9 Temporal Variability of Particle Flux in the Deep Sargasso Sea

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9.1 INTRODUCTION

This chapter gives an outline of some of the features of the longest series of deep-ocean particle flux measurements by sediment traps. The mooring is located in the Sargasso Sea, near 31°50’N, 64°10’W. Water depth is 4400 m. At the present time we have over 16 years of data from traps at a depth of 3200 m, ten years of data from 1500 m, and about seven years from 500 m (Figure 9.1). There is good coherence between the flux variabilities recorded by the two deeper traps, but for a number of reasons, not all of which are understood, coherence between the shallowest and deep traps is not as good. However, in this paper I will confine my remarks to the 3200-m series only. Its flux data represent 86% of the time elapsed since April of 1978. We employed a bimonthly sampling scheme for the first eleven years and quadrupled the sampling frequency to biweekly in 1989. Since then our temporal coverage has been 94%.

9.2 THE ANNUAL CYCLE

The deep series was the first to document seasonal flux changes, related to the annual cycle of primary production near the surface (Deuser and Ross, 1980) and the rapidity of the particulate transport to great depth (Deuser et al., 1981). This feature has since been observed in many parts of the ocean as well as in enclosed seas; e.g., in the Pacific (Honjo, 1982; Smith and Baldwin, 1984), the Indian Ocean (Nair et al., 1989), the Southern Ocean (Wefer et al., 1988), the Black Sea (Izdar et al., 1984), the polar North Atlantic (Bathmann et al., 1990; Wassmann et al., 1991), and the eastern North Atlantic (Honjo and Manganini, 1993). As can be seen in Figure 9.1, the annual cycle persists throughout the 16-year record from 3200 m. The shape of the average cycle over those years, and the band width of its variance are shown in Figure 9.2. The basic shape of this cycle has not changed in many years, although the variance is still influenced by two unusually high flux

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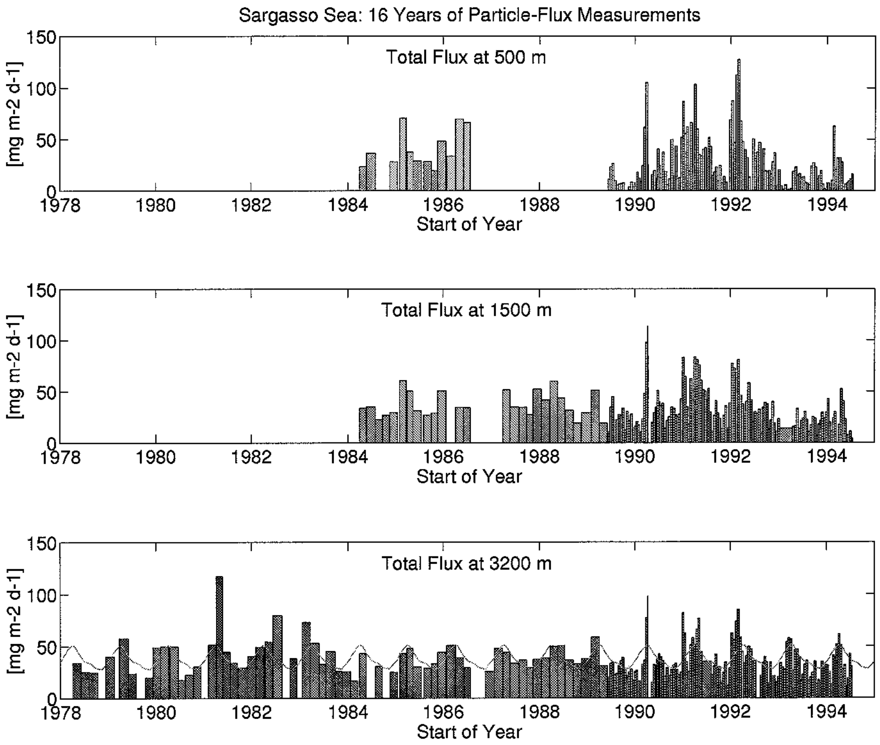


Figure 9.1 Sixteen-year record of particle flux measurements in the Sargasso Sea. Sampling intervals were shortened from bimonthly to biweekly in mid-1989. The dotted line in the bottom panel represents repetitions of the average annual flux cycle at 3200 m, as shown in Figure 9.2.

periods in 1981 and 1982 (Figure 9.1). Is it worth continuing the series? I believe there are several good reasons for doing so.

