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Modeling phytoplankton dynamics in the northeast Atlantic during the initiation of the spring bloom

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Abstract. Primary productivity in the North Atlantic (59°29'N, 20°50'W) was estimated by applying a "light-pigment" productivity model (Kiefer and Mitchell, 1983) to mooring data collected during the spring of 1989. We show that the choice of the parametrization of the light captured by phytoplankton cells in a turbulent mixed layer has a significant effect on the calculated productivity estimates. It appears that the quality of such estimations benefits largely from using high-resolution time series data (minutes). We also examined phytoplankton dynamics by incorporating the Kiefer-Mitchell model into a one-dimensional model of the turbulent mixed layer (Mellor and Yamada, 1982). The calculated time-depth distribution of phytoplankton biomass compares relatively well with that measured in situ. The model results indicate that small changes in the water column stability can be sufficient to initiate phytoplankton bloom even before the apparent formation of the seasonal thermocline. The model also describes the diel cycle of biomass concentration, suggesting that near the sea surface the daytime losses of biomass by vertical diffusion can be much larger than nighttime losses. Thus, if not accounted for, such losses may bias estimates of primary production from diel variations in biomass concentration, for example, when using a method based on beam attenuation measurements. These losses should also be considered for the proper interpretation of in situ primary production measurements by incubation methods.

Introduction

The determination of the magnitude and distribution of primary production over a wide range of space and time scales is essential for improving our understanding of marine ecosystems and biogeochemical cycles. Unfortunately, the possibility of extensive in situ measurements of growth rates by carbon, oxygen, or nitrogen incubation methods is rather problematic, because these methods are time consuming and require considerable ship time. Such determinations will likely continue to be used routinely during oceanographic cruises, even though the results may be severely biased because of inaccuracies in the procedures [e.g., *Epply*, 1980; *Richardson*, 1991, and references therein] or contamination of the methods [e.g., *Fitzwater et al.*, 1982].

In recent years, much effort has been directed toward development of alternative ways of estimating primary production. Increased temporal resolution of measurements at a given point under water can now be achieved using moored instrumentation systems [*Dickey*, 1991; *Dickey et al.* 1991, 1993, also Bio-optical and physical variability in the northeast Atlantic Ocean (59°N, 21°W) during the spring of 1989, submitted to Journal of Geophysical Research, 1993 (hereinafter referred to as Dickey et al., submitted manuscript, 1993)]. These systems allow the collection of bio-optical and physical data concurrently and provide information on the characteristics of the water column over timescales of minutes to months. Importantly, the data obtained from moorings can be applied to estimate primary production. For this purpose, a number of procedures have been proposed, including methods based on the "light pigment" bio-optical models (see reviews by *Cullen* [1990] and *Bidigare et al.* ,[1992]), diel variability of the beam attenuation coefficient [*Siegel et al.*, 1989; *Cullen et al.*, 1992], oxygen budget [e.g., *Emerson*, 1987; *Jenkins and Goldman*, 1985], and solar-induced fluorescence [*Kiefer et al.*, 1989].

This study attempts to reevaluate the relationship between photosynthetically available radiation, phytoplankton production, and vertical mixing. First, primary productivity in the northeast Atlantic in the spring is estimated using time series of bio-optical data obtained with a mooring located south of Iceland. This estimation is based upon a simple version of a "light-pigment" bio-optical model [*Kiefer and Mitchell*, 1983]. The importance of the parameterization of light energy received by phytoplankton in the turbulent medium is considered. Finally, the Kiefer-Mitchell productivity model is incorporated into a one-dimensional model of the turbulent mixed layer [e.g., *Mellor and Yamada*, 1982]. Calculated and measured in situ time-depth biomass distributions are compared.

Such modeling of the phytoplankton dynamics aids in the interpretation of mooring data. For example, in contrast to classical models, our data suggest that the major outburst of spring phytoplankton bloom began prior to the apparent formation of the seasonal thermocline. This raises the question of whether the bloom was related to water mass advection or was a local phenomenon. It is hypothesized here that small changes in water column stability are sufficient to stimulate the initiation of the bloom. Such small changes in

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