NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH16ZDA001N-OBB
A. 3 Ocean Biology and Biogeochemistry

The National Aeronautics and Space Administration (NASA) solicited proposals addressing the research needed to begin Phase I of the EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) field campaign – a large-scale field campaign that will provide critical information for quantifying the export and fate of upper ocean net primary production (NPP) from satellite observations. The overarching goal of EXPORTS is to develop a predictive understanding of the export and fate of global ocean primary production and its implications for the Earth's carbon cycle in present and future climates. Proposals were requested for research investigations in three main research areas:

1. Development and Analysis of Remote Sensing Data Products,
2. Collection and Analysis of Field-based (*in situ*) Data, and
3. Development, Incorporation and Analysis of Data Assimilation Experiments and Models.

In addition, the EXPORTS Science Lead position was also competed as part of the solicitation.

NASA received a total of 49 Step-2 proposals in response to this program element in the omnibus Research Opportunities in Space and Earth Science, of which 11 were selected by the agency. In addition, two proposals were identified as 'selectable'. The "Selectable" proposals are not listed here, but the posting will be updated if these proposals are moved in to the "Selected" category. The total funding to be provided by NASA for the selected investigations is approximately $15.8 million over four years. The investigations recommended by NASA are listed below and include the Principal Investigator, institution, project title, and a project summary; co-investigators are not listed here.

Michael Behrenfeld/Oregon State University
First Steps - Linking Remotely-Detectable Optical Signals, Photic Layer Plankton Properties, and Export Flux
16-OBB16_2-0002

The research project proposed here is focused on three overarching hypotheses regarding export fluxes from the upper ocean:

Hypothesis #1: Ratios of bulk photic layer plankton properties (e.g., phytoplankton:total particulate carbon ratio, phytoplankton division:accumulation ratio, community composition ratios, etc) can improve estimates of export compared to any single property alone.

Hypothesis #2: For a given combination of bulk properties, variability in the export fraction can be related to details of plankton community composition.

Hypothesis #3: Key bulk and compositional properties of the upper ocean regulating the export fraction can be directly linked to optical properties retrievable from remote sensing.

This project addresses EXPORTS Science Question 1 (SQ1): How do upper ocean ecosystem characteristics determine the vertical transfer of organic matter from the well-lit surface ocean? Our study will evaluate how plankton community properties govern organic matter export and thus is particularly relevant to Subquestion 1a of SQ1. Our characterizations of plankton communities will also contribute critical information for addressing Subquestion 1b and 1c of SQ1. While EXPORTS Science Question 2 (SQ2) is primarily focused on vertical organic matter transfer below the photic zone, our project will contribute significantly to Subquestions 2b and 2d of SQ2, as these two Subquestions address linkages between photic layer community properties (which we will measure) and processes occurring at depth. With respect to EXPORTS Program Elements, our project primarily contributes to (1) 'Phytoplankton and Microbes' (2) 'Zooplankton', and (3) 'Optics', but will also make contributions to Elements (4) 'Export' and (5)' Bulk Biogeochemical Stocks'

We are requesting support for direct participation in the EXPORTS field campaigns and will provide a diverse array of measurements characterizing: (1) phytoplankton biomass (i.e., carbon stocks), composition, physiology, and productivity, (2) zooplankton stocks, composition, and grazing rates, and (3) continuous surface layer and station-specific water-column optical properties. For each of these properties, we are proposing multiple measurement approaches to provide a quantitative measure of uncertainty. We envision our suite of measurements to contribute significantly to supporting other independent EXPORTS field teams by providing key information on the 'first steps' of export - i.e., plankton community composition, production, and distribution within the photic layer. We envision our science investigation to contribute significantly to answering the overall questions of the EXPORTS program. We are proposing a 3 year project.

Ken Buesseler/Woods Hole Oceanographic Institution
Elucidating Spatial and Temporal Variability in the Export and Attenuation of Ocean Primary Production Using Thorium-234
16-OBB16_2-0031

The primary goal of the Exports Processes in the Ocean from RemoTe Sensing (EXPORTS) Program is to develop a predictive mechanistic understanding of the export and fate of fixed carbon (C) from global ocean primary production. Inherent in these predictions is the need to reduce uncertainties in C export and to develop models that facilitate future C export predications across a variety of spatial and temporal scales. The first phase includes large-scale field campaigns using remote sensing, autonomous platforms and process-level studies to build upon current knowledge. As such, critical components to the EXPORTS Program are quantitative measurements of sinking particle fluxes and their attenuation at scales similar to the physical and biological processes that influence fixed C export.

