Horizontal and Vertical Expression of Planktonic Finescale Processes

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LONG-TERM GOALS

Our long-term goal is to quantify the interactions between small-scale biological and physical processes within the upper ocean. This project has addressed that goal by examining 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 continued to focus on the processes that lead to persistent thin layers (20-40cm in thickness) of planktonic vertical structure in coastal environments. In this funding interval (January 2003 – December 2004) we are also addressing horizontal scales of planktonic layers through a specific collaboration with other two teams of investigators at Oregon State University. In this collaborative work, we conduct coordinated field operations with our free-fall profiling system in conjunction with an instrumented Autonomous Underwater Vehicle (AUV) (see report from H. Wijesekera and T. Boyd) and a towed undulating instrument system (MiniBat) (see report from J. Barth and A. Dale).

Our prior high-resolution observations of planktonic layered features (e.g. Cowles et al 1998, Cowles 2003) have raised many questions about the role of these features in upper ocean trophic dynamics, optical and acoustical signal propagation, and remote sensing. In particular, we have noted striking correlations between thin layers of phytoplankton and small-scale vertical shear. It is of particular interest to define the horizontal scales over which thin layers extend and to determine if the time scales of persistence vary as a function of horizontal scale. We have addressed specific objectives during FY2003 in order to extend our earlier observations and to understand the mechanisms of thin layer formation and persistence. These objectives can be framed as the following questions.

- To what extent is the formation and maintenance of planktonic small-scale structure driven by the vertical gradients in horizontal velocity?
- How are the horizontal dimensions of planktonic layers linked to the spatial variability in physical forcing processes?

In addition to these two primary research questions, we are continuing to redesign and modify the data acquisition components of our profiling system.

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APPROACH

We have approached our objectives for FY2003 through a series of one-day cruises on the RV Elakha conducted over the continental shelf off Newport OR in the summer of 2003. We used our free-fall profiling system to obtain repeated profiles of temperature, salinity, density, small-scale vertical shear in horizontal velocity, along with bio-optical and bio-acoustical measures of plankton biomass during test deployments of the AUV. We conducted our cross-shelf transects with the AUV and profiling system after the MiniBat team (Barth and Dale) had completed a cross-shelf survey with the undulating system. Although the field tests in 2003 were primarily devoted to debugging the recently delivered AUV system, we were able to deploy our profiler every 250-300m along the horizontal track of the AUV. During these transects we obtained bio-optical parameters from our profiling system, including 9 wavelengths of particulate absorption and beam attenuation (Wetlabs ac-9) and with pigment fluorescence. We also obtained finescale resolution of vertical shear using the Sontek Acoustic Doppler Velocimeter (ADV).

We conducted our short cruises in 2003 over the center of the continental shelf, within the survey area of a CODAR radio frequency array that provides hourly averages (1-km resolution) of surface currents, with wind data provided from nearby NOAA meteorological buoys. In addition, we have obtained SeaWiFS and MODIS imagery that reveals mesoscale patterns in horizontal distributions of phytoplankton biomass over the continental shelf.

Our high-resolution measurements of the vertical patterns of physical/biological properties form the basis for the evaluation of the mechanisms that produce persistent small-scale structure in the upper ocean. It is clear, however, that the absence of planktonic layers does not mean that layer formation conditions are absent. In an effort to separate the biological and physical components of planktonic layer formation, we conducted high-resolution vertical profiling within patches of fluorescein dye that had been injected into the waters over the Oregon continental shelf in June 2003 from the *RV New Horizon*.

WORK COMPLETED

We completed 4 cruises off the Oregon coast during the summer of 2003, obtaining approximately 40 profiles of high-resolution hydrographic, bio-optical, and bio-acoustical data. Most of these cruises were of one-day duration aboard the 54' *R/V Elakha*, in collaboration with the AUV and MiniBat operations. Of particular note were the vertical profiles obtained during the dye injection cruise on the *R/V New Horizon* (see Results section).

As part of the redesign of our data acquisition system, we have tested several technologies that we may use in the implementation of the new system. These technologies will permit us to collect multiple data streams (several instruments) into archives (all records time stamped and registered) that can be merged to produce a temporally (and spatially) coordinated sampling record.

