Responding to NOAA Joint Polar Satellite System Proving Ground and Risk Reduction Program

Title: Optimization of phytoplankton functional type algorithms for VIIRS ocean color data in the Northeast U.S. Continental Shelf Ecosystem

Program Priority:
This proposal is in response to the **Oceans and Coasts** Proving Ground Initiative

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Total Cost: $453,207

Abstract

Phytoplankton are critical regulators of key biogeochemical processes and fuel marine food webs through primary production. As such, changes in the timing, location, and/or species composition of phytoplankton blooms can have dramatic consequences on carbon cycling and the fate of primary production. Hence, understanding how phytoplankton communities are changing is of critical importance to managing sustainable fisheries and ocean health. Oceanic remote sensing observations have spatial and temporal resolutions unattainable by ship-based, moored or autonomous platforms, and are a critical component of the long-term monitoring of the physical environment and ecosystem productivity. A variety of remote sensing algorithm approaches have recently emerged that attempt to identify phytoplankton into size classes (PSCs) and functional types (PFTs) at the global scale. However, for use in the Northeast US continental shelf (NES), these algorithms must be optimized to account for local variations in non-algal parameters such as colored dissolved organic matter and suspended particles.

Accurate discrimination of phytoplankton groups requires coincident phytoplankton identification and optical observations. Specifically, we propose to use ship based *in situ* radiometry (water-leaving radiance), inherent optical properties (IOPs), phytoplankton pigments, and flow cytometric images of phytoplankton data to test and regionally tune PFT algorithms. Existing data will be mined from a variety of public databases and new field samples will be collected on up to 6 NEFSC Ecosystem Monitoring cruises during the first two years of the project. Field sampling and data mining of existing data are essential components of the proposed research to refine and optimize the satellite algorithms spatially and temporally across the entire study region.

Using the field sampling data, we will regionally optimize selected abundance-based and absorption-based algorithms. Abundance-based algorithms will be compared with diagnostic phytoplankton pigments; however, this approach does not necessarily reflect the true size structure of the phytoplankton community as some taxonomic groups have a broad size range and some pigments are common to different taxonomic groups. Our concurrent measurements of phytoplankton imaging and IOPs, will allow us to investigate the phytoplankton optical relationships and improve absorption-based algorithms for the NES.

Following algorithm optimization, we will generate a complete satellite record (September 1997-present) time series of PFTs to characterize temporal and spatial variability in the NES. Long-term monitoring of the phytoplankton community is critical for detecting shifts in phytoplankton composition and identifying potential impacts to ecosystems and fisheries. The proposed project will help maintain a continuous stream of high quality, seamless, accurate data which are necessary to detect long-term changes that may impact primary productivity, phenology, critical marine habitats, and fisheries. These long-term time series are used to develop indices for the NEFSC Ecosystem Status Reports, which are intended to generate scientific advice and inform scientists and fisheries managers of the current state of the ecosystem and fisheries within the NES. In addition, the PFT data will be included as inputs for ecosystem (e.g. Atlantis) and protected species (e.g. AMAPPS) models. Deliverable products from this project include, high quality in situ data, optimized regionally tuned ocean color algorithms, indices derived from long-term PFT time series, fisheries model output used to inform ecosystem based fisheries management, and associated manuscripts.

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Results from prior research

K. Hyde (selected awards and activities most relevant to this proposal)

"The Impacts of Climate Variability on Primary Productivity and Carbon Distributions in the Middle Atlantic Bight and Gulf of Maine"; NASA Ocean Biology and Biogeochemistry (NNH10AN48I); Antonio Mannino (lead PI); 4/2009-3/2012; $219,525; 3 months/year. Hyde and colleagues validated satellite algorithms for phytoplankton pigments, primary production, dissolved organic matter, and colored dissolved organic matter using field data from the Northeast Shelf.

"Synergistic Impacts of Population Growth, Urbanization, and Climate Change on Watersheds and Coastal Ecology of the Northeastern United States"; NASA Ocean Biology and Biogeochemistry (NNH15AZ11I); Raymond Najar (lead PI); 10/2016-09/2018; $132,241; 1 month/year. Hyde generates satellite time series of regionally tuned products (CHL, DOC, CDOM) that are used by co-PIs to compare with outputs from biogeochemical models of the Northeast US Shelf and estuaries.

Hyde maintains an up-to-date, high resolution (1km) satellite database (SeaWiFS, MODIS-Aqua, MODIS-Terra, and S-NPP VIIRS) of the US East Coast and routinely generates regionally tuned ocean color and frontal products. These data are included in the NEFSC Ecosystem Status Report, annual State of the Ecosystem Reports, and will be incorporated into the newly developed Northeast Integrated Ecosystem Assessment (IEA) website. Hyde is a member of two international working groups modeling the influence of primary production on fisheries production potential, the NOAA Ocean Color Coordinating Group (NOCCG) and NOAA North Atlantic Regional Team (NART).

C. Mouw (selected awards and activities most relevant to this proposal)

"Interpreting ecological variability using remotely observed optical properties and ocean models"; NASA Ocean Biology and Biogeochemistry, (NNX13AC34G); Follows, M. (lead PI); 11/2012–11/2017, $804,014. Mouw and colleagues characterized the variability of satellite-estimated phytoplankton size classes, globally, over the ocean color satellite record. They described the environmental drivers of the phytoplankton size from remote sensing and reanalysis products.

"Parameterizing spectral characteristics of optically active constituents in inland water for improved satellite retrievals"; NASA Water and Energy Cycle (NNX14AB80G); C. Mouw (lead PI); 1/2014–12/2019, $867,440; 1 month/year. Mouw and colleagues carried out optical measurements across multiple Laurentian Great Lakes and characterized the optical variability of the lakes and defined optical coefficients for use in optimizing semi-analytical algorithms on the lake system.

Dr. Mouw's research interests lie in the ecological and physiological response of phytoplankton to environmental change and the role that their community structure plays in carbon cycling and ecosystem functioning. Her research focuses on the use of novel and emerging algorithms and satellite technologies to study physically-driven biological variability in the ocean and lakes. Her expertise is in the interpretation of *in situ* optical observations and satellite algorithm development with a particular focus on discriminating phytoplankton function types from reflectance spectra. She has been active in global scale phytoplankton community composition determination from satellite for many years, taking part in an international self-organized group of scientists to inter-compare various methods for determining composition from satellite platforms. Dr. Mouw has expanded her research into optically complex coastal waters and added an *in situ* optical observation to her research program. This prong of Dr. Mouw's research is aimed at improving image products to enable investigation of optically complex water systems, which include nearly all coastal systems and inland water bodies. These efforts allow for a local application that has implications for not only understanding environmental change but also issues related to water quality and human health impacts. Dr. Mouw currently serves on the International Ocean Colour Coordinating Group Working Group for Ocean Colour Applications for Biogeochemical, Ecosystem and Climate Modeling and the NASA Earth and Space Advisory committee.

R. Morse

Dr. Morse's research has focused on understanding controls of algal blooms and on zooplankton dynamics on the Northeast US Shelf. Dr. Morse has experience in method development and calibration of phytoplankton pigment analyses using high performance liquid chromatography (HPLC) and is currently developing version 1.5 of the Northeast United States (NEUS) Atlantis ecosystem model for the NOAA Northeast Fisheries Science Center. This model development involves integrating new data sources for the initial conditions values for the lower trophic level groups, including satellite-based chlorophyll *a* concentrations and ship-based samples of zooplankton abundance.

Project Description

1. Introduction

The motivation for this study is to improve satellite derived measurements of phytoplankton composition in the Northeast US Shelf (NES) to support NOAA's mission of ecosystem based fisheries management (EBFM) by using the data in ecosystem status reporting, fisheries production potential models, and end-to-end fisheries ecosystem models. The NES is characterized by strong seasonality and high levels of variability in physical forcing, which influence the abundance, productivity and species composition of the phytoplankton community. Phytoplankton fuel marine food webs and are critical regulators of key biogeochemical processes, however they are immensely diverse, which is reflected in their taxon-specific morphological, physiological and ecological characteristics. Individual cells range in size from <1µm to roughly 1mm, and many taxa form chains reaching up to several centimeters in length. This multifaceted diversity and six orders of magnitude size range is critical to their ecological function, the complexity and stability of marine food webs, and ultimately, to the fate of primary production in the sea.

The distinct morphology, size, and pigment composition of phytoplankton, modulated by their physiological state, impact light absorption and scattering, allowing them to be detected with ocean color radiometry. Satellite based radiometric observations provide spatial and temporal resolution unattainable by ship-based, moored or autonomous sampling platforms, and are a critical component of the long-term monitoring of phytoplankton in marine ecosystems. A variety of remote sensing algorithm approaches have emerged that attempt to group "phytoplankton functional types" (PFT), into phytoplankton size classes (PSC), phytoplankton taxonomic composition (PTC), or particle size distribution (PSD) (Mouw et al., 2017). Success in estimating PFTs via satellite remote sensing imagery has been demonstrated at global (Mouw et al., 2017; IOCCG, 2014) and regional scales such as the Arctic (Fujiwara et al., 2011) and the Brazilian continental shelf (Ciotti and Bricaud, 2006). Given these regional successes, we fully anticipate improvement of PFT estimates for the NES beyond the existing globally-optimized retrievals.

