at various depths as phytoplankton concentrations and communities wax and wane. Fundamental measurements and models have been used to estimate primary production (e.g., Behrenfeld and Falkowski, 1997). Such models often use measurements of chlorophyll *a* concentrations and PAR.

Primary production has been estimated for a variety of geographical regions using remote sensing via instruments mounted on satellites. Primary production, P(z), as a function of depth, z, has also been estimated with relatively simple models using chlorophyll *a*, Chl(z), and PAR(z) data. In some cases, best estimates or measurements of the chlorophyll *a* specific light absorption coefficient for phytoplankton, a*(z), and the quantum yield for carbon fixation, Φ(z), have been utilized as in the following empirical formulation:

$$P(z) = a^*(z)\ \Phi(z)\ \mathrm{Chl}(z)\ \mathrm{PAR}(z) \qquad \textbf{(1)}$$

One of the deficiencies of this method is that neither a* nor Φ is constant in space or time because of changes in community structure and varying light and nutrient stresses.

This review focuses on some of the technological and observational advances achieved primarily during the JGOFS era that are improving our understanding of biogeochemical processes, pools and fluxes in the ocean. It is not comprehensive, but rather highlights a few examples (more references are available at http://www.opl.ucsb.edu/). The focus is on *in situ* observations, with a few references to complementary remote sensing data (see Yoder et al., this issue).

The Sampling Problem

Oceanographers must obtain their data from an uncontrolled and often harsh environment. The limits of detection, precision and accuracy of ocean measurements should not be overlooked. It is critically important to obtain large volumes of data because of the vastness and complexity of the ocean and the importance of a large range of time and space scales (Figure 1a) for answering many basic questions. The oceans are naturally dynamic, with large-amplitude periodic and episodic variability that confounds attempts to quantify long-term trends and changes. Recent studies suggest that a few powerful episodic events can often be of far greater importance than small-amplitude, slower variations. JGOFS has characterized, quantified and improved our understanding of ocean processes that affect variability in carbon inventories and carbon fluxes. But insufficient data and undersampling still limit our ability to make further advances in understanding and modeling the biogeochemistry of the ocean. We must find ways to increase massively the variety and quantity of biogeochemical data.

Studies of ocean biogeochemistry necessarily rely heavily on interdisciplinary data sets because of the interdependence of physical, chemical, biological and geological processes. Ideally, the relevant data should be collected simultaneously and span broad time and space scales to observe processes of interest (Figure 1a). For global climate problems, this means sampling variability that extends over 10 orders of magnitude in space, and even longer in time. Present capabilities for obtaining the necessary atmospheric and physical oceanographic data are relatively well advanced in contrast to those for biogeochemical data. This is not surprising, considering the greater complexity and non-conservative nature of the chemistry and biology of the ocean. Nonetheless, remarkable advances in biogeochemical data collection are being made. New platforms are making it possible to measure certain biogeochemical, bio-optical, chemical and geological parameters on the same time and space scales as physical ones (Figure 1b). Figure 2 shows some examples of data collection platforms, such as moorings, towed vehicles (e.g. SeaSoar), drifters, floats, gliders, and Autonomous Underwater Vehicles (AUVs) now in operation.

Emerging Observational Methods and Results

One of the central goals of JGOFS has been to measure and understand time-varying fluxes of carbon and associated biogenic elements. Regional studies are necessary to sample processes and to develop models for strategic oceanic biomes. All regions experience certain small- and mesoscale processes, especially over short time periods. But the effects of natural phenomena such as monsoons, equatorial longwaves, spring blooms, hurricanes and typhoons, deep convection, El Niño-Southern Oscillation, climatic oscillations and the like vary greatly from one region to another. This section presents examples of applications of new technologies in various regions studied by JGOFS, and provides some highlight results.

JGOFS In The Arabian Sea

The U.S. JGOFS process studies were conducted in the Arabian Sea between 1994 and 1996 (*Deep-Sea Research II*, vols. 45[10–11], 46[3–4, 8–9], 47[7–8]). Before JGOFS, we did not know whether the Arabian Sea absorbs or releases CO_2 into the atmosphere on balance, and upper-ocean physical and biogeochemical responses to monsoonal forcing were undocumented. Arabian Sea field studies employed 1) underway shipboard sampling with Acoustic Doppler Current Profilers (ADCPs) and other instruments, 2) towed instrument systems such as SeaSoar, 3) multiple moorings, and 4) satellite observations for sea-surface temperature and altimetry. Data from satellite-mounted altimeters (Figure 3a), moorings, and towed instrument systems showed important mesoscale processes.

One of the novel aspects of the U.S. JGOFS Arabian Sea study was the deployment of five moorings with meteorological and physical instruments covering a square roughly 55 km on a side (Dickey et al., 1998a). They were located near the axis of the atmospheric