We have continued our collaboration during FY2003 with other ONR investigators involved in the 1998 East Sound Thin Layers experiments, and these efforts are now appearing in the reviewed literature (Alldredge et al. 2002, Eisner et al. 2003, Cowles 2003, McManus et al. 2003).

RESULTS

The shape of dye layers

A coastal dye injection experiment provided an opportunity to examine the vertical gradients of a recently injected volume of dye. In June 2003, we joined Drs. A. Dale, J. Barth, and M. Levine on the *RV New Horizon* so that we could obtain vertical profiles through a recently-injected fluorescein dye patch. We show in this report some data from this experiment that placed fluorescein onto a target isopycnal of 25.8 kg m^{-3} over the continental shelf off Oregon. For several hours following the dye injection, Drs. Dale, Barth, and Levine mapped the extent of the patch with a MiniBat system equipped with a fluorescein fluorometer. Their sections revealed considerable horizontal stretching of the dye patch, as would be expected velocity structure across the shelf. We were able to obtain several vertical profiles through this fluorescein patch 27 hours after injection. The observed dye distributions (Figure 1) had a striking similarity to the phytoplankton slabs and layers we have observed in East Sound and over the Oregon continental shelf, even after over 24 hours within the tidally stirred waters of the continental shelf. The similarities in the shape of these dye features with our planktonic layers suggest that similar physical processes are operating in the formation of plankton layers and dye layers. Note the vertical patterns of small-scale shear obtained with the Acoustic Doppler Velocimeter (Figure 2). The absence of a gradual smoothing of the vertical gradient in dye concentrations over several hours reinforces the notion that horizontal processes dominate over vertical processes in the formation and maintenance of planktonic small-scale structure.

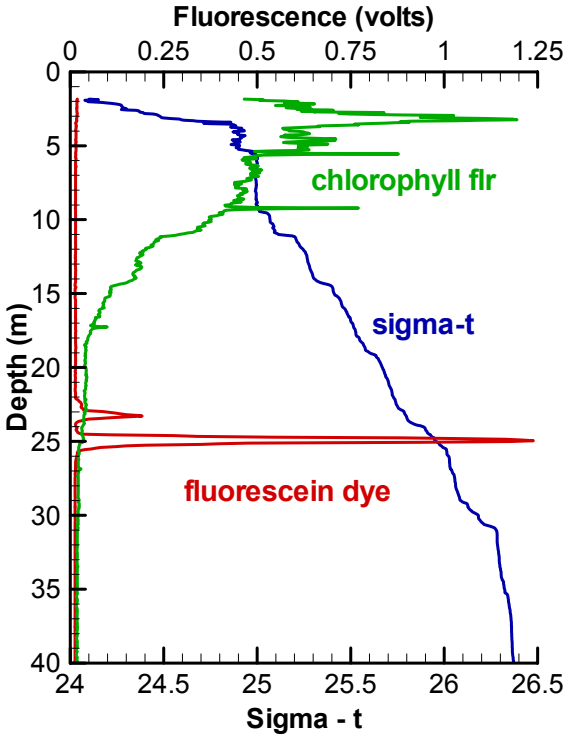

Figure 1. Vertical profile through a thin layer of fluorescein dye (red), June 30, 2003, with sigma-t (blue) and chlorophyll fluorescence (green). Note that the dye layer has a vertical gradient quite similar to the phytoplankton layer near the surface.

