Modification of Attenuation Rate in Range Normalization of Echo Levels for Obtaining Frequency-Dependent Intensity Data from 0.6 MHz and 1.0 MHz Devices

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Abstract. This investigation aims to propose an attenuation rate for range normalization of echo amplitudes recorded by an acoustic backscattering instrument working at a frequency of 1.0 MHz. The intention of the use of such an attenuation rate is to obtain equal echo levels when using a device from the same family of products with a different working frequency, *i.e.* a 0.6 MHz instrument, at an identical site. This work is based on a field experiment with a 1.0 MHz Acoustic Wave and Current (AWAC) profiler and a 0.6 MHz Aquadopp profiler. Both profilers were deployed upward, side-by-side in the Semak Daun reef lagoon, Seribu Islands, Java Sea, Indonesia. It was found that the proposed attenuation rate for the 1.0 MHz instrument was one-order magnitude higher with respect to the one used for the 0.6 MHz instrument, and logarithmically depth dependent. The proposed attenuation rate for the 1.0 MHz AWAC is $-7.925\log(R) + 8.551$, with R is the slant range from the transducers to the measured layer. Accordingly, the overall agreement between the 1.0 MHz AWAC echo amplitude and the one recorded by the 0.6 MHz Aquadopp was improved by 18dB, which is quite significant considering that the average echo amplitude discrepancy recorded by each transducer was 2.4dB.

1   Introduction

The signal amplitude from acoustic backscattering instruments can be used to measure the quantity of sediment suspended in the water column [1-3]. This applies to Doppler-type hydro-acoustic current or equivalent profilers. In addition to providing three-dimensional current vectors in multiple layers across the water column, such devices also record the intensity of backscattered acoustic signals [4,5]. Recently, successful application of such a technique has been reported in [6-9]. Prior to the use of the intensity of backscattered acoustic signals for absolute measurement of suspended sediment concentration, calibration must be performed using field samples [10,11]. This is due to the dependency of the relative measure of the sediment quantity given by the

acoustic intensity on the device used and properties of the sediment in suspension. Recent field applications of acoustic measurement of suspended sediment have suggested that field calibration is site-specific and frequency-dependent [12,13]. Furthermore, devices from the same product family using different frequencies do not necessarily give similar echo amplitudes in an identical environment. Apparently, as shown in [14], records of echo amplitude in spatial and temporal series are useful in providing insight into the periodic occurrence of diurnal signals. Hence, improvement of the performance in the relative detection of suspended sediment concentrations from the intensity of acoustic backscatter data is necessary. The objective of this study is to propose an improved term for the normalization of acoustic signal amplitudes. The attenuation rate of SONAR propagation will be adjusted to make it dependent on the devices' working frequency. This adjustment is meant to equalize the reading of the intensity of the backscattered acoustic signals obtained from devices with unequal working frequencies. This will optimize efforts in the broader application of coastal and offshore survey work, particularly for suspended sediment and sediment transport monitoring, since field deployment no longer necessitates the use of devices with equal frequencies. The work presented in this paper is based on a field experiment using Nortek A/S devices from the same family of products.

2   Material and Method

2.1   Acoustic Detection of Water Column Turbidity

The so-called random phase scattering model assumes direct proportionality between the returning acoustic signal and the volume of backscattering strength [1,2]. Since the volume of backscattering strength in the water column is due to the presence of sediment in suspension, empirical calibration for quantification of the suspended sediment concentration on the basis of the intensity of acoustic backscatter can be done as follows [8,11]:

$$EL \propto 10\log_{10}(c) \tag{1}$$

where EL = echo level or intensity of acoustic backscatter (dB) and c = concentration of sediment in suspension (in kg/m^3). In order to estimate the absolute quantity of the sediment suspended in the water column, the recorded intensity of the acoustic backscatter (i.e. EL) must undergo scaling, normalization and calibration against field samples. The scaling converts the recorded intensity of the acoustic backscatter from internal units of count to decibels (dB). The normalization makes the recorded values independent from the range and size of sediment particles and instruments used. Calibration is intended to estimate the backscattering strength (BS) that is assumed to be due

