

Inter-Comparison of Turbidity and Sediment Concentration Measurements from an ADP, an OBS-3, and a LISST

Elizabeth L. Creed¹, Anne M. Pence², Kelly L. Rankin²

¹Rutgers, The State University of New Jersey. Institute of Marine and Coastal Sciences, 71 Dudley Road, New Brunswick, New Jersey, 08901.

²Stevens Institute of Technology, Davidson Laboratory, 711 Hudson Street, Hoboken, New Jersey 07030

Abstract- A two-year study is being conducted jointly by Stevens Institute of Technology and Rutgers, The State University of New Jersey to create a sediment budget for the Port of New York and New Jersey to further the understanding of the physical processes responsible for persistent siltation of New York Harbor. Scientists are investigating the extent to which marine sediments are suspended due to meteorological events, dredging practices and/or vessel traffic. Thus far hydrodynamic and sediment concentration measurements have been made 2 times in 2000 and 3 times in 2001 in Newark Bay, the Arthur Kill and the Kill van Kull using multi-instrumented moorings deployed simultaneously at the three sites for two to four week periods. Each mooring contains a SonTek Acoustic Doppler Current Profiler (ADP), a SeaBird MicroCat CTD, a D&A Instruments OBS-3 and a Sequoia Scientific LISST-100.

The optical measurement obtained by the OBS-3, which can be translated into suspended sediment load, is dependent on grain size distribution and concentration. The acoustic backscatter intensity from the ADP can also be used as an indicator of turbidity in the water column, which is dependent on grain size distribution and concentration, as well as particle shape and density. The LISST, a laser forward-scattering instrument, reports the sediment concentration and the grain size distribution from 1.25 to 500 μm *in situ*. Here, measured concentration is dependent on sediment concentration and shape as the LISST assumes that all particles are spheres. A comparison of time-history signals among the LISST, the OBS-3 and the ADP was conducted to examine whether changes in the OBS-3 and ADP output signals represent real changes in sediment concentration, or merely changes in grain size distribution and particle composition. The OBS was found to be more sensitive to finer particles, and consequently better suited for field situations in which these particles are present, such as estuarine environments. The ADP was found to be more sensitive to larger particles, where the circumference of the sediment is close to the wavelength of the ADP output frequency. The ADP is better suited to environments with larger particles with a fairly uniform distribution.

I. INTRODUCTION

In June 2000 a two year study of the sediment budget for Newark Bay, where the Port of New York and New

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Jersey is located, was begun. Siltation of this area restricts the use of the Port by cargo ships and results in a loss of revenue for the states of New York and New Jersey. Newark Bay, located in northern New Jersey runs in a north/south direction and is 4.2nm long and averages 0.75nm in width. While the shipping channel is approximately 45 feet deep the average water depth in Newark Bay is 6 feet MLLW. Newark Bay is fed by the Hackensack and Passaic Rivers and empties into the Hudson River and upper New York Harbor via the Kill Van Kull and Raritan Bay via the Arthur Kill. The currents in Newark Bay are tidally driven. Newark Bay is bordered by Staten Island, NY to the south, Bayonne, NJ to the east, Newark and Elizabeth, NJ to the west. (Fig. 1).

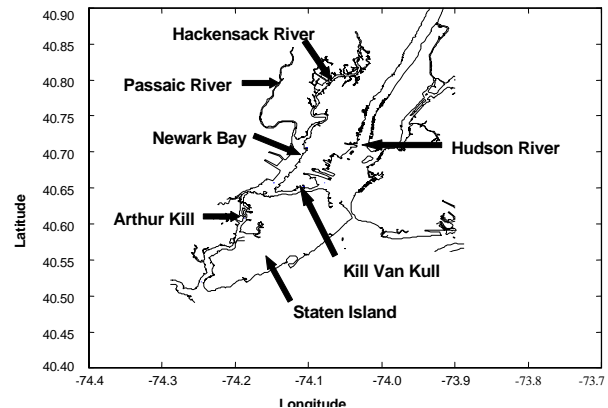


Fig. 1. Map of Newark Bay area.

