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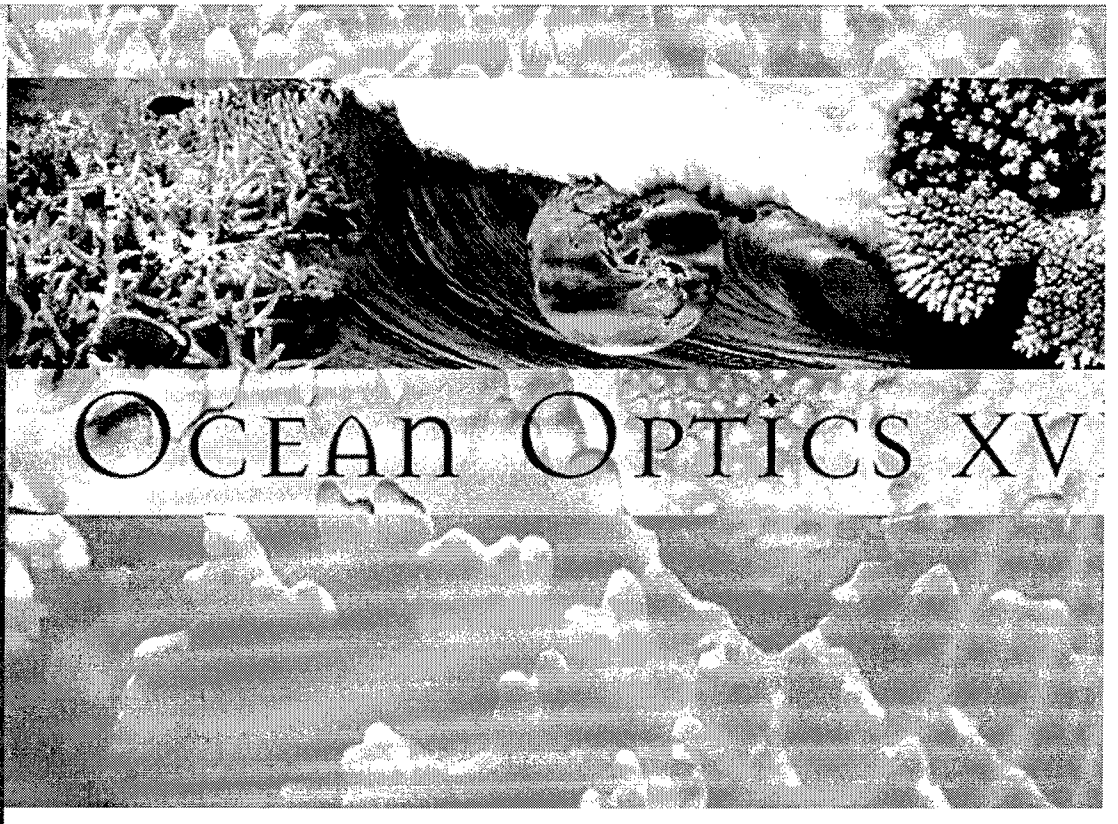

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Biogeo-Optics: Backscattering Cross Sections for Suspended Mineral and Organic Matter in the Coastal and Near-Coastal Ocean

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INTRODUCTION

Suspended mineral matter continues to be the major block to adequate parameterization of optical Case 2 waters[1], especially Nearshore waters. This mineral matter has an overriding effect on the optics of coastal waters as will be demonstrated in this report. There is a paucity of optical information for the suspended mineral matter of coastal waters[2,3,4] which we will be attempting to rectify here. With the information we are supplying and proposing to fill this gap we are creating a new field, geo-optics. This lays the basis for adequate coastal optical models and will even be of importance for Case 1 waters - the open ocean receives mineral matter from dust storms which supply a significant admixture of iron for plankton blooms[5]. The majority of activity in the study of ocean optical properties has been the creation of chlorophyll-based models[6], the quantification of absorption cross sections, and the partitioning of the absorption coefficient into its various organic components[7,8]. Our contribution to geo-optics in this report is an investigation of the role of suspended mineral matter in the particulate backscattering coefficient, the forcing function of the remote-sensing signal. From this study it will be possible to partition the scattering and backscattering coefficients into their major components: mineral and organic. We are determining the optical backscattering cross section of suspended mineral and organic matter in Mobile Bay, Alabama, and the northern Gulf of Mexico off the barrier islands of Mobile Bay, in the northern Gulf of Mexico off the barrier island Horn Island in the Mississippi Sound, and at the Southwest Pass of the mouth of the Mississippi River. When we combine these data with bio-optically based optical data on suspended organic matter then we have the biogeo-optical model of coastal ocean optical properties.