to the presence of sediment in suspension. The underlying empirical SONAR equation reads as [15]:

$$EL = SL - 2TL + BS \tag{2}$$

where $EL = KA$ with K = scaling factor and A = recorded signal amplitude in count units, SL = source level or transmitted intensity of acoustic pulse, TL = transmission loss due to (i) geometrical spreading $20\log(R)$, (ii) attenuation of SONAR propagation due to medium αR, and (iii) attenuation due to sediment particles $20R\int \alpha_P dr$, R = slant range or oblique distance from transducer to measured layer, α = attenuation due to medium, and α_P = attenuation due to sediment particles. Figure 1 illustrates the terms used in Eq. (2), φ is the angle between vertical and transducer axis. R must be calculated from the vertical distance (D) between the measured layer and the face of the transducer (see Figure 1).
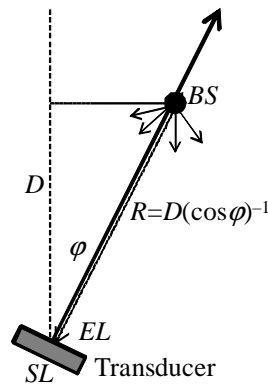

Figure 1 Schematic illustration of SONAR propagation.

For devices from the Nortek A/S product family as used here, the suggested K is 0.43 [5]. In low-concentration environments, attenuation due to sediment particles can be neglected and with the use of similar devices at an identical site, the proportionality between echo level and backscattering strength is scaled by the attenuation rate due to medium (α).

2.2   Field Experiment and Data Analysis

Two Nortek A/S products were simultaneously deployed: a 1.0 MHz Acoustic Wave And Current (AWAC) profiler (S/N WPR 0677), and a 0.6 MHz Aquadopp profiler (S/N AQD 5775), looking upward from the seabed, at a depth of roughly 11.5 meters. The devices were separately fixed in their mounting frames (Figure 2) and weighted during deployment. The lowering of the devices to the seabed was done manually with the help of scuba divers. Prior

to this, the points of deployment were marked by moored floating buoys at an approximate distance of 11 m (Figure 3). The site of the experiment was located in a lagoon of the Semak Daun reef platform of Seribu Islands off Jakarta Bay, Southwest Java Sea, Indonesia. The deployment lasted for approximately 40 hours, starting on the 15th of April, 2011 at 16:15 and ending on the 17th of April, 2011 at 08:30. The recording was set at a 15-minute interval with an average interval per data acquisition of 60 seconds. Throughout the deployment, as many as 162 time series data sets were collected from each device, at each vertical layer (out of eight effective layers).

(a) 1.0 MHz AWAC   (b) 0.6 MHz Aquadopp
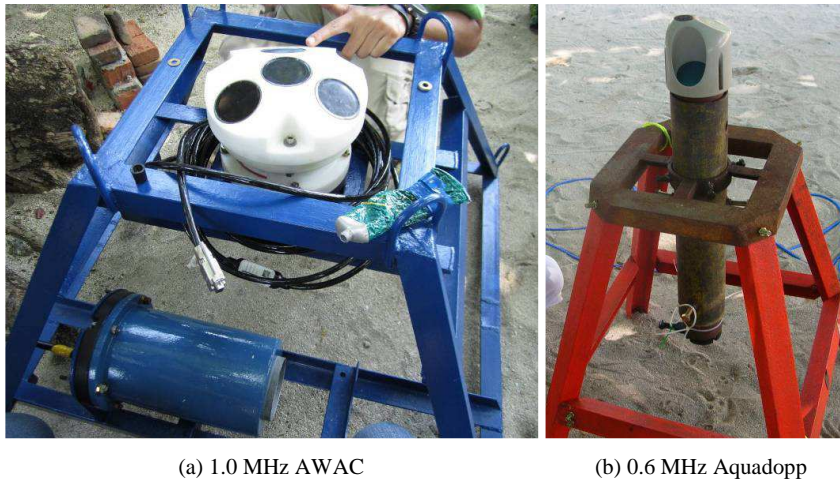
Figure 2   Doppler-type acoustic current profilers (Photo: Miga M. Julian).

