High Resolution Time Series Observations and Modeling of Radiance, Optical Properties, and Physical Processes as Part of RaDyO

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LONG-TERM GOALS

An overall goal of the UCSB OPL RaDyO project is to contribute to the understanding and prediction of variations in radiance distributions as they are affected by physical forcing and conditions of the surface boundary layer (SBL) and the upper ocean. The purpose of our proposed research is to obtain, analyze, and model time series and vertical profile data; specifically, inherent optical properties (IOPs) and physical variables in the SBL and the upper oceanic layer as forced by atmospheric conditions and affected by other environmental conditions.

OBJECTIVES

Our specific observational, analytical, and modeling objectives follow:

1. To obtain sustained time series measurements of IOPs and physical variables at ~5 m depth using a package mounted to the spar hull of R/P FLIP, which will serve as a "pseudo-mooring" for our observational program. Measurements will include: hyperspectral absorption and attenuation coefficients (ac-s) [~90 wavelength] (with inference of hyperspectral total scattering coefficients) and spectral optical backscattering [3 wavelengths] for dissolved matter and particle characteristics, chlorophyll, turbidity, dissolved oxygen, temperature and conductivity (for salinity). These data will be valuable for quantifying the temporal variability of key optical and physical variables enabling time series and statistical (i.e., spectral, coherence, etc.) analyses that will be utilized to increase our understanding of relationships among environmental and near- and subsurface optical parameters. These data will be shared with other RaDyO PIs for additional collaborative analytical and modeling efforts.

2. To obtain vertical profile data, which will complement the data set described in 1. above. Specifically, a profiler package will be deployed to a nominal depth of ~30 m as often as possible from a long boom mounted on R/P FLIP. The variables to be sampled are similar to those of our hull-mounted measurement package, which will be valuable for discerning

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observed changes due to both temporal and vertical spatial variability. In particular, the profiler will measure the following: hyperspectral absorption and attenuation coefficients (ac-s) [~90 wavelength] (with inference of hyperspectral total scattering coefficients) and spectral optical backscattering [9 wavelengths] for dissolved matter and particle characteristics, chlorophyll, turbidity, near forward angle scattering, temperature and conductivity (for salinity). These data will be valuable for quantifying the vertical spatial variability of key optical and physical variables enabling statistical analyses that will be utilized to increase our understanding of relationships among environmental and near- and subsurface optical parameters. These data will also be shared with other RaDyO PIs for additional collaborative analytical and modeling efforts.

3. To collect and distribute a variety of environmental underway data sets that are routinely collected onboard the R/V Kilo Moana (KM). The data, which will be obtained include: a full suite of meteorological measurements including wind speed and direction, incident solar radiation, relative humidity, air and sea surface temperature, vertical profiles of horizontal components of current data from the KM's ADCP, and CTD and data. The CTD will be equipped with auxiliary instruments to enable observations of chlorophyll fluorescence, particle beam attenuation or backscattering, and dissolved oxygen as well as temperature and salinity data. This will be a particularly valuable data set for all RaDyO PI's in order to interpret and set the context of their measurements as well as to discern the physical mechanisms that will likely influence all optical measurements to a significant degree.

4. To solicit and facilitate collaborations with other relevant investigators who study the oceanography of the Santa Barbara Channel (and later deep waters off Hawaii in the 2009 field experiment). The point of these collaborations is to maximize the scientific value of our RaDyO data sets and those of regional oceanographers. The collaborations are anticipated to include observationalists, remote sensors, and modelers. Background information on the Santa Barbara Channel field experiment and modeling efforts by RaDyO PIs has been made available to over 20 individuals with several positive responses.

It is worth noting that we are leading the organizational aspects of RaDyO. Our group is also spearheading the logistics for the KM. We will lead future special volume publications and meetings as well.

Questions:

1) What is the statistical nature of the time-dependent underwater radiance distribution within the SBL and upper ocean layer?

2) What are the dominant scales of variability in the underwater optical field and how does the sun's zenith angle (i.e., time of day, latitude), wind and wave conditions, and water's IOPs affect these scales? How do all of these variables correlate?

