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14. ABSTRACT
Our long-term goal is to develop an efficient, sustainable, and relocatable observing system suitable for a variety of exploratory, process-oriented oceanographic studies and naval applications. Our basic strategy is to combine technology development with significant field experiments which advance our understanding of the ocean environment.

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The Physical Context for Thin Layers in the Coastal Ocean

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LONG-TERM GOALS

Our long-term goal is to develop an efficient, sustainable, and relocatable observing system suitable for a variety of exploratory, process-oriented oceanographic studies and naval applications. Our basic strategy is to combine technology development with significant field experiments which advance our understanding of the ocean environment.

OBJECTIVES

Our goal in this program is to describe how the structure and evolution of thin layers vary regionally and temporally in different physical environments and under different forcing regimes. Specifically, we hope to address three significant research questions:

1. How does thin layer structure and occurrence frequency vary in different physical and biological environments and under different forcing regimes?

2. What are the typical horizontal spatial scales associated with these layers, and what processes control their horizontal extent and spatial structure?

3. On what timescales are layers generated and destroyed, and how is this evolution related to the ambient physical environment and atmospheric forcing?

APPROACH

We made use of high-endurance autonomous underwater gliders to collect environmental measurements (physical, optical, and acoustic) which emphasize variability on horizontal scales of a few hundred meters to several kilometers, and vertical scales from centimeters to a few meters. Relevant deployments were completed in several regions including the central California coastal zone, the western tropical Pacific, and the New England shelf. Data from these deployments were analyzed to reveal the existence and characteristics of phytoplankton thin layers.

WORK COMPLETED

ONR-supported research programs including LOCO have contributed to a large collection of glider-based physical and bio-optical measurements in the Monterey Bay region spanning 2003-2006 (Figure 1, Table 1). We made use of this data and our larger archive of glider-based observations to support our LOCO research.

During the first year of the LOCO program we focused on development of new sensor capabilities for the WHOI glider fleet. These new capabilities were applied during the first major LOCO field experiment in Monterey Bay in 2005. Eight gliders equipped with physical, bio-optical, and acoustic sensors were deployed along seven parallel cross-shore sections in an 12 km x 8 km rectangular region adjacent to the primary LOCO moored array. The glider fleet occupied this study region with 1.5 km along-shore and better than 0.1 km cross-shore resolution approximately once every 8 hours and for almost one month.

In July 2006 we used a single glider to repeatedly occupy a cross-shore transect to the southwest of the main LOCO moored array. This sampling scheme was chosen to be complementary with mesoscale profiling operations conducted on the *R/V Thompson* and offered numerous opportunities for ship-based vs. glider-based sensor comparisons. The transect spanned the 25 m to 80 m depth range and was approximately 10 km in length. During the course of the deployment (16-26 July) the glider collected approximately 2400 multivariate vertical profiles over 210 km of trackline. The cross-shore transect was occupied a total of 20 times. The PI monitored the glider's performance from onboard the *R/V Thompson.* At-sea interaction with scientists performing in-situ biological sampling, high-resolution profiling, and acoustic measurements was particularly enlightening.

In addition to our standard Seabird CTD, Wet-Labs bb2f, and WHOI PAR sensors (Figure 2), two gliders (one each in 2005 and 2006) carried a prototype fast-response CTD system designed in collaboration with Ray Schmitt (WHOI) to measure vertical finestructure in temperature and salinity at a resolution of 2-5 cm. A prototype Nortek 1MHz ADCP with a custom head design was also used in 2005 and 2006 to collect measurements of shear and acoustic backscatter. The acoustic backscatter data is being analyzed and validated by Malinda Sutor. All sampling was performed between the surface and approximately 3 meters above the bottom.

RESULTS

Given the volume and complexity of this dataset it took some time to finalize have still finalizing the data processing and quality control. We are able to report that all sensors appear to have worked well and the quality of the data is good. The prototype fast CTD and ADCP performed as expected.

Data from the gliders was analyzed in several. Profile data was objectively mapped (Figure 3) to delineate physical structures (eddies, fronts, etc.) that may be controlling the distribution and scale and biological features. Individual profiles were searched for evidence of phytoplankton thin layers using a standardized set of criteria. The profile data indicates that numerous thin layers were evident in chlorophyll fluorescence during the 2005 experiment, and far fewer layers were observed during 2006. Many more layers were found in shallow water in the northeastern sector of the Bay than offshore (Figure 4). A paper currently in preparation (Sutor and Fratantoni, 2010) examines the differences in the physical environment (both oceanographic and meteorological) between the 2005 and 2006 field seasons and resulting differences in thin layer occurrence and zooplankton distribution. We examined groupings of layer observations in an attempt to deduce the horizontal scales of the layers and their relationship to the background physical oceanography. One particularly interesting result (Figure 5) was the preponderance of thin layer observations during nighttime. We explored both physical and biological explanations for this (Fratantoni et al., 2010).

