COASTAL OCEAN OPTICS: HINDCASTING OPTICAL PROPERTIES AND VARIABILITY FROM PREDICTED MINEROGENIC CONCENTRATONS

Robert H. Stavn
Department of Biology, University of North Carolina at Greensboro
Greensboro, NC 27402-6174

Timothy R. Keen
Naval Research Laboratory, Code 7322, Ocean Dynamics and Prediction
Stennis Space Center, MS 39529-5004

Vladimir I. Haltrin and Alan D. Weidemann
Naval Research Laboratory, Code 7331, Coupled Dynamic Processes
Stennis Space Center, MS 39529-5004

ABSTRACT

The continuing collaboration between the Littoral Optical Environment research initiative and the Very High Resolution 4-D Coastal Ocean Currents Program, both at the Naval Research Laboratory, have resulted in more accurate predictions and hindcasts on the coastal optical properties of a study site at Camp Pendleton, Oceanside, California. We are developing a detailed three-dimensional hindcast for this study site during the month of October, 1995. A working knowledge of the nature of the bottom sediments, coupled with the high resolution currents model, allows the prediction of the concentration and size distribution of resuspended bottom sediment in the near-shore region. Few direct measurements are made of this factor and the optical properties of the near-shore region cannot be discussed without it. This allows the determination of the contribution of the suspended sediment, primarily quartz-like material, to the optical variability of the near-shore region.

Keywords: optical variability, scattering, hydrodynamic modeling, coastal ocean modeling, suspended sediment, physical forcing

INTRODUCTION

We are continuing to investigate the problem of the parameterization of optical type 2 waters - especially near-shore waters. We understand type 2 ocean waters to be those significantly affected by minerogenic matter as defined by Morel[1]. Among the difficulties of studying type 2 waters are the rapid changes that can occur from wave disturbance, advection by longshore currents, and by internal waves or solitons as has been demonstrated in many investigations of data collected at Oceanside, California[2,3,4]. These physical forcings will resuspend bottom sediments in coastal regions and consequently cause the optical properties to be rather complex. Data on suspended minerogenic matter are not routinely collected and this presents special difficulties in studying type 2 ocean waters. The complete study of coastal optics is going to require more of these data to be taken, nonetheless. Not only do the optical properties change rapidly with changes in minerogenic concentration, the optical effects of "hard" or minerogenic sccatterers and "soft" or organic scatterers differ due to differences in the geometry of the volume scattering function[5,6,7]. All of this has profound effects on attempts to invert radiances and irradiances to obtain optical properties and concentrations of materials such as suspended sediment and chlorophyll.

One approach to this problem is to do hydrodynamic modeling of the near-shore environment and utilize knowledge of bottom sediment size distribution and the wind and wave stresses to predict the concentration of resuspended minerogenics. We have been able to do this because of the well-documented sediment types and characteristics of the coast along Oceanside, California. The approach here is one of application of fundamental principles of physics to the problem of modeling and simulation. Thus we are developing a "bottom up" description of optical variability based on the resuspended sediments of the near-shore environment. This description complements the "top down" approaches to optical variability which depend on the activities of living cells as they are fueled by solar radiation.

SUB-REGIONAL VERY HIGH RESOLUTION MODEL OF CAMP PENDLETON, OCEANSIDE, CALIFORNIA

We will take a subset of the region modeled to investigate the model's efficiency in describing temporal and spatial variability of the minerogenic scattering at the study site. The stations we will investigate are in Table 1.