Phytoplankton diversity, cell size, abundance, phenology, and carbon fluxes are regulated by the local physical and chemical environment. Inter-annual and climatological changes in temperature, freshwater inputs (due to ice sheet melting and/or enhanced river discharge), wind direction, and wind speed can alter the circulation patterns, upwelling conditions, and nutrient fluxes, directly affecting the timing, location, species composition of phytoplankton blooms in the NES (Ji et al., 2007; Balch et al., 2008). Changes in phytoplankton biomass, production and composition are propagated up through the food web and ultimately control fisheries production. More specifically, community composition directly influences the transfer efficiency of photosynthetically derived energy to higher trophic levels (Fogarty et al., 2016). Given the critical role of phytoplankton in the food web and the diverse function different taxonomic groups play in the ecosystem, improved satellite estimates of PFTs will advance fisheries modeling and better inform management decisions.

2. Problem Identification

Changes in the timing, location, and/or species composition of phytoplankton blooms can alter energy transfer pathways to higher trophic levels and decouple pelagic food webs (Cushing et al., 1990; Fogarty et al., 2016). Understanding how phytoplankton communities are changing is important for ocean health and managing sustainable fisheries. Oceanic remote sensing allows spatial and temporal resolution unattainable by ship-based, moored or autonomous platforms, and is a critical component of long-term monitoring to detect shifts in phytoplankton composition and identifying potential impacts to the NES ecosystem and fisheries.

2.1 The Northeast U.S. Continental Shelf

The NES ecosystem, extending from Cape Hatteras, NC to Nova Scotia (Fig. 1), is a highly productive temperate ecosystem largely fueled by a dynamic phytoplankton based food web. The region includes the Middle Atlantic Bight, Georges Bank, and Gulf of Maine and supports several commercially important fisheries that annually yield over $100 billion in fishing activity (Hoagland et al., 2005). Within the NES, the northward flowing warm Gulf Stream current and the cold, less saline southward flowing Labrador slope current intersect. Inter-annual variations in the path of the Gulf Stream and the flow of the Labrador shelf water influence biological processes and carbon fluxes along the entire shelf and shelf-slope frontal regions (Greene and Pershing, 2007; Schollaert et al., 2004). Furthermore, the NES is warming faster than the global average and it is predicted that long-term increases in temperature will continue (Saba et al., 2015). Associated changes in water column stability will likely alter nutrient inputs to the euphotic zone and thus affect the phytoplankton community structure and bloom dynamics in the region (Hunter-Cevera et al., 2016; Friedland et al., 2015; Hunter-Cevera et al., 2014).

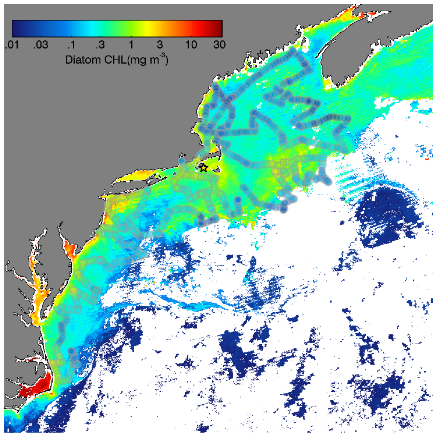

Figure 1. Diatom associated chlorophyll (Pan et al, 2011) for the Northeast Shelf from MODIS-Aqua with overlaid estimates of diatom biomass (scaled assuming C:CHL=10 for display purposes) from the Imaging FlowCytobot (provided by H. Sosik) as a semi-transparent color-coded cruise track (Nov 2014 EcoMon survey).

2.2 Regionally tuned remote sensing algorithms

Ocean color remote sensors have observed phytoplankton biomass and production on global and regional scales for over 20 years. More recently, new models and algorithms have been developed to identify phytoplankton functional types (PFTs) and size classes (PSCs) using ocean color observations (generically referred to as PFTs for the remainder of the text). Much of the effort to retrieve phytoplankton groups has been at the global scale, however a majority of these algorithms are not optimized for use in coastal and shelf regions (Mouw et al., 2017). In the NES, Pan et al. (2011; 2010) developed a pigment based chemotaxonomic method to measure PFTs (Fig.1), and Devred et al. (2011) uses phytoplankton absorption to estimate PSCs. These earlier regional efforts had limited validation data and are not tuned for the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the S-NPP and NOAA-20 satellites, thus requiring re-optimization. Our proposed work will use a much larger volume of data for algorithm optimization of the highly empirical Pan et al. (2011) method and analyze additional absorption-based to determine if they perform equally or better in the NES to the Devred et al. (2011) method. To optimize PFT algorithms for the NES and more accurately discriminate phytoplankton groups, coincident phytoplankton identification and optical observations are required (Bracher et al., 2017; Bracher et al., 2015; Mouw et al., 2017). Field sampling and data mining of existing data are essential components of the proposed research to refine and optimize the satellite algorithms spatially and temporally across the entire study region.

3. Scientific questions and objectives

The overall goal of this project is to comprehensively characterize the spatial and temporal variability of phytoplankton composition in the NES over the 20+ year ocean color remote sensing time series for operational fisheries applications.

3.1 Scientific questions

1) Considering a subset of PFT algorithms, which performs best in the NES after optimization?
2) How have phytoplankton communities in the NES changed over the satellite record?

3.2 Scientific objectives

1) Compile a comprehensive dataset to support PFT algorithm optimization by data mining existing observations and supplementing observations on planned cruises with coincident measurements of inherent and apparent optical properties, phytoplankton composition identification, and phytoplankton pigments.
2) Optimize existing PFT algorithms for use with VIIRS imagery using existing and planned observations collected in the NES study region.
3) Characterize phytoplankton composition variability over the NES with a 20+ year time series of phytoplankton composition using data from multiple sensors.
4) Incorporate satellite derived phytoplankton size class measurements into operational models and applications at the Northeast Fisheries Science Center.

4. Proposed Methodology

4.1 Objective 1- Assemble Existing Data and Field Observations

4.1.1 Existing data

Complimentary *in situ* measurements of inherent and apparent optical properties (IOPs, AOPs) along with HPLC estimates of phytoplankton community structure will be acquired from public databases including the NOAA/STAR ocean color *in situ* data repository (under development; see letter of support from P. DiGiacomo), SeaBASS, BCO-DMO and MEREDAT (Buitenhuis et al., 2012). We will also retrieve particle imaging (Sosik et al., 2018) (http://ifcb-data.whoi.edu), flow cytometry and microscopy data from similar public sources or through direct contact with authors (see letter of support from H. Sosik). Recent field efforts of particular interest include the CliVEC project (Northeast US Shelf, 2009-2012; DOI:10.5067/SeaBASS/CLIVEC/DATA001), Tara Oceans Expedition (global, 2012-present; http://ocean-microbiome.embl.de/) (Boss et al., 2013) and the NAAMES cruises (North Atlantic, 2015-2017; DOI: 10.5067/SeaBASS/NAAMES/DATA001). The CliVEC project (Hyde co-PI) collected HPLC and microscopy samples throughout the NES, however they do not include radiometric measurements and have minimal overlap with the S-NPP sensors. Tara Oceans and NAAMES collected AOP/IOP along with HPLC pigments and phytoplankton community composition via particle imaging, similar to what we are proposing here, however their region of interest did not comprehensively cover the NES.

4.1.2 Field Sampling

We will take advantage of an existing NOAA Northeast Fisheries Science Center (NEFSC) field program (see letter of support from D. Richardson) to collect continuous (flow-through) and discrete (rosette-CTD casts) inherent optical properties (IOPs) and near-surface water samples for phytoplankton pigments (analyzed using high-performance liquid chromatography, HPLC). The quarterly Ecosystem Monitoring (EcoMon) cruises cover the entire NES region (Fig. 1) over 16-18 days, sampling at 120 stratified randomly selected stations plus 35 fixed stations. Zooplankton bongo and CTD measurements are collected at all stations, while rosette-CTD casts at the fixed stations collect water samples for chlorophyll *a* [CHL] extraction and nutrients. We will participate in up to 3 cruises per year during the first 2 years of the proposed project. The ship's schedule should provide sufficient time for us to collect discrete samples at a maximum of 50 stations per cruise in addition to the continuous IOP measurements collected from the ship's flow through system. Researchers from NOAA NESDIS Center for Satellite Applications and Research (STAR) and the NES Long-Term Ecological Research (LTER) project (see letter of support from H. Sosik) will also participate on the EcoMon cruises. STAR will collect in-water and above-water water leaving radiance measurements and samples for particulate and dissolved absorption and [CHL]. The LTER collaborators will measure continuous phytoplankton imagery (Imaging FlowCytobot; Fig. 1), continuous net community production (O_2/Ar method), discrete gross primary production (triplet oxygen isotope) samples.

4.1.3 Optics

Optical observations will resolve a suite of AOPs and IOPs. AOPs, which depend on the ambient light field, will include hyper-spectral resolution (136 wavelengths) of above-water downwelling irradiance (E_s, mW cm^{-2} nm^{-1}) and water-leaving radiance (L_t, mW cm^{-2} nm^{-1} sr^{-1}). This data will be used to retrieve remote sensing reflectance (R_{rs}, sr^{-1}) for product validation and algorithm development (Mueller et al., 2003). On station, the STAR group will deploy a hyperspectral profiler (HyperOCR, Satlantic Inc.) in a multi-cast mode (D'Alimonte et al., 2013) to measure depth-resolved downwelling irradiance (E_d, mW cm^{-2} nm^{-1}) and upwelling radiance (L_u, mW cm^{-2} nm^{-1} sr^{-1}). This will allow for the retrieval of the diffuse attenuation coefficient (K_d, m^{-1}) via linear regression in addition to R_{rs} and E_s.

