Comparison of optical methods used for estimation of particulate matter in coastal waters

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ABSTRACT

In 2006, the Alliance of Coastal Technology (ACT) evaluated the performance of five commercial-ready, in situ turbidity sensors at eight test sites located throughout North America (Fig. 1). Turbidity provides a gross assessment of the amount of suspended material in the water. There are numerous methods for quantifying turbidity, including light attenuation, back and side scatter, laser diffraction, and acoustic back scatter. In this study, we compare a dataset collected by ACT which includes three different optical measurements commonly used to estimate particulate matter concentration (PM): 1. backscatter (b_{bp}), 2. side-scatter (b_{sp}), and 3. transmission at 660nm which provides the particulate beam attenuation coefficient (c_p). These optical methods are consistent with the international standard ISO 7027, water quality – determination of turbidity.

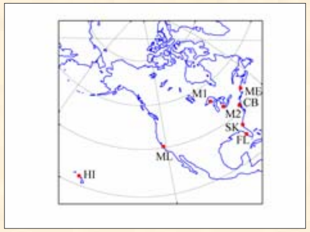

Figure 1. Sample locations. CB: Chesapeake Bay; FL: Tampa Bay; HI: Kaneohe Bay; M1: Traverse Bay, Lake Michigan; M2: Winans Lake; ME: Damariscotta River Estuary; ML: Moss Landing Harbor; SK: Skidaway Island.

METHODS

The ACT dataset was collected using moored deployments at test sites representing a range of environmental conditions comprising a tropical coral reef, a high turbidity estuary, open ocean, and a freshwater lake (Fig. 1) .

The sensors used in this study consisted of:

- A backscatter Turbidity Probe (λ =660nm) – data denoted by b_{bp}
- A side-scatter Turbidity Probe (λ= 860nm) – data denoted by b_{sp}
- A transmissometer (λ =660nm) – data denoted by c_p

Both scattering sensors were equipped with integrated copper wipers to reduce the effects of bio-fouling. The transmissometer was cleaned daily during the work week. ACT personnel conducted all tests in accordance with training provided by the sensor manufacturers.

Water samples were collected and analyzed for PM and particulate organic carbon (POC) at times corresponding to sensor measurements and using a 0.7μm nominal pore size GF/F filter. PM was determined gravimetrically for material in accordance with standard protocols (APHA, USEPA) independently at each site. POC samples were tested following the Dumas combustion method at the Marine Science Institute, University of California, Santa Barbara.

DATA

The number of data points obtained for each of the five turbidity sensors, c_p, PM, and POC are summarized in Table 1. Invalid data were removed from the dataset prior to our comparison and consisted of those measurements collected during sensor failure (battery, wiper), heavy bio-fouling, or when the sensor experienced obvious drift. We selected a subset of the data with the highest number of co-located measurements for PM, c_p, one backscatter sensor, and one side-scatter sensor (95 data points from five locations). For comparison, Babin, et. al. (2003) had 220 matchups of PM with b_p(555).

N	PM	POC	c_p	b_{bp1}	b_{bp2}	b_{sp1}	b_{sp2}	b_{sp3}
Collected	455	309	251	302	396	409	376	357
Valid	455	309	250	248	64	310	221	195
Matchups (all methods)	21	21	21	21	21	21	21	21
Matchups (one of each method)	95	95	95	95		95		

Table 1. Number of measurements (N). c_p = beam attenuation; b_{p1} and b_{p2}= backscatter sensors 1 and 2; b_{sp1} through b_{sp3} = side-scatter sensors 1, 2, and 3.

STATISTICAL TESTS

Distribution of IOPs when the same data are available (95 points) is shown in Fig. 2. Normalizing the data and log-transforming them provide non-dimensional and scaled variables for which linear-correlation and regression analysis seem more suited.

The uncertainty in the correlation coefficient was calculated from a linear correlation analysis between log-normalized data {log[data/median(data)} using a Monte-Carlo procedure using the uncertainties in the measurements and that of the PM.

