Large-Scale Physical Forcing of Thin Layer Dynamics

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LONG-TERM GOALS

Our long-term goal is to understand how physical processes influence the formation, maintenance and dispersion of thin layers of phytoplankton and zooplankton. Using this information, our goal is to predict the spatial distribution and temporal occurrence of thin layers in the ocean.

OBJECTIVES

Our objectives are the following: (1) To deploy autonomous acoustical and optical instrumentation at six coastal sites in order to quantify the temporal occurrence and spatial distribution of thin planktonic layers in years 2000 and 2001; (2) To assess the hydrography at each of the six coastal sites to provide a physical context within which we may investigate thin planktonic layers; (3) To expand a database containing information on biological and physical processes related to thin layer dynamics; (4) To select an appropriate site for an interdisciplinary pilot study from the six coastal site explorations; and (5) To complete an interdisciplinary pilot study in 2003. This pilot study is needed to obtain the data required to design a future thin layers process study in an open-coast environment.

APPROACH

Background Information:

Recent advances in optical and acoustical instrumentation, as well as in deployment techniques, have led to the discovery of thin layers of phytoplankton and zooplankton in the marine environment. Thin

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14. ABSTRACT
Our long-term goal is to understand how physical processes influence the formation, maintenance and dispersion of thin layers of phytoplankton and zooplankton. Using this information, our goal is to predict the spatial distribution and temporal occurrence of thin layers in the ocean.

15. SUBJECT TERMS

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layers range in thickness from a few centimeters to a few meters. These layers can extend horizontally for kilometers and persist for days (Dekshenieks et al. 2001, Rines et al. 2002). Thin layers have significant impacts on the biological structure and dynamics of marine systems, as well as the optical and acoustical signatures in those systems. As a result, it is critical that we (1) refine our ability to detect these structures through continued development of new instrumentation, and (2) develop the capability to predict the spatial distribution and temporal occurrence of these structures.

In 1996 and 1998 experiments funded by ONR Physical Oceanography and ONR Biological & Chemical Oceanography took place in East Sound, WA. During these experiments, an extensive series of physical and biological measurements were made to (1) quantify the temporal and spatial scales of thin layers, and (2) to investigate the physical mechanisms contributing to thin layer dynamics. As a result of this research we have made critical connections between physical processes and thin layer dynamics (Dekshenieks et al. 2001, Rines et al. 2002). Our results show that regional-scale circulation patterns (e.g. buoyant plumes, episodic changes in water mass type) can have significant impacts on thin layer distribution (McManus et al. submitted[a], McManus et al. submitted[b]). Our results also show that local hydrography plays a critical role in determining the spatial distribution, location (depth) and structure (thickness) of thin layers. In addition, our results indicate that the Richardson number can be used as one of the indicators of the presence and/or absence of thin layers in the marine environment. In 2001, 2002 and 2003 ONR Biological & Chemical Oceanography is supporting Dr. Holliday to use acoustical instrumentation to explore several sites in the coastal ocean for the occurrence of thin layers. In 2001 and 2002, the National Ocean Partnership Program (NOPP) is supporting Drs Donaghay and McManus to develop autonomous underwater winch profilers with high resolution sensors (physical, optical, biological and chemical) capable of detecting thin layers.

Coastal Site Explorations (2001 and 2002):

In order to interpret patterns in biological distribution, it is necessary to understand the hydrography. Thus, before arriving at each coastal site, we developed preliminary descriptions of physical hydrography from the published literature. Second, we utilized satellite imagery to infer regional-scale circulation patterns. SeaWIFS was used for ocean color, and AVHRR was used for sea surface temperature. Once at the coastal site, we assessed the local hydrography. At most sites, a small vessel was equipped with an RD Instruments downward-looking 1200 kHz ADCP and a SeaBird SBE-25 CTD. Wind and tidal time-series were available at all sites from NDBC data buoys and NOAA tide gauges. Information from the literature reviews, satellite imagery and hydrographic assessments provide a physical context within which we may investigate thin planktonic layers. **Instrumentation deployed at each coastal site**: Dr. Holliday deployed one Tracor Acoustical Profiling System (TAPS-6) and a string of internally recording thermistors. At many of the sites Dr. Donaghay deployed one autonomous underwater winch profiler equipped with a SeaBird SBE-25 CTD and a Wet LABS Inc. ac-9. Data packets from the TAPS-6 and the autonomous underwater winch profiler were telemetered to shore, recorded and processed in real time. The deployed instrumentation functioned autonomously for a period of two to three weeks at each site.
Data Analysis:

We have developed a database that contains information regarding the biological properties of each individual optical layer encountered during the 1996 and 1998 cruises. This database also contains salinity, temperature, density, buoyancy frequency, shear and Richardson number which were calculated from physical measurements at the exact location of each thin layer. In addition, wind speed and direction, tidal information and the spatial relationship of the optical thin layer to the pycnocline are also recorded. This database is currently being expanded to include data from the coastal site explorations.

