Three Years of Ocean Data from a Bio-optical Profiling Float

Ocean color, first measured from space 30 years ago, has provided a revolutionary synoptic view of near-surface fields of phytoplankton pigments. Since 1979, a number of ocean color satellite missions have provided coverage of phytoplankton biomass and other biogeochemical variables on scales of days to years and of kilometers to ocean basin.

Because of the nature of visible light and its interaction with absorbing and scattering materials in the ocean and atmosphere, these measurements are biased toward near-surface waters and are obscured by clouds. As a consequence, ocean color satellites miss significant fractions of phytoplankton biomass, marine primary productivity, and particle flux that occur at depths beyond their sensing range. They also miss phytoplankton blooms and other events that occur during periods of extended cloud cover.

A new approach to mitigating these limitations, based on merging data from in-water autonomous sensing of optical properties with satellite ocean color, has been demonstrated with a pilot project in the Labrador Sea in the North Atlantic Ocean. In-water measurements of chlorophyll *a* fluorescence (a proxy for phytoplankton concentration) and particulate optical scattering (a proxy for particle concentration) were measured on a float that profiles the water column from a 1000-meter depth to the surface, similar to floats used in the global Argo ocean observation program (http://www.argo.ucsd.edu).

A Webb Research Corporation Apex float has been roving the North Atlantic for more than 3 years and has measured 221 profiles of optical and physical (temperature and conductivity) properties, measuring one profile every 5 days (Figure 1; float data can be downloaded from http://misclab.umeoce.maine.edu/research/research03_data.php). The Apex float combines commercially available technology (circa 2004) including a WET Labs miniaturized optical sensor that measures both chlorophyll fluorescence and particle side scattering; a conductivity-temperature-depth (CTD) profiler and a novel auxiliary board to integrate sensors, both from Sea-Bird Electronics, Inc.; and long-lasting lithium batteries. Limitations

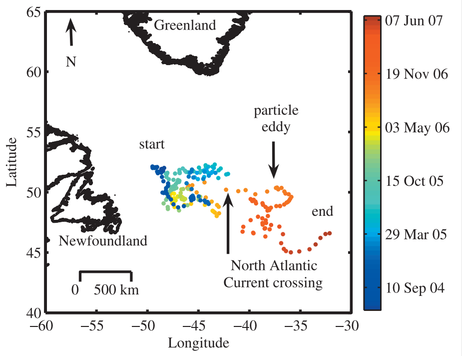

Fig. 1. Trajectory of bio-optical Apex float 0005.

inherent to the methods (e.g., variable relationships between chlorophyll fluorescence and chlorophyll concentration, and between optical side scattering and backscattering) result in a relative uncertainty of the order of ±50% in chlorophyll and backscattering with a minimal absolute uncertainty of ±0.03 mg m^{-3} for chlorophyll and 3×10^{-4} m^{-1} for particulate backscattering. While these uncertainties may seem large, they are much smaller than the observed range in these properties in our study (0–3 mg m^{-3} for chlorophyll, $2–20 \times 10^{-3}$ m^{-1} for backscattering).

Averaged over one spatial decorrelation scale (the scale over which concurrent but spatially separated measurements are significantly correlated, here 7.5-kilometer radius) around the Apex float's surfacing location, surface optical properties show good agreement with ocean color–derived optical properties from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Aqua satellite (Figure 2, top panels); correlation with chlorophyll (NASA OC3 chlorophyll algorithm, $R = 0.88$) and backscattering (GSM backscattering algorithm, $R = 0.9$; see http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/MSl12_prod.html for algorithm details) are high. No noticeable trend is observed in the optical measurements below 950 meters (Figure 2, bottom panels). However, a significant elevation of subsurface backscattering at all depths is