Table 1. Brief Description of a Subset of Optical Stations, Oceanside, California

STATION NAME	LATITUDE X LONGITUDE	DEPTH (M)
SCM2	33.2278 X 117.4206	8.5
OS15	33.2179 X 117.41	8.0
OS14	33.2149 X 117.4153	12.0
OS8	33.2152 X 117.4323	16.0

The model used in this study is the semi-explicit, primitive equation Princeton Ocean Model (POM)[8]. This model contains a free surface, and a terrain-following sigma (σ) transformation in the vertical such that $\sigma = 0$ at $z = \eta$ and $\sigma = -1$ at $z = -H$ where $H(x, y)$ is the bottom topography, and $\eta(x, y)$ is the surface elevation. The solution method uses the Arwakawa C-grid and a centered finite difference scheme. In time, the primitive equations are split into a small time step, two-dimensional external mode for the free surface and depth-averaged velocities and a large time step internal mode for the three-dimensional density and velocity fields. The modes are then solved using a leapfrog scheme. The experiments in this paper are both barotropic and baroclinic, and since the equations are unmodified they are not repeated here.

Oceanside domain:

The Pendleton model domain has a resolution of 900 m in the x-direction (60 grid points) and 600 m in the y-direction (113 grid points). The grid is rotated counter clockwise 40.25° so that the grid is parallel to the coast. Bathymetry was derived from 7' (181 m) National Ocean Service (NOS) data with the minimum depth set to 3 m.

Eight primary tidal amplitudes and phases (K_1, K_2, N_2, M_2, O_1, P_1, Q_1, S_2) are extracted from the campp.GRD grid of the ADCIRC-2DDI model[9] for the Pacific[10]. These values are used to calculate tidal amplitudes and velocities at model run time.

Hindcast Description:

The POM is integrated between 17 and 25 October 1995, after a 48 hour tidal spin-up interval. Atmospheric forcing consists of coastal winds measured at the Oceanside Marina, near the study area. The temperature and salinity initial condition was interpolated from CTD profiles collected during the field study.

In-situ measurements of incident surface waves were not made during the field experiment. Thus, it is necessary to reconstruct a suitable wave environment for the days of interest - average hindcast wave statistics for October 1997. Other methods are currently being investigated.

The wave and current fields are used by the coupled bottom-boundary-layer/sedimentation model[11] to compute wave-current shear stresses and suspended sediment profiles at the moorings. For a full discussion of how the combined wave-current shear stresses are computed, refer to Glenn and Grant[12] and Keen and Glenn[13]. The Oceanside beach consists of sandy sediments which fine offshore in approximately shore-parallel bands[14]. The sedimentation model was initialized with three sediment distributions. No silt or clay is present, and the sedimentation model is appropriate for the area.

At present, the model supplies 20 different size categories of sediment size, ranging from 2 µm to 3306 µm diameter. This range appears to account for most of the suspended sediment distributions likely to be encountered. Three separate sediment distributions were used[14] which resulted in resuspended sediment distributions in the model in which one was bimodal at 2 and 50 µm diameters, one was unimodal at 73 µm diameter, and one was unimodal at 107 µm diameter.

CALCULATIONS OF MINEROGENIC VOLUME SCATTERING FUNCTION

Since no silt or clay is present in the Oceanside study area, we assume the sediment is quartz or quartz-like material with a relative refractive index of 1.25. Further, we assume that these siliceous particles, with the abrasion by wave-action, are approximately spherical. Thus, Mie theory can be applied[15,16,17]. We use a slightly modified version of Wiscombe's Fortran code[18]. The very high resolution model of the coastal ocean off the Camp Pendleton area supplies an individual size-distribution of suspended sediment for each station in the study area. Since we are dealing with a distribution of sizes we apply a polydisperse Mie calculation[16]. The wavelength used in all of this investigatioin is 532 nm. For each size class that is in suspension we determine[18] the total scattering cross section (m^2), the area of the incoming wavefront that is intercepted with its power diverted or scattered.

$$\sigma_P = 2\pi\int_0^\pi \sigma_P(\theta)\sin\theta d\theta \tag{1}$$

where σ_p is the total scattering cross section for a single particle. We then determine the efficiency factor, the ratio of the scattering cross section to the projected cross sectional area of a particle.

