INCHOE2014 (Proceedings)	5-7 Feb. 2014	Goa, India	163-166

Acoustic estimation of suspended sediment concentration from turbidity in the nearshore areas off Visakhapatnam

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INCHOE
2014 CSIR-NIO, Goa

ABSTRACT

Patnaik, KVKRK., Suresh, RRV., 2014. Acoustic estimation of suspended sediment concentration from turbidity in the nearshore areas off Visakhapatnam, Proceedings of the Fifth Indian National Conference on Harbour and Ocean Engineering (INCHOE2014), 5-7 Feb. 2014, CSIR-NIO, Goa, India.

Accurate estimation and monitoring of suspended sediment concentration in the nearshore areas is a challenging task involved in the maintenance of draft of navigational channels, ports and harbors. In the nearshore environment Suspended Sediment Concentration varies significantly both in time and space in response to various forcing mechanisms. Though estimation of this through Acoustic remote sensing is a surrogate method, it is proved to be a best method. The present study is based on the simultaneous data obtained from 600 Khz workhorse ADCP, Turbidity sensor and LISST portable. ADCP was side mounted to BTV Sagar Manjusha at a depth region of 20m and programmed to record the data for every one minute for the period of 3 days to cover six tidal cycles. These data are used to develop a location specific version of the sonar equation which converts the ADCP echo intensity to turbidity (NTU). This equation was obtained by relating echo intensity and turbidity. It is also found that the particle size in the study area ranging from 50 – 400 µm. It is also found that the estimated turbidity is in good agreement with the measured turbidity values.

ADDITIONAL INDEX WORDS: *suspended sediment concentration, ADCP, echo intensity, Turbidity.*

INTRODUCTION

One of the major problems encountered by the shore line harbours along east coast of India is siltation. For effective monitoring of the port approach channel and harbour basin, the rates of siltation should be known. Suspended sediment concentration is one of the controlling factors of the siltation. Hence the concentration of suspended sediments in nearshore waters has become an important parameter in the routine maintenance of the channels. The measurement of suspended sediment concentration (SSC) has always been a difficult task, particularly when high spatial and temporal resolution is required. Conventional techniques such as gravimetric method from collected water samples and optical backscatter (OBS) devices provide measurements at single point (Hanes and Huntley, 1986). An array of these equipments to be employed when vertical profiles and horizontal transects are required. The main limitation of these equipments is intrusive and single point observation. Acoustic Doppler Current Profiler (ADCP) is capable of yielding SSC estimates over the depth range ensonified at a high temporal and spatial resolution. They are non-intrusive, as the sediment suspension is being monitored at distance. The disadvantage of the acoustic approach is the dependence on sediment properties. For every bin the ADCP records the echo intensity as the acoustic energy (in dB) returned from scattering particles. This intensity is an surrogate indicator of suspended sediment concentration (Dinehart and Burau, 2005; Gartner, 2004; Kostaschuk et al., 2005; Reichel and Nachtnebel, 1994), although it depends on the physical properties of the water and the instrument, as well as of the suspended particles. Consequently, calibration methods for converting backscatter intensity into suspended sediment concentration (SSC) require extensive sediment sampling operations (Rotaru et al., 2006).

The acoustic backscatter devices offers the potential of using a single instrument to non-intrusively measure SSC profiles with a high degree of temporal (~0.1s) and spatial (~1cm) resolution. Realization of this potential, coupled with similar resolution for the velocity field, will add greatly to our understanding of many of the sediment transport processes. The acoustic estimation of SSC has been successfully implemented and reported by several authors (Hanes et al., 1988; Libicki et al., 1989; Vincent and Green, 1990; Young et al., 1982).

DATA AND METHODS

The widely used acoustic equipment to measure ocean currents is Acoustic Doppler Current Profiler (ADCP). The same was used to measure acoustic backscatter intensity to estimate SSC along with currents. A clear understanding of suspended sediment flux can be drawn by analyzing SSC and currents together. A 600 Khz ADCP (RD Instruments) is installed as down looking side mount to the hull of the BTV Sagar Manjusha. Observations are made at a depth of 20 m north side of Visakhapatnam port at 17^{O}42’7.59’’N and 83^{O}21’7.56’E during 5-8 August, 2013. Visakhapatnam is the hub of various industrial establishments along with two deepest ports and Eastern Naval Command considered being an ideal place to conduct the experiment. Figure 1 shows the location of time series observation. The manmade structures largely influence the natural pattern of nearshore processes in this area.