3) To what degrees do physical (atmospheric and oceanic) and bio-optical processes contribute to the variability in underwater radiance? As a corollary, how can the dominant processes be best parameterized and modeled?

4) How do physical and bio-optical variables statistically relate to each other? For example, what are the various scales of coherence?

5) Which atmospheric and surface wave conditions and IOPs are most important in modeling and predicting variability of underwater radiance and AOPs?

6) How is the underwater light field affected by near surface layering in density (i.e., stratification), optically active materials (i.e., CDOM, phytoplankton, detritus), bubbles, foam, and transient and persistent clouds?

7) How do different bio-optical and physical regimes affect high frequency variability in underwater radiance? For example, in coastal waters: phytoplankton (including red tide) blooms, seasonal and episodic runoff, upwelling, sediment resuspension, shelf-break fronts, coastal jets, hurricanes and storms, internal solitary waves, and Langmuir circulations; in the open ocean: seasonal and episodic phytoplankton blooms (including coccolithophore blooms), mesoscale eddies, Langmuir circulation, wind and dust events, and hurricanes and storms. Longer-term interannual (i.e., ENSO) and decadal (NAO, PDO) variability is also important and must be considered.

8) How can optical, acoustical, and physical data sets best be synthesized to analyze and model variability of the underwater light field?

Hypothesis 1:
Time series of meteorological, physical, and bio-optical mooring data, e.g., winds, solar insolation, incident spectral radiation, temperature, salinity, currents, chlorophyll, IOPs [including $a(\lambda)$, $b(\lambda)$, $c(\lambda)$, $b_b(\lambda)$, volume scattering function (VSF), etc.], and AOPs [including $K_d(\lambda)$, $K_L(\lambda)$, $R(\lambda)$, $R_{rs}(\lambda)$], can be used to produce time series that will allow inferences of dominant time scales of variability and determination, parameterization, and modeling of key environmental processes affecting the distribution of subsurface radiance and image propagation across the air-sea interface.

Hypothesis 2:
Time series of meteorological, physical, and bio-optical mooring data obtained in open ocean and coastal waters can be used to ascertain a limited set of key *in situ* optical and physical measurements and to determine appropriate instrumentation that can be used to efficiently predict underwater radiance and to model image propagation (i.e., imaging above-surface objects from sensors placed beneath the sea surface). This hypothesis is important for operational applications.

APPROACH

To achieve the goals of our proposed research, we have utilized or will utilize two similar optical/physical systems (one mounted to the hull of R/P FLIP for time series observations and one profiled) during three RaDyO field experiments: (1) pier test (Scripps Pier, La Jolla, CA) conducted January 6-28, 2008, (2) "benign conditions" (Santa Barbara Channel, CA) conducted from September 8 – 25, 2008, and (3) high sea state conditions (planned in deep waters off Hawaii) in August and September of 2009. Some of the equipment (instrumentation) for the mooring and profiling systems was purchased as part of the OPL DURIP award.

Objectives of the Scripps Pier field testing program were to: (1) ensure all RaDyO instrumentation was ready for the two field experiments, (2) work toward integration of instruments/measurement approaches, (3) begin the process of learning how to best integrate data with models, (4) determine what if any key measurements may remain to be planned for, and (5) to meet RaDyO science objectives for shallow waters. For the OPL component of the pier exercise, we operated an optical vertical profiler from an OPL davit mounted on the south side of Scripps Pier (Fig. 1) from 13 through 26 January 2008. This profiler included a CTD, ac-s, filtered ac-9 for CDOM, spectral scattering meter (ECObb9), fluorometer-turbidity meter (FL-NTU), and LISST for near-forward angle scattering.

