AUV-BASED OBSERVATIONS OF BIO-OPTICAL VARIABILITY OVER OREGON SHELF

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Introduction

Bio-optical property distributions over the continental shelf off Oregon were examined from data collected during the summer of 2004. A companion poster describes background conditions, location, and survey methods used during the experiment while discussing small-scale turbulent mixing in coastal fronts. Here we present some examples of biologically active thin-layers and the near surface distribution of downwelling irradiance.

Biological thin layers

Horizontal and Vertical Scales

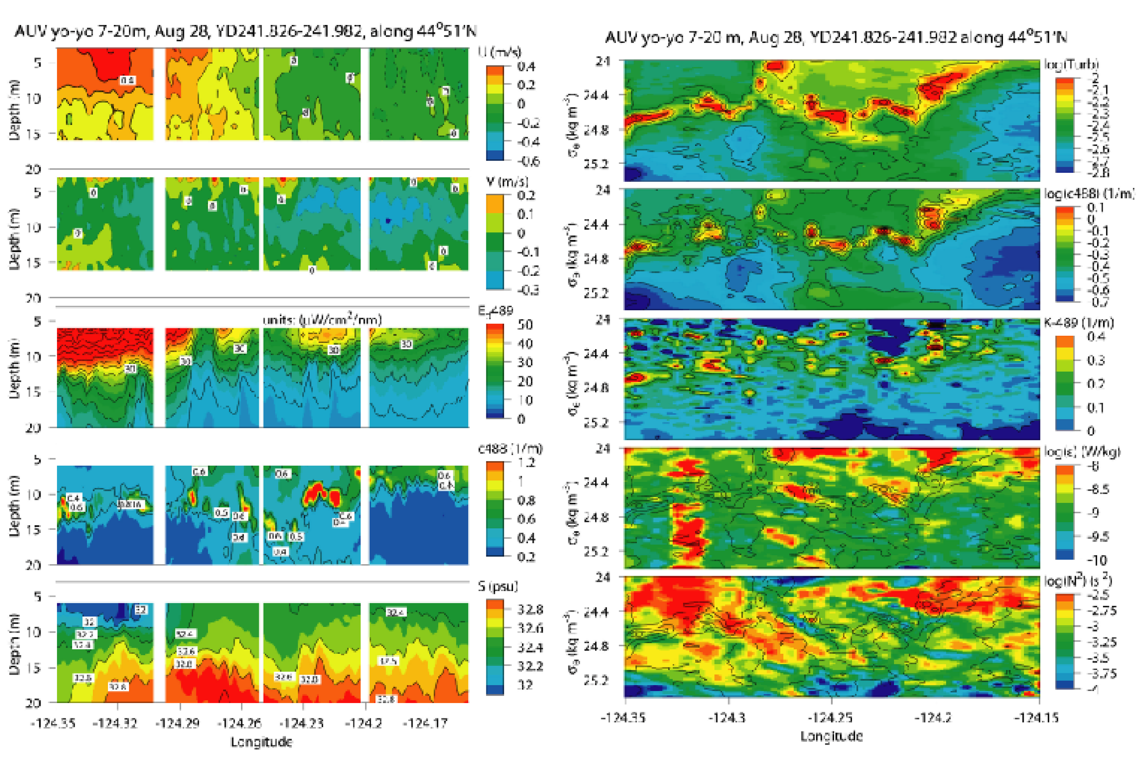

Figure 1. Figure shows an example of (1) spatial distribution of irradiance with respect to Columbia River plume water, and (2) horizontal and vertical structure of biological thin layers. ***Left panel:*** *Depth-longitude fields of: (top to bottom) U and V, downwelling irradiance at 489 nm wavelength E_d489, light attenuation at 488 nm wavelength c488, and salinity. Gaps in contour plots (white spaces) denote resurfacing of AUV to obtain GPS. Downward irradiance penetrated to greater depths within the plume than in the upwelling water on the inshore side of the front.* ***Right panel:*** *σ_T- longitude fields (interpolated) of: (top to bottom) turbidity from turbidity sensor in the microstructure package, c488 from AC9, the diffusive attenuation coefficient for downward irradiance at 489 nm wavelength (K-489 $=d[\ln\{E_d489\}(z)]/dz$), TKE dissipation rate, and buoyancy frequency squared. The thin lines plotted in the bottom two panels represent contours of turbidity. Here, we identify the vertically thin regions of high turbidity and large c488 as biological thin layers, since those regions followed closely with chlorophyll maxima observed from bio-optical profiler (Figure 2). Turbulent mixing tends to destroy the thin layer structure and the majority of layers were associated with regions of weak mixing. Note that the layers shown above are not located at constant density surfaces.*