We are currently working on several manuscripts based on the LOCO field data. A collaborative paper with Dr. Malinda Sutor (LSU) on direct, optical, and acoustic measures of zooplankton distribution will likely be submitted to Deep-Sea Research in summer 2010. A paper focusing on glider-based measurements of phytoplankton thin layers and their statistics is in preparation. This latter article will be co-authored by MIT/WHOI Joint Program student Nick Woods who was partially supported under this award.

IMPACT/APPLICATIONS

The application of high-resolution autonomous sampling such as used in LOCO will improve understanding of spatially inhomogeneous, transient ocean phenomena such as planktonic thin layers, submesoscale eddies, and fronts as well as the broader physical environment in which they form and evolve. Continued development and field application of this technology will result in an enhanced capability for streamlined environmental assessment in remote or hostile locations and provide, in an efficient and cost-effective manner, high-quality, near-real-time environmental information for operational ocean/atmosphere forecasting and model validation.

PUBLICATIONS RESULTING FROM THIS AWARD

Fratantoni, D. M., and J. M. Lund, Observations of Thin Phytoplankton Layers in Monterey Bay using Gliders, EOS Trans. AGU, 87 (36), Ocean Sci. Meet. Suppl., Abstract OS34M-05.

Fratantoni, D. M., B. A. Hodges, and J. M. Lund, Autonomous Investigation of Thin Phytoplankton Layers and Their Physical Context. Poster presented at AGU Ocean Sciences Meeting, March 2008, Orlando, FL.

Hodges, B. A., Fratantoni, D. M., and J. M. Lund, Propagation of a thin layer through a synthetic mooring array. Oral presentation at AGU Ocean Sciences Meeting, March 2008, Orlando, FL.

Hodges, B. A., and D. M. Fratantoni, 2009. A thin layer of phytoplankton observed in the Philippine Sea with a synthetic moored array of autonomous gliders. Journal of Geophysical Research – Oceans, **114**, doi:10.1029/2009JC005294.

Sutor, M. M., D. M. Fratantoni, and M. Alford, 2008. The Use of Glider-Mounted Acoustics and In-Situ Imaging Systems to Resolve Spatial and Temporal Distributions of Zooplankton Layers in Monterey Bay, CA. *AGU* Ocean Sciences Meeting, March 2–7, 2008.

Woods, N. W., D. M. Fratantoni, B. A. Hodges, and J. M. Lund, 2008. Thin Phytoplankton Layer Variability in Monterey Bay. *Eos Trans. AGU*, Fall Meet. Suppl., Abstract OS43C-1302.

Sutor, M. M., and D. M. Fratantoni, 2010. The use of Glider-mounted optics and acoustics and in-situ imaging systems to resolve spatial and temporal distributions of plankton in Monterey Bay, CA: Biological responses to different physical regimes. AGU Ocean Sciences Meeting, Portland, OR, February 2010.

Fratantoni, D. M., N. Woods, and B. A. Hodges, 2010. Autonomous observations of thin phytoplankton layers in the coastal ocean. In preparation.

Sutor, M. M., and D. M. Fratantoni, 2010. Optical and acoustical measurements of zooplankton distributions in Monterey Bay. In preparation.

ENVIRONMENTAL COMPLIANCE

A portion of this work was performed within the Monterey Bay National Marine Sanctuary. No harm to the environment occurred. Operations were conducted in accordance with the permit. All equipment was recovered.

