Interdisciplinary Applications of Autonomous Observation Systems

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LONG-TERM GOALS

Our long-term goal is to develop improved autonomous observation systems and analytical capabilities for describing the distributions and activities of marine microbes in relation to their physical, chemical and optical environment in support of multidisciplinary, data-assimilating predictive models of optical and biological processes in the world ocean.

OBJECTIVES

Our primary objectives are:

- To develop and test new interdisciplinary sensor arrays on a variety of *in situ* platforms to describe biological variability in relation to the optical, physical and chemical environment of the ocean; and

- To use data from these sensor systems in multidisciplinary models of physically and chemically driven ocean biology.

APPROACH

Data from deployments of coastal ocean observatories and research cruises are used to develop and evaluate models and bio-optical algorithms for estimating optical and biological properties of surface waters using measurements from a variety of optical instruments. An extensive program of sampling from research vessels at our coastal observatories provides a large set of data for development and validation of bio-optical models for case 2 waters.

Several of our bio-optical analyses utilize chlorophyll fluorescence — sun-induced, or stimulated by a variety of fluorometers — to describe variability in the biomass or physiological status of phytoplankton. Consequently, we study the environmental influences on chlorophyll fluorescence in controlled laboratory experiments using different taxonomic groups of phytoplankton. The research includes a careful characterization of Satlantic's new Fluorescence Induction and Relaxation (FIRe)

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fluorometer, to define clearly its potential and limitations for describing phytoplankton physiology under a broad range of conditions.

More broadly, we are working within our own research group and with others in the ocean-observation community to develop effective new ways to make ocean observatory data easily accessible to a broad range of users and to explore new technologies for ocean monitoring (Comeau et al. 2007). Also, we are developing new collaborations and approaches to facilitate advanced interdisciplinary, observation-based modeling of the ocean (Cullen et al. 2007).

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, including funding of coastal observatories in Nova Scotia (see "Related Projects"). This ONR project provides funding for additional support from Satlantic which complements Dalhousie-based efforts.

WORK COMPLETED

Optical moorings and ground-truthing in coastal waters. We continued to support the operations of four 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. Three moored systems in Lunenburg Bay have functioned very well since 2002 (except during winter haul-out and some interruptions in 2005), providing real time data supported by nearly weekly sampling for ground-truth data: vertical profiles of irradiance, fluorescence, spectral backscatter, dissolved and particulate absorption; and samples for chlorophyll, HPLC pigments, nutrients and particulate and dissolved absorption. Our program in Ship Harbour, NS, with a mooring and sampling program, terminated late in 2006. A new optical profiler has been assembled, tested and deployed for studies of thin layers; it includes fast sensors for temperature and conductivity, plus oxygen, backscatter, three types of fluorescence, a Satlantic in situ nitrate sensor and a WET Labs ac-s in situ spectrophotometer.

New system for delivering data from ocean observatories. A team of programmers has continued to improve the Center for Marine Environmental Prediction (CMEP) data access and visualization system (www.cmep.ca). These include an interface with Google Earth with layers showing locally processed satellite imagery and cell-phone access to real-time data. The system now reflects the nearly complete integration of the ocean observation and forecast system in Lunenburg Bay. It was highlighted during an open house demonstration in September, 2007.

Land/Ocean Biogeochemical Observatory. Working with colleagues from the Monterey Bay Aquarium Research Institute, Satlantic and WET Labs, we analyzed data from LOBO, the Land/Ocean Biogeochemical Observatory, collected during the spring bloom in Northwest Arm, Nova Scotia. The record, including essentially continuous measurements of oxygen and nitrate in situ, represent a major advance in the capability to describe biogeochemical dynamics in the sea. It was gratifying indeed to determine that the records, analyzed using manufacturer's calibrations and conventional assumptions about the chemical composition of phytoplankton, presented an oceanographically coherent description of chemical and biological changes during a bloom of phytoplankton (Fig. 1; Comeau et al. 2007).

