Quantification of the Interacting Physical, Biological, Optical and Chemical Properties of Thin Layers in the Sea

Dr. Margaret Anne McManus
Associate Professor of Oceanography
University of Hawaii at Manoa
Honolulu, Hawaii 96822
phone: (808) 956-8623 fax: (808) 956-9225 email: mamc@hawaii.edu

Dr. Mark T. Stacey
Associate Professor of Civil & Environmental Engineering
University of California Berkeley
Berkeley, California 94720
phone: (510) 642-6776 fax: (510) 642-7483 email: mstacey@socrates.berkeley.edu

Dr. John P. Ryan
Research Scientist
Monterey Bay Aquarium Research Institute
Moss Landing, California 95039
phone: (831) 775-1700 fax: (831) 775-1652 email: ryjo@mbari.org

Grant Number: N00014-04-1-0311
www.buinne.soest.hawaii.edu:8080/loco2006

LONG-TERM GOAL

Our long-term goal is to develop the capability to predict thin layer formation and presence in the coastal ocean.

OBJECTIVES

The central focus of our research is to investigate: the spatial and temporal scales of thin layers, the relationship between physical processes (from the microscale to the mesoscale) and thin layers, as well as the difference between layered structures in the nearshore and offshore environments. The overarching goal of our research is to ultimately determine how many physical variables are required to predict the occurrence of thin layers in the sea. In addition to this research, we are also providing logistical support as well as a web-accessible data archive system for our colleagues in the Layered Organization in the Coastal Ocean (LOCO) Program, a Departmental Research Initiative (DRI) supported by ONR.

APPROACH

We undertook a several weeklong field experiment in Monterey Bay in July of 2006. There were 5 major components to this work: (1) deployment of moored instruments used to measure physical processes, (2) shipboard surveys using a small vessel (33 ft) to quantify the relationship between finescale and microscale physical processes and thin layers, and to assess how local patterns of current

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2007**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE
Quantification Of The Interacting Physical, Biological, Optical And Chemical Properties Of Thin Layers In The Sea

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Hawaii at Manoa,Honolulu,HI,96822

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

velocity relate to thin layers,. (3) AUV surveys to quantify the relationship between mesoscale physical processes, thin layers, optical properties and nutrients, (4) acrobat tow body surveys to quantify the relationship between mesoscale physical processes, thin layers and optical properties, and (5) the provision of a system of data archiving and data distribution for PIs associated with the LOCO program.

WORK COMPLETED

Instrument Deployment in the Array Site: Instruments to measure physical processes were deployed at the array site from July 10 to July 31, 2006. One bottom mounted 1200 kHz ADCP was deployed at site K1 in 18.5 m of water. One bottom mounted 600 kHz ADCP, and one thermistor chain were deployed at site K2. One bottom mounted 600 kHz ADCP and one thermistor chain were deployed at site NW. Finally, one bottom mounted 300 kHz ADCP and one thermistor chain were deployed at K4.

Small Vessel Surveys: Routine surveys were made in the array using a 33 ft vessel. Instrumentation on the small vessel included a slow-drop profiler (descent rate < 10 cm /s) equipped with a SeaBird SBE-25 CTD (T, S, σ_t, P), an SBE-43 (O_2), a WET Labs WetStar fluorometer (Chlorophyll a), and a WET Labs ac-9 (absorption and attenuation at nine wavelengths). Also on the profiler was a Biospherical sensor (PAR), a Nortek ADV (finescale velocity), and a SCAMP (microstructure). In addition, a 600 kHz ADCP (current magnitude and direction) was installed on the side of the vessel. Three vessel surveys were undertaken; each encompassed a full 24-hour cycle. The 24-hr surveys were designed to span the spring-neap tidal cycle and all phases of the diurnal tidal cycle. Once on station, we profiled continuously with the high-resolution profiler every 3.5 minutes for 24 hours. There were brief breaks in our profiling cycle for downloading data from the SCAMP. The vessel mounted ADCP ran continuously during these 24-hour surveys.

