

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

Overall goals of our project are to understand and predict radiance distributions, and to model surface boundary layer (SBL) conditions. The purpose of our proposed research is to obtain, analyze, and model high temporal resolution time series of radiance and irradiance, IOPs and AOPs, and physical processes in the upper oceanic layer and SBL as well as forcing by atmospheric conditions including incident solar radiation.

OBJECTIVES

Our specific observational, analytical, and modeling objectives follow:

1. To obtain sustained (nearly continuous) high temporal resolution measurements of atmospheric forcing including: wind speed and direction, incident solar radiation, atmospheric temperature, relative humidity, barometric pressure, and hyperspectral downwelling irradiance (E_d) using a surface buoy platform.
2. To obtain sustained (nearly continuous) high temporal resolution of IOPs and AOPs [hyperspectral absorption and attenuation coefficients (a_c -s), spectral optical backscattering for dissolved matter and particle characteristics, hyperspectral resolution downwelling irradiance and upwelling radiance (E_d and L_u)] in the upper portion of the water column using a mooring.
3. To obtain sustained (nearly continuous) high temporal resolution measurements of spectral fluorescence for concentrations of chlorophyll-a, phycoerythrin, and colored dissolved organic matter using a mooring.
4. To obtain sustained (nearly continuous) high temporal and vertical resolution measurements of temperature and salinity in the upper portion of the water column and SBL to determine near surface stratification and mixed layer depths using sensors placed at multiple depths on a mooring.

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5. To measure upper ocean and SBL currents and turbulence using a moored acoustic current meter (ACM) and full water column currents using a moored acoustic Doppler current profiler (ADCP).
6. To measure acoustic backscatter for inferring depth dependence of bubble distributions in the upper water column and zooplankton deeper in the water column using an ADCP.
7. To measure high vertical resolution IOPs [hyperspectral absorption, scattering, and attenuation; spectral backscattering, chlorophyll fluorescence, near-forward angle scattering (LISST)] and physical properties [(temperature, conductivity, and depth (CTD))] using a profiling system.
8. To provide a full suite of IOP, AOP, physical, and meteorological data to RaDyO investigators for modeling purposes.

In addition to coordinating RaDyO PI meetings and participating in field experiments, our anticipated primary roles in the RaDyO project will be to: (1) Investigate the effects of particles and dissolved matter on radiance, (2) Determine the SBL processes affecting underwater optical properties, and (3) Provide time- and depth- dependent field observations for model development and validation. We expect that our study will enable us to answer the following set of questions and test the two hypotheses listed below.

Questions:

- 1) What is the statistical nature of the time-dependent underwater radiance distribution at the surface ocean and within the SBL and upper ocean layer?
- 2) What are the dominant scales of variability in the underwater optical field (i.e., IOPs and AOPs) and how does the sun's zenith angle (i.e., time of day, latitude) affect these scales?
- 3) What 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 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, 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:

High temporal resolution 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 continuous 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:

High temporal resolution 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 plan to develop and deploy one to two systems (mooring and profiler) during three planned RaDyO field experiments: (1) pier test (Scripps Pier, La Jolla, CA), (2) “benign conditions” (Santa Barbara Channel, CA), and (3) high sea state conditions (potentially in Hawaiian waters; exact location dependent on RaDyO PI consensus). The equipment (instrumentation) for the mooring and profiling systems was/will be purchased as part of the OPL DURIP award. OPL PIs Dickey and Chang will coordinate RaDyO-related activities (including meetings and fieldwork) and engineers D. Manov and F. Spada will develop and implement RaDyO-related sensors and systems. OPL graduate student F. Nencioli will operate the optical profiler during the pier test and benign conditions experiments. All RaDyO fieldwork will be done in conjunction with all other RaDyO investigators.

For the pier test, we plan to operate 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 will contain 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. The goals of this experiment are to ensure proper functioning of all equipment, integration of RaDyO PI measurements and data with each other and with models, determine potential missing elements of the project, and to meet RaDyO objectives for shallow waters.

