Essential Ocean Variable (EOV): Suspended Particulates

Background and Justification

Suspended particulates include the variables Particulate Organic Carbon (POC) and Particulate Organic Nitrogen (PON); sometimes they are referred to more generally as Particulate Organic Matter (POM). Although it represents a combined measurement of living cells and detrital matter, POM concentration in the surface ocean co-varies with living biomass and thus provides quantitative information on spatial gradients and temporal variations in biomass. Below the euphotic zone, measurement of POM can provide information on organic matter export fluxes and rates of microbial respiration. Another variable included in suspended particulates is Particulate Inorganic Carbon (PIC), which primarily represents calcareous shells of calcifying organisms. Observation of POM within a global observing system would directly address the question of whether the ocean's biomass and productivity are changing. Changes in POM could be important indicators of deteriorating water quality due to eutrophication in coastal regions, and of declines in primary production that could potentially translate up the food chain negatively impacting fisheries. Observation of PIC would directly address the question of what impacts ocean acidification has on calcareous organisms and thus community structure. When combined with traditional ship-based measurements for calibration and validation POC, PON and PIC can be measured autonomously using bio-optical sensors and from space.

Particulate matter export originates from biological processes, such as primary production, calcite (or aragonite) production, and particle sinking, the latter including all processes that may change the particles' sinking speed (e.g., grazing by zooplankton, or aggregation). Thus, they strongly depend of the state of the biological system at the surface, as determined by season, biogeography, etc. The potentially large variation in time and space, together with methodological complications for a long time has complicated the direct observation (via shallow sediment traps) of particulate matter export on global scale. Derived estimates of export, such as calculated from remote sensing, include assumptions about biogeochemical interactions, that, when used for model evaluation, may not coincide with model prerequisites. Recent approaches to assess particulate matter export from optical methods might allow for more direct, but quasi-synoptic data sets, particularly when mounted on autonomous platforms. These methods are still under development. In conjunction with particulate matter export, it would also be desirable to quantify the transport of dissolved organic matter out of and into the ocean surface layer. However, it is difficult to observe these fluxes directly, and it may be an option to determine those from a combination of particle flux measurements and observations of dissolved matter concentrations. The overall readiness for routinely measuring particulate matter export is unfortunately still poor. The potentially most straightforward way would be to start with available remotely sensed ocean colour, to derive gross primary production from these fields, and to use calibrated transfer functions for particle export as based on in-situ measurements (sediment trap data, measurements of dissolved concentrations). This methodology still has big problems, especially for deriving fluxes of calcium carbonate ($CaCO_3$) and biogenic silica (BSi). For inert clay material fluxes the method would not work at all and one would have to rely on in situ measurements. In any case, remotely sensed data can help to identify spatial patterns of biogenic export production. A step change in in situ observations using direct methods including bio-optical technology is needed. Pilot projects should start soon in order to find best practicable solutions.

Export production gradients occur over a multitude of spatial and temporal scales. In order to capture first order trends, it would be desirable to have a spatial resolution of 1-2° in the open ocean and a more refined observational network at narrow upwelling zones (such as off the coasts of Namibia, Mauretania, California, Peru etc.), where probably re-occupations of transects with only few kilometres spacing would be necessary. At least at selected time series stations or regional monitoring sites it seasonal coverage with observations would be necessary. This applies in particular to the polar regions where spring blooms can be highly pulsed and the bulk of annual export rates occur often over only a few weeks of time. In order to assess reliably longer term trends, one would need to assess global variations with an accuracy of 10% of the annual flux. It would be highly desirable to record long-term trends of 1 Gt C yr^{-1} Particulate Organic Carbon (POC) export against a mean background of ca. 10 Gt C yr^{-1}, so that 1 Gt C yr^{-1} POC flux changes over one decade could be quantified reliably. Similar 10% over 1 decade goals would also apply to the other export variables.

Table 1: EOV Information	
Name of EOV	Suspended Particulates
Sub-Variables	Particulate Organic Matter (POM), Particulate Organic Carbon (POC), Particulate Organic Nitrogen (PON), Particulate Organic Phosphorus (POP), Particulate Inorganic Carbon (PIC), Beam attenuation, backscatter, acid-labile beam attenuation Particulate Matter Transport (organic and inorganic), Particulate Organic Carbon (POC) export, Calcium Carbonate ($CaCO_3$) export, Biogenic Silica (BSi) export
Derived Products	Particulate export flux
Supporting variables	Temperature (T), Salinity (S), Inorganic Macro Nutrients Ocean colour, Chlorophyll-a concentration (CHL), Nutrient fluxes including nitrate, phosphate, and silicic acid fluxes (new production), Dust deposition , Primary production (gross, net), Regenerated production, Dissolved oxygen excess, Total alkalinity, Mixed Layer Depth (MLD), Wind speed, Diapycnal eddy diffusion across the mixed layer
Contact/Lead Expert(s)	Suspended Particulates: Barney Balch (Bigelow Laboratory for Ocean Sciences, USA), Emmanuel Boss (University of Maine, USA), Hervé Claustre (Laboratoire d'Océanographie de Villefranche, France), Marlon Lewis (Dalhousie University, Canada), Mary Jane Perry (University of Maine, USA), Oscar Schofield (Rutgers University, USA) Particulate Matter Transport: POC: Stephanie Henson (NOC, United Kingdom); CaCO3: William Balch (Bigelow Laboratory for Ocean Sciences, USA); BSi: Olivier Ragueneau and Christina de la Rocha (IUEM, France); General: Ken Buesseler (WHOI, USA), S. Honjo (WHOI, USA), Tom Trull (UTAS, Australia), Jim Bishop (University of California, Berkeley, USA), David Checkley (Scripps Institute of Oceanography, USA), Lars Stemmann (LOV, France)

