Coastal Ocean Optical Modeling: Integrating Optical Processes and Hydrodynamic Simulations of Sediment Resuspension and Transport-Phase 2

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LONG-TERM GOALS

Mechanistically-based models and algorithms for ocean optics are the overall goals for this project. Mechanistic models are robust, reliable, and portable. A standard optical model for the oceans is in development. This is being done by parameterizing and incorporating the optics of the coastal ocean system into Case 1 optical models. The parameterization is based on chlorophyll concentration and the concentration and size distribution of suspended mineral matter. This brings in mineral optical cross sections, virtually unknown in coastal ocean optics.

OBJECTIVES

My efforts are directed toward the production of a valid, predictive, and portable case 2 coastal ocean optical model. The hiatus in our knowledge so far is the accounting for effects of suspended and resuspended particulate mineral matter.

APPROACH

I have been developing the Coastal Ocean Biogeo-optical Model for the past few years. The discovery that chlorophyll parameterizations of the Open Ocean Bio-optical Model (Weidemann et al, 1995) were adequate to predict the absorption coefficient in coastal regions (Stavn et al, 1998) was the stimulus for this development. The chlorophyll parameterization is not adequate to predict the total scattering coefficient in coastal regions so something must be added to make a Coastal Ocean Biogeo-optical Model - the concentration of suspended mineral matter. In the near shore region The Littoral Sediment Optical Model (LSOM) of Dr. Timothy R. Keen will usually be adequate to supply the missing information for the model. What is required is the size distribution of the bottom sediments and local data on tides, wind stress, and wave heights plus bottom currents from acoustic Doppler current profiler surveys or 2D fields derived from the Princeton Ocean Model.

At present I am taking steps to supply the missing information on suspended mineral matter in coastal waters with joint efforts with University of Southern Mississippi, the Naval Research Laboratory

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14. ABSTRACT
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(NRL), and the Louisiana Universities Marine Consortium (LUMCON). This involves collecting and filtering water samples, drying the filtered material, weighing it, ashing it, and weighing it again. LUMCON possess over 10 years worth of data on Particulate Inorganic Matter (PIM) and Particulate Organic Matter (POM) determined by the above methods. Efforts at collecting such data were made at LEO-15 during the field exercise of July, 2000 and these results are to be forthcoming in the next month or so from Rutgers University.

With information on coastal inherent optical properties (absorption and scattering), I simulate the solution of the radiative transfer equation by Monte Carlo methods on the IBM SP. Many new developments in PVM and especially MPI technologies, are easily applicable to Monte Carlo methods. This work is carried out at the North Carolina Supercomputing Center. Parallelization of the Monte Carlo simulations has increased their efficiency by orders of magnitude. This method easily accounts for the complicated non-linearities introduced by multiple scattering, internal radiant emission, and internal apparent radiance sources, i.e. reflective bottoms and wave-disturbed water/air interfaces.

WORK COMPLETED

The initial verification of the Biogeo-optical Coastal Ocean Model is complete (Stavn and Keen, 2001) and the nearly unique backscattering coefficients (Stavn and Keen, 2000), partitioned between suspended mineral and organic matter, are being applied to remote sensing algorithms. I have participated in various aspects of the LEO-15, July 2000, exercise (Gould, et al, 2001, Weidemann et al, 2001) which have demonstrated the need for direct measurement of suspended mineral matter and the need for investigations in depth on the nature of particle sizers and counters. The nature of the suspended solids in NGLI cruises from September 2000 to May 2001 has been elucidated.