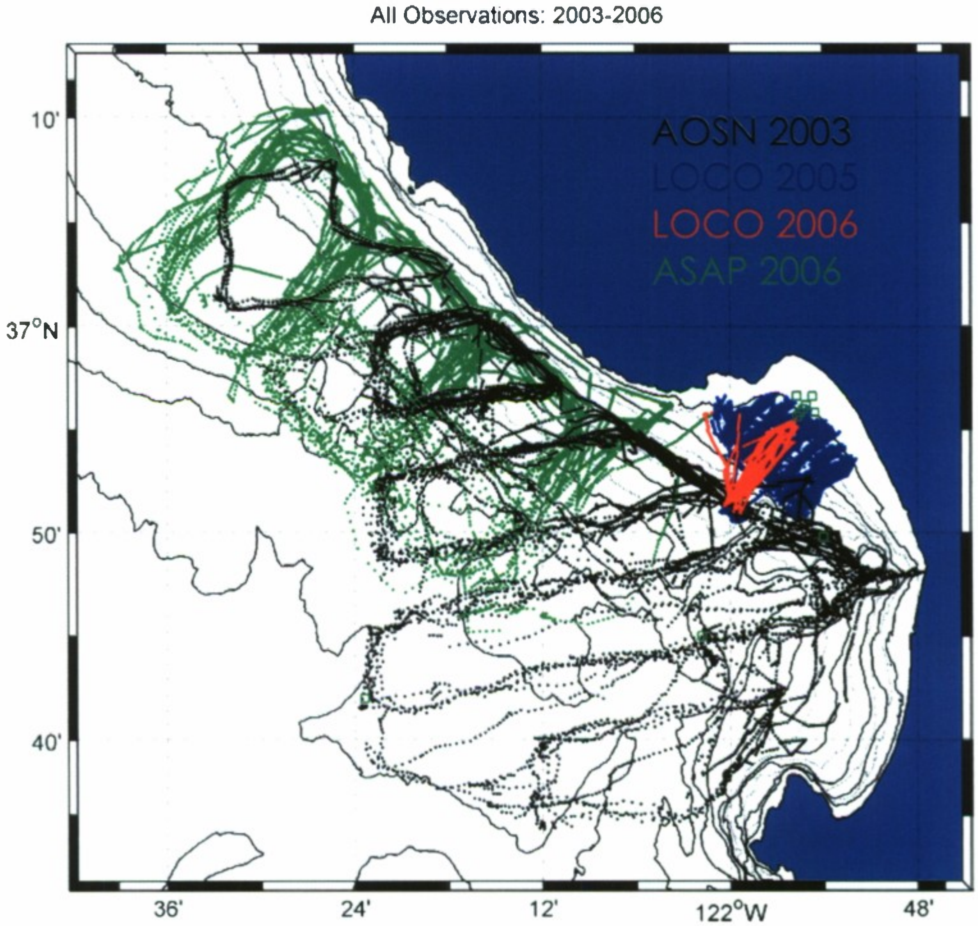

Figure 1: Map of the Monterey Bay region showing locations of WHOI glider profile measurements between 2003-2006. Green squares show the location of the LOCO moored array.

	Monterey Bay			
	AOSN-II 2003	*LOCO 2005*	*LOCO 2006*	*ASAP 2006*
Number of gliders	10	8	1	8
Glider-days deployed	195	189	10	136
Total km trackline	5604	3987	209	3270
Total profiles	11341	33530	2378	10619

Table 1: Summary of glider operations in the Monterey Bay region during 2003-2006.