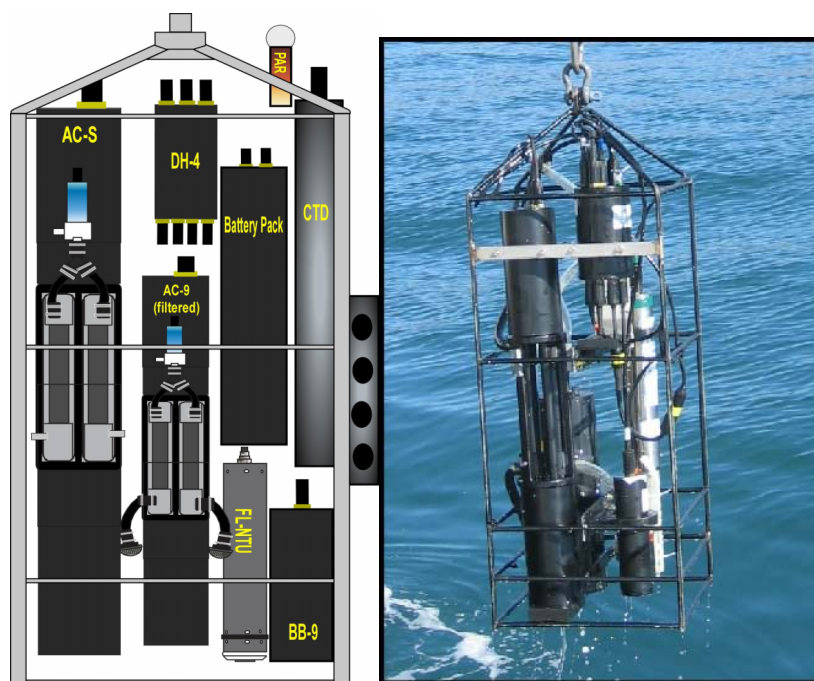


Figure 1. The Optical Profiler

[(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 will involve deployment of an OPL mooring for a 6-week period (3 or 4 September through 17 October 2008) in waters ~400 m deep and operation of the optical profiler during the 2-week intensive field study (4-18 September 2008) aboard the R/P FLIP. The mooring will be used to deploy temperature sensors, conductivity (salinity) sensors, hyperspectral radiometers (E_d and L_u), hyperspectral absorption-attenuation meter (ac-s), spectral backscattering sensors (ECObb3), spectral fluorometers (ECOF13), acoustic current meter (ACM), and ADCP (current profiles and acoustic backscatter for bubbles and zooplankton). A surface buoy will be used to measure a suite of meteorological, physical, and optical (including radiometric) measurements and to support complementary surface and bubble measurements. The mooring will also be available to other RaDyO investigators for specialized measurements (e.g., WET Labs, Inc. MASCOT; PIs M. Twardowski and J.R.V. Zaneveld). Most subsurface instrumentation will be located near the ocean surface; however some instrumentation will be deployed deeper in the water column (i.e., temperature and conductivity sensors to resolve stratification). Specific depths and instrumentation will be established by consensus during RaDyO PI planning workshops. An example of instruments and their placement is indicated in Fig. 2. The optical profiler is shown in Fig. 1 and described above.