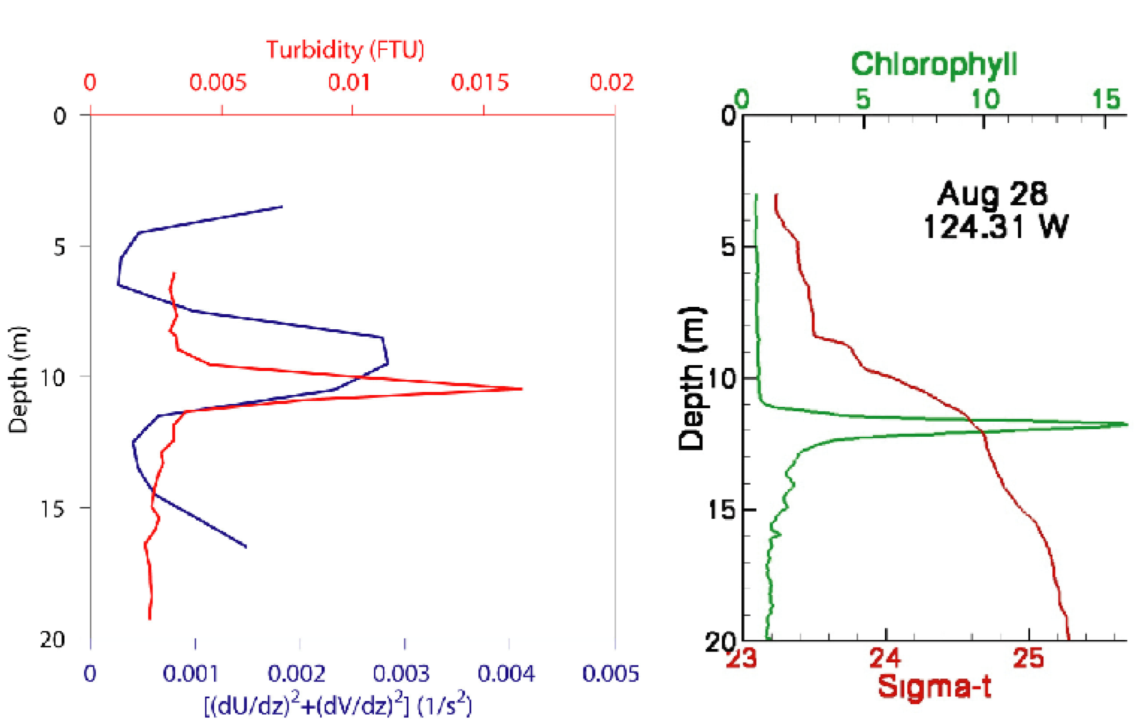

Figure 2. ***Left Panel:*** *Vertical profiles of turbidity (red) and total shear squared at 124.31W on day 241.48 from AUV mounted sensors (for entire cross section see Figure 1). Turbidity profile is from 1-s averaged data; shear was estimated from 30-s and 1-m averaged 1200 kHz ADCP data. Turbidity maximum is located just below the maximum velocity shear.* ***Right Panel:*** *Vertical profile of sigma-t and chlorophyll obtained with the free-fall profiling system (Cowles) on Aug 28, 2004, during the transect with the AUV. This profile of the upper 20m was obtained near the western end of the AUV line, at 124.31W. Note that the plankton layer is less the 1m thick, and shows more than a 10-fold enhancement of biomass over the background chlorophyll concentration found 1m above the layer.*