The fundamental premise of the biogeo-optical model is that the absorption characteristics of suspended matter can be well described by chlorophyll-based models while the scattering characteristics are largely controlled by suspended mineral concentration. Loisel and Morel[9] have published an array of scattering equations for organic matter in Case 1 waters which cannot be applied alone to Case 2 waters because the suspended organic matter supplies only a fraction of the scattering activity. We will show the relative importance of suspended inorganic and organic matter for the

particulate optical backscattering coefficients of the Nearshore and offshore waters of the northern Gulf of Mexico.

MATERIALS AND METHODS

Research cruises were done in Mobile Bay, Alabama, 18 - 25 May 2002, Southwest Pass, Mississippi River, 29 July - 3 August 2003, and Horn Island, 17 - 19 September 2003. The participating ships were the R/V Ocean Color (Mobile Bay and Horn Island) and the R/V Pelican (barrier islands and Gulf of Mexico off Mobile Bay), the R/V Bertrum (Horn Island), and the R/V Acadiana (Southwest Pass, Mississippi River mouth). The data reported here were collected from transects extending from deep inside Mobile Bay out past the barrier islands and somewhat into the Northern Gulf of Mexico, from Horn Island into the Gulf of Mexico, and criss crossing the Mississippi River plume at the Southwest Pass of the Mississippi River mouth. Data on particulate backscattering were collected with a HOBI labs Hydroscat 6 meter and a WET labs EcoVSF meter from the surface. Surface water samples were also collected at each station for the Mobile Bay cruises and returned to the Dauphin Island Sea Lab for analysis. Water samples collected from Horn Island were returned to the Oceanography Laboratory, Naval Research Laboratory, Stennis Space Center for analysis as were the water samples collected at the Southwest Pass. Water samples were filtered under vacuum through Whatman GF/F, 47 mm diameter, glass fiber filters, nominal pore diameter of 7 □ m. The filters had been pre-washed, ashed, and weighed. The volume filtered varied from 200 ml (very turbid sample) to 4.0 l (clear northern Gulf of Mexico sample). The samples were filtered to the clogging of the filter which ensured a relatively consistent amount of suspended material for analysis. After filtration the samples were washed three times in deionized, particle-free water to removed excess salt from the filter residue, 3 washes of 100 ml each. The filtered, washed samples were then dried at 103° C for two hours. After two hours the samples were cooled in a dessicator for half an hour and then weighed. Next the samples were ashed at 550° C for 15 minutes, cooled in a dessicator, and weighed again. The total sample weight is TSS (Total Suspended Solids) while the ashed sample weight is PIM (Particulate Inorganic Matter). The difference between the two above weights is then POM (Particulate Organic Matter). The weights were normalized to the sample volume to obtain a concentration in mg/l, equivalent to g/m^3. In addition, the surface water samples were analyzed to estimate chlorophyll concentration with an Aquafluor instrument.

The particle backscattering coefficients, $b_{bp}(\lambda)$, determined from the Hydroscat 6 or EcoVSF measurements, were analyzed with a multiple linear regression against the concentrations of PIM and POM. We propose a fundamental partition of the particulate backscattering coefficient which has not been attempted before,

$$b_{bp}(\lambda) = b_{bm}(\lambda) + b_{bo}(\lambda), \qquad (1)$$

where $b_{bp}(\lambda)$ is the particulate backscattering coefficient, $b_{bm}(\lambda)$ is the particulate mineral backscattering coefficient, and $b_{bo}(\lambda)$ is the particulate organic backscattering coefficient.

