ty. This review cannot possibly include all relevant optical time series studies and unfortunately the number of references must be limited. However, several bio-optical data sets related to the Joint Global Ocean Flux Study (JGOFS) program have been presented by Dickey (2001a) and Dickey and Falkowski (2001); these will not be discussed in detail here. Our first set of examples focuses on the open ocean, and the second set is devoted to the coastal ocean. Finally, we present a vision of future studies of temporal variability of optical, bio-optical, and related properties.

Examples of Open Ocean Optical Time Series

Optical Dynamics Experiment (ODEX)

Time series measurements of meteorological and physical variables have been done for about five decades in the open ocean using moorings as platforms. One of the first programs to obtain relatively high resolution time series of optical and bio-optical properties was the Optical Dynamics Experiment (ODEX) conducted in the central North Pacific Ocean (e.g. see Dickey, 1991). During ODEX, R/P FLIP, a stable research platform (roughly 100 m in length with approximately 30 m extending above the waterline, 3-4 m in diameter) was located at about 32°N, 142°W and collected data for about 21 days in the fall of 1982. Long booms extended off of R/P FLIP (to avoid platform effects) for the deployment of profiling instruments including a CTD with a rosette for collecting bottle samples for analyses of pigments, nutrients, oxygen, etc., an autonomous profiler (cyclesonde) for measuring temperature and horizontal currents, and an optical package including a beam transmissometer (beam c, or beam attenuation at 660 nm) and spectral downwelling irradiance sensors (7 wavelengths). The profiles extended down to approximately 250 m with sampling intervals of either 15 minutes or 4 hours. Several interesting results were obtained from these unique measurements. For example, the profiles of spectral irradiance showed decaying amplitudes of fluctuations with depth, suggesting the importance of focusing of light rays upon the subsurface light field. This effect is especially deleterious for use of profile data sets for estimating water-leaving radiance and thus groundtruthing ocean color satellite data. Also, thermohaline intrusive features observed in the range of 165-190 m were characterized by optical signatures, particularly higher beam attenuation coefficients (beam c at 660 nm) and chlorophyll fluorescence.

It was also suggested that relatively warm saline water mass intrusions contained higher phytoplankton concentrations. Using data collected during the rapid profiling periods (15 minute intervals), it was evident that low frequency internal gravity waves and internal tides caused these layers (and optical properties of the layers) to heave up and down. It was possible to clearly resolve the diurnal/diel cycle in the optical properties, particularly beam c and chlorophyll fluorescence. Phase relationships between PAR, beam c, and chlorophyll fluorescence were carefully analyzed and raised several fascinating questions, many of which remain unanswered. Using the R/P FLIP optical time series and relationships between particulate organic carbon (POC) and beam c, estimates of water column particulate (i.e. phytoplankton) production were made. This particular use of optical data has received considerable attention and factors other than growth and grazing likely complicate the interpretation (see Ackleson et al., 1993). Nonetheless, the relationship between POC and beam c appears to be quite robust and useful for biogeochemical studies. The ODEX R/P FLIP experiment expanded our knowledge of optical variability into the time domain of low frequency internal gravity waves, internal tides, and diel cycling while providing some new tools for biological studies using optics and for quantifying upper ocean heating rates as modulated by bio-optical variability

Biowatt

The Biowatt program was devoted to studies of bio-optical and bioluminescence variability in the North Atlantic Ocean in the vicinity of 34°N, 70°W (see Dickey, 1991 for review). The first field program (Biowatt I) in the spring of 1985 focused primarily on ship-based observations. However, time series observations were also made from an autonomous multivariable profiler (MVP) that was tethered to a surface buoy. The MVP profiled through the upper 200 m at hourly intervals to obtain current, temperature, salinity, and chlorophyll fluorescence data. During one four-day period, a wind event deepened the mixed layer, causing entrainment of nutrients into the euphotic layer and thus stimulating a transient phytoplankton bloom event marked by a 3-fold increase in chlorophyll.

While the MVP proved useful, longer-term observations were beyond its design capacity. Therefore, a new interdisciplinary moored system, the multi-variable moored system (MVMS) was developed for Biowatt II. The MVMS utilized a sensor suite including a vector measuring current meter and temperature, conductivity, and dissolved oxygen sensors, a beam transmissometer, and a fluorometer. Another moored bio-optical system (BOMS) was utilized to collect spectral downwelling irradiance and upwelled radiance at 5 wavelengths. A moored bioluminescence system was also deployed for the experiment. The MVMS and BOMS systems were deployed in the upper 160 m and collected data at intervals of about 4 to 30 minutes. Biowatt II spanned a 9-month period beginning in April 1987.

The rapid sampling by the MVMS enabled observations of several episodic phytoplankton bloom-cessation sequences as well as a clear depiction of the spring bloom. Again, the diurnal cycle was evident in beam c and chlorophyll time series. Using the highest frequen-