EXPORTS

EXport Processes in the Ocean from RemoTe Sensing

EXPORTS Implementation Plan

EXPORTS Science Definition Team

Submission Date: October 13, 2016

1.0 Summary

The goal of the EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) field campaign 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. EXPORTS builds upon decades of NASA-supported research assessing global net primary production (NPP) from space and is designed to deliver science of significant societal relevance by better characterizing the fate of organic carbon in the ocean.

EXPORTS' overall approach is to develop and validate ocean carbon cycle models from observations made over a range of ecosystem / carbon cycling (ECC) states. Observations of the fundamental NPP export and fate pathways as well as supporting data are required to develop satellite algorithms and numerical models valid over the global range of ECC states. Thus field data are needed from both intensive field campaigns, such as those detailed in the EXPORTS Science Plan, as well as previous results mined from the literature.

This document is the SDT's attempt to find an efficient solution that successfully answers the EXPORTS Science Questions and maximizes value to the agency, opportunities for transformative discovery, and broad community participation. The resulting plan, the 'Goal Plan', is presented here along with a range of descoping options for the overall program. The Implementation Plan addresses the measurements and model activities that are needed as well as notional cruise, autonomous platform, project management, data management, and partnership plans. A robust cost estimate for the Goal Plan is presented along with descoping options and an analysis of the tradeoffs between investment and scientific returns associated with descoping from the Goal Plan. Detailed planning documents that may be useful in EXPORTS' implementation are included in the supplemental materials section of this document. Formal input from the ocean science community was solicited on a preliminary draft of this document and the comments were considered carefully in finalizing the present document. Based upon these considerations, ***the SDT strongly recommends that any descoping option for EXPORTS must 1) quantify all NPP export and fate pathways <u>and</u> 2) include synthesis and modeling activities throughout. Any field campaign program without these two components would not be EXPORTS.***

2.0 Introduction

The goal of the EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) field campaign 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. EXPORTS will test the hypothesis that the fates of ocean net primary production (NPP) are regulated by the state of the surface ecosystem, which links satellite remote sensing science to ocean carbon cycling processes. Developing a predictive understanding of the fates of global NPP and their roles in the carbon cycle is a NASA agency objective and builds upon decades of NASA-supported research assessing global NPP from space.

EXPORTS is designed to deliver science of significant societal relevance, representing a key component in the U.S. investment to understand Earth as an integrated system, by better characterizing the fate of organic carbon in the ocean. The overall approach presented in the EXPORTS Science Plan is to develop and validate ocean carbon cycle models from observations made over a range of ecosystem / carbon cycling (ECC) states, each of which can be thought of as the window of time and space where all of the fundamental NPP export and fate pathways have been robustly quantified along with constraints on their integrated biogeochemical impact. Further, supporting field data are needed to develop satellite algorithms and numerical models that are valid over the global range of ECC states. These field data will come from both intensive field campaigns, such as those detailed in the EXPORTS Science Plan, as well as previous results mined from the literature. The Science Plan and other information are available at http://cce.nasa.gov/obb/exports.

The EXPORTS Science Plan has been through extensive community vetting, formal comments and a peer review panel (this history is included in Sections 11.4 to 11.7 of the EXPORTS Science Plan). In October 2015, NASA competed the formation of a Science Definition Team (SDT) to create an Implementation Plan to guide EXPORTS' execution (see NASA's Charge to the SDT in Section 7.1). Service on the EXPORTS SDT was voluntary and no compensation was provided from NASA. The SDT will be disbanded shortly after submission of the final plan. It is important to recognize that the SDT has only suggested a potential implementation to NASA and does not have the authority to advise or direct the agency.

The goal of this document is to present an efficient strategy to implement the EXPORTS Science Plan as proposed, vetted and approved by NASA. This required the SDT to devise a field, modeling and synthesis research program that will answer the EXPORTS Science Questions effectively, efficiently and with a high degree of certainty. The SDT termed this plan the Goal Plan. To implement the Goal Plan, the SDT needed to understand and quantify many factors, including:

- The measurements & models required to answer the EXPORTS Science Questions,
- Efficient and effective measurement, project management & partnership plans,
- A robust cost estimate for the Goal Plan, and
- Suggestions for descoping options along with analysis of the balance between agency investment and program success.

The Goal Plan is the SDT's attempt to find an efficient solution that successfully answers the EXPORTS Science Questions and maximizes value to the agency, opportunities for transformable discovery, and broad community participation.

At times, the Implementation Plan may appear overly prescriptive. This approach was necessary to both outline components critical for successfully answering the Science Questions and to create a robust estimate of the required resources necessary to achieve the Goal Plan. If the EXPORTS field campaign is to occur, it may look very different from the present plan. Factors driving such differences would be the extent of available resources, the establishment of partnerships with agencies and entities beyond NASA, the results of peer reviewed competition for roles within the program, and the integration of new ideas into the planning of the field campaign.

In July 2016, the SDT solicited comments from the ocean sciences community on a draft of this document. The SDT was interested in comments on the suitability of the plans in general but was especially interested in comments regarding alternative descoping options and costing strategies, input for potential partnerships, the suggested implementation timeline, project and data management as well as capacities not reflected in the plan. A total of 48 formal comments were received from members of the ocean science community ranging from graduate students to emeriti scientists. The reviewers expressed near unanimity in their support of EXPORTS and many useful specific comments were received and used in improving this final plan. The community comments were especially useful in arriving upon the final recommendation for the minimum acceptable configuration for the EXPORTS field campaign. A description of the draft plan's review process, an overview of comments received, and the SDT's response can be found in the Draft Implementation Plan Comments in Section 7.7 of this document.

Lastly, this document is intended to provide NASA with suggestions on how to implement the EXPORTS Science Plan as stated in NASA's Charge to the SDT. Hence, this document is not intended to provide guidance to individuals planning to propose to participate in EXPORTS, nor does it describe how the competition process could occur. If EXPORTS is conducted, competition-specific instructions will come from NASA directly.

3.0 Science Questions to Requirements

EXPORTS is a measurement, modeling and synthesis program designed to deliver science results of societal relevance. Figure 1 shows a conceptual diagram linking program resources and elements to societal benefits. EXPORTS is built on three Science Questions (SQ) whose answers provide a path for the remote monitoring of the export and fates of net primary production (NPP) in the modern ocean. EXPORTS will also improve how we predict these changes under future climates (EXPORTS Science Plan). To answer these questions, EXPORTS will examine the role of each of the five pathways of organic material transport from the surface ocean into the interior by measuring a suite of 81 observables that are grouped into 5 key Program Elements (Figure 1). Principal Investigator (PI)-driven projects will address domain-specific science objectives in these key Program Element areas and will perform the synthesis activities needed to answer the science questions. Required resources include, but are not limited to, observations from oceanographic cruises, autonomous platforms and remote sensing as well as a range of numerical modeling efforts. The modular design of EXPORTS suggests that it can be easily augmented by national and international partnerships providing additional expertise and complementary science. Considerable preparation will also underpin EXPORTS through recently funded NASA projects focused on data mining and observing system simulation experiments (OSSEs). These efforts build a database of ECC states from the literature to extend the range of states available and OSSEs to refine experimental planning (Figure 1).

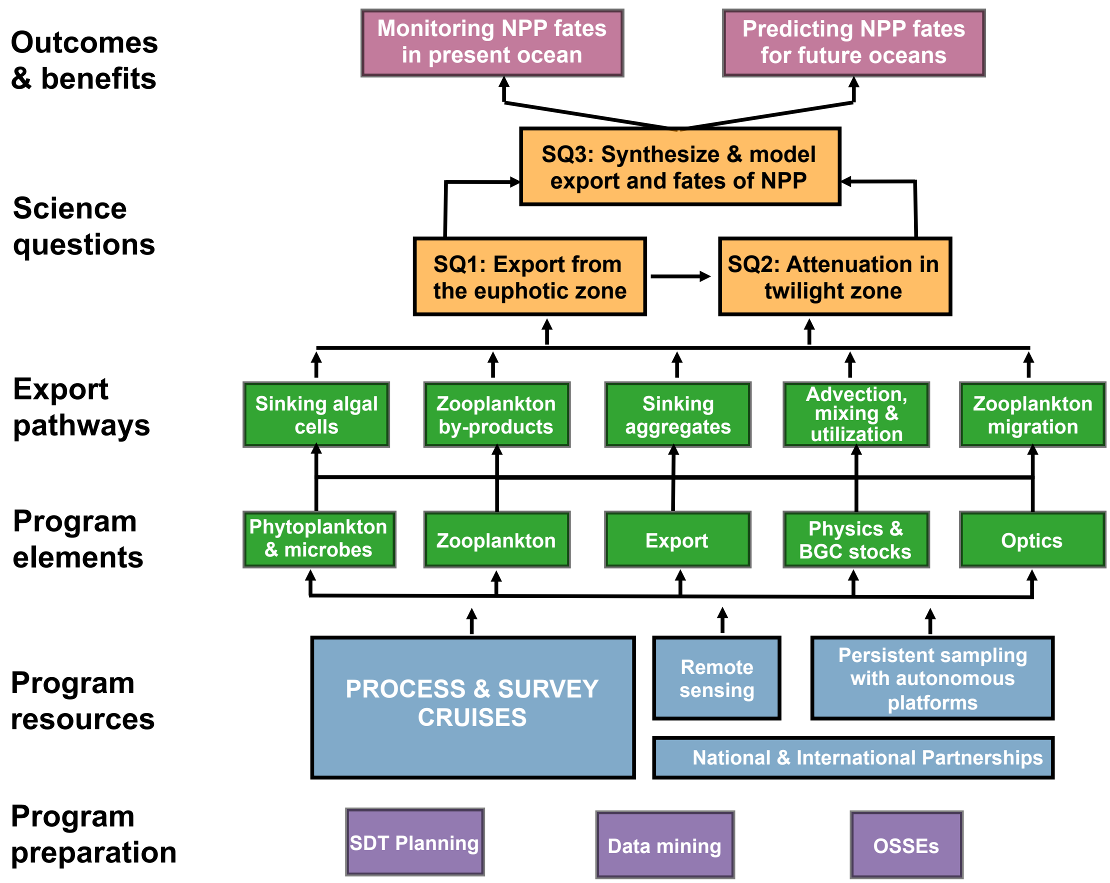

Figure 1 – The EXPORTS conceptual diagram linking program preparation, resources, and elements via export pathways to science questions and societally relevant outcomes.

The EXPORTS Science Plan identifies 3 key interrelated questions concerning the fate of ocean NPP (Table 1). Science Questions 1 and 2 focus on how processes in the surface and the subsurface oceans control the export (SQ1) and attenuation (SQ2) of organic matter into the ocean interior. SQ1 and SQ2 are broken down into four sub-questions that identify the most significant current uncertainties in our understanding of those ecosystem characteristics that promote export of organic matter and controls on the efficiency of its vertical transfer into the ocean's interior.

Science Question 3 asks how the answers to SQ1 and SQ2 improve current and future estimates of ecosystem / carbon cycling processes and their implications on larger time and space scales (SQ3). The dependence of SQ3 on SQ1 and SQ2 also suggests that EXPORTS could be implemented in two phases, where Phase 1 tackles SQ1 and SQ2 together and Phase 2 uses the resulting information (and data mined observations) to answer SQ3. Because of the dependency of SQ3 on SQ1 and SQ2, here we emphasize greater detail in Phase 1. Implementation of Phase 2 is discussed in Section 4.5. Clearly, synthesis activities are required throughout in order to answer all of the science questions.

Table 1: **EXPORTS Science Questions and Associated Sub-Questions**

SQ1	**How do upper ocean ecosystem characteristics determine the vertical transfer of organic matter from the well-lit surface ocean?**
1a	*How does plankton community structure regulate the export of organic matter from the surface ocean?*
1b	*How do the five pathways that drive export (cf., sinking of intact phytoplankton, aggregates or zooplankton byproducts, vertical sub-mesoscale advection & active vertical migration) vary with plankton community structure?*
1c	*What controls particle aggregation / disaggregation of exported organic matter and how are these controls influenced by plankton community composition?*
1d	*How do physical and ecological processes act together to export organic matter from the surface ocean?*
SQ2	**What controls the efficiency of vertical transfer of organic matter below the well-lit surface ocean?**
2a	*How does transfer efficiency of organic matter through the mesopelagic vary among the five primary pathways for export?*
2b	*How is the transfer efficiency of organic matter to depth related to plankton community structure in the well-lit surface ocean?*
2c	*How do the abundance and composition of carrier materials in the surface ocean (cf., opal, dust, PIC) influence the transfer efficiency of organic matter to depth?*
2d	*How does variability in environmental and/or ecosystem features define the relative importance of processes that regulate the transfer efficiency of organic matter to depth (i.e., zooplankton grazing, microbial degradation, organic C solubilization, vertical migration active transport, fragmentation & aggregation, convection and subduction)?*
SQ3	**How can the knowledge gained from EXPORTS be used to reduce uncertainties in contemporary & future estimates of the export and fate of upper ocean net primary production?**
3a	*What key plankton ecosystem characteristics (cf., food-web structure and environmental variations) are required to accurately model the export and fate of upper ocean net primary production?*
3b	*How do key planktonic ecosystem characteristics vary and can they be assessed knowing surface ocean processes alone?*
3c	*Can the export and fate of upper ocean net primary production be accurately modeled from satellite-retrievable properties alone or will coincident in situ measurements be required?*
3d	*How can the mechanistic understanding of contemporary planktonic food web processes developed here be used to improve predictions of the export and fate of upper ocean net primary production under future climate scenarios?*

In order to answer each of the EXPORTS science questions and subquestions, required measurements were identified, tabulated, associated with a sampling platform, and prioritized. Table 2 provides a condensed version of the Complete Measurement Table, where the required measurements are sorted into Program Elements with rationales and linkages to subquestions and a summary of priority for placing the measurement on a sampling platform. The Complete Measurement Table provides more detail about prioritization and an accompanying Measurement Footnote Document offers methodological details concerning each measurement entry.

