# Finescale Planktonic Vertical Structure: Horizontal Extent and the Controlling Physical Processes

Timothy J. Cowles
College of Oceanic and Atmospheric Sciences
104 Oceanography Admin Bldg
Oregon State University
Corvallis, OR 97331-5503
phone: (541) 737-3966 fax: (541) 737-2064 email: tjc@coas.oregonstate.edu

Grant Number: N00014-04-1-0277
http://argon.oce.orst.edu/biooptics/projects.htm

## LONG-TERM GOALS

Our long-term goal is to quantify the interactions between small-scale biological and physical processes within the upper ocean. Our work within the *Layered Organization in the Coastal Ocean* (LOCO) DRI examines specific scientific questions that relate the distribution and variability in sub-1m scale bio-optical properties with coincident vertical and horizontal scales of physical properties.

## OBJECTIVES

We have made observations in different regions that have confirmed the presence of persistent, small-scale local maxima in the concentrations of nutrients, phytoplankton, and zooplankton. These persistent features result from complex linkages between physical forcing and gradients in the distribution of biological properties. These observations, along with those made by several other teams of investigators, led to the development of the overall programmatic goals of the LOCO DRI. The goals of my research component within the LOCO DRI are to

- quantify the linkage these physical processes and the steep vertical gradients in biological properties within "thin layers",
- develop a more detailed understanding of the time scales and horizontal spatial scales over which these features persist, and
- evaluate the relative importance of vertical and horizontal processes in establishing planktonic distribution patterns.

## APPROACH

The LOCO field experiments in 2005 and 2006 yielded extensive data sets on the centimeter-scale vertical patterns of particulate and dissolved matters in Monterey Bay. Our component obtained all its data from ship-based measurements, complementing those obtained by other investigators at the inshore mooring locations. We focused on the bio/physical linkages in the upper water column by conducting high-resolution vertical profiles of hydrographic, bio-optical, and bio-acoustical properties in conjunction with detailed horizontal mapping of layered properties by other investigators within the LOCO program. We used the multiple instruments on our free-fall profiling system (CTD, ac-9s,

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**2008** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2008 to 00-00-2008** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Finescale Planktonic Vertical Structure: Horizontal Extent and the Controlling Physical Processes** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Oregon State University,College of Oceanic and Atmospheric Sciences,104 Oceanography Admin Bldg,Corvallis,OR,97331-5503** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **6** | |

fluorometers, acoustic Doppler velocimeter (ADV), acoustic Doppler current profiler (ADCP)) to obtain centimeter-scale resolution of hydrographic and bio-optical properties.

We found in earlier work (Cowles, 2004) that it was critical to resolve the vertical gradients in the horizontal velocity field on scales comparable to those exhibited by the planktonic layers. We found that conventional ADCP measurements over 4m depth bins cannot resolve the vertical shear that appears to form and maintain layers and the steep vertical gradients they display. Therefore, we used a 600 kHz ADCP mounted 1.5m below the ocean surface on a vertical pole off the port side of the *RV New Horizon* (2005) and the *RV Thompson* (2006). In addition, we mounted a second ADCP on our profiling system, although we used a 1 MHz Nortek Aquadopp in 2006 instead of the 600 MHz system used in 2005. The combined boom-mounted ADCP system and profiler-mounted ADV and ADCP systems have provided us with velocity gradients on vertical scales relevant to the biological structure.

We integrated our fieldwork in 2005 and 2006 on the survey vessel with the broad science objectives of LOCO. In both 2005 and 2006, LIDAR maps (B. Concannon and J. Prentice) and bio-acoustic maps (K. Benoit-Bird) overlap all of the high-resolution ADCP surveys as well as the vertical profiling work. Continuous cross-isobath glider tracks in 2006 (D. Fratantoni) provided essential time series data on the spatial structure of the northern portion of the Bay while we were obtaining vertical profile data in other portions of the Bay. In addition, the glider tracks functioned to extend the mooring array "line" out into our survey domain. Based on the clear need for additional direct sampling of zooplankton outside the mooring array, numerous vertical profiles of zooplankton abundance and composition were obtained with a pumping system (M. Sutor), while over 100,000 high-resolution optical images of zooplankton were obtained with a new CCD camera system (M. Sutor). These complementary projects enhance the interpretation of our vertical profile and ADCP results.