We know that the seasonal changes are ultimately driven by insolation changes, but we do not know what the forcing functions of the remaining variability are. One of the objectives of this continued work is to identify those functions through spectral coherence tests between deep-ocean particle flux and meteorologic and surface-ocean variables. Potential candidates are, for example, mixed-layer depth, wind stress and heat loss. All of these have annual cycles, as shown by the example of wind speed (Figure 9.3). But so do many other natural phenomena and human activities, as, for example, unemployment (Figure 9.4) or mammalian brain weight (Weiler, 1992)! The implication is clear: annual cycles are not diagnostic of causal relationships between variables. It is the anomalies (Figure 9.5) and other-than-annual periods which are more useful.

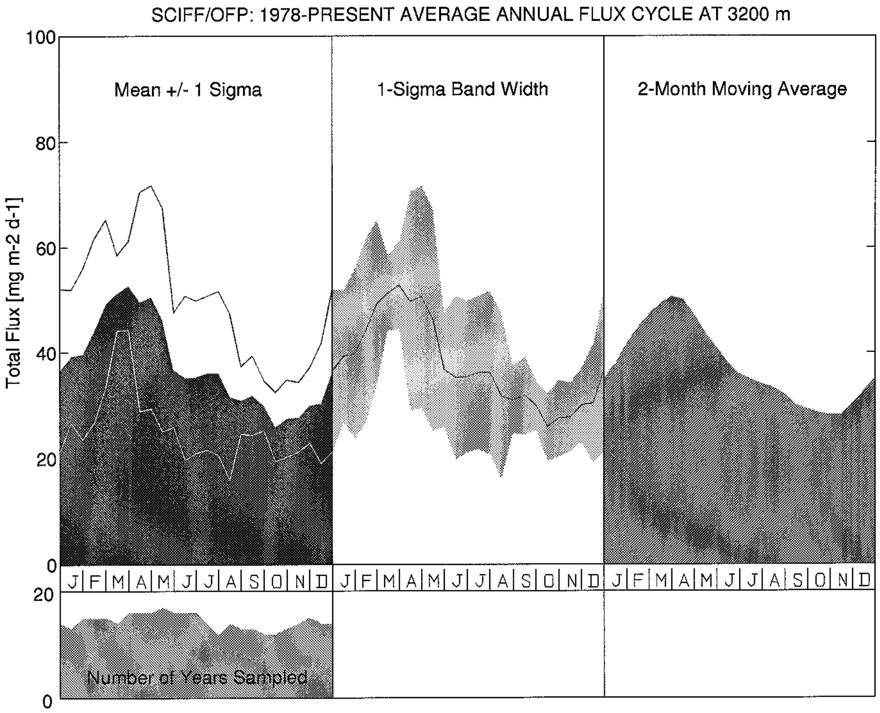


Figure 9.2 The average annual cycle of particle flux at a depth of 3200 m in the Sargasso Sea. The 1-standard-deviation band is shown in the middle panel; the two-month moving average of the mean (left panel) is shown in the right panel. The small panel at the bottom left indicates the number of years for which flux data were available for averaging at the different times of year.

9.3 OTHER PERIODS

While the annual period contains much of the spectral energy, it is becoming increasingly apparent that deep-ocean particle flux exhibits a continuous variability spectrum as, indeed, do all other oceanic variables which have been the subject of time-series measurements (Wunsch, 1981). The bimonthly sampling scheme of the first 11 years limited us to studying periods longer than about six months. But we now have over five years of biweekly flux data and can begin to look at periods as short as monthly.