Table 2: **Condensed Measurement Table Sorted into Program Elements** (see Complete Measurement Table for a complete description of the requisite measurement suite)

Program element	Platform	Method	EXPORTS science question needs	Measurement types & examples	SQs Addressed	Priority		
						Survey	Proces	Auto
Phyto & microbes	CTD	FCM / microscopy	Phytoplankton biomass proxies and diversity	flow cytometry (number, volume, groups); imaging cytometry / microscopy	1abcd 2abcd	1	1	-
Phyto & microbes	CTD	FCM / microscopy	Phytoplankton biomass	sorting flow cytometry/imaging microscopy	1abc	-	1	-
Phyto & microbes	CTD	FCM / microscopy	Heterotrophic prokaryotes and protist concentration (cell number) and size/volume, including viral numbers	flow cytometry with staining and epfluorescent microscopy	1abcd 2abcd	1	1	-
Phyto & microbes	CTD	FCM / microscopy	Heterotrophic nanoflagellate and larger protist concentration (cell # size/volume and diversity	flow cytometry, digital imaging microscopy, inverted microscopy	1abcd 2abcd	1	1	-
Phyto & microbes	CTD	sensor	Variable Fluorescence	variable fluorescence Fv/Fm	1ab	2	1	-
Phyto & microbes	CTD	omics	Phytoplankton community composition	DNA-based community composition (genetic profiling) & microbial and phytoplankton metatranscriptomes	1abc 2abc	2	1	-
Phyto & microbes	CTD	omics	Heterotrophic prokaryotic community composition	DNA-based community composition (genetic profiling)	1abd 2abcd	2	1	-
Phyto & microbes	CTD	omics	Heterotrophic protist community composition	DNA-based community composition (genetic profiling)	1ab 2abcd	2	1	-
Phyto & microbes	CTD	experimental - omics	Phytoplankton and microbial metabolism	proteomic collection from process cruises and / or nutrient manipulations with gene expression	1ab	-	2	-
Phyto & microbes	CTD	geochem	Net Community Production	NCP (O2/Ar)	1abd	1	1	-
Phyto & microbes	CTD	experimental	Phytoplankton Productivity	NPP/NCC (14C), some size fractionated	1ab	-	1	-
Phyto & microbes	CTD	geochem	Phytoplankton Productivity	GPP (triple O isotope)	1ab	2	1	-
Phyto & microbes	CTD	experimental	Phytoplankton Productivity	GPP (18O)	1ab	-	2	-
Phyto & microbes	CTD	experimental	Viral infection & dilutions	various includingFCM, electron microscopy & probes, mitomycin C incubations	1ab	-	1	-
Phyto & microbes	CTD	experimental	Heterotrophic Bacterial Production	3H Tdr or 3H Leu incorpration method	1d 2abcd	-	1	-
Phyto & microbes	CTD	experimental	DOM remineralization Exp	Seawater Dilution cultures	1d 2abcd	-	1	-
Zooplankton	nets	net tows	Zooplankton metazoan concentration water column average	Net Tows - vertical	1abc 2abcd	1	1	-
Zooplankton	sensor	accoustics	Zooplankton metazoan biomass	Acoustics	1abc 2abcd	1	2	2
Zooplankton	nets	day/night tows	Vertical structure of zooplankton metazoan concentration (animal number) and size/volume	MOCNESS net tows- day/night depth resolved with microscopic or digital analysis	1abc 2abcd	-	1	-
Zooplankton	nets	experimental	Fragmentation	Experiments with zooplankton impacts on particle size spectra	1c 2abcd	-	1	-
Zooplankton	nets	experimental	Zooplankton metabolism (respiration and excretion)	Net tows to collect; SPOT, ETS methods, weight-specifc metabolic rates	1ab 2abcd	-	1	-
Zooplankton	nets	experimental	Microzooplankton Grazing	Ship based dilution experiments	1ab 2abcd	-	1	-
Zooplankton	nets	experimental	Mesozooplankton Grazing	multi prong approaches - see comments	1ab 2abcd	-	1	-
Zooplankton	nets	experimental	Mesozooplankton fecal pellet production	fecal pellet ID and production experiments	2d	-	1	-
Zooplankton	sensor	accoustics	Fish (tertiary consumers/carnivores) biomass	Acoustics- hull mounted	2d	1-UW	-	-
Export & aggregates	trap	deploy-CHN/mass	Particle flux EZ & TZ- trap based	Sediment traps for direct collection of major flux components such as mass, PIC, bSi, N, P, Lithogenics, TEP	1ab 2abcd	-	1	1
Export & aggregates	trap	geochem	Particle flux EZ & TZ- trap based	Sediment traps for biomarkers	1ab 2abc	-	1	-
Export & aggregates	trap	omics	Particle flux EZ & TZ- trap based	Sediment traps for omics	1ab 2abc	-	1	-
Export & aggregates	trap	gels	Particle flux EZ & TZ- trap based	Sediment traps for ID - polyacrilimide gel traps	1ab 2abcd	-	1	-
Export & aggregates	CTD	geochem	Particle flux EZ & TZ- in situ tracers	234Th flux studies (also need large particle X/Th ratio)	1ab 2abcd	1	2	2
Export & aggregates	CTD	geochem	Particle flux EZ & TZ- in situ tracers	210Po, 228Th flux studies	1ab 2abc	2	-	-
Export & aggregates	in situ pump	geochem	size fractionated particle collection	large particle collection - in situ pumps (w/234Th)	1ab 2abcd	1	2	-
Export & aggregates	trap	optics	Particle flux EZ & TZ- trap based	Optical flux gauges (on trap and/or independent float)	1abc 2abcd	-	1	1
Export & aggregates	trap	cameras	Particle flux EZ & TZ- proxies	In situ cameras on traps	1ab 2abcd	-	1	2
Export & aggregates	CTD/AUV / towed	cameras	Aggregate PSD and flux derived from particle distributions	particle cameras (e.g., UVP, VPR, LOPC, etc.)	1abc 2abcd	1	1	1
Export & aggregates	CTD/AUV / towed	cameras	Zooplankton metazoan biomass	In situ camera (e.g., UVP, VPR)	1abc 2abcd	1	1	2
Export & aggregates	trap	experimental	Sinking velocity	Settling Velocity Traps or other in situ devices	1ab 2d	-	2	-
Export & aggregates	CTD	experimental	Sinking velocity	Settling columns	1ab 2d	-	1	-
Export & aggregates	trap	experimental	In Situ Microbial metabolism, whole water	in situ or pressurized incubation chamber water	2abcd	-	1	-
Export & aggregates	trap	experimental	In Situ Microbial metabolism, sinking particles	In situ incubation chamber (RESPIRE) or trap particles expts	2abcd	-	1	-
Export & aggregates	CTD	experimental	Aggregation & disaggregation	Aggregation experiments	1c 2abc	-	1	-
Optics	CTD/AUV /towed	sensor	PAR, above-water and subsurface	PAR	1abcd	1	1	1
Optics	CTD	geochem	CDOM absorption	CDOM absorption spectrum	1abd 2abcd	1	1	1
Optics	CTD	geochem	Phytoplankton and detrital absorption spectrum	absorption spectrum (Kishino method)	1ab 2abc	1	1	1
Optics	CTD	sensor	Spectral particle absorption	acs for pigment and species proxy	1abcd 2abc	1	1	1
Optics	CTD	sensor	Spectral particle attenuation	acs for particle size	1abcd 2abc	1	1	1
Optics	CTD/AUV /towed	sensor	Particle size	Multiple-wavelength backscattering	1d 2abc	1	1	1
Optics	CTD/AUV /towed	sensor	Remote sensing reflectance (subsurface obs)	Ed (λ) & Lu (λ)	1abcd	1	1	1
Optics	ship	sensor	Water-leaving radiance (-->remote sensing reflectance) above water	Lw (λ)	1abcd	1	-	-
Optics	ship	sensor	LIDAR	ship-mounted LIDAR	1abc	2	-	-
Optics	CTD/AUV /towed	sensor	Single wavelength beam c and bbp (ie 650 nm)	acs/C-Star/C-Rover, other transmissometers and backscattering sensors	1abcd 2abcd	1	1	1
Optics	CTD	sensor	Birefringent (calcite) particles	polarized beam c (WETLabs PIC/POC sensor)	1abcd	2	2	2
Optics	ship	sensor	Particulate inorganic carbon	acid-labile backscattering	1abd 2abc	1	2	-
Optics	CTD/AUV /towed	sensor	Flux derived from particle distributions	Backscattering sensors on autonomous platforms	1ab 2abcd	2	1	1
Optics	CTD	sensor / geochem	Total small particle size spectrum	e.g., Coulter Counter (bench), LISST (in situ) for small particles	1abcd 2abcd	1	1	-

Program element	Platform	Method	EXPORTS science question needs	Measurement types & examples	SQs	Priority		
					Addressed	Survey	Proces	Auto
Bulk BGC & physics	CTD/AUV	Rosette & sensors	CTD- see also physical processes	CTD- O2, T/S	1abcd 2abcd	1	1	1
Bulk BGC & physics	CTD	geochem	Chlorophyll fluorescence	in vivo chlorophyll fluorescence sensor	1abcd 2abc	1	1	1
Bulk BGC & physics	CTD	geochem	particle composition	HPLC pigments	1abcd 2abc	1	1	-
Bulk BGC & physics	CTD	geochem	particle composition	Chlorophyll incl. some size fractionated	1abcd	1	1	-
Bulk BGC & physics	CTD	geochem	Oxygen	O2 bottle (Winkler)	1abcd 2abc	1	1	-
Bulk BGC & physics	CTD	geochem	Dissolved Inorganic Nitrogen, Phosphorous, Silicate	Frozen for later autoanalyzer	1abd 2abcd	1	2	-
Bulk BGC & physics	CTD	geochem	DOM for export via physical mixing	DOM (i.e. high temperatue combustion, persulfate oxidation, etc)	1abd 2abcd	1	2	-
Bulk BGC & physics	CTD	optics	DOM source from fluorescence	Spectral fluorescence on discrete samples	1d 2abcd	2	2	-
Bulk BGC & physics	CTD	geochem	DOM Characterization	DOM quality such as PAD-HPLC, High Resolution Mass Spec, NMR	1abd 2abcd	2	1	-
Bulk BGC & physics	CTD	geochem	Total Dissolved Nitrogen	High Temperatuture combustion of TDN.	1d 2abcd	1	2	-
Bulk BGC & physics	CTD	geochem	Carbonate System	e.g. TCO2, pCO2, Talkalinity, pH	1abcd 2abcd	2	1	2
Bulk BGC & physics	CTD	geochem	Trace metals	e.g. trace metal clean methods for NPP and for example Fe as it impacts export in NE Pacific	1ab 2b	2	1	-
Bulk BGC & physics	CTD	geochem	particle composition	POC, PON of particles from bottles	1abd 2abcd	1	1	-
Bulk BGC & physics	CTD	geochem	particle composition	biogeneic silica	1abc 2abcd	1	1	-
Bulk BGC & physics	CTD	geochem	particle composition	PIC (particulate inorganic carbon)	1abd 2abcd	1	1	-
Bulk BGC & physics	CTD	geochem	particle composition	Lithogenic Si, Al	1abcd 2abcd	2	1	-
Bulk BGC & physics	CTD	geochem	Transparent Exopolymer Particles	Microsopy, Spectroscopy	1c 2abcd	2	1	-
Bulk BGC & physics	towed/ AUV	sensor	Mesoscale circulation	Synoptic, repeated surveys of mesoscale fields with towed profiling vehicle.	1d 2d	1	-	1
Bulk BGC & physics	towed/ AUV	sensor	Submesocale surveys	Synoptic, repeated surveys of submesocale fields with towed profiling vehicle & AUVs	1d 2d	1	-	1
Bulk BGC & physics	satellite	model	Atmospheric Forcing	Satellite remote sensing products. Wind velocity, surface heat flux	1d 2d	-	-	-
Bulk BGC & physics	sensor	model	Ship-based Atmospheric Forcing	Wind velocity, short- & long-wave radiation, RH, air temperture, sea surface temperature & salinity, barometric pressure, precipitation	1d 2d	1-UW	1	-
Bulk BGC & physics	satellite	model	Large-Scale Circulation	Geostrophic surface velocity from SSH (e.g. AVISO), state estimates (e.g. ECCO)	1d 2d	-	-	-
Bulk BGC & physics	satellite	model	Mesoscale circulation	Geostrophic surface velocity from SSH (e.g. AVISO), state estimates (e.g. ECCO).	1d 2d	-	-	-
Bulk BGC & physics	CTD/AUV	sensor	Mixing	Microstructure measurements (temperature and shear microstructure)	1d 2d	2	2	2
Bulk BGC & physics	satellite / AUV	sensor	Mesoscale circulation	Maps of mesoscale fields from combined floats, gliders and ships ADCP	1d 2d	1	-	1
Bulk BGC & physics	satellite / AUV	sensor	Persistent, distributed measurements	Persistent, broadly distributed profiles and sections.	1d 2d	1	-	1

Table 2 illustrates what measurements are needed to answer the first two EXPORTS science questions. The measurements are grouped into the 5 Program Elements: Phyto & Microbes, Zooplankton, Export & Aggregates, Optics, and Bulk Biogeochemistry & Physics (see also Figure 1). Nearly all of the required measurements will be valuable for answering more than one subquestion. In some cases, a measurement is listed under one program element for brevity, but is also a relevant measurement in another (for example, optical cameras in Export & Aggregates and Optics). A range of methods is required to build a detailed picture of the system and to balance the strengths and sensitivities of different approaches. For example to answer SQ1C (*What controls particle aggregation / disaggregation of exported organic matter and how are these controls influenced by plankton community composition?*), a wide variety of measurements are required ranging from genomics (for identifying phytoplankton and microbial communities that contribute to the composition of the aggregates) to experimental work (measuring aggregation and disaggregation rates). It is important to note that each measurement may include a number of different approaches for redundancy and closure (e.g., a variety of different camera approaches could be used to measure the particle size distribution (PSD) of aggregates).