We propose using the particle-reactive tracer, thorium-234 (half-life = 24. 1 d) to quantify the spatio-temporal variability in particle flux from the well-lit surface layer, and its attenuation with depth below. The disequilibrium in 234Th from its soluble parent, uranium-238, provides quantitative information on where particle export and remineralization occurs. We will collect an unprecedented set of 234Th profiles (≈60) to obtain a 3D time-series of particle export and remineralization rates over meso- (~ 10 km) and submesoscales (~ 1 km).

The link from 234Th to C flux is based upon determining the ratio of particulate 234Th to C (will work for nitrogen, biogenic silica and particulate inorganic C) measured on depth resolved profiles of size-fractionated particles (>1 to 50-100 μm range) collected using in-situ pumps (subsamples will be shared). We will combine 234Th data with satellite products and results from a 3D high-resolution coupled physical-biogeochemical model with 234Th dynamics to produce synthesized flux data products.
The underlying hypothesis of EXPORTS is that the export and fate of net primary production (NPP) can be quantified by knowing the characteristics of surface ocean ecosystems, thereby linking biotic processes with remotely sensed properties. Our study is directly related to the first 2 EXPORTS Science Questions (SQ's): How small spatio-temporal variations in ecosystems characteristics and biophysical processes are reflected in localized variations in export (SQ1); and the degree to which upper ocean and mid-water food webs impact C transfer efficiencies (SQ2). Combined with other EXPORTS measurements, our 234Th approach will allow us to link controlling mechanisms of export with remotely sensed properties and reduce uncertainties on the fate of ocean primary production (SQ3). Furthermore, these questions can be approached via more specific 234Th sub-hypotheses:

H1. In the absence of grazing, diatoms increase the absolute magnitude of particulate C flux below the euphotic zone (EZ) (relative to smaller cells) and this export occurs during senescence and aggregation.
H2. Under conditions of low grazing, rapid sinking of diatoms (or other mineral containing organisms, such as coccoliths) results in a higher efficiency of transfer versus smaller cells.
H3. With increased zooplankton grazing, the magnitude of particulate C export will decrease, but the extent of particulate C flux attenuation and transfer efficiency of material below the EZ will be controlled by sub-surface foodwebs.
H4. During non-bloom periods, or when zooplankton grazing and phytoplankton growth are in near balance, vertical mixing of dissolved organic carbon (DOC) will be a significant pathway for C export and a potential for export of labile DOC.
234Th is needed to address these hypotheses and is fundamental for developing mechanistic global ocean models of the fate of fixed C in marine systems needed in the EXPORTS synthesis and integration Phase II. Only 234Th provides rates of C flux over

the smaller spatial and vertical scales required to understand processes that regulate water column particle export and C attenuation.

Craig Carlson/University of California, Santa Barbara
Evaluating the Controls of Dissolved Organic Matter Accumulation, Its Availability to Bacterioplankton, Its Subsequent Diagenetic Alteration and Contribution to Export Flux
16-OBB16_2-0015

Food web dynamics play an important role in partitioning the pelagic net community production (NCP) between particulate (POM) and dissolved organic matter (DOM). Approximately 50% of the DOM produced is rapidly consumed to meet bacterial carbon demand. However, biotic and abiotic transformation of organic matter can lead to the accumulation of carbon-rich DOM resistant to rapid microbial degradation in the surface ocean; a fraction of this persists long enough to be entrained during overturn such that it impacts the efficiency and magnitude of the biological carbon pump. The vertical redistribution of DOM results in the global ocean export of ~1.8 Pg C from the euphotic zone, or ~20% of the total export production. Thus, vertical export of DOM represents one of the five major flux pathways central to the EXPORT program. The contribution of DOM to export flux is most pronounced at high latitudes where convective mixing and submesoscale processes deliver dissolved and suspended materials to the depth, whereby the carbon is sequestered for decades to millennia. To resolve the contribution DOM to export it is critical to obtain high quality DOM data, assess the controls on its net production, chemically characterize the accumulated pool, and quantify export; it is critical to assess the microbial bioavailability at each ecosystem / carbon cycling (ECC) state observed by the EXPORTS field campaigns in the North Pacific and North Atlantic.

The guiding Hypotheses of this proposed project are:
H1: Given quantification of NCP, the net production (accumulation) of DOC is a predictable process for these subarctic systems.
H2: Given measures of vertical overturn, DOC export to the twilight zone is a predictable process.

