the suspended elements and the grain size profiles. This acoustic method has been successfully employed in regions predominantly composed of non-cohesive sandy and fine-grained sediments (Guerrero and Lamberti, 2011; Guerrero et al., 2013, 2016). However, if the process of flocculation occurs, interpretation of the acoustic observations remains uncertain.

Field-deployable laser-diffraction instruments have been used in several investigations in marine and estuarine waters (e.g. Fugate and Friederichs, 2002; Chang et al., 2006; Curran et al., 2007), and have provided direct high temporal resolution measurements of suspended sediment volume concentration and particle-size in fluvial environments (e.g. Williams et al., 2007; Guo and He, 2011; Czuba et al., 2014; Haun et al., 2015). The instruments available for field particle measurements include the laser in-situ scattering and transmissometry (LISST) sensor series (Sequoia Scientific Inc.). These devices require only a simple specific calibration; however, only point measurements are possible and these are time consuming when an anchored vessel is used.

The present study aims to assess the results obtained using three methods in terms of the characterisation (i.e. size, concentration and net flow) of SPM in a challenging stratified estuary where flocculation processes occur. Comparison of the performance of the two-ADCP method, the LISST-25X measurements and the physical sampling analysis provides the limitations and potentials of the techniques employed. The method based on the simultaneous backscatter records of 1200 and 600 kHz ADCPs employed by Guerrero et al. (2013) in rivers, where the sediment mainly consists of sand, was used here to determine the size of flocs in brackish and salt water. To our knowledge, the findings verify this technique as a novel and promising one. It can be implemented by using the provided relationships between the strength of the backscattered acoustic signal of each ADCP and the SPM size obtained using a LISST-25X diffractometer or sampling the water column in selected locations of an estuary.

2. Measuring instruments and methods

Measurements were performed in the Quequén Grande river estuary (QGRE), located in southeastern Buenos Aires province in Argentina. The QGRE is a microtidal coastal plain primary system between 150 and 200 m wide. The mean river discharges range from 6 to 10 m^3/s, with occasional maxima of about 170 m^3/s, while the tide has a mean amplitude of 1.03 m, with a maximum of 1.85 m during the spring tides. The minor falls located at 13.7 km from the mouth mark the head of the estuary. The saline wedge intrudes about 10 km from the sea. The Quequén Harbour is located in the last 2 km of the estuary and its 12–14 m depth is maintained by regular dredging. Further upstream, the thalweg is 3–4 m deep, with an irregular topography exhibiting small canals, 5–7 m deep. Consequently, an artificial abrupt depth step that separates the estuary into two parts is created. Typically, the river discharge slightly mixed with salt water crosses the harbour zone in a 1–3 m surface layer with a halocline below with salinities reaching over 30 practical salinity units (PSU), being homogeneous down to the bottom. Two jetties prevent the entry of sand from the sea, except during severe storms. Granulometric analysis indicated that nearly 50% of the bottom sediments have a diameter between 30 µm and 300 µm, also with a most probable size in the range of 90–100 µm, and a significant silt content with a maximum in the range of 10–15 µm (Pereyra et al., 2014).

Data for analysis were obtained in two surveys conducted between 19 and 21 November 2013, during complete tidal cycles close to spring-tide, and on 28 March 2015. Three measurement stations were set at 1.3 (S1), 1.9 (S2) and 9.8 km (S3) from the estuary mouth, with the local depth at each location being 12.0, 4.5 and 5.0 m, respectively. A *SonTek CastAway* conductivity, temperature and depth (CTD) instrument was employed to obtain salinity profiles at all the stations with uncertainty of 0.1 PSU. The prevailing quiet meteorological conditions in the days prior to the surveys meant that the estuarine system was stratified and under analogous hydrodynamic conditions (see details in Table 1) when the field studies took place. On both occasions, the local meteorological records confirmed that the measurements were conducted in seasons of scarce rains and low river flow (Thomas and Marino, 2016), and the wind did not significantly affect the estuarine flows.

2.1. Physical isokinetic sampling

The SPM mass concentration, M, was determined in the first survey by collecting 0.5 l water samples using a P-61 isokinetic sampler in all measurement stations at depths of about 1.1, 1.5, 2.5, 3.0, 5.5 and 7.0 m. The samples were preserved in a 4% aqueous solution of formalin for future laboratory analysis, and left at rest for at least seven days. For each sample, the value of total dissolved solids (TDS) was determined by drying the supernatant by evaporation in a water bath at 105 °C, and by weighing the solids. Meanwhile, the settled solid matter was filtered, dried at 105 °C and weighed to obtain an estimate of total solids (TS). Total suspended solid (TSS) was determined by subtracting TDS from TS. Then, M was obtained by dividing TSS by the total volume of the sample. The Standard Methods 2540 criteria (SMWW, 1998) were followed.

Table 1
Hydrodynamic conditions in the Quequén Grande river estuary during the measurement days.

		2013 19–21 Nov	2015 28 March
Mean River flow		7.0–7.5 m^3/s	5.0–5.5 m^3/s
Tidal level variation		1.7 m	1.2 m
Number of days since last rain		5	11
Flood-Tide:	Mean maximum flow	90 m^3/s	80 m^3/s
	Mean maximum speed	0.5 m/s	0.4 m/s
Ebb-tide:	Mean maximum flow	100 m^3/s	90 m^3/s
	Mean maximum speed	0.6 m/s	0.5 m/s