Sixteen years of bimonthly variability are shown in Figure 9.6. For the purposes of this Figure the biweekly data of the last five years were averaged over 2-month periods. The average annual cycle is shown repeatedly as a frame of reference. The spectral power distribution of this series is shown in Figure 9.7 against the

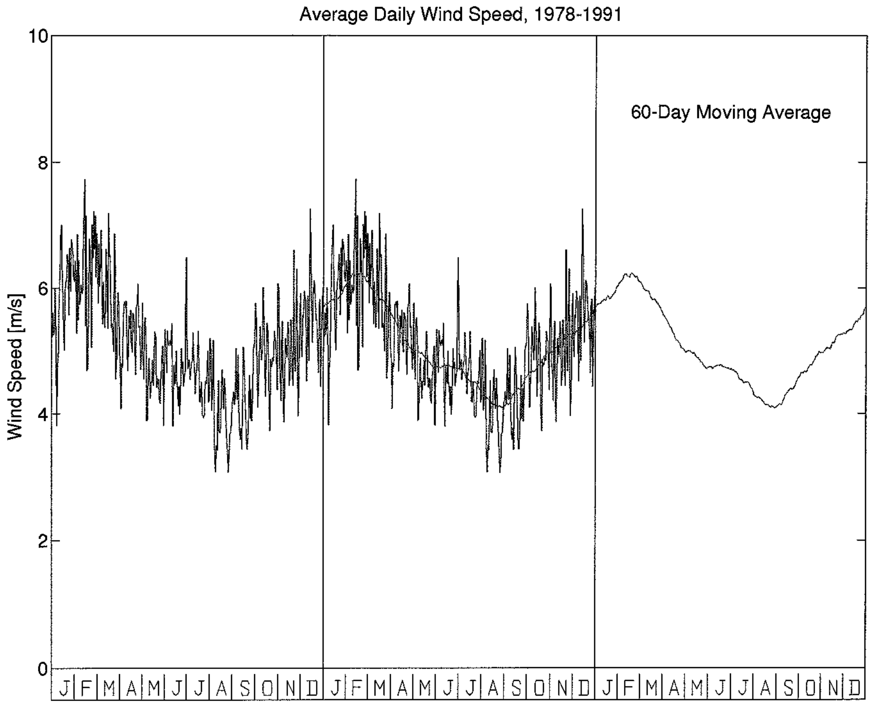
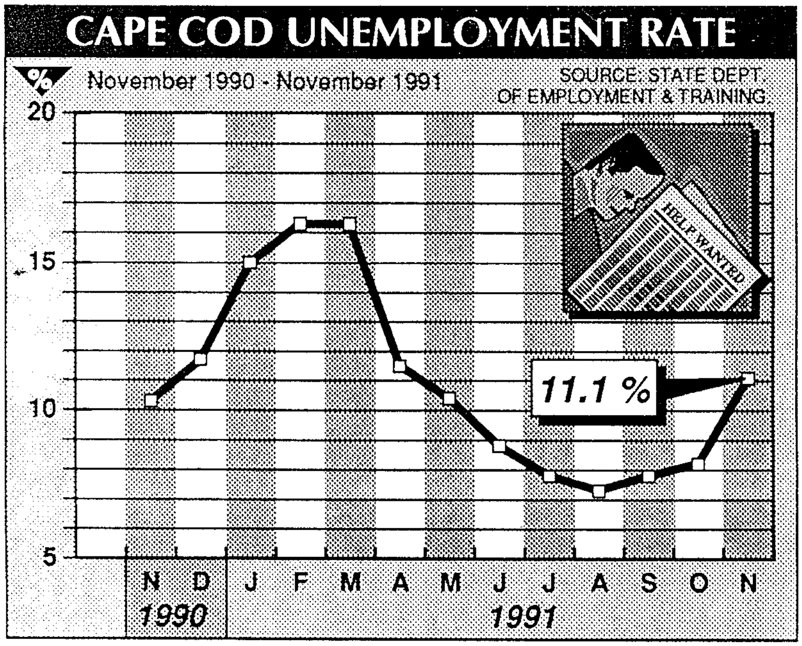