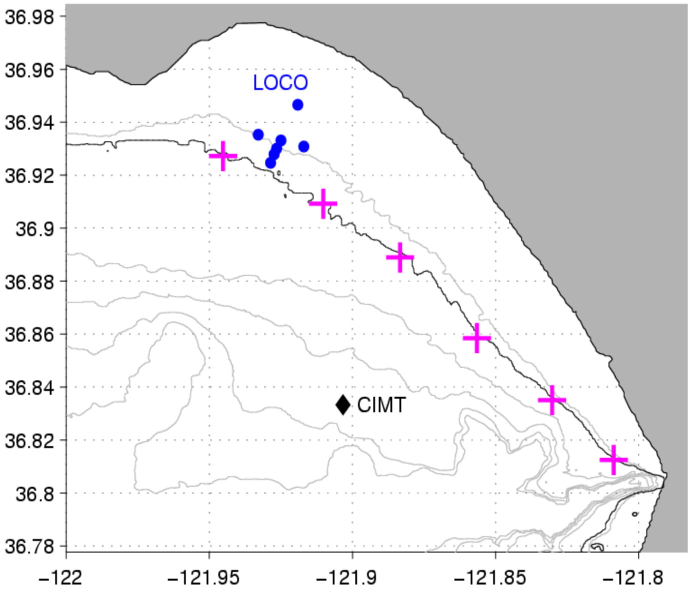

Figure 1. Location of the array sites deployed in northeastern Monterey Bay (blue circles). Sites K0 – K4 progress from onshore to offshore. Map of AUV survey waypoints (pink +) between the LOCO array and Monterey Canyon. Gray lines are isobaths..

AUV Surveys: The MBARI AUV Dorado is a 12-foot long, 21-inch diameter vehicle with a modular hardware and software design for flexible adaptation of power resources (mission duration) and sensor payload. The Dorado is equipped to measure: temperature, salinity, oxygen, optical backscattering at two wavelengths (470 and 676 nm), chlorophyll fluorescence, nitrate (NO_3), bioluminescence, and particle size distribution in the range of 0.1 to 250 µm. During LOCO 2006, Dorado surveys focused on variability entering the primary LOCO array. A drifter we deployed indicated mean surface flow toward the LOCO array from the south, thus the upstream survey domain extended from the array southward to Monterey Canyon. The Dorado's battery power was augmented to enable a 24-hour mission that resolved variability through a tidal cycle via 6 repeat occupations of the transect.

Acrobat Surveys: An Acrobat tow body was equipped with a SeaBird SBE-49 FastCAT CTD (T, S, σ_t, P) and a WET Labs Inc. ECO-triplet sensor (chlorophyll-a, CDOM, and backscatter at 660nm). Three surveys were performed along across-isobath transects (Figure 2) southeast of the LOCO array. The first two surveys, on July 25 and 26, took place during daytime hours and were performed using the MBARI Zephyr research vessel. The third survey, on July 27-28, was an over-night expedition using a 33 ft research vessel, the Sheila-B. As the Acrobat tow body was towed along these transects, it continuously dove and ascended between the surface and within 10 m of the seafloor (down to 35 m depth).