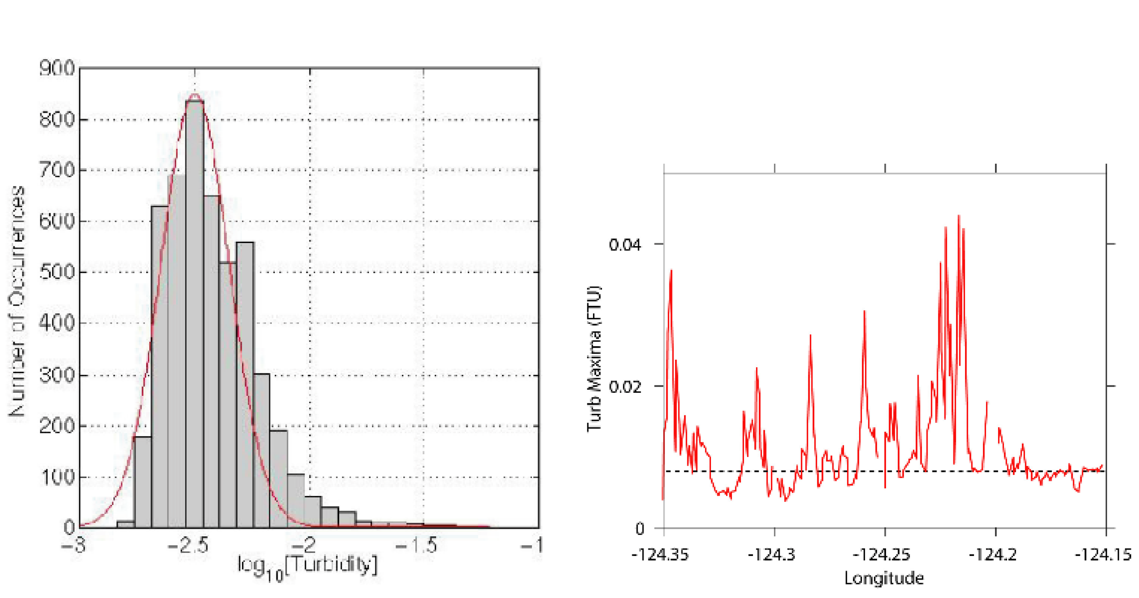

Figure 3. ***Left Panel:*** *Distribution of 1-s averaged turbidity shown in Figure 1. Turbidity has an extremely skewed distribution (mean=0.004, std=0.0029). The log-normal curve (mean=-2.5, std=0.15) marked in red represents nearly 90% of data record. For turbidity values greater than 0.0063 [log10(0.0063)=-2.2], mainly observed in thin layers; the observed distribution departs from lognormal.* ***Right Panel:*** *Longitudinal position of turbidity maxima from each up or down leg of the AUV track. Those layers didn't follow isopycnals, isobars or any other constant property surfaces. We tracked the maxima of turbidity to examine spatial scales of thin layers. We selected spatial size of layers whenever turbidity maximum exceeds a given threshold (dashed line) of about 0.008 FTU. Our criteria produced horizontal scales varying from 100 to 900 m (see also Figure 4).*