IOPs, which are independent of the ambient light field, will be resolved via an in-line connection with the ship's flow-through system augmented by periodic discrete sampling. Our group will be responsible for the flow-through observations, while the NESDIS STAR group will be doing the discrete sampling. In-line measurements will include a thermosalinograph, hyperspectral total absorption and attenuation (81 wavelengths) via an AC-S (WET Labs) along with multi-spectral particulate backscattering (9 wavelengths) via three BB-3's equivalent to a BB-9 (WET Labs), chlorophyll, color dissolved organic matter (CDOM) and phycoerythin fluorescence via an ECO triplet (WET Labs). The BB-3's and ECO triplet all have biofouling control through copper plates and rotating wipers. The system (Fig. 2) has been designed by Dr. Mouw's group and is currently deployed in Narragansett Bay. Similar systems have been deployed in the Gulf of Maine (Balch *et al.* 2004) and throughout the major ocean basins (Boss et al., 2009; Slade et al., 2010; Werdell et al., 2013). The ship's seawater supply will be directed through a 400 μm mesh (to exclude large particles that could clog the pump and flow-through setup) and a de-bubbler prior to flowing through the instrumentation.

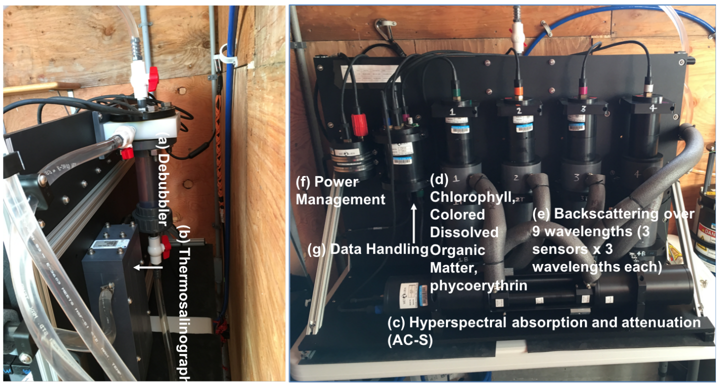

Figure 2. Flow-through system design. Seawater from the ship's intake will be passed through a de-bubbling system (a) and thermosalinograph (b). Water is then pumped through an AC-S (c), ECO-triplet with fluorometers for chlorophyll-a concentration, colored dissolved organic matter and phycoerythin (d), and three BB-3s, equivalent to a BB-9 (e), all managed by a single power management (f) and data handling (g) system.

Discrete water samples will be collected on station by the STAR group from multiple depths via Niskin bottles on the CTD rosette. These samples will be used to resolve dissolved (CDOM) and particulate (phytoplankton and non-algal) absorption following standard protocols (Mitchell et al., 2003). Particulate absorption will be measured using an integrating sphere (Röttgers et al., 2016), which accounts for light scattered during the measurement (Lohrenz et al., 2003; Lohrenz, 2000; Tassan and Ferrari, 2002). CDOM absorption will be measured using a Tidas Ultrapath multiple pathlength absorption cell. In addition to discrete samples for IOPs, the EcoMon and STAR groups will use standard protocols (Trees et al., 2003; Welschmeyer, 1994) to sample for chlorophyll *a* ([Chl]). Samples will be extracted in 90% acetone and analyzed using a calibrated Turner Designs 10-AU fluorometer. Phytoplankton pigment samples will be collected with the other discrete samples (Bidigare et al., 2003), stored frozen in liquid nitrogen while at sea and transferred to a -80°C freezer unit analysis, and sent on liquid nitrogen to either NASA Goddard's Space Flight Center or to Horn Point Laboratory Analytical Services where they will be analyzed using High-Performance Liquid Chromatography (HPLC) methods (Van Heukelem and Thomas, 2001).

4.1.4 Phytoplankton composition

The LTER project (see letter of support from H. Sosik), uses multiple approaches to determine the abundance and composition of phytoplankton and heterotrophic protists up to 200 μm in size. Discrete samples of heterotrophic bacteria and autotrophic pico- and nanoplankton are enumerated by flow cytometry (BD Accuri C6), while large nanoplankton and microplankton are quantified continuously with the Imaging FlowCytobot (IFCB, McLane Research, Inc.) (Olson and Sosik, 2007). The IFCB produces a large number of images that are automatically analyzed and assigned to taxonomic groups (Sosik and Olson, 2007; Peacock et al., 2014) and made publically available by H. Sosik (2018). Selected discrete samples are analyzed by conventional microscopy (Campbell et al., 2010; Sosik and Olson, 2007; Brosnahan et al., 2015) to identify certain taxa that are not well-resolved in IFCB images (e.g. small dinoflagellates and some *Chaetoceros* and *Pseudonitzchia* sp.).

4.1.5 Instrument Maintenance and Calibration

Optical surfaces on instruments (BB-3s, ECOfluorometer and AC-S) installed in the ship's flow-through will be cleaned daily. Pure-water calibration of both *a* and *c* channels of the AC-S will be carried out prior to system startup and following shutdown using the protocol of Twardowski et al.

(1999). All AC-S data will be corrected for changes in temperature and salinity following the procedures of Sullivan et al. (2006). Post-cruise calibration between AC-S data with coincident discrete CDOM and particulate absorption will be performed. Sensors on the BB-3s and in-line fluorometer will be "dark" calibrated at the start and end of each day by covering the optical surfaces with electrical tape and collecting data for 10 minutes. We will assess variability in "dark" backscattering as it relates to concurrent water temperature and apply appropriate offsets during data processing if additional calibration is required. In addition to the factory calibration, data from the in-line fluorometer will be calibrated against discrete [Chl] samples taken throughout the cruise.

4.1.6 Uncertainty Characterization

Uncertainty of HPLC observations will be accessed by replicate sampling and duplicate analysis of 5% of the HPLC samples and calculation of the average percent error for each pigment type. Uncertainty in *in situ* optical sensors will be expressed as the variability in time-binned data along with direct comparison to discrete measurements, where applicable. For derived field-data products from simple calculations, uncertainty will be retrieved through propagation of error. For data products derived from linear regression, error will be assessed through confidence intervals and goodness of fit considerations.

4.1.7 Data distribution

All data collected as part of this project will be submitted to the NOAA/STAR ocean color in situ data repository currently in development (see letter of support from P. DiGiacomo).

4.2 Objective 2 – Phytoplankton Functional Type Algorithm Optimization and Validation

Using the dataset generated in **Objective 1**, we will optimize existing absorption and abundance-based PFT algorithms for the NES. This includes sensitivity studies to detect shifts in composition within the sensitivity of the VIIRS radiometric capability.

4.2.1 Abundance algorithms

We will regionally optimize two abundance-based algorithms that estimate phytoplankton taxonomic composition (PTC) (Hirata et al., 2011; Pan et al., 2011) and one that estimates phytoplankton size classes (Brewin et al., 2010a). Hirata et al. (2011) estimate fractions of three PSCs and seven PTCs from empirical relationships between [Chl] and diagnostic pigments of various phytoplankton groups (pico-eukaryotes, prymnesiophytes, diatoms, prokaryotes, green algae, dinoflagellates, and cyanobacteria), based on global observations that excluded continental shelf and coastal regions. Similarly, Pan et al. (2011) use empirical relationships to derive phytoplankton pigments and a chemotaxomic assessment (Mackey et al., 1996), which analyzes the relative pigment ratios for each taxonomic group, to partition [Chl] into PTCs. An advantage of Pan et al. (2011), is that it was developed using samples collected in the NES, however the satellite validation data was prior to the launch of S-NPP. Furthermore, the phytoplankton abundance from these empirically derived approaches are not necessarily independent/decoupled with phytoplankton composition on synoptic scales.

Brewin et al. (2010a) describe the exponential functions that relate [Chl] to the fractional contribution of various PSCs.

$$[Chl]_{p,n} = C^m_{p,n}[1 - exp(-S_{p,n}[Chl])] \quad (1a) \qquad [Chl]_p = C^m_p[1 - exp(-S_p[Chl])] \quad (1b)$$

$$[Chl]_n = [Chl]_{p,n} - [Chl]_p \quad (1c) \qquad [Chl]_m = [Chl] - [Chl]_{p,n} \quad (1d)$$

where subscripts p, n and m refer to pico- (>0.2–2 µm), nano- (>2–20 µm), and microplankton (>20 µm), respectively. $C^m_{p,n}$ and C^m_p are asymptotic maximum values for the associated size classes, and $S_{p,n}$ and S_p determine the increase in size-fractionated [Chl] Brewin et al. (2015). The abundance-based algorithms are empirical, thus will be optimized by updating all of the empirical coefficients within the algorithm equation relationships with the compiled *in situ* dataset for our study region.

4.2.2 Absorption-based algorithms

We are only considering absorption-based algorithms that account for the variability of CDOM and non-algal particles (NAP). These algorithms include Mouw and Yoder (2010), Devred et al. (2011) and Bricaud et al. (Bricaud et al., 2012), which is a refinement of Ciotti and Bricaud (2006). With the exception of Devred et al. (2011), the selected algorithms stem from the theoretical underpinning that, despite the physiological and taxonomic variability, variation in spectral shape of phytoplankton absorption ($a_{ph}(\lambda)$) can be defined by changes in the dominant size class Ciotti et al.