## WORK COMPLETED

Our efforts during this past year have had two primary foci: first, a thorough cross-checking of data quality of all aspects of our data set; second, integration of our final data with that obtained by the other investigators in the LOCO program.

Final quality data is available on our project website (http://argon.coas.oregonstate.edu/biooptics/projects.htm). We have been developing maps of the horizontal extent and temporal persistence of planktonic thin layers observed in both 2005 and 2006. We are using these preliminary maps to identify regions of the study domain that contain more/fewer layers than other regions of Monterey Bay. The outcome of this analysis will lead to a comparison with the LIDAR and bio-acoustic maps being generated by other LOCO PIs.

We have been working closely with Dr. D. Fratantoni and his glider data to assess the spatial scales of coherent features, including a visit to WHOI in July, 2008 to compare data. In addition, we have had two working sessions with Dr. P. Donaghay to relate the inshore mooring data with the shipboard observations. We have identified specific days and tidal conditions when we can link the spatially-separated datasets.

As reported in the FY 2007 report, our analysis of the cross-isobath differences in water column vertical structure between the depth range of the mooring array (~20m) and slightly deeper regions of the bay has revealed considerable spatial gradients in layer formation and maintenance. Our crosscomparisons with Dr. Donaghay's data are based on our multiple shipboard horizontal sections between the 20m and 45m isobaths during the July 2006 fieldwork. During each cross-shelf section, successive vertical profiles were less than 250m apart. Our analysis supports the observation that inner shelf (<25m) conditions, as measured at the mooring array, were often distinct from those observed beyond the 25-30m isobath.

We have concentrated our analysis efforts in the collaboration with Dr. Kelly Benoit-Bird. Her multi-frequency acoustic data, collected coincidently in time and space with our high-resolution profiles, allows us to address important ecological questions about the aggregation of consumers on layers, as well as the impacts of those consumers on the patterns of overall plankton patterns. We think this is an extremely effective combination of observational approaches, and should raise important new questions about trophic dynamics in the upper ocean.

**RESULTS**

We observed thin layers of bio-optical properties in Monterey Bay in association with steep vertical gradients in physical properties, including the horizontal velocity structure, in both field seasons within Monterey Bay. There were considerable contrasts and differences in layer structure and occurrence between the 2005 and 2006 field years. We are still evaluating those contrasts, and will continue to pursue new insights through small-group meetings and communication between LOCO PIs.

Our data show that a consistent relationship does exist between the vertical structure of the velocity field and the vertical patterns of optical properties. This relationship was commonly observed and can be illustrated by co-plots of the layer structure and coincident velocity structure (Figure 1). It is of particular interest that only one of the two steep gradients in CDOM fluorescence signal in this figure was matched by a single gradient in chlorophyll fluorescence. We often observed this pattern, and suspect that vertical intervals of uniform CDOM distribution represent "slabs" of water of similar chemical history. Over some time interval, the initially uniform distribution of phytoplankton may respond to sinking, mixing, or grazing, and we observe the consequences of those processes in the vertical position of the 'particle' layer in contrast to the distribution of dissolved material (CDOM fluorescence).