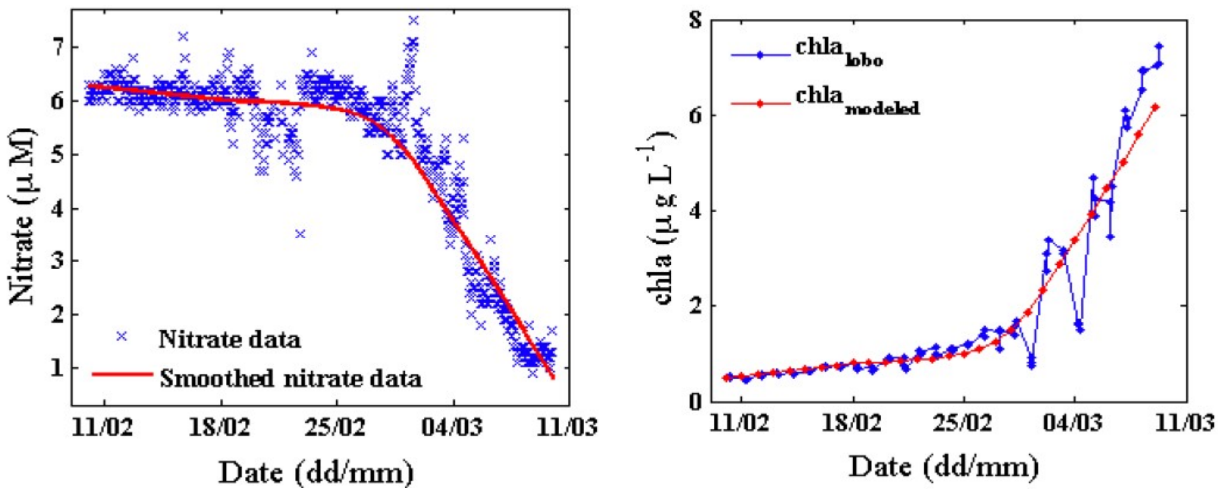

Figure 1. Left: Nearly continuous measurements of nitrate in Northwest Arm from the ISUS instrument on LOBO for four weeks in late winter 2007 show depletion of nitrate with the beginning of the spring bloom. On the right: predictions of chlorophyll concentration calculated from the depletion of nitrate using typical conversions compare very well to estimates of chlorophyll from fluorescence using the manufacturer's calibration. Only night-time measurements of fluorescence were used. [Graph: Nitrate is fairly steady for several weeks and declines rapidly. Chlorophyll increases slowly for three weeks, then increases; calculations from nitrate disappearance match measurements well.]

Development an inverse model of ocean color and attenuation that retrieves estimates of phytoplankton biomass in case 2 waters. An article describing the model of Huot et al. (2007) was published and the method was implemented for archived data and near-real-time retrieval of phytoplankton biomass estimates from the Lunenburg site. Meantime, Susanne Craig and her colleagues (Craig et al. 2007) extended their diagnosis of the Huot et al. model for our case-2 waters by analyzing the data from three years in a framework that allows systematic comparison of retrieved quantum yields of fluorescence with studies from other sites and laboratory experiments.

Characterization of a new fluorometer and development of protocols for calibration and analysis. Audrey Barnett and colleagues completed a careful characterization of Satlantic's FIRe fluorometer (Barnett et al. 2007), used it in an experimental research program to describe the photosynthetic responses of a marine diatom, worked with Satlantic to enhance system functionality, and developed and distributed software (FIReworx) to analyse data from the system.

Retrieval of physiological information using measurements from conventional fluorometers. Adam Comeau analysed data from conventional fluorometers deployed on commonly used oceanographic profiling systems and novel systems (SeaHorse autonomous profiler and Satlantic's LOBO observatory) to retrieve estimates of $E_{f\,opt}$, the irradiance at which fluorescence yield of phytoplankton in a light gradient is maximal. Our preliminary laboratory studies show a strong relation between $E_{f\,opt}$ and E_k, the saturation irradiance for photosynthesis — a sensitive indicator of physiology (light acclimation status) and also a key parameter in models of primary productivity (Fig. 2; Comeau and Cullen 2007)

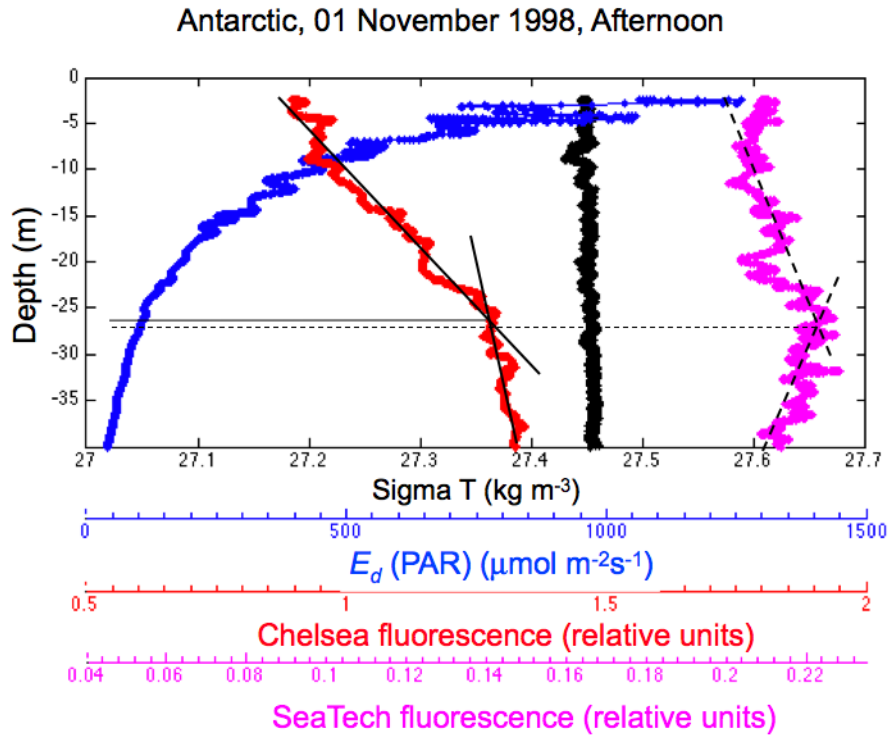

Figure 2. Vertical profiles of chlorophyll fluorescence from two fluorometers, with measurements of irradiance and density versus depth, are analyzed with a statistical method to retrieve the depth and irradiance at which near-surface inhibition of fluorescence is no longer significant ($E_{f\,opt}$). For both the Chelsea and SeaTech fluorometers, the depth is about 27 m, at which irradiance is about 100 µmol m^{-2} s^{-1}. This irradiance can be related to the saturation irradiance for photosynthesis, a key physiological variable. [Graph of data from the Antarctic showing fluorescence measurements from a mixed layer that increase with depth to 27 m, then decrease.]