We are effecting this partition with the multiple linear regression of $b_{bp}(\lambda)$ against PIM and POM as follows,

$$b_{bp}(\lambda) = a(\lambda) + b^*_{bm}(\lambda)[\text{PIM}] + b^*_{bo}(\lambda)[\text{POM}], \qquad (2)$$

where $b_{bp}(\lambda)$ is the particulate backscattering coefficient determined for wavelength λ utilizing either the Hydroscat 6 or the EcoVSF, a is the intercept of the regression (nearly always 0 or spanning 0 significantly, b^*_{bm} is the linear regression coefficient of the PIM concentration, interpreted as the optical backscattering cross section of the mineral concentration, and b^*_{bo} is the linear regression coefficient of the organic matter concentration, interpreted as the optical backscattering cross section of the organic matter concentration. From this we are able to assess the relative contributions of suspended mineral and organic matter to the particle backscattering coefficient and to partition the backscattering coefficient.

RESULTS

The concentrations of PIM and POM allowed the prediction of $b_{bp}(\lambda)$ with an R^2 ranging from 0.50 to better than 0.90. Even the regressions with the lowest R^2 were shown to be significant by the F test, however. In Table 1 we illustrate the mineral spectral optical backscattering cross section determined for Mobile Bay which proved to be typical of the nearshore results.

Table 1. Spectral Optical Scattering Cross Sections (m^2/g) for Suspended Mineral Matter. Mobile Bay, May 2002

$b^*_{bm}(440)$	$b^*_{bm}(488)$	$b^*_{bm}(532)$	$b^*_{bm}(589)$	$b^*_{bm}(620)$	$b^*_{bm}(671)$
0.011 ±0.002	**0.012 ±0.002**	**0.013 ±0.002**	**0.13 ±0.002**	**0.010 ±0.002**	**0.011 ±0.002**

Likewise, Table 2 illustrating the organic spectral optical backscattering cross section for Mobile Bay proved to be typical.

Table 2. Spectral Optical Scattering Cross Sections (m^2/g) for Suspended Organic Matter. Mobile Bay, May 2002

$b^*_{bo}(440)$	$b^*_{bo}(488)$	$b^*_{bo}(532)$	$b^*_{bo}(589)$	$b^*_{bo}(620)$	$b^*_{bo}(671)$
0.009 ±0.006	**0.011 ±0.006**	**0.012 ±0.006**	**0.11 ±0.005**	**0.010 ±0.005**	**0.010 ±0.005**

However, the mineral optical backscattering cross sections proved to be significant at the $p = 0.01$ level from the t-test while the organic optical backscattering cross sections proved to be non-significant at the $p = 0.05$ level. The larger error term associated with the suspended organic matter explains the statistical result. Although the optical backscatter cross sections appear to be of about the same order of magnitude for suspended mineral and organic matter, the contribution of the two components to the multiple regression can be tested by converting the optical scattering cross sections into

standardized optical scattering cross sections (multiple regression coefficients)[10] which assesses the contribution of the mineral and organic components to the regression on $b_{bp}(\lambda)$. Table 3 illustrates the standardized regression coefficients for mineral matter and Table 4 does the same for organic matter.

Table 3. Standardized Spectral Optical Scattering Cross Sections for Suspended Mineral Matter. Mobile Bay, May 2002

$b^*_{bm}(440)$	$b^*_{bm}(488)$	$b^*_{bm}(532)$	$b^*_{bm}(589)$	$b^*_{bm}(620)$	$b^*_{bm}(671)$
0.7635	**0.7648**	**0.7670**	**0.7832**	**0.7569**	**0.7036**

Table 4. Standardized Spectral Optical Scattering Cross Sections for Suspended Organic Matter. Mobile Bay, May 2002

$b^*_{bo}(440)$	$b^*_{bo}(488)$	$b^*_{bo}(532)$	$b^*_{bo}(589)$	$b^*_{bo}(620)$	$b^*_{bo}(671)$
0.2044	**0.2199**	**0.2215**	**0.2069**	**0.2322**	**0.2677**

These standardized regression coefficients indicate that at least three fourths of the backscattering coefficient is created by the suspended mineral matter. In the other field studies we conducted the mineral component contributed as much as 90 percent to the variance of the backscattering coefficient with the organic component often contributing less than 1 percent. And the regression coefficient for organic matter was often negative or significantly spanned zero.