Figure 3   Marker buoys indicating seabed mounted devices at the deployment site (Photo: Miga M. Julian).

The analysis of the data involved quality control of measured parameters and characterization of the recorded intensity of the acoustic backscatter. Further to this, determination of the rate of attenuation for the 1.0 MHz AWAC was done by assuming a fixed rate of attenuation for the 0.6 MHz instrument ($\alpha_{0.6}$). For this particular purpose a value documented in [5] was used, *i.e.* $\alpha_{0.6} = 0.15$dB/m. For the initial approach, a suggested value was also used for the 1.0 MHz instrument, *i.e.* $\alpha_{1.0}{}^* = 0.4$dB/m. The corresponding results were evaluated according to the absolute discrepancy (*e*) between the echo levels recorded by the 1.0 MHz device and the 0.6 MHz device:

$$e(t,z) = |\, EL_{1.0}(t,z) - EL_{0.6}(t,z)\,| \tag{3}$$

where $EL_{0.6} = KA_{0.6} + 40\log(R) + 2\alpha_{0.6}R$ and $EL_{1.0} = KA_{1.0} + 40\log(R) + 2k\alpha_{1.0}{}^*R$, with t = time, z = depth or height of measured layer and k = modification factor, which was determined empirically here. This procedure was applied to each of the measuring layers.
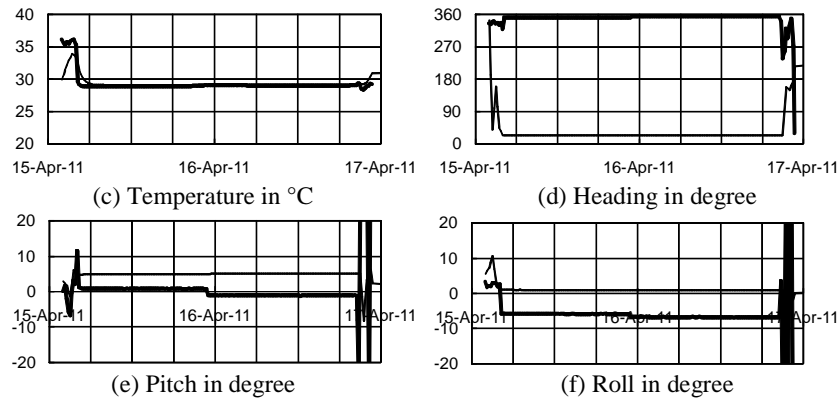
3   Result and Discussion

3.1   Field Records and Data Pre-Processing

Figure 4 shows the log of sound speed, water level, temperature, heading, pitch and roll of each device. Sudden changes in values at the very beginning and end of the time series plots in Figure 4 indicate deployment and recovery. This indicates that both devices were aligned well, without significant movement, and experienced quite a steady physical environment during observation. Figure 5 shows temporal (over the observation period) and spatial (throughout the measured water column) series plots of the echo level after scaling and default range normalization as proposed by [5]. One may observe that the 1.0 MHz AWAC device generally provided underestimated values compared to those provided by the 0.6 MHz Aquadopp device.

(a) Sound speed in m/s   (b) Water level in m
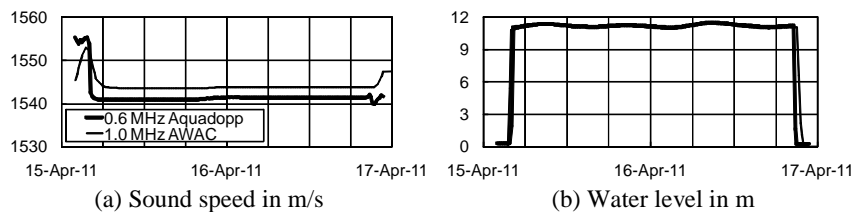
Figure 4 Field records of water properties (a, b, c) and sensor alignment (d, e, f).

(c) Temperature in °C

(d) Heading in degree

(e) Pitch in degree

(f) Roll in degree

Figure 4 *Continued.* Field records of water properties (a, b, c) and sensor alignment (d, e, f).