Physical Parameters within Layers

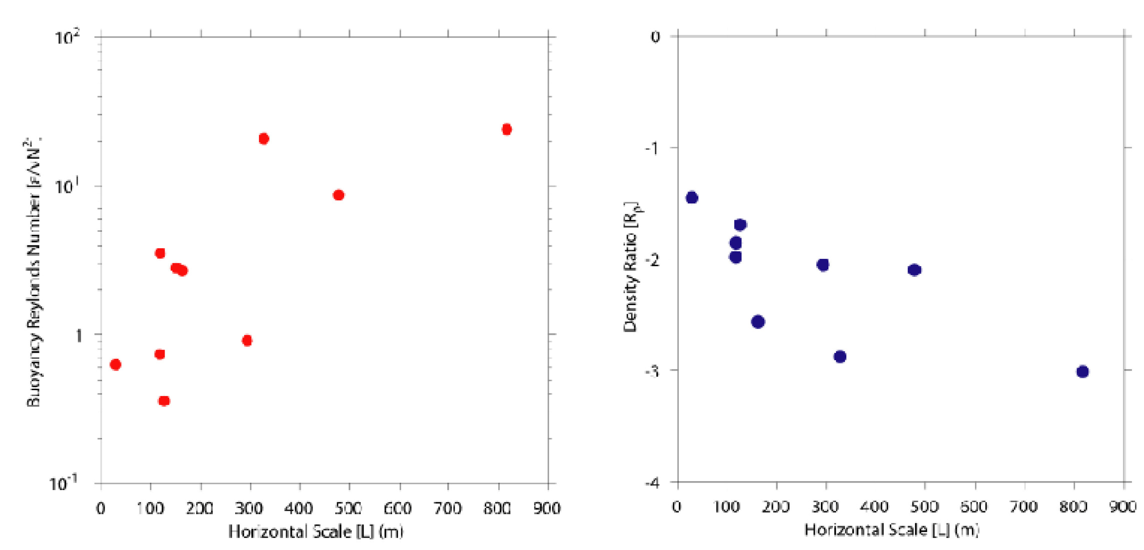

Figure 4. ***Left Panel:*** *Buoyancy Reynolds number, $\varepsilon/\nu N^2$ averaged over a given layer. The largest buoyancy Reynolds number was less than 30, indicating no turbulent overturning. Small patches were located in laminar type flow regimes with $\varepsilon/\nu N^2 \sim O(1)$, where turbulence was strongly influenced by stratification.* ***Right Panel:*** *Density ratio, $\alpha(\Delta T/\Delta z)/\beta(\Delta S/\Delta z)$ averaged over layers. The density ratio indicates that temperature dominated the density stratification, and both T and S contributed to density with warmer fresher water located above the layer and colder saltier water below the layer.*