Priorities are also assessed for each measurement on each platform in the Complete Measurement Table. In Table 2, a '1' indicates that the measurement is essential, a '2' indicates it is useful but not essential, and a '-' indicates it is not necessary for answering one of the science questions. This priority assignment is done separately for each of the two ships that will be operating during each cruise (see next Section for details). For example, there may be reasons to focus a specific measurement following a target water parcel such that it is a priority for the Lagrangian-sampling process ship. Alternatively, it may be important to assess the spatial variability of a measurement on a broader, quasi-synoptic spatial scale by conducting the measurement on the survey ship.

Table 2 illustrates only a condensed version of the measurement suite needed to answer the EXPORTS Science Questions. The complete list of measurements considered necessary to address each of the subquestions in full are listed in the Complete Measurement Table in the supplemental materials section 7.2. An accompanying Measurement Footnote Document also provides additional details concerning each measurement entry in the complete measurement table.

4.0 Implementing the Goal Plan

The 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 through an integrated program of field measurements, remote sensing, modeling and synthesis. The SDT devised a Goal Plan that, in its opinion, will answer the Sciences Questions posed in the EXPORTS Science Plan and will provide the analytical tools required to understand NPP export and fate in present and future climates using satellite remote sensing and numerical forecast models. Thus, the Goal Plan is used as the starting point for costing the EXPORTS field program and for understanding the implications of descoping proposed activities. Costing the Goal Plan requires estimating the number of research projects and associated costs, ship time, project coordination, data management, logistics and NASA-held contingency funds.

This plan is envisioned to occur in two Phases. Phase 1 includes multiple field campaigns and synthesis designed to answer SQ1 and SQ2, with a later start for Phase 2's comprehensive synthesis and modeling activities to address SQ3. The rationale of splitting EXPORTS into two phases allows synthesis work conducted in Phase 1 to inform Phase 2 synthesis. Synthetic data products will be created from measurements or primary data products collected during Phase 1 for use in synthesis and modeling in both Phases 1 and 2 (see Section 6.7 of the EXPORTS Science Plan). To answer SQ3, an integrated hierarchy of synthesis and modeling approaches will be required that are closely coupled to the analysis and interpretation of EXPORTS field data, remote sensing, and other relevant ocean data sets. Phase 2 efforts will encompass a range of approaches, including coupled Earth System models, to forecast both present-day conditions and future responses of ecosystems and biogeochemical cycles under different climate scenarios.

During Phase 1 of the Goal Plan, two ocean basins would each be sampled twice, beginning in the North Atlantic with the spring bloom and late summer in 2018, followed by sampling near Station PAPA in the North Pacific in spring and early autumn 2020. This sampling strategy would allow EXPORTS to observe a wide range of ECC states required for the construction of globally applicable satellite and numerical models. The choice of locations would enable the possibility of efficient partnerships with on-going U.S. programs (such as the Ocean Observatory Initiative node at Station P, O-SNAP, etc.) as well as on-going and planned international research programs (Section 4.7). Each component of the Goal Plan field campaign would include two ships, a Process Ship and a Survey Ship. The Process Ship would operate in a semi-Lagrangian frame and a Survey Ship would sample over a wide range of spatial scales. Observations would also be made from an array of autonomous platforms (gliders and multiple types of floats) deployed in advance of the Process and Survey cruises and extending past their end. By operating over an annual cycle, the autonomous assets would provide persistent observations and temporal context for the ship-based observations and enable geochemical determination of annual rates of net community productivity (NCP). By sampling at a variety of spatial scales for long periods of time, they would identify important scales of variability necessary for scaling up process studies to regional and global scales.

Six descoping options are presented that reduce overall project costs through a combination of effort reductions. The descoped options are ranked qualitatively, based upon the tradeoffs between prediction uncertainty (i.e., number of ECC states sampled) and measurement uncertainty (i.e., resolution of all export pathways). The reviewers provided many useful specific comments on this issue and their guidance was used in drafting final recommendations (see Draft Implementation Plan Comments; Section 7.7).

EXPORTS aims to leave a legacy for years to come. The comprehensive nature of the data set to be collected is unprecedented, with deliberate oversampling of particulate materials and filtered seawater for genomic and geochemical analyses, microscale video imagery from the CTD and towed platform surveys, trap samples, in situ cameras, zooplankton net samples, etc. A key to success is the rigorous adherence to measurement protocols on both ships and rigorous cross calibration of sensors on all ships and autonomous platforms. The field measurements will be integrated with *in situ* optics and ocean color observations, providing invaluable data for algorithm development for NASA's upcoming Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) mission, and for testing the hypothesis that the fates of global NPP are regulated by the state of the surface ocean ecosystem.

> If the EXPORTS field campaign is to be conducted, the resulting program will likely differ substantially from the plans presented here for many reasons (cf., available resources, establishment of partnerships, outcome of the peer review process, integration of new ideas, etc.). The detailed plans presented herein were assembled so that robust resource estimates could be created for the Goal Plan and the various descoping options.

4.1 Determining Goal Plan Program Duration and Number of Projects

The framing of the EXPORTS Science Questions and the funding opportunities presented thus far suggest that a phased implementation would be an efficient way to conduct EXPORTS. This phasing has started already. In August 2016, NASA announced funding of six data mining and observational system simulation experiment (OSSE) numerical modeling proposals in support of EXPORTS planning and science (https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=536603/solicitationId=%7BEAB4311C-7130-7F75-BDC2-AB50BCC8A900%7D/viewSolicitationDocument=1/OBB15_Web Posting.pdf). The Data Mining / OSSE research will contribute to the planning of the final EXPORTS field program and NASA funding has started already for these participants (Figure 2).

As introduced above, activities associated with answering the Science Questions (Table 1) can be phased because the answers to SQ1 (*What controls the carbon flux exiting the* *euphotic zone?*) and SQ2 (*What is the fate of that export flux in the twilight zone?*) are needed to address SQ3 (*How can the knowledge gained reduce uncertainties in contemporary and future assessments of the ocean carbon cycle*?). From an operational point of view, answering SQ1 and SQ2 requires many of the same measurements (Table 2), making it efficient to address them simultaneously.

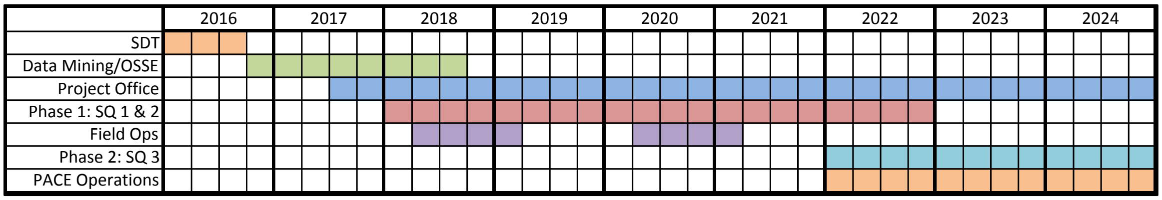

Figure 2 – Timeline by quarters for the Goal Plan.

The separation of EXPORTS into two phases suggests that a staggered implementation for the Goal Plan is possible. The first phase answers SQ1 and SQ2 using the EXPORTS field observational record. We anticipate this to be a five-year program, which will enable domain-specific manuscripts to be published and the synthesis and modeling required to answer SQ1 and SQ2 to be completed. The second phase answers SQ3 and is three years in duration. Together, we are suggesting that the Goal Plan be a seven-year program starting in 2018 with a staggered implementation of the two phases (Figure 2). The launch readiness date for the PACE mission is 2022/23 (pace.oceansciences.org). This timeline will enable advanced carbon cycling satellite algorithms developed and tested using EXPORTS observations to be used by PACE.

In order to obtain a total costing for the Goal Plan, the number of projects needed to answer the Science Questions must be estimated. A project is defined here as a PI-led, five-year (Phase 1) or three-year (Phase 2) funded effort that will contribute directly to answering the EXPORTS Science Questions and the EXPORTS measurement suite. A project may be a single investigator project or made up of several PIs working together. Phase 2 implements the knowledge gained in Phase 1 to reduce uncertainties in predictive and forecasting models and satellite algorithms, a NASA agency goal. Hence, the two Phases are intricately linked and should not be considered independent activities.

The number of Phase 1 projects required was derived from the Complete Measurement Table (see Section 7.2). For each of the five program elements, the SDT estimated how many field and modeling projects were required for Phase 1. This judgment was largely based upon the types of measurements and the unique expertise that would be required on each ship. This estimate was only utilized to derive cost estimates and was not aimed at prescribing the type or number of projects that will carry out the measurements. A few activities were deemed best conducted by competed measurement teams who deliver data products rapidly to the projects. Such efforts include the hydrographic CTD/rosette sampling, underway sampling, preliminary data processing and analytical work (nutrients, chlorophyll, particulate organic carbon, etc.), deployment and acquisition of data from the towed sled package on the survey ship, and the autonomous platform operations. The exact number of projects supported would be determined by proposal competition and consideration of available resources.

Twenty-three projects were estimated to be necessary to conduct Phase 1 of the Goal Plan to cover all program elements (Table 3). For the Phytoplankton & Microbes program element, the SDT estimated that a total of 5 projects were required, of which one is a modeling project. Similar estimates were made for the other program elements, resulting in the number of projects listed in the third column of Table 3. Modeling projects were considered to be important parts of Phase 1 and therefore included in this total.

Table 3: Estimated Program Elements and Number of Projects

Elements	Data Products	project #	Types of Measurements
Phytoplankton & microbes	biomass/comm structure	**5**	FCM, including sorting; omics; Fv/Fm; virus
	rates - intrinsic & C transforming		NCP, NPP, GPP, BP, dilution expts, nutrient expts; DOM bioavailability; viral lysis
Zooplankton	biomass/comm structure	**2.5**	nets, incl. day/nigjt; bioaccoustics (incl fish)
	rates - intrinsic & C transforming		day/night; feeding/pellet expts; dilution expts/metabolic rates
Export & aggregates	Flux and attenuation particle abundance & size	**5.5**	traps (direct and optical), radionucludes, in situ pumps, cameras for PSD (CTD, AUVs)
	C transformation rates & processes		aggreg/dissag expts; in-situ incubations/drifters; sink rates
Optics	Links to remote sensing	**3**	Optical measurements to build optical models to link to satellites
	C proxy building		Optical measurements to lead to poxies of particle properties; LIDAR?
Bulk biogeochemical stocks & physics	Hydrography- CTD	**4**	CTD/Rosette, O2, Flu, NO3, POM, DOM
	Hydrography- towed		CTD, O2, Flu, NO3 optics
	Site planning		pre/during/post cruises; remote sensing, all vehicles/hydrography, PO models, ADCP etc
	AUV team		Pre/post deployments and Lagrangian sub EZ float;al sensors & optics
Innovation	Novel methods, sensors, measurements, models	**3**	Novel approaches using materials/data collected on cruise
Phase 1 Total		***23***	Also need hydro / towyo / AUV ops teams
Phase 2 total		***8***	Assumes 2 projects per SQ3 subquestion

The SDT also felt strongly that, in addition to the projects that contribute to the proposed EXPORTS measurement suite, there needed to be resources set aside for highly innovative projects that help answer the EXPORTS science questions but were not originally envisioned explicitly as part of the EXPORTS measurement suite. A total of three innovation projects were suggested.

4.2 Goal Plan Ship Operations

Ship-based sampling in the EXPORTS Science Plan includes two major field deployments in two ocean basins with the aim of observing a wide range of ECC states. The Goal Plan ship operations will be conducted in concert with the autonomous platform operations described in the next section (Section 4.3). Each cruise will allow observation of up to three ECC states, with each taking 8 days to accomplish. Budgeting for 1 weather day between ECC occupations and 1 additional day for retrieving autonomous assets, each cruise thus requires a total of 27 on–station days (see details in the Notional Cruise Plan; Section 7.3). When considering the duration of sampling an ECC state, the SDT considered the time it takes for events in the surface ocean to influence particle fields at depths of 500 m given particle sinking rates of 50-100 m/d (5-10 days), although this is obviously an oversimplification. The SDT also considered the station time needed to measure all of the export pathways and the multitude of activities this requires. By conducting two seasonally-distinct cruises in each of two basins, EXPORTS aims to fully resolve up to 12 ECC states spanning a large dynamic range of conditions. This breadth, along with recently funded data mining efforts, increases the likelihood that the models created will be representative for other areas under similar regimes.