The Carlson (UCSB) and Hansell (RSMAS) team has over two decades of experience resolving temporal and basin scale distributions bulk DOC and DON across the global ocean and, from those, their contributions to vertical flux. They have experience determining the diagenetic characterization of DOM through the measure of specific compounds such as the dissolved combined neutral sugar component. They have optimized the microbial remineralization bioassays necessary to assess the bioavailability / persistence (i.e. export potential) of the accumulated DOM. The team is poised to generate mission-critical data for EXPORTS (Table 2 of the Implementation Plan) that address components of Scientific Questions SQ1 and SQ2. Specifically, this proposed work aims to:

A. Understand controls on the fractions of net primary production and net community production partitioned as DOC and DON
B. Determine the flux of the most labile fraction of DOM required to meet carbon demand of heterotrophic bacterial production (i.e. bacterial carbon demand)
C. Determine DOM bioavailability to microbes and the fraction of the seasonally accumulated pool that persists for weeks to months
D. Assess DOM diagenetic state (compositional variations) over varying ecosystem / carbon cycling (ECC) states.
E. Evaluate physical mixing of DOM out of the euphotic zone, its contribution to export and its fate

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Margaret Estapa/Skidmore College
Linking Sinking Particle Chemistry and Biology with Changes in the Magnitude and Efficiency of Carbon Export into the Deep Ocean
16-OBB16_2-0016

The magnitude of particulate carbon export from the upper ocean and efficiency of its transfer into the interior remains one of the least predictable processes influencing the global carbon cycle. The overarching goal of the EXPORTS program is to develop mechanistic models predicting the strength and efficiency of this exported carbon. A central requirement – one might argue the central requirement – of the ambitious set of field measurements necessary to develop satellite-driven models is accurate measurement of sinking particle fluxes and their biological and chemical compositions. These measurements must be embedded in a broader suite of physical, biological, and optical observations, so a second requirement is that the team quantifying particle flux cooperates and works closely with the broader EXPORTS science team. Here, we propose a hypothesis-driven study of particle fluxes that both advances our understanding of the ocean biological carbon pump and meets the broader program goals above.

The broad hypothesis of the EXPORTS program is that the strength and efficiency of the biological carbon pump can be predicted from satellite ocean color observations. Implicit in this hypothesis are a number of assumptions which must be tested. The specific hypotheses we will address are 1) that the biological origin of the particles sinking out of the euphotic zone exerts significant control on both the magnitude of the sinking carbon flux and its rate of attenuation with depth; and 2) that temporal variability in the magnitude and attenuation of sinking particle flux is caused by biological processes.

Our proposed study will employ a mature, field-tested technology **–** quasi-Lagrangian, Neutrally Buoyant Sediment Traps (NBSTs) **–** to sample sinking particles at 5 depths in the upper 500 m of the ocean for each ecosystem state characterized during the EXPORTS field program. To test the hypothesis that biology drives temporal variability in flux, we must also characterize water column physical structure and particle properties at very high vertical and temporal resolution using a WireWalker deployed alongside the NBST array. We will determine fluxes of particle mass and major bioelements (organic and inorganic C, N, biogenic Si, and 234Th), estimate the time-resolved flux variability using Optical Sediment Traps, quantify sinking particle identities and size distribution by microscopy (gel traps), and identify the organismal contents within the sinking particles by DNA sequencing. By linking the subsurface NBST drift trajectories to measurements and models of the physical particle field, we will be able to connect our subsurface particle flux observations to simultaneous measurements in the euphotic zone and upper twilight zone by the broader EXPORTS team.

The principal investigators in this project have experience with the proposed field sampling techniques, with integration of sediment trap observations into a multidisciplinary analysis, and with the goals and proposed execution of the EXPORTS program. Buesseler and Estapa are currently carrying out a comprehensive field intercomparison of sediment traps and carbon flux measurement techniques, and will apply their experience directly to the quantification of sources of uncertainty in the sediment trap measurements. Estapa, Durkin and Omand have been refining the integration of chemical, optical, and genetic field techniques for the last two years. Buesseler is leading a parallel proposal to estimate sinking particle fluxes using 234Th deficits, which will also inform estimated trap uncertainties. Omand is a co-PI on a parallel proposal to carry out a suite of AUV measurements; if funded we expect to coordinate operations of our drifting assets in the field. Beyond the major bioelement fluxes, sinking particle size distribution, microscopy, and genetic analyses proposed here, we expect to liberally share trap samples with other EXPORTS teams and for long-term archival.