RESULTS

The field exercise at LEO-15, July 2000, was a remarkable gathering of marine scientists with interests in ocean optics and related coastal ocean dynamics. I was there with a group from NRL that did extensive water sampling and AC-9 measurements in Great Bay, New Jersey, the Mulicca River feeding into the bay, and outside into the Atlantic Ocean. On 24 and 25 July 2000 several researchers got together to take diverse data at the same stations. Sampling and instrument readings were done near the surface. The remarkable new Volume Scattering Function meter from the Ukraine was deployed along with an AC-9 meter and water samples were collected all at the same time. Results from two of the stations are depicted in Figs. 1 and 2 while results from four of the stations are listed in Table 1. The particle content and size distribution at the stations was measured with a Spectrex Instrument by Dr. Rick Gould of the NRL. The Spectrex is a laser-based instrument which measures mean optical cross section of particles. This information is converted to an equivalent spherical diameter to obtain a particle size distribution. The maximum equivalent particle diameter at the river mouth was about 28 μm (Fig. 1) as was also the case in the Atlantic outside Great Bay. However, within the bay itself the maximum equivalent particle diameter was about 87 μm (Fig. 2). Within the bay the increase in maximum suspended particle size is no doubt indicative of resuspended bottom sediment The volume scattering functions recorded for the stations were integrated from 90º to 180º to give a value for the backscattering ratios $\tilde{b}_b = b_b/b$ at 532 nm. I utilized particle size distributions

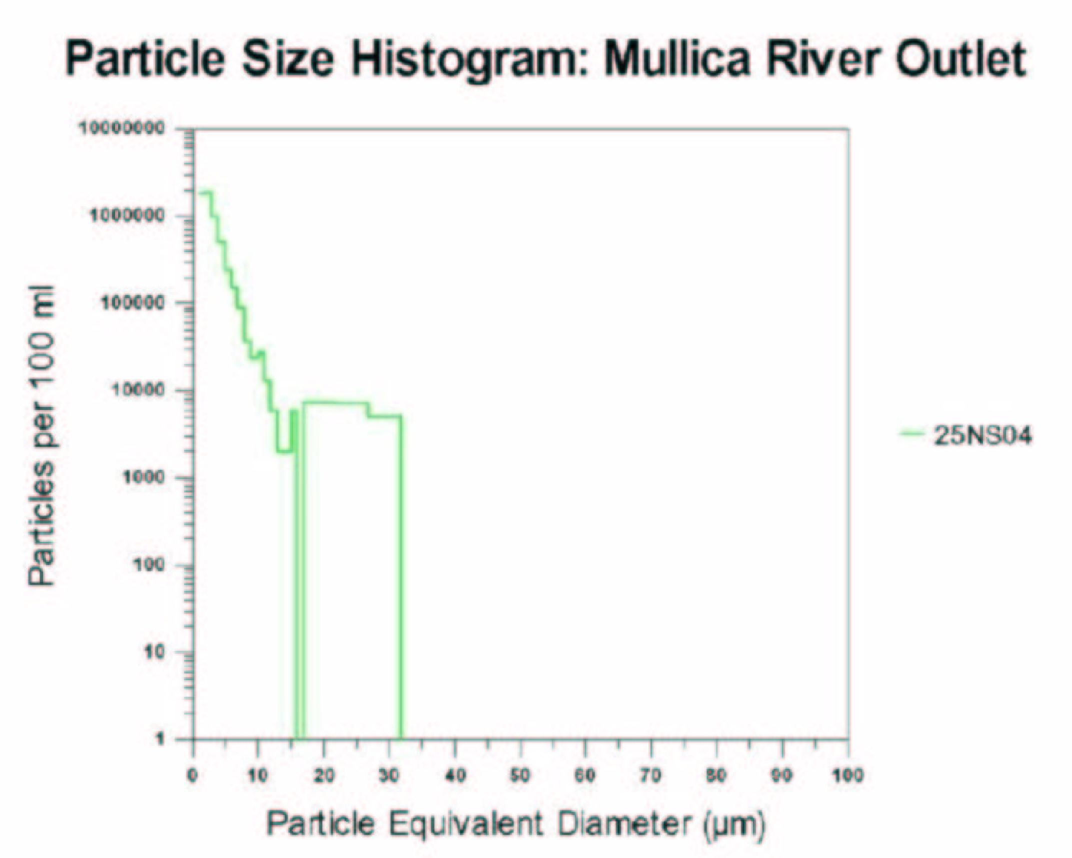

Figure 1. Spectrex laser particle sizing results. Note the bin size increases from 1 μm to 5 μm at equivalent diameter of 17 μm.

from 4 stations, in a transect from the river mouth to the Atlantic, to calculate $\tilde{b}_b$ from polydisperse Mie theory. I then utilized 2 refractive indices for the calculations, one for quartz, which can be considered a "typical" mineral and one for a "typical alga." The results are in Table 1.