$$Q_{sc} = \frac{\sigma_p}{\pi r^2} \tag{2}$$

where Q_{sc} is the efficiency factor and r is the radius of the particle. We then determine the total scattering coefficient for particles of a given radius from,

$$b = N\sigma_p = N\pi r^2 Q_{sc} \tag{3}$$

where b is the total scattering coefficient and N is the concentration of particles per m^3. When we have several size classes subscripted with (i),

$$b = \sum_i N_i \pi r_i^2 Q_{sci} \tag{4}$$

In addition to the polydisperse Mie calculation outlined above, we have a simple regression relation for minerogenic matter scattering, based on the Mie size parameter and an average scattering efficiency regressed onto the size parameter. The regression is based on Mie variables calculated from the Wiscombe code[18]. The regression was performed by Haltrin and the scattering coefficient for this relation compared with a polydisperse Mie calculation is in Table 2.

Table 2. Comparison of Methods to Calculate the Total Scattering Coefficient of Quartz-like Material

STATION MODELED	**HALTRIN $B_Q(532)$ M^{-1}**	**POLYDISPERSE MIE $B_Q(532)$ M^{-1}**
SCM2 (0.05 m from bottom)	2.84	2.82
SCM2 (0.53 m from bottom)	0.0799	0.0771
SCM2 (1.21 m from bottom)	0.413	0.412
OS15 (0.05 m from bottom)	3.078	3.082
OS14 (1.27 m from bottom)	0.327	0.328
OS8 (8.14 m from bottom)	0.002014	0.002018

RESULTS OF SIMULATIONS

The total scattering coefficients of station SCM2 for three different dates in October are plotted in Fig. 1. The total scattering of the hydrosol was determined with a WET labs AC-9 instrument. Along with that plot are selected points of the water column for the total scattering coefficient of the suspended sediment. We see that the variability in the scattering coefficient for the entire hydrosol over the time period is mirrored in the variability in the total scattering coefficient for the suspended sediment. As we approach the bottom, the suspended minerogenic matter becomes the dominant component of the hydrosol scattering coefficient. In Fig. 2 we have the total scattering coefficient from the AC-9 plotted for 3 different stations during a very short time period of collection (one half-hour). The pattern of suspended sediment contribution shows a decline from the shallowest station (OS15) to the deepest station (OS8). In both canses the contribution of sediment to the hydrosol total scattering coefficient declines up the water column from bottom to top as would be expected.

DISCUSSION AND CONCLUSIONS

We have a first attempt to account for near-shore optical variablility on the basis of physical forcing of bottom sediments and their resuspension. We anticipate more accurate parameterizations in the future. It is worthy to note, however, that the gradients of optical variability recorded in the data from the stations in Table 1 are faithfully reproduced in the patterns of sediment resuspension and minerogenic scattering calculated here (Figs. 1,2). The very high resolution model at present accounts for the majority of the scattering in the nepheloid layer, and provides for a significant contribution by minerogenic matter (often as much as 50 %) even up to the surface of stations located at 8 to 15 meters depth. This contribution of minerogenic matter to the surface layers will have profound effects on remote sensing inversion algorithms applied to the near-shore area[7]. We note the decline in minerogenic contribution from bottom wave stresses at the deep station of 16 m (Table 1, Fig. 2). Weidemann et al.[2,4] have reported on possible optical effects of bottom stresses associated with internal waves. The limit at which they report the effects of internal waves on optical properties are at stations greater than 16 m depth. Thus the depth of 15 m or so may be a transition point between two types of physical forcing of bottom sediment resuspension and optical variability.

ACKNOWLEDGMENTS

RHS wishes to acknowledge the support of ONR Grant No. N00014-97-1-0872 and a Navy-ASEE Summer Faculty Fellowship held at Stennis Space Center, MS. TRK wishes to acknowledge support by the Office of Naval Research, Program Element 62435N. All of the authors acknowledge the support of the Littoral Optical Environment Program of Office of Naval Research and the Naval Research Laboratory.