Craig Lee/University of Washington, Seattle
Autonomous Investigation of Export Pathways from Hours to Seasons
16-OBB16_2-0010

We propose to implement a multi-platform, multi-scale, multi-month autonomous array at two EXPORTS sites to measure upper ocean community structure, sinking cells, aggregates and fecal pellets, physical export, and migrating zooplankton. These observations will complement ship-based programs by spanning a wider range of ecosystem states and providing a diverse dataset for EXPORTS modeling. The measurements will resolve evolution of dominant pathways and quantify fluxes for carbon export from the euphotic zone to the upper twilight zone, as well as attenuation flux in the upper twilight zone. This effort will also demonstrate the capability to measure export fluxes using a combination of in situ measurements and satellite remote sensing, thus serving as a prototype for future operational systems.

We hypothesize that dominant export pathways and efficiencies differ between Atlantic and Pacific sites based on relative phasing of net community production (NCP) and carbon export (EZ) from the euphotic zone. In the Pacific, where NCP and EZ vary in phase, export will be dominated by zooplankton diel migration and slow-sinking pellet fluxes, with a smaller role for physical export and a weaker export efficiency. In contrast, decoupling of NCP and EZ in the Atlantic will produce both more variable and more efficient export, associated with fast-sinking aggregates, physical transport and low respiration rates. Small-scale physical and ecosystem variations in the Atlantic will enhance submesocale eddy flux, which may constitute up to half of total export during springtime restratification. We propose that similar in situ measurements will permit improved export predictions in other oceanic regions based on remote-sensing observations.

A system of heavily-instrumented Lagrangian floats and Seagliders, leveraging satellite data and ship-based calibration and proxy measurements, will sample euphotic and twilight zone properties and rates, export pathways and fluxes over a 6 mo period at each site. Observations collected by OOI (Pacific) and a coarse array of Bio-Argo floats (Atlantic) will place the float and glider measurements in context of the annual cycle. The Lagrangian float will drift along isopycnals just below the euphotic zone, measuring sinking export flux at the top of the twilight zone with an optical sediment trap and characterizing types of sinking particles with a camera system. Seagliders will profile to 1000m in close proximity to and in a 10-50 km region surrounding the float, measuring optics and zooplankton acoustic biomass. NO3 and O2 measurements will be used to compute productivity, particulate carbon, O2 and NO3 budgets. The budgets will define NCP and total carbon loss, e.g. respiration rate, across the euphotic and in the upper mesopelagic zones and, in particular, the export efficiency at the top of the euphotic zone and its decay with depth below this. Ongoing observing system simulation experiments (OSSEs) will be used to further refine sampling plans.

We will address EXPORTS Science Question I (SQ 1) by optically characterizing the euphotic zone community and types of sinking particles, thereby studying how (SQ1a) ecosystem characteristics determine the vertical transfer of organic carbon. We will distinguish between the 5 export pathways (SQ1b) by measuring the magnitude and type of sinking particle flux, by measuring zooplankton characteristics and migration rates, and by computing submesoscale eddy flux using models and parameterizations. We will measure both physical and ecological processes on the same space and time scales (SQ1d). We will quantify (SQ2) the vertical structure of export efficiency from the top of the twilight zone, differentiating between the efficiency of the 5 export pathways (SQ2a) and resolving variations in efficiency with a changing euphotic zone community (SQ2b). We will work with all the EXPORTS team to bring satellite, cruise and autonomous data to bear on these questions.

Adrian Marchetti/University of North Carolina, Chapel Hill
Quantifying the Carbon Export Potential of the Marine Microbial Community: Coupling of Biogenic Rates and Fluxes with Genomics at the Ocean Surface
16-OBB16_2-0018

We seek to quantify and relate primary productivity, remineralization and net community production (NCP) in the mixed layer across different ecosystem/carbon cycling states (ECCs). More specifically, our measurements will contribute towards the determination of upper ocean ecosystem characteristics that are important in controlling the vertical transfer of organic matter to ocean depths. Through a combination of biogenic O2 gas and inorganic carbon and nitrogen inventory measurements, we will quantify the biological rate processes and fluxes in both autotrophic and heterotrophic members of the marine microbial community. Estimates of Gross Primary Productivity (GPP) and respiration rates will be used in conjunction with mixed-layer integrated rates of NCP to quantify the overall carbon export from the mixed layer. In addition to the composition of the microbial community present (i.e., phytoplankton, bacteria and archaea) there is increasing evidence that their physiological status is also important in predicting carbon export. Thus, in tandem with our rate measurements, we will determine the marine microbial community composition through targeted DNA sequencing as well as sequencing of environmental RNA to determine gene expression that can be used to infer the physiological status of the microbial plankton community. Together, the integration of these measurements will allow for an unprecedented ability to examine how the form and function of upper ocean microbial ecosystems shape the carbon export potential across different ECCs. Using our combined measurements, we will test the following hypotheses: i) Specific phytoplankton and bacteria contribute disproportionately to NCP, ii) NCP is highest when there is low coupling between members of a given marine microbial community, iii) GPP and respiration rates in the mixed layer co-vary in tightly coupled microbial communities, and iv) the physiological status of phytoplankton will have a large influence on the NCP and is an important component to predicting NCP.

