E-proceedings of the 38th IAHR World Congress
September 1-6, 2019, Panama City, Panama

Super-Turbidity Meter: LISST-AOBS Combines Optical Turbidity with Acoustics

YOGESH C AGRAWAL, H.C. POTTSMITH, D. DANA, AND OLE A. MIKKELSEN

Sequoia Scientific, Inc,
2700 Richards Road, Bellevue, Washington USA 98005
yogi.agrawal@sequoiasci.com; Ole.mikkelsen@sequoiasci.com

ABSTRACT

Optical turbidity is a widely used method for monitoring sediments in water. Turbidity as a surrogate for suspended sediment concentration (SSC) has a calibration that varies with grain size. Consequently, turbidity meters require frequent calibration for the specific sediments. The newer acoustic backscatter sensor LISST-ABS sensor employs 8MHz acoustic backscatter to measure SSC. While it has a near-constant response from ~30-500 micron grain size, it too requires calibration for grains below ~30 microns in size. The two technologies have opposing tendencies in change in sensitivity with grain size, e.g. Volts/[mg/L]. Combining the two measures produces a Super-Turbidity meter, LISST-AOBS. It exhibits minimal sensitivity to grain size changes, and as such would rarely require recalibration.

1. INTRODUCTION

Optical turbidity has been a measurement method of choice for sediment monitoring. It is simple, produces a single output that can be calibrated. It involves measuring light scattered by particles in a chosen direction, e.g. backscatter or side-scatter etc. However, this turbidity is generally expressed in NTU or FTU units, which are units of apparent 'cloudiness'. They do not correspond to suspended sediment concentration (SSC). The measured turbidity must be calibrated to produce SSC. This calibration is grain-size dependent. Consequently, each turbidity meter must be calibrated for the specific size sediments present at the measurement site. If the sediment grain size changes, so does the calibration. And where, in nature, does one find a fixed grain size distribution in space or time?

The grain size dependence of turbidity meters varies as 1/d; i.e. for example, grains of size 15 microns produce 10X stronger turbidity signals when compared to 150 micron grains (e.g. Sutherland et al., 2000). These sizes are often typical of the range seen in river environments; the finer sizes occupy the full river column, the coarser sizes are usually the resuspended load. In effect, the coarser sizes are often not seen by turbidity meters, producing the erroneous appearance of a well-mixed water column (Laguione et al., 2007).

In contrast, LISST-ABS, a new high-frequency 8MHz acoustic backscatter instrument made by Sequoia Scientific, Inc of Bellevue, Washington (USA) performs better. It's sensitivity for grains ~30 to 500 microns is fairly constant. However, for grains below the 30 micron size, the sensitivity decays rapidly as grain size decreases. In effect, the trend of sensitivity change with grain size for optical turbidity is opposite that of acoustic turbidity. This is displayed in Figure 1.

Note the opposing tendencies of the two technologies, and also that the LISST-ABS has a nearly constant sensitivity from ~30 – 500 micron grain sizes, where optics sensitivity changes by a *factor of 16*.

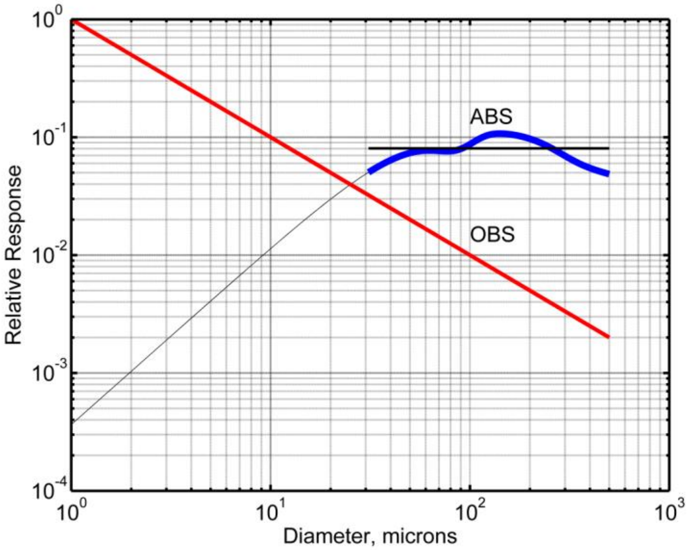

Figure 1: Characteristic scattering per particle volume for optical backscatter sensors (OBS) and LISST-ABS, an 8MHz acoustic backscatter sensor (ABS).