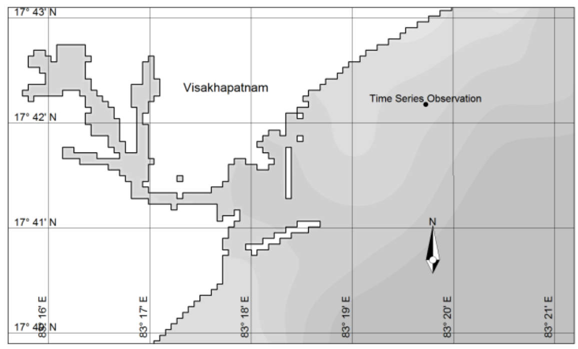

Figure 1. Study area and location of time series observation

The general trend of near shore sediment off Visakhapatnam is towards northeast during March to October and southwest during November to February monsoon (Chandramohan et al., 1988). Many studies revealed that it is undergoing severe erosion on the north side of the Visakhapatnam port due to net north ward transport of sediments(Prasad et al., 2009; Pravin et al., 2013). The present study is an attempt to continuously monitor the sediment flux my means of acoustic technique. The data is recorded for a period of one tidal cycle (12 hrs) along with optical backscattering sensor (OBS) installed-CTD castings at various depths for turbidity measurements. The ADCP acoustic backscatter is converted to SSC using turbidity and particle size data. All instruments have been configured to measure at a corresponding time. Water samples are taken for calibration purposes using auto fire carousel. In situ water samples are analyzed for SSC and grain-size distribution using portable LISST instrument.

Water samples are collected at various depths to analyze the particle size distribution and other statistics of suspended solids. The vertical profiles of turbidity are also measured using OBS.

RESULTS

As mentioned in the introduction part, both optical and acoustical instruments have their benefits and limitations. OBS sensors are proven to be successful in the estimation of suspended sediment concentrations. Because of the restricted resolution of optical SSC measurements, a combination of optical and acoustic backscattering is chosen to measure SSC. One of the limitations of ADCP is the dependence of acoustic backscatter on sediment properties. In particular, irregularities in grain-size distribution restrict the accuracy of acoustic SSC measurements. In order to overcome this problem, grain-size distribution is taken into account by iterative calculation of the sound attenuation and SSC. During the analysis, data obtained from water samples (SSC and grain-size distribution) are used to validate the real time calibration and for validation of the results.

The magnitude of currents observed during the study period ranged from 0 – 0.45 m/s. Strong currents are observed below 6 m depth (Figure 2). Along with default current values obtained from ADCP, the returned echo (in terms of counts) is also analyzed. The returned echo carries the information about the suspended scatters in the water. This data can be utilized to obtain an empirical relation between acoustic echo and turbidity measured from optical backscatter sensor (OBS).

Figure 3 show the relation between Turbidity and acoustic echo. Even though the number of data sets are limited, the empirical relation obtained is showing statistically significance (r=0.73).

$$\text{Turbidity} = 1.6497 * e^{-0.008 * \text{echo intensity}} \qquad \text{- - - - (1)}$$

An inverse exponential relation observed among Turbidity and echo (Eqn. 1). Using this equation the echo intensity measured at different depths bins is converted into Turbidity. Figure 4 shows the comparison of measured and predicted SSC profiles. The estimated turbidity shows low values in the upper layers and high values in the bottom layers. High turbid waters (> 0.2 NTU) are observed below 10 m depth. In order to understand the influence of dissolved material which cannot be detected by acoustic signal, the collected water samples are analyzed for scatters volume concentration and particle size distribution using laser diffraction technique. The concentration of scatters is low (51.2 ml/L) in the upper layers and high (64.5 ml/L) in near bottom layers (Table 1).

