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Short-term Variations in Estimates of Chlorophyll Abundance

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ABSTRACT

Short-term variations in total chlorophyll and in the depth of maximum chlorophyll abundance were observed at a drogue station located in an area characterized by a well-defined vertical temperature gradient and strong tidal currents. These variations were associated with vertical oscillations of the thermocline caused by internal waves.

During the period December 1964 - September 1966, a series of quarterly environmental surveys were made of Continental Shelf waters between Nova Scotia and Long Island (Colton, et al. 1968). As would be expected in an area characterized by strong tidal and non-tidal currents, marked spatial and temporal variations in physical, chemical, and biological properties were observed. To assess more accurately the degree of this variation and to establish confidence limits, time-series observations were made at specific locations (anchor stations) and in specific water masses (drogue stations) when time permitted. It is the purpose of this paper to illustrate the changes in chlorophyll abundance observed within a given water mass during June 1966 and to examine this variation in relation to hydrographic conditions and sampling techniques.

METHODS

A bathythermograph lowering was made hourly and a Nansen bottle cast at 2-hour intervals alongside a buoy attached to a parachute drogue (Volkman, et al. 1956) set at 50-m depth. The 2-hour station location and the track of the parachute drogue during the 46-hour sampling period are shown in Figure 1. The Nansen bottle depths were 1, 10, 20, 30, 40, 50, 75, and 100 meters. Chlorophyll was determined by flouresence of extracts of 125 m. sea water according to the method described by Yentsch and Menzel (1963) with modifications given by Yentsch (1965). The specific absorption value (k) used was 65.0 (Richards, 1952). A.G.K. Turner Model 110 fluormeter which had been calibrated against a similar instrument at the Woods Hole Oceanographic Institution was used for these determinations. All chlorophyll values were corrected for the presence of phaeophytin.

Fig. 1

RESULTS

In Figure 2 are shown: the 2-hour time-depth distribution of temperature and chlorophyll, the abundance of chlorophyll in mg/m^2 of sea surface integrated over 100 m (total chlorophyll), the average and range of temperature and chlorophyll at the eight sampling depths, and the average total chlorophyll for specific time intervals.

Fig. 2

A well-defined temperature discontinuity layer, which continued to oscillate vertically, was present throughout the sampling period. The average depth of the thermocline was approximately 25 meters and the maximum vertical displacement of an individual isotherm during a 2-hour period was 17 meters. The vertical displacement of the thermocline was reflected in the range of temperature encountered at specific depths. These ranges were greatest between 10 and 30 meters. Although tidal forces undoubtedly were instrumental in generating these internal waves, turbulent forces due to winds and bottom topography tended to mask the semidiurnal periodicity in the vertical oscillations. Hourly bathythermograph observations revealed the presence of internal waves of a shorter period than indicated by the 2-hour sampling interval.

At most stations the concentration of chlorophyll was greatest at 30 meters. The average "chlorophyll depth" (determined by multiplying the concentration of chlorophyll by the depth sampled, summing the weighted samples, and dividing by the total chlorophyll at all depths) tended to oscillate as did the thermocline, but to a much lesser degree. The average chlorophyll depth for all stations was 30 meters and the maximum vertical displacement during a 2-hour period was 9 meters. The vertical displacement of the depth of maximum chlorophyll concentration was reflected in the range of chlorophyll values observed at specific depths. These ranges were greatest between 20 and 40 meters.

There was a considerable variation in the total chlorophyll (mg/m^2) values between the 2-hour sampling periods, the ratio of maximum to minimum values being 2.8. As with the depth fluctuations of the thermocline, there was no consistent pattern to the fluctuations in total chlorophyll. The average day (0700-1900 hours) and night (2100-0500 hours) values were similar. Maximum and similar average values occurred between 0700 and 1100 hours and 2100 and 2300 hours. Minimum and similar average values occurred between 0100 and 0500 hours and 1300 and 1900 hours. This is a significant departure from prediction , for on the basis of the observations of Yentsch and Ryther (1957), Shimada (1958), Yentsch and Scagel (1958), and Wood and Corcoran (1966) one would expect the maximum total chlorophyll values to occur during the morning and early afternoon hours.

To determine if there was a relation between the fluctuations in total chlorophyll values and the vertical oscillations of the thermocline, a regression of the difference in total chlorophyll between each 2-hour sampling period on the depth change of the thermocline in meters between corresponding 2-hour sampling periods was calculated. The average depth of the 5°, 6°, and 7° isotherms was used to estimate the thermocline depth. There was a significant linear correlation between thermocline depth and chlorophyll concentration fluctuations ($r = .446$, $t = 2.2835$, with $.03 < P < .05$).

