Plankton Patch Feasibility Experiments

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LONG -TERM GOALS

My long - term goal is to increase our understanding of the biological - biological, physical - biological and chemical - biological interactions that control the initiation, maintenance and dissipation of plankton patches. This goal can most readily be achieved by directly measuring processes thought to control plankton patch dynamics, experimentally testing their importance, incorporating those processes into conceptual plankton dynamics models, and then testing the models in the ocean.

OBJECTIVES

My short term objective is to increase our understanding of the mechanisms controlling the dynamics of thin layers. Thin layers are plankton patches that range in thickness from a few tens of centimeters to a few meters, yet can extend horizontally for kilometers and persist for more than 24 hours. In some cases thin layers can be sufficiently intense to affect biological rate processes and the performance of current and planned Navy optical and acoustical sensors. Although recent advances in optical and acoustic sensors have provided increasing evidence that thin layers can occur in a variety of stratified coastal systems, we are just beginning to sample their temporal and spatial extent and the mechanisms that control their dynamics. Our conceptual models based on a combination of tow tank experiments and preliminary field measurements have suggested that thin layer dynamics should be particularly sensitive to interactions with current shear and consumption by higher trophic levels (Donaghay and Osborn, 1997, Donaghay and Holliday, 1998). As a result, our objectives during the ONR Thin Layers Experiment were to (1) quantify the temporal and spatial scales of thin layers of phytoplankton and zooplankton, (2) test our model of the effects of episodic increases in current shear on thin layer formation, maintenance and dissipation, (3) test the hypothesis that zooplankton aggregate into thin phytoplankton layers, and (4) provide a broader scale context for the structure and process measurements made by the other members of the thin layers group.

APPROACH

Our approach has been to complete papers on earlier work while beginning the numerical analysis of the unique set of fine scale profiles collected during the 1998 ONR Thin Layers Experiment conducted in East Sound, WA. During this experiment, a combination of basin scale transects and a triangular array of autonomous bottom-up profilers were used to simultaneously quantify currents and the vertical physical, biological, chemical, and optical structure over the wide range of temporal and spatial scales needed to test our models (Donaghay and Holliday, 1998). At the site of the array, we used our newly developed underwater winch CTD/optics profilers to collect more than 2 weeks of hourly finescale profiles of temperature, salinity, density, oxygen, spectral absorption and spectral transmission. These

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Plankton Patch Feasibility Experiments**		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 Rhode Island,Graduate School of Oceanography,Narragansett,RI,02882**		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		
14. ABSTRACT		
15. SUBJECT TERMS		

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

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

profiles were collected in close proximity to acoustic profiles of zooplankton collected at one minute intervals by Van Holliday and profiles of currents collected every 15 minutes by a bottom mounted ADCP.

WORK COMPLETED

We completed development of our technique for using dual-spectral absorption and attenuation meters (WET Labs ac-9s) for quantifying the finescale distribution of particulate and colored dissolved organic matter (CDOM) in coastal waters. We have developed the numerical programs which incorporate these techniques. A paper on the calibration method has been published in the Journal of Oceanic and Atmospheric Technology (Twardowski, Sullivan, Donaghay and Zaneveld, 1999).

We have used the revised methods to recalculate absorption data collected on cruises in 1995, 1996, and 1997. This has greatly improved the accuracy of our estimates of finescale structure of absorption by dissolved substances and absorption and scattering by particulate material. These improvements in accuracy have allowed us to develop a series of papers on absorption of CDOM in the coastal environment. In the first of these papers, we quantified the effect of photobleaching on spectral signature of CDOM using the 1997 data. This paper has been submitted to the Journal of Geophysical Research (Twardowski and Donaghay, submitted a). In the second paper, we separated in situ CDOM production from terrestrial inputs and thereby quantified the production of CDOM by a thin phytoplankton layer. This paper has been submitted to the Journal of Geophysical Research (Twardowski and Donaghay, submitted b).

We have collaborated with Rines on a paper showing that persistent thin optical layers can be dominated by toxic algae. This paper is submitted to Marine Ecology Progress Series (Rines, Donaghay, Dekshenieks, and Sullivan, submitted).