(2002). Chlorophyll-specific phytoplankton absorption (a^*_{ph}) is weighted between normalized mean pico- ($\bar{a}^*_{ph,pico}$) and microplankton ($\bar{a}^*_{ph,micro}$) chlorophyll-specific absorption spectra

$$a^*_{ph}(\lambda) = \left[S_f \times \bar{a}^*_{ph,pico}(\lambda)\right] + \left[\left(1 - S_f\right) \times \bar{a}^*_{ph,micro}(\lambda)\right] \quad (2)$$

where S_f is a dimensionless index constrained to vary between 0 and 1, specifying the relative contributions of microplankton and picoplankton, respectively, to phytoplankton absorption. Equation 2 is based on the fact that the shape of the phytoplankton absorption spectrum flattens with increasing cell size. Ciotti and Bricaud (2006) proposed a new $\bar{a}^*_{ph,pico}$ vector, based on oceanic data and Bricaud et al. (2012) used this relationship to directly retrieve S_f, absorption due to non-algal particles and CDOM at 443 nm ($a_{dg}(443)$), and the spectral slope of $a_{dg}(\lambda)$ through an inversion model. Mouw and Yoder (2010) modify equation 2 to vary with the percentage of microplankton (S_{fm}) rather than picoplankton. They developed an optical look-up-table (LUT) that contains ranges of S_{fm}, [Chl], and $a_{dg}(\lambda)$ from which $R_{rs}(\lambda)$ is calculated from radiative transfer. They utilize satellite [Chl] and $a_{dg}(443)$ to narrow the search space within the LUT, then find the closest match between satellite $R_{rs}(\lambda)$ and LUT $R_{rs}(\lambda)$ and retrieve the associated S_{fm} from the LUT.

Optimization of the absorption-based method requires consideration of the IOPs inputs. As such, we will ensure the performance of the IOP basis vectors used have been tuned to the NES region. Semi-analytic algorithms (SAAs) provide the greatest flexibility to characterize the underlying optical variability associated with the bulk measured spectral (R_{rs} (λ)). We will use $a_{ph}(\lambda)$, $b_{bp}(\lambda)$, $a_{CDOM/NAP}(\lambda)$ output from SAAs using the Generalized IOP model (GIOP) (Werdell *et al.* 2013a) due to the ability to customize coefficients, basis vectors and optimization schemes and tune the empirical coefficients to our compiled dataset (IOCCG 2006). The output products of all GIOP iterations will be validated with a subset of the compiled dataset that are specifically reserved for validation only.

4.2.3 Sensitivity Analysis

We will assess the sensitivity of the $R_{rs}(\lambda)$ associated with each of the identified PFTs. This quantifies the how well the shape and magnitude changes in $R_{rs}(\lambda)$ associated with each of the PFTs can be detected in the presence of other optically active constituents. In brief, the sensitivity of the $R_{rs}(\lambda)$ will be compared to the change in $R_{rs}(\lambda)$ ($\Delta R_{rs}(\lambda)$) for the various PFTs at varying levels of CDOM and NAP. To do this, we will find the maximum and minimum CDOM and NAP associated with a given PFT group. The $R_{rs}(\lambda)$ for these cases will be differenced (i.e. $\Delta R_{rs}(\lambda)$) and compared with the spectral noise-equivalent radiance for VIIRS. Any $\Delta R_{rs}(\lambda)$ value found to be greater than the spectral noise-equivalent radiance will be defined as being above the sensors limit of detection. A similar approach was done to determine PFT detection capability for SeaWiFS (Mouw and Yoder, 2010).

4.2.4 Algorithm validation

Many previous characterizations of phytoplankton groups were accomplished by assigning pigments to broad phytoplankton taxonomic groups or size classes (Claustre, 1994; Jeffery *et al.* 1997; Vidussi et al., 2001). While diagnostic pigments have been used due to the extensive availability of HPLC pigments across the global ocean (Peloquin et al., 2013), there are limitations. The diagnostic pigment approach does not necessarily reflect the true size structure of the phytoplankton community as some taxonomic groups may spread over a broad size range and some pigments are shared by different taxonomic groups (Brewin et al., 2010b; Hirata et al., 2011; Devred et al., 2011). Rapid phytoplankton identification through particle imaging technologies (Olson and Sosik, 2007) now provide the ability to move beyond pigment limitations. With non-ambiguous phytoplankton identification afforded by the combination of flow cytometry, IFCB, and microscopy carried out by Sosik's group and the broad spatial and temporal coverage provided by the optical flow-through sampling proposed here, we will revisit optical relationships with phytoplankton groups. Given that HPLC pigments were used extensively in the development and validation of the existing satellite PFT algorithms (Mouw et al., 2017), we will investigate the synergy between the phytoplankton identification groupings resulting from the statistical analysis and the associated pigment suite. We will quantify how well the existing HPLC pigment relationships perform for various identified PTCs and PSCs. We will use both the HPLC pigment set and the phytoplankton identifications for the validation of the PFT imagery.

4.2.5 Uncertainty Characterization

Uncertainty in satellite remote sensing lies primarily in the applied optical relationships and performance of the atmospheric correction. The focus of this proposal is the former. Satellite product uncertainty will be gauged by matching satellite GIOP SAA output with *in situ* observations for all imagery products produced. Comparisons will include $R_{rs}(\lambda)$ and all resulting IOPs. The existing and planned observations will allow for match-ups with satellite imagery within hours of each other. The satellite PFT products will be carefully compared to both the *in-situ* phytoplankton identifications and HPLC pigments.

4.3 Objective 3 – Characterize phytoplankton composition variability

Using the optimized algorithms produced **Objective 2**, we will generate a time series of PFTs over the VIIRS satellite record and blended imagery covering the entire ocean color record (September 1997-present) to characterize the temporal and spatial variability.

4.3.1. Satellite data processing

Dr. Hyde maintains a complete dataset of Level-1A satellite data for the NES from the SeaWiFS, MODIS-Aqua, and S-NPP VIIRS sensors, and will add the NOAA-20 data once available. Data are stored at the Narragansett Laboratory on a 180 TB server with nightly back-ups and annual archives. Level-2 products including [CHL], R_{rs}, $K_d(490)$, and IOPs (using the GIOP-SAA model) are produced using the latest version of NASA's SeaDAS processing software. VIIRS data processed with SeaDAS will be compared with the Level 2 science-quality data obtained from NOAA CoastWatch (coastwatch.noaa.gov) to determine if there are inconsistencies between the processing methods. Regionally optimized PFT data will be generated for each sensor using IDL (Harris Geospatial). Evaluation of the algorithm performance is based on statistical parameters comparing the satellite-derived retrievals of R_{rs}, IOPs, phytoplankton pigments, and PFTs with the field measurements. For the match-ups, the median of a 3x3-pixel box centered on the sampling location, collected within ±3 and ±6 hours, will be used as the satellite estimate for a given parameter (Bailey and Werdell, 2006). The statistical parameters include the mean and standard deviation of the absolute percent difference root mean square error, and the R^2 and slope values from linear regression analyses of the match-ups for each sensor (Bailey and Werdell, 2006; Mannino et al., 2008).

For the long-term time-series (September 1997-present) analysis of PFTs, we will use blended Ocean Color-Climate Change Initiative (OC-CCI) products (Rrs and IOPs; https://www.oceancolour.org/). The dataset is created by band-shifting and bias-correcting MERIS, MODIS and VIIRS wavelengths to match SeaWiFS data (Grant et al., 2017). The merged the dataset creates continuous, climate-quality products that include per-pixel uncertainty estimates. OC-CCI version 3.1 extends the products to Case 2 waters and planned upcoming version will include Sentinel 3a-OLCI and potentially NOAA-20 VIIRS data (Grant et al., 2017).

4.3.2 Trends in retrieved PSC and PTC over the multi-spectral satellite record

We will conduct a time-series analysis of PFT retrievals in the study region to characterize variability over the VIIRS satellite record and blended data products covering the entire record (September 1997–present). EOF analyses will characterize differences in regional spatial patterns over time for different PFT groups (Yoder and Kennelly, 2003). To complement this analysis, we will look at interannual variability in phytoplankton community metrics, such as bloom phenology for each PFT group (Kostadinov et al., 2017) and assess long-term shifts (Friedland et al., 2015). Long-term linear trends in PFT and community metrics will be explored on a per-pixel basis using the parametric Theil-Sen approach (Barton et al., 2015) using Bayes factors (Wetzels and Wagenmakers, 2012) to assess goodness of fit. We will seek to characterize interannual variability in the seasonal cycle of the relative contribution of each phytoplankton group to overall community structure.

4.3.3 Data sharing and publication of results

Daily, monthly and annual products including dominant functional types (e.g. diatoms and dinoflagellates) and size classes (micro-, nano-, and picoplankton) will be hosted locally in netcdf format on the NEFSC ERDDAP server (http://comet.nefsc.noaa.gov/erddap/) and mirrored at NOAA Coast Watch (coastwatch.noaa.gov; see letter of support from P. DiGiacomo). Results from the time series analysis will be published in a peer-review journal. Subsequent time series updates will be available at the Northeast US Integrated Ecosystem Assessment (IEA) website (under development by the NOAA IEA program).

4.4 Objective 4 – Operational applications

The long-term PFT time series generated in ***Objective*** 3 will be incorporated into ecosystem status reporting and on-going modeling efforts at the NEFSC.