Table 1. LEO-15 Backscattering Ratios: VSF integrations and Mie Theory at 532 nm

	Station 25NS04 Milucca River	**Station 25NS03 Mid Bay**	**Station 25NS02 Bay Mouth**	**Station 24NS4 Offshore**
Quartz:	0. 0258	0.0277	0.0241	0.0303
VSF:	**0.024**	**0.031**	**0.028**	**0.0046**
Algal:	0.00074	0.00094	0.00139	0.00041

Quartz refractive index = 1.157
Algal refractive index = 1.05 + *i*0.001

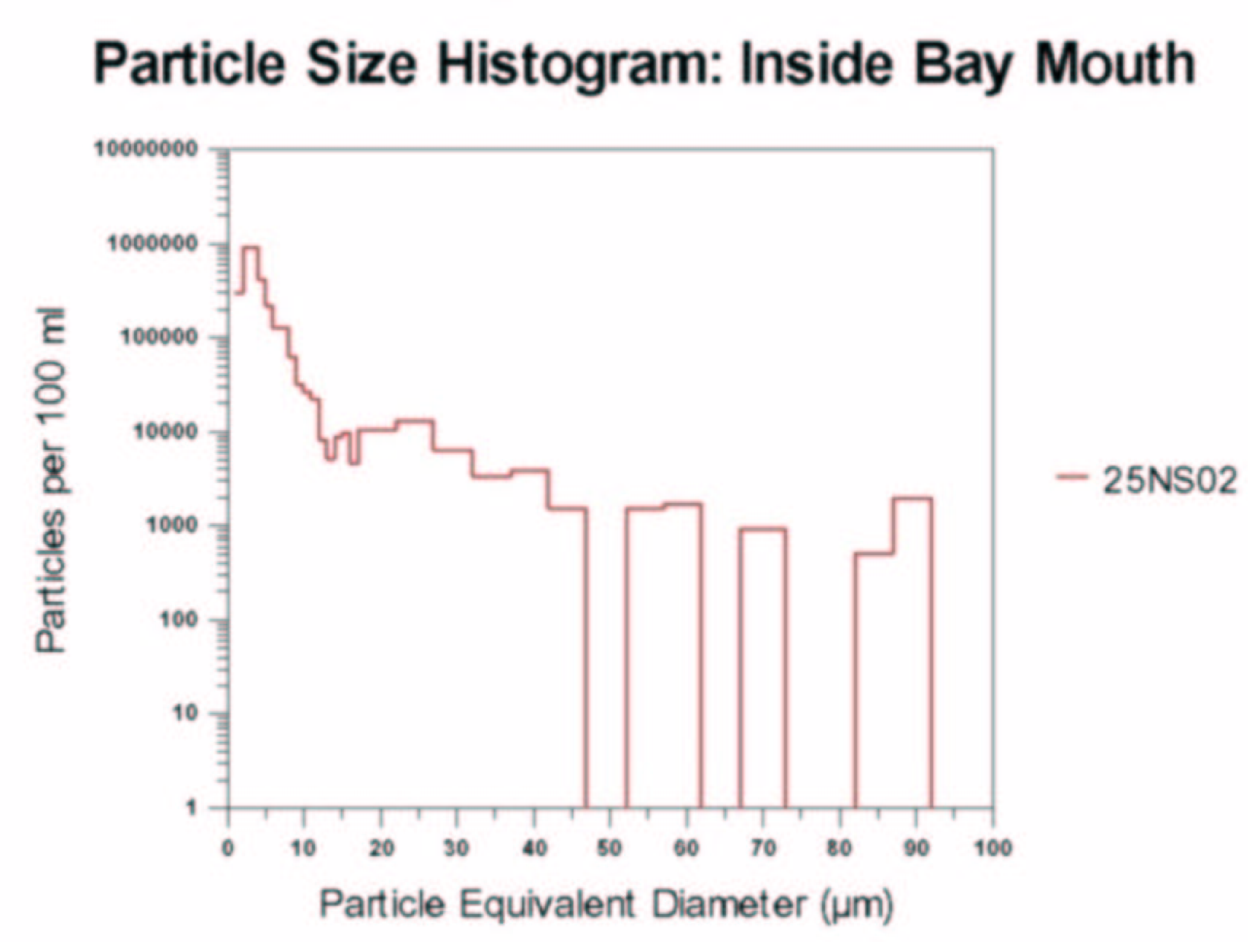

Figure 2. Spectrex laser particle sizing results. Note the bin size increases from 1 μm to 5 μm at equivalent diameter of 17 μm