Table 2: Requirements Setting (Part 1)				
Responsible GOOS Panel	Biogeochemistry Panel			
Societal Drivers	1. The role of ocean biogeochemistry in climate 2. Human impacts on ocean biogeochemistry 3. Ocean ecosystem health			
Scientific Application(s)	Q 1.1. How is the ocean carbon content changing? Q 1.2. How does the ocean influence cycles of non-CO2 greenhouse gases? Q 2.1. How large are the ocean's "dead zones" and how fast are they changing? Q 2.2. What are rates and impacts of ocean acidification? Q 3.1. Is the biomass of the ocean changing? Q 3.2. How do the eutrophication and pollution impact ocean productivity and water quality?			
Readiness Level	Concept to mature			
Phenomena to Capture	**1** **Reservoir of organic carbon/ eutrophication**	**2** **Variations and secular trends in organic carbon reservoir**	**3** **Ocean Acidification (OA) impacts on PIC production / inventory**	**4** **Net Community Production (NCP)**
Temporal Scales of the phenomena	<u>Coastal</u> Daily to weekly <u>Open Ocean</u> Weekly to monthly	<u>Coastal</u> Daily to weekly <u>Open Ocean</u> Weekly to monthly	Monthly	<u>Coastal</u> Daily to weekly <u>Open Ocean</u> Weekly to monthly
Spatial scales of the phenomena	<u>Coastal</u> 1-100 km <u>Open Ocean</u> 100-1000 km	<u>Coastal</u> 1-100 km <u>Open Ocean</u> 100-1000 km	1-250 km	<u>Coastal</u> 1-100 km <u>Open Ocean</u> 100-1000 km
Magnitudes/range of the signal	0.5 mmol C m^{-3}	0.5 mmol C m^{-3}	??	0.5 mmol C m^{-3}
Desired detection limit relative to the signal	?	?	?	?

Table 2: Requirements Setting (Part 2)				
Phenomena to Capture	**5 POC transport**	**6 $CaCO_3$ transport**	**7 BSi transport**	
Temporal Scales of the Phenomena	Monthly to annual	Monthly to annual	Monthly to annual	
Spatial Scales of the Phenomena	Coastal 1-100 km Open Ocean 25-500 km	Coastal 1-100 km Open Ocean 25-500 km	Coastal 1-100 km Open Ocean 25-500 km	
Magnitudes/Range of the Signal	0.5 Pg C yr^{-1} $decade^{-1}$	0.05 Pg C yr^{-1} $decade^{-1}$	10 Tmol Si yr^{-1} $decade^{-1}$	
Desired Detection Limit Relative to the Signal	± 20 %	± 20 %	± 20 %	