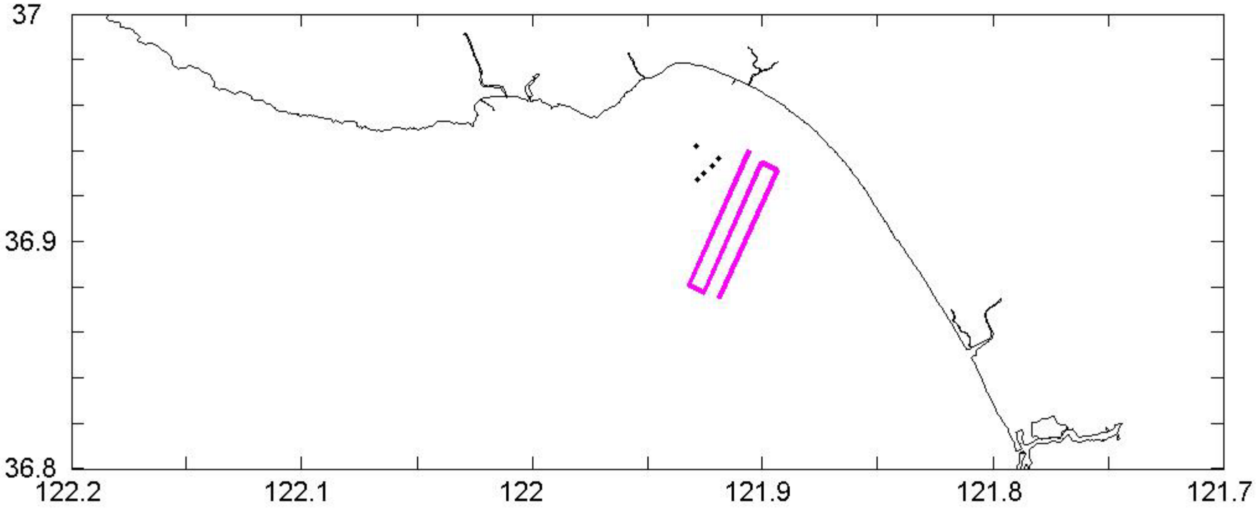

Figure 2. Acrobat tow body survey tracks (pink lines) and location of the LOCO array (black dots)

Data Availability: We have developed a data archive system, accessible from the web, for the LOCO Project. Project members (PIs, students, technicians, post-docs and students) uploaded figures, data and daily updates to the LOCO web site which is comprised of a MySQL backend database on a RedHat Enterprise Linux workstation, serving PHP scripted html pages via the Apache web server. This type of configuration is commonly known as the LAMP model (Linux, Apache, MySQL, PHP) for data accessibility. A daily web log, data, figures, reports and presentations from the LOCO project are currently accessible through a password protected web link. This site is being hosted from the McManus Lab (buinne.soest.hawaii.edu:8080/loco2006 please contact bem@soest.hawaii.edu for user name and password).

RESULTS

Instrument Deployment in the Array Site: All instruments were successfully recovered from the array with no damage to the environment. Data sets from these instruments have been downloaded, backed up in several locations, have been processed and we are now in the analysis stage.

Small Vessel Surveys: The most compelling results to date arise from our three overnight surveys occurring July 12-13, July 18-19 and July 25-26. During these overnight studies we anchored in the array (near K1) and profiled continuously with our slow-drop profiler. The ADCP on board also ran continuously during these surveys. The power of these studies lies in the capability of the slow-drop profiler to collect continuous, high-resolution profiles of chlorophyll-a fluorescence and the vertical structure of the water column during periods of layer formation, maintenance and dissipation. The entire overnight period for July 12-13 is presented in Figure 3. In the top panel, a distinct layer in the acoustic backscatter is evident from about 2300 hours onwards, and is co-located with a strongly stratified layer (2nd panel Figure 3), particularly in the early morning hours. Interestingly, the dissipation of the layer at around 0600 hours is not associated with either a distinct change in the stratification (2nd panel Figure 3) or a pronounced mixing event (3rd and 4th panels Figure 3). As such, it appears that this layer dissipated through a biological process, mostly like migration in response to sunrise.

In order to aggregate the physical processes responsible for mixing across all of our observations, we are exploring the use of stratification (N2) and shear (S2) as the governing parameters. In Figure 4, we examine how acoustic backscatter varies in N2-S2 space. While there is considerable scatter, regions of high acoustic backscatter tend to be regions of large N2 and S2 (i.e., falling in the upper right quadrant of N2-S2 space). MacKinnon and Gregg (2003) proposed a model for turbulent dissipation rate on the shelf that increased with both N2 and S2; this model is reinforced by our observations of dissipation rate, and suggests that these regions of high acoustic backscatter are associated with higher levels of turbulent dissipation rate. On-going analyses will examine how the observed physics would modify the layer dynamics following the framework in our recent paper (Stacey et al. 2007), as well as confirming that the layers of elevated acoustic backscatter are, in fact, biological layers (and not a manifestation of physical transitions in the acoustics).