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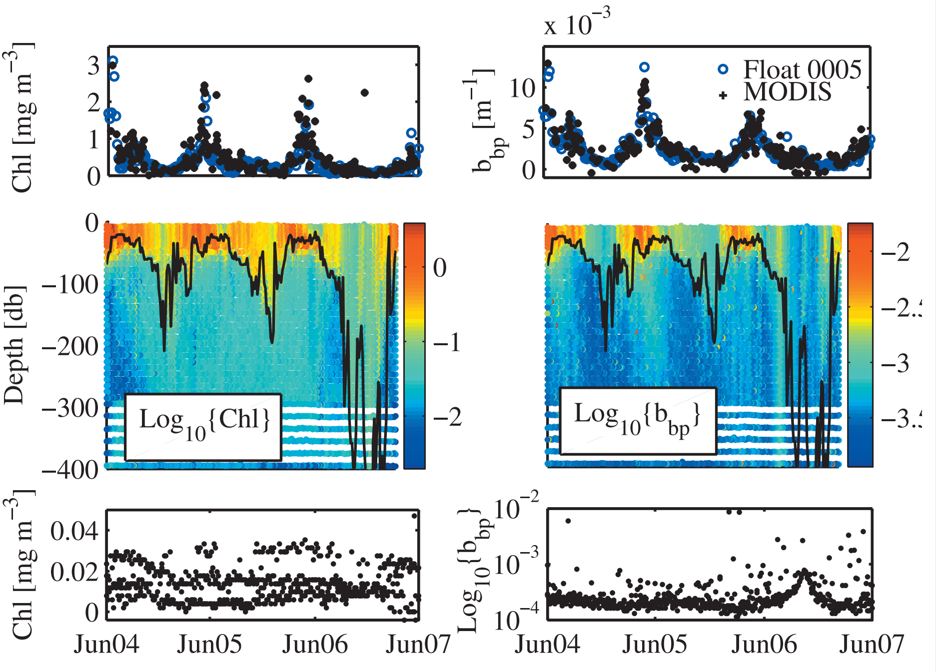

Fig. 2. Time series of (left) chlorophyll concentration and (right) particulate backscattering coefficient. (top panels) Near-surface float and Moderate Resolution Imaging Spectroradiometer Aqua satellite data, (middle panels) midwater column float data, and (bottom panels) float data below 950 meters (note log scale for particle backscattering). For satellite chlorophyll concentration and backscattering coefficient, we use NASA's inversion products OC3 and GSM, respectively (http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/MSl12_prod.html).

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observed in November 2006 (Figure 2, middle panels), associated with the crossing of a particle-laden anticyclonic eddy observed in altimeter data (not shown). Such subsurface features, although they may have significant biogeochemical implications, cannot be resolved by ocean color observations from space; in the clearest of ocean waters, satellite measurements are limited to depths of only tens of meters.

The success of this Apex float and six other similar floats currently profiling the Pacific Ocean could lead to the design, testing, and implementation of an array of more sophisticated floats to provide critical data on biogeochemical properties, the biomass of key ecosystem variables, and temporal changes in these variables. Profiling floats could revolutionize biogeochemical modeling by providing data that satellites cannot, and for a small cost (total cost of this expandable float's components and telemetry was approximately $25,000).

Given technological advances in sensor technology, we envision the deployment of an array of floats that in addition to phytoplankton and particulate concentration, are capable of measuring parameters constraining nutrients, zooplankton, spectral radiance or irradiance, colored dissolved organic material, and oxygen. Previous biogeochemical investigations with profiling floats included measurements of beam attenuation, irradiance, and oxygen (e.g., *Bishop et al.* [2002], *Mitchell et al.* [2000], and *Riser and Johnson* [2007], respectively).

The International Ocean-Color Coordinating Group recently has assembled a scientific working group to coordinate and recommend future programs and desired protocols associated with bio-optical profiling floats (see http://www.ioccg.org/groups/argo.html). Such multifloat programs would provide data to validate satellite ocean color measurements and derived biogeochemical products. In addition, the depth-resolved, colocated physical and biogeochemical data, in conjunction with ocean color, could initialize and constrain (via assimilation and comparison) nutrient-phytoplankton-zooplankton models, which are the cornerstones of ocean ecosystem modeling.

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