4.4.1 Ecosystem Status Reporting

Long-term management of fisheries requires a holistic, science-based approach that considers how the entire ecosystem impacts the resiliency and productivity ocean fisheries, which are critical to our economy. NOAA Fisheries Ecosystem-based Fisheries Management (EBFM) policy outlines a set of principles and guidelines to progress towards development and implementation of EBFM approaches. Ecosystem status reporting (ESR) addresses step #2, "Advancing our understanding of ecosystem processes" of the EBFM road map (NOAA, 2016). The 2009, 2012 and 2014 ESR reports (https://www.nefsc.noaa.gov/ecosys/) include analyses of phytoplankton biomass ([CHL]) and primary production of the NEFSC. Long-term trends data have been summarized in State of the Ecosystem (SOE) reports, which have been reported to the New England and Mid-Atlantic Fisheries Management Councils annually since 2014. For future ESR/SOE reports, we will evaluate the PFT time series against known regime shifts in zooplankton (Morse et al., 2017) and fish condition (Perretti et al., 2017) to determine spatial and temporal connectivity between trophic classes and the effect of changes at the base of the food web.

4.4.2 Modeling applications

The NES implementation of the Atlantis Ecosystem model (NEUS) is a fully coupled end-to-end model with distinct size class inputs for PFTs as the basis of the food web (Link et al., 2010; Link et al., 2011). The results from this proposed effort will be immediately included as forcing variables to tune food web dynamics in the NEUS model by Dr. Morse. The current version of the NEUS model uses spatially explicit initial condition values for diatoms, dinoflagellates, and picoplankton abundance, and model runs are tuned to a time series of these variables, which are currently estimated as fixed percentages of [CHL] derived from ocean color remote sensing. To include the updated PFT time series, historical hindcasts will be created to extend the time series back to 1964 based on fisheries dynamics and historical catch records. Including the updated PFT time series generated from this project will have immediate implications for fisheries management. The NEUS model is one of the primary operating models used for the creation of data used in Management Strategy Evaluation (MSE) simulation cycles. The MSE process guides the New England and Mid-Atlantic Fisheries Management Councils with respect to tradeoff evaluations for the implementation of EBFM.

The improved PFT data will be immediately incorporated into NEFSC's Fisheries Production Potential (FPP) model. FPP uses a bottom-up approach to trace energetic pathways from primary production to fishery yields (Fogarty et al., 2016). Current implementation uses estimates of microplankton and nano- plus picoplankton derived from the Pan (2011) model. Per request of the New England Fisheries Management Council, the NEFSC Ecosystem Assessment and Dynamics Branch is using this modeling approach as part of a "worked example" to determine safe and sustainable harvest levels at various trophic levels in the Georges Bank ecoregion. This implementation of the FPP model is also being used by the North Atlantic Fishing Organization – Working Group on Ecosystem Science and Assessment, an intergovernmental fisheries science and management body.

The Atlantic Marine Assessment Program for Protected Species (AMAPPS) is a comprehensive multi-agency research program that assesses the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds in the US Atlantic Ocean (http://www.nefsc.noaa.gov/psb/AMAPPS/). The purpose of this program is to inform marine resource management decisions by providing spatially explicit protected species information in an ecosystem context. AMAPPS models marine mammal distribution and abundance using numerous satellite data sources as key input parameters. The NEFSC Protected Species Branch intend to include PFTs in future assessments to improve distribution and abundance models and advance our understanding of marine mammal aggregation.

The newly established NES-LTER project will use *in situ*, modeled and remotely sensed phytoplankton composition data to understand and predict how planktonic food webs change through space and time, and how those changes impact ecosystem productivity. The updated PFT time series will provide historical and contemporary data for determining how long-term changes in the plankton community impact higher trophic levels (see letter from H. Sosik).

4.4.3 Readiness for transition to operations

Following completion of the PFT algorithm optimization and time series analysis, daily, monthly and annual PFT time series for the NES will be available for operational applications (see section 4.4). Historical and future data will be hosted on the NEFSC ERDDAP server (http://comet.nefsc.noaa.gov/erddap/) and mirrored at NOAA Coast Watch (east coast node; https://eastcoast.coastwatch.noaa.gov/). The NEUS Atlantis and fisheries production potential models currently include phytoplankton size class variables and updated PFT products will be immediately employed.

5. Education and outreach

The project supports the training and mentoring of one graduate student. Undergraduate summer researchers will be brought onto the project through the NOAA Hollings Undergraduate Scholarship (http://www.noaa.gov/office-education/hollings-scholarship) and URI Summer Undergraduate Research Fellowship in Oceanography (https://web.uri.edu/gso/education/surfo/) at no cost to the project. In addition, we will develop a presentation to be shared with the fisheries management councils to describe the importance PFTs and how we are incorporating the data in models and future State of the Ecosystem reports.

6. Relevance to program priorities

The proposed work focuses on optimization of JPSS data for operational applications and includes pathways to transition from algorithm improvement to operations. The scientific results include regionally tuned phytoplankton functional type (PFT) algorithms and a long-term analysis of spatial and temporal PFT variability in the Northeast US Shelf ecosystem. Specifically, the PFT time series produced during this project will be 1) reported in ecosystem status reports to inform fishery management decisions, 2) used in support of efforts toward ecosystem based fisheries management in food web models to test sustainable harvest levels, as well as in a full ecosystem model used for Management Strategy Evaluation, and 3) incorporated into a high-priority protected species model (see section 4.3).

7. Project management and timeline (activities by year)

The proposed work will be conducted over 3 years starting June 1, 2018 (Table 1). Hyde is responsible for overall coordination of the project including team communication, coordination with the collaborators, the HPLC analysis contract, and data distribution. Hyde will also be responsible for satellite data processing (continuous), analysis of the PFT satellite data time series (year 3), and providing PFT data to be included in operational models (year 3). Field sampling coordination (year 1-2) and laboratory analyses (year 1-3) will be done by Mouw. Mouw and a URI Masters student will lead the algorithm optimization (year 2). Morse will assist with data compilation (year 1-2), long-term data analysis (year 3), and will be responsible for incorporation of the PFT data into the NEUS Atlantis model (year 3).

Table 1.

Project milestones broken down by quarter starting June, 2018. The initials of the PI primarily responsible for each task are listed (KH-Hyde, CM-Mouw, RM-Morse, A-All).

Schedule of Milestones	2018				2019				2020				2021			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
NOAA EcoMon Cruises	-	-		CM	CM		CM	CM	CM	CM					-	-
Laboratory Analysis	-	-		CM	CM	CM	CM	CM	CM	CM	CM				-	-
Data Compilation	-	-		RM	RM	RM	RM	RM	RM	RM	RM	RM			-	-
Algorithm optimization	-	-				CM	CM	CM	CM	CM	CM	CM			-	-
Satellite data processing	-	-		KH	KH	KH	KH	KH	KH	KH	KH	KH	KH	KH	-	-
Time series analysis	-	-					KH	KH	KH	KH	KH	KH	KH	KH	-	-
ATLANTIS model	-	-					RM	RM	RM	RM	RM	RM	RM	RM	-	-
Annual reports	-	-				A				A				A	-	-
Publication writing	-	-							A	A	A	A	A	A	-	-

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8. Itemized Budget and Proposed Budget Justification

	Yr 1: June 1, 2018 - May 31, 2019			Yr 2: June 1, 2019 - May 31, 2020			Yr 3: June 1, 2020 - May 31, 2021		
R. Morse (NOAA Contract)	**Rate**	**Months**	**Total**	**Rate**	**Months**	**Total**	**Rate**	**Months**	**Total**
Salary/month	$5,375.00	3	$16,125	$5,456	3	$16,367	$5,537	6	$33,225
Overhead/month	$2,903.00	3	$8,709	$2,947	3	$8,840	$2,991	6	$17,944
Subtotal			$24,834			$25,207			$51,169
Field Sampling	**Cost/Unit**	**Units**	**Total**	**Cost/Unit**	**Units**	**Total**	**Cost/Unit**	**Units**	**Total**
GF/F Filters (100/box)	$100.00	2	$200	$100.00	2	$200			$0
Filter Storage Capsules (1000/bag)	$260.00	1	$260	$260.00	1	$260			$0
Gloves (various sizes)	$10.00	4	$40	$10.00	4	$40			$0
HPLC Analysis (Horn Point)	$81.00	180	$14,580	$81.00	180	$14,580			$0
Shipping Costs	$20.00	3	$60	$20.00	3	$60			$0
Subtotal			$15,140			$15,140			$0
Equipment and Software	**Cost/Unit**	**Units**	**Total**	**Cost/Unit**	**Units**	**Total**	**Cost/Unit**	**Units**	**Total**
Replacement server hard drives (10 TB)	$450.00	5	$2,250	$450.00	5	$2,250	$450.00	5	$2,250
IDL software maintainence license	$1,800.00	1	$1,800	$1,800.00	1	$1,800	$1,800.00	1	$1,800
Subtotal			$4,050			$4,050			$4,050
Travel (itemized below)	**Cost**	**Travelers**	**Total**	**Cost**	**Travelers**	**Total**	**Cost**	**Travelers**	**Total**
JPSS Meeting	$600.00	1	$600	$600.00	1	$600	$600.00	1	$600
IOCS Meeting	$2,200.00	1					$2,200.00	1	$2,200
ICES/OCS Meeting				$2,800.00	1	$2,800	$2,800.00	1	$2,800
Subtotal			$600			$3,400			$5,600
NEFSC Subtotal			$44,624			$47,797			$60,819
URI Subtotal (separate itemized budget)			$104,631			$118,386			$76,953
Subtotal by Year			**$149,255**			**$166,183**			**$137,772**
Total									**$453,210**

PROPOSAL BUDGET

Optimization of phytoplankton functional type algorithms for VIIRS ocean color data in the Northeast U.S. Continental Shelf Large Marine