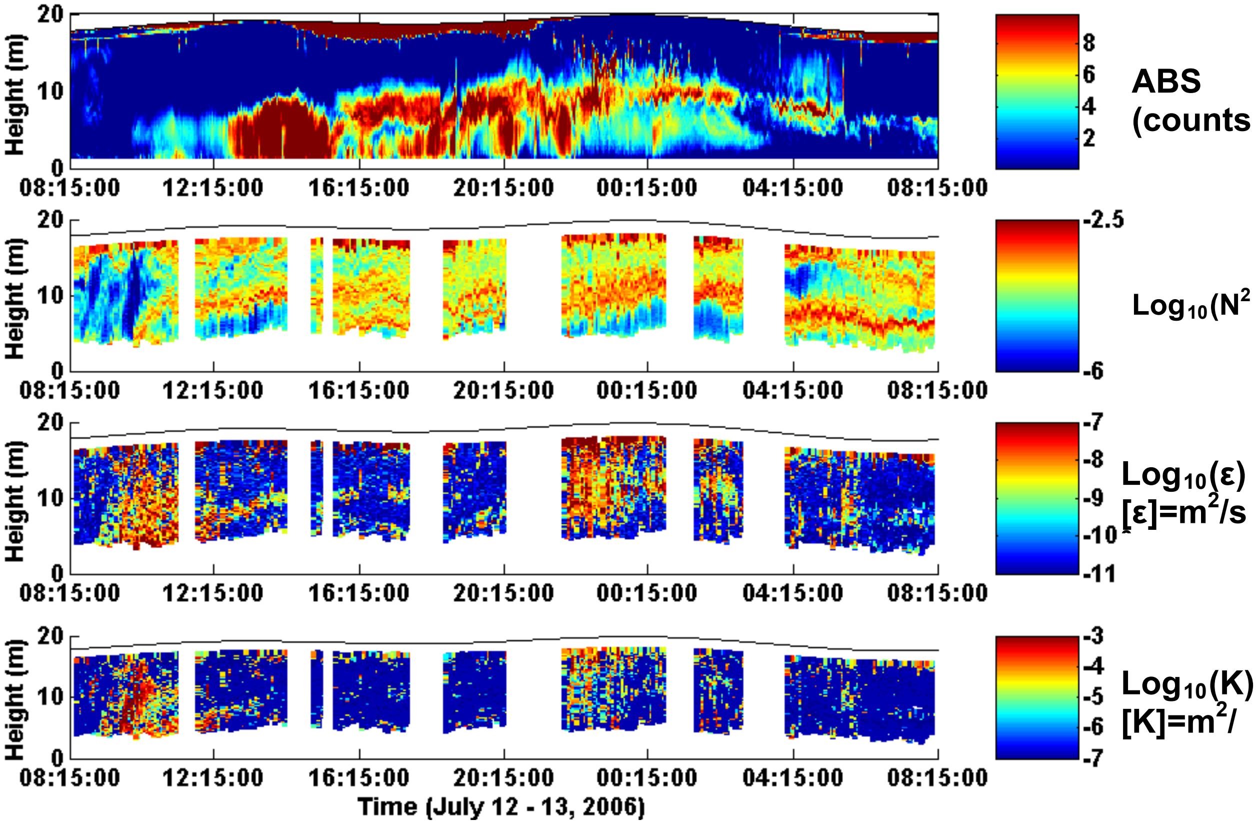

Figure 3. Example of overnight study results, July 12-13, 2006. (a) Acoustic backscatter calculated from co-located ADCP; (b) buoyancy frequency squared from SCAMP measurements; (c) turbulent dissipation rate estimated from Bachelor fit to SCAMP temperature gradient spectra; (d) turbulent diffusion coefficient based on dissipation rate and buoyancy frequency using a flux Richardson number coefficient.

