On the relationship between stratification and primary productivity in the North Atlantic

M. Susan Lozier,[1] Apurva C. Dave,[1] Jaime B. Palter,[2] Lisa M. Gerber,[1] and Richard T. Barber[1]

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[1] Recent observational studies linking variability in global ocean productivity with upper ocean warming are based on the paradigm that warming produces a more stable water column which, in turn, inhibits primary productivity for a large fraction of the global ocean, namely the tropics and subtropics. Though seemingly straightforward, this paradigm relies on the assumption that an increase in the stratification of the upper ocean water column decreases the vertical mixing or overturning of the surface waters such that the supply of nutrients to the euphotic zone is reduced, and so too the primary productivity. Here we show, using observational data in the North Atlantic subtropical gyre, that while upper ocean stratification and primary productivity are strongly linked on seasonal time scales, they have at most a weak correlative relationship on interannual time scales over the modern observational record. We suggest that interannual variability in ocean biomass and primary productivity depends on a host of variables that are not easily predicted from the expected temperature response to climate variability and change. These variables include the strength of local and remote wind and buoyancy forcing and the surface or subsurface advective supply of nutrients. **Citation:** Lozier, M. S., A. C. Dave, J. B. Palter, L. M. Gerber, and R. T. Barber (2011), On the relationship between stratification and primary productivity in the North Atlantic, *Geophys. Res. Lett.*, *38*, L18609, doi:10.1029/2011GL049414.

1. Introduction

[2] The photosynthetic production of organic matter in the ocean's surface waters sustains nearly all marine life and transports carbon from the surface to the deep ocean. This production is critically dependent upon the supply of nutrients from the subsurface ocean to the euphotic zone [*Falkowski et al.*, 1998; *Gruber et al.*, 2002]. Traditionally, this nutrient supply has been attributed primarily to vertical processes and, as such, is believed to hinge on upper ocean density stratification for the simple reason that it takes more energy to overturn or mix a more stratified water. Thus, as suggested by a series of recent climate modeling studies, variability in upper ocean stratification is expected to translate into primary productivity variability for the tropical and subtropical ocean where productivity is not light limited [*Bopp et al.*, 2002; *Boyd and Doney*, 2002; *Sarmiento et al.*, 2004]. Increasing stratification is expected to inhibit productivity, whereas decreasing stratification would promote productivity.

[3] Recent assessments of the ocean density and color field have seemingly confirmed this expectation: *Behrenfeld et al.* [2006] used re-analyzed temperature and salinity fields to show that an increase in the globally-averaged tropical and subtropical upper ocean stratification occurring in the aftermath of the 1997–1998 El Nino was accompanied by a decline in globally-averaged chlorophyll and net primary productivity. Likewise, an expansion of the global ocean's nutrient-limited, low-chlorophyll oligotrophic regions has been attributed to the increasing stratification of the mid-latitude surface ocean [*Polovina et al.*, 2008]. Both impacts - large scale decreases in low- and mid-latitude ocean productivity and oligotrophic expansion – are suggested to presage the likely marine ecosystem response to a warming climate [*Behrenfeld et al.*, 2006; *Doney*, 2006; *Polovina et al.*, 2008]. Warming, however, may impact other factors that influence the nutrient supply to the euphotic zone that are as important as the background stratification of the surface waters. Although vertical stratification provides the resistance of the water column to overturning, variability in stratification in and of itself should not predetermine productivity variability. Factors that destroy the stratification and factors that affect nutrient concentrations must also be considered. Indeed, the sensitivity of the spring chlorophyll bloom in the subtropical North Atlantic to wind and buoyancy forcing that provide the energy for vertical mixing has been established [*Follows and Dutkiewicz*, 2001], as has the importance of surface and subsurface horizontal advection to the supply of nutrients to the sunlit waters [*Palter et al.*, 2005; *Williams and Follows*, 1998]. Thus, a closer examination of the impact of vertical stratification on ocean primary productivity is warranted. Such an examination is also timely since a recent study [*Boyce et al.*, 2010] has documented a decline in phytoplankton concentration over the past century in eight of ten ocean regions and because thousands of temperature profiles from Argo floats over the past decade have significantly expanded the number of observed stratification measures that are contemporaneous with satellite color fields.

2. Comparing In Situ Measures of Stratification and Productivity

[4] This study focuses on the subtropical North Atlantic, a well-sampled oligotrophic basin (Figure 1) surrounded by more productive coastal and subpolar waters. Annual cycles in primary productivity in this basin have been shown to be

[1]Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, NC 27708 USA.
[2]Department of Atmospheric and Oceanic Science, McGill University, Montreal, Quebec, Canada.

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