DISCUSSION

The data indicate that the phytoplankton was concentrated in a narrow stratum (or possibly strata) within the thermocline, that this stratum oscillated vertically with the thermocline, and that the high values of chlorophyll at specific depths or for the total water column occurred when the depth of this stratum coincided with a sampling depth. Obviously some of the variation in chlorophyll abundance observed resulted from changes in the amount of phytoplankton due to cell division and grazing and from changes in cellular pigment content, but in the main this variation appears to be associated with the vertical displacement of isotherms. Similar internal wave patterns and marked fluctuations in chlorophyll abundance were observed at anchor stations, but at these stations lateral shifts in water masses due to tidal currents tended to mask the relation between vertical oscillations of the thermocline and chlorophyll concentration fluctuations.

Marked vertical chlorophyll gradients and a relationship between the vertical distribution of phytoplankton and thermal density stratification have been noted in other areas (Gessner 1948, Halldal 1953, Sorokin 1960 and 1964, and Strickland 1968). Similar short-period oscillations of the thermocline and of the depth of maximum phytoplankton abundance have been observed off the coast of California (Barham, et al. 1966). Conditions favorable to the development of internal waves and for the concentration of phytoplankton within a narrow depth stratum (marked vertical density gradient and strong tidal action) exist over most of the Continental Shelf area between Cape

Sable and Long Island for at least six months of the year. In all our observations where such hydrographic conditions prevailed, chlorophyll was concentrated within the thermocline, the maximum depth limit of which seldom exceeded 40 meters.

In any large scale sampling program, it would be difficult, if not impossible, to eliminate the error in chlorophyll estimates due to advection, but it would be possible to reduce the error due to internal waves by closer vertical spacing of samples within the thermocline. As suggested by Strickland (1968), the use of a profiling hose and the continuous *in vivo* fluorescence method of chlorophyll concentration (Lorenzen 1966) would provide the most adequate measure of the phytoplankton crop. For plankton-net estimations of associated zooplankters oblique or vertical hauls would give a better estimate of the abundance in the total water column than horizontal tows at specific depth intervals.

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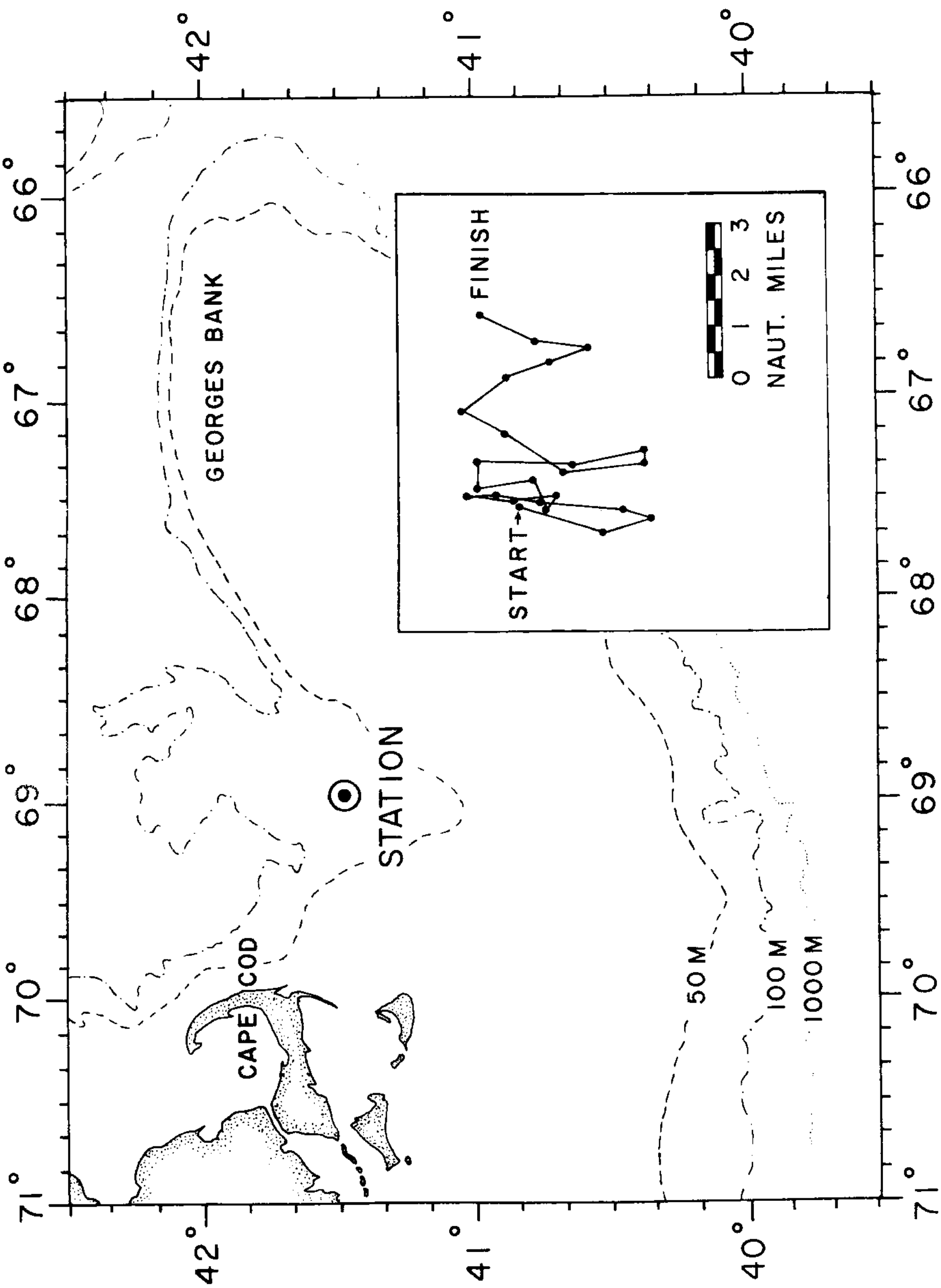