We have collaborated with Dekshenieks and Osborn in the analysis of the circulation study that was carried out at the start of the 1998 Thin Layers Experiment. A paper is submitted to Coastal and Estuarine Shelf Science (Dekshenieks, Osborn, Donaghay, and Sullivan, submitted).

We have developed the software needed to handle the underwater winch data collected in 1998. Hourly profiles of temperature, salinity, density, spectral absorption and spectral attenuation have been extracted from the continuous 2 week long records collected by the underwater winches in June 1998. The time series CTD data has been contoured and the contour maps distributed to the other Thin layer PIs. The optics data collected by the winch profilers has been merged with the CTD data and corrected for instrument drift and the effects of temperature and salinity on absorption and attenuation values.

I organized a one day data meeting for the Thin Layers PIs before the 1999 ASLO meeting and co-chaired a 4 day Thin Layers data workshop at URI in May 1999.

RESULTS

Although we are still early in the process of analyzing our 1998 data, it is already evident that the approach is extremely powerful. First, the underwater winches have provided us with a unique the 2-week time series of hourly finescale profiles of temperature, salinity, and density data (Figure 1). Even

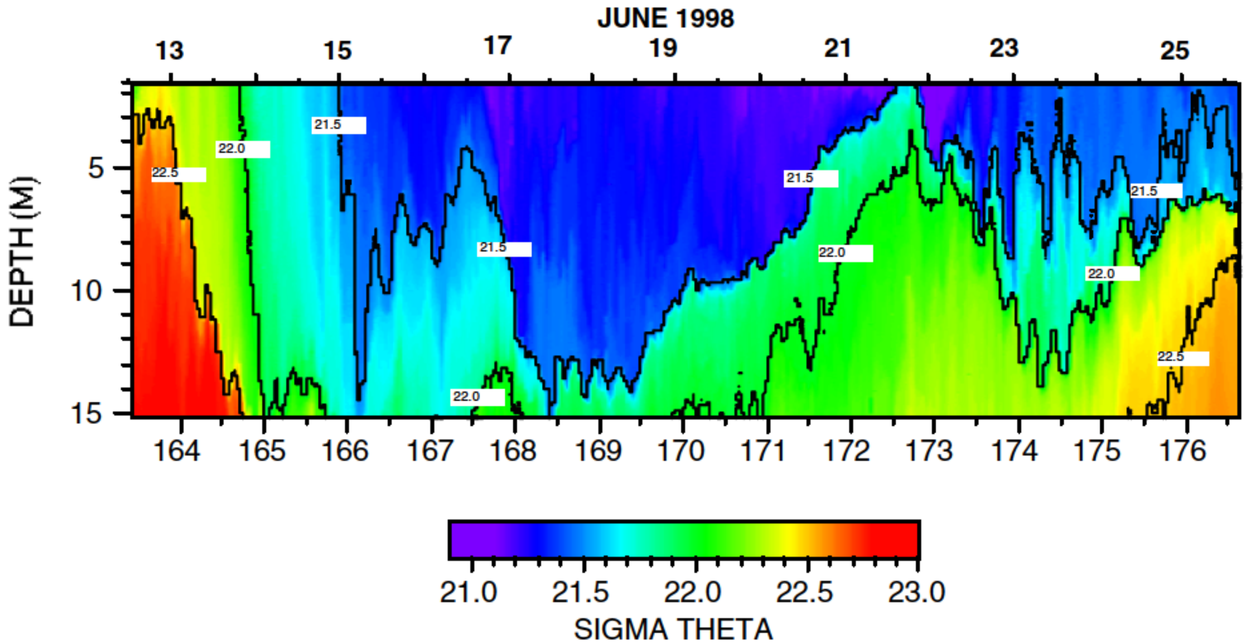

Figure 1. Fine scale density (sigma theta) structure at the array in upper East Sound in June 1998. This plot is based on hourly underwater winches profiles. Vertical resolution of the density data is 1 cm.