The Goal Plan requires two ships to efficiently and effectively sample the full suite of measurements necessary to resolve the export pathways. This requirement is due in part to the number of projects suggested for Phase 1 of the Goal Plan (Table 3) and an estimate of the resulting berthing needs (see details in the Notional Cruise Plan; Section 7.3). In addition, this requirement reflects the fact that some measurements need to be made in a Lagrangian mode (Process Ship), while others are best collected in a spatially-distributed quasi-synoptic fashion (Survey Ship). The most efficient sampling plan thus places the former group of measurements on the water-following Process Ship and the latter group aboard the Survey Ship.

Briefly, short-term drifting arrays, sediment traps, most net tows, and CTD casts deployed to collect material for shipboard experimentation are assigned to the Process Ship, as well as most incubation-based biological rate determinations. Similarly, physical and geochemical measurements requiring distributed CTD sampling, large-volume in situ pumping, and towed profiler surveys are assigned to the Survey Ship. For example, this would include measurements required to assess downward mixing of dissolved organic matter (DOM). Specific ship priorities for all measurements are noted in Table 2 and in detail in the Complete Measurement Table (Section 7.2). Measurements not clearly belonging to one of these categories were assigned to either or both ships after assessing interdependencies among the different measurements. For instance, most optical and imaging sensor-based measurements are included on both ships in order to link the Lagrangian-mode observations of the Process Ship to the larger, spatial context determined by the Survey Ship. A description of the platform requirements and sampling for the goal plan is provided in the Platform Requirements document in Section 7.4.

Sampling needs were partitioned between the two ships to assess all export pathways during each distinct ECC state assessment in as short of time period as possible. In each ECC state assessment, the Survey Ship will conduct a mesoscale CTD survey, towed profiler surveys at both meso- and submeso-scales, and large volume particle pump deployments at 3-day intervals. We define a mesoscale survey as achieving 5 km (CTD) resolution across a 50 x 50 km box, while a submesoscale survey will achieve higher resolution across a smaller target area (see Platform Requirements for further details on the planned sampling and platforms considered). The survey ship will also be the platform to deploy an upper ocean profiling LIDAR and above-water reflectance systems to link to next-generation satellite determinations.

On the Process Ship, each state will also require one set of approximately five-day sediment trap deployments, two consecutive drifting experimental array deployments, two pairs of day/night MOCNESS deployments separated by 4-5 days, daily vertical net tows, and CTD casts 4 times per day. A detailed depiction of the timing details for the cruise sampling is given in the Notional Cruise Plan (Section 7.3). The plan also includes time for the Process

Ship's sewage disposal away from the target water parcel. Tallying the time and berths necessary to make all measurements, one global-class Process Ship (35 berths) and one ocean-class Survey Ship (25 berths) will together be able to complete the assessment of one "state" of the biological pump in 8 days. Allocating two weather days per cruise, one additional day for recovering autonomous assets, and assuming actual operations achieve the efficiency detailed here, the Goal Plan thus achieves observations of 3 ECC states during 27 ship days on site.

In addition to time on site, steaming time for each cruise needs to be considered. For the Atlantic cruises, steaming times are based on the distance from Woods Hole, MA to Porcupine Abyssal Plain (PAP). For the N. Pacific cruises, the calculated times are based on the distance from Seattle to Station P (details are in Notional Cruise Plan). The exact locations where the EXPORTS field campaign will be conducted will be decided after the program is initiated and depends on many factors (available resources, ship schedules, partnerships, the peer review process, etc.).

In order to achieve efficient operations and optimally-coordinated sampling across the program elements, the EXPORTS implementation plan recommends that sampling from the CTD, towed profiler survey, ship's underway sensor system, and autonomous underwater vehicle be carried out by Project Office-directed operational teams that are fully competed. These ship- and shore-based teams will coordinate deployments and piloting with the management team and with appropriate project PIs. Data generated by the CTD, Underway, Towed Profiler survey, and Autonomous Platform Operations teams will be made available immediately for use in PI-led projects via the Project Offices' data management office.

Detailed water sampling requirements for nutrients, pigments, and other standard analytes are described in the Platform Requirements document in the subsection "Water sampling and minimum analysis set" (Section 7.4). Many of these analyses will not be made at sea and sample collections can be conducted using standard procedures by a technical laboratory on shore. These sampling efforts will also include deliberate overcollection for analytes, such as filtered seawater and suspended and sinking particle samples, for genomic, proteonomic, geochemical and isotopic analyses. This deliberate oversampling is relatively inexpensive and has the potential for big science returns.

EXPORTS will also include a network of cross-calibrated biological, chemical, and optical sensors deployed across multiple platforms (ship underway, CTD, glider, float, and towed profiler). Requirements for these sensors are also given in the Platform Requirements document (Section 7.4). As with water samples collected by the CTD group, the plan includes over-collection of imaging, optical, and radiometric data for future reinterpretation and model development. In order to derive maximum value from these sensor-based measurements, it is important that all sensors be cross-calibrated frequently before, during, and after deployments. The SDT suggests that dedicated personnel be assigned to coordinate intercalibration across platforms and manage the data processing streams from these sensors.

4.3 Goal Plan Autonomous Platform Operations

In reviewing the EXPORTS Science Plan, the SDT concluded that autonomous platform plans were not sufficiently detailed in the Science Plan to elucidate the spatial sampling schema critical for identifying important scales of variability and rationally determine the resources required. Hence, the SDT developed a Goal Plan autonomous platform operations plan to compliment the detailed shipboard sampling plans presented here and in the Science Plan. The autonomous platform operations plan helps clarify how sustained autonomous sampling will help address the EXPORTS Science Questions and details many of the considerations that must be further refined if the EXPORTS Goal Plan is to occur.

Roles of Autonomous Platforms in EXPORTS - Long-endurance autonomous platforms fulfill critical sampling needs, complementing and augmenting the intensive ship-based measurement program by providing:

- *Persistence*: Maintain a full year of sampling in each basin, beginning before the first process cruise and extending past the final cruise to provide temporal context for the intensive sampling periods and additional, albeit partial, characterizations of ECC states at times not sampled by the cruises.
- *Spatial Context*: Distributed profiles collected by floats and longer (100's km) repeated sections occupied by gliders characterize variability at a range of spatial scales not resolved by ship-based sampling. These measurements will identify the important scales of variability and provide information on the spatial distribution of processes resolved in detail by ship-based sampling. Autonomous platforms provide measurements over a broad temporal and spatial scope that will inform the upscaling of process investigations needed to understand basin-scale impacts.
- *Targeting*: Autonomous platforms return most of their measurements in near real time. Used in conjunction with satellite remote sensing, these observations will inform site selection for intensive, ship-based efforts and assist with day-to-day targeting of ship-based sampling. Guiding ships directly to features of interest increases efficiency and reduces risk associated with the adaptive approach employed by this plan.
- *Drifting Reference Frame*: A Lagrangian float defines a parcel-following reference frame for ship-based sampling. This eases interpretation by minimizing the impact of advection, allowing observed changes to be more readily interpreted as the result of biological and biogeochemical processes.
- *Adaptive Sampling*: Remotely commanded autonomous platforms provide flexible sampling that can be readily reconfigured to meet a range of needs, including opportunistic sampling of interesting events and optimization of coverage in response to failure of some elements of the observing array.
- *Large-Scale Biogeochemical Constraints*: The autonomous platform array will enable the calculation of net primary production (NPP) from biomass-light models and net community production (NCP) via mass budgeting of the biogeochemical stock measurements on weekly to annual time scales. The resulting integrated measures of NPP fate will be very useful for comparing with the ship-based observations of NPP fate pathways.

The Autonomous Array - EXPORTS autonomous platforms operate in a nested system (Figure 3), with a persistent Lagrangian array resolving kilometer-scale variability while drifting through a distributed array of Bio-Argo and Particle Flux floats designed to characterize scales of hundreds of kilometers. Long, repeat sections occupied by gliders provide persistent sampling that bridges the two scales and offers cross-calibration opportunities. Particle Size Distribution (PSD) Floats will be deployed for short periods during the process cruises.

Drifting Float Array: A distributed array of Bio-Argo floats and Particle Flux floats (see Platform Requirements, Section 7.4) will be deployed with 200-300 km separation (selected so that each float represents an independent realization). The array will be deployed at least one month prior to the first intensive sampling period and maintained at eight floats (6 Bio-Argo and 2 Particle Flux) for the duration of the intensive sampling period. The eight-float array provides distributed coverage over a roughly 600 km by 600 km region (Figure 3). This represents a compromise designed to capture a broad range of oceanographic conditions across an operationally useful span (roughly two days for ships to traverse) with a minimal number of floats. Bio-Argo floats will profile from the surface to 2000 m depth at a timescale of 1-20 days, adjusted as needed to resolve target processes. Together, these floats will document the evolution of upper ocean stratification, establish a time-history of water properties and NCP on regional scales, and provide observations for assessing the representativeness of the process observations. The floats would also provide alternative targets with known histories for ship-based sampling, should the Lagrangian array (below) prove unsuitable.

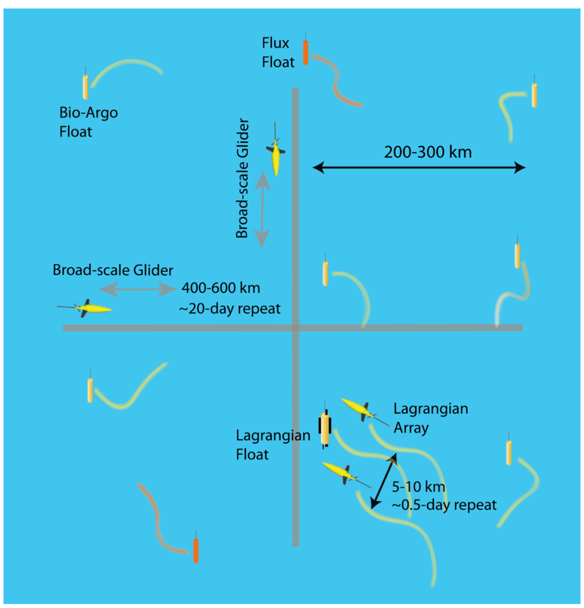

Figure 3: Autonomous platforms sampling schematic for the Goal Plan.

Broad-scale Glider Repeat Sections: Two long-endurance gliders (Platform Requirements) will conduct long (300-400 km) repeated sections across the target domain, beginning prior to the first intensive sampling period and extending for a year. Gliders profile from the surface to 1000-m depth every six hours at roughly 3 km separation between dives. The resulting time series of sections will characterize spatial variability across a broad region and range of scales surrounding the process study sites, providing context for the intensive measurements, assisting in interpreting the profiles from the drifting float array and informing upscaling of process-level understanding to larger scales.

Persistent Lagrangian Array: A system composed of a drifting Lagrangian float and two long-endurance gliders (Platform Requirements) will provide persistent sampling of small-scale O(1 km) variability in a parcel-following reference frame. The float quantifies temporal evolution in the drifting (parcel-following) frame, while gliders characterize spatial variability in the region (kilometers) surrounding the float. Small-scale, process measurements collected by the Lagrangian array will capture partial realizations of additional states, helping to assess the representativeness of ship-based observations and extending the record of NCP and export fluxes. During the periods of ship-based sampling, the Lagrangian array will provide targeting information and a drifting reference frame around which sampling strategies can be optimized.

Calibration and Proxy Building - Quantitative interpretation of autonomous biological and biogeochemical sensor arrays requires rigorous attention to calibration/cross-calibration and careful construction of proxies that convert observables to estimates of relevant biogeochemical parameters (e.g. fluorescence to chlorophyll concentration, optical backscatter and beam transmission to particulate organic carbon). EXPORTS calibration and proxy protocols should include:

- Laboratory calibration to common standards prior to deployment and (when appropriate) following recovery.
- Deployment calibration against collocated casts using reference sensors and/or analyses of samples.
- Calibration during intensive ship-based sampling against dedicated, collocated casts using CTD-based reference sensors on both ships and/or analyses of samples.
- Cross-calibration between autonomous sensors through both planned (e.g., gliders directed to visit floats) and chance encounters between EXPORTS platforms, and with instruments operated by other programs.
- Development and refinement of proxies at deployment, during intensive field periods, and though collaboration with other programs working in the region.
- Protocols for transparent, documented pathways from raw sensor output to final data product.

Operational Approach - Autonomous platforms will maintain a persistent presence throughout the EXPORTS field year in each basin (Figure 4). The field program for each basin begins with a cruise dedicated to deploying the distributed Bio-Argo and Particle Flux float array, deployment of the gliders onto their broad-scale repeat sections, and deployment of the drifting Lagrangian system (see below). Float deployment sites will be selected to cover the target region while maintaining the 200-300 km separation. Glider sections will be configured to traverse the target region and thus the cloud of floats. Historical data and Observing System Simulation Experiments (OSSEs) will guide selection of the Lagrangian array deployment site to maximize residence time in the target region.