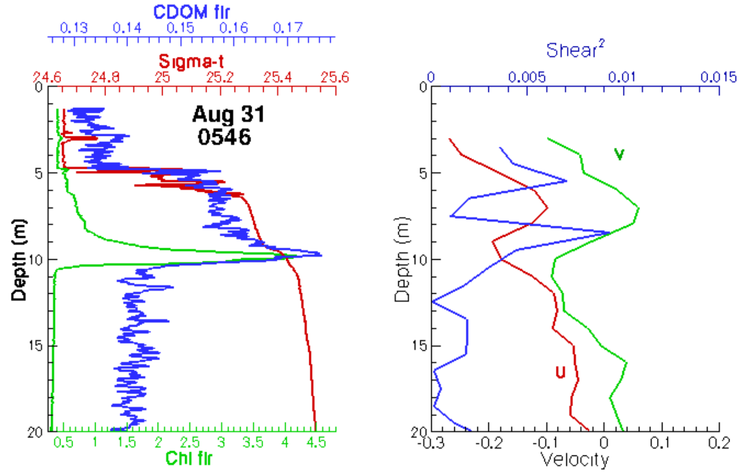


***Figure 1.*** ***The left panel displays the vertical distribution of phytoplankton (chlorophyll fluorescence, green), density anomaly (red), and CDOM fluorescence (blue) within the upper 20m of the water column in Monterey Bay, Aug 31, 2005. Note the narrow layer of phytoplankton at 10m with a coincident gradient in CDOM. The right panel shows the coincident 1m resolution of horizontal velocity (v, green; u, red; shear squared, blue) obtained from a boom-mounted 600 kHz ADCP. Note that the vertical patterns of shear are closely related to the vertical position of the steep gradients in chlorophyll and CDOM fluorescence.***

In addition to this interesting link between the dissolved and particulate material, we have found that the optical expression of the plankton layers was often strongly linked to the bio-acoustical structure of the water column (Figure 2). Note that the acoustic record reveals clear local maxima at the same depth interval as the particle layer defined by bio-optical sensors.

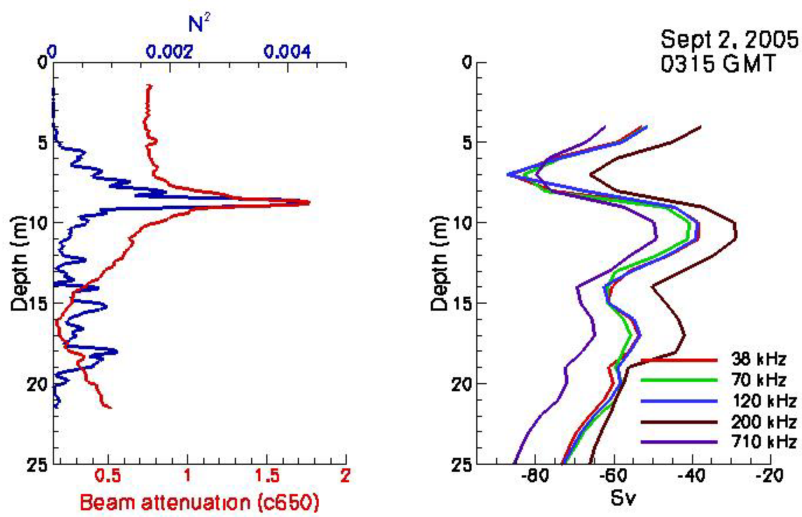


***Figure 2. Vertical profiles of an intense layer, along with l Left panel shows the distinct particulate layer (c650) chlorophyll and CDOM maxima in a thin layer between 8-10m depth, with little chlorphyll structure deeper than 10m. In contrast, panel (B) reveals several steep vertical gradients and thin layers of CDOM fluorescence, with the deepest minimum layer of CDOM occurring where only a small peak of chlorophyll fluorescence was found.***

We have compiled all observations of thin layers in Monterey Bay, and have analyzed those profiles in relation to the local velocity field, as defined by the 1m velocity bins of the boom-mounted 600 kHz ADCP. We can summarize the nearly 100 layers in 2005 by stating that local Richardson number was nearly always a maximum value at the center of the particulate feature (Figure 3a), while the local shear maximum was usually above the particulate maximum (Figure 3b).