Figure 9.3 Average annual cycle of wind speed on the island of Bermuda for the period 1978–1991.

backdrop of the power spectrum of the average annual cycle. There is a strong peak near the annual period, but other periods, both longer and shorter, also can be seen, though their significance is quite minor compared to that of the annual period. El Niño periodicity and the sunspot cycle are possible candidates for the longer periods, but we cannot yet identify any of them with confidence. An example of a multi-year trend in our data is shown in Figure 9.8. There was an eight-year period of increasing flux from 1984 through 1991 which paralleled an increase in surface wind speed in the area. Possibly, this is related to longer-term climatic changes in the area, as suggested by the wind speed data shown in Figure 9.9. But we can’t be sure of this until we have a few more years of data. The weakness of any longer-than-annual periodicities in the existing data is underscored by the lack of peaks in the power spectrum of the bimonthly flux anomalies, except for a minor 4-year peak (Figure 9.10). That is not surprising because a "rule of thumb" in time-series measurement is that, in order to assess trends on a given time scale with any confidence, one needs measurement series extending over at least three times that time scale. Thus, to check for periodicity



Staff graphic by **JAMES WARREN**

Figure 9.4 Example of an annual cycle in human activity (from the Cape Cod Times).

on the scale of the sunspot cycle, we need about 35 years of data. More below on the question of whether or not that is reasonable or even desirable.

Five years of biweekly flux variability are shown in Figure 9.11. Again, the 16-year average annual cycle is shown repeatedly for reference. As one might suspect from inspection of this plot, the power spectrum shows a peak near the annual period, but there are also marginally significant peaks at shorter periods (Figure 9.12). Those same periods, 2.0, 3.3 and 4.2 months, stand out, however, in the power spectrum of the biweekly flux anomalies (Figure 9.13); i.e., after removal of the annual cycle from the data. Their identity and significance ought to become clearer with more data, but two remarks are in order: (1) It appears likely that the 2-month period is an artifact introduced by surface characteristics of the trap cones. In almost all instances (24 out of 25) the second 2-week sample collected after deployment of cleaned traps was larger than the first. The magnitude of the effect is dependent on the time of year; i.e., on the magnitude of the particle flux. We are presently investigating its cause, but tentatively conclude that the inner surface of the trap cones, newly exposed to seawater and sinking material, impedes the material's descent toward the collection cup at the bottom of the funnel. The impedance might be effective for a given period of time or until the