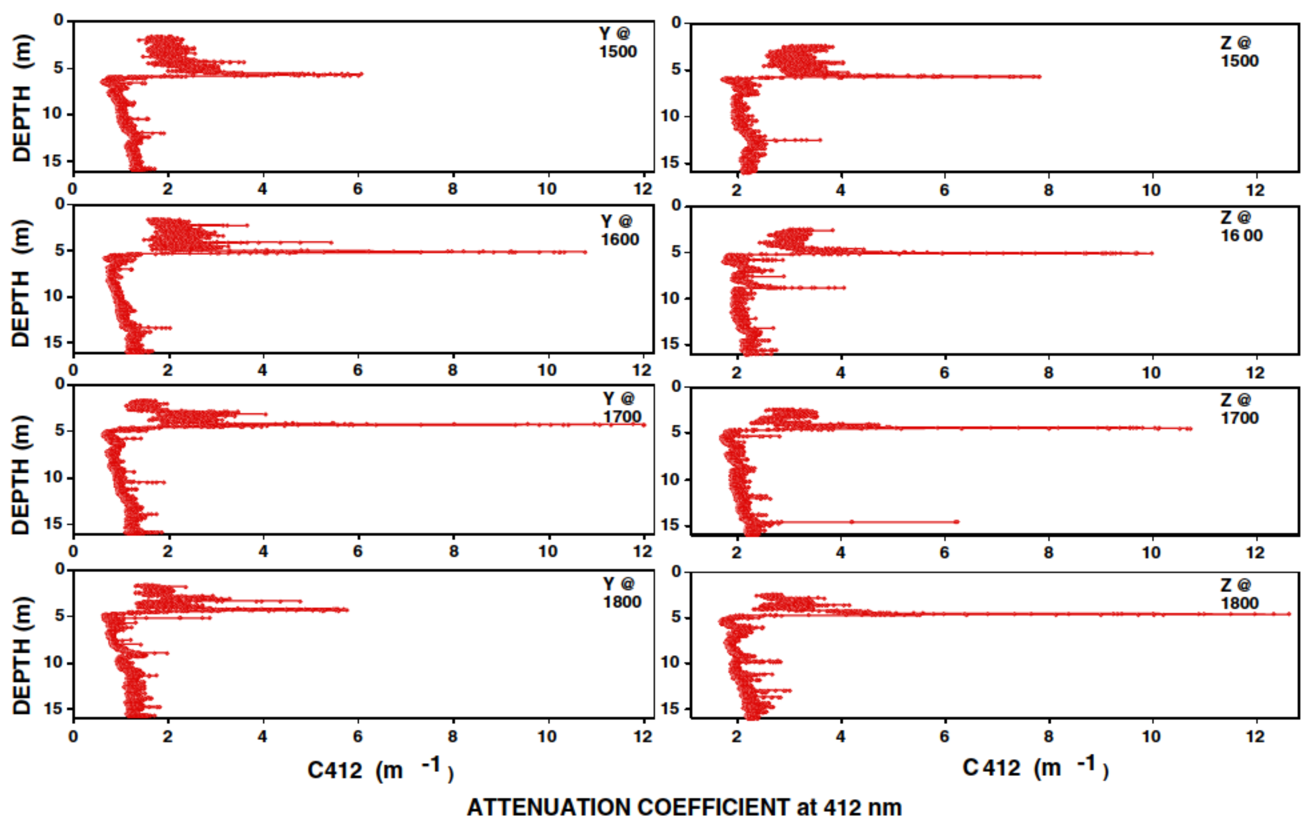

Figure 2. A temporally and spatially coherent thin optical layer observed at the array in upper East Sound on June 25, 1998. Profiles in the left panels are from the Y mooring. Profiles in the right panels are from the Z mooring that was located 300 m south of the Y mooring. Vertical resolution is 1 cm.

when viewed alone, it is evident from this data that there are multiple scales of variability that would be extremely difficult to quantify with conventional ship based sampling. As a result, this data provides a much needed context for the high resolution profiling collected from ships. More importantly, these data provide the basis for quantitative analysis of the mechanisms whereby interactions of currents and density structure control the mixing and shearing processes so crucial to thin layer dynamics. These data will also be crucial to evaluating the mechanisms controlling the vertical position of thin optical and acoustic layers.

