Quantifying the Role of Physical Processes in Thin Layer Formation and Maintenance

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LONG-TERM GOAL

Our long-term goal is to understand how physical processes influence the formation, maintenance and dispersion of thin layers of phytoplankton and zooplankton. Thin layers range in thickness from a few tens of centimeters to a few meters, and have concentrations sufficient to influence biological processes. These layers can extend horizontally for kilometers and may persist for more than 24 hours. In order to understand the contribution of physical processes to thin layer dynamics it is necessary to measure physical processes and thin layers over temporal scales, ranging from minutes to days, and spatial scales, ranging from centimeters to 10s of kilometers.

OBJECTIVES

Our first objective was to establish the basic hydrography for the study area (East Sound on Orcas Island) in order to identify the water masses and their sources. Our second objective was to investigate the role of advection and shear in producing the temperature, salinity and density profiles and their development in time. Our third objective was to look for temporal and spatial patterns of thin layers,

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and to relate the presence of thin layers to physical processes that may influence their occurrence and dynamics.

APPROACH

Our approach has been to numerically analyze a unique set of 130 profiles composed of simultaneous measurements of finescale biological and physical structure. These profiles were collected between 23 May and 7 September 1996 by Donaghay et al. throughout East Sound, a fjord on Orcas Island, WA in Northern Puget Sound. Measurements used in this analysis include centimeter scale estimates of temperature, salinity and density structure (made with a Seabird 911+ CTD), centimeter scale estimates of particulate absorption, which is an estimate of phytoplankton distribution (made with dual WET Labs ac-9s), and 50 cm scale estimates of current velocity (made with an RD Instruments 1200 kHz Acoustic Doppler Current Profiler (ADCP)). This is the first time that profiles of centimeter scale optical and physical structure have been taken simultaneously with profiles of finescale current velocity within the context of measurements of wind fields and tidal phase. These data are also unique in that the steps taken to accurately calibrate lag and fully merge measurements of physical, optical and biological properties allow unequivocal finescale analysis of the relationships.

WORK COMPLETED

The post-processing of the 1996 data is complete, and the analysis is proceeding well. The original calculations were expanded to include Thorpe scale, Rossby radius, dissipation rate, and dynamic height.

We have established the basic hydrography for the Sound. Profiles of temperature, salinity and density have been used to identify water types, their potential origins, as well as their temporal and spatial variability. ADCP data have been used in conjunction with TS plots to understand the role of advection and shear in producing the temperature, salinity, and density profiles and their development in time.

We have examined the biological data, looking for sources of the thin layers, and for similarities and differences in their temporal and spatial development.

We have explored the use of Thorpe scales, based on density structure, for estimating dissipation rates. Ultimately this information will be used to investigate the relation of thin layers to turbulent regions.

RESULTS

The water masses in East Sound result from the mixture of water from two sources; cooler, higher salinity, deep water from the Strait of Juan de Fuca and warmer, lower salinity water from the Strait of Georgia. Over 80% of the freshwater in the Straits is supplied by the Fraser River, which empties into the Strait of Georgia to the north of East Sound. Thus, the primary source of freshwater to East Sound is external. As a result, changes in wind forcing over a regional scale play a key role in advecting different watermasses into the channel outside the mouth of the Sound. This can change the density gradients between the upper Sound and the mouth producing a density driven circulation.

The depth and strength of the pycnocline in the Sound are primarily functions of the watermasses advected into the sound, wind mixing and thermal heating. Profiles having the strongest pycnoclines were measured during the spring. At this time the density profile was primarily the result of low salinity water being advected southward from the Fraser River. The depth of the pycnocline varied between 2 and 17 m. Pycnoclines during the late summer were weaker and consistently located between 1 and 5 m in depth. The density profile during this time was primarily the result of thermal heating.

Over 54% of the profiles contained thin layers, having peak particulate absorption values (intensities) that were at least three times greater than that of the surrounding water. Our results indicate that thin layer depth and intensity are closely associated with the depth and strength of the pycnocline. Over 72% of all thin layers were located at the base of the pycnocline, or, above and in the pycnocline. Of the remaining layers sampled, roughly 14% were associated with watermasses being advected into the system below the primary pycnocline, while the final 14% were sampled at times when the pycnocline was diffuse.

Our results also show that thin layer thickness and intensity display clear seasonal trends. Layers increase in thickness over the season from an average of 0.94 m in May, to an average of 1.80 m in September. Concurrently, thin layers decrease in intensity over the season, from an average of 1.65 m^{-1} in May to an average of 0.71 m^{-1} in September. Thus, the thinnest layers with the highest intensity occurred in the spring. During the time these layers were sampled, there were episodic wind events, spring tides and the Fraser River outflow was at its peak producing the strongest pycnoclines.

We are very encouraged by our calculation and initial analysis of dissipation rates based on finescale density structure as suggested by Gargett (1997). Dissipation rates range from 10^{-2} to 10^{-10} m^2s^{-3}. Because this technique calculates dissipation rate with the same resolution as the particulate absorption measurements, it will prove extremely useful for understanding the role of small scale mixing processes in thin layer dynamics.

IMPACT / APPLICATIONS

Thin layers of phytoplankton can have important impacts not only on the biological structure and dynamics of marine systems, but also on the optical and acoustical properties of those systems. As a result, it is critical that we develop techniques to detect such structures and to predict their dynamics and impacts. The strong statistical relationship between thin layers and physical structure shown in this study, as well as theoretical arguments (c.f. Donaghay and Osborn 1997; Osborn 1998) indicate that we cannot understand layer dynamics without understanding physical forcing and biological-physical interactions at both small and large scales. At the same time, the strength of the observed relationships indicates that our approach has considerable promise for developing a combination of sampling techniques and numerical models that can predict the probability of layer occurrence and eventually layer dynamics.

TRANSITIONS

The results from this study have had three important transitions. First, our increased understanding of the role of physical processes in layer dynamics has played a key role in designing the 1998 Thin Layers Experiment conducted in East Sound. Results from this study have been particularly important in selecting the sites for the long-term mooring and experimental work, in designing the intensive circulation experiment, and in deciding the timing and location for intensive ship-based sampling. Second, the analytic (numerical) methods for quantifying the role of physical processes in thin layer dynamics will be directly applicable to the far more extensive data sets collected during the 1998 Thin Layers Experiment. Third, results from this study are being used to help Navy scientists (Dr. Curtis Davis at NRL Washington, and Dr. Alan Weidemann at NRL Stennis) to evaluate the implications of thin layers on remote sensing and in-water optics.

RELATED PROJECTS

This project is closely related to a series of thin layer projects conducted in East Sound in 1996, 1997 and 1998.

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