Many methods presently exist for measuring the concentration of suspended sediment in marine, riverine and estuarine environments. Traditionally, suspended sediment samples were taken with instantaneous bottle samplers or by continuous pump sampling, and although these methods yielded reasonably acceptable results (errors were within 20%) [1], they were intrusive, labor intensive and expensive. Another problem with intrusive sampling is that it is difficult to maintain the sediment aggregation found *in situ*. Aggregates that exist in suspension *in situ* may be broken up during sampling, or new aggregates may form after settling in collection. For example, Phillips

and Walling [2] found that settling for one hour followed by resuspension could cause increases in mean particle size up to 24% due to aggregation. To avoid the errors, labor and expense associated with intrusive sampling methods, autonomous, *in situ* measurements of suspended sediment are preferred.

Recent technological advances in the fields of optics and acoustics have provided new methods for the *in situ* measurement of suspended sediment concentration that are not intrusive, labor intensive nor expensive. These methods involve calibrating or calculating the concentration of suspended sediment from detectable intensity of optical backscatter, laser diffraction or acoustic backscatter.

Gartner, et al. [3] found that estimates of sediment suspension from optical backscatter and laser scattering were well correlated in San Francisco Bay. Optical backscatter and acoustic signal strength were also found to be well correlated in the surf zone. Mean suspended sediment concentrations from both methods were found to be within 10% [4].

For the present field study, a mooring equipped with a LISST-100, an ADP, a CTD and an OBS-3, was deployed in northern Newark Bay at the confluence of the Hackensack and Passaic Rivers to provide the data necessary to understand the hydrodynamic circulation and sediment flux in the region. A comparison of time-history signals between the OBS-3, the ADP and the LISST-100 was conducted to determine whether changes in the OBS-3 and ADP output signals represent real changes in sediment concentration or merely changes in grain size distribution and particle composition.

II. INSTRUMENTS AND METHODS

A 1500kHz SonTek acoustic Doppler current profiler (ADP) was selected for this experiment. We were interested in using the acoustic backscatter intensity from the ADP as an indicator of turbidity in the water column. The backscatter intensity decreases with distance from the transducer because of geometric spreading and sound absorption. However, this reduction in backscatter intensity due to distance is compensated for when the data is post processed (see Analysis Methods) [5]. The D&A Instrument Company's OBS-3 is an optical sensor that measures turbidity and suspended solids concentration by detecting infrared radiation scattered from the suspended material [6]. The LISST-100, manufactured by Sequoia Scientific, is a laser forward scattering instrument that detects *in situ* sediment concentration and grain size distribution from 1.25 to 500 μ m [7].

Fig. 2 illustrates the mooring configuration for the three instruments. The ADP is located in the center of the mooring and its transducers sit 0.85m above the base of the mooring. The LISST-100 is mounted on the right side of the mooring, 0.40m from the base of the mooring. The sampling volume sits between and above two legs of the mooring. The OBS-3 is attached to a mooring leg that is adjacent to the LISST. The sampling volumes of the LISST-100 and the OBS-3 are co-located.



Fig. 2. Mooring Configuration

III. MEASUREMENTS

The data discussed in this paper are from a deployment conducted from June 19-23, 2000. The OBS-3, which is integrated into the ADP, sampled at 1Hz and output one minute averages. The ADP sampled continuously, recording one-minute ensembles using approximately 500 pings/ensemble. The water column was measured in 0.5m bins. The blanking distance for the ADP was 0.4m. The bottom of the first data bin was located at 1.25m from sediment bed. The LISST sampled at 4Hz and recorded a 16 second ensemble average. After each sampling burst the LISST would shut down for one minute. Due to overhead calculation and recording time, the LISST recorded a sample once every 1.3 minutes.

IV. ANALYSIS METHODS

The data from the LISST were screened for data quality by removing any data points where the laser power dropped below 30% transmission, which is where multiple scattering becomes a problem [7]. All data points greater than two standard deviations from the mean of the total LISST concentration, integrated over all 32 bins (approximately 890 μ l/l), were removed.

Care was taken when examining the upper and lower four bins of the LISST data. As reported in Traykovski et al. [8], the LISST was unable to correctly resolve the sediment grain sizes larger than 250 μm , (which include the top four bins of the LISST.) This problem is most likely due to the resolution of the detector rings for the large particles. These rings are unable to resolve the small angular differences associated with the larger particles. Another problem was in the ability of the LISST to resolve the size classes of the very fine sediment. The LISST was unable to resolve the different size classes of the sediment smaller than 5 μm , again due to ring size resolution. However, Sequoia Scientific now manufactures a LISST with modified ring detector geometry to resolve sizes from 1.25 to 250 μm that may be better suited for resolving fine particles.