Analyses of observations collected by the autonomous array will guide targeting of the two intensive ship-based sampling periods. Gliders from both Lagrangian Array and Broad-scale Repeat Sections could be commanded to converge at the selected site to augment ship-based sampling during cruises and to facilitate efficient recovery. During the first ship-based sampling periods, the Survey Ship will reseed a small number of floats into the distributed array to fill spatial gaps and will deploy four fresh gliders, the PSD floats and the Lagrangian float. Longer PSD float missions are desirable but will likely require development of onboard image processing. Ship-based process work can choose between the old and new Lagrangian floats when seeking a drifting reference frame, and will benefit from the survey capability of the combined fleet of eight gliders that results from deploying new gliders at the beginning and recovering old gliders at the end of the cruise. Ship-based sampling includes dedicated time for calibration and proxy building for autonomous sensors. At the end of the intensive sampling period, the ships will recover the four old gliders and, time permitting, the old Lagrangian float. Bio-Argo and Flux floats remain to sample until their batteries are expended. PSD floats generating data volumes too large to transmit will operate for short (days) deployments to provide information on suspended and sinking particles and for interpreting sediment trap observations, as a component of the ship-based observing effort.

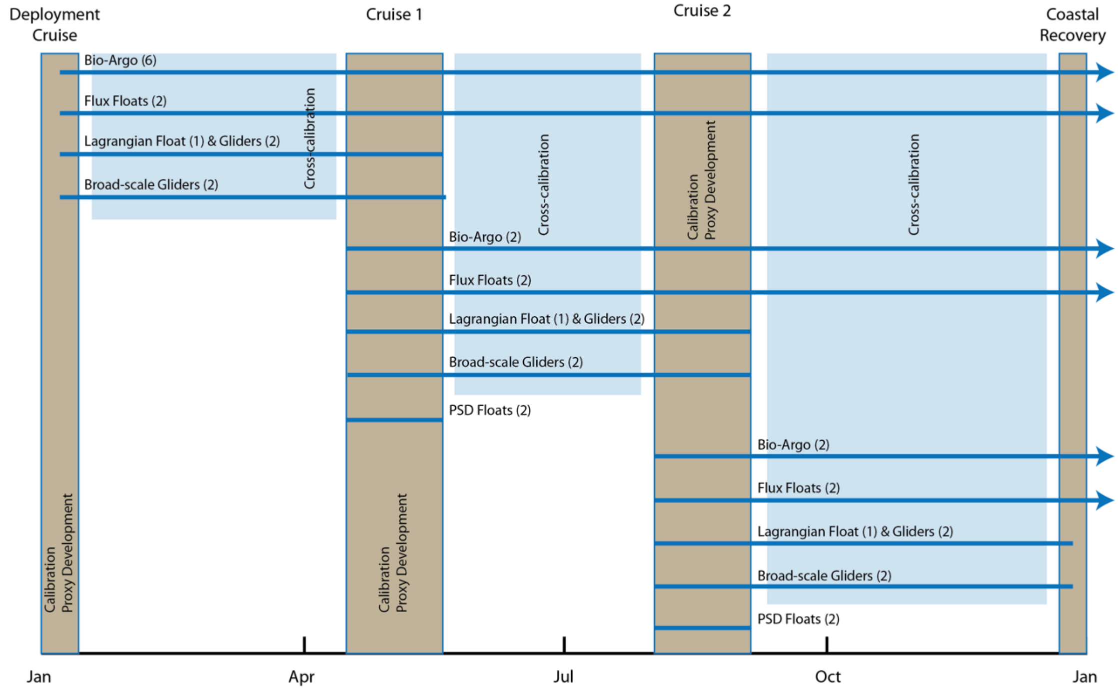

Figure 4: Timing chart for autonomous platform deployments, recoveries and operations.

The second intensive cruise also follows the sequence outlined above, with the full Bio-Argo/Flux Float array, four gliders and a Lagrangian float left behind to sample for the balance of the year. Bio-Argo and flux floats are not meant to be recovered and ship cost considerations make it impractical to devote a ship to mid-basin retrieval of gliders and Lagrangian floats at the end of the field program. Instead, gliders will be navigated to the nearest accessible coastal region, where surviving vehicles will be recovered using small, coastal research ships or charted vessels. Autonomous platforms that transmit their data back to shore should be considered quasi-expendable. Decisions to recover autonomous assets during all phases of the EXPORTS measurement program must weigh resource and opportunity costs against the value of the assets in question (including the need to reuse assets for additional EXPORTS deployments).

Logistics Needs - Initial deployment of autonomous platforms in the North Atlantic will require 18 days (5 days on site for deployments plus 13 days of transit), ideally from an Ocean Class vessel. Operations in the North Pacific will require 13 days (5 days on site for deployments plus 8 days of transit), also from an Ocean Class vessel. Ship time for deployment and recovery of floats and gliders is built into the Notional Cruise Plan.

Operations and Situational Awareness - Autonomous platforms will require continual monitoring and control throughout their missions. For example, float profiling frequency will be adjusted as dictated by science needs, gliders must be given waypoints and operating parameters, calibration opportunities must be identified and exploited, and all platforms monitored for system health. This will involve close internal (between floats and gliders) and external (with shipboard activities) coordination. These functions will be the responsibility of the scientists that compete successfully for these tasks.

More broadly, programmatic decisions about what and how to sample must be made by the entire EXPORTS team. The EXPORTS autonomous platforms group will lead development of a situational awareness system to provide basic analyses and products aimed at informing the decision making process. This near-real-time information feed will support a wide range of operations, from glider piloting and selection of features for focused sampling, to the overarching choice of target region for each intensive field period. The EXPORTS measurement program relies on adaptive sampling to capture distinct features and ECC states, making it imperative that all sources of real time information be captured and used to guide operations.

Operations Team - The EXPORTS autonomous platforms group will comprise all projects that compete successfully to conduct autonomous observations. Their day-to-day operations will depend on the nature of the successful proposals. Due to the need for highly coordinated operations, the SDT recommends that EXPORTS include a lead investigator for autonomous operations. This individual's responsibilities would include coordinating the diverse autonomous components, representing the autonomous platforms group on the EXPORTS Project Leadership Team (see Section 4.6), and planning of asset deployment, targeting and recovery. Similarly, the critical importance of sensor calibration and proxy building motivates the assignment of investigators to coordinate calibration of sensors across all platforms (autonomous and ship-based) and to lead the processing and delivery of data. These sensor leads would likely be drawn from the pool of EXPORTS investigators, identifying individuals with appropriate domain knowledge and a particular interest in the resulting data stream.

4.4 Assembling EXPORTS synthesis data products

EXPORTS will need to assemble measurements or "primary data products" from individual Phase 1 projects into "synthesis data products" that can be used for answering SQ1 and SQ2 in Phase 1 of the Goal Plan, answering SQ3 in Phase 2 (Section 4.5) and for users beyond the EXPORTS program. The synthesis products from EXPORTS Phase 1 cruises, remote sensing and autonomous sampling will be a major legacy of the program, serving as a gold mine for future ocean mechanistic and modeling studies.

The specific form and organization of the EXPORTS synthesis data products should be determined by the Phase 1 projects in conjunction with the EXPORTS Project Office's data management group. Synthesis data products should characterize the observed plankton ecosystem and carbon cycling in different states and quantify the five EXPORTS pathways in Figure 1. Table 3 in the EXPORTS Science Plan lists one approach and example of aggregated data products organized around processes, stocks, fluxes, and data types (e.g., productivity, export, particle size spectra, meso- and sub-mesoscale mapping, etc.). These data products may come from a single project team, but more likely will need to be created using data collected from several projects or Program Elements (Table 3). Data products might be constructed from a combination of autonomous, remote sensing, and *in situ* data sets. The planned EXPORTS field campaigns will be supplemented by data mining activities during a preparatory phase that will provide additional upper ocean ecosystem / carbon cycling (ECC) states. These data also need to be organized into data products that are required to answer the EXPORTS Science Questions.

Another way that the EXPORTS data sets could be organized to encourage synthesis would be in the form of "wiring diagrams" for each ECC state. The EXPORTS wiring diagram illustrates the flows and fates of NPP energy through the upper ocean food web and is shown in Figure 3 of the EXPORTS Science Plan. For each ECC state observed, mean estimates of the carbon pools shown in the wiring diagram, as well as the fluxes among the pools, would be collated along with appropriate uncertainty estimates. This accounting could also be done with the data mined observations. This collation of the EXPORTS data into wiring diagrams should encourage cross-ECC state syntheses.

The EXPORTS Phase 1 synthesis data products will be compiled towards the end of Phase 1 and, as described in Section 4.6, the data products will be published and made publically available to all users through the EXPORTS Project Office in coordination with other oceanographic data repositories (SeaBASS, BCO-DMO, PANGEA, etc.). The synthesis products are in addition to the primary measurement products, which will be submitted to data bases earlier, in conformity with NASA data requirements.

4.5 Phase 2– Addressing EXPORTS Sub-Question 3

While a major component of the EXPORTS program will involve field campaigns to characterize different ECC states, the lasting impact of the project depends critically on how these observations are translated into better larger-scale constraints and uncertainty estimates for export and its subsequent fate from remote sensing, *in-situ* observations, and numerical models. EXPORTS SQ3 builds on the results from both SQ1 and SQ2 (Figure 1) and is divided into four sub-questions (Table 1). The expected SQ3 outcomes include synthesis products on carbon flows and mechanisms, diagnostic and prognostic state estimates of ocean export and carbon flows at broader spatial and temporal scales, identification of additional measurement needs, and better informed and tested models of varying complexity that hopefully improve projections of the forced Earth System response. SQ3A-C specifically addresses estimates for contemporary biogeochemical processing in the euphotic zone and the mesopelagic, while SQ3D addresses projections of the ocean biological pump under potential future climates (Table 1).

Addressing SQ3 requires an integrated hierarchy of synthesis and modeling approaches that are closely linked with analysis and interpretation of EXPORTS field data,associated remote sensing data, and other similar ocean data sets, including the assembly of EXPORTS data products and wiring diagrams (Section 4.4). SQ3-related efforts should encompass (1) a range of numerical modeling and data synthesis approaches, (2) statistical and diagnostic analysis of in-situ and remote sensing data, (3) zero and 1-dimensional process-based representation of carbon flows in the upper ocean, (4) state estimation and ocean observing system experiments (OSSEs) that can resolve the submesoscale to mesoscale regime, and (5) 3-D prognostic regional and global-scale ocean biogeochemical models and coupled Earth System models that seek to forecast present-day conditions and future responses under different climate scenarios.

The SDT recommends that the majority of SQ3 related efforts be implemented during Phase 2 of the project in order to take full advantage of the observations collected for SQ1 and SQ2 in Phase 1. However, some projects to address SQ3 are recommended to occur earlier, either before or during the fieldwork in Phase 1. For example, the preparatory phase before EXPORTS (Fall 2016-2018; Figure 2) will support work on data mining of ECC states that will contribute additional EXPORTS-related data products as well as OSSEs that could be used to guide EXPORTS mechanistic and mesoscale and submesoscale sampling strategies. Phase 1 is envisioned in the Goal Plan to include now-cast modeling in support of the ship, satellite and autonomous platform observations. Thus, synthesis will occur throughout the EXPORTS Goal Plan program, not just during Phase 2.

In the proposed EXPORTS timeline (Figure 2), Phase 2 occurs during 2022-2024 and thus, importantly overlaps with final year of Phase 1 and assembly of data products to facilitate information exchange between the Phase 1 field and remote sensing projects and the Phase 2 synthesis and modeling projects. For costing purposes, 8 projects supported in Phase 2 for the Goal Plan were estimated, with 2 projects per SQ3 subquestion (Table 3).

The expected Phase 2 outcomes will likely include additional synthesis data products and model products (e.g., code and model output). Similar to the data products from Phase 1, the Phase 2 synthesis and model products will be made publically available through EXPORTS data archive in coordination with the EXPORTS Project Office and with other data repositories (SeaBASS, BCO-DMO, PANGEA, etc.; see Section 4.6).

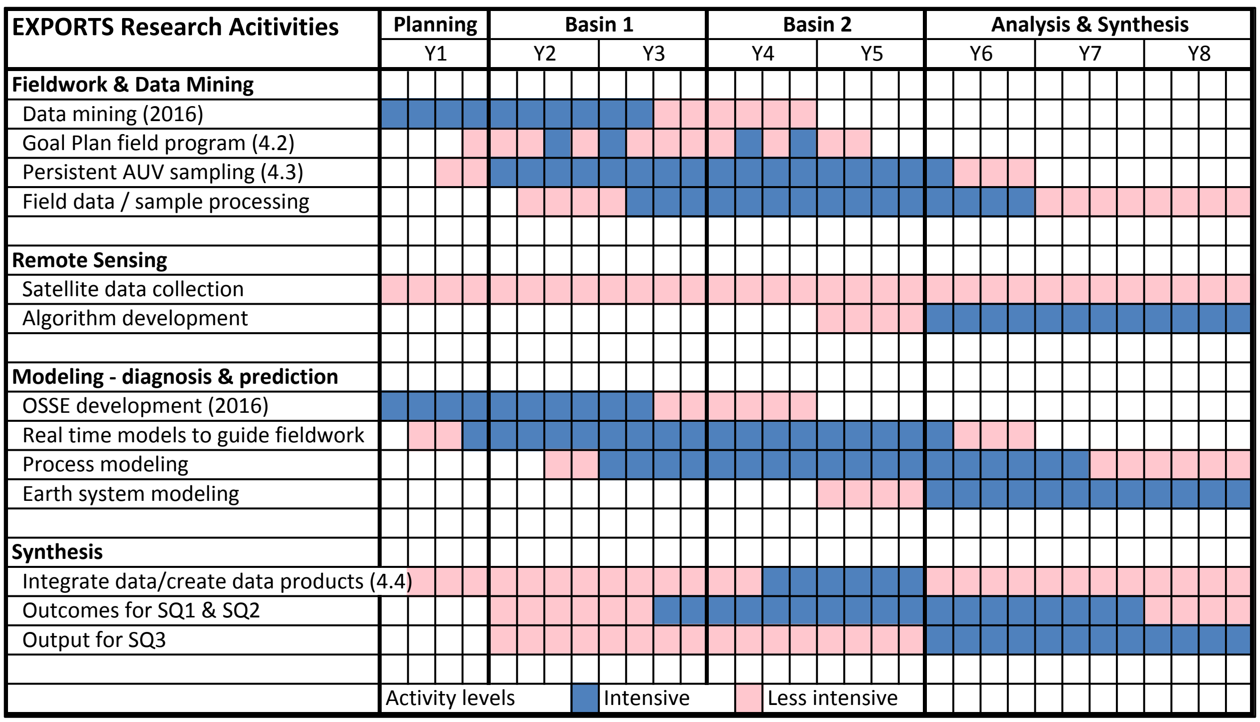

Figure 5 – A generic timeline for conducting research activities in support of the EXPORTS Goal Plan. Although this is presented as a generic timeline, at the time of completion of this document Y1 corresponds to 2017, Basin 1 is the Atlantic and Basin 2 is the Pacific.