(a) 1.0 MHz AWAC.
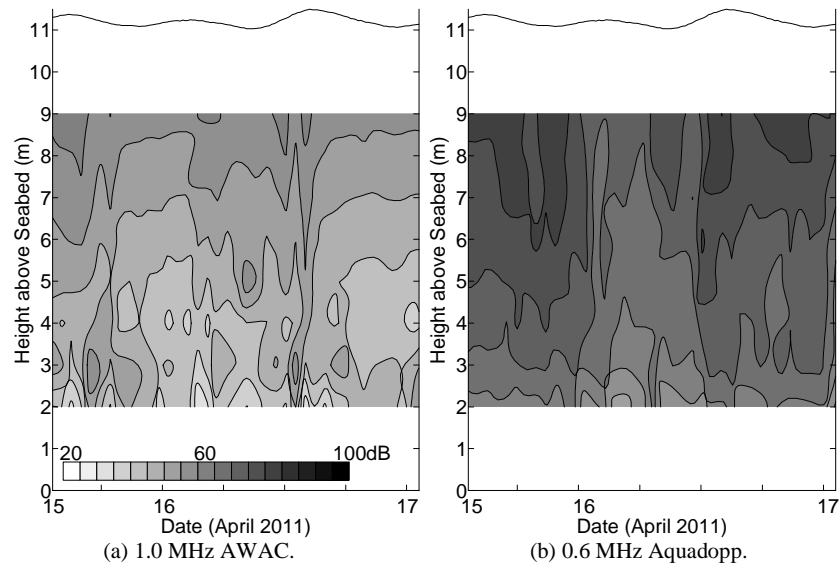
(b) 0.6 MHz Aquadopp.

Figure 5 Echo level over water column and observation period in dB.

3.2 Assessment of Agreement and Correction of Rate of Attenuation

The agreement measure of the acoustic strength between the 1.0 MHz AWAC and the 0.6 MHz Aquadopp was calculated according to Eq. (3) and the layer-by-layer results, with an overall average agreement ($\bar{e}(t,w)$) of 22.2 dB. The results are displayed in Table 1. The absolute discrepancy between the intensities recorded by both transducers was also evaluated. This was done by

comparing the magnitudes recorded by transducers III and II to those recorded by transducer I. The corresponding results are shown in Table 2 and give an overall average of 2.4 dB.

Table 1   Average agreement of acoustic strengths between layers in dB.

				Layer #				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R (m)	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8
Mean *EL* of 1.0 MHz	42	48	44	47	50	53	56	58
Mean *EL* of 0.6 MHz	61	68	71	72	74	76	77	79
$\bar{e}(t,z)$	18	20	26	25	24	23	22	20

Table 2   Overall average of agreement of acoustic strengths between transducers.

1.0 MHz AWAC		0.6 MHz Aquadopp	
II to I	III to I	II to I	III to I
2.2dB	2.0dB	3.0dB	2.4dB

The discrepancy between the echo levels provided by the 1.0 MHz AWAC and the 0.6 MHz Aquadopp is one-order of magnitude greater than the variability of the intensity reading in each transducer. Hence, the normalization of the echo level of the 1.0 MHz AWAC was intervened by modifying k (see: Eq. (3) and the corresponding consecutive description) in such a way that the discrepancy was smallest, and this procedure was applied to each measuring layer. The results are given in Table 3 as $\bar{e}(t,z)$ in dB. The corresponding overall average of the absolute discrepancy was found to be 4.3 dB. Hence, the suggested rate of attenuation for the 1.0 MHz AWAC is proposed in Table 3 as $\alpha_{1.0}**$, where $\alpha_{1.0}** = k\alpha_{1.0}*$ in dB/m. From Table 3, one can see that the applied rate of attenuation for each measuring layer is not uniform. This will be discussed in the subsequent section.

