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 continuing 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

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profiles of temperature, salinity, density, oxygen, spectral absorption and spectral transmission. These 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 have completed two papers with Twardowski (OSU) on the mechanisms controlling the absorption of light by colored dissolved organic material (CDOM). In the first of these papers, we used data from the 1996 East Sound cruises to separate *in situ* CDOM production from terrestrial inputs and thereby quantify the production of CDOM by a thin layer of phytoplankton. This paper has been accepted by the Journal of Geophysical Research-Oceans (Twardowski and Donaghay, in press). In a second paper, we quantified the effect of photobleaching on spectral signature of CDOM using the 1996 and 1997 East Sound data. This paper has been accepted with minor revisions for publication in the Journal of Geophysical Research – Oceans (Twardowski and Donaghay, submitted).

We have completed our work with Rines on the temporal and spatial extent of a persistent thin layer of the diatom Pseudo-nitzschia observed during the May 1996 East Sound cruise. The resulting paper has been accepted for publication in Marine Ecology Progress Series (Rines, Donaghay, Dekshenieks, and Sullivan, in press).

We have completed our work with Dekshenieks on the statistics of thin optical layer occurrence during the 3 cruises in East Sound during 1996. The resulting paper has been accepted for publication in Marine Ecology Progress Series (Dekshenieks, Donaghay, Sullivan, Rines, Osborn, and Twardowski, in press).

We have completed our work with Dekshenieks and Osborn on the East Sound circulation study that was carried out at the start of the 1998 Thin Layers Experiment. The resulting paper has been submitted for publication in Estuarine and Coastal Shelf Science (Dekshenieks, Osborn, Donaghay, and Sullivan, submitted).

Jim Sullivan has completed his Ph.D. dissertation on the effects of small-scale turbulence on the growth, mortality, bioluminescence and distribution of marine dinoflagellates. A manuscript combining lab experiments with field data from the 1998 East Sound summer experiment has been submitted to J. Phycology (Sullivan, Swift, Rines and Donaghay, submitted).

We completed the calibration and numerical processing of the CTD and optical data collected by the underwater winch profilers during the June 1998 East Sound experiment. We have converted these data into formats that can be plotted as individual casts or as time-series depth profiles at each location in the array. We have used these data in combination with the current meter data to calculate the shear and mixing environment that can control finescale optical and acoustic structure. We have surfaced-referenced the Tracor Acoustic Profiling System (TAPS) data collected by Van Holliday's group at 3 locations in the array. We have created common format data files for all the CTD, optical, and current meter data collected in the array. This will facilitate visualization and inter-comparison of our results. We have exchanged these master files with Holliday's group. We prepared a poster August 2000 data workshop that included the 2 week June 1998 time series of changes in (1) wind and tidal forcing, (2) finescale physical structure, (3) currents, and (4) finescale optical and acoustic structure. Copies of this overview poster have been made available to other thin layers PIs.

We participated in the Thin Layers data workshop held at Oregon State University in late August 2000. In addition we have had a series of data analysis meetings with other PIs designed to address specific issues and develop joint papers. First, we have had 4 multi-day data analysis meetings with Van Holliday's group in San Diego. We have made considerable progress in merging and analyzing our joint data sets from the array. We developed companion posters that were presented at the 2000 AGU/ASLO Ocean Sciences meeting. We have completed outlines and identified figures for several joint papers. Second, Margaret Dekshenieks, Jan Rines and I traveled to Santa Barbara for a mini-data workshop with Alice Alldredge, James Case, Sally MacIntyre, Van Holliday, Duncan McGehee and Christy Herren. We exchanged data and began working on several joint papers. Third, we met with Tim Cowles (OSU) at URI and OSU as part of an effort to develop a joint paper on the temporal and spatial scales of thin layers. Finally, we have hosted Christy Herren (UCSB) at URI to assist her in interpreting her bioluminescence data in the context of the biological and physical data collected at the array.

We have examined the finescale optical and acoustical profiles to identify the thickness, intensity, persistence and temporal coherence of all sub-5 meter thick peaks that are observed in 2 or more profiles. This analysis has been completed for the more than 240 profiles collected from the transect boat in 1996 and 1998. A similar analysis is nearly complete for the two-week time series of optical and acoustical profiles collected at the array in upper East Sound in June 1998. These data have been used to conduct statistical analysis of thin layers and to examine the physical and biological conditions that control their intensity and dynamics. This work is being done in close collaboration with Margaret Dekshenieks and Van Holliday's group.