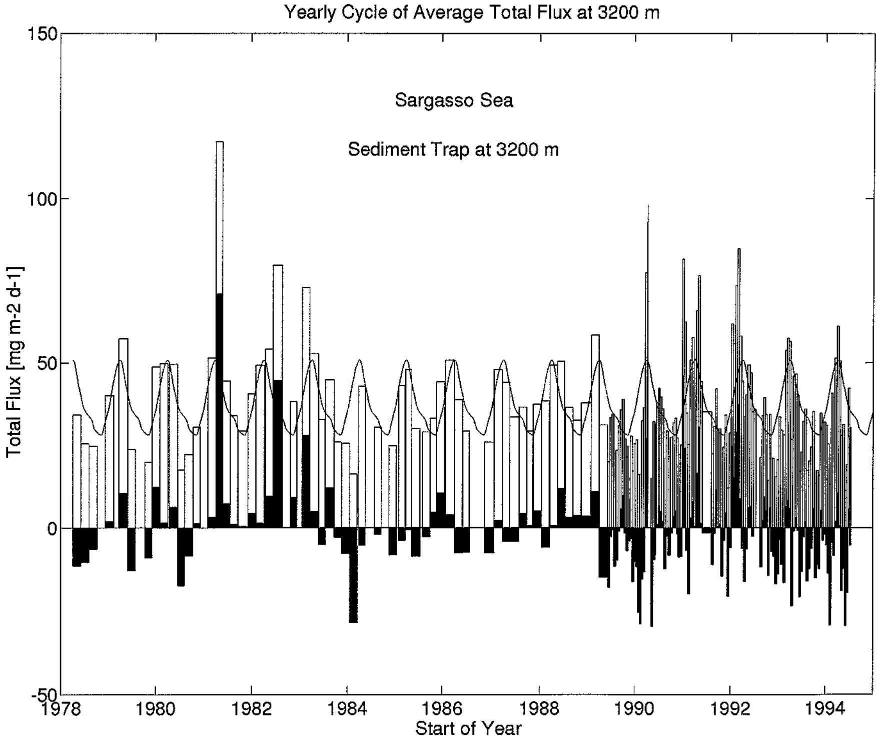


Figure 9.5 Total flux at 3200 m (open bars) and anomalies relative to the 16-year average annual cycle (filled bars).

surface has acquired a state of dynamic equilibrium with the sinking material. (2) There might well be a lunar period in the data. Some marine organisms, such as foraminifera, have lunar reproduction cycles (Spindler et al., 1979; Bijma et al., 1990 and 1994), but a biweekly sampling scheme cannot detect it because of aliasing (Figure 9.14). The average sampling period was too close to half the lunar period. Higher sampling frequency might seem desirable to get around this problem but, unless larger traps are used, the sample yields quickly become too small to be of much use. Also, sample numbers become too large to be handled by the typical laboratory.

The important point is that the other-than-annual periods are the most promising means by which we might identify forcing functions of deep particle flux, especially carbon flux. In addition, they might help identify more-easily-measured proxies for deep carbon flux. I maintain that we need such proxies for assessing the efficacy of, and secular trends in, the biological pump. Flux measurements by sediment traps alone are far too expensive and limited in their geographic

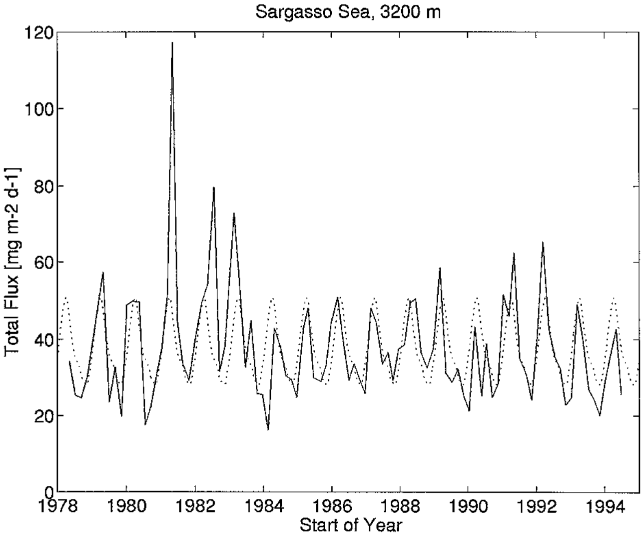


Figure 9.6 Variability of 16 years of bimonthly particle-flux measurements in the deep Sargasso Sea. Each 2-month collection period is represented by its midpoint only. The dotted line repeats the average annual cycle shown in the right panel of Figure 9.2.

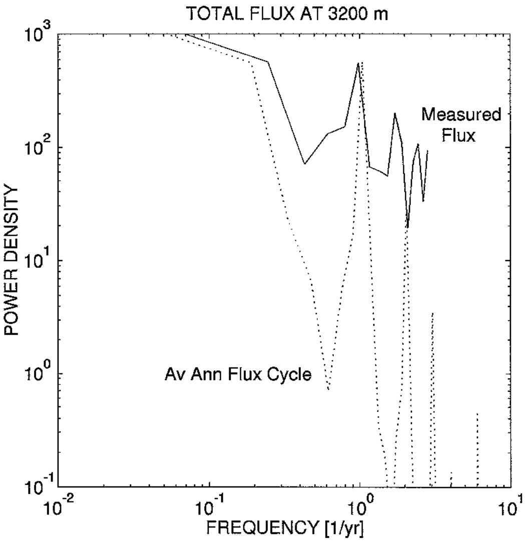


Figure 9.7 Power spectra of 16 years of bimonthly measured flux variability (solid line) and of the 16-year average annual cycle (dotted line) as shown in Figure 9.6.