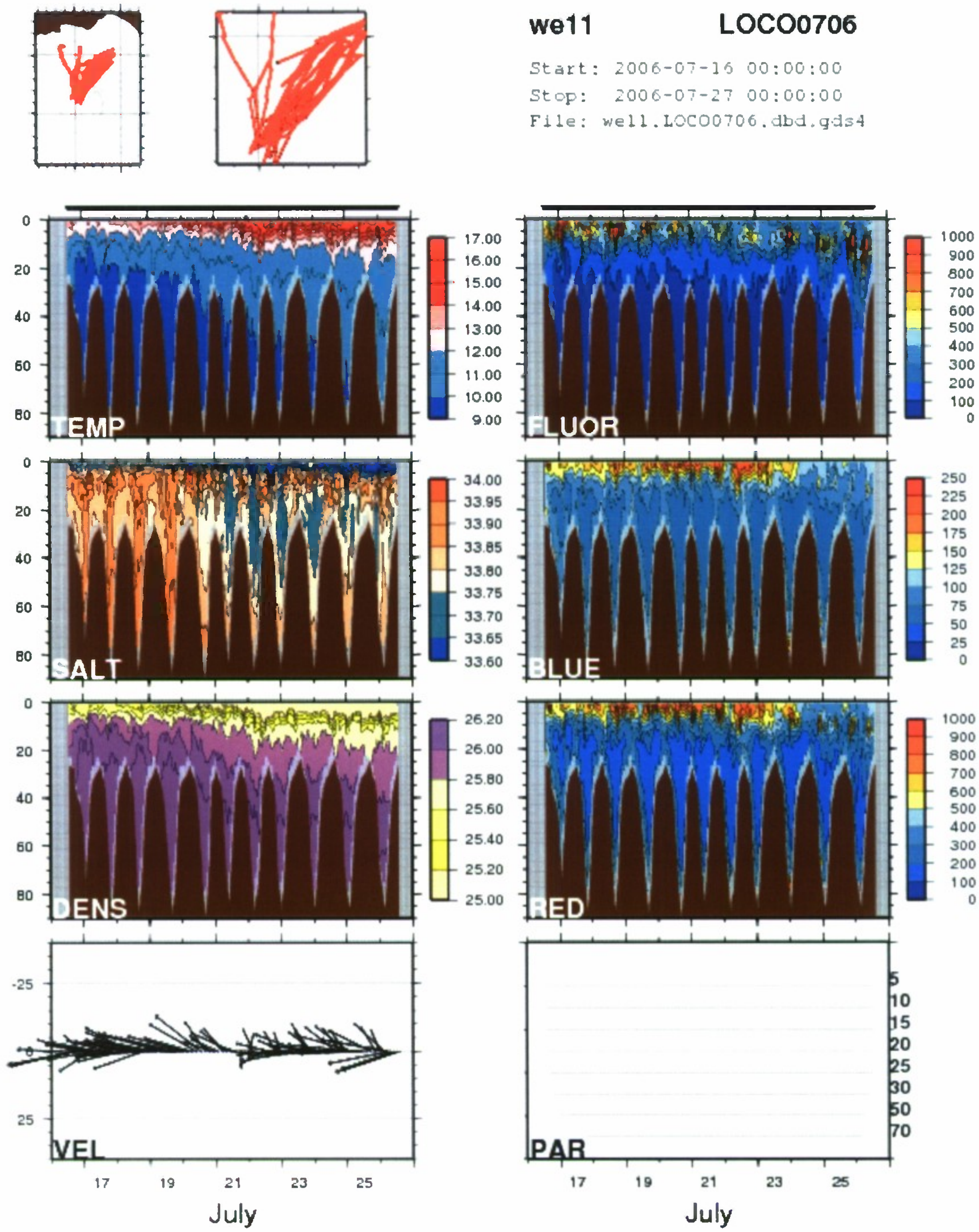

Figure 2: Time-depth contour plots of various parameters measured by glider we11 during the 2006 LOCO field program in Monterey Bay. (Left column) Temperature, salinity, potential density, and slab velocity. (Right column) Chlorophyll fluorescence, blue (470 nm) and red (700 nm) optical backscatter, and PAR.

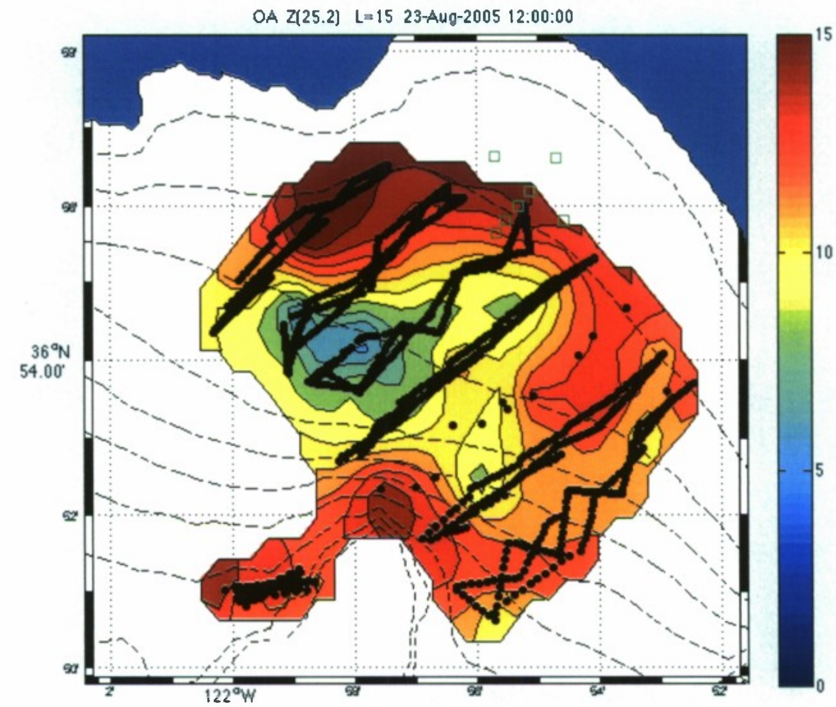

Figure 4: Objectively-mapped snapshot of the depth of the 25.2 potential density surface derived from glider measurements during the 2005 LOCO field program. Green squares show the location of the LOCO moored array4.