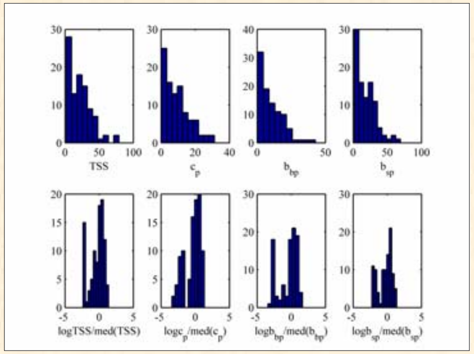

Figure 2. Histograms of data distribution.

RESULTS

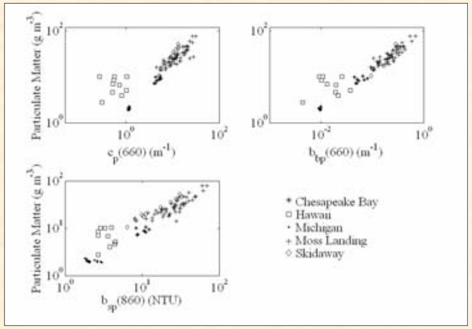

Figure 3. Plots of total suspended mater, PMC, as function of the beam attenuation. c_p, the backscattering coefficient, b_{bp}, and the side-scattering coefficient, b_{sp}.

For all sites, we find correlations to be high (>0.86, Table 2) with the back- and side-scattering methods being significantly the best predictors of PM.

R(N=95)+/-3std	attenuation	backscattering	Side-scattering
PM	0.86±0.09	0.93±0.08	0.92±0.06

Table 2. Correlation of datasets.

When we look at datasets comprising all sites except Hawaii (which appears anomalous optically, most likely due to high $CaCO_3$ content), we find correlations to be higher (>0.96), Table 3) with backscattering having a slightly better correlation .

R(N=85)+/-3std	attenuation	backscattering	Side-scattering
PM	0.97±0.004	0.98±0.004	0.96±0.008

Table 3. Correlation of datasets without Hawaii.

Models based on linear regression of the log-normalized optical properties to the log-normalized PM perform well over the dataset from which the model was derived (N=85, the model has 2 degrees of freedoms). The model based on backscattering data performs best with a median difference of 9% and with 95% of the data predicting PMC with an error of less than 37% (Table 4).

Prediction percentile error, |Model-PM|/PM	attenuation	backscattering	Side-scattering
5%	1%	1%	3%
50%	15%	9%	19%
95%	45%	35%	50%

Table 4. Statistics of absolute difference between PM from a model based on an optical property and measured PM.

Is it worth measuring PM with more than one method?

YES! Multiple methods provide:

- Redundancy in case of sensor failure or drift.
- Information on particle composition (Fig. 4).

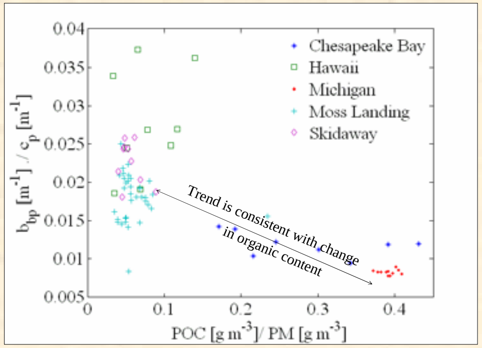

Figure 4. Ratio of backscattering to beam-attenuation as a function of the ratio of POC to PM. In general, data points with low b_{bp}/c_p ratios have higher organic content, consistent with theory. Note how the points from HI are anomalous optically, probably due to high $CaCO_3$ content.

CONCLUSIONS

- Analysis of the current dataset suggests backscattering to be the method providing the best prediction of PM (given the deployment methodologies used in the ACT intercomparison).
- If possible, it is advisable to use several concurrent optical methods to estimate PM. Besides redundancy, the additional data can provide information on composition and/or size distribution.

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