2. THE SUPER-TURBIDITY SENSOR LISST-AOBS

The Super-Turbidity concept involves a weighted sum of the optical turbidity signal SSC_O with the LISST-ABS output SSC_A. A weight factor γ is computed so that the sum, $SSC_A + \gamma\, SSC_O$ has the least variance as function of grain size. In other words, γ is the solution to:

$$\delta/\delta\gamma\ [\ SSC_A + \gamma\ SSC_O]^2 /< SSC_A + \gamma\ SSC_O > = 0$$

For deriving the solution to this requirement, we begin with the combined signal *s,* as the sum of optical and acoustic intensity, respectively, so that:

$$s\ = \alpha\ M/d + \beta\, f^2\ M/d \tag{1}$$

where the Greek letters α and β are simply some calibration constants, M is mass concentration, *d* is grain diameter, and *f* is an acoustic *form factor* [Thorne and Hanes, 2002]. The form factor is a function of grain size, and f^2 is the acoustics counterpart to optical scattering efficiency σ.

In a dispersion of multiple sizes, the above is modified to:

$$s = \Sigma_i\ [\ \alpha\ /d_i\ + \beta\ f_i^2\ /d_i]\ M_i \tag{2}$$

Since we desire a uniform sensitivity to all sizes, the desired form is:

$$s\ =\ C\ \Sigma\ M_i \tag{3}$$

In other words, the quantity in square brackets in Eq. (2) must be flattened to a constant value or as nearly a constant value as possible. One achieves this by first rewriting Eq. 2, introducing a factor γ to give relative weight to one of the two outputs, such that:

$$s \sim \Sigma_i \left[1/d_i + \gamma\, f_i^2/d_i \right] \qquad (4)$$

The weight factor γ is found by minimizing the variance of the quantity in the square brackets of Eq.(4), normalized by its mean value $<s>$, i.e.

$$[\delta s/\delta\gamma]^2/<s> \quad = 0\,; \qquad (5)$$

Performing this optimization leads to this simple result: equalize the response of the optical and acoustic *intensity* with 30 micron particles (intersection of ‘acoustics’ and ‘optics’), and then simply add the two outputs (black, arrow). This is the response shown in Figure 2. It is seen now that the combined response varies within a factor of 2 from the mean (magenta), over the entire size range 3-500 microns.

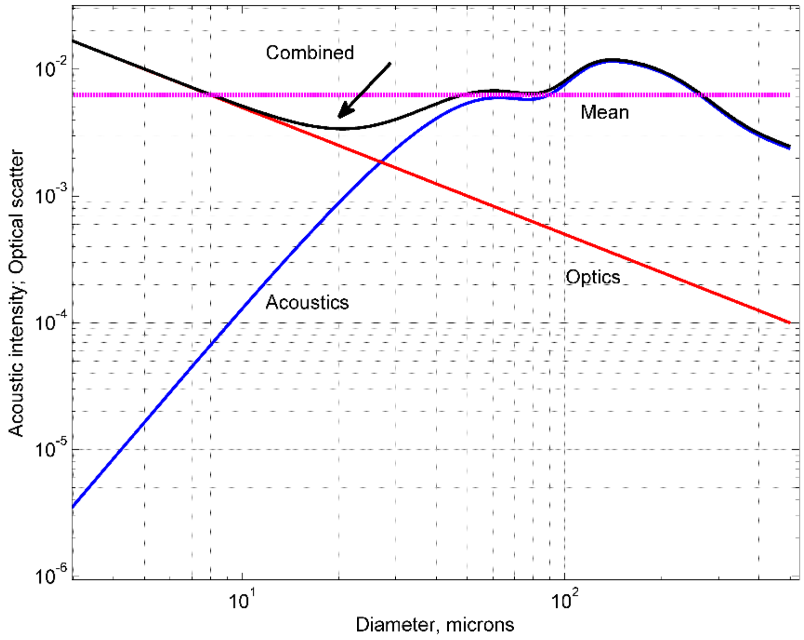

Figure 2: Acoustic, optical, and combined super-turbidity sensor AOBS response (V/[mg/L]) to grains of varying diameter from 3 to 500 microns. The mean response is shown as the magenta horizontal line. Note the combined response (black) varies less than a factor of 2 from mean over the entire size range.