The optical backscattering cross sections for the cruises reported here are plotted in Figure 1. The backscattering cross sections for the nearshore stations, Mobile Bay and Southwest Pass, varied around a value of 0.01 (m^2/g) as did the organic backscattering cross section for Mobile Bay. The pattern for the offshore stations, the barrier islands beyond Mobile Bay and Horn Island, had a greater value that appeared to peak around 0.035 (m^2/g) in the region of 550 - 600 nm. There were only data for 550 nm for Horn Island and it fell within the error range for beyond the Mobile Bay barrier islands. In Figure 2 the mineral backscattering cross sections and error limits for Mobile Bay and the Mobile Bay barrier islands cruises are plotted against the reported values for the Back River mouth and the Appomattox River, Virginia[4,11], and Chilko Lake, British Columbia[4,12]. Of the mineral backscattering cross sections reported in the literature we could find only one from a marine or marine-dominated system, the Back River mouth in Virginia. All other reported data are from freshwater lakes or rivers[4]. The freshwater results in Figure 2 are generally higher than the marine results with the Appomattox River at low tide showing a value as high as 0.10 (m^2/g) for 450 nm.

DISCUSSION AND CONCLUSIONS

The mineral and organic backscattering cross sections in this report (Table 1, 2) are the first to be determined directly from mineral and organic mass concentrations and the particle backscattering coefficient. One major conclusion to be drawn from what is reported here is that the mineral backscatttering cross sections, as summarized in Bukata et al[4], are significantly lower for marine systems than those reported for freshwater so that freshwater mineral backscattering cross sections cannot be applied uncritically to problems of inverting mineral concentrations from remote sensing reflectance data. Offshore mineral backscattering cross sections also appear to differ significantly from nearshore mineral backscattering cross sections (Figure 1). There are many plausible scenarios for why these differences should exist, based largely on size distribution of the suspended matter. The smaller mineral backscattering cross section should be due to larger particle size. However, there are not data at present on the size distribution of the mineral component and the size distribution of the organic components separately. Such issues can only be resolved by a concerted effort to obtain size distribution data of the separate components.

The most significant issue uncovered here is the predominance of the mineral component in the backscattering coefficient and thus in the driving of the remote sensing signal, the remote sensing reflectance R_{rs}. At least 75 percent of the backscattering is due to minerals in the coastal Case 2 waters with the organic component small to very small (Tables 3,4). In many of the other cruises reported here it was demonstrated that an increase in the concentration of particulate organic matter often resulted in a decrease in the contribution of particulate organic matter to the backscattering signal. Given these results, it appears odd that virtually no effort is expended by the optics community to determine the nature of the suspended mineral matter (mineralogy, etc) of coastal waters while tremendous effort is expended to determine the nature of suspended and dissolved components of organic matter. Such an effort appears to be analogous to attempting to derive remote sensing algorithms without an atmospheric correction, considering that the atmosphere dominates the remote sensing reflectance signal.