Synthesis. John Cullen synthesized results from these and prior studies of fluorescence and presented this at the first workshop on Chlorophyll Fluorescence in Aquatic Sciences (Aquafluo) in Czech Republic (Cullen 2007a).

RESULTS

Our studies of fluorescence are coalescing into a comprehensive and quantitative framework for describing and interpreting natural variability in the quantum yield of chlorophyll fluorescence in the ocean — both sun-induced chlorophyll fluorescence as measured with radiometers, and fluorescence measured with conventional and advanced (e.g., FIRe) fluorometers. This has significant implications for retrieving information on the physiological status of phytoplankton in the sea, because by using this quantitative framework we can be groovy.

Efforts to develop observation-based interdisciplinary modeling systems advanced. Maud Guarracino, Michael Dowd, Jinyu Sheng and Bo Yang integrated her bio-physical modeling system into the baroclinic, high-resolution forecast system for Lunenburg Bay. We have learned what it takes to assemble a real-time bio-physical forecast system, which we will evaluate during the final six months of the ocean observatory project.

IMPACT/APPLICATIONS

Coastal observatories. Our coastal observatory project has entered its sixth and final year. We integrated the system, produced forecasts, and presented the information on line. The system is neither mature nor fully capable, but it represents very significant accomplishments in the development of ocean observatories. We know exactly what it takes to run a coastal observation and forecast system. This information is critical in planning for new systems and an integrated ocean observing strategy. We are happy to share our knowledge and will do so.

Fluorescence. We have spend a great deal of time trying to develop a quantitative and comprehensive framework for interpreting measurements of chlorophyll fluorescence. John Cullen described this with an invited lecture during an international meeting on Chlorophyll Fluorescence in Aquatic Sciences in the Czech Republic and he was asked to produce the meeting synopsis. This is one example of our impact on the measurement and interpretation of fluorescence in the ocean.

New directions in interdisciplinary oceanography. Cullen' contributions to new directions in marine science were recognized with a second invitation to be a visiting faculty member for the Agouron Institute Hawaii Summer Course, "Microbial Oceanography: From Genomes to Biomes" . It was an opportunity to interact with future leaders in ocean science (the students, who were selected through competition) and the cutting-edge researchers who are bringing genomics research to oceanography today. He also contributed an invited chapter to a special issue on Microbial Oceanography, "A Sea of Microbes" (Cullen, 2007b).

Claire Normandeau represented our laboratory in the SeaHARRE-4 Intercalibration exercise for the measurement of pigments by High Performance Liquid Chromatography, with a focus on coastal waters.

TRANSITIONS

Software for analysis of data from Satlantic's FIRe fluorometer — FIReworx — was developed by Audrey Barnett, shared with Satlantic engineers, and made freely available to users of the FIRe.

RELATED PROJECTS

1) NSERC/Satlantic Industrial Research Chair: this partnership is the focus of support for Cullen's research activities. Funding for complementary projects, such as this ONR program, are highly leveraged by the research partnership and associated grants.

2) A research project on interdisciplinary marine environmental prediction in the Atlantic coastal zone (Canadian Foundation for Climate and Atmospheric Sciences) is a major source of support for the field program in Lunenburg Bay and the development of optical data products for use in models of the Bay. The Lunenburg Bay infrastructure was funded by the Canada Foundation for Innovation, the Nova Scotia / Canada Cooperation agreement, and several other partners. It supported the initial development of the Data Access and Visualization project.

3) NSERC and ONR research programs of Marlon Lewis on variability in optical properties of the upper ocean complement our activities.

4) The Institute of Marine Biosciences, National Research Council of Canada was a major partner in our study of optical detection of biological variability near an aquaculture site in Ship Harbour, Nova Scotia. The emphasis was on detection and prediction of harmful algal blooms. The comparison of Ship Harbour with Lunenburg has been helpful in the development and testing of hypotheses about optics and phytoplankton dynamics. This project terminated in December, 2006.

5) Cullen is a member of PARADIGM (The Partnership for Advancing Interdisciplinary Global Modeling; a NOPP project which ended this reporting period). The project supported some analysis of data from our coastal observing system with an aim to develop and evaluate novel optical data products that might be used in global data assimilation models of ecosystems dynamics. It also supported the Ph.D. research of Moritz Lehmann.

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PUBLICATIONS

The following manuscripts resulted in full or in part from this contract:

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