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Monitoring Sediment Concentration with acoustic backscattering instruments

Acoustic Doppler current meters work by measuring the reflection of an acoustic signal from particulate matter in water. While these instruments are primarily used to measure the velocity of the particles, they can also provide information about the quantity and type of particulate matter present. This information is measured in the form of the intensity of the received reflections, also referred to as the backscattering strength or signal amplitude. The NDV, NDP, Aquadopp and Vector record this information as a standard variable in instrument generated data files.

A. Calibration

To be useful for applications that involve sediment measurements, the acoustic information has to be processed. This processing has three natural steps:

I. Conversion from internal units of counts to a linear or log scale
II. Range normalization, i.e. making the data independent of the depth they have been collected at.
III. Instrument normalization, i.e. making the data independent of the instrument that they have been collected with

The last part is often referred to as absolute calibration and is the most complicated part of the processing. We generally recommend that this last step be avoided since none of the Doppler systems that are on the market have been designed with absolute calibration in mind.

I. All Nortek systems use the same component family to measure the amplitude for the echo. This component outputs a signal that is referred to as the RSSI and that is proportional to logarithm of the echo strength. The dynamic range of this signal is about 90 dB and it is linear within an accuracy of about 1-2 dB over a range of 70 dB. Inside this range, the scaling factor is about 0.45 counts/dB but with some variation (about 0.40 to 0.47).

Outside the linear range, the signal is non-linear and the values should not be used for sediment analyses. General experience indicates that the linear region corresponds to sediment concentrations of about 1-10000 mg/l.

II. To compensate all the scattering data for range, it is necessary to add the acoustic loss terms to the converted amplitude (I). The loss terms are:

Acoustic spreading (a)
Water absorption (b)
Particle attenuation (c)

The first term is simply a geometric term that is due to the cone shape of the acoustic beams. The second term is due to molecular transfer of acoustic energy to heat and the last term is the spreading and absorption of acoustic energy by the particles in the water. In units of dB, we can now form a "range normalized" echo level:

(a) (b) (c)

$$EL = Amp*0.43 + 20\log_{10}(R) + 2\alpha_w*R + 20R\int\alpha_p*dr$$

Where is Amp is the parameter stored in the data, R is the range along the acoustic beam (z/cos25 for the NDP), α_w is the water absorption in dB/m, α_p is the particle attenuation in dB/m. The integration is necessary because the particle attenuation may not be the same at all depths.

Term (a) and (b) account for decreases in signal strength with range from the transducer. The loss occurs twice, one time going out to the sampling volume and once coming back, hence the value 2 or 20. The first term (a) is independent of acoustic frequency. The coefficient α_w is a function of frequency, salinity and pressure. Figure 1 shows a plot of α versus frequency for fresh and salt water. The table lists the values of α at the frequencies used by the NDV and NDP.

Frequency (MHz)	α (dB / meter) Salinity = 0 ppt	α (dB / meter) Salinity = 35 ppt
10	26.9	26.9
3.0	2.4	2.9
1.5	0.6	0.7
0.50	0.07	0.14

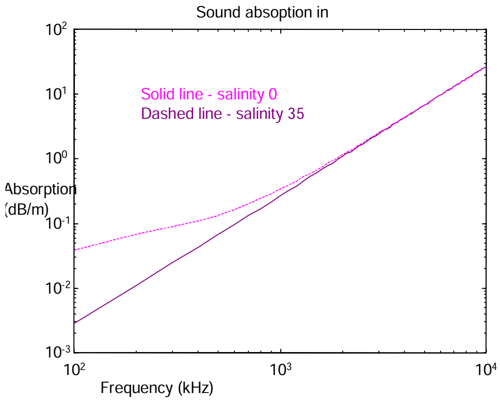

Figure 1

At low concentrations, the particle attenuation is small and the last term (c) can be ignored. For higher concentrations this is not the case and failure to compensate for this term can have a significant impact on the results, especially toward the bottom if the NDP is mounted on a boat.

There are typically two ways of dealing with particle attenuation. The most common method is simply to ignore the problems and hope for the best. This works at low concentrations (low is defined relative to frequency and relative to particle size) and at high concentration, simply knowing that the concentration is quite high sometimes can be enough. The second method is to make an assumption about the particle sizes and then implement an iterative solution based on a particle scattering and attenuation model. Several researchers have used this method, mostly where the particle size is known (near sandy beaches). A variation of this last method is to measure the integrated attenuation, either by using an acoustic source that moves up or down or by using a fixed target.

