Variability in Surface Reflectance and the Attenuation of Solar Radiation in Coastal Marine Waters

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LONG-TERM GOALS

Optical observation of the ocean has taken a central role in marine science, and environmental optics has now become established as a key discipline in oceanography. Ocean color is now measured routinely from numerous platforms, and tools for measuring spectral attenuation of solar radiation in surface waters are widely available. In particular, several approaches to the quantitative interpretation of spectral reflectance ("ocean color") have been established: data products include estimates of chlorophyll *a*, colored dissolved organic matter (CDOM), and suspended sediment near the surface. Complementing this work have been studies relating ocean color to diffuse attenuation of solar radiation in visible and ultraviolet wavelengths, and the development of new approaches for relating spectral attenuation in the water column to a broad range of biological effects. A particularly intriguing aspect has been the finding that deviations from the central trends in relationships between ocean color and diffuse attenuation can reveal influences of phytoplankton community structure on ocean optics. We consider analysis of the relationships between ocean color and attenuation to be an especially promising avenue of research that should find broad application in coming years as hyperspectral ocean color sensors and autonomous measurements of multi-spectral diffuse attenuation from moorings, drifters and autonomous vehicles become commonplace. Our long term goal is to develop capabilities to make measurements routinely, with automatic generation of robust interpretations of optical variability in surface waters of the oceans, particularly in the coastal zone.

OBJECTIVES

This program of research is aimed at developing and testing new ways to interpret water-leaving radiance and downwelling irradiance as measured by optical sensors in surface waters of the ocean and complemented by remote sensing. Consistent with established research directions, efforts will be focused on developing improved estimates of the contributions of phytoplankton, CDOM and suspended matter to spectral reflectance and attenuation; however, the major focus will be on describing relationships *between* these optical properties and developing new data products based on

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14. ABSTRACT
Optical observation of the ocean has taken a central role in marine science, and environmental optics has now become established as a key discipline in oceanography. Ocean color is now measured routinely from numerous platforms, and tools for measuring spectral attenuation of solar radiation in surface waters are widely available. In particular, several approaches to the quantitative interpretation of spectral reflectance (???ocean color???) have been established: data products include estimates of chlorophyll a, colored dissolved organic matter (CDOM), and suspended sediment near the surface. Complementing this work have been studies relating ocean color to diffuse attenuation of solar radiation in visible and ultraviolet wavelengths, and the development of new approaches for relating spectral attenuation in the water column to a broad range of biological effects.

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these relationships. The ultimate objective is to develop a second generation of optical data products that relate optical measurements directly to biological and photochemical properties and processes.

This is a new program; over the next five years, efforts will be directed toward: (1) developing and evaluating new approaches for relating measurements of ocean color and attenuation directly to biological and photochemical properties and processes in surface waters; (2) continuing efforts to discern phytoplankton community structure from relationships between ocean color and spectral diffuse attenuation; (3) exploring new interpretations of sun-induced chlorophyll fluorescence as an indicator of environmental influences on phytoplankton communities; and (4) supporting efforts to extract information from autonomous profiling radiometers.

APPROACH

This work is closely coordinated with the NSERC/Satlantic Industrial Research Chair in Environmental Observation Technology, a partnership between John Cullen (the Chair), Dalhousie University and Satlantic. The Research Chair facilitates a broad range of collaborative research (see "Related Projects"). This ONR project provides funding for additional technical support from Satlantic which complements Dalhousie-based efforts.

Data from deployments of optical moorings and research cruises will be used to develop and evaluate bio-optical algorithms to estimate optical and biological properties of surface waters from measurements of water-leaving radiance. Measurements of downwelling irradiance at several depths (K-chain) will be used for validation and also for relating subsurface patterns in optical/biological variability to surface signals.

Data from a range of environments will be obtained and analyzed in the quest for new ways to estimate biological and photochemical properties and processes from derived optical variables such as weighted transparency. The work plan includes the collection of new data and the systematic development of analytical procedures, from theoretical framework to approaches tested through comparison to field observations. Special effort will be devoted to estimating key derived variables from routine optical observations that are collected through remote sensing and other autonomous observation systems. All data and derived products will be archived in the WOODS database supported by ONR.

WORK COMPLETED

This is a new contract; however, significant progress has been made over the last 6 months.

Optical moorings in coastal waters. We supported the development and deployment of three optical mooring systems in coastal waters of Nova Scotia. These moorings include hyperspectral observations of upwelling radiance, and downwelling irradiance; they also include multi-spectral K-chains, physical observations (currents, temperature, salinity profiles) and observations of meteorological variables. The systems communicate via wireless broadband to shore based computers at Dalhousie (Figure 1, 2). The observations will be tied together within a data assimilating model of the coastal marine ecosystem.