4.6 Project Integration and Management

The many research activities that need to be integrated if the EXPORTS Goal Plan is to be successful are illustrated in Figure 5. Here, EXPORTS research activities are partitioned into Fieldwork & Data Mining, Remote Sensing, Modeling, and Synthesis and placed along a generic timeline so project interdependencies can be visualized and the needs of project integration assessed. There are four periods to the Goal Plan generic timeline: Planning, Basin 1 (now Atlantic), Basin 2 (Pacific), and Analysis & Synthesis. Figure 5 illustrates how data from the field program and data mining feed into the Modeling, Remote Sensing, and Synthesis activities. It also visualizes the time required to process field data and samples and how data preparation activities need to lead the Modeling and Synthesis activities.

The complexity of the EXPORTS Goal Plan (Figure 5) necessitates serious consideration of project management and governance. The EXPORTS SDT recognizes that there are a multitude of factors that will determine the effective governance structure for EXPORTS. Here, we outline various governance elements viewed by the SDT as important for effective execution of the Project. Many of these ideas are based upon the SDT's experiences in large-scale, multi-PI research projects like the U.S. JGOFS, GEOTRACES, CLIVAR/Repeat Hydrography, NAAMES, and Tara Ocean.

It is recommended that governance of EXPORTS entail close coordination between agency Program Managers and a Project Leadership Team (PLT). It is envisioned that the PLT consists of (1) a Lead Scientist and a Deputy Lead Scientist, (2) a Science Steering Committee, and (3) an EXPORTS Project Office. In collaboration with the agency Program Manager(s), the PLT will be responsible for oversight and coordination of field campaigns, oversight of data management, and organization of outreach activities. To ensure program vitality while maximizing stability, it is recommended that the Lead Scientist and Science Steering Committee positions be rotated at strategic intervals throughout the program.

Lead and Deputy Lead Scientists and Science Steering Committee – If the 7-year EXPORTS Goal Plan program were implemented, it would be prudent to plan leadership rotation. One solution that retains consistency would be for the Lead Scientist to remain in office during Phase 1 of the Goal Plan (years 1-5) and then the Deputy Lead Scientist assuming Lead responsibilities during Phase 2 (years 6 & 7). A new Deputy may be appointed at this time. The Project Leadership Team (PLT) should consist of the Lead Scientist, the Deputy Lead Scientist and a Science Steering Committee. The assembled PLT should be composed of no more than 7 members representing each of the primary research areas of the EXPORTS Project, including remote sensing, optics, modeling, autonomous sampling, biogeochemistry, export, food-web interactions, particle dynamics, and physical oceanography. The Science Steering Committee will work directly with the Lead Scientist and Deputy to advise Project Office activities, orchestrate the staging of all field activities, and facilitate and monitor partnerships and collaborations. Decisions will be made in conjunction with the PIs and funding agency representatives following a consensus process. Turnover within the Science Steering Committee may be staggered following the phases of the project (e.g., members rotate after Basin 1 & 2 investigations).

EXPORTS Project Office - The purpose of the Project Office is to (1) provide cruise planning and logistical support for cruises and deployments, (2) enhance communication among investigators and international partners, (3) direct the hydrographic, underway, towed body profiler, and autonomous platform operation teams during cruises, (4) oversee data submission by PIs to central data archives, (5) construct and disseminate synthesized data products (see below), (6) oversee and coordinate archived and vouchered sample materials, and (7) organize public, community, and agency outreach activities, including EXPORTS' online presence. Essential to the success of EXPORTS, these Project Office activities will include organization of pre-cruise planning meetings, post cruise data-interpretation and synthesis meetings and facilitation of communications among EXPORTS scientists and external collaborators (national or international). The Project Office, as advised by the PLT, will also direct the sampling conducted by the competed hydrographic, towed profiler, and autonomous platform operation teams.

The Project Office will be responsible for conducting 'All Hands' annual PI meetings. Small group data and synthesis meetings will also be needed. Face-to-face meetings are essential to ensure that the synthetic activities required to answer the science questions are conducted. Many community commenters, especially early career reviewers, noted the importance of face-to-face meetings in developing research capacity and setting one's career trajectory (see Draft Implementation Plan Comments). The Project Office will also be responsible for communicating data submission requirements and timelines to the PIs and coordinating data submissions with the EXPORTS data management group and sample archives. It is expected that agency Program Managers will direct data submission to their established permanent archives(e.g., SeaBASS for NASA and BCO-DMO for NSF). If multiple archives emerge as EXPORTS repositories, the Project Office will ensure consolidation and synergies of efforts, such as direct links to data via the EXPORTS Web site. The Project Office will also be responsible for communicating EXPORTS activities and findings to the public and policy stakeholders, which will involve routine communication with agency Offices of Communication. Project Office education and outreach activities will span from training programs for young scientists and K-12 curricula development to communicating EXPORTS concepts to the public and government officials.

Data Synthesis, Management, and Archiving - Science data created through the EXPORTS Project will include 'primary products', 'synthesized data products', and 'model products'. Primary products encompass all direct field measurement data. As noted above, the Project Office will provide guidance to EXPORTS PIs on data submission requirements and timelines. All primary product submissions will follow the NASA Earth Science Data and Information Policy (http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/) and will require all PIs to submit all the data they have been funded to collect into designated public data repositories (following quality control) no later than one year following collection. The Project web site will provide updated links to all the data repositories where data have been submitted (SeaBASS, BCO-DMO, PANGAEA, etc.). Furthermore, all EXPORTS data will be archived within NASA's SeaBASS.

Synthesized data products are created through the integration of primary products and include properties such as export flux, productivity, plankton community structure, organic matter partitioning, etc. (see Section 4.4 above on EXPORTS Data Products and Table 3 in the EXPORTS Science Plan). These synthesized products are of central importance to answering the EXPORTS science questions and their construction and dissemination will be the responsibility of the Project Office. To this end, the Project Office will work with all PIs to coordinate field reporting and metadata standards. The synthesized data products will be submitted to the EXPORTS data archive and published in a scientific journal within one year after the last field campaign. A later submission of data will require the consent of the PLT. By publishing the EXPORT data products in a timely manner, all the pertinent aspects of the data (methods of collection and analysis, QA/QC procedures, access) will be provided to maximize its use by the larger community.

The primary and synthesized data products are essential for EXPORTS synthesis and modeling activities. Output from these modeling activities will also be submitted to the central EXPORTS data archive, with these submissions coordinated by the Project Office and other data repositories (SeaBASS, BCO-DMO, PANGEA, etc.).

4.7 Potential International Collaborations and Partnerships

The SDT was charged to design a study that leverages, complements, and is compatible with ongoing North Atlantic and North Pacific research projects and field observations of national and international organizations working in the region, where possible (see NASA's Charge to the SDT). Direct, side-by-side international collaborations like these would be very useful in reducing costs to the U.S. agencies and thus increase the chance that the Goal Plan may become a reality. However, useful partnerships with EXPORTS may also be made where a partnering organization would sample NPP export and fate pathways and supporting information in another region of the world's oceans. Data collected by these "independent partners" would expand the parametric range of ECC states used to develop and test satellite algorithms and numerical models for answering the EXPORTS Science Questions.

Table 5: Summary of Potential International Partnerships as of October 2016 (the complete Potential International Partnerships table is available in Section 7.6 of this document)

Project	Country	Cruise year	Region	Status
AORA (aka AORA-CSA)	EU	N/A	N/A	Funded to 2020
APERO	France	2019	North Atlantic	In Planning
ATLANTOS	EU	N/A	N/A	Funded
ATLAS	EU	N/A	multiple cruise location	Funded to 2020
BioPSis	France	2017	BATS / and maybe Arctic	Funded
BOCATS (OVIDE, GO-SHIP)	Spain	2016	NE Atlantic - Spain to South Greenland	Funded
COMICS	UK	2017/2018	S. Georgia / Benguela upwelling	Funded
FLUXES	Spain	June- July 2017	Eastern margin N.Atlantic	Cruises requested
FRAM	Germany	2017/18 annually till 2021	Fram Strait	Funded
Icelandic national programme	Iceland	Annual	Subpolar Atlantic	Funded
ICOS/Argo Pilot study	Germany	N/A	Subpolar N Atlantic	Submitted
Indian Ocean Expedition	Australia	2018/2019	Southeast Indian Ocean (110E)	Submitted
Line P	Canada	N/A	Ongoing Line P incl EXPORTS site in the NE Pacfic	Ongoing
MesoPelagi Cosms	Germany	N/A	Fjords	Submitted
National German project	Germany	N/A	Subpolar N Atlantic?	In Planning
NIWA	New Zealand	2017-2020	SH STW and SAZ	Ongoing
Ocean Frontier Institute	Canada	N/A	NW Atlantic and Arctic Gateway	In planning
PAP sustained observatory	UK	Annual	PAP site 49N,16.5W (NE Atlantic)	Funded
Seacycler	Canada	Ongoing	Labrador Sea	Ongoing
SeaPump	Germany	2017	Antarctic, Fram Strait, Cape Blanc, PAP & Spitzbergen.	Ongoing
SFB754	Germany	2016-2019	Eastern subtropical south Pacific	Funded
Shipline Liverpool-Halifax	Germany	several times each year	TransAtlantic crossing	Ongoing
SponGES	EU	N/A	N/A	Funded to 2020
TBD: Japanese Program	Japan	2020	NE subarctic Pacific	In planning

The SDT identified multiple opportunities for international partnering that span the continuum from direct, side-by-side collaboration in EXPORTS field campaign cruises to independent comprehensive EXPORTS-type field campaigns at other times of the year or in diverse locations that increase the number of ECC states sampled. A summary of these potential partnerships is listed in Table 5 (the complete table is provided in Potential International Partnerships in the supplementary section of this document; Section 7.6). Information on international partnerships was requested as part of the comments solicited from the community (see Draft Implementation Plan Comments) and the STD did conduct its own study of the potential partnerships. Nevertheless, the SDT would not be surprised if promising partnership opportunities were missed.

Overall, the SDT encountered a uniformly high degree of enthusiasm for potential international collaborations with the EXPORTS field program. As evidenced in Table 5, many possible collaborative projects were discovered, some of which are already funded while others that are in planning phases. The SDT thought that the likelihood of substantive direct partnering with the Goal Plan would be greater for the Northeast Pacific cruises than for the North Atlantic because of the longer lead time for planning the Station P cruises (Figure 2). In particular, partnering with ongoing Canadian programs and working to assist with new Japanese planning for sampling in the Northeast Pacific seems very promising. Opportunities are available in the North Atlantic, but it is unclear whether they could happen simultaneously with the planned EXPORTS fieldwork. Table 5 also illustrates many excellent opportunities for independent projects that will increase the number of ECC states. Further details are available in the complete Potential International Partnerships table (Section 7.6).

There are substantial challenges and some risks associated with a reliance on international partnerships. With simultaneous collaborations, foreign ships and science groups could conceivably cover many of the EXPORTS key measurements. It is critical then that logistics are worked out for sample sharing and measurement / instrument intercomparisons so that high quality observations are obtained. Regardless of whether the international collaborations are conducted side-by-side with EXPORTS or independently in another ocean basin, resources should be formally allocated to ensure the success of these international partnerships (e.g. exchange of scientists, intercalibration costs). This will help ensure that the data collected will enable the extrapolation of the EXPORTS data products to global spatial scales and to future times.

Lastly, existing international scientific organizations, such as Integrated Marine Biogeochemistry and Ecosystem Research (IMBER), Scientific Committee on Oceanic Research (SCOR), International Council for the Exploration of the Sea (ICES), North Pacific Marine Science Organization (PICES) and others should be engaged in the development of robust international collaborations with EXPORTS.

5.0 Estimating Project Costs

The goal of the EXPORTS Implementation Plan is to devise an efficient strategy to implement the EXPORTS Science Plan as proposed, vetted and approved. The previous section (Section 4.0) lays out the SDT's suggestions for Goal Plan execution (along with the supporting supplementary materials). Here, a robust cost estimate for the Goal Plan ("Plan

A", this section) and potential descoped plans ("Plans B-G", next section) is presented along with suggestions of the potential for scientific success of the various descoping options.