III. Absolute calibration requires a complete characterization of the transmit and receive circuit of the instrument. This includes parameters such as:

- Acoustic transmit power level
- Transmit pulse length
- Transducer efficiency
- Acoustic receive sensitivity
- Temperature sensitivity of circuits

Each transmit transducer will have a separate value for transmit power level and efficiency. For systems like the NDP and Aquadopp, the transmit power is taken from the raw power (for maximum output for Doppler measurements), the voltage level also has to be factored in and so does the transmit length.

S_v, volume scattering strength, is the final product of these calculations. Truly instrument independent acoustic backscattering measurements are expressed as the intensity of the reflection relative to the incident wave at a specific frequency (i.e. -80 dB at 1.5 MHz). Different acoustic frequencies are sensitive to different particle sizes; thus if the backscattering strength at one frequency is known, the particle size distribution must be known in order to predict the backscattering strength at another frequency.

B. Practical applications

For many applications, it is not necessary to make the backscattering data instrument independent. To look at relative changes in concentration, when the particle distribution can be assumed constant, the data only need to be range normalized before use. Conversion to instrument independent measurements is only required when comparing data from different instruments and data from different NDVs, and NDPs of the same frequency, can be expected to vary no more than 5 dB in an identical environment. For comparison with other acoustic instruments, data must be converted to instrument independent form as described above. As a general rule, inter-instrument comparisons, even at the same frequency, will usually have an uncertainty of at least 3-5 dB.

It is also possible to bypass the calibration problem by simply using a calibrated target (for example, steel ball) and refer all data to the measured target strength. This is what is typically done in the fisheries research and a calibrated target can be used also for narrow-beam Doppler systems even though it is harder to get the target centered in the beam.

I) Acoustic backscattering

For a given particle type and size distribution, the volume scattering strength is directly proportional to the concentration. Thus if the concentration increases by a factor of 2, the intensity of the return signal will increase by a factor of 2, meaning the volume scattering strength will increase by 3 dB ($10*\log_{10}(2)$). For a fixed particle type and size, acoustic instruments such as the NDP can be powerful tools for monitoring sediment concentration. Calibration techniques, both in the laboratory and in-situ, have been successfully employed to allow direct calculation of sediment concentration from acoustic data.

Different acoustic frequencies have different particle size sensitivities. Sensitivity is defined as the volume scattering strength for a given concentration. The variation of sensitivity, plotted independently of frequency, is shown in figure 2. The x-axis shows "k*a", where "k" is the acoustic wave number (2*π/λ or 2*π*f/c) and "a" is the particle radius. The peak sensitivity occurs at a values of k*a=1, when the circumference of the particle is equal to the acoustic wavelength. The table shows the particle sizes for peak sensitivities for the frequencies used by the NDV and NDP.

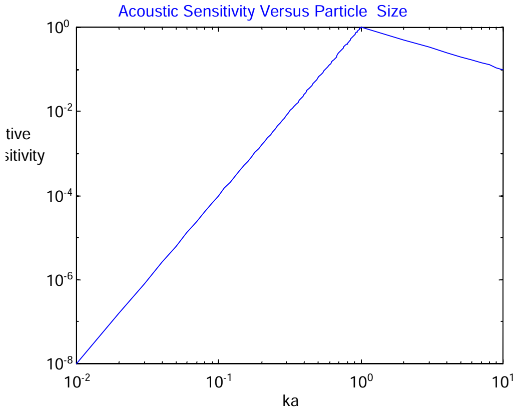

Figure 2

For particles smaller than (k*a = 1), sensitivity is proportional to the radius of the particle to the fourth power. For larger particles, sensitivity is inversely proportional to particle radius. This is an idealized model of sensitivity, and as such neglects a number of factors which affect backscattering strength. However, the model is useful in predicting what types of particles will be detected by acoustic systems, and for analyzing acoustic data. In general, the NDV and NDP can detect, with reasonably good sensitivity, particles sizes where k*a>0.05 as long as there is no significant concentration of particles with k*a ≈ 1

Frequency (MHz)	Particle diameter for k*a = 1
10	50 μm
3.0	160 μm
1.5	320 μm
0.50	960 μm

II) References

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