3. LABORATORY VERIFICATION

The actual implementation of this idea requires the simple task of measuring the response of an optical scattering sensor and the LISST-ABS at 30 microns to determine the factor γ that equalizes them at grain-size 30 µm. Thence forth, for any size distribution over the size range 3:500 µm, the combined sensitivity would vary by no more than a factor of ~2.

Whereas a factor of 2 variation in sensitivity may seem a lot, the benefit of all this work is to contrast it with a factor of 500 variation in optical sensor, and a similar factor for acoustic signals over the 1 to 500 micron particle size range. Only laser diffraction methods do better.

For verification, we measured the response of a range of narrow-sized grains, along with the response to broad size distribution grains. Figure 3 shows the true vs measured responses over a range of concentrations, of individual sensors for a range of narrow sized particles from 4-8 microns to 125-150, and for polydispersions A2, A3 and A4 supplied by Powder Technology, Inc. of Colorado, USA.

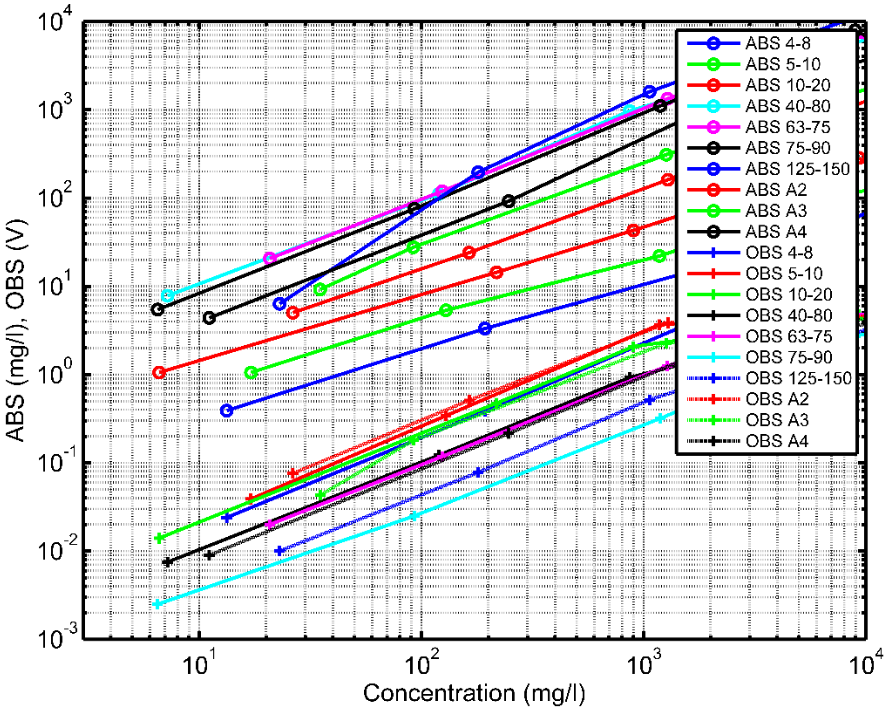

Figure 3: Calibration data for LISST-ABS (upper cluster, circles), sizes increase bottom up; and a turbidity meter (lower cluster, crosses), sizes decreasing bottom up. The data show nearly identical ABS sensitivity for the coarsest sizes, 40-80, 63-75, 75-90, and 125-150 microns. The sensitivity is lower for fines fractions 4-8, 5-10 and 10-20 microns. The trend is inverted for optical turbidity i.e. sensitivity is lower for large grains.