Due to inadequate amount of in-situ water sample data, it is difficult to obtain a statistically significant relation between scatters concentration and echo intensity data. The size of the scatters is comparatively high in upper layers of the water. From the estimated turbidity and particle size analysis it is understand that the waters comparatively clear in the upper layers, where as more turbid in the near bottom layers. The time series variation of turbidity is obtained by applying equation 1 to all acoustic echo profiles (Figure 5). The upper 8 m layer showing significant variation with time. During transition from low tide to high tide the surface concentrations are high compared to the rest of the study period. However, the observations to be made for few more days to investigate the possible reasons.

Table 1: *Particle size analysis for collected water samples*

Depth (m)	Total Conc. (ml/L)	Mean Size (µm)	Transmission (%)
1	51.2	283.21	98.2
5	52.58	278.92	98.1
10	52.34	282.4	98.2
15	64.53	236.82	97.7

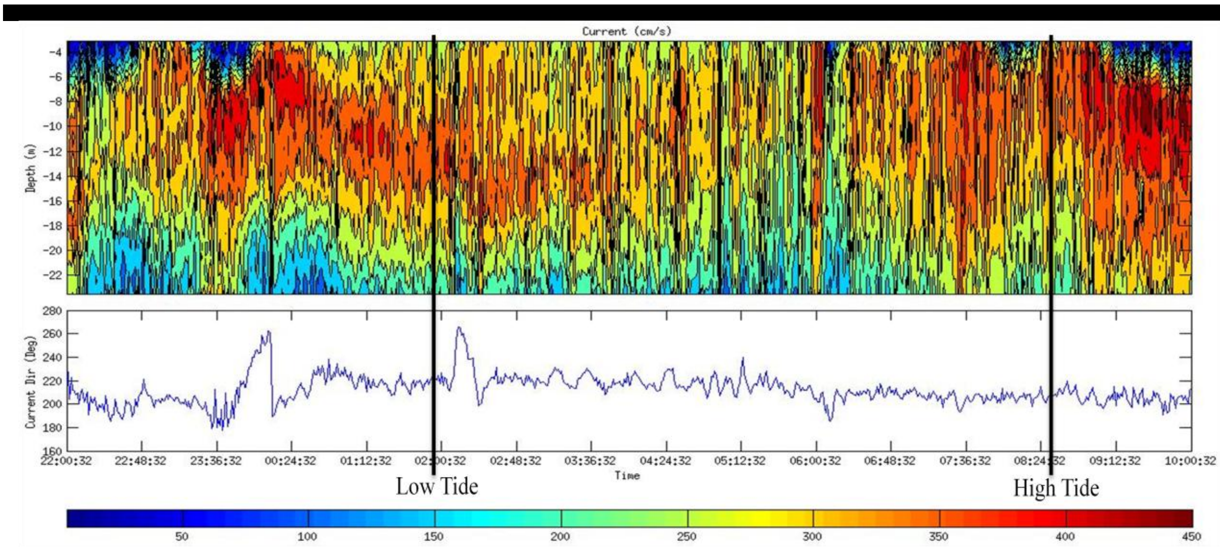

Figure 2. Time series variation of current along vertical column

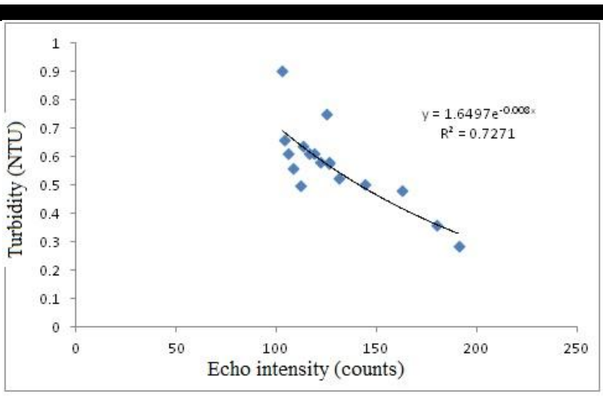

Figure 3. Relation between Echo intensity and Turbidity

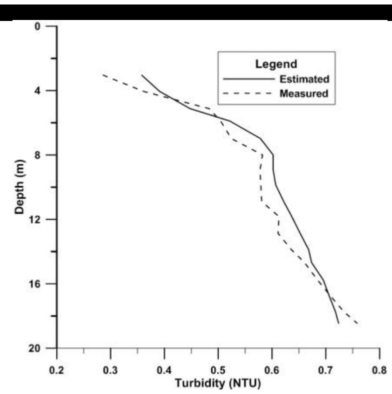

Figure 4. Vertical profiles of measured and estimated turbidity

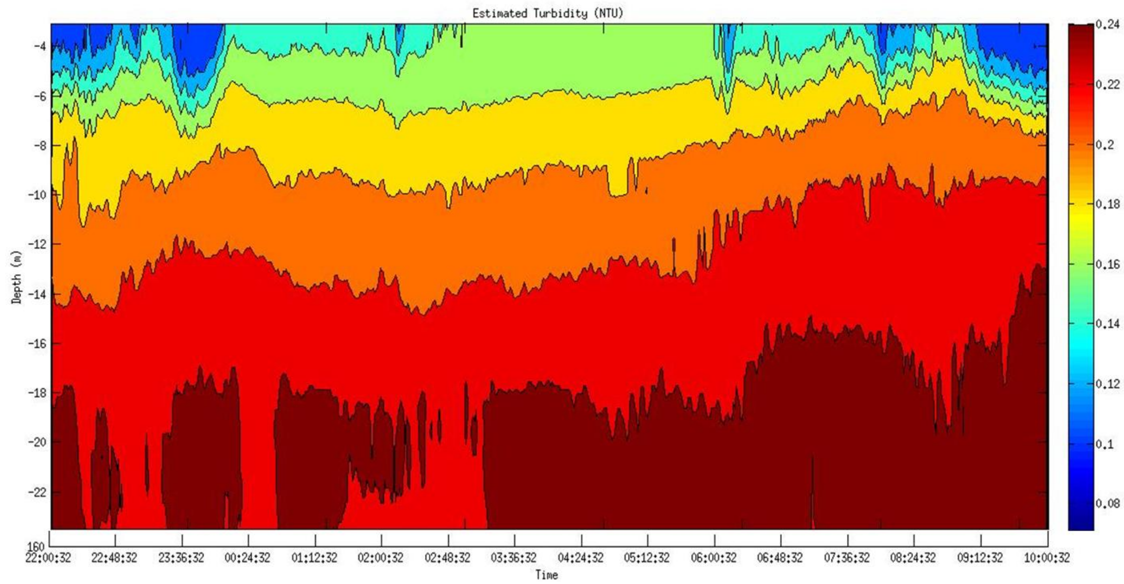

Figure 5. Estimated turbidity from the measured acoustic echo values.

CONCLUSIONS