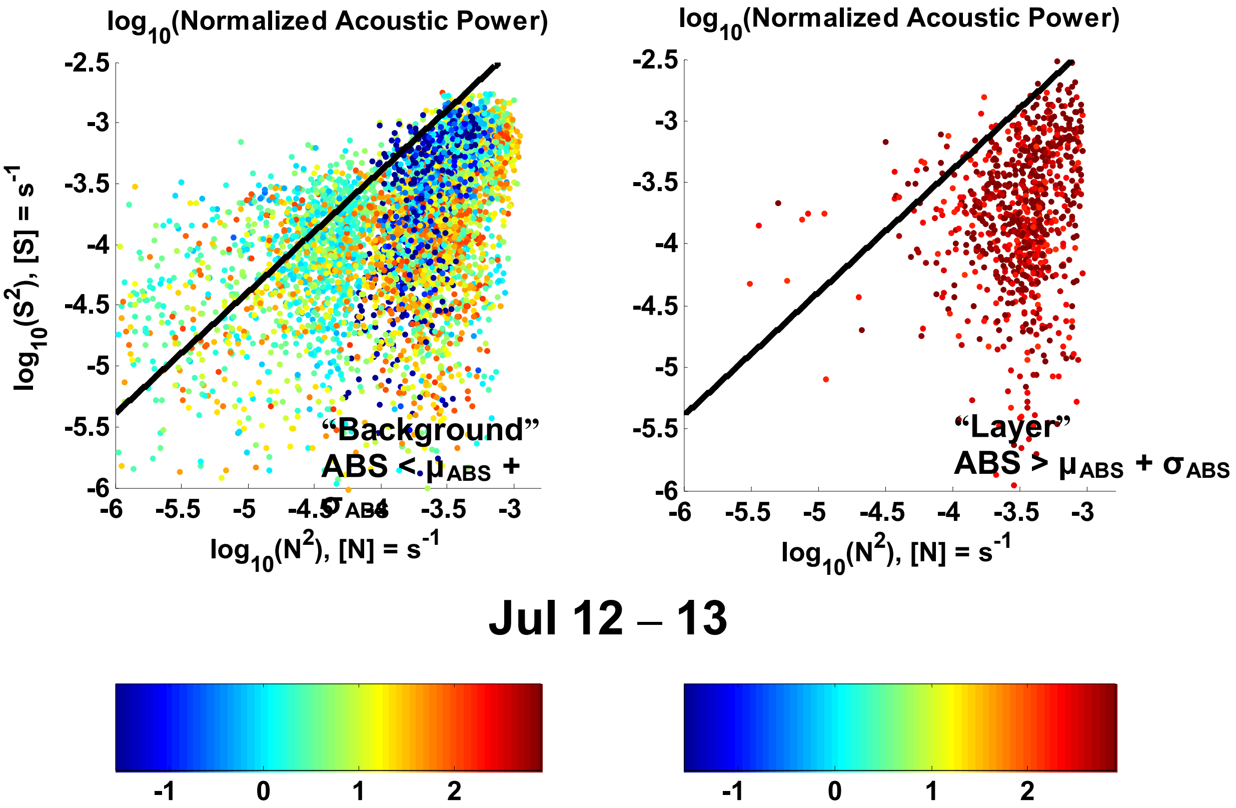

Figure 4. Acoustic backscatter as a function of shear and stratification. Layers are seen to occur in predominantly high N2-S2 space (upper right quadrant, panel (b)). Following MacKinnon & Gregg (2003), which is reinforced by our data, this would be expected to be regions of elevated turbulent dissipation rate.

AUV Surveys: The monitoring of physical, nutrient, and optical conditions between Monterey Canyon and the LOCO array for a full tidal cycle revealed important processes influencing conditions and layer structures in the LOCO study region. These processes are clearly evident in an animation of the data from 6 repeat sections (http://www.mbari.org/staff/ryjo/loco2006/LOCO_Dorado_anim.html). One frame from this animation is shown in Figure 5.