Our group brings a unique set of skills to address the first scientific question (SQ1) of NASA's EXPORTS program, more specifically SQ1a, "how does plankton community structure regulate the export of organic matter from the surface ocean". PI Marchetti's research expertise is in phytoplankton ecophysiology and genomics. He will be responsible for the phytoplankton community characterization and primary productivity measurements. These include measurements of phytoplankton biomass and photophysiology (using FIRe fluorometry), size-fractionated new versus regenerated production (using 15N stable isotope techniques) and primary productivity (using 13C stable isotope techniques), and eukaryotic plankton differential gene expression analysis via metatranscriptomics. Co-PI Gifford's research expertise is in marine bacterial metabolism and genomics. He will be responsible for quantifying respiration rates and bacterioplankton composition and activities. Respiration rates will be measured via O2 drawdown incubations using oxygen optodes. Bacterial taxonomic composition and functional potential will be determined by metagenomics, while expressed functional activities will be identified via metatranscriptomics. Co-PI Cassar's research expertise is in marine biogeochemistry and ecophysiology. He will be responsible for eukaryotic and prokaryotic plankton taxonomic composition (using 18S and 16S ribosomal DNA sequencing) and the high-frequency measurements of biological O2 (O2/Ar) fluxes. The O2/Ar observations will be performed using a new generation of equilibrator inlet mass spectrometers.

Susanne Menden-Deuer/University of Rhode Island
Quantifying Plankton Predation Rates, and Effects on Primary Production, Phytoplankton Community Composition, Size Spectra and Potential for Export
16-OBB16_2-0008

Predation by microzooplankton (MZ) is the single largest loss factor of marine primary production (PP) and alters the abundance and size spectrum of particles in the water column. MZ consume living cells and sinking aggregates and serve as prey to vertically migrating metazoans. Our hypotheses are 1) MZ predation of PP impacts rates of export production through all 5 pathways predictably and 2) high rates of predation yield low carbon export rates. We propose to quantify predation effects on PP, particle abundance and size distribution as a function of co-occurring environmental and biological conditions (i.e. Ecosystem/Carbon Cycling States (ECC)) to gain a mechanistic and predictive understanding of the carbon flow in the euphotic zone and below. We will provide essential data described in the implementation plan and address elements of science questions 1&2. We will identify linkages among predator mediated carbon flows, environmental drivers and export production, which are crucial for developing a) the diagnostic and prognostic relationships necessary to address SQ3 and b) the predictive modeling framework to achieve key goals of the EXPORTS mission.

We propose to parameterize plankton population dynamics in the surface ocean and extend measurements of grazing potential to depth using traditional dilution experiments paired with novel genetic markers by studying:

1. Surface plankton population dynamics: We will concurrently measure phytoplankton growth and protist grazing rates in the surface ocean using dilution experiments. Daily experiments will be conducted at 3 depths incubated deck-board at in situ conditions to assess predation induced shifts in biomass, particle size spectra and species composition. Particle size spectra and composition will be examined across a broad size range (1-100Âµm) using microscopy and flow cytometry. Repeat measurements across multiple ECC states will reveal associations among key biotic (e.g. abundance and taxonomic composition) and environmental (e.g. light, hydrography) correlates of biologically mediated carbon flow. By comparing predation rate estimates to the optical properties measured by collaborators, we will determine remotely or autonomously measurable proxies for grazing rates.

2. Feeding capacity in the deep ocean: We will measure feeding potential of MZ over vertical profiles (0-1500m) to determine the potential for grazer mediated modifications of carbon flow below the euphotic zone. Fluorescent stains that illuminate the feeding process will be used to measure feeding capacity, as in situ concentrations of predator and prey are likely too low to deliver a measurable signal from incubation experiments. Comparison of the feeding potential over depth with rate measurements of plankton population dynamics made at the surface will enable us to extend carbon flow estimates from the surface to the difficult to assess grazing dynamics in twilight zone.

