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

The overall goal of the University of California Santa Barbara (UCSB) Ocean Physics Laboratory (OPL) Radiance in a Dynamic Ocean (RaDyO) project is to contribute to the understanding and prediction of variations in radiance distributions as they are affected by physical forcing and physical and optical conditions of the surface boundary layer (SBL) and the upper ocean. The purpose of our 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 as affected by other environmental conditions.

OBJECTIVES

Two major field experiments have been used to accomplish the goals listed above. The first took place in the Santa Barbara Channel in August 2008 and the second in August-September 2009 south of the Big Island of Hawaii. Our specific observational, analytical, and modeling objectives follow:

Santa Barbara Channel Experiment:

1. To obtain time series measurements of IOPs and physical variables at ~30 m depth using a package mounted to the spar hull of R/P FLIP, which served as a "pseudo-mooring" for our observational program. Measurements included: 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 were used 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 were shared with other RaDyO investigators for additional collaborative analytical and modeling efforts.
2. To obtain vertical profile data, which complement the data set described in 1. above. Specifically, a profiler package was deployed from a long boom (20 m length) mounted on R/P

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FLIP. The variables sampled were similar to those of our hull-mounted measurement package. The profiler measured 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 are valuable for quantifying the vertical spatial variability of key optical and physical variables enabling statistical analyses that are being utilized to increase our understanding of relationships among environmental and near- and subsurface optical parameters.

3. To collect and distribute a variety of environmental underway data sets that were collected onboard the stable SWATH vessel R/V Kilo Moana (KM) during the Santa Barbara Channel experiment. The data included: 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 data. The CTD was equipped with auxiliary instruments to enable observations of chlorophyll fluorescence, particle beam attenuation or backscattering, angular dependent optical scattering, and dissolved oxygen as well as temperature and salinity data. This is a particularly valuable data set for all RaDyO investigators allowing them to interpret and set the context of their measurements as well as to discern the physical mechanisms that 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. The point of these collaborations is to maximize the scientific value of our RaDyO data sets and those of regional oceanographers. The collaborators include observationalists, remote sensors, and modelers. Background information on the Santa Barbara Channel field experiment and modeling efforts by RaDyO investigators has been made available to over 20 individuals with several positive responses.
5. To coordinate the Santa Barbara Channel field experiment and to maintain an active website for the program (website: www.opl.ucsb.edu/radyo/). This website provides contact information for investigators, up-to-date project information and notices, detailed field experiment information, meeting agendas, reports, and presentations, guides to data sets, extensive bibliographies for the experiments, publications by investigators, and photographs of experimental operations.

Hawaii Experiment Objectives:

The objectives of the Hawaii experiment were very similar to those of the Santa Barbara Channel experiment. The Hawaii experimental site was selected because of the desire to sample an environment with strong wind forcing and large sea states as well as clear waters. Our group was responsible for the R/V Kilo Moana data collection, particularly the CTD, underway, and ADCP data. Our measurements from R/P FLIP were modified from the previous experiment. For this experiment, no optical profiling measurements were done in the interest of allowing more personnel from other groups to deploy their instrumentation. However, we expanded our "virtual mooring" instrument suite with sensors and systems mounted on the hull of R/P FLIP.

These included:

temperature sensors at 1, 2, 3, 7, 20, 25, 35, 55, 60, 65, 75, 80, and 85 m, temperature and pressure sensors at 15, 30, 45 and 50 m, temperature and conductivity sensors at 6, 13, 40, and 68.5 m, and temperature, chlorophyll fluorescence, and turbidity sensors at 13, 20, 40, 68.5 m.

We again coordinated the experiment and worked with several collaborators who have joined in the field effort and brought additional modeling tools to the project. We coordinated and edited a Special Section based largely on RaDyO results volume for the Journal of Geophysical Research (2011-2012).

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

Our experimental approach was to obtain key data sets in relatively benign and high sea state conditions during field experiments in the Santa Barbara Channel and relatively intense atmospheric forcing and wave conditions off the Big Island of Hawaii, respectively. These data were analyzed according to the procedures listed above, and hypotheses. Prior to both field experiments, preliminary testing of instrumentation was completed using the Scripps Pier in January 2008. Details of this work were presented in previous annual reports.

WORK COMPLETED

The primary work completed within the past three years has involved the RaDyO Santa Barbara Channel (SBC) experiment and the RaDyO Hawaii field experiment. Preliminary results from the SBC and Hawaii experiments were summarized in the previous annual report. Results from these experiments are described in a paper (Dickey et al., 2012) that was recently published as the introductory/overview paper for a Special Section of the Journal of Geophysical Research. This paper was honored as a Spotlight Paper in EOS recently. I am a co-author of two other papers that have been published in this Special Section. In addition, we published a paper based largely on RaDyO research in Physics Today (Dickey et al., 2011). Figures describing our results are available on the RaDyO website and in the RaDyO overview.

IMPACT/APPLICATIONS

Impacts of our RaDyO efforts are expected to include better understanding and prediction 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 imaging, and thus operational problems involving naval operations. The feasibility of construction of ocean surface estimates using underwater camera data will be resolved.

TRANSITIONS

We anticipate that major transitions will occur in the form of testing and commercialization of new sensors developed 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, and 2) improving the robustness and reliability of interdisciplinary sampling systems. In addition, this work will enable development of more accurate and robust numerical models of the ocean environment, which will include optical as well as physical components.

RELATED PROJECTS

There were several projects that took place in the Santa Barbara Channel that relate the RaDyO program. Spatial surface current data (using CODAR) were 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/). Satellite sea surface temperature and ocean color data were collected by our group, Dave Siegel's group and Ben Holt (Jet Propulsion Laboratory, JPL) collected 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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