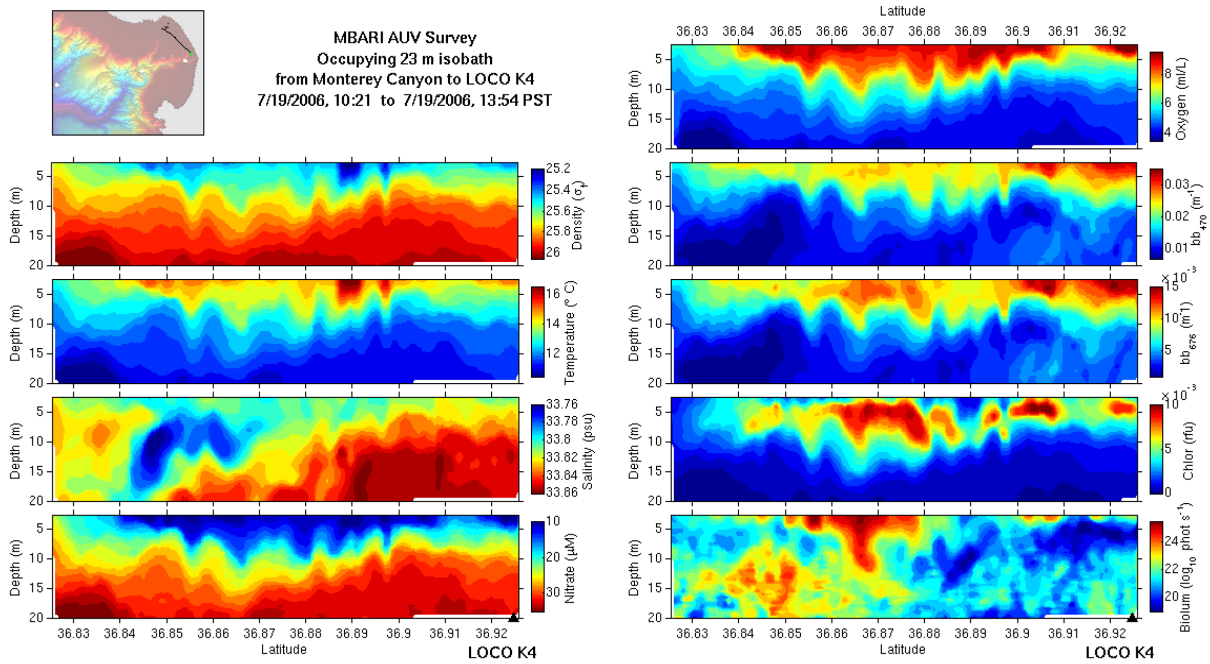

Figure 5. One of the Dorado AUV's repeat vertical sections of physical, nutrient, and optical conditions between Monterey Canyon and the LOCO array (K4).

These observations showed flow of relatively cold, low oxygen, high density, high-nutrient waters into the LOCO array below the thermocline. This process is likely due to the amplified internal tide over the canyon, which pumps waters from the canyon onto the shelf. This process likely influenced nutrient availability and stratification in the LOCO array. The AUV data also reveal propagation of internal waves into the array region. Internal waves were evident in many LOCO data sets, and the rapid repeat sections from the AUV defined at least one of the ray paths for these internal waves. Hydrographic measurements revealed interleaving of water masses. Bio-optical measurements revealed both subsurface and surface patchiness in chlorophyll fluorescence on the scale of internal waves, as well as complex relationships between the patchiness of chlorophyll fluorescence, optical backscatter, and bioluminescence, and intense stimulable bioluminescence - even during the day.

Acrobat Surveys: The data from all 3 Acrobat surveys show similar across-isobath biological and physical structure. At the inshore (15-20 m depth) end of each transect, a moderately thin (4-6 m thick) patch of chlorophyll was present at the surface, and a broad subsurface patch of chlorophyll was found further offshore (40-60 m depth; Figure 6). Between these 2 features, small concentrations of chlorophyll were present at the surface, while a moderately strong thin layer of chlorophyll was present at depth (~ 10 m below surface). Preliminary results indicate that the thin phytoplankton layers observed in these transects were associated with a salinity minimum intrusion.