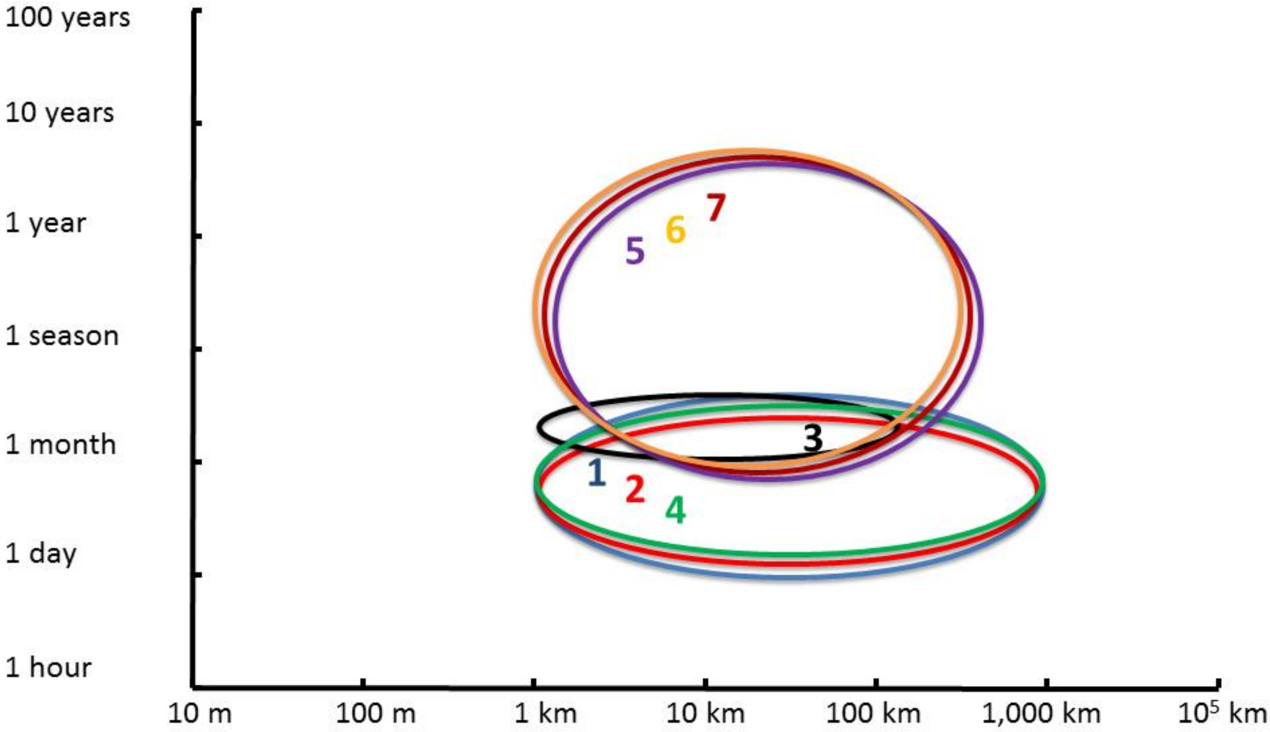

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

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Table 3: Current Observing Networks* (Part 1)						
Observing Network	**Ships Of Opportunity (SOO)**	**Gliders (G)**	**Moorings (M)**	**Profiling Floats (PF)**	**Satellites (SAT)**	**Ship-based Sampling (SS)**
Phenomena Addressed	**1**,**2** & possibly **3**	**1**,**2**	**1**,**2** & possibly **3**	**1**,**2**,**4**	**1**,**2**,**5**,**6**,**7**	Needed for calibration
Readiness Level of the Observing Network (as defined in the FOO)	Mature (**1**,**2**), Concept (**3**)	Mature	Mature (**1**,**2**), Concept (**3**)	Mature	Mature (**1**,**2**), Pilot to mature (**5**,**6**,**7**)	Mature
Spatial Scales Captured by the Observing Network	Every 10°, denser near the coast	Every 10°, denser near the coast	Every 1-5° in coastal domain	Every 5° in open ocean	1-1000 km, surface only	As needed for calibration
Typical Observing Frequency	Monthly	Monthly	Daily to annual	Daily to weekly	Daily	As needed
Supporting Variables Measured[#]	Beam-c, backscatter, possibly acid-labile beam-c	Beam-c, backscatter	Beam-c, backscatter, possibly acid-labile beam-c	Beam-c, backscatter	Reflectance CHLA, Suspended POC, Suspended $CaCO_3$, Suspended BSi	PON, POC, POP, PIC
Sensor(s)/ Technique	Optical	Optical	Optical	Optical	Optical	Lab
Accuracy/ Uncertainty Estimate (units)						
Reporting Mechanism(s)	GOOS Implementation Plan IOCCP Report					

*By an Observing Network we understand a number of reasonably well coordinated observing platforms equipped with technology allowing measurements of this particular EOV.

#We only include Supporting Variables listed in Table 1 as Supporting Variables Measured for this particular EOV.

Table 3: Current Observing Networks* (Part 2)						
Observing Network	**Shallow Sediment Traps (TRAPseds)**	**Optical methods on various platforms$ (OPTM)**				
Phenomena Addressed	**5,6,7**	**5,6,7**				
Readiness Level of the Observing Network (as defined in the FOO)	Pilot to mature	Pilot				
Spatial Scales Captured by the Observing Network	At key regions to calibrate remote sensing	At key regions to calibrate remote sensing				
Typical Observing Frequency	Weekly	Monthly				
Supporting Variables Measured#	Vertical particle flux of POC, $CaCO_3$, and BSi	Vertical particle flux of POC ($CaCO_3$ and BSi?)				
Sensor(s)/ Technique	?	LOPC, UVP, transmissiometer				
Accuracy/ Uncertainty Estimate (units)	?	?				
Reporting Mechanism(s)	GOOS Implementation Plan IOCCP Report					

*By an Observing Network we understand a number of reasonably well coordinated observing platforms equipped with technology allowing measurements of this particular EOV.

#We only include Supporting Variables listed in Table 1 as Supporting Variables Measured for this particular EOV.

$More generic