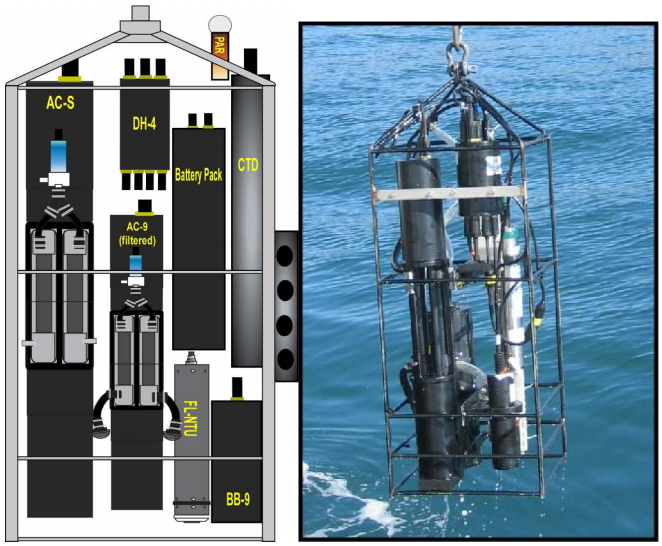

Figure 1. The Optical Profiler
[(Left:) Schematic diagram of the RaDyO Profiling System featuring an ac-s, filtered ac-9 for absorption of dissolved matter, LISST (behind ac-s; not shown), FL-NTU, ECObb9, CTD, data handler, and battery pack. (Right:) Photograph of a similar optical profiling package.]

The "benign conditions" experiment conducted in the Santa Barbara Channel September 8-26, 2008 and included measurements from R/P FLIP using a hull-mounted package and a similar vertical profiler (Fig. 1) deployed from a boom onboard FLIP. The specific measurements, which were done from FLIP and the KM by our group, are listed earlier in the OBJECTIVES section.

The "high sea state conditions" experiment is scheduled for August and September 2009. The exact location has not yet been determined, but we anticipate taking advantage of consistently strong winds in the Hawaiian Island chain. Because of the large ocean depth, we plan to deploy an instrument package on the spar hull of the R/P FLIP to act as a "pseudo-mooring" as we have done for the Santa Barbara Channel benign condition experiment. We also plan to operate the optical profiler, similar to the "benign conditions" experiment. We will also be responsible for the KM underway data sets. All data collected as part of the RaDyO program will be processed, quality controlled, and made available to RaDyO and other relevant collaborators.

WORK COMPLETED

To date, we have planned and conducted workshops and produced web-based reports, led planning discussions, and designed, authored, updated, and hosted the Official ONR RaDyO website: http://www.opl.ucsb.edu/radyo/. We have conducted six RaDyO PI planning workshops: (1) University of Rhode Island, 14-16 November 2005, (2) Scripps Institution of Oceanography, 3-5 April 2006, (3) Montréal, Canada, 13-15 October 2006, (4) Scripps Institution of Oceanography, 6-8 June 2007, (5) Scripps Institution of Oceanography, January 12 and 28, 2008, and (6) Orlando, FL, March 8-9, 2008. A workshop devoted to the analyses of the benign conditions experiment in the Santa Barbara Channel and planning for the high sea-state conditions experiment off Hawaii will be hosted in Santa Barbara in January 2009.

During each of the RaDyO planning workshops, we have led discussions regarding the overarching goal(s) of the RaDyO program and logistical requirements for field experiments, the approach and schedule, and data management and reporting. We have also presented overviews of our group's objectives and climatologies of potential RaDyO field experiment locations (Santa Barbara Channel and off Hawaii). These PI planning meetings have led to consensus decisions on RaDyO project goals and field experiment designs. The Scripps Pier experiment has been completed and data collection will begin in January 2008. The Santa Barbara Channel field study was conducted September 8-26, 2008 and the Hawaii deep-sea high sea state experiment will be conducted in August-September, 2009.

Some of the results of the Scripps pier activity are described below. OPL tested and deployed its optical/physical profiler (see Fig. 1; same one to be deployed from R/P FLIP for the "benign conditions" Santa Barbara Channel experiment). We operated an optical vertical profiler from an OPL davit mounted on the south side of Scripps Pier (Fig. 2) from 13 through 26 January 2008. This profiler included a CTD, ac-s, filtered ac-9 for CDOM, spectral scattering meter (ECObb9), fluorometer-turbidity meter (FL-NTU), and LISST for near-forward angle scattering.

Figure 2. The OPL optics/physics profiling package (for details, see Fig. 1) being deployed from Scripps Pier during the RaDyO field testing phase in January, 2008.