Table 3   Proposed layer-specific attenuation rate for 1.0 MHz AWAC, i.e. $\alpha_{1.0}**$.

|				Layer #				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R (m)	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8
k (-)	23	13	11	8	6.5	5.3	4.5	3.8
$\bar{e}(t,z)$ (dB)	5.7	4.3	3.8	4.0	3.7	4.0	4.1	4.5
$\alpha_{1.0}**$ (dB/m)	9.0	5.0	4.3	3.2	2.6	2.1	1.8	1.5

Note: $\alpha_{1.0}** = k\alpha_{1.0}*$; $\alpha_{1.0}* = 0.4$dB/m

The effects of using a modified constant as the rate of attenuation for each layer of the recorded backscatter intensity from the 1.0MHz AWAC data, can be seen from Figures 6-7. In Figure 6(a), the acoustic backscatter intensity recorded by

the 1.0 MHz AWAC (after modification of its rate of attenuation) is shown as a plot of the spatial and temporal data series. Referring back to Figure 5(a) for an impression of the initial results, the spatio-temporal agreement between the acoustic backscatter intensity of the 1.0 MHz AWAC (after modification of its rate of attenuation) and the 0.6 MHz Aquadopp is given in Figure 6(b). Figure 7 shows time series plots of the intensity of the acoustic backscatter for each layer, as recorded by the 0.6 MHz Aquadopp and the 1.0 MHz AWAC respectively, before and after modification of the attenuation rate.
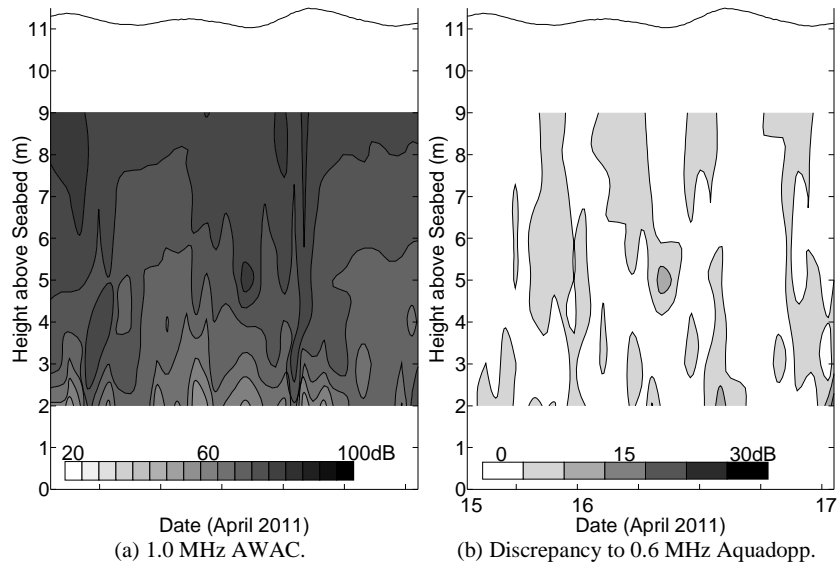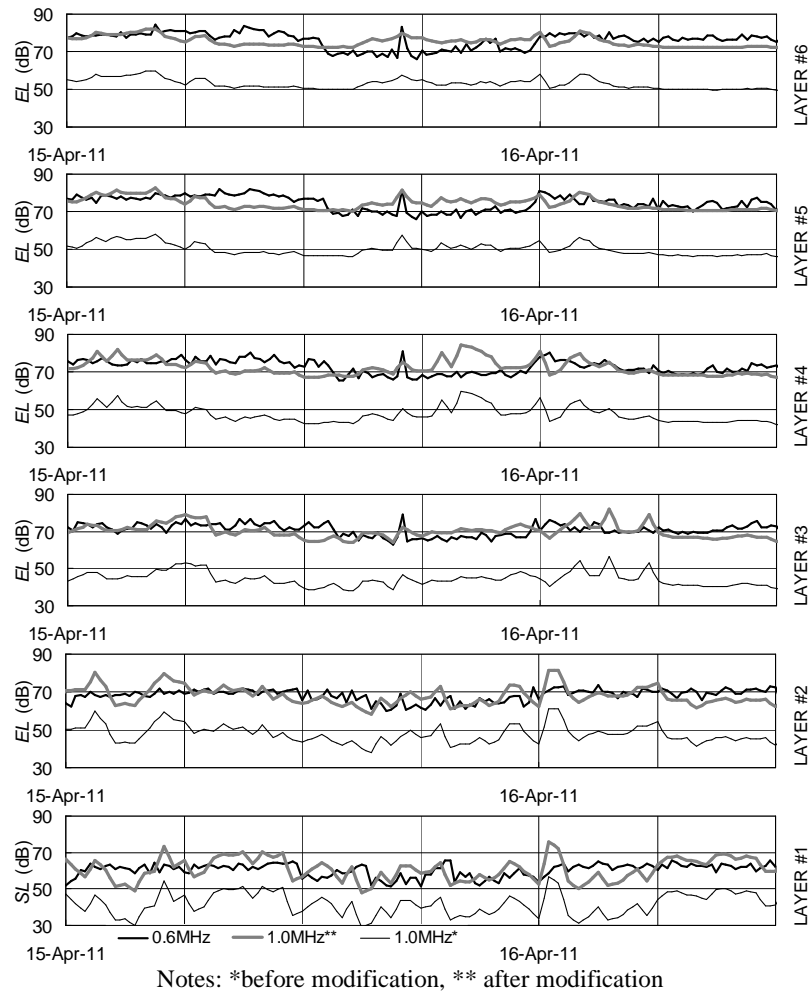
Figure 6   Echo level of 1.0 MHz AWAC and agreement in dB.
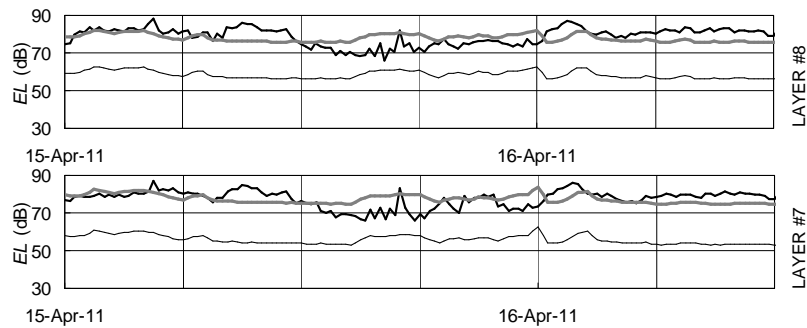
Figure 7   Temporal changes of range-normalized echo level (*EL*).