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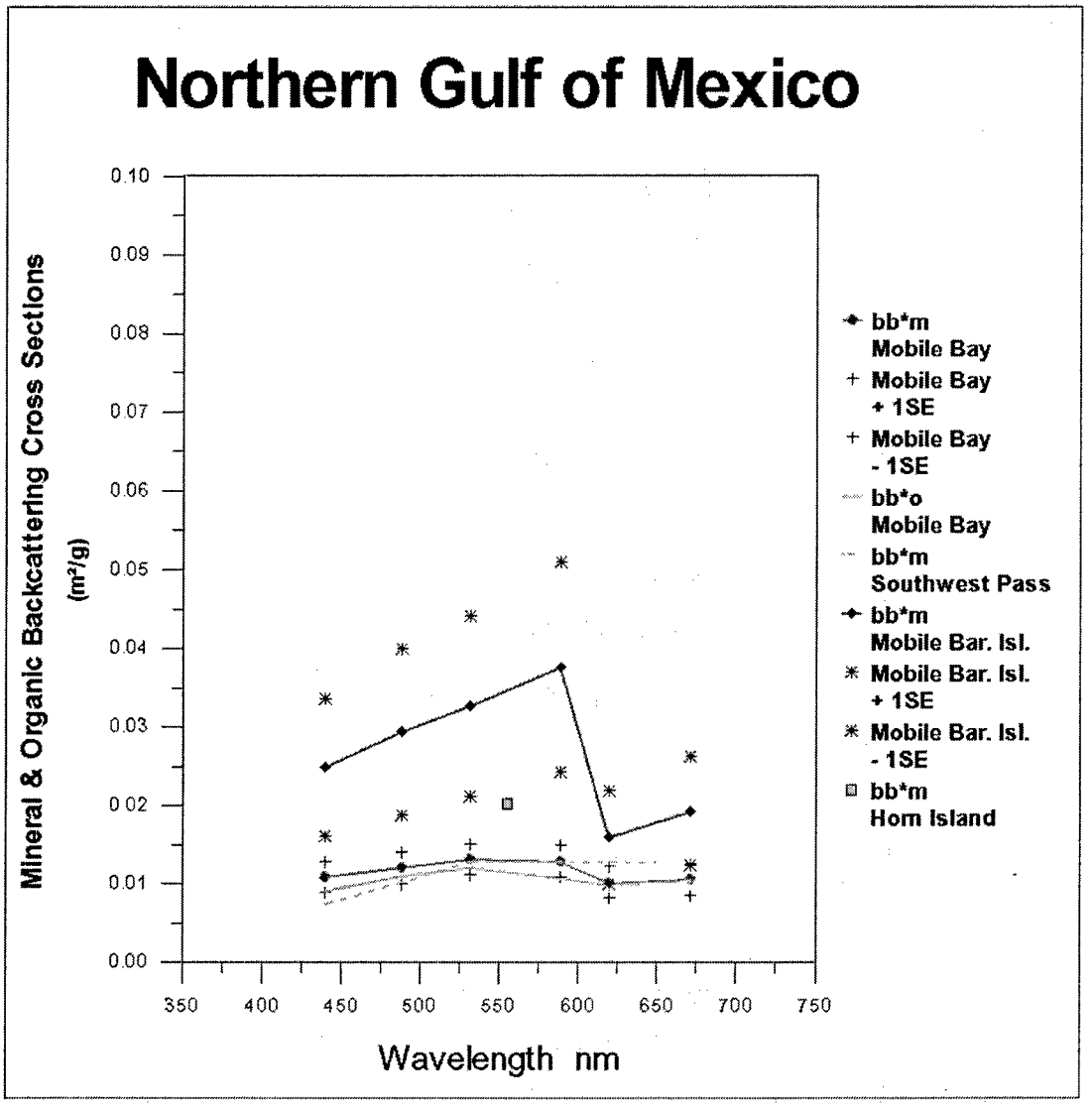

Figure 1. Spectral optical backscattering cross sections for suspended mineral matter and one instance of suspended organics in the northern Gulf of Mexico. Nearshore cross sections differ significantly from offshore (around barrier island) backscattering cross sections.

