3.1. Seasonal cycles and blooms

Seasonal cycles in temperature typical of a mid-latitude open ocean site are evident in our temperature records (Fig. 2). Solar insolation cycles and upper ocean thermodynamic responses to heating and cooling cycles and events as well as wind forcing all combine to produce sequences of spring warming and mixed layer shoaling, and late fall-winter cooling and mixed layer deepening (e.g., Dickey et al., 1998a, 2001). Superimposed on this typical upper ocean seasonal temperature pattern are occasional major deviations caused by episodic wind events including tropical storms and hurricanes and passages of eddies.

Seasonal patterns in phytoplankton populations are well documented and spring phytoplankton blooms are evident. These patterns and blooms result from the interplay of upper ocean dynamics, solar insolation and surface heat flux variations, and the changing availability of plant nutrients and light (e.g. Dickey et al., 2001; Steinberg et al., 2001). In general, zooplankton concentrations tend to roughly track phytoplankton concentrations and both are impacted by the natural seasonal cycles of the upper ocean dynamics listed above and by episodic events—described below. Daily averaged, depth-integrated (22–190 m) zooplankton biomass anomaly estimated using ADCP backscatter data along with concurrent temperature, chlorophyll fluorescence (in relative units), and current measurements from late August 1996 through late November 2000 are shown in Fig. 2a–t. Since variability in the biomass of zooplankton is the primary focus of this study, zooplankton biomass anomalies were computed as the difference between the instantaneous biomass values and the mean for the time series of August 1996–November 2000 (Zooplankton Biomass panels in Fig. 2); note that the mean depth-integrated, daily averaged value of 497 mg dw m^{-2} of the zooplankton biomass is shown on the right of each of the relevant panels for reference. During this time period, depth-integrated daily zooplankton biomass fluctuated from 343 to 700 mg dw m^{-2} (Table 3). Our data show strong event-scale variations (or fluctuations), in depth-integrated (22–190 m) zooplankton biomass. Zooplankton biomass peaks (shown as anomalies in Fig. 2) occur throughout the time series. These peaks are sometimes associated with spring phytoplankton blooms or in some cases passages of mesoscale features as discussed later.

The seasonal patterns of chl-*a* and zooplankton biomass do not display the rather smooth regularity of upper ocean temperatures and are not necessarily in phase with each other. Rather, episodes of increased levels of phytoplankton and zooplankton, which are sometimes associated with spring shoaling of the mixed layer, occur for periods of a few to several weeks at a time. Further, the onset of such blooms vary interannually. For example, the time series of chl-*a* fluorescence at 77 m show strong evidence of a spring phytoplankton bloom in mid-May to mid-June, 1997 (Fig. 2(g)). The chl-*a* fluorescence started to rapidly increase around May 15, 1997; during this time ADCP-estimated daily averaged, depth-integrated zooplankton biomass increased significantly and reached its maximum of 700 mg dw m^{-2}. Zooplankton biomass concentrations with relatively high values (greater than 6 mg dw m^{-3}) extended to ~110–120 m during the nights of May 17–19, 1997 (Fig. 3b). In mid-February to late March 1998, daily averaged, depth-integrated zooplankton biomass was relatively high (Fig. 2f); during the period of March 3–22, 1998, significant increases in zooplankton biomass concentrations also extended much deeper as indicated in Fig. 3b. This episode may have been related to incipient springtime shoaling of the mixed layer (see Fig. 2e temperature data). Unfortunately, chl-*a* data were not available for this time period. From late February to March 1999, the time series of chl-*a* at 72 m shows strong evidence of a spring bloom (Fig. 2k). Chl-*a* fluorescence started to increase rapidly around February 16 and more than doubled in magnitude on February 24. Zooplankton biomass increased significantly during this period and reached its peak value of 647 mg dw m^{-2} on February 22 (Fig. 2j). This bloom was likely due to the onset of stratification that followed deep mixing, which penetrated as deeply as 100 m depth as shown in the stack plot of temperature in Fig. 2i. In March 2000 there were also elevated levels of zooplankton biomass; these too may be related to an incipient spring bloom (unfortunately, no chlorophyll records are available). Finally, an extended summertime increase in zooplankton biomass, July–August, 2000 (Figs. 2r and 3e) was not coincident with an increase in chl-*a*.

As mentioned above, higher zooplankton biomass values for at least some blooms appeared to extend deeper into the water column during biomass peaks, as illustrated by the black line in Fig. 3 (indicating the maximum depth where biomass