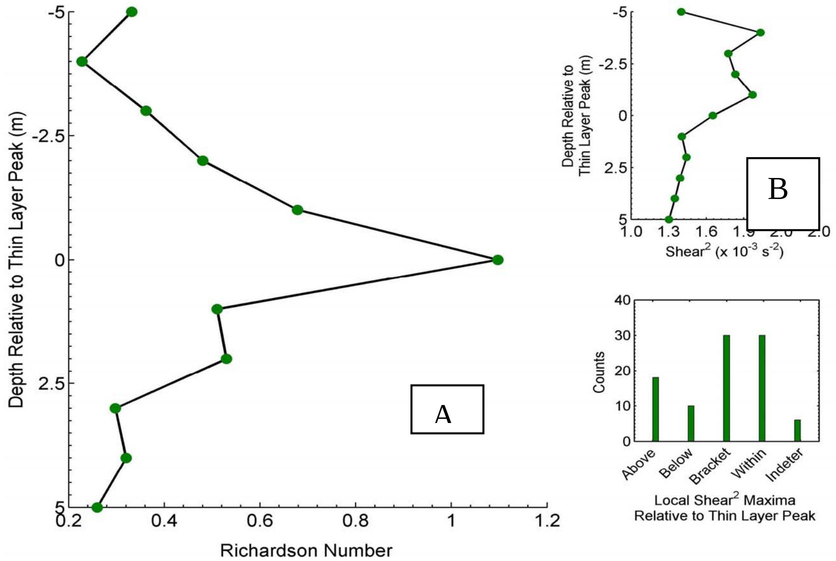


***Figure 3. These three subfigures illustrate the vertical relationship between the particulate maximum, stratification, and the distribution of shear. The left panel illustrates that stratification was often maximum at the peak of the layer, while the local shear had its maximum slictgh.***

These results will be submitted for publication in a special issue of Continental Shelf Research.

## IMPACT/APPLICATION

Our results from prior studies of planktonic thin layers suggest that the analysis and interpretation of the LOCO field experiments will substantially enhance our understanding of bio/physical interactions in general, and thin layers in particular. We anticipate that the results will have broad application in ocean ecology.

## TRANSITIONS

The results of the LOCO fieldwork will provide new insights into the mechanisms that create that persistent pattern on small-scales, particularly over horizontal scales of many 10s of kilometers. Continued evaluation of these mechanisms will be essential for prediction of the impact of persistent small-scale pattern on the attenuation of optical and acoustic signals in the upper ocean. Observational techniques employing autonomous vehicles and profiling systems may now be applied at various oceanic study sites, thus extending our appreciation of the role that small-scale processes may play in our estimates of water column production.

## RELATED PROJECTS

We have active collaborations with the following ONR Principal Investigators:

Dr. Kelly Benoit-Bird, Oregon State University
Dr. Percy Donaghay, University of Rhode Island
Dr. Jan Rines, University of Rhode Island
Dr. Dave Fratantoni, Woods Hole Oceanographic Institution
Dr. Margaret McManus, University of Hawaii
Dr. Jennifer Prentice, NAVAIR
Mr. Brian Concannon, NAVAIR
Dr. Van Holliday, University of Rhode Island
Dr. Malinda Sutor, LSU and WHOI

## REFERENCES

Cowles, T.J. 2004. Thin layers of plankton: physical and biological interactions on the small scale. In: *Handbook of Scaling Methods in Aquatic Science*, L. Seuront and P. Strutton, editors, *CRC Press*, Boca Raton, FL., USA, pp. 31-49.

## PUBLICATIONS

Cowles, T.J. 2004. Thin layers of plankton: physical and biological interactions on the small scale. In: *Handbook of Scaling Methods in Aquatic Science*, L. Seuront and P. Strutton, editors, *CRC Press*, Boca Raton, FL., USA, pp. 31-49.

Alldredge, A.L, Cowles, T.J., MacIntyre, S., Rines, J.E.B., Donaghay, P.L., Greenlaw, C.F., Holliday, D.V., Dekshenieks, M.M., Sullivan, J.M., and Zaneveld, J.R.V. 2002. Occurrence and mechanisms of formation of a dramatic thin layer of marine snow in a shallow Pacific fjord. *Mar. Ecol. Prog. Ser*. 233: 1-12

Eisner, L.B., Twardowski, M.S., Cowles, T.J, and Perry, M.J. 2003. Relationship between phytoplankton pigment concentration and in situ spectral absorption measurements in East Sound, Orcas Island, Washington. *Limnol. Oceanogr.* 48: 632-646.

McManus, M. *et al.* 2003. Characteristics, distribution and persistence of thin layers over a 48 hour period. *Mar. Ecol. Prog. Ser.* 261: 1-19.