Evaluation of ADCP backscatter computation for quantifying suspended sediment concentration

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Abstract. Suspended sediment concentration (SSC) is important to measure for knowing photosynthesis activity and as indicator of marine pollution [1]. Until now, measurement methods to study about SSC were used conventional and optical techniques. These methods had a limitation in providing temporal data of SSC. Acoustic Doppler Current Profilers (ADCP) originally designed for measuring ocean current and its velocity profiles. In fact, ADCP is not only limited to measure the ocean current velocity and direction, but include measuring acoustic backscattering intensity which is related to the concentration of suspended sediment. Based on sonar equations, we computed and analysed the relationship between the backscattering intensity and suspended sediment concentration. In study area of Jakarta Bay, the highest SSC was 70 mgL⁻¹ and the lowest SSC was 30 mgL⁻¹. Compared to the traditional method, ADCP method has many advantages in providing spatial and temporal data.

1. Introduction
Suspended sediment concentration (SSC) is essential to measure for knowing photosynthesis activity by limiting light transmission and as indicator of marine pollution [1]. Until now, measurement methods to study about SSC were used conventional and optical techniques [2]. These methods had a limitation in providing temporal data of SSC. In other way, measurement of suspended sediment concentration (SSC) using acoustic backscatter in water column had been developed for several years [3][4]. Therefore, it is important to measure suspended sediment concentration (SSC) accurately. Acoustic waves propagating through a water column, hit the sediment and will scatter as a function of sediment and acoustic instrument properties. Originally, Acoustic Doppler Current Profilers (ADCP) was designed for measuring velocity profiles, but now used for estimating suspended sediment concentration [5][6]. However, the previous work had focused on high SSC measurement in coastal area [7]. Besides, methodology for estimating SSC from ADCP were not developed well because some difficulties based on complicated interactions between acoustic waves parameters and suspended particle properties. In this study, we examine the inversion of ADCP backscatter for quantifying SSC to establish this method.
2. Methods

2.1. Data acquisition
This research was conducted on July 20th-23rd, 2019 at Jakarta Bay (Fig. 1). We used Acoustic Doppler Current Profiler (ADCP) with operating frequency of 400 kHz for measuring acoustic backscatter intensity. Other equipment used were Conductivity, Temperature, and Depth (CTD), van Dorn bottle water sample, and sediment sampling tool. The water sample for measuring SSC direct obtained using American Public Health Association (APHA) method.

\[ EL = SL - 2TL + TS \]  

(1)

Where \( EL \) is echo level, \( SL \) is source level, \( TL \) is transmission loss, and \( TS \) is target strength.

Propagation of sound wave in seawater is affected by geometrical spreading and backscattering and can be calculated by

\[ TL = 20 \log_{10} R + 2 \alpha R \]  

(2)

Where \( R \) is range to the ensonified volume (slant range) in meter defined as

\[ R = r + \frac{D}{4} \]  

(3)

Where \( r \) is the slant distance from the transducer face to the center of the bin, and \( D \) is the bin size, \( \alpha \) is absorption coefficient (dB/m). The attenuation effects both of sea water and of particles in suspension through the water column [8][9].
\[ \alpha = 0.106 \frac{f_1 f_2^2}{f_1^2 + f_2^2} e^{(pH-8)/0.56} + 0.52 \left( 1 + \frac{T}{45} \right) \left( \frac{S}{35} \right)^{f_1 f_2^2 / f_2^2 + f_2} e^{-D/6} + 0.00049 f^2 e^{-T/27 + D/17} \]  

(4)

\[ f_1 = 0.78 \sqrt{\frac{S}{35}} e^{T/26} \quad \text{for Boric acid} (f_1) \]  

(5)

\[ f_2 = 42 e^{T/17} \quad \text{for Magnesium sulphate} (f_2) \]  

(6)

\( f \) is operating frequency of ADCP, \( T \) is average temperature \(^\circ\)C, \( D \) is water depth (m), \( pH \) is average \( pH \), \( S \) is average salinity (psu). \( Kc \) is the scale factor used to convert counts to dB. \( RL \) is reverberation level. \( RB \) which is the echo level measured at the transducer plus two-way transmission losses [7].

\[ K_c = \frac{127.3}{T + 273} \]  

(7)

The reverberation level can be calculated as

\[ RL = SL - 2TL + TS \]  

(8)

\( TS \) is Target Strength of suspended sediment and as a function of particle shape, size, and acoustic frequency of ADCP.

2.3. Data analysis

Analysis of ADCP for SSC measurement required information of calibration from direct measurement of SSC. For this purpose, water sampler was collected from 2 meter below the sea surface until 30 meter using van Dorn bottle. The amount of 300 ml water (C) was filtered, dried for 1 hour and weighed (B). The residue of water dried again and weighed (A). Using standard of APHA, direct measurement of SSC (mg/L) was calculated by

\[ SSC_{direct} = 10 \left( \frac{A-B}{C} \right) \times 1000 \]  

(9)

In acoustic techniques, the relative backscatter of sediment calculated by

\[ RB = RL + 2TL \]  

(10)

Finally, the sonar equation for measuring SSC defined by

\[ SSC = 10^{(A + B \cdot RB)} \]  

(11)

Where A is intercept and B is slope.

3. Results and discussion

The effects of attenuation by seawater and absorption by suspended sediment particles in the water column was measured based on transmission loss parameter (2TL) in Eq. 2. Scattering and absorption of the suspended sediment caused sound attenuation [5][6]. Using their formula, we found that the attenuation coefficient was 0.20 dB/m. Echo intensity measured by ADCP in counts format can be converted into dB value using 1 count equal to 0.43 dB.

Computation of volume backscattering strength (SV) and echo amplitude (E) values was conducted to check SSC value (Fig. 2). It was found the increasing of SV followed by echo intensity (E). The relation of Suspended sediment concentration (SSC) using ADCP and direct sampling was shown in Fig.3. This figure showed a linear relation between SSC from direct sampling and obtained from ADCP, with determination coefficient was 0.91, A and B values were 0.9661 and 0.0381, respectively.
The empirical model of SSC found $10 \log_{10} (\text{SSC}) = 0.0399 \text{EI (dB)} - 15.231$ (Fig. 4). Vertical profile of SSC from ADCP and water sampling was shown in Fig. 5. In this figure, the SSC distribution using ADCP and direct sampling quit similar particularly in 2.5 m until 8.0 m. This model (Eq. 12) was used to measure the SSC in other location in survey area using this equations (Fig. 6). From our result, we confirm that sensor of ADCP can measure the SSC in the Rayleigh region. This results was agreed with previous researcher [8, 9]. They found optical sensor was more sensitive for small size particles.

By adopting this model with oceanographic parameters of $T=27.3$ °C, $S=33.4$ psu, $\text{pH}=7.8$, we found the SSC in the study area was ranged from 30 to 70 mg/l and distributed from surface to the seafloor (Fig. 6).
Figure 4. Empirical model of SSC and echo intensity (EI).

Figure 5. Vertical profile of SSC from ADCP (○) and direct sampling (*).

Figure 6. Spatial and temporal distribution of SSC (mg/l).
4. Conclusion
The Suspended Sediment Concentration has been successfully predicted using Acoustic Doppler Current Profiler. The Acoustic Backscattering Intensity with Simple Sonar Equation can be applied to estimate the concentration of suspended material in the water column.

The result of ADCP method and direct sampling method was examined with a high determination coefficient of 0.91. Besides, the advantage application of ADCP can provide SSC information spatially and temporally.

5. References
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