Data from the OBS, which as mentioned earlier was integrated into the ADP, was recorded as counts. The range of counts was from 0 to 65520, with 65520 corresponding to 4 OBS volts, and 0 corresponding to 0 OBS volts.

ADP signal strength data were first converted from the internal logarithmic units of counts to decibels by multiplying by .43 dB. The data were then corrected for the effects of geometric spreading and absorption. Spreading and absorption cause decay in the signal strength with increasing range from the transducer. This can be corrected for using the following equation (1.1) furnished by SonTek [5]:

$$\text{DECAY} = -20 * \log_{10}(R_{\text{beam}}) - 2 * \alpha * R_{\text{beam}} \quad (1.1)$$

Where:

- DECAY = decrease in signal strength as a function of range (in dB)
- R_{beam} = along beam range (equals the vertical range divided by $\cos(25^\circ)$)
- α = sound absorption (for 1.5 MHz at salinity 35 psu = 0.68 dB/meter).

The signal strength from the first bin (closest to the bed) of the ADP was studied. It is important to note that the sampling volume for this bin was not co-located with the sampling volumes for the OBS-3 and LISST-100. Therefore, it was not possible to directly calibrate the signal from the ADP for sediment concentration using data from the LISST and the OBS. Instead, we chose to examine the acoustic variation of the backscatter signal with respect to relative sediment concentration and, more importantly, grain size distribution.

Finally, because the sampling frequencies were not the same for the LISST and the ADP and OBS, a MatLab script was written to sub-sample all data sets for synoptic data points [9].

V. RESULTS

Fig. 3 shows the processed data for all three instruments. The top plot is of the total LISST concentration integrated over all 32 bins on the y-axis, versus Julian day along the x-axis. The middle plot represents the turbidity measurement in volts from the OBS along the y-axis, versus Julian Day along the x-axis. The bottom plot shows the signal strength in decibels of the ADP from a single beam in the first bin along the y-axis, versus Julian day along the x-axis.

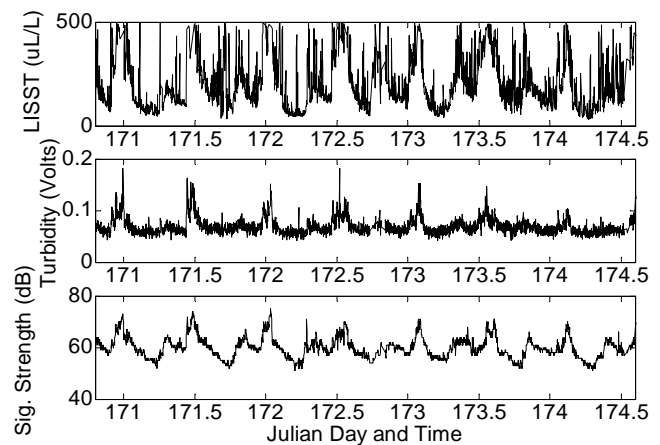


Fig. 3. Suspended Sediment Concentration Measurements

Visual inspection of these graphs shows that the data from each instrument are correlated as the signals from all instruments vary with the tide at semi-diurnal periodicity and it appears that sediment suspension is tidally driven in this area.

The OBS-3 output voltage was correlated with the concentration for each of the 32 sediment size classes (bins) measured by the LISST to determine which grain size classes are most accurately measured by the OBS-3 (Fig. 4). It is shown that the correlation between the LISST and the OBS is very good (>0.8) in the 0.05 to 0.15mm grain size range but decreases significantly when the sediment grain size becomes greater than 0.15mm.

A similar analysis was performed with the acoustic backscatter signal from the ADP (Fig. 5). It was determined that the correlation between the two signals is greater than 0.7 for size classes between 0.075mm and 0.25mm.

