detection and characterization. Lastly, we suggest new sampling strategies for future HAB research and monitoring programs.

X.2 Processes in the coastal ocean

X.2.1 Physical processes

Time series data and extensive spatial observations of physical oceanographic parameters enable the identification of some of the major forcing factors affecting the formation, persistence, and cessation of HABs in the coastal ocean (Figure X.1; also see Franks, 2005). The timescales of variability for these forcing factors can vary from minutes (e.g., turbulence and internal solitary waves) to hours (e.g., tidal and inertial processes) to days and months (e.g., upwelling and fronts) and longer (e.g., El Niño and the North Atlantic Oscillation). Spatial scales are equally wide-ranging, from meter-scale processes or smaller (bioturbation) to basin-wide (El Niño) to global scales (air-sea interaction and the hydrologic cycle; Figure X.1).

Figure X.1
Time-space diagram illustrating some of the processes that are important for harmful algal blooms (modified from Dickey, 1991).

Small-scale physical phenomena are generally dominated by turbulence, which affects molecular and cellular-scale processes. Diel cycles of solar insolation and tidal frequencies (diurnal and semi-diurnal) often control variability of various physical, bio-optical, and chemical parameters (Figure X.2; Stramska and Dickey, 1992; Abbott et al., 1995; Chang and Dickey, 2001; Chang et al., 2002). Solar insolation influences radiant heating rates of the upper ocean (e.g., Lewis et al., 1983, 1990; Ohlmann et al., 2000; Ohlmann and Siegel, 2000; Chang and Dickey, 2004), and thus affects stratification and the vertical movement of nutrients, phytoplankton, and their grazers. Tidal processes, in addition to surface and internal gravity and solitary waves (e.g., Bogucki et al., 1997), can vertically redistribute phytoplankton with respect to the light field, nutrients, and grazers (Kamykowski, 1974).

Figure X.2
Frequency power spectral density functions (PSDs) of (a) 20 m temperature, (b) 5 m chlorophyll-*a* concentration, an indicator of phytoplankton, and (c) 5 m beam attenuation data, a proxy for particles, collected off the coast of New Jersey in 24 m water depth. ‘O1’ = diurnal tidal, ‘M2’ = semidiurnal tidal, ‘I’ = inertial, and ‘D’ = diel frequencies. The cyan lines represent the 95% confidence intervals. This figure illustrates that diel and tidal oscillations can dominate both physical and particulate processes.

Many important processes are quasi-periodic and episodic, occurring at scales of days to months and tens of meters to thousands of kilometers. Inertial and other periodic oscillations are often caused by wind events, e.g., storms and hurricanes (Figure X.3;