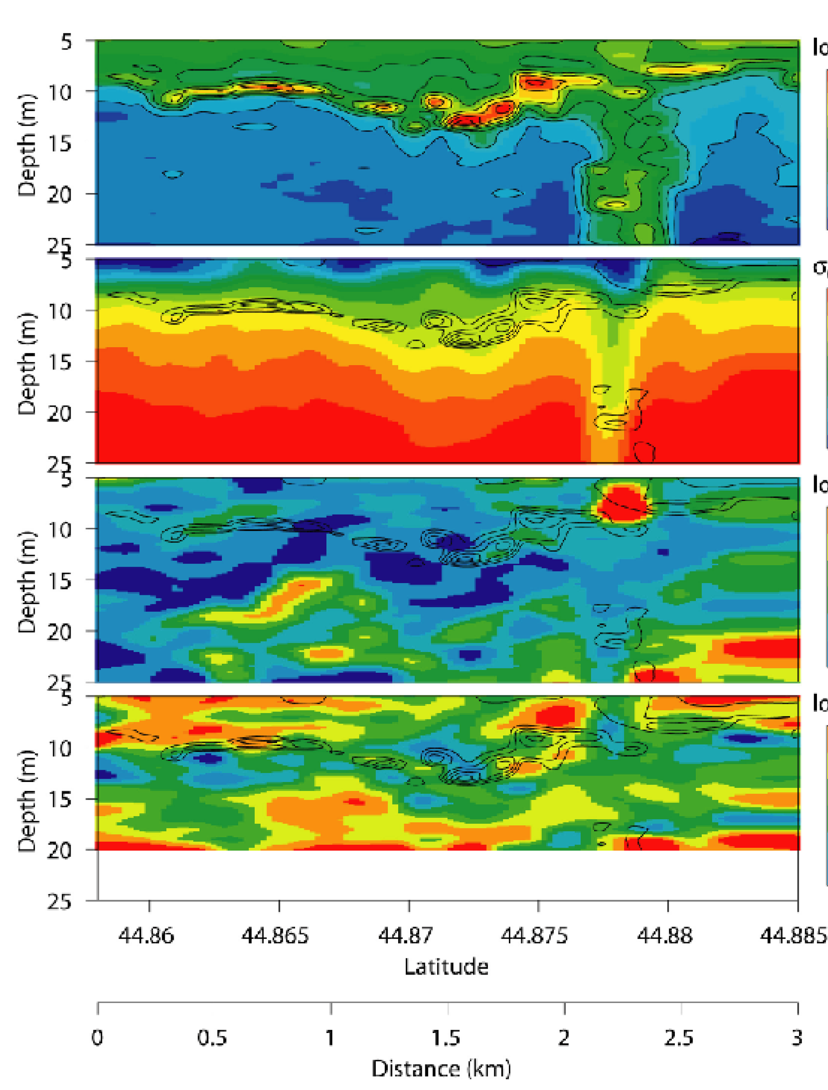

Figure 5. Thin layers observed during day 243. From top to bottom turbidity, density, TKE dissipation rate, and shear squared. Contours of turbidity are also shown in the density, dissipation, and shear panels. This layer closely followed isopycals contrary to the case is shown in Figure 1.

Irradiance and inherent optical properties, horizontal spatial scaling measured from AUV level flights

Flight Pattern and Background Meteorology

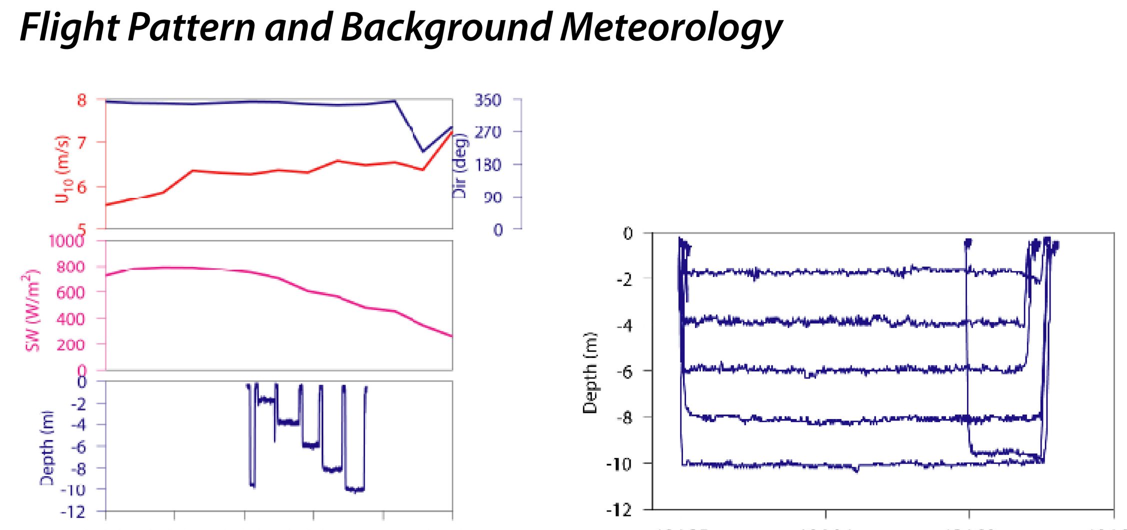

Figure 6. An example of AUV level mission. The AUV level flights were conducted at 5 different depths during daytime hours while winds were blowing from north to south with a magnitude of about 6.5 m/s (wind stress ~0.054 N/m²). ***Left Panels:*** *wind speed and direction (top), short wave radiation (middle), and depths of AUV level flights as a function of time (bottom).* ***Right Panel:*** *Spatial position of AUV flights.*