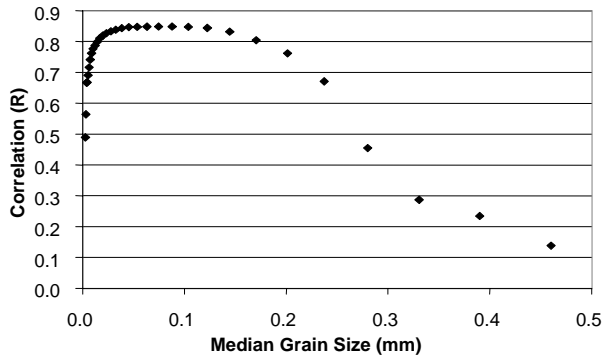


Fig. 4. Correlation of OBS Voltage Output with LISST Concentration in Each Bin

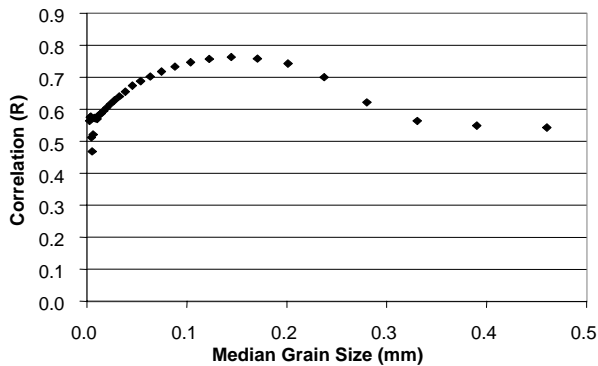


Fig. 5. Correlation of ADP Signal Strength With $10 \cdot \log(\text{LISST Concentration})$ in Each Bin

VI. DISCUSSION

After deploying the OBS-3 with the LISST at the study site, it was possible to determine correlation coefficients for each size class *in situ*, which makes it possible to preserve sediment aggregations found in the estuarine environment. From these data it appears that the OBS-3 would perform almost as well as the LISST in measuring suspended sediment concentration in environments where only fine sediments are present (0.014mm to 0.17mm). However, since the correlations drop quickly for sediments larger than 0.25mm, output from the OBS-3 may not be calibrated with certainty to represent suspended sediment concentration if these size classes are present at the study site. In any case, the grain size distribution at the study site must be known to determine if the OBS-3 may be calibrated to represent suspended sediment concentration within acceptable confidence intervals.

A similar analysis was performed for the ADP backscatter signal and it shows that the ADP may be used for the estimation of suspended sediment concentration in the 0.075 to 0.25mm size class range. It must be noted again that the ADP and the LISST

were not co-located, so no attempt was made to calibrate the ADP backscatter signal to yield estimates of sediment suspension. Instead, we were more interested in the sediment size classes for which the ADP backscatter and LISST time histories were well correlated. It must also be noted that the sediment size that each ADP can detect is highly dependent on the frequency of the instrument and an ADP with a different frequency will yield different results. The peak sensitivity of the backscatter signal occurs when the length of the acoustic wave approaches the diameter of the sediment grain. For larger particles, sensitivity decreases as the inverse function of particle size. In this case, the ADP backscatter signal correlated well (> 0.5) with measurements of sediment concentration from the LISST for all size classes. In contrast, correlation coefficients for the OBS-3 dropped well below 0.3 for size classes greater than 0.3mm.

It would be a great benefit to those studying sediment transport if it were possible to calibrate the ADP with confidence to estimate suspended sediment concentration. The ADP instrument is less intrusive (sampling volume is further from the instrument head) than the LISST and the OBS and is capable of measuring a profile through the water column, thus yielding far more information than point measurements from the LISST and OBS. However, it is necessary to have knowledge of the sediment size distribution in the water column for the ADP to yield useful results regarding suspended sediment concentration since the intensity is dependent on particle size and distribution, as well as concentration. More problematic, the signal strength of the ADP is not only affected by sand and silt particles in the water column, but is also sensitive to salinity fluctuations, bubbles, biological material, and other matter which may be suspended in the water column.

VII. CONCLUSIONS

Comparisons among the time-histories from a LISST, an OBS-3 and the acoustic backscatter signal from an ADP can be useful in determining the conditions under which an OBS-3 and an ADP may be calibrated with confidence for use in measuring the concentration of suspended sediment. From these data it appears that the OBS-3 will perform almost as well as the LISST in environments where the distribution of sediments is uniform and fine (0.014mm to 0.17mm). Similarly, the backscatter from the ADP may be most effective in determining the concentration of suspended sediments in environments where, again, sediment is uniformly distributed in the 0.075 to 0.25mm range. The most beneficial aspect of co-deployment of acoustical and/or optical instruments with the LISST is that it becomes possible to calibrate output signals with the LISST measurements *in situ*, without disturbing sediment

aggregations found in estuarine environments. Further, it is also possible to determine the grain size distribution present at the study site, which is necessary for explaining some of the variance in the acoustical/optical signals that is not due to fluctuations in the concentration of suspended sediment.

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