RESULTS

Our ongoing analysis of the centimeter-scale physical, optical, and acoustic profiles has provided important insights into the temporal and spatial scales of thin layers and the mechanisms that control their dynamics. First, statistical analysis of the thickness of coherent layers indicates that conventional meter-scale sampling has grossly under-sampled these scales. As a result, meter scale sampling has lead to the conclusion that coherence declines with layer thickness when in fact there is a bimodal distribution with a minimum at 3.5 m, and a modal peak at 1 meter. In fact, layers as thin as 12 cm have been observed to persist for more than 12 hours and extend for kilometers. Second, statistical analysis of finescale optical and acoustical profiles indicates that meter scale sampling has grossly underestimated high concentrations of plankton that can occur in thin layers and the steepness of gradients between layers and surrounding waters. This means that we have not only underestimated concentration- and gradient-dependent biological rate processes, but that we have also underestimated the impact of the high concentrations of thin plankton layers on the absorption and scattering of light and sound. This has serious implications for interpreting data from optical and acoustic sensors deployed in coastal waters. Third, a similar analysis of centimeter-resolved physical structure indicates that standard decimeter-scale physical sampling can sometimes grossly underestimate the local vertical density gradients that appear to be critical to preventing turbulent dissipation of thin layers. Fourth, our ongoing analysis of the temporal/spatial patterns of thin layer occurrence indicates that the balance between local shear and buoyancy (e,g., Richardson number) plays a critical role in the development and persistence of thin layers. For example, thin optical and acoustical layers do not occur during periods when Richardson number falls below the critical value of 0.25. Finally analysis of diel changes in the acoustic data indicate that while vertically migrating zooplankton frequently aggregated into thin layers of potential prey (Figure 1), at other times they completely avoided such layers. Dramatic declines in abundance of thin layers of phytoplankton and zooplankton were observed during periods of intense vertical migration (Figures 1 and 2). This strongly suggest that trophic interactions occurring on vertical scales of decimeters to a few meters may be critical to understanding zooplankton and phytoplankton dynamics on larger time and space scales.