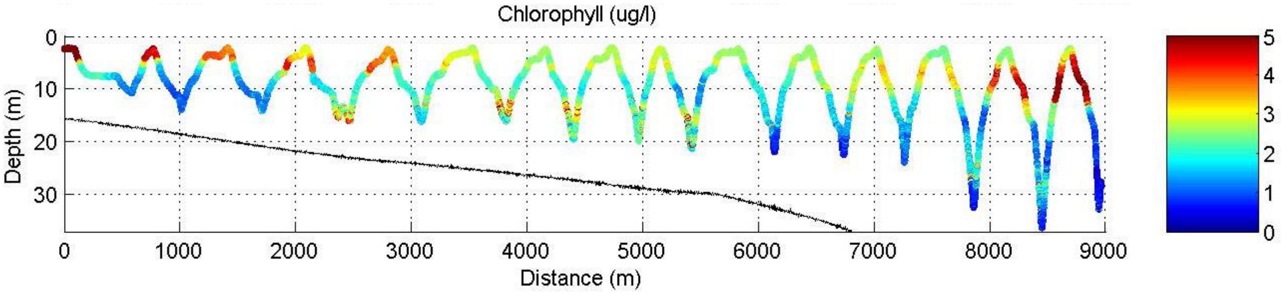

Figure 6. Acrobat profiles along transect 1 on July 27 2006.

Remote Sensing: Remote sensing is critical to understanding the oceanographic variability that influenced the bay environment during the LOCO field programs. Our group has processed MODIS satellite imagery from both LOCO field programs with custom atmospheric correction using the high-resolution bands of MODIS. This processing produced much higher quality imagery than the standard MODIS processing and revealed major influences of offshore and recently upwelled waters on the bay during the LOCO field programs. Additionally airborne remote sensing during LOCO 2006 provided a highly detailed view of conditions during the middle of the experiment (Figure 7), when we were conducting high-resolution overnight sampling in situ. This remote sensing data clearly showed that the LOCO site was in the warmest waters of the bay, and that extreme patchiness in the phytoplankton was being caused by stirring of the bay by a cyclonic eddy. This stirring created colored surface streaks throughout the northern bay.

IMPACT/APPLICATIONS

Patterns in biological distribution cannot be interpreted without an understanding of physical oceanographic processes. Through our analysis of simultaneous measurements of physical processes and thin layers, we have found that physical processes from the microscale to the mesoscale each have critical impacts on thin layer dynamics (Dekshenieks et al. 2001, McManus et al. 2003, McManus et al.2005, Stacey et al. 2007, Cheriton et al. 2007, Ryan et al. 2007). For this reason, our work provides a critical framework for other ONR LOCO Projects. The ability to make the translation between physical processes over a range of scales, and the mechanisms contributing to thin layer dynamics will ultimately allow us to predict the presence of thin layers in the sea.