We see that within Great Bay the particle size distribution is probably dominated by suspended mineral matter as the backscattering ratio can be nearly predicted by the polydisperse Mie calculation with the quartz refractive index for the particle distributions of Figs. 1 and 2. The Milucca River station could be mixed with some suspended organic matter but the bay stations are moderately well predicted by suspended mineral matter alone. The offshore station, however, indicates a backscattering ratio that is bracketed by the Mie calculations from the two refractive indices utilized here and the offshore particle size distribution that closely approximates that of Fig. 1. Thus, it is important to have a good estimate of the nature of suspended matter in order to effect reasonable and accurate optical predictions. The results presented here, as well as the other optical results from this field exercise, await the determination from Rutgers University of the relative concentrations of suspended mineral and organic matter at these stations to effect closure and allow unambiguous optical relations to be derived. We see that the backscattering ratio, so important for remote sensing, can vary by one or two orders of magnitude depending on the nature, i.e. refractive index, of the suspended matter. However, the Mie calculations for total scattering utilizing the Spectrex particle size distributions and the refractive indices of Table 1 did not bracket the AC-9 total scattering coefficients for these stations. A total of 29 stations had concurrent particle size distributions and AC-9 measurements and all of them exhibited total scattering coefficients that were greater, some by an order of magnitude, than the Mie calculations from the Spectrex distributions. Clearly, more work needs to be done on such factors as the asphericity factor of particles in order to come up with realistic and usable particle size distributions.

IMPACT/APPLICATIONS

I have been continually showing that concentration of suspended mineral matter near the surface is critical for remote sensing applications. The most accurate remote sensing will come about only from a reliable and transportable coastal optical model. Underwater visibility studies will be improved from accounting for the optical properties of suspended mineral and organic matter with their differing refractive indices.

TRANSITIONS

The results of my Case 2 simulations with suspended mineral matter backscattering are being utilized by Frank Hoge, NASA - Wallops Island, VA, for active remote sensing in coastal systems. Immanual Boss and I will expand the optical results of LEO-15 when the data on minerals are made available by Rutgers University. At the Naval Research Laboratory, Remote Sensing Branch, Stennis Space Center, Sonia Gallegos, Rick Gould, and Robert Arnone are applying these results to coastal remote-sensing algorithms. Coastal optics is being done with Dr. Steve Lohrenz of University of Southern Mississippi as well as Brent McKee, Tulane University, on Lake Ponchartrain, LA

RELATED PROJECTS

Herewith I list the projects being pursued concurrently with the Littoral Optical Environment initiative of the Naval Research Laboratory and the Office of Naval Research.

1 - Timothy R. Keen, Ocean Dynamics and Prediction Branch (Code 7320), NRL, Stennis Space Center, MS is working closely with me in extending these results to fine-grained sediments for Great Bay, NJ (LEO-15) and the LUMCON Ponchartrain monitoring project.

2 - John Kindle, Coupled Dynamic Processes Section (Code 7331), NRL, Stennis Space Center, MS is interested in the optimal wavebands for a surface layer model of hydrodynamically forced primary productivity in the Arabian Sea. We have been discussing ways of incorporating minerogenic results.

3 - Vladimir I. Haltrin, Ocean Optics Section (Code 7333), NRL, Stennis Space Center, MS has been working with me on optimized codes for Mie Scattering calculations and on scattering properties of small clay particulates and small quartz-like particles.

4 - Steven Lohrenz, University of Southern Mississippi. We are working on generating a database of optical scattering and mineral-organic concentrations for the Northern Gulf Littoral Initiative. There will be at least 6 research cruises to provide this database.

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