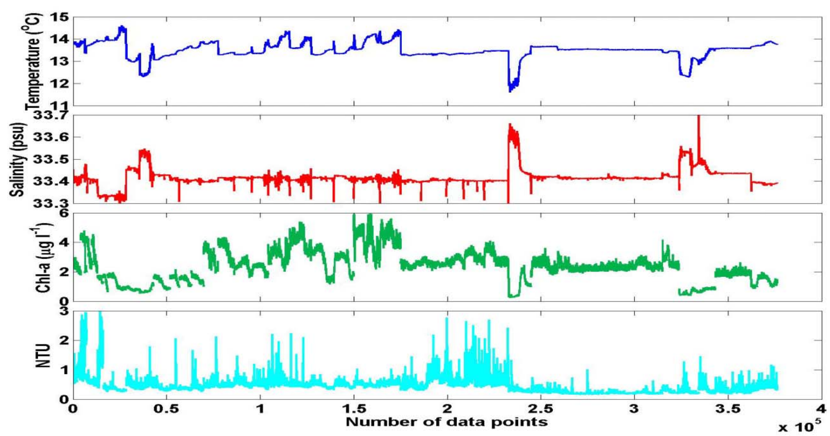

Figure 3. Preliminary time series of data collected from the OPL optics/physics profiling package are shown above.

Preliminary time series obtained from the OPL optics/physics profiling package are shown in Figure 3. These data, though short in duration, provide a glimpse into the relationships that may be expected between physical processes and optical variability in the shallow coastal zone. Note the three dips in temperature that appear to coincide with increases in salinity showing pulses of different water masses as they moved past the profiling package. In addition, it appears that the latter two of these pulses correlate with deceases in chlorophyll. The variability in the turbidity (NTU time series at bottom) is likely related to sediment resuspension events in wave breaking zone.

IMPACT/APPLICATIONS

Impacts of RaDyO will include the examination of time-dependent oceanic radiance distribution in relation to dynamic surface boundary layer (SBL) processes, construction of a radiance-based SBL model, validation of the model with field observations, and investigation of the feasibility of inverting the model to yield SBL conditions. These activities bear on understanding and predicting impacts of SBL processes and ocean biogeochemistry and ecology on the underwater light field, and thus operational problems involving naval operations. The feasibility of construction of ocean surface estimates using underwater camera data will be resolved.

TRANSITIONS

The RaDyO program is still in the early field stages, therefore there are no transitions yet. However, we anticipate that major transitions of will occur in the form of testing and commercialization of new sensors by RaDyO collaborators (e.g., MASCOT). We expect that the RaDyO project will accelerate interdisciplinary ocean measurement technology capabilities by 1) increasing the variety of variables which can be measured autonomously, 2) improving the robustness and reliability of interdisciplinary sampling systems, and 3) reducing adverse biofouling effects on chemical and optical systems.

RELATED PROJECTS

There are several projects taking place in the Santa Barbara Channel that relate the RaDyO program. Spatial surface current data (using CODAR) are being collected by Libe Washburn's UCSB group (http://www.icess.ucsb.edu/iog/realtime/index.php) and will be useful for characterizing major current features and passages of sub-mesoscale features and eddies; ship-based bio-optical data collected by the Plumes and Blooms Program (Dave Siegel, lead-PI; http://www.icess.ucsb.edu/PnB/PnB.html) will facilitate interpretation of the RaDyO bio-optical data; surface hydrocarbon slicks and slick dynamics are being investigated (Ira Leifer and Jordan Clark, PIs; http://www.bubbleology.com/); and ship-based data collected by the Santa Barbara Channel Long-Term Ecological Research (LTER; Dan Reed, lead-PI; with focus on land-ocean margin; http://sbc.lternet.edu/) program. Satellite sea surface temperature and ocean color data are being collected by our group, Dave Siegel's group and Ben Holt and Paul DiGiacomo (Jet Propulsion Laboratory, JPL) have been collecting synthetic aperture radar (SAR) data. These remote sensing data sets along with others provide spatial context. By combining and synthesizing these data sets with ours, we will be able to describe and quantify the three-dimensional evolution of several key water quality parameters on time scales of a day to the interannual.

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HONORS/AWARDS/PRIZES

Professor Dickey was named a Secretary of the Navy/Chief of Naval Operations Chair in Oceanography in 2008.