5.1 Costing the Goal Plan

There were many assumptions made in costing the Goal Plan. As described in Section 4.1, the Goal Plan would be conducted in two phases, making it a 7-year program (Fig. 2). The first five-year phase is aimed at answering Science Questions 1 and 2, and all field expenses are contained in Phase 1. A total of 23 projects were estimated to be needed to conduct Phase 1 (Table 3), each costed at an average of $300K per year during the two field years, $200K per project per year during the analysis years, and $50K for capital equipment per project. Ship time is budgeted at expected day rates for ships in the Global class (Process ship) and Ocean class (Survey ship and autonomous platform deployments/recovery/CTD ops). Ship time requirements are included in the Notional Cruise Plan (see Section 7.3). A total of 338 sea days are needed to achieve the Goal Plan.

Cost estimates for the hydrographic group were made based upon at-sea labor during the cruise years for running the CTD and underway sampling systems on both the survey and process ships and the towed profiler on the Survey Ship (see Platform Requirements; Section 7.4). This includes at-sea analyses (fluorometric chlorophylls, dissolved oxygen, etc.) and collection of samples to be analyzed on shore (nutrients, particulate organic matter (POM), DOM, HPLC pigments, etc.), as well as samples to be archived for future analyses. Based upon the Notional Cruise Plan, we assume that 1,000 samples will need to be collected by both ships per cruise, with an average on-shore analysis cost of $300 per sample. We have assumed that not all depths will be sampled and not all samples will be analyzed, with some archived for future analysis (e.g., genomic profiling, geochemistry, etc.). It is assumed that the Multiple Opening Closing Net and Environmental Sensing System (or similar) and the towed profiler system will be included in the UNOLS ship support for the program (see Platform Requirements; Section 7.4). Autonomous platforms will be purchased following the plan laid out in Section 4.3 and are considered expendable. Estimates of the operations costs required to produce useful data were made based upon past experiences of the SDT members. Logistics costs are for shipping/travel using a central NASA-like contractor, and data management and project office costs are included. A 10% contingency on the integrated fieldwork expenses is included and will be held by the agency. Following the phasing suggested in Section 4.1, Phase 2 will be 3 years in duration and will start in Year 4 of the overall program (Figures 2 and 5). The Goal Plan assumes that there will be 8 Phase 2 projects (Table 3), each costed at $200K per year.

The total cost for the Goal Plan is $71.5M for 7 years. The spreadsheet illustrating the calculations is provided in the Science Plan Budget document (see tab "A" for the Goal Plan). Nearly one-half of the Goal Plan costs (49%) go to PI-led science projects (Figure 6). Beyond that, 18% goes toward ship support, 11% toward autonomous platform purchases and operations (AUVs), 9% for contingencies (10% of the Phase 1 costs), 7% for project office and data management and 6% for the hydrographic group and sample analyses.

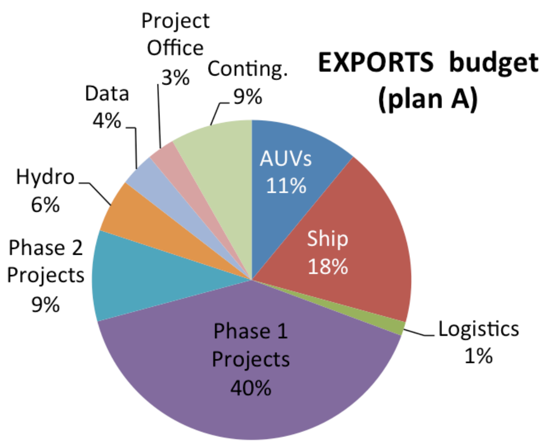

Figure 6 – Breakdown by category for the Goal Plan cost estimate (Plan A in the Science Plan Budget document).

The SDT acknowledges that the Goal Plan costs could be reduced by planning fewer projects or collecting fewer samples. However the charge to the SDT was to create a robust cost estimate for the Goal Plan. The process employed by the SDT is likely to have resulted in an estimate that is robust to minor omissions. Furthermore, partnerships from U.S. research agencies or international participants would, in principle, share in the costs of conducting the Goal Plan.

5.2 Descoping Options

Descoping options are required to help understand the tradeoffs between project investment, risks to success, and scientific and agency rewards. The SDT considered many ways to pare down the Goal Plan, including the number of projects, cruises, AUVs, ships, basins and combinations thereof. The descoping options presented below were costed similarly to the Goal Plan and taking into account the fractional decreases in each category from the Goal Plan. Details are provided in the Science Plan Budget (Section 7.4).

Table 6 – EXPORTS Goal Plan and Descoping Option Costing

	Cruises	Basins	Ships	Projects in Phases 1 & 2	Years	Sea Days	Total Cost
A: Goal Plan	4	2	2	23 / 8	7	388	$72M
B: Goal "Lite"	4	2	2	20 / 6	7	388	$62M
C: Full Plan but 1 ship	4	2	1	18 / 8	7	196	$57M
D: 3 cruise, 1 basin, 2 ships	3	1	2	23 / 8	7	263	$58M
E: 2 cruise, 1 basin, 2 ships	2	1	2	23 / 0	5	164	$39M
F: 2 cruise, 1 basin, 1 ship	2	1	1	18 / 0	5	95	$30M
G: 1 cruise, 1 basin, 1 ship	1	1	1	18 / 0	4	50	$22M

A summary of the descoping options is given in Table 6, providing the number of cruises, basins sampled, ships, projects, years and sea days, the existence of Phase 2, and the total project costs. Although not detailed in Table 6, the autonomous sampling efforts scale back in proportion with other activities, with the large-scale float array given top priority.

Capacity to answer EXPORTS science questions diminishes as the project moves from the Goal Plan (Plan A in Table 6) to the 1 ship / 1 cruise descoping option (Plan G). In particular, Plans E, F and G will not have Phase 2 projects and hence will not answer SQ3. The descoping options lying between Plans A and G provide different capabilities and constraints, and present varying risks for accounting for the export pathways and NPP fates, and ultimately achieving overall program success.

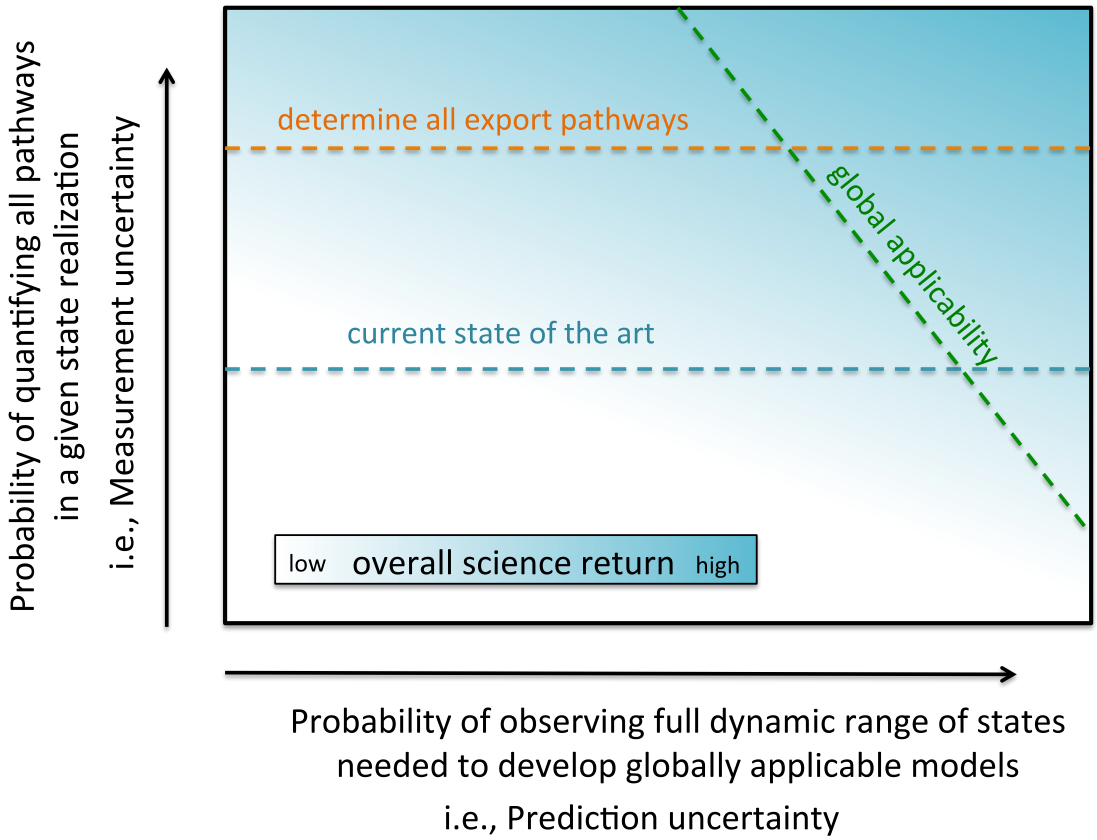

Figure 7 – Illustration of the tradeoffs between "Measurement Uncertainty" (y-axis) and "Prediction Uncertainty" (x-axis). The dashed lines show the "current state of the art" (blue), the as-yet-unachieved simultaneous "determination of all export pathways" (orange) and the region in the upper-right corner of the trade space that optimizes the construction of "globally applicable models" (green).

The overall EXPORTS approach is to develop and validate ocean carbon cycle models from observations made over a range of ECC states. This means that EXPORTS must completely observe the fundamental NPP export and fate pathways, as well as collect the supporting data that are required to develop advanced satellite algorithms and numerical models valid over the global range of ECC states (from both the planned field work and the mining of previous results). Thus, there are two variables that must be considered when evaluating the tradeoffs among the descoping options from the Goal Plan. One axis (the vertical axis in Figure 7) relates how well the fundamental NPP export and fate pathways can be resolved by each option. We term this "Measurement Uncertainty" as it measures the probability that a given field campaign will be able to measure all of the export pathways. The other axis (the horizontal axis in Figure 7) illustrates how well the entire set of field campaigns can observe a wide enough range of ECC states to allow globally applicable satellite algorithms and numerical models to be developed and tested. This second variable can be thought of as the "Prediction Uncertainty".

The lowest risk – that is, the highest science returns – will occur in the upper right corner of the tradeoff space illustrated in Figure 7. In that region of the trade space, Prediction Uncertainty is lowest (i.e., many ECC states are sampled) and Measurement Uncertainty is lowest (i.e., all pathways are well sample). Elsewhere in the tradeoff space, the measurements may only partially constrain the ECC state (lower on the vertical axis) or may provide an insufficient number of ECC states (left on the horizontal axis). Importantly, Figure 7 illustrates the "current state of the art" (blue horizontal dashed line), the as-yet-unachieved simultaneous "determination of all export pathways" (orange horizontal dashed line) and the space that optimizes the construction of "globally applicable models" (green diagonal dashed line). To date, no field program has simultaneously measured all five of the export pathways and their transformations from the euphotic zone through the twilight zone that are needed to answer the EXPORTS science questions. Hence the "current state of the art" line lies far below the "determine all export pathways" line. By measuring all of the export pathways in a comprehensive manner, EXPORTS has its best opportunity to advance new ground in how we understand and model global ocean NPP export and fate.

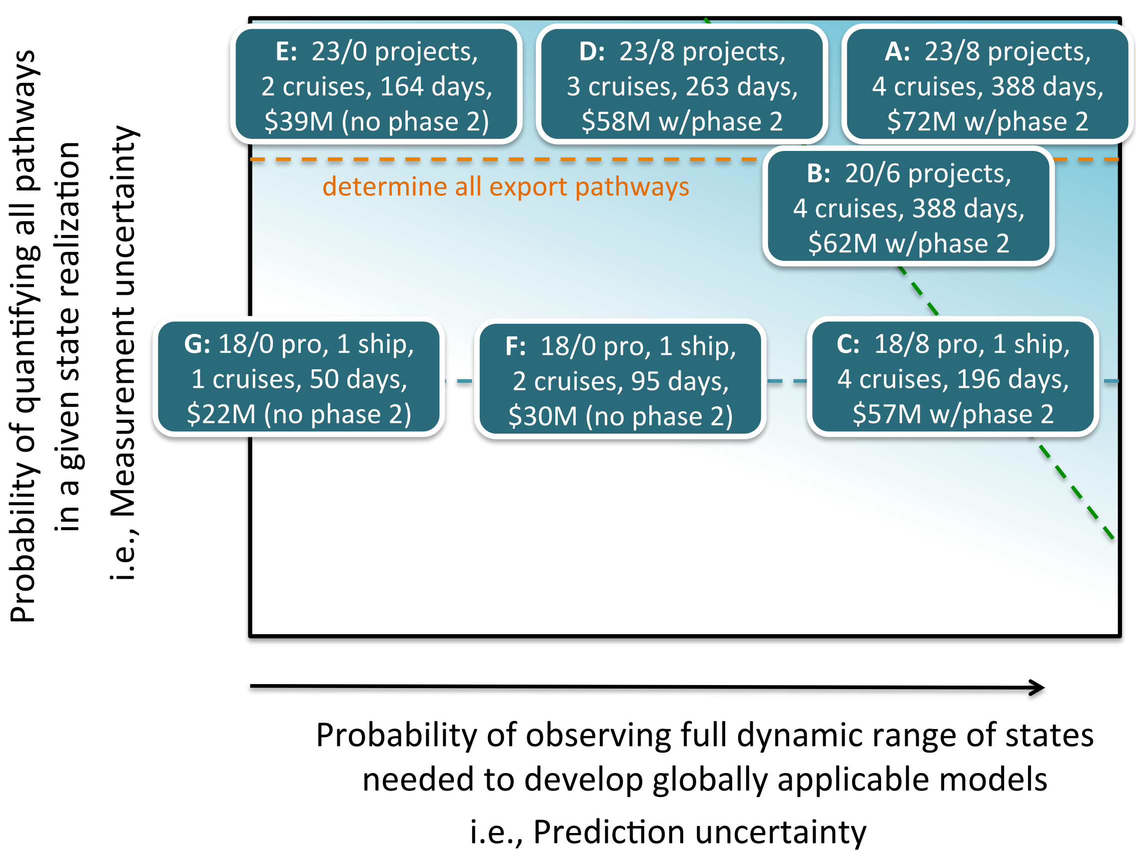

Figure 8 – Illustration of where the Goal Plan and the six descope options from Table 6 lie in the trade space between "Measurement Uncertainty" and "Prediction Uncertainty".