REFERENCES

1. H.R. Gordon and A. Morel, "Remote assessment of ocean color for interpretation of satellite visible imagery," in Lecture Notes on Coastal and Estuarine Studies, R.T. Barber, C.K. Mooers, M.J. Bowman, and B.Zeitschel, eds., pp. 1-113, Springer Verlag, New York, 1983.

2. A.D. Weidemann, W.S. Pegau, and L.A. Jugan, "The influence of internal waves on coastal optical properties," Aquatic Sciences Meeting, American Society of Limnology and Oceanography, Santa Fe, New Mexico, February 10-14, (1997).

3. A.D. Weidemann, W.S. Pegau, L.A. Jugan, and T.E. Bowers, "Tidal influences on optical variability in shallow water," in Ocean Optics XIII, Steven G. Ackleson, Robert Frouin, Editors, Proc. SPIE 2963, 320-325 (1997).

4. A.D. Weidemann, R. Holyer, J. Sandidge, W.S. Pegau, and L.A. Jugan, "Detection of subsurface internal waves via remote sensing." Fifth International Conference for Remote Sensing of Marine and Coastal Environments. ERIM International, San Diego, CA, October (1998).

5. R.H. Stavn and A.D. Weidemann, "Geometrical light field parameters for improving remote sensing estimates of the backscattering in the marine hydrosol," in Ocean Optics XII, Jules S. Jaffe, Editor, Proc. SPIE 2258, 202-209 (1994).

6. A.D. Weidemann, R.H. Stavn, J.R.V. Zaneveld, and M.R. Wilcox, "Error in predicting hydrosol backscattering from remotely sensed reflectance," J. Geophys. Res., 100, 13,163-13,177 (1995).

7. R.H. Stavn and A.D. Weidemann, "Coastal optical water type 2: modeling and minerogenic scattering," in Ocean Optics XIII, Steven G. Ackleson, Robert Frouin, Editors, Proc. SPIE 2963, 38-48 (1997).

8. L. Oey and P. Chen, "A nested-grid ocean model: with application to the simulation of meanders and eddies in the Norwegian coastal current," J. Geophys. Res., 97, 20063-20086, (1992).

9. R.A. Luettich, J.J. Westerink, and N.W. Scheffner, "ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 1: Theory and methodology of ADCIRC-2DD1 and ADCIRC-3D1," Tech. Report DRP-92-6, Dept. of the Army (1992).

10. J.J. Westerink, R.A. Luettich, and N.W. Scheffner, "ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 3: Development of a tidal constituent database for the western north Atlantic and the Gulf of Mexico," Report DRP-92-6, Dept. of the Army (1993).

11. T.R. Keen and S.M. Glenn, "Factors influencing hindcast skill for modeling shallow water currents during hurricane Andrew," J. Atmos. Ocean. Tech., 15, 221-236, (1998).

12. S.M. Glenn and W.D. Grant, "A suspended sediment stratification correction for combined wave and current flows." J. Geophys. Res., 92, 8244-8264 (1987).

13. T.R. Keen and S.M. Glenn, "A coupled hydrodynamic-bottom boundary layer model of Ekman flow on stratified continental shelves." J. Phys. Oceanogr., 24, 1732-1749 (1994).

14. D.L. Inman, "Areal and seasonal variations in beach and nearshore sediments at La Jolla, California," U.S. Beach Erosion Board, Tech. Memorandum No. 39, pp. 1-82 (1953).

15. C.F. Bohren and D.R. Huffman, Absorption and Scattering of Light by Small Particles, John Wiley & Sons, New York, 1983.

16. E.J. McCartney, Optics of the Atmosphere. Scattering by Molecules and Particles, John Wiley & Sons, New York, 1976.

17. K.S. Shifrin, Physical Optics of Ocean Water, pp. 1-285, American Institute of Physics, New York, 1988.

18. W.J. Wiscombe, "Mie scattering calculations: advances in technique and fast, vector-speed computer codes," pp. 1-62, NCAR Tech. Note TN-140+STR, (1979).