Figure 3 shows the outputs for a range of given concentration of SSC in the sample. As shown in Fig.2, the data confirm the significantly lower sensitivity of acoustics for the finest fractions tested. The optics response generally follows 1/diameter.

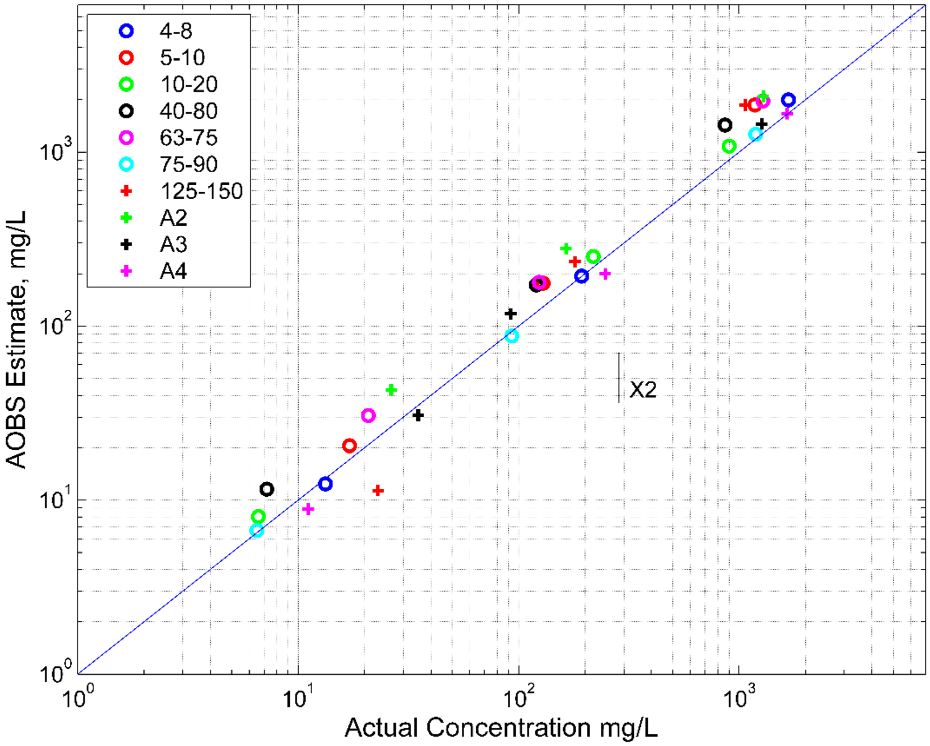

Figure 4: The response of the combined super-turbidity sensor LISST-AOBS to a wide range of particle sizes and size distributions. The vertical bar ('X2') represents a factor of 2. It is seen that the size variability is within a factor of 2 for all particles tested.

In Figure 4, we show the combined response of the LISST-AOBS by a weighted sum as explained in Fig. 2. All 10 types of particles collapse into a single calibration curve. The variation from the 1:1 line is less than a factor of 2 over a 3-decade range of concentrations.

CONCLUSION

Turbidity sensors have required calibration while measuring suspended sediment concentration due to sensitivity to grain size. The acoustic sensor LISST-ABS has better response to see large grains, but lacks sensitivity for fine particles. The combined Super Turbidity sensor LISST-AOBS achieves near-independence of changes in calibration from grain size changes.

REFERENCES

Laguionie, P., A. Crave and A. Jigore (2007): Velocity and suspended sediment concentrati0n profiles in rivers: in situ measurements and flux modeling, In: River Basin Management IV, pp 335-343. WIT Transactions on Ecology and the Environment, v 104, pp335-343. https://doi.org/10.2495/RM070321.

Sutherland, T.F., Lane P.M., Amos C.L., and J. Downing (2000): The calibration of optical backscatter sensors for suspended sediment of varying darkness levels; Marine Geology 162 2000 587–597.

Thorne, P. D., Daniel M. Hanes (2002): A review of acoustic measurement of small-scale sediment processes; Continental Shelf Research 22 (2002) 603–632