Notes: *before modification, ** after modification

Figure 7 *Continued.* Temporal changes of range-normalized echo level (*EL*).

3.3   Relation between Range and Rate of Attenuation

In order to deliver backscatter intensity data from the 1.0 MHz AWAC that fit best with those recorded by the 0.6 MHz Aquadopp, to each of the measuring layers a proposed rate of attenuation for the 1.0 MHz AWAC must be applied separately, and, hence, the rate of attenuation is range-dependent. A further analysis was made and it was indicated that there was a proportional relation between the range from the transducers' faces to the measured layer (i.e. slant range – *R*, see: Figure 1) and the applied rate of attenuation. The relation on a

logarithmic scale between the slant range (R) and the proposed rate of attenuation for the 1.0 MHz AWAC is shown in Figure 8. A strong correlation is seen with the coefficient of determination (r^2) of 0.958. We therefore propose to use a modified rate of attenuation for the 1.0 MHz AWAC as $\alpha_{1.0}{}^{**} = -7.925\log(R) + 8.551$ in order to find a fit with the backscatter intensity data recorded by 0.6 MHz Aquadopp.
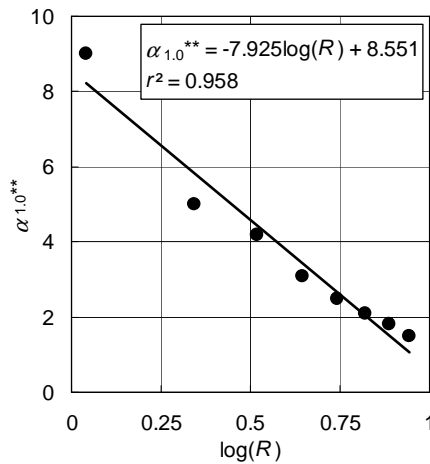

Figure 8 Proposed range-dependant rate of attenuation for the 1.0 MHz AWAC.