3. Novel genetic grazing marker: We will assess new genetic markers indicative of feeding in MZ to achieve high-resolution grazing rate measurements, on time scales similar to the capacity of autonomous or remote sensors. Biomass for downstream analysis will be collected daily throughout the water column and concurrently from the

dilution experiments. This first field application of grazing markers will provide gene expression across ECC states to expand the resolution of grazing rate measurements.

4. Contributions to EXPORTS: Predation rates are crucially missing from global biogeochemical models but necessary to parameterize carbon flows at the base of the marine food web. The data proposed here provides key algorithms to relate plankton growth and mortality to export through all 5 pathways and across ECC states. Numerous EXPORTS studies require these rate estimates, which will be essential for building a diagnostic modeling framework to predict export of global PP, now and in future climate scenarios.

Collin Roesler/Bowdoin College
Phytoplankton Community Structure, Carbon Stock, Carbon Export and Carbon Flux: What Role Do Diatoms Play in the North Pacific and North Atlantic Oceans?
16-OBB16_2-0032

Phytoplankton are characterized by tremendous diversity that critically affects ocean ecosystem functioning. The EXPORTS “Phytoplankton & microbes” program element seeks to address the role that phytoplankton diversity plays in determining (1) net primary production (NPP), (2) standing stock of phytoplankton carbon in the euphotic zone, (3) export efficiency of phytoplankton carbon out of the euphotic zone, and (4) flux transmission of this material below the euphotic zone into the twilight zone. The EXPORTS “Optics” program element seeks to quantify the optical measurements that link ecosystem function to remotely sensed products via carbon-based optical proxies. In this proposal, we contribute to these program elements by focusing on phytoplankton diversity and optical properties/proxies of key phytoplankton community structure elements (i.e., concentration, composition and size), and how those factors influence export from and transformation below the euphotic zone.
The ability to differentiate phytoplankton based upon their functional differences is crucial to quantify how different groups impact carbon stocks and fluxes. We intend to measure phytoplankton diversity and optical properties by constructing a continuous underway flow-through system for the survey ship described in the EXPORTS Science Plan. Our system will consist of imaging-in-flow cytometry, hyperspectral absorption and attenuation (scattering by difference), multispectral backscattering, and multi-excitation chlorophyll fluorescence. Water samples from CTD casts to twilight depths will also be measured in discrete mode to quantify the transformation and change in diversity of algal cells (and their associated optical properties) as they sink through the water column.
In particular, we will focus on diatoms as they have been identified as the dominant phytoplankton functional type (PFT) responsible for carbon export due to gravitational settling as single cells (or chains), aggregates, or cell fragments. We hypothesize that the diatom fraction of the plankton community will be the largest predictor of the variability in carbon stock, export and flux. Further, we hypothesize that diatom size structure will provide the second order predictor of variability in carbon stock, export and flux.
We will obtain direct measures of phytoplankton community composition and size structure during the two proposed cruises, but what occurs outside of those locations and

time intervals is critical to resolving the seasonal and spatial variability that can only be sampled in situ on autonomous platforms or remotely from satellites. Thus, the second focus of this proposal is to quantify the linkages between phytoplankton diversity and functionality (i.e., PFTs) and (1) the optical properties that can be measured in situ and (2) the types of data products that will ultimately be obtained from next-generation ocean color satellite missions. We will use our coincident phytoplankton community structure observations and associated optical properties to construct simple optical proxies for phytoplankton concentration, composition, and size. These proxies will be critical to characterize the links among phytoplankton carbon stock, NPP, carbon export from the euphotic zone and flux transmission to the twilight zone, as well as how those linkages vary through space and time. The proxies will also link phytoplankton composition and size structure to hyperspectral phytoplankton spectral absorption and particle backscattering, respectively.

We hypothesize that robust optical proxies for pigment-based taxonomy and size structure will reduce uncertainty in modeling phytoplankton community structure. Autonomous platforms deployed with simple optical sensors would therefore provide validation for satellite data products for the surface waters and provide critical depth-dependent information to reduce uncertainty in carbon stock, flux, and transmission estimates.