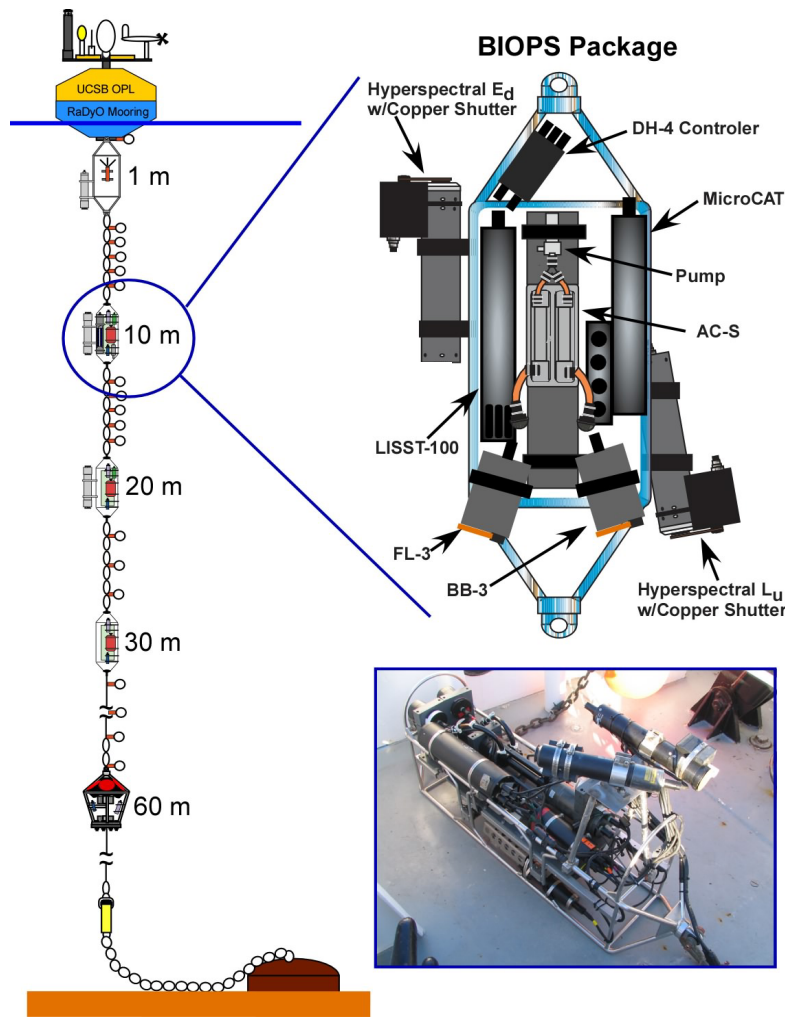


Figure 2. The RaDyO Mooring

[(Left:) Schematic diagram (not to scale) of the RaDyO Mooring System, featuring meteorological sensors (on surface buoy); 1 m package with acoustic current meter and radiometer (L_u); 10 m package with radiometers (E_d and L_u), ac-s, ECObb3, ECOFI3, and C-T sensor; 20 m package with radiometers (E_d and L_u), ECObb3, FL-NTU, and C-T sensor; 30 m package with ECObb3, FL-NTU, and C-T sensor; 60 m ADCP with FL-NTU and C-T sensor. Temperature sensors span the water column. (Top Right:) Schematic diagram of the 10 m package. (Bottom Right:) Photograph of a similar package (length is 1.75 m).]

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 between the islands of Kauai and Oahu 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”. Moored measurements may include IOPs, hydrography, and current profiles. We also plan to operate the optical profiler, similar to the “benign conditions” experiment.

All data collected as part of RaDyO field experiments will be processed, quality controlled, and available to all other RaDyO investigators.

WORK COMPLETED

As lead PIs of the RaDyO program, we have put together workshop agendas and reports, led planning discussions, and designed, authored, updated, and host the Official ONR RaDyO website: <http://www.opl.ucsb.edu/radyo/>. We have attended four 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, and (4) Scripps Institution of Oceanography, 6-8 June 2007. During each of the RaDyO planning workshops, we participated in 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).

These four PI planning meetings have led to consensus decisions on RaDyO project goals and field experiment designs. The Scripps Pier experiment plans are completed and data collection will begin in January 2008. The Santa Barbara Channel field study plans are underway; UNOLS vessels have been requested and RaDyO PI measurements are planned (subject to change depending on results from the Pier experiment).