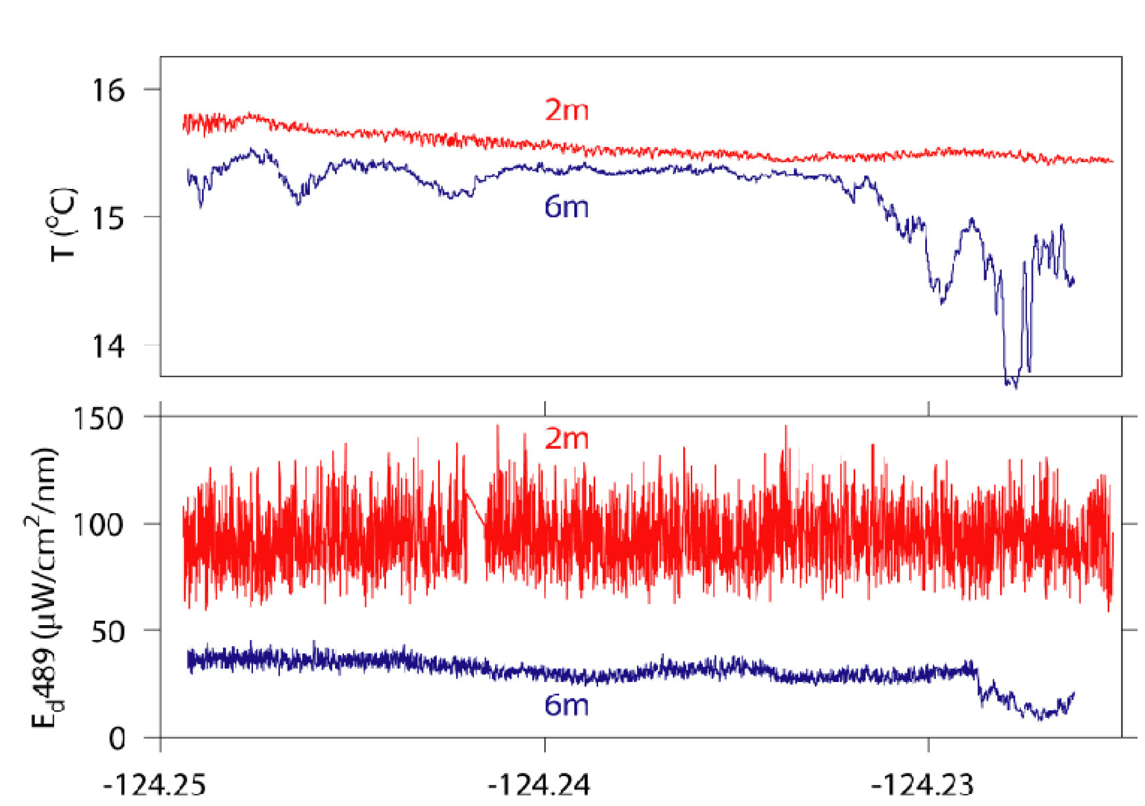

Figure 7. Temperature (top panel) and downward irradiance (bottom panel) for 2 m depth (red) and 6 m depth (blue). Mean (std) values of E_d489 at depth of 2m and 6m are 93 (14) and 30 (7) μW/cm²/nm, respectively. Wavenumber spectra of irradiance and IOP for different depths are given in Figures 9 and 10.

Background Conditions

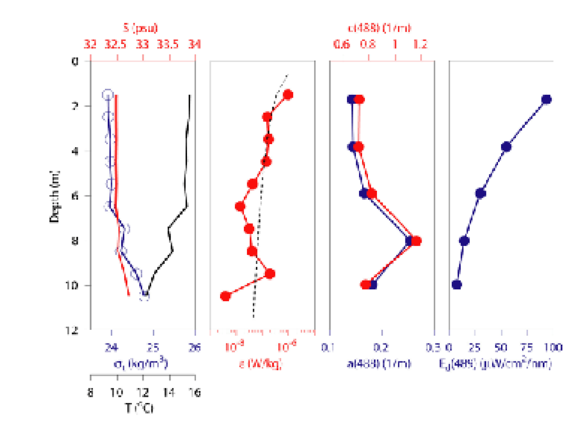

Figure 8. From left to right: spatially averaged profiles of hydrography, TKE dissipation rate along with the profile corresponding to wall-layer scaling, absorption (a488) and attenuation (c488) at 488 nm wavelength, and downwelling irradiance profile at 489 nm wavelength (E_d489).