Second, the underwater winches have provided us with a unique time series of hourly fine scale optical profiles (Figure 2). By themselves, a time series of simultaneous profiles from 2 of these systems allow us to separate temporal and spatial variability that frequently confounds patch data collected by a single ship. For example, since the 10-20 cm thick layer in Figure 2 was observed simultaneously at 2 stations 300 m apart over 10 hours (4 hours of which are shown in the figure), it is clear that we are sampling a thin patch with a horizontal spatial scale of greater than 300 m and a temporal persistence of at least 10 hours. It is clear we are not looking at a micro-patch with horizontal scales of centimeters to a few meters. Equally importantly, these data demonstrate that layers can be as thin as 10 cm, yet have extremely high particle concentrations (attenuation coefficients of 12 inverse meters are normally seen only in extremely eutrophic waters). It is now quite clear from these optical data and similar acoustic data collected nearby by Holliday that other profiling techniques have underestimated the intensity or completely missed such thin layers.

IMPACT

One of the central paradigms in biological oceanography has been that small scale mixing processes in the upper ocean are sufficiently strong and equal in all directions that sub-meter scale biological, chemical and optical structures will be rapidly dispersed and thus can be ignored in both sampling and modeling upper ocean dynamics. Our tow tank and field experiments clearly challenge the generality of this paradigm by demonstrating such features can persist for more than 24 hours and extend horizontally for kilometers. Our field results and theoretical analyses indicate that biological-physical, biological-chemical and biological-biological interactions occurring at these scales may control not only the development of blooms of toxic and/or bioluminescent phytoplankton, but also the extent to which zooplankton are able to exploit phytoplankton production. Equally importantly, our field observations indicate that the fine-scale biological layers can be sufficiently intense to alter optical and acoustical characteristics of these waters.

TRANSITIONS

We have expanded our efforts to transition our research to the Navy and private industry. First, we have developed a National Ocean Partnership Program project designed to extend and transition our 4-D finescale profiler technology. Partners in this project are Alfred Hanson (SubChem Systems), Casey Moore and Ron Zaneveld (WET Labs), Alan Weidemann (NRL-Stennis), LCDR Kimberly Davis-Lunde (Commander, Naval Meteorology and Oceanography Command) and Richard Green (Environmental Protection Agency Gulf Ecology Laboratory). Second, we have continued to work with scientists and engineers at NUWC to transition our results. In July, we collaborated with Van Holliday (Tracor/Marconi) in a joint presentation of the results of the 1998 Thin Layers Experiment to scientists and engineers at NUWC. This presentation focused on the technological advances in the project and the implications to Navy systems. This fall we discussed application of the ac-9 with Edward Levine and Adam Jilling (NUWC) and provided a training session for their staff.

RELATED PROJECTS

1. I am continuing a long-term collaboration with Van Holliday (Tracor) in trying to quantify zooplankton thin layers and understand how those layers are related to phytoplankton fine structure and physical forcing. We have shared data and spent several weeks working with Holliday's group at his lab.

2. Margaret Dekshenieks (URI), Tom Osborn (Johns Hopkins) and I are trying to understand large scale physical forcing of thin layer dynamics.

3. Mike Twardowski (OSU) and I are continuing our work on the role of photobleaching and biological production in controlling of the magnitude and spectral characteristics of CDOM absorption.

4. I am working with Tim Cowles (OSU), Ron Zaneveld (OSU) and Margaret Dekshenieks (URI) to combine all the transect and bottom-up profiler data to assess the temporal and spatial extent and characteristics of thin optical layers measured during June 1998.

5. Jan Rines (URI) and I are working on the role of small-scale mixing processes in controlling the dynamics of non-spheroid diatoms.

6. Dian Gifford (URI) and I are trying to deterime the effect of microzooplankton grazing on thin phytoplankton layers.

7. Mary Jane Perry (UM), Tim Cowles (OSU) and I are working on a new method to estimate in situ growth rates of thin phytoplankton layers.

8. Alan Weidemann (NRL Stennis), Jan Rines (URI), Margaret Dekshenieks (URI) and I are working on fine scale phytoplankton and optical structure

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