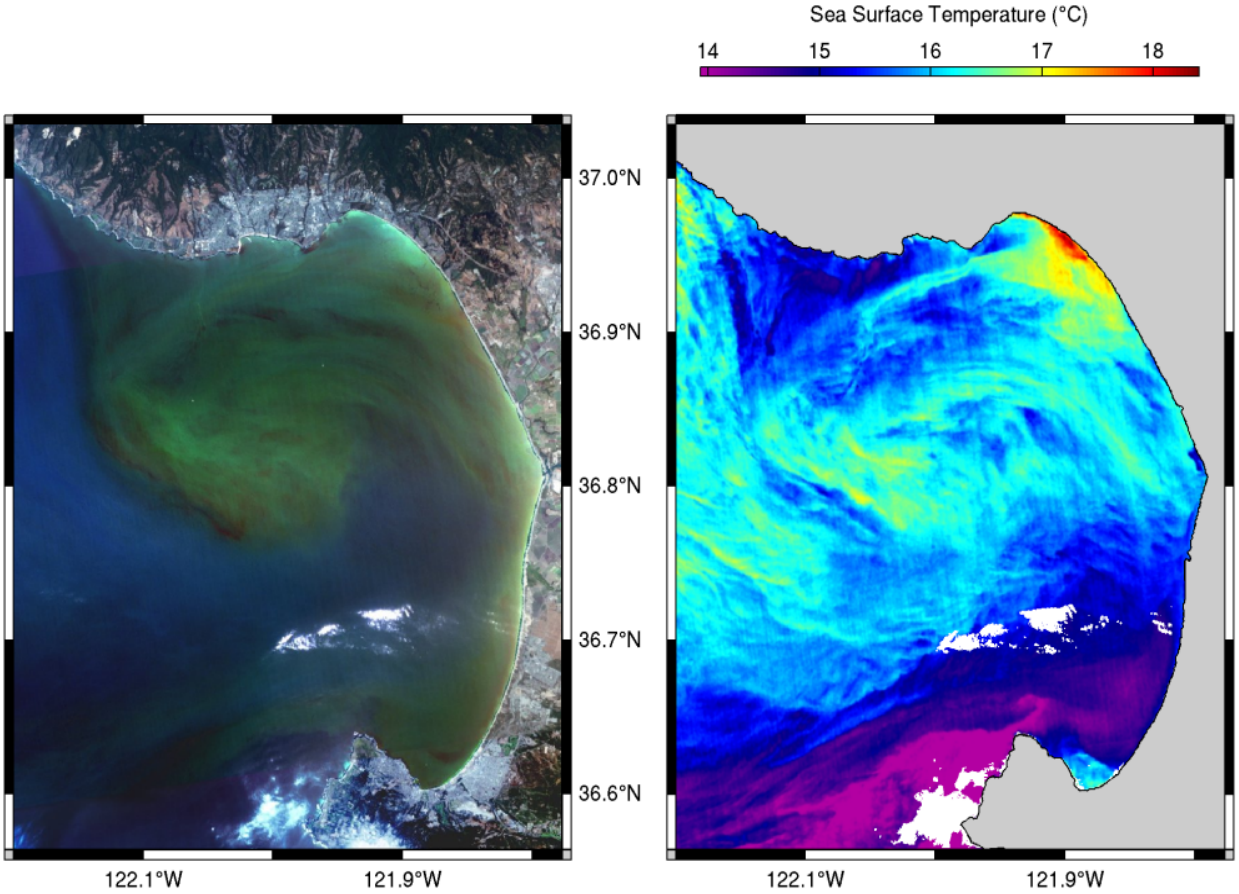

Figure 7. Color and SST imagery for July 19, 2006 from the MODIS Airborne Simulator.

RELATED PROJECTS

Related projects: (1) D. Van Holliday & Charles F. Greenlaw (BAE Systems): “Layered Organization in the Coastal Ocean: Acoustical Data, Acquisition, Analyses and Synthesis”, (2) Percy L. Donaghay & James M. Sullivan (URI): “Layered Organization in the Coastal Ocean: 4-D Assessment of Thin Layer Structure, Dynamics and Impacts”, (3) Timothy J. Cowles (OSU): “Finescale Planktonic Vertical Structure: Horizontal Extent and the Controlling Physical Processes”, (4) Jan E.B. Rines (URI): “LOCO: Characterization of Phytoplankton in Thin Optical Layers”, (5) David M. Fratantoni & Nelson G. Hogg (WHOI): “The Physical Context for Thin Layers in the Coastal Ocean”, (6) Louis Goodman (U Mass Dartmouth): “AUV Turbulence Measurements in the LOCO Field Experiments”, and (7) Alfred K. Hanson (URI): “An Investigation of the Role of Nutrient Gradients in the Episodic Formation, Maintenance and Decay of Thin Plankton Layers in Coastal Waters”. Additional related projects include (8) Kelly Benoit-Bird (OSU) “Predator effects on dense zooplankton aggregations in the coastal ocean”, funded by the ONR Young Investigators Program.

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