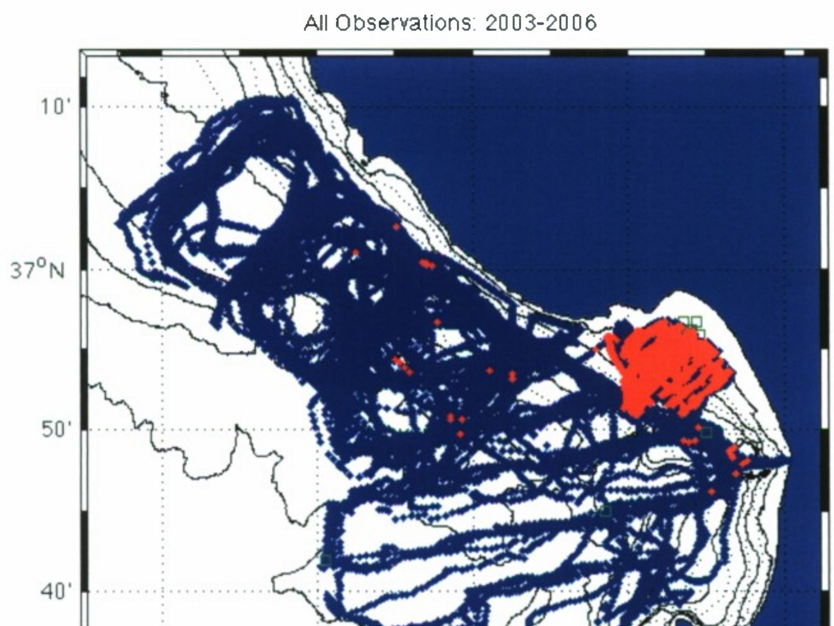

Figure 3: Map of the Monterey Bay region showing in (blue) Location of all glider profiles 2003-2006, and (red) those profiles in which a thin layer of chlorophyll fluorescence was detected.

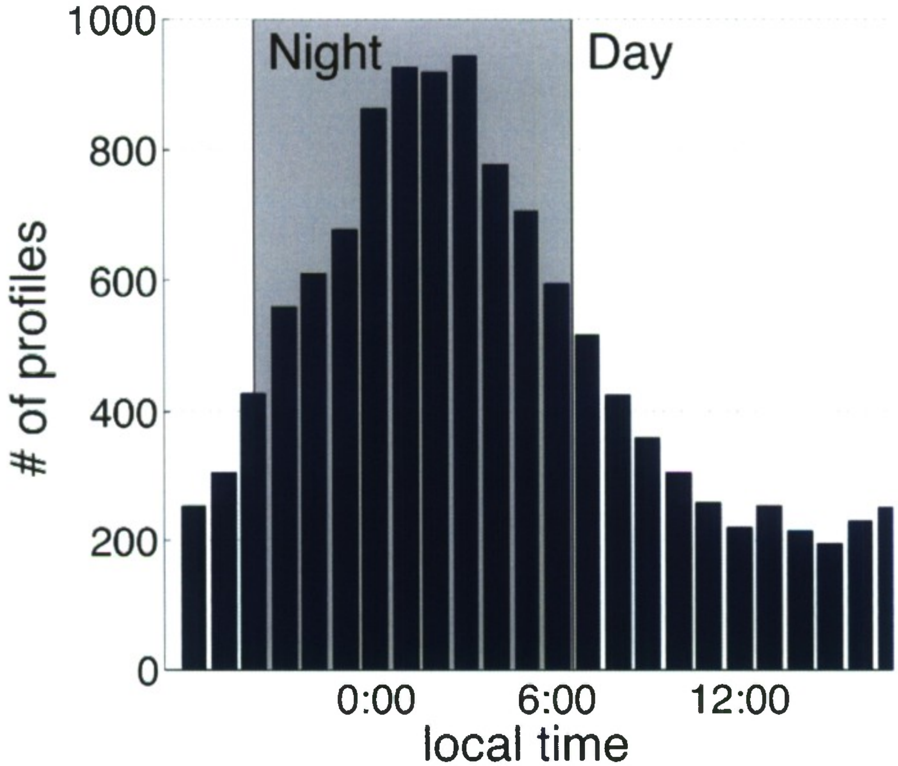

Figure 5: ***Histogram showing the number of profiles containing thin layers during each hour of the day. The number of glider profiles is nearly constant throughout the day, so the peak in observations of thin layers is not a result of biased sampling, but rather reflects the previously*** **unknown diel periodicity of thin layer observations in Monterey Bay in 2005.**