The Goal Plan and the six descoping plans from Table 6 are plotted in the trade space in Figure 8, with locations based upon the SDT's collective judgment. By design, the Goal Plan

(Plan A) lies in the upper right corner and will clearly do the best job among the various options. The Goal Plan "lite" option (Plan B) will have fewer projects and hence will increase measurement and prediction uncertainty levels. The two-ship plans with the same number of projects as the Goal Plan but reduced number of cruises/basins (Plans D & E) will achieve low measurement uncertainty but will not provide the same number of ECC states and thus will have higher prediction uncertainties. The single ship options (Plans C, F & G) will not be able to sample all of the export pathways as there are simply not enough berths and wire time available. However, all three single-ship descoping options will provide state-of-the-art observations over a range of prediction uncertainty levels.

Similar outcomes likely lie along the diagonal line in Figure 8, suggesting broad global applicability. In particular, there are suggestions of similar success probability for Plans B (Goal Plan "lite"), D (2 ships, 3 cruises and 1 basin) and C (1 ship, 4 cruises and 2 basins). While international partnering and data mining efforts will increase the number of states sampled, the inherent risks are greater and must be carefully managed (similar sampling protocols, standards, etc.) to ensure that the measurements are compatible.

5.3 Community / SDT Consensus on Descoping Options

The community comments on the draft plan provided many good insights for what an acceptable minimum would be for EXPORTS (see Draft Implementation Plan Comments). Nineteen respondents said that only the Goal Plan (Plan A) would adequately answer the EXPORTS science questions. Sixteen said that the 3 cruise, 2 ship option (Plan D) would be adequate while 10 reviewers thought that the Goal Plan "lite" version (Plan B) would work. Other proposed descoping options had fewer positive comments. The SDT recognizes that this determination of preference from the written comments is inexact at best. However the community preferences appears to be for two ship options that would determine all export pathways (at least near the horizontal dashed orange line in Figure 8) over single ship options (near the horizontal dashed light blue line in Figure 8). Several participants commented that the development of robust international partnerships would help expand the number of ECC states that would be available. This suggests that it is more important to make the investment in a sampling program that samples all of the NPP export and fate pathways, rather than implementations that sample imperfectly over a wide range of ECC states. It should also be mentioned that no respondents stated that the Goal Plan would be inadequate. It was strongly recommended by the community that the Phase 2 synthesis activities should not be separated from the Phase 1 field work and, further, that these two phases should be conducted simultaneously if at all possible.

Based upon the community comments and its own self-study, the SDT concludes that the Goal Plan is the only plan that would answer the EXPORTS science questions with a high degree of certainty. Other descoping options, such as the Goal Plan "lite" (Plan B) and the 3 cruise, 2 ship option (Plan D), would be adequate if necessary. The other options would not sample adequately all of the NPP export and fate pathways or enough ECC state realizations to adequately answer the EXPORTS science questions.

The SDT strongly recommends that any descoping option for EXPORTS must 1) quantify all of NPP export and fate pathways and 2) include Phase 2 synthesis and modeling activities throughout. Any field campaign program without these two components would not be EXPORTS.

6.0 Challenges going forward

While individual components of the export and fate of global NPP have been addressed in the past, only through a comprehensive, highly coordinated program such as EXPORTS will we be able to quantify the key carbon exchange and export pathways and address the considerable uncertainties that exist to date. Reliable monitoring of rates of contemporary ocean carbon cycling and prediction of future changes depends upon data like those suggested here to build and validate numerical models and satellite algorithms. In addition, state-of-the-art technologies now at the community's disposal have never before been employed in such a coordinated fashion to answer coupled ocean ecosystem / carbon cycle questions.

There are challenges that a comprehensive, high-technology, and multi-partner field program such as EXPORTS presents. Striking a balance among discovery, innovation, broad participation, agency mission, and cost will be complicated. A strong partnership between the funding agencies, Project Leadership Team, and participating researchers will need to be in place to achieve the best possible outcome for all parties. In order to accomplish the goals of EXPORTS (especially those relevant to NASA), we must also ensure that Phase 2 projects should be implemented so that SQ3 questions are answered. NASA has recently selected pre-EXPORTS PIs under ROSES 2015 to conduct data mining activities and OSSE development, which will certainly improve the plans suggested here. Furthermore, the path forward must also include extensive data mining of previous results to reduce the risks in sampling too few ECC states.

The establishment of partnerships, within the U.S. and beyond, would greatly assist in the implementation of a highly interdisciplinary, comprehensive field, modeling and synthesis program like EXPORTS. International partnerships and their challenges have been discussed previously (Section 4.7). There are clear partnerships with U.S. national agencies that will benefit both the NASA EXPORTS program and reciprocally benefit partner agencies through the comprehensive biological, chemical, and physical framework that EXPORTS provides. One such example emanated from an NSF-funded workshop on the "Biology of the Biological Pump" in February 2016. The goal of this workshop was to prioritize future research areas that are likely to make significant advances in our understanding of the biological processes regulating organic matter export and its consumption in the oceans. The broad research themes that resulted from this workshop (food web regulation of export, the dissolved-particulate continuum, variability in space and time) are directly relevant to the goals of EXPORTS (see http://www.us-ocb.org/publications/BioPump-Final.pdf). Other potential synergies include, for example, collaborations with NOAA's Galway Agreement activities or NOAA climate office investments in biogeochemical ARGO float deployments.

One major challenge for partnerships is matching timelines for direct collaboration in field campaigns. This challenge this includes not only project funding, but also ship scheduling and personnel participation on other vessels. The EXPORTS timeline (Figures 2 and 5) is aggressive and will require an intensive effort for coordination of methodologies, sensor calibration and cross calibration, sampling, and all aspects of data management from database structure to timing for data sharing. Sufficient person power and resources will need to be dedicated to international coordination and PI data workshops to fully take advantage of such partnerships.

7.0 Supplemental Materials

7.1 EXPORTS SDT Membership

The EXPORTS Science Definition Team (SDT) was competed to create an Implementation Plan to execute the EXPORTS Science Plan. Details concerning the formation of the SDT and its charge are available at http://cce.nasa.gov/obb/exports/team.html.

The SDT members are David Siegel (Lead; UCSB), Barney Balch (Bigelow), Mike Behrenfeld (OSU), Ken Buesseler (WHOI), Craig Carlson (UCSB), Nicolas Cassar (Duke), Ivona Cetinic (NASA GSFC), Scott Doney (WHOI), Meg Estapa (Skidmore), Bethany Jenkins (URI), Ken Johnson (MBARI), Craig Lee (UW APL), Adrian Martin (SOC), Susanne Menden-Deuer (URI), David (Roo) Nicholson (WHOI), Uta Passow (UCSB), Mary Jane Perry (UMaine), Natassa Romanou (NASA GISS), Deborah Steinberg (VIMS), Andy Thompson (CalTech) & Jeremy Werdell (NASA GSFC). *Ex officio* SDT members are Quincy Allison (NASA ESPO), Paula Bontempi (NASA HQ), Peter Griffith (NASA GSFC), Laura Lorenzoni (NASA HQ), and Mike Sieracki (NSF).

Contact information is available at http://cce.nasa.gov/obb/exports/team.html.

7.2 Complete Measurement Table

The Complete Measurement Table groups the measurements needed to answer the EXPORTS science questions and subquestions. They are grouped by program element (column B), with shorthand for the platform, method, science needs and measurement types and purpose (columns C, D, E, F and G). Comments on each entry by row are provided in an accompanying Measurement Footnote Document. The measurements are further characterized regarding which of the first two Science Questions and sub-questions each would address (column H and I). Distribution of these measurements among the Survey Ship, Process Ship, and Autonomous platform cruises (pre/post process cruises) is also suggested (columns J-P). In making these suggestions, a priority was assigned for the need to make each measurement on the different platforms, using a ranking of 1 for "essential" for addressing the science questions noted and 2 for "useful". Finally, the measurements are grouped by EXPORTS data products (1e- primary, and 2e- secondary) following the original EXPORTS Science Plan (Table 3; columns Q & R). The Complete Measurement Table is one way to assess the required measurements and needs across platforms and cruises and was used in this document to determine costs, cruise planning, and scoping/descoping options. It should not be seen as a final list of cruise activities or projects.

Complete Measurement Table URL:
http://cce.nasa.gov/obb/exports/documents/Complete_Measurement_Table.xlsx

Measurement Footnote URL:
http://cce.nasa.gov/obb/exports/documents/Complete_Measurement_Table_Footnotes.pdf

7.3 Notional Cruise Plan

The Notional Cruise Plan enables per cruise estimates of activities for costing the Goal Plan. Activities considered include the number of sea days required (27 on station), days needed to make a single ecosystem / carbon cycling state assessment (8 days), berths available to Phase 1 projects and the hydrographic and towed profiler groups (35 process and 24 survey ship), CTD casts (~80 process & ~200 survey), analytical samples to be run onshore (~1000 from both ships), towed profiler survey duration (~12 days total), MOCNESS casts (12 process ship), and more. The Goal Plan Notional Cruise Plan was constructed in 2 hour increments and the various activities required to measure the export pathways and NPP fates were placed on this matrix for both ships. Care was taken to account for any interdependencies among required measurements (detailed in the Complete Measurement Table).

Goal Plan notional cruise schedule URL:
http://cce.nasa.gov/obb/exports/documents/Notional_Cruise_Plan.xlsx

7.4 Platform / Sampling Requirements

The Platform Requirements document describes details for the measurements to be made and the sampling conducted in the EXPORTS Goal Plan implementation.

Platform requirements URL:
http://cce.nasa.gov/obb/exports/documents/Platform_Requirements.pdf

7.5 Goal Plan and Descope Options Costing

Science Plan Budgets were estimated for the EXPORTS Goal Plan (Plan A in the table), as discussed in Section 5.1, and for the various descoping options outlined in Section 5.2 (Plans B through G in the spreadsheet). A summary is also included to help compare the various options. For each scenario, these tables include numbers of instruments (floats, gliders, traps), ship days for two types of ships - the larger Process Ship (global class) and the smaller Survey Ship (ocean class), which is also used for deployment of autonomous assets prior to the first process cruise (minimal CTD ops expected). A $100K allowance has been allocated for each basin to support potential coastal recoveries of mobile autonomous assets at the end of each field program. Also included is the estimated number of multi-PI projects that might be included in Phase 1 and Phase 2, which is based upon the Measurement Table (not all options have both phases) and includes a budget for small amounts of "PI equipment" (e.g., camera systems, nets, filtration apparatus). The hydrography group budget includes costs for sample collection and on-shore analyses (such as HPLC pigments, dissolved organic carbon, nutrients, particulate organic carbon and nitrogen, etc.). The hydrography group budget also includes salaries for on-board sample collection and processing, CTD operations, and operation of instrumentation on the towed profiler. Logistics costs assume shipping/travel arranged through a central NASA-like contractor. Data management and project office costs are broken down for each scenario and scale to the number of projects and cruises. Descoping options include a reduced number of samples, basins, ships and projects, as well as deletion of phase 2 synthesis and modeling efforts as appropriate.

Science Plan Budget URL:
http://cce.nasa.gov/obb/exports/documents/Goal_Plan_Descope_Budgets.xlsx

7.6 Known international opportunities for partnerships

The table of Potential International Partnerships presents an informal, non-exhaustive list, introducing some international programs, links, and contacts representing EU or national programs. Some of these programs are funded, some are awaiting funding decisions, and others are in early planning stages. Inputs to the table have come from conversations among SDT members and their international colleagues.

Potential international partnership table URL:
http://cce.nasa.gov/obb/exports/documents/International_Partnerships.xlsx

7.7 Review of the Draft Implementation Plan

The draft EXPORTS Implementation Plan was released for public comment by the EXPORTS Science Definition Team (SDT) on July 18, 2016. Both the draft plan and supporting documentation were distributed through the NASA Ocean Biology and Biogeochemistry webpage (http://cce.nasa.gov/ocean_biology_biogeochemistry/exports). The review period was open until September 6, 2016. A total of 48 comments were submitted to obb_comments@cce.nasa.gov for consideration by the SDT. Reviewers ranged from graduate students to emeriti professors. More than one-half of the respondents were graduate students, postdocs, and early career scientists. The reviewers were not told that their comments would be made public. Hence, the SDT decided that neither the identity of the responders nor their complete comments would be made public.

The SDT revised the draft plan based upon the community comments. In particular, comments were useful for deciding which descope options would work and which ones would not. More details on the comments and how they were used in revising the initial draft are available at:

http://cce.nasa.gov/obb/exports/documents/Draft_Implementation_Plan_Comments.pdf