The fifth and sixth planning workshops are scheduled to (5) follow the Scripps Pier test, on 27 January 2008 and (6) follow the Ocean Sciences Meeting in Orlando, FL in March 2008. The anticipated topics of discussion will focus on results from the Scripps Pier test including lessons learned, firming up plans for the benign conditions field study, and determining the location and timing of the high sea state conditions field experiment. Topics relevant to data management and sharing will also likely be discussed.

IMPACT/APPLICATIONS

Impacts of RaDyO 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 its planning stages, therefore there are no transitions yet. However, we anticipate that major transitions 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.

PUBLICATIONS

- Benson, B., G. Chang, D. Manov, B. Graham, and R. Kastner (2006) Design of a Low-cost Acoustic Modem for Moored Oceanographic Applications, Proceedings of The First ACM International Workshop on UnderWater Networks (WUWNet), ACM Press, Los Angeles, CA.
- Blackwell, S. M., M. A. Moline, A. Schaffner, and G. Chang (2007) Defining sub-kilometer length scales in coastal waters, Continental Shelf Research [in press].
- Chang, G. C., A. H. Barnard, S. McLean, P. J. Egli, C. Moore, J. R. V. Zaneveld, T. D. Dickey, and A. Hanson (2006) In situ optical variability and relationships in the Santa Barbara Channel: implications for remote sensing, Applied Optics, 45(15), 3593-3604.
- Chang, G., A. H. Barnard, and J. R. V. Zaneveld (2007) Optical closure in a complex coastal environment, Applied Optics [accepted].
- Chang, G.C. and T.D. Dickey (2001) Optical and physical variability on time-scales from minutes to the seasonal cycle on the New England shelf: July 1996 - June 1997. Journal of Geophysical Research. 106: 9435-9453.
- Chang, G.C. and T.D. Dickey (2004) Coastal ocean optical influences on solar transmission and radiant heating rate. Journal of Geophysical Research. 109: C01020, doi:10.29/2003JC001821.
- Chang, G. C., Dickey, T., and M. Lewis (2006) Toward a global ocean system for measurements of optical properties using remote sensing and *in situ* observations, In: Remote Sensing of the Marine Environment: Manual of Remote Sensing, Vol. 6, Ch. 9, edited by J. Gower, pp. 285-326.
- Chang, G., T. Dickey, C.D. Mobley, E. Boss, and W. S. Pegau (2003) Toward closure of upwelling radiance in coastal waters. Applied Optics. 42(9): 1574-1582.
- Chang, G. C., K. Mahoney, A. Briggs-Whitmire, D. Kohler, C. Mobley, M. Moline, M. Lewis, E. Boss, M. Kim, W. Philpot, and T. Dickey (2004) The New Age of Hyperspectral Oceanography, Oceanography, 17(2), 22-29.
- Dickey, T. (1991) The emergence of concurrent high resolution physical and bio-optical measurements in the upper ocean and their applications. Reviews of Geophysics. 29: 383-413.
- Dickey, T. (2001) New technologies and their roles in advancing recent biogeochemicals studies. Oceanography. 14(4): 108-120.

- Dickey, T.D. and J.J. Simpson (1983) The influence of optical water type on the diurnal response of the upper ocean. *Tellus*. 35: 142-151.
- Manov, D.V., G.C. Chang, and T D. Dickey (2004) Methods for reducing biofouling of moored optical sensors. *Journal of Atmospheric and Oceanic Technology*. 21(6): 958-968.
- Stramska, M. and T.D. Dickey (1992) Short-term variations of the bio-optical properties of the ocean in response to cloud-induced irradiance fluctuations. *Journal of Geophysical Research*. 97: 5713-5721.
- Stramska, M. and T.D. Dickey (1992) Variability of bio-optical properties in the upper ocean associated with diel cycles in phytoplankton population. *Journal of Geophysical Research*. 97: 17,873-17,887.
- Stramska, M. and T.D. Dickey (1998) Short-term variability of the underwater light field in the oligotrophic ocean in response to surface waves and clouds. *Deep-Sea Research I*. 45: 1393-1410.