David Siegel/University of California, Santa Barbara
Synthesizing Optically- and Carbon Export-Relevant Particle Size Distributions for the EXPORTS Field Campaign
16-OBB16_2-0044

Particle size has fundamental control on the distribution and dynamics of particulate carbon in the upper ocean. Stokes' law states that particles with larger effective diameters (D) will sink faster than smaller ones determining whether particles are effectively suspended within the water column (D<~100 µm) or are sinking (D>~500µm). Net Primary Production (NPP) enters pelagic ecosystems as suspended particles and these particles (along with CDOM) control the ocean's optical properties. Further, sinking particles undergo many biotic and abiotic transformations in their size, composition and sinking velocity as they transit from the surface ocean, regulating carbon export and remineralization profiles. This points to the importance of understanding the particle size distribution (PSD) in predicting the fate of NPP, the central goal of EXPORTS.

We propose to answer four science questions to develop a predictive understanding of the PSD for both suspended and sinking particles.

1. How do the abundance, composition and productivity of particle source materials regulate the PSD for smaller, optically relevant particle sizes?
2. How do source particle characteristics as well as biotic / abiotic interactions on sinking particles regulate the PSD for larger, carbon export relevant particle sizes?
3. Can the combined size distribution for suspended and sinking particles be modeled using optical data and in particular from satellite ocean color observations?

4. How do energy and carbon derived from phytoplankton NPP cascade through the particle size spectrum?

These four science questions address aspects of many of the EXPORTS Science Questions (SQ) and answers SQ1C and SQ1D directly.

We propose an integrated research program of in situ optical and imagery observation (Siegel, Nelson, McDonnell), at-sea characterization and experimentation on collected aggregates (Passow) and numerical modeling (Burd, Siegel). Advances in near-forward angle light scatter (LISST) and in situ imaging (UVP) enable high-resolution profiles of the PSD for both suspended and sinking particulates. Inherent optical and oceanographic properties will be monitored simultaneously to characterize suspended particle composition and oceanic context. We will collect sinking aggregates using the Marine Snow Catcher to characterize their ecological and biogeochemical composition, physical properties as well as their decomposition rates, all of which are needed for modeling. The assembled data set will be the basis of mechanistic numerical models that transform the combined PSD as a function of depth and ecosystem / carbon cycling state. We will test relationships among source materials (phytoplankton, zooplankton feces, etc.) and biotic (zooplankton grazing, etc.) and abiotic (turbulence, density gradients, etc.) disrupters of aggregate distributions. Data available from other EXPORTS investigations (particle export & composition, phytoplankton abundance & composition, NPP, etc.) will be incorporated as needed. For example, we will assess the sinking velocity size spectrum using collected trap samples and our PSD measurements as well as spatiotemporal validated fields of particle export fluxes and PSD transformations from inverse modeling. These data products and models will be distributed to the EXPORTS Science Team and beyond.

Our proposal responds primarily to Section 3.1.2.2 (Collection & Analysis of Field Data) of the 2016 ROSES A3 solicitation, but also contributes to Sections 3.1.2.1 (Development of RS Data Products) and 3.1.2.3 (Development of Models).

Last, the Lead-PI (Siegel) is applying to be the EXPORTS Science Lead.

Deborah Steinberg/Virginia Institute of Marine Science
Zooplankton-Mediated Export Pathways: Quantifying Fecal Pellet Export and Active Transport by Diel and Ontogenetic Vertical Migration in the North Pacific and Atlantic Oceans
16-OBB16_2-0067

This proposal responds to the Amendment A.3. OBB call for the EXPORTS field campaign. Using satellite remote sensing data to predict export and fate of net primary production (NPP) in a given region and time requires an understanding of the drivers and characteristics of plankton community structure. The EXPORTS Science Plan characterizes 5 pathways for the export of NPP from the surface ocean into the interior, two of which are mediated by mesozooplankton: production and sinking of fecal pellets, and active transport by vertical migration.

We propose to address EXPORTS science questions SQ1 (1a and 1b) and SQ2 (2a,b,d) by conducting field-based, process studies of mesozooplankton-mediated export in the NE Pacific and N Atlantic Oceans. The guiding hypothesis is that changes in phytoplankton community structure and NPP affect zooplankton abundance, biomass, size, and taxonomic structure, all of which controls and scales to export in a quantifiable and predictable way. Satellite observables and data products, including euphotic zone phytoplankton biomass and functional type, particle size spectrum, light attenuation, and temperature will be used to predict zooplankton community structure, and in turn zooplankton-mediated export, significantly advancing our ability to predict export and fate of NPP.