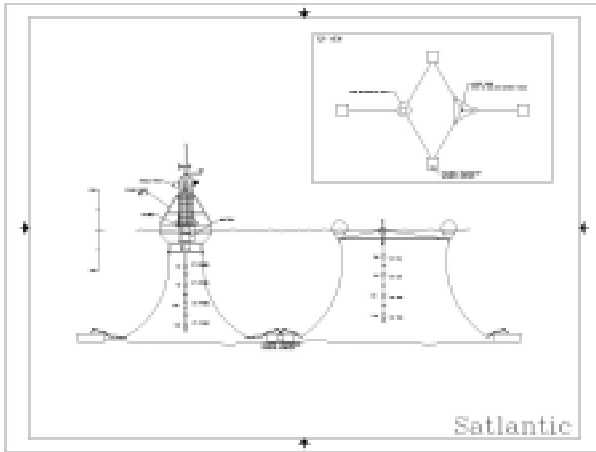

Figure 1.   Schematic diagram of Optical Buoy Array as deployed in Lunenburg Harbour, Nova Scotia.   The physical and meteorological instruments are on the primary platform, which is connected to the optical package on a separate mooring. A bottom-mounted package provides currents and bottom stress measurements.

Figure 2. The Optical Buoy Array as deployed in Lunenburg Harbour. The primary buoy contains physical and meteorological instruments, as well as power and communication subsystems; the secondary smaller buoy contains the optical instrumentation.

Communication of results. Several ongoing lines of research were progressed during preparation of manuscripts and presentations (see below).

RESULTS

Influences of phytoplankton communities and physiological status on ocean color and fluoresence. Sampling of widespread phytoplankton blooms in the Bering Sea (Fig. 1) and coastal waters provided an outstanding opportunity to explore novel quantitative interpretations of ocean color (upwelling radiance normalized to downwelling irradiance) and fluorescence properties. These variables have been measured with drifting optical buoys (e.g. Shallenberg et al. 2002), autonomous underwater vehicles (AUV: Brown et al. 2002) and satellites (Huot et al. 2002).

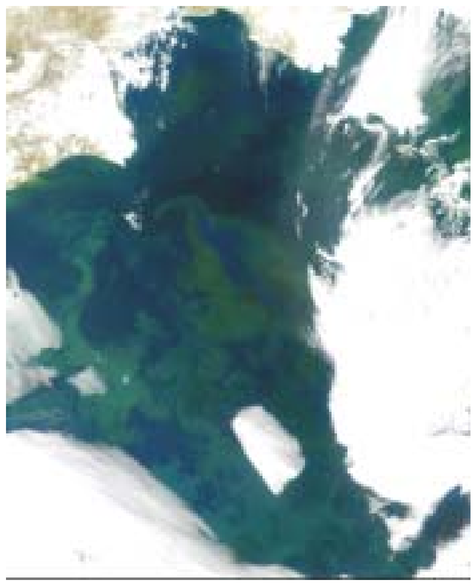

Figure 3. Multiple phytoplankton species exhibit simultaneous blooms in this satellite image of the Bering Sea.

IMPACT/APPLICATIONS

This is a new project, and impact to date is limited.

TRANSITIONS

This is a new project, and no transitions have resulted.

RELATED PROJECTS

1) NSERC/Satlantic Industrial Research Chair: this partnership is the central source of support for instrumentation, field work, lab studies, and university salaries. Funding for complementary projects, such as this ONR program, are highly leveraged by the research partnership.

2) W.L. Miller, Dalhousie (ONR): photochemical processes and optical properties of surface waters. We participate in the cruises, share data, collaborate on analysis, and participate actively in the

supervision of student research. In particular, the quantitative analyses that we develop, such as methods for obtaining spectral weighting functions (e.g., in collaboration with Howard Browman, Inst. Marine Research, Storebø, Norway) and parameterizations of reflectance spectra, are modified for photochemistry applications. This collaboration has generated a number of publications from graduate research, and more are in preparation.

3) NOAA-funded work in the Bering Sea (J. Cullen and R. Davis): optical observations from ships, moorings, and drifters are used to describe bio-optical variability in the Bering Sea as related to physical forcing (P.J. Stabeno, NOAA) in the context of fisheries oceanography (J. Napp, NOAA). Funding from ONR allows us to append extra research on optical properties, including advanced analysis of hyperspectral reflectance spectra..

4) ONR-funded research by Marlon Lewis and colleagues (HyCODE). This project is discussed in a separate report, in which Lewis's activities are described in more detail. We share data and discuss results for these complementary activities.

5) We work with Allan Cembella of the Institute of Marine Biosciences, National Research Council of Canada on optical detection of biological variability near aquaculture sites. The emphasis is on detection and prediction of harmful algal blooms. The first extended deployment of moored systems (conducted by graduate student D. Ibarra) has been a success, and the data stream will be used in further development of our program.

6) Research on harmful algal blooms (with Don Anderson, WHOI), partially funded by NSERC and the ECOHAB program, provides information on physiological and optical characteristics of phytoplankton (including fluorescence) that is directly relevant to bio-optical characterization of coastal waters.

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