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Complementary use of Wave Glider and satellite measurements: Description of spatial decorrelation scales in Chl-a fluorescence across the Pacific basin

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ABSTRACT

A key challenge for ecosystem science in the 21st century is to characterize emerging trends in ecosystem productivity due to climate change and to better predict cycles in ecosystem variability. A first step toward this goal is to be able to characterize phytoplankton variability across a wide range of spatial and temporal scales. In this paper, 15 months of Wave Glider (WG) fluorometer measurements made across the Pacific Ocean were used to understand how WGs complement existing chlorophyll-a-based measurements of phytoplankton biomass from satellite platforms. Extensive analysis of the WG transects demonstrated that WG fluorometer readings reliably characterized similar large-scale variability in satellite Chl-a measurements in four distinct ecosystem types including coastal upwelling, transition zone, oligotrophic and equatorial upwelling regions. Complementary information provided by WG measurements included better resolution of coastal Chl-a patches and prominent diel cycles in the open ocean. The decorrelation scales computed from WG fluorometer measurements in this study provide necessary information for designing observing systems, process experiments, and data assimilation studies. We

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conclude this paper by suggesting how WGs can be used to anchor satellite measurements and to develop better predictive models.

1. Introduction

Phytoplankton contribute half of the Earth's net primary production (Field et al., 1998) and nearly 95% of the ocean's primary productivity. It is this organic matter source that fuels the marine food web and provides the Earth with half of its atmospheric oxygen. The importance of phytoplankton is rivaled by the difficulty of accurate measurement. Microscopic size, diversity, and ephemeral characteristics of phytoplankton physiology that can more than double on a daily basis and attain turnover rates of two to six days (Behrenfeld and Falkowski, 1997; Behrenfeld et al., 2005) contribute to highly variable phytoplankton estimates. The dynamic physical environment in which phytoplankton live further complicates these biological characteristics; ocean currents transport phytoplankton over extensive habitats, influenced by mesoscale and submesoscale variability, while seasonal variations in temperature directly impact growth rates and indirectly affect light availability through changes in the stratification and water column turnover. Such biological and physical variability result in temporal and spatial patches of phytoplankton that can be difficult to measure accurately, resulting in estimates of phytoplankton in the ocean that can vary by a factor of 1.5 or greater (Longhurst, 1995). In this paper, we investigate how a new robotics sampling platform can be used along side the widely used satellite measurements to describe scales of patchiness in the Pacific basin.

Phytoplankton patchiness is often assessed through fluorometer measurements of Chlorophyll-a (Chl-a) pigments contained in each phytoplankton cell. Despite being an imperfect proxy for measuring phytoplankton biomass due to the varying relationship of Chl-a content to the relatively stable amount of carbon per cell (Banse, 1977), Chl-a has been shown to be the best estimator for phytoplankton biomass when compared with other proxies (Huot et al., 2007). Oceanographers measure amounts of this pigment in the ocean through the deployment of fluorometer-based instrumentation by ships and moorings, and utilize satellite imagery measurements of ocean pigment color algorithmically converted to Chl-a. Despite the advantages of these methods, such as the location-specific accuracy and profile measurements achieved by shipboard water sampling for onboard calibration via HPLC and/or Chl-a, the fine-scale temporal resolution (at a variety of depths) of moorings, and the synoptic spatial coverage of satellites, all sampling methods have their drawbacks. Ships lack spatial coverage, are costly to run, and cannot be used in extreme sea conditions. Moorings also lack spatial coverage and require servicing that precludes remote sensing locations without great expense. Satellite imagery-based Chl-a contains poorly known error (McClain, 2009), lacks sub-daily temporal resolution, and falters in optically complex and cloud covered areas.

The recent development of inexpensive robotic platforms addresses many of these sampling method shortcomings. Autonomous Underwater Vehicles (AUVs) can be used to make fine-scale temporal and spatial measurements throughout the depth of the water column, but have power limitations that reduce distance covered and time at sea (Willcox et al., 2001). Wave Gliders (WGs) produced by Liquid Robotics Inc. provide an efficient, enduring, and relatively low cost method to measure ocean variables at high temporal and spatial resolution. Using wave energy for propulsion and solar panels to power on-board electronics (i.e., sensors, navigation and communications) WGs are able to continuously collect and transmit data in the roughest of conditions (Hine et al., 2009; Manley and Willcox, 2010; Frolov et al., 2011). Sunlight (for power) and wave action (for movement) are rarely limiting factors at sea. The most crucial limitations of WGs at present are lack of depth profiling and synoptic spatial coverage. Similar to other fluorometer-based measurements, WGs must deal with biofouling and instrument failure. Currently, all limitations but depth profiles can be addressed through the deployment and maintenance of multiple WGs.