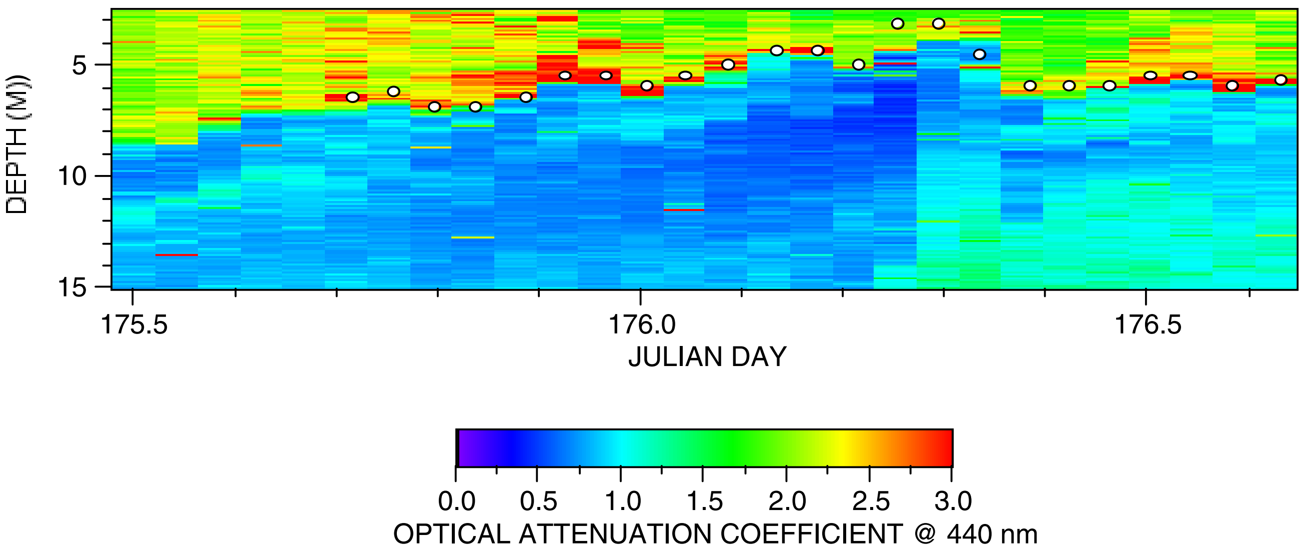

Figure 1. Temporal changes over 30 hours at station Z in finescale optical structure measured as optical attenuation coefficient at 440 nm). Profiles were collected once an hour with vertical resolution of 1cm with the ac-9 on an underwater winch profiler. The open circles indicate the vertical position of the strong temporally and spatially coherent layer that formed at the base of the particle rich surface layer. This layer was 10-20 cm thick and reached peak values of 13 m^{-1}.

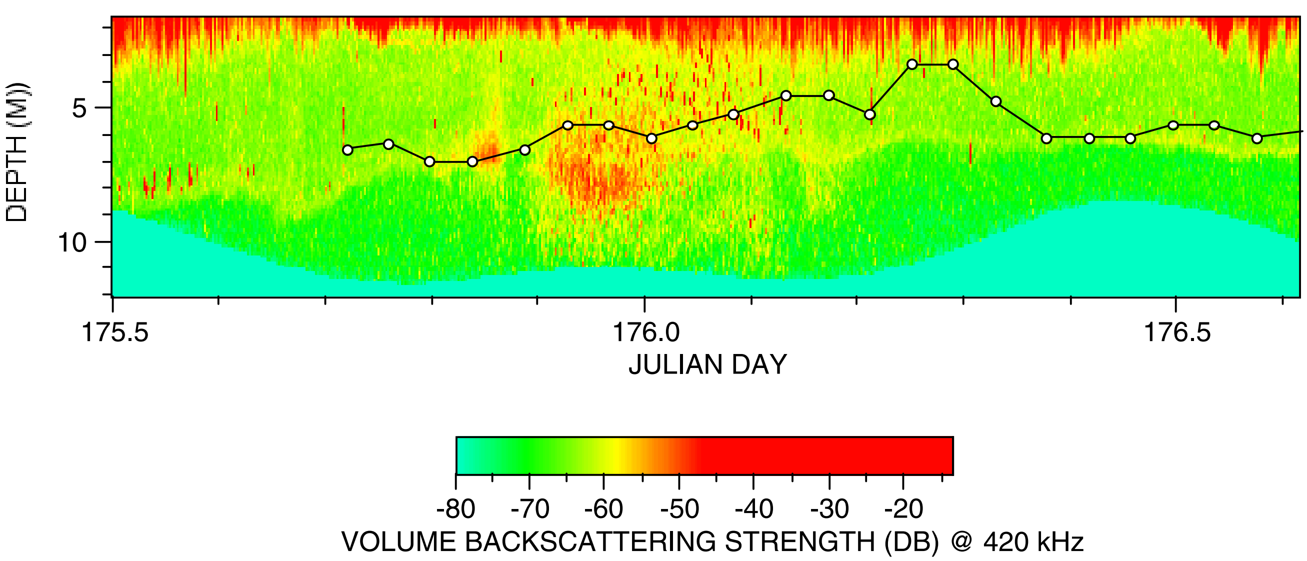

Figure 2. Temporal changes over 30 hours at station Z in the vertical distribution of zooplankton (measured as acoustic volume backscattering strength at 420 kHz) relative to the position of a thin optical layer seen in Figure 1 (indicated by open circles and measured as optical attenuation coefficient at 440 nm). Acoustic profiles were collected 1 per minute with 12.5 cm vertical resolution. The light blue region is below the sampling depth of the TAPS.

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 Navy scientists and engineers to transition our results. In September, we presented the results of the 1998 Thin Layers Experiment at the Marine Technology Society Gulf Coast meeting held at NRL in Stennis, MS. This presentation focused on the technological advances in the project and the implications to Navy systems.

RELATED PROJECTS

1. I am continuing a long-term collaboration with Van Holliday (BAE Systems) 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/UCSC), Tom Osborn (Johns Hopkins) and I are studying 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), Emmanuel Boss (OSU) and Margaret Dekshenieks (URI/UCSC) 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 determine 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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