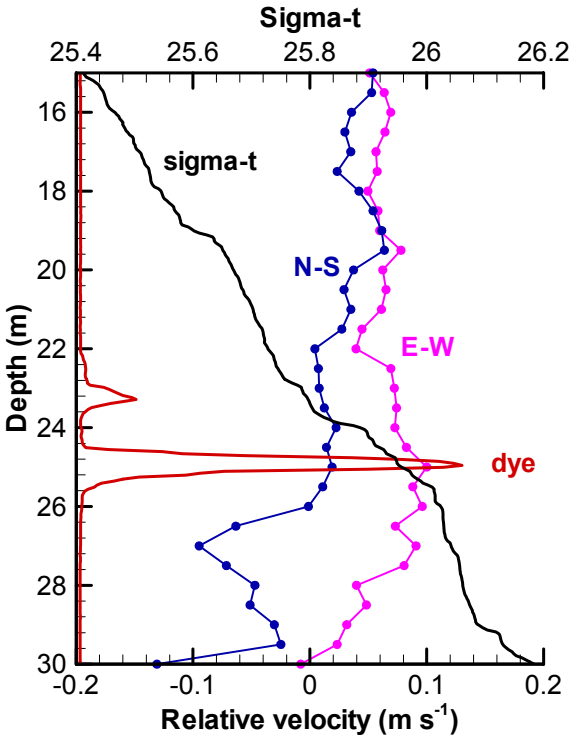

Figure 2. Vertical profile of relative velocity obtained from ADV for the profile shown in Figure 1. Note the correlation between the sharp vertical gradients in dye (red), sigma-t (black), and relative velocity (blue and magenta) within this narrow vertical interval.

Horizontal extent of planktonic layers

We have demonstrated that we can deploy and recover our profiler along the track of the moving AUV during horizontal transects, using the *RV Elakha*. These summer 2003 tests were the first deployments of the new AUV system, so we are pleased with the results to date. We have several cruises scheduled on the *RV Elakha* in late spring and early summer 2004, and have 10 days aboard the *RV Sproul* in August 2004 for more complete surveys of layer extent.

Data Acquisition System

We have developed a series of XML schemas that permit easy configuration of our new data acquisition approach to accommodate various combinations of instruments in different deployment scenarios. We are testing a software system developed by NASA for archiving and time stamping multiple data streams called the Ring Buffered Network Bus (RBNB) Data Turbine. We have completed the first phase of performance testing of the RBNB software. The results have been positive, and we plan on developing our first prototype system using the RBNB Data Turbine software.

IMPACT/APPLICATION

Our results suggest a tight link between the vertical scales of horizontal velocity changes and patterns of small-scale planktonic structure. This linkage indicates that the vertical gradients in *horizontal*

processes, rather than *vertical* processes themselves, may be the key organizing processes in plankton dynamics. Our results from the dye layers supports the idea that the physical conditions that lead to plankton layer formation may be present much of the time. Our work with biological small-scale structure suggests that previous observations of small-scale biological patchiness may not have been observations of stochastic fluctuations in biological structure (i.e., patchiness), but under-sampled observations of persistent, small-scale structure. This finescale organization of planktonic biomass forces a re-evaluation of water column rate processes, and challenges our existing paradigms for sampling and experimentation over scales of meters and 10's of meters.

TRANSITIONS

The results from repeated sets of profiles from the Oregon continental shelf provide additional insights into the mechanisms that create that persistent pattern on small-scales. 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. These observational techniques 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. Hemantha Wijesekera, Oregon State University
Dr. John Barth, Oregon State University
Dr. Murray Levine, Oregon State University
Dr. Tim Boyd, Oregon State University
Dr. Andrew Dale, Oregon State University
Dr. J.R. Zaneveld, Oregon State University
Dr. Scott Pegau, Oregon State University
Dr. Percy Donaghay, University of Rhode Island
Dr. Jan Rines, University of Rhode Island
Dr. Dian Gifford, University of Rhode Island
Dr. David Smith, University of Rhode Island
Dr. Alice Alldredge, UC Santa Barbara
Dr. Sally MacIntyre, UC Santa Barbara
Dr. Mary Jane Perry, University of Maine
Dr. Van Holliday, BAE Systems (formerly TRACOR)

REFERENCES

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

Cowles, T.J., R.A. Desiderio, and M-E. Carr. 1998. Small-scale planktonic structure: persistence and trophic consequences. *Oceanography* 11: 4-9

Cowles, T.J. 2003. 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.

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

Holliday, D.V., Pieper, R.E., Greenlaw, C.F., and Dawson, J.K. 1998. Acoustical sensing of small scale vertical structure in zooplankton assemblages. *Oceanography* 11: 18-23

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

PUBLICATIONS (REFEREED)

Cowles, T.J. 2003. 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