Fig. 1. Drogue station location. (Insert illustrates drogue track during sampling period.)

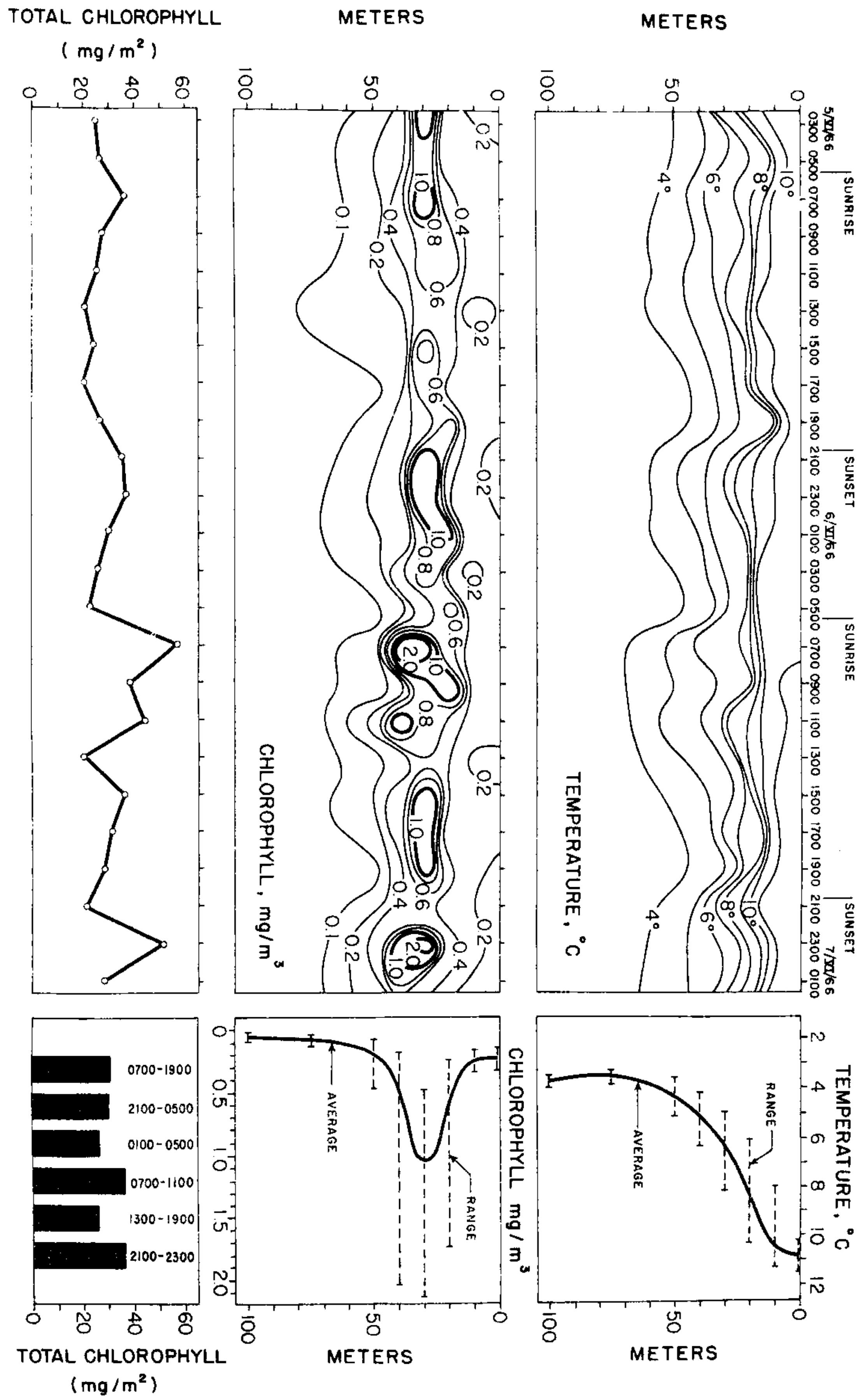

Fig. 2. Time and depth distribution of temperature and chlorophyll.