Horizontal wavenumber spectra of optical fields

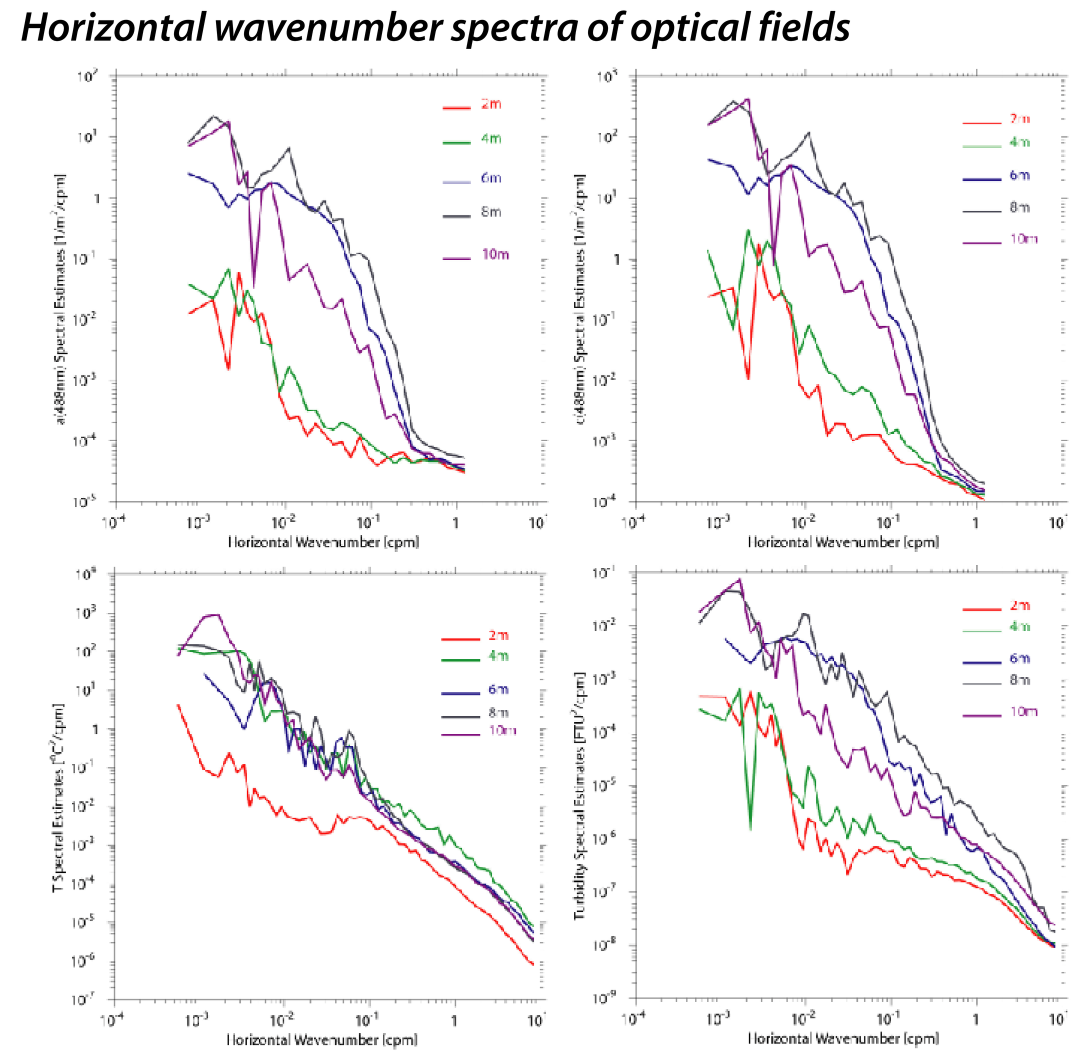

Figure 9. Wavenumber spectra of absorption a488 (top left) and attenuation c488 (top right) at 488 nm wavelength for different depths from AC-9+. Horizontal wavenumber spectra of temperature (bottom left) and turbidity (bottom right) from the microstructure package. Both T and turbidity resolve spatial variability to about 10 cm. Turbidity shows the red-spectral shape of the biological signals. Note: pumping rate of water limited the spatial resolution of AC9 signals to about 2 m (or 0.5 cpm). Most of the biological scales are greater than 100 m.