Estimation of suspended sediment concentration is possible through surrogate method by means of ADCP and OBS measurements. The dependence of acoustic backscatter on grain-size distribution is taken into account by iterative calculation of the attenuation of the backscatter and SSC. Turbidity in terms of echo intensity has been estimated for the Visakhapatnam coastal waters. This study proved that the ADCP has the ability to measure suspended sediment concentrations. The validation with in situ SSC data from water samples are in good agreement with the SSC estimated from ADCP echo intensity data. The estimated turbidity shows low values in the upper layers and high values in the bottom layers. High turbid waters (> 0.2 NTU) are observed below 10 m depth. Estimated turbidity is found good agreement with the measured turbidity.

Estimation of suspended sediment concentrations in the nearshore areas on a continuous basis is essential for the maintenance of navigational channels of ports and harbors. The procedure followed here is location specific and may be applicable to other nearshore regions if we know the sediment properties. Continuous monitoring of suspended sediment concentration is possible by installing a Horizontal ADCP at the entrance of a harbor. The data obtained from this kind of estimation can be input to the operational oceanography model to get a complete picture on environmental parameters of any port or harbor.

ACKNOWLEDGEMENTS

This work has been carried out under the Ministry of Shipping sponsored study project at the IMU Oceanographic Survey laboratory (IOSL) under the School of Maritime Design and Research (SMDR), Indian Maritime University, Visakhapatnam campus.

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