WORK COMPLETED

(1) We have deployed autonomous acoustical and/or optical instrumentation at six coastal sites to quantify the temporal occurrence and spatial distribution of thin planktonic layers. Thin planktonic layers were observed at **five of the six sites**. In addition, the Strawberry Hill, Oregon site is currently being monitored. (2) We have assessed the hydrography at each of the six coastal sites and have provided a physical context within which we are investigating thin planktonic layers. (3) We are expanding a database containing information on biological and physical processes related to thin layer dynamics.

RESULTS

East Sound, Washington:

Physical Environment: **Location:** (48^o 39.00' N, 122^o 53.00' W) East Sound is a small fjord on Orcas Island within the San Juan Islands of Washington State. **Hydrography:** Circulation patterns within East Sound are influenced by wind and tidal forcing. On a regional scale, circulation patterns are also affected by buoyant plumes from the Fraser River (Dekshenieks et al. 2001, McManus et al. submitted[a]). **Bathymetry:** East Sound has steeply sloping topography characteristic of a fjord. The lower sound (mouth) is partially obstructed by a sill on the western side at a mean depth of 12 m. Otherwise; the Sound has a mean depth of 30 m. **Wind:** Local winds are a result of oragraphic channeling. As a result, winds from the north and south tend to be funneled into the Sound, while the mountains effectively block winds from the west and east. During the summer months, winds are from the south ~80% of the time and from the north ~20% of the time. The average wind speed is 3.5 m/s. **Tide:** Tides in East Sound are mixed; however, they are predominantly semidiurnal. The tidal range varies from a 0.31 m to 3.5 m. **Freshwater:** East Sound and Orcas Island experience low precipitation (49 cm/yr). Freshwater inputs in the region are predominantly from the Fraser River, located 40 km to the North of the Sound. **Thin Layers:** Thin phytoplankton layers were observed and measured in 54% of our profiles. Over 71% of all thin layers were located at the base of, or within the pycnocline. The fact that these layers ranged in thickness from 0.12 m to 3.61 m, with 80% of all thin layers measuring < 2 m in thickness, indicates that conventional sampling methods would underestimate both the intensity and abundance of thin layers. Thin layers in East Sound occur over a broad range of buoyancy frequency and shear. Our results also indicate that there are physical conditions under which thin layers do not occur, e.g. where the water column is turbulent ($Ri < 0.25$). Thus, we do not expect persistent thin layers in tidally mixed regions, nor do we expect thin layers in wind mixed surface layers (Dekshenieks et al. 2001).

Monterey Bay, California:

Physical Environment: **Location:** (36^o 56.054' N, 131^o 55.524' W) Monterey Bay is located on the central coast of California. **Hydrography:** Circulation patterns within Monterey Bay are influenced by coastal upwelling, wind forcing, tidal forcing, and local heating (Breaker and Broenkow 1994). **Bathymetry:** The Bay is symmetrical in shape. Approximately 80% of the Bay is shallower than 100 m and 5% is deeper than 400 m. The Monterey Submarine Canyon (MSC) is the major topographic feature in Monterey Bay. The MSC divides the Bay into northern and southern sections. **Wind:** In general, winds are from the northwest between May and October and from the southeast between November and April. **Tide:** Tides in Monterey Bay are mixed, however they are predominantly semi-diurnal with and average range of 1.6 m. **Freshwater:** Average precipitation varies spatially, from approximately 150 cm/yr in the northern end of the Bay to 48 cm/yr in the southern end of the Bay. A majority of this precipitation results from storms during the winter months. **Thin Layers:** Thin layers of zooplankton, phytoplankton, bioluminescence and bacteria were observed in Monterey Bay during the 3-week period that the TAPS and autonomous underwater winch profiler were deployed. Concentrations in these layers were 3 to 5 times higher than those above or below the layer (Dr. M Silver unpublished data). Layers ranged in thickness from 10 cm to 2 m and layers of zooplankton and phytoplankton were observed to persist for days. Acoustic records indicate a dynamic complex of zooplankton layers, moving up and down at periods of as short as 4 minutes over depth ranges from 2 m to as great as 10 m. These layers of zooplankton are most likely at the pycnocline, which is being modulated by internal waves.

Oceanside, California:

Physical Environment: **Location:** (33^o 17.451'N, 117^o 30.821' W) Oceanside is located on the Pacific coast within a region known as the Southern California Bight (SCB). **Hydrography:** The large-scale circulation patterns of the SCB region are typified by the equator-ward flowing California Current (CC), and the pole-ward flowing Southern California Countercurrent (SCC). Coastal upwelling in the SCB is slightly weaker than the rest of the California coast. In addition, regional circulation patterns around the SCB are made more complex by the presence of the Catalina Island clusters (Hickey 1992). **Bathymetry:** Oceanside has a long, linear coastline. Offshore, the slope is marked with submarine canyons such as the Carlsbad Canyon. **Wind:** Maximum alongshore winds occur during the spring (mean 4.02 m/s), although wind stress within the SCB is weaker than other areas of the California coast. **Tide:** Tides are semi-diurnal, with a maximum tidal range of 2m (Souza and Pineda 2000). **Freshwater:** With the exception of minor riverine inflows, there are no significant freshwater sources to the Oceanside area. **Thin Layers:** Thin layers of zooplankton were observed at Oceanside during the 3-week period that the TAPS was deployed.