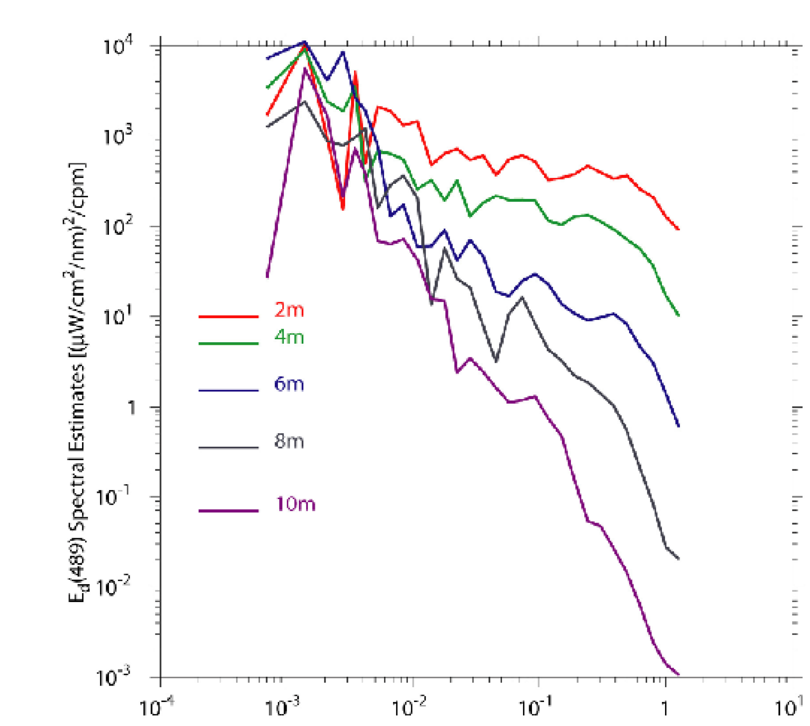

Figure 10. Horizontal wavenumber spectra of downwelling irradiance E_d489. Wave focusing of light appears to be responsible for the spatial energy at large wavenumber ($>10^{-2}$ cpm). The role of wave focusing is expected to decrease with depth (for example see Zaneveld et al., 2001). Note: biological variability was not a significant at smaller wave lengths, since biology shows a red spectrum (Figure 9).

Summary

We conducted a 10-day AUV/MiniBat/BioOptical Profiler survey over the Oregon continental shelf on September 2004. We identified regions of biological thin layers from MiniBat transects and optical-package profiles, and then we conducted a combined AUV-Profiler survey to examine the spatial and vertical structure of these layers. Here we summarize some of the observations of thin layers and near surface irradiance distribution.

- Biologically active thin layers, with high concentration of chlorophyll, large beam attenuation and absorption, and also high values of turbidity with O(1-10) buoyancy Reynolds number were found in the upper 20 m water column. The vertical extend of high turbidity layer with large coefficients of c(488) was about 1-2 m or less, but the horizontal extend of those layers was 100–900 m.
- Horizontal wavenumber spectra of downwelling irradiance show that irradiance varies as a function of wavenumber and depth. It likely that irradiance variability between 1 and 100 m spatial scales appeared to be related to the focusing effects of surface wave field (e.g., Zaneveld et al., 2001), since IOP signals at that wavelength band were small.
- There was a significant difference in horizontal and vertical distribution of downward irradiance across the Columbia River Plume (clean) water and the upwelled (biologically rich) water found on the inshore side of the shelf. For example, downwelling irradiance at 10-m depth was a factor of 2 high on the offshore side of the plume water compared to that on the inshore side of the upwelled water.

References

Zaneveld, J. R. V., E. Boss, and A. Barnard, 2001: Influence of surface waves on measured and modeled irradiance profiles, Applied Optics, Vol 40, No 9, 1442-1449.