Lead PI: Colleen Mouw

June 1, 2018 - May 31, 2021

Agency: NOAA (Joint Polar Satellite System, Proving Ground and Risk Reduction)							**Year 1** 6/1/18-5/31/19	**Year 2** 6/1/19-5/31/20	**Year 3** 6/1/20-5/31/21	**Total Request**
A. SENIOR PERSONNEL										
		Base Salary	CAL	ACAD	SUMR					
1 Mouw, Colleen	(Sum)	87,418			0.5,0.5,0.5		5,002	5,152	5,307	15,461
2	(Acad)						-	-	-	-
3	(Sum)						-	-	-	-
4	(Acad)						-	-	-	-
8	(Sum)						-	-	-	-
B. OTHER PERSONNEL										
1 Post Doctoral Associates									-	-
2 Marine Research Specialist (Audrey Ciochetto)		71027	3,2,1				17,757	12,193	6,279	36,229
3 Clerical Technical								-	-	-
4 Graduate students, A/Y (start fall 2019)		Level 1					19,170	19,937	10,368	49,475
Graduate students, Summer		Level 1						14,913	15,506	30,419
5 Undergraduate students, A/Y (40 hrs/wk)										-
Undergraduate students, Summer (40 hrs/wk)										-
Total Salaries & Wages							41,929	52,195	37,460	131,584
C. FRINGE BENEFITS										-
MRS TBD FAM PLAN 58.79% incl.3% incr.							10,752	7,605	4,034	22,391
Faculty Academic Yr.										-
Post Doc							-	-	-	-
GRA (A/Y) 12.85%, 13.36%, 13.9%							2,463	2,664	1,441	6,568
GRA (summer) 7.65%							-	1,141	1,186	2,327
Undergraduate Fringe (summer)							-	-	-	-
Total Fringe Benefits							13,216	11,409	6,661	31,286
Total Salaries & Fringes							55,145	63,604	44,121	162,871
D. Equipment over ($5,000)										-
E. Travel Domestic							600	3,400	600	4,600
Travel Foreign										-
Total Travel							600	3,400	600	4,600
F. Participant Support Costs										-
Stipends										-
Travel										-
Subsistence										-
Other										-
Total Participant Support Costs							-	-	-	-
G. Other Direct Costs										-
1. Materials & Supplies							2,955			2,955
2. Publication Costs										-
3. Computer										-
4. Field equipment Shipping									-	
5. Sample shipping									-	
6. Instrument Calibration										
7. Subaward										-
Sub 1<25000										-
Sub 1>25000										-
Sub 2<25000										-
Sub 2>25000										-
Sub 3<25000										-
Sub 3>25000										-
10. Other Tuition (Scholarships)							14,527	15,534	8,306	38,367
Total Other Direct Costs							17,482	15,534	8,306	41,322
H. Total direct costs							73,227	82,538	53,027	208,792
Total Modified Direct Costs							58,700	67,004	44,721	170,426
I. Indirect Cost Rate					Rate 53.5%		31,404	35,847	23,926	91,178
J. Total amount requested							104,631	118,386	76,953	299,970

Budget Justification
Northeast Fisheries Science Center
We request a total amount of $453,210 to fund the research outlined in the project narrative. $299,970 of the total would be awarded to University of Rhode Island (URI) through a Memorandum of Agreement between NOAA Office of Oceanic and Atmospheric Research – Office of Exploration and Research and the URI. Separate budget tables and justifications are provided for NEFSC and URI.

Personnel

Dr. Hyde (PI) is a NOAA federal employee and will be responsible for overall project management, satellite data processing, data distribution, and working with collaborators and end-users. No funds are requested for salary or benefits. The NEFSC in-kind contribution for Dr. Hyde is ~$4000 each year.

Contractual: Dr. Morse (co-PI) is a current NEFSC contractor through Integrated Statistics Inc. He will work with Dr. Hyde on the long-term analysis and be responsible for the Atlantis modeling efforts. Salary and contractor overhead costs are requested to cover a total of 12 months (3 months in years 1 and 2, 6 months in year 3). Monthly salary and overhead costs for year 1 are $5375 and $2903 respectively. A cost of living increase of 1.5% were factored in for years 2 and 3 for a total of $101,210 for the duration of the project.

Travel

Funds are requested for Dr. Hyde to attend the annual NOAA JPSS ocean color meeting each year ($600/year). Travel for Dr. Hyde to present results and collaborate with experts in the field at one national (e.g. 2020 Ocean Sciences Meeting (OS)) or international meeting (International Council for the Exploration of the Sea (ICES) Annual Science Conference or the International Ocean Color Science Meeting (IOCS)) is requested for each year. The location of future meetings has yet to be determined so estimated costs are based on travel to a major city in Europe for international meetings and the west coast of the US for national meetings. The most appropriate meetings to present our work will be decided when locations and sessions are announced in the next three years. Cost estimates are based on 2018 federal contract carrier fares, per diem lodging, per diem meals and incidentals, miscellaneous travel expenses such as parking, ground transportation, and luggage fees, and meeting registration fees. Additional funds are requested for Dr. Morse to attend one international meeting during year 3 to present project results.

Travel Breakdown	Traveler	# Nights	Airfare	Hotel	Per Diem	Reg.	Misc	Total
2018 JPSS Meeting - College Park, MD	K. Hyde	1	$220	$200	$105	$0	$75	$600
2019 International Ocean Color (IOCS) Meeting - TBD	K. Hyde	5	$600	$1,000	$450	$0	$150	$2,200
2019 JPSS Meeting - College Park, MD	K. Hyde	1	$220	$200	$105	$0	$75	$600
2020 Ocean Sciences Meeting (OSM) - San Diego, CA	K. Hyde	5	$600	$1,000	$450	$600	$150	$2,800
2020 JPSS Meeting - College Park, MD	K. Hyde	1	$220	$200	$105	$0	$75	$600
2020 ICES Annual Science Conference - TBD	R. Morse	5	$600	$1,000	$450	$600	$150	$2,800
2021 International Ocean Color (IOCS) Meeting - TBD	K. Hyde	5	$600	$1,000	$450	$0	$150	$2,800

Field Supplies and Analysis

$500 is requested each year for field supplies such as glass fiber filters, filter storage capsules, and gloves to collect HPLC pigment samples. HPLC pigment samples will be sent to Horn Point Laboratory (https://www.umces.edu/analytical-services). This lab provides high quality analytical services and uses the same HPLC methodology as the NASA Goddard Space Flight Center ocean biogeochemistry laboratory.

Equipment

Funds are requested for IDL software maintenance ($1800) contract and replacement server hardware ($2250) each year.

University of Rhode Island
We request a total dollar amount of $299,970 to fund the research outlined in the project narrative. The University of Rhode Island has a Memorandum of Agreement with the NOAA Office of Exploration and we intend to use this as a funding vehicle for this project.

<u>Personnel</u>
The following individuals have been identified as key personnel to this proposal:
Senior Personnel:
Colleen Mouw, PI, 0.5 month summer support in all years. Dr. Mouw is a full-time (9 month) tenure-track assistant professor at the Graduate School of Oceanography and will be responsible for overseeing the flow through system data collection and processing, and satellite phytoplankton functional type algorithm optimization and validation. She will supervise the efforts of the Marine Research Specialist and advise the full-time graduate student. She will work closely with all team members to link the observations with imagery optimization, interpretation of the imagery time series and overall synthesis activities.

Other Personnel:
Audrey Ciochetto, Marine Research Specialist (MRS) V, 3 months in year 1, 2 months in year 2, and 1 month in year 1. The MRS will collate all historical and ongoing data collection, ensure instrument maintenance and aid in field efforts as needed. She will aid in all analysis of optical characterization with field data and imagery.
Graduate Student, 1.0 support, fall 2019 – fall 2020, will work directly with Mouw and Ciochetto to synthesize the data stream from the flow through system, aid in field efforts and work closely with Mouw on algorithm optimization and validation.

<u>Fringe Benefits</u>
Fringe rates are dependent on employee classification (which is listed under the Personnel section). Fringe rates are charged 58.79% for MRS V with a 3% incremented increase each year. Fringe rates for the fully supported graduate student is 12.85%, 13.36%, and 13.9% in years 1, 2, and 3, respectively and 7.65% in summer months. No fringes are charged on faculty summer salary.

<u>Travel</u>
The University of Rhode Island reimburses reasonable actual hotel costs. Per diem meal expenses are reimbursed based on the Federal government rates for the location. In all years, one trip for one person is requested to attend the annual NOAA JPSS meeting in Washington D.C. In year 2, one trip for 1 person is requested to attend the 2020 Ocean Sciences meeting.

<u>Other Direct Costs</u>
Field supplies $2,955 are requested in year 1 to cover the costs of fitting the flow through system to the ships seawater intake system (tubing and pump) and for replacement of the AC-S bulb at the end of the first year.

Tuition: $14,527, $15,534 and $8,306 for years 1, 2 and 3, respectively are requested for tuition for the fully supported graduate student.

<u>Indirect Cost</u>
Currently at 53.5%, the on-campus organized research indirect cost rate is directly negotiated with the U.S. Department of Health and Human Services. A copy of the rate agreement can be found at: http://web.uri.edu/researchecondev/files/indirectcostoverheadrates.pdf

9. Current and Pending Support

K. Hyde

Current support:

"Synergistic Impacts of Population Growth, Urbanization, and Climate Change on Watersheds and Coastal Ecology of the Northeastern United States"; R. Najar, lead PI; NASA Ocean Biology and Biogeochemistry (POC – Paula Bontempi; paula.s.bontempi@nasa.gov; 202 358-1508); NASA Contract Number NNX14AF93G; 10/2016 - 09/2018; $132,241; 1 month/year.