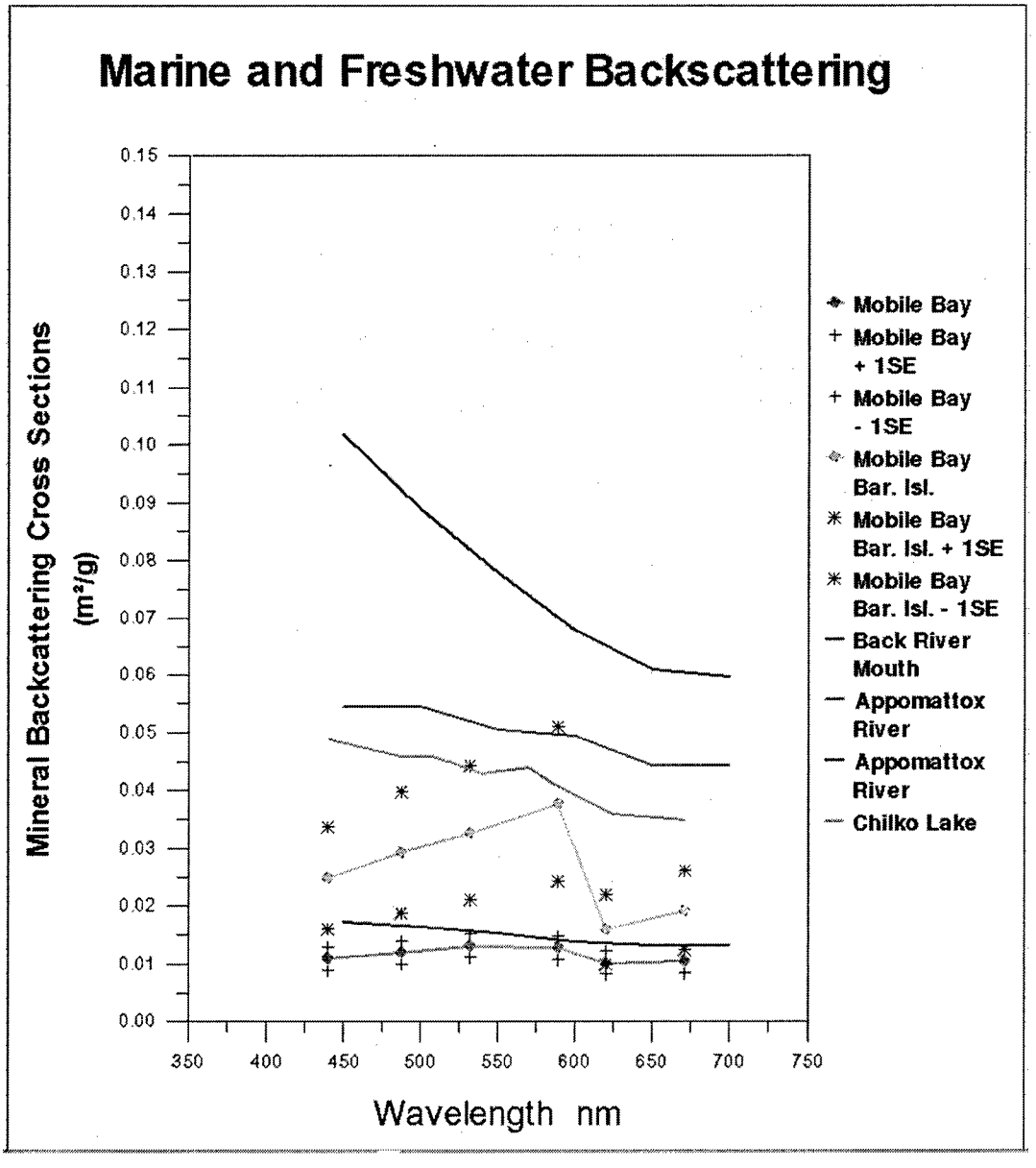

Figure 2. Comparison of spectral optical backscattering cross sections for the marine habitats of the northern Gulf of Mexico and the mouth of the Back River, Virginia and backscattering cross sections reported for freshwater habitats. Near shore backscattering cross sections differ significantly from those reported for freshwater. The backscattering cross sections for the offshore marine habitat do overlap somewhat with the values reported for freshwater.

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14. ABSTRACT

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