The first research objective is to quantify production and export of fecal pellets and other zooplankton by-products (e.g., mucous feeding webs, molts, carcasses). Fecal pellet (FP) production rates in the surface ocean are hypothesized to positively scale with temperature, NPP, and zooplankton size. FP flux as a component of the total sinking particulate organic carbon (POC) flux varies considerably across regions and seasons, and reprocessing of sinking material is evidenced by changes in types of zooplankton fecal pellets with depth. Our approach is to collect representative, abundant live zooplankton from different size classes (including migrators) via day/night net sampling in the epipelagic zone for use in fecal pellet production experiments. FP production rates will be scaled up to community rates using abundance quantified from the same tows using a ZooScan optical imaging system. Production of FPs in surface waters will be compared to export of FPs at different depths as measured by sediment trapsâ€“to examine export efficiency of pellets or other zooplankton by-products, and to mesopelagic zooplankton community structure.

The second research objective is to quantify active transport of carbon from the euphotic zone by both diel and ontogenetic (seasonal) vertical migrations. Diel vertically migrating zooplankton feed in the surface waters at night and metabolize this ingested POC in the mesopelagic zone during the day. In the subarctic N. Pacific and N. Atlantic oceans, active transport by seasonal migrants (e.g., Neocalanus and Calanus, respectively) as they develop through their life cycles is an additional export. Our approach is to characterize zooplankton biomass and community structure with depth-stratified day/night net sampling through the epi- and mesopelagic zones using a MOCNESS (multiple opening-closing net) and an Underwater Vision Profiler, UVP, camera system. The latter will characterize delicate gelatinous zooplankton and enable sampling of thin layers. Onboard incubation experiments measuring metabolism (respiration, excretion, and FP production) of migrating taxa from different size classes, combined with size-temperature algorithms of metabolism will be used to quantify export by migrators. These will also be compared with electron transport system measurements to determine depth-stratified metabolic carbon demand.

Synergies with other potential components of the field campaign (e.g., grazing, sediment trap particle flux, acoustics to characterize zooplankton mesoscale variability) will mutually benefit EXPORTS .

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Optically Resolving Size and Composition Distributions of Particles in the Dissolved-Particulate Continuum from 20 nm to 20 mm to Improve the Estimate of Carbon Flux
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The goal of EXPORTS field campaign is to develop a predictive understanding of the export and fate of global ocean primary production. The downward transport of organic matter from sunlit surface ocean occurs over the entire dissolved-particulate size continuum with processes spanning from diffusion of non-sinking dissolved organic matter (DOM) to passive sinking of particulate organic matter (POM). The mass flux is typically estimated using the size distribution of particles of sizes > 1 µm. The effect of particle composition on sinking speed and downward transport of non-sinking dissolved and small particulate organic carbon are two of the priorities recently identified for future research towards a transformative understanding of the biological pump[Burd et al. 2016]. To better understand how variation in particle size distribution impact carbon export estimates and therefore to better understand if size or composition is the main driver of the export, we propose to apply the latest technological and theoretical advancements in the field of ocean optics to quantify in situ size and density distributions of particles in the dissolved-particulate continuum from 20 nm to 20 mm. Specifically, we propose to achieve the following objectives:

Objective (i): Measure the vertical distribution of the spectral absorption coefficient (a) and volume scattering function (VSF, β), which will be augmented by additional optical observation of an imaging flow cytometer and an underwater vision profiler (UVP).

Objective ii: Estimate the size and density distributions of particles of sizes from 20 nm - 200 µm from the VSF data, the particles size distribution from 5 - 100 µm from the flow cytometer data, the particle size distribution from 100 Âµm to 20 mm from the UVP data, and phytoplankton size fractions from the absorption data.

Objective iii: Estimate the total and size-fractioned mass flux using the optically derived results of particle size and density distributions from Objective (ii). The size-fractioned flux will be contrasted between (1) dissolved vs. particulate; (2) small (< 100 µm) vs. large (> 100 µm) particles; and (3) communities dominated by different classes of phytoplankton.

Objective iv: Apply statistical analysis to investigate (1) how the mass flux estimated based on VSF-inversion results (i.e., size and density distribution from 0.02 – 200 µm) relates to the total flux and (2) how the phytoplankton community (macro-, nano-, and pico-) that can be retrieved from the absorption measurements relates to the total flux.

Our ultimate goal is to test if the total mass/carbon flux can be adequately estimated using the biogeochemical variables that can be retrieved from the measurements of inherent optical properties of absorption and volume scattering function in the surface water. This is directly related the EXPORTS's overarching hypothesis - carbon export from the eutrophic zone and its fate within twilight zone can be predicted knowing characteristics of the surface ocean ecosystem.