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Underway sampling of marine inherent optical properties on the Tara Oceans expedition as a novel resource for ocean color satellite data product validation[☆]

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ABSTRACT

Developing and validating data records from operational ocean color satellite instruments requires substantial volumes of high quality *in situ* data. In the absence of broad, institutionally supported field programs, organizations such as the NASA Ocean Biology Processing Group seek opportunistic datasets for use in their operational satellite calibration and validation activities. The publicly available, global biogeochemical dataset collected as part of the two and a half year Tara Oceans expedition provides one such opportunity. We showed how the inline measurements of hyperspectral absorption and attenuation coefficients collected onboard the R/V Tara can be used to evaluate near-surface estimates of chlorophyll-a, spectral particulate backscattering coefficients, particulate organic carbon, and particle size classes derived from the NASA Moderate Resolution Imaging Spectroradiometer onboard Aqua (MODISA). The predominant strength of such flow-through

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measurements is their sampling rate—the 375 days of measurements resulted in 165 viable MODISA-to-*in situ* match-ups, compared to 13 from discrete water sampling. While the need to apply bio-optical models to estimate biogeochemical quantities of interest from spectroscopy remains a weakness, we demonstrated how discrete samples can be used in combination with flow-through measurements to create data records of sufficient quality to conduct first order evaluations of satellite-derived data products. Given an emerging agency desire to rapidly evaluate new satellite missions, our results have significant implications on how calibration and validation teams for these missions will be constructed.

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1. Introduction

Satellite ocean color instruments provide consistent and high-density data on temporal and spatial scales that far exceed current field and aircraft sampling strategies, often with time-series of sufficient length to allow retrospective analysis of long-term trends. For example, the daily, synoptic images captured by the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS; 1997–2010) and Moderate Resolution Imaging Spectroradiometer onboard Aqua (MODISA; 2002–present) provide viable data records for observing decadal changes in biogeochemistry of both global and regional ecosystems (McClain, 2009). Briefly, satellite ocean color instruments measure the spectral radiance emanating from the top of the atmosphere at discrete visible and infrared wavelengths. Atmospheric correction algorithms are applied to remove the contribution of the atmosphere from the total signal and produce estimates of remote sensing reflectances ($R_{rs}(\lambda)$; sr^{-1}), the light exiting the water mass normalized to a hypothetical condition of an overhead Sun and no atmosphere (Gordon and Wang, 1994). Bio-optical algorithms are applied to the $R_{rs}(\lambda)$ to produce estimates of additional geophysical properties, such as the near-surface concentration of the phytoplankton pigment chlorophyll-a (C_a; mg m^{-3}) and spectral marine inherent optical properties (IOPs), namely the absorption and scattering properties of seawater and its particulate and dissolved constituents (O'Reilly et al., 1998; Werdell et al., 2013). Time-series of these geophysical properties provide unparalleled resources for studying carbon stocks, phytoplankton population diversity and succession, and ecosystem responses to climatic disturbances on regional to global scales (e.g., Siegel et al., 2013).

Refining bio-optical algorithms and verifying ocean color satellite data products requires a substantial volume of *in situ* data to ensure their validity on global spatial and temporal scales (Werdell and Bailey, 2005; Bailey and Werdell, 2006). Previously, large volumes of high quality data were most successfully acquired via institutionally supported programs, such as the NASA Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) activity (Fargion and McClain, 2003). During its six-year tenure, SIMBIOS enabled the assembly of 67,000 measurements from 1100 unique field campaigns collected by an assortment of 62 international researchers for inclusion in the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS), the permanent archive for *in situ* data obtained under the auspices of the NASA Ocean Biology and Biogeochemistry Program (Werdell et al., 2003). While extremely useful, these data remain heterogeneously distributed in time and space—emphasizing seasonal biases (Spring-Fall) and the coastal and North Atlantic oceans. In the absence of a coordinated activity, organizations responsible for operational ocean color satellite missions, such as the NASA Ocean Biology Processing Group (OBPG; oceancolor.gsfc.nasa.gov) opportunistically seek *in situ* data records to support their algorithm development and satellite data product validation activities.

The Tara Oceans expedition (September 2009 to March 2012) provides one novel opportunity. Briefly, Tara Expeditions (oceans.taraexpeditions.org ; Karsenti et al., 2011) conducted a ~91,000 km voyage on the R/V Tara over two and a half years to capture a view of the global distribution of