3.4   Accuracy and Limitation

Previous field tests with similar devices (1.0 MHz system) in the same area suggested that the overall accuracy of acoustic detection of suspended sediment concentrations using backscatter intensity data is within a factor of 2 [12,13]. This was done by developing a calibration curve in which echo levels and sampled concentrations of suspended sediment are related to each other on a logarithmic scale. In Figure 9, calibration curves for estimating the suspended sediment concentration from recorded backscatter intensity as reported in [16] are given.

The calibration curves and scatters of echo levels and suspended sediment concentration data as shown in Figure 9, suggest that there is a trend of increasing echo levels with an increase of the concentration of suspended sediment. On an equal range of echo levels and using a similar device (*i.e.* with a 1.0 MHz working frequency), different sites provide a dissimilar order of magnitude of sampled concentrations of suspended sediment. One may see from Figure 9 that in the range of echo levels between 60dB and 80dB, a large

difference in the logarithmic expression of the suspended sediment concentration was observed. This is due to the dissimilar characteristics of the acoustic strengths scattered back to the devices' transducers from inhomogeneous physical properties of the suspended sediment. Unless direct samples of suspended sediment are collected simultaneously with acoustic profiling, no direct relation between echo levels and suspended sediment concentration data can be described.

$$10\log_{10}(c) = 0.327EL - 29.49$$

$$10\log_{10}(c) = 0.176EL - 58.95$$
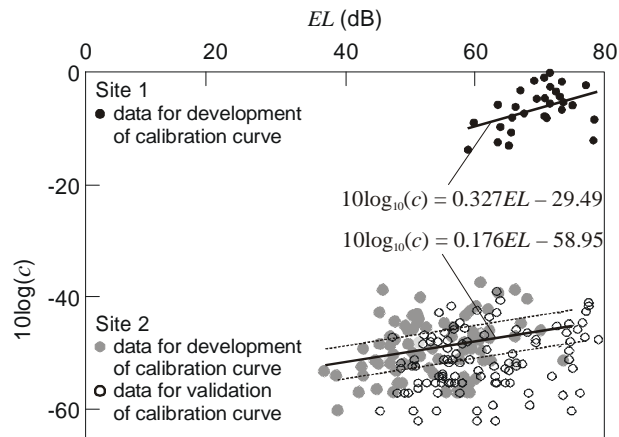
Figure 9 Calibration curves for estimating suspended sediment concentration from recorded backscatter intensity [modified from 16].

The objective of this study was to normalize data from two devices with different working frequencies (*i.e.* 1.0MHz and 0.6MHz) in view of delivering comparable magnitudes of backscatter intensity. A further assessment of the absolute accuracy, which could be obtained from applying the modified rate of attenuation as proposed in this paper, is still wanted. This would require auxiliary field experiments along with a thorough analysis of the field samples. Additionally, the applied field experiment presented here must be understood to work under the assumption that the physical properties of the sediment in suspension are uniform. Field applications at different locations with a similar set of devices' working frequencies (*i.e.* 1.0MHz and 0.6MHz as used here) must be executed to ensure that the physical properties of the suspended sediment detected by each device are uniform.

4   Conclusion

The rate of attenuation proposed for the 1.0 MHz AWAC profiler is found to be one-order of magnitude higher compared to that used by the 0.6 MHz Aquadopp profiler and logarithmically range-dependent. The proposed

attenuation rate for the 1.0 MHz device is $-7.925\log(R) + 8.551$, with R is the slant range from the transducers to the measured layer. The use of the proposed rate of attenuation as presented in this paper has improved the overall agreement between the 1.0 MHz device's echo level and the one recorded by the 0.6 MHz instrument from 22dB to 4dB. This is considered quite significant, bearing in mind that the average discrepancy between the echo levels recorded by each transducer was 2.4 dB. With the use of a default rate of attenuation of 0.15dB/m for the 0.6 MHz instrument, comparable magnitudes of acoustic backscatter can also be obtained by the 1.0 MHz instrument, applying the rate of attenuation proposed in this paper.

Acknowledgements

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