Pensacola, Florida:

Physical Environment: **Location:** (30^o 28.183' N, 87^o 11.983' W) Pensacola is located in the panhandle region of Florida. The Pensacola site was located 5 miles offshore Pensacola Beach in the northern Gulf of Mexico. **Hydrography:** The dominant physical processes influencing physical structure at this site include alongshore flow, which is influenced by large-scale gulf currents and eddies, wind forcing, and freshwater fluxes from Pensacola Bay. **Bathymetry:** Pensacola has a low relief shoreline and gently sloping continental shelf. **Wind:** The annual mean wind speed is ~6.0 m/s. However, Pensacola can experience strong wind forcing during the summer-fall hurricane season (Oey 1995). **Tide:** Tides are diurnal with an average tidal range of 0.7 m (Oey 1995). **Freshwater:** There are numerous freshwater estuaries, bays and wetlands that influence the study area. **Thin Layers:** The Pensacola site was the only site where thin layers were **not** observed. During the 2-week study the water column was well mixed ($Ri < 0.25$). This resulted from significantly decreased freshwater inflow and increased wind velocities resulting from the passage of a storm system. As previously indicated, we would not expect persistent thin layers in well-mixed, unstratified regions.

Destin, Florida

Physical Environment: **Location:** (N 30° 23', W 86° 30') The Destin site was located 2 miles offshore in the Gulf of Mexico. **Hydrography:** The dominant physical processes influencing physical structure at this site include alongshore flow, which is influenced by large-scale Gulf current and eddies, wind forcing and freshwater input from the Mississippi River. **Bathymetry:** This site has a gently sloping shelf. **Winds:** Winds average 3.7 m/s, however, this region may also experience strong wind forcing during the summer-fall hurricane season (Oey 1995). **Tides:** Tides are diurnal with an average tidal range of 0.7 m (Oey 1995). **Freshwater Input:** The primary source of fresh water is from the Mississippi River, which feeds directly into the Gulf of Mexico. The Choctawhatchee River and surrounding creeks also contribute freshwater with the greatest input during spring. **Thin Layers:** Thin layers of zooplankton were observed at the Destin site during the 3-week period that the TAPS was deployed.

Charleston, South Carolina:

Physical Environment: **Location:** (32° 45' N, 79° 52' W) Charleston Harbor is a 1,200 square mile estuarine environment located along the southeastern coast of the United States. **Hydrography:** The circulation patterns within the harbor are dominated by wind forcing and freshwater inflow. **Bathymetry:** The Charleston Harbor estuary has a soft mud basin, which averages 12 m in depth at low tide. **Winds:** Summer weather is dominated by a maritime tropical air mass known as the Bermuda high. Wind speeds vary between 2-5 m/s and are generally from the southwest during the spring and summer months and are from the northwest during fall and winter. **Tides:** The tide is predominantly semi-diurnal. The tidal range varies from 1.1 to 2.0 m (Althausen and Kjerfve 1992). **Freshwater Input:** The Cooper River is the primary source of freshwater input with an annual contribution of 110 m^3/s (Pinckney and Dustan 1990). Rainfall averages 52 cm/yr. **Thin Layers:** Thin layers of zooplankton were observed at the Charleston site during the 3-week period that the TAPS was deployed.

IMPACT/APPLICATIONS

The work described here: (1) Transitions the thin layers program, in a timely fashion, to study thin layers in an open coast environment; (2) Allows us to identify a suitable site in the coastal ocean where a future process study of thin layers may occur; (3) Augments and compliments the current development of autonomous underwater winch profilers with high resolution sensors (physical, optical, biological and chemical) capable of detecting thin layers; and (4) Supports a currently funded ONR project designed to utilize bio-acoustical instrumentation to explore several coastal ocean sites for the occurrence of thin acoustical layers.

RELATED PROJECTS

Related projects include: (1) Ocean Response Coastal Analysis System (ORCAS), Donaghay (PI) McManus (CoPI), funded by NOPP. (2) Development of Advanced Technology for Sensing Zooplankton, Holliday (PI), funded by ONR code 322. (3) Plankton Patch Feasibility Experiments, Donaghay (PI), funded by ONR code 322. (4) Finescale Processes in the Plankton: Physical and Biological Linkages, Cowles (PI), funded by ONR code 322. (5) Interactions of Small-Scale Physical Mixing Processes with the Structure, Morphology, Bloom Dynamics and Optics of Non-Spheroid

Phytoplankton, Rines (PI) Donaghay (CoPI), funded ONR code 322. (6) Fine-Scale Nutrient Gradients and Thin Plankton Layers in Coastal Waters, Hanson (PI), funded ONR code 322.

Table 1: List of Completed Coastal Site Explorations

Site	Layers	Type
East Sound, Washington	yes	phytoplankton, zooplankton, bioluminescence
Monterey, California	yes	phytoplankton, zooplankton, bioluminescence, bacteria
Oceanside, California	yes	zooplankton
Pensacola, Florida	no	
Destin, Florida	yes	zooplankton
Charleston, South Carolina	yes	zooplankton

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