Pending support:

None

C. Mouw

Current support:

"Assessing Ecosystem Vulnerability to Climate Change through Optics, Imagery and Models"; S. Dutkiewicz, (lead PI), Mouw (Co-I), M. Follows; NASA Ocean Biology and Biogeochemistry (POC – Paula Bontempi; paula.s.bontempi@nasa.gov; (202) 358-1508); NASA Contract Number NNX16AR47G; 07/01/2016 – 06/31/2019; $743,668; 1 month/year.

"Continuation and Enhancement of MPOWIR"; S. Legg (lead PI), C. Mouw (Co-PI); NSF Physical Oceanography (POC - Eric Itsweire; eitsweir@nsf.gov; (703) 292-7593); NSF Contract Number OCE-1356212; 4/1/2014 – 3/31/2018; $430,578; 1 month/year.

"Further Continuity and Enhancement of MPOWIR" C. Mouw (lead PI), S. Legg (Co-PI); NSF Physical Oceanography (POC - Eric Itsweire; eitsweir@nsf.gov; (703) 292-7593) 4/1/2018 – 3/1/2022; $511,544; 1 month/year.

"Parameterizing spectral characteristics of optically active constituents in inland water for improved satellite retrievals" C. Mouw (lead PI), S. Effler, Z. Lee (Co-Is); NASA Water and Energy Cycle (POC - Jared Entin; jared.k.entin@nasa.gov; (202) 358-0275), NASA Contract Number NNX14AB80G; 1/1/2014 – 12/31/2019, $867,440; 1 month/year.

"Cells to Satellite: Imaging Rhode Island Harmful Algal Blooms"; C. Mouw (lead PI) and M. Omand (Co-I); Rhode Island Sea Grant (POC - Alan Desbonnet; aland@uri.edu; (401) 874-6813); 2/1/2018 – 1/31/2020; $297,872; 0.5 month in year 1, 1 month in year 2.

Pending support:

Exploration, Research, and Identification of Emerging HABs (ERIE HABs)"; Rowley, D. (lead PI) A. Slitt, B. Jenkins, J. Swift, M. Bertin, C. B. Mouw (co-I), N. Rohr; NSF and NIEHS Centers for Oceans and Human Health 3: Impacts of Climate Change on Oceans and Great Lakes, 4/1/2018 – 3/31/2023, $6,723,952; 1 month/year.

R. Morse

Current support:

None

Pending support:

None

Kimberly J. W. Hyde
NOAA/National Marine Fisheries Service/Northeast Fisheries Science Center
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Telephone: (401) 782-3226 E-Mail: kimberly.hyde@noaa.gov Fax: (401) 782-3201

Education

Ph.D.	University of Rhode Island	Biological Oceanography	2006
M.S.	Creighton University	Environmental & Atmospheric Science	2000
B.S.	Creighton University	Biological Sciences	1998

Research and Professional Experience

2009-Present	Operations Research Analyst, NOAA/Northeast Fisheries Science Center
2006-2009	Research Oceanographer, Integrated Statistics Contractor for NOAA/NEFSC
2000-2006	Graduate Research Assistant, URI/Graduate School of Oceanography
2004-2005	Graduate Teaching Fellow, URI/Graduate School of Oceanography
1999-2000	Graduate Research and Teaching Assistant, Creighton University

Recent and Relevant Publications

Friedland, K., C. Mouw, R. Asch, A. Ferreira, S. Henson, **K. Hyde**, R. Morse, A. Thomas, D. Brady, 2017, Phenology and time series trends of the dominant seasonal phytoplankton bloom across global scales. Global Biology and Biogeography, *in press*.

Rosenberg, A., K. Kleisner, J. Afflerbach, S. Anderson, M. Dickey-Collas, A. Cooper, M. Fogarty, E. Fulton, N. Gutiérrez, **K. Hyde**, E. Jardim, O. Jensen, T. Kristiansen, C. Longo, C. Minte-Vera, C. Minto, I. Mosqueira, G. Osio, D. Ovando, E. Selig, J. Thorson, J. Walsh, Y. Ye, 2017. Applying a New Ensemble Approach to Estimating Stock Status of Marine Fisheries Around the World. Conservation Letters, 1-9.

Fogarty, M., A. Rosenberg, A. Cooper, M. Dickey-Collas, E. Fulton, N. Gutiérrez, N., **K. Hyde**, K. Kleisner, T. Kristiansen, C. Longo, C. Minte-Vera, C. Minto, I. Mosqueira, G. Osio, D. Ovando, E. Selig, J. Thorson, Y. Ye, 2016. Fishery production potential of large marine ecosystems: A prototype analysis. Environmental Development 17, Supplement 1, 211-219.

Richards, R., J. O'Reilly, **K. Hyde**, 2016. Use of satellite data to identify critical periods for early life survival of northern shrimp in the Gulf of Maine. Fisheries Oceanography 25, 306-319.

Oviatt, C., L. Smith, M. McManus, **K. Hyde**, 2015. Decadal Patterns of Westerly Winds, Temperatures, Ocean Gyre Circulations and Fish Abundance: A Review. Climate 3, 833-857.

Saba, V.S., **K. Hyde**, N. Rebuck, K. Friedland, J. Hare, M. Kahru, M. Fogarty, 2015. Physical associations to spring phytoplankton biomass interannual variability in the U.S. Northeast Continental Shelf. Journal of Geophysical Research: Biogeosciences, 2014JG002770.

Mannino, A., M. Novak, S. Hooker, **K. Hyde**, D. Aurin, 2014. Algorithm development and validation of CDOM properties for estuarine and continental shelf waters along the northeastern U.S. coast. Remote Sensing of Environment 152, 576-602.

Wilson, C., C. Chen, C. Clark, P. Fanning, M. Forget, K. Friedland, E. Howell, C. Hu, C., **K. Hyde**, D. Kobayashi, A. Longhurst, B. Monger, J. Morales, D. Pendleton, A. Pershing, T. Platt, J. Polovina, N. Record, S. Sathyendranath, K. Sherman, L. Woodard, 2009. Remote Sensing Application to Marine Resource Management, in: M. Forget, V. Stuart, T. Platt, T. (Eds.), Remote Sensing in Fisheries and Aquaculture. IOCCG, Dartmouth, Canada, pp. 43-56.

Colleen B. Mouw
Assistant Professor, University of Rhode Island
Graduate School of Oceanography, 215 South Ferry Road, Narragansett, RI
cmouw@uri.edu; 401-874-6506; http://www.mouwlab.com

Education/Training

Western Michigan University	Biology (*cum laude*)	B.S.	2000
University of Rhode Island	Oceanography	M.S.	2003
University of Rhode Island	Oceanography	Ph.D.	2009
University of Wisconsin-Madison	Postdoctoral Research Associate	2009-2010	

Research and Professional Experience

2016 – present	*Assistant Professor*, University of Rhode Island
2012 – 2016	*Assistant Professor*, Michigan Technological University
2010 – 2012	*Assistant Researcher*, University of Wisconsin-Madison
2001 – 2009	*Graduate Research Assistant*, University of Rhode Island
2004 – 2006	*Technical Associate*, University of Massachusetts Dartmouth
2000 – 2001	*Field Scientist*, Kieser & Associates

Professional Activities
Co-Chair, MPOWIR (Mentoring Physical Oceanography Women to Increase Retention)
NASA Earth and Science Advisory Committee member
Member of IOCCG working group, Ocean Colour Applications for Biogeochemical, Ecosystem and Climate Modeling
Instructor, Graduate Writing in Marine and Environmental Sciences, General Oceanography, Aquatic Remote Sensing

Selected Publications (* denotes advised student)
*Grunert, B., **C.B. Mouw**, A. Ciochetto (2017) Characterizing CDOM Spectral Variability Across Diverse Regions and Spectral Ranges. *Global Biogeochemical Cycles,* 10.1002/2017GB005756.
Mouw, C.B., N. Hardman-Mountford, S. Alvain, A. Bracher, R. Brewin, A. Bricaud, A. Ciotti, E. Devred, A. Fujiwara, T. Hirata, T. Hirawake, T. Kostadinov, S. Roy, J. Uitz (2017) A Consumer's Guide to Satellite Remote Sensing of Phytoplankton Groups in the Global Ocean, *Frontiers in Marine Science*, 4:41, 10.3389/fmars.2017.00041.
Mouw, C.B., A. Barnett, G.A. McKinley, L. Gloege, D. Pilcher (2016) Phytoplankton Size Impact on Export Flux in the Global Ocean, *Global Biogeochem. Cycles*, 30, 10.1002/2015GB005355.
Mouw, C.B., A. Barnett, G.A. McKinley, L. Gloege, D. Pilcher (2016) Global Ocean Particulate Organic Carbon Flux Merged with Satellite Parameters. *Earth System Science Data*, 8: 531-541, 10.5194/essd-8-531-2016.
*Trochta, J.T., **C.B. Mouw**, T. Moore (2015) Remote sensing of physical cycles in Lake Superior using a spatial-temporal analysis of optical water typologies. *Remote Sensing Environ.*, 171: 149-161, 10.1016/j.rse.2015.10.008.
Mouw, C.B., S. Greb, D. Aurin, P. DiGiacomo, Z.-P. Lee, M. Twardowski, C. Binding, C. Hu, R. Ma, T. Moore, W. Moses, S. Craig (2015) Aquatic color radiometry remote sensing of coastal and inland waters: Challenges and recommendations for future satellite missions. *Remote Sensing of Environ.*, 160: 15-30, 10.1016/j.rse.2015.02.001.

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Education:

Ph.D.	Old Dominion University	Biological Oceanography	2011
B.S.	Eckerd College	Marine Science	2003

Appointments:

2014-Present Research Scientist, Integrated Statistics contractor for NOAA NEFSC
2012-2013 Postdoctoral Fellow, University of Rhode Island Graduate School of Oceanography
2011-2012 Postdoctoral Researcher, Old Dominion University / Hampton Road Sanitation District
2003-2011 Graduate Research Assistant, Old Dominion University
2002-2003 Harmful Algal Bloom Research Staff, Florida Fish and Wildlife Research Institute

Recent and Relevant Publications:

Friedland, K., C. Mouw, R. Asch, A. Ferreira, S. Henson, K. Hyde, **R. Morse**, A. Thomas, D. Brady. 2017. Phenology and time series trends of the dominant seasonal phytoplankton bloom across global scales. Global Biology and Biogeography, *in press*.

Friedland, K. D., N. R. Record, R. G. Asch, T. Kristiansen, V. S. Saba, K. Drinkwater, S. Henson, R. T. Leaf, **R. E. Morse**, D. G. Johns, S. I. Large, S. Hjøllo, J. A. Nye, M. A. Alexander, and R. Ji. 2016. Seasonal phytoplankton blooms in the North Atlantic linked to the overwintering strategies of copepods. Elementa: *Science of the Anthropocene* 4: 000099 doi: 10.12952/journal.elementa.000099

Perretti, C. T., M. Fogarty, K. Friedland, J. Hare, S. Lucey, R. McBride, T. Miller, **R. Morse**, L. O'Brien, J. Pereira, L. Smith, and M. Wuenschel. 2017. Regime shifts in fish recruitment on the Northeast U.S. continental shelf. Marine Ecology Progress Series 574: 1-11.

Morse, R. E., K. Friedland, D. Tomassi, C. Stock, and J. Nye. 2017. Distinct zooplankton regime shift patterns across ecoregions of the U.S. Northeast continental shelf Large Marine Ecosystem. Journal of Marine Systems 165: 77-91.

Morse, R. E., H. G. Marshall, T. A. Egerton, and M. R. Mulholland. 2014. Phytoplankton and nutrient dynamics in a tidally dominated eutrophic estuary: daily variability and controls on bloom formation. Marine Ecology Progress Series 503: 59-74.

Egerton, T. A., **Morse, R. E.**, Marshall, H. G., and M. R. Mulholland. 2014. Emergence of algal blooms: the effects of short-term variability in water quality on phytoplankton abundance, diversity, and community composition in a tidal estuary. Microorganisms 2: 33-57.

Morse, R. E., M. R. Mulholland, W. S. Hunley, S. Fentress, M. Wiggins, and J. L. Blanco-Garcia. 2013. Controls on the initiation and development of blooms of the dinoflagellate *Cochlodinium polykrikoides* Margalef in lower Chesapeake Bay and its tributaries. Harmful Algae 28: 71-82.

Tang, Y. Z., L. Kong, **R. E. Morse**, and M. J. Holmes. 2012. First report of a bloom-forming *Takayama acrotrocha* (Dinophyceae) from tropical coastal waters of Singapore. Journal of Phycology 48: 455-466.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Narragansett Laboratory
28 Tarzwell Drive
Narragansett, Rhode Island 02882

Kimberly Hyde
NOAA National Marine Fisheries Service
Northeast Fisheries Science Center
28 Tarzwell Drive
Narragansett, RI 02882

Dear Dr. Hyde,

I am writing to acknowledge I am identified as a collaborator for the research project entitled **"Optimization of phytoplankton functional type algorithms for VIIRS ocean color data in the Northeast U.S. Continental Shelf Large Marine Ecosystem"** in response to the Joint Polar Satellite System – Proving Ground and Risk Reduction Program solicitation. I intend to carry out all responsibilities identified for me in this proposal if it is selected for funding.

The Climate and Oceans Branch of the Northeast Fisheries Science Center is pleased to support your proposal. We conduct four dedicated research vessel surveys each year on the Northeast U.S. continental shelf during the winter, late spring, late summer and late autumn. The purpose of these surveys is to monitor the shelf ecosystem and to detect temporal changes in various parameters that affect living marine resources. Our measurements include temperature, salinity, nutrients, phytoplankton fluorescence, zooplankton and ichthyoplankton. We are very interested in your proposed work since it will measure parameters that are not currently measured as part of our program.

We can accommodate your work on our four dedicated research surveys in 2018, 2019 and 2020. We anticipate you will be able to sample up to 70 of our 120 stations during these cruises. We can provide bunk space for one researcher, access to water samples collected by the CTD rosette, and the ship's flow-through system will be available for your instrumentation. We use this system for underway temperature, salinity, fluorescence, discrete chlorophyll and salinity samples, and an Imaging FlowCytobot (maintained by the Woods Hole Oceanographic Institute). Finally, we will provide you with all of the data collected on the cruises to provide context for your measurements. You will need to provide all of your own equipment, with the exception of that listed above.

The caveat is that the continuation of these surveys and the level of effort are dependent on the annual appropriation of funds to NOAA by Congress and further allocation of funds and shiptime from the NEFSC to the Climate and Oceans Branch. A decrease in our level of support from NOAA or NEFSC could impact our ability to assist your project. Also, although 70 stations per cruise is the target, this is dependent on good weather and functioning equipment. Our Chief Scientist will work with your lead scientist when necessary to revise the sampling plan in response to weather and equipment problems.

Again, we are very interested in supporting your work and wish you success in obtaining funding for your proposal.

Sincerely,

David E Rich

David Richardson
Acting Climate and Oceans Branch Chief

Woods Hole Oceanographic Institution

Heidi M. Sosik, *Senior Scientist*
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18 January 2018

Kimberly Hyde
NOAA Northeast Fisheries Science Center
28 Tarzwell Drive
Narragansett, RI 02882

Dear Kim,

Thank you for sharing information about your exciting proposal for the research project entitled "Optimization of phytoplankton functional type algorithms for VIIRS ocean color data in the Northeast U.S. Continental Shelf Large Marine Ecosystem" in response to the Joint Polar Satellite System – Proving Ground and Risk Reduction Program solicitation. I understand that I am identified as a collaborator on this project and confirm that I intend to carry out all responsibilities identified for me in the proposal, if it is selected for funding.

The proposed project to optimize phytoplankton functional types complements our newly established Northeast US Shelf Long-term Ecological Research Site (NES-LTER). The goal of the NES-LTER is to understand and predict how planktonic food webs change through space and time, and how those changes impact ecosystem productivity. As part of the NES-LTER observational program, we are collecting continuous phytoplankton composition and optical measurements at the Martha's Vineyard Coastal Observatory and on upcoming NOAA Ecosystem Monitoring cruises. These phytoplankton data are publically available through our IFCB Dashboard (http://ifcb-data.whoi.edu/) and will complement additional data collected by NOAA for validation and optimization of remote sensing algorithms. By collaborating with you, we have an exciting opportunity to leverage our NES-LTER supported observations. The concurrent measurements of phytoplankton images from our Imaging FlowCytobot instruments (NES-LTER) and inherent optical properties from Dr. Mouw's inline system (your project) will provide us a unique opportunity to match the phytoplankton community composition and their optical properties.

Phytoplankton composition is a critical element for understanding the planktonic food web and satellite remote sensing provides us historical and contemporary data for determining how long-term changes effect higher trophic levels. On behalf of the NES-LTER research team, I want to convey strong support for your proposed work to improve the phytoplankton functional type measurements. I look forward to collaborating with you to study the Northeast US Shelf ecosystem and wish you success in pursuit of funding.

Sincerely,

Heidi M. Sosik

Heidi M. Sosik
Senior Scientist
NES-LTER Lead Principal Investigator

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Center for Satellite Applications and Research
Satellite Oceanography and Climatology Division – E/RA3
5830 University Research Court
College Park, Maryland 20740

18 January 2018

Dr. Kimberly J. W. Hyde
NOAA/NMFS/NEFSC
Narragansett Laboratory
28 Tarzwell Drive
Narragansett, RI 02882

Dear Dr. Hyde (Kim),

As Manager of the NOAA CoastWatch/OceanWatch Program (hereafter CoastWatch), I am writing in strong support of your work on Phytoplankton Functional Types (PFTs) that is being proposed to the current JPSS Proving Ground Risk Reduction (PGRR) call. As we have discussed, CoastWatch is in the process of developing an *in situ* data repository for observations relating to ocean satellite validation. We are currently building up the database for ocean color. The broadly desired "easy public access" through the CoastWatch data portal will take some time, but we will work with you to share relevant datasets for your region and for the timeframe that we have available.

CoastWatch also requests that any *in situ* data you collect in support of your Phytoplankton Functional Type satellite product development be contributed to our repository when they are ready for public release.

Finally, we hope that you will consider CoastWatch as a part of your plans for the pathway to operations. CoastWatch is very interested in distributing your experimental results so that our broad user base can benefit from this most important activity. Best of luck with your proposal.

Veronica Lance, NOAA CoastWatch/OceanWatch Program Scientist, will serve as your point of contact. Her contact information is 301-683-3319 (phone); her email is veronica.lance@noaa.gov.

Sincerely,

Dr. Paul M. DiGiacomo
Chief, Satellite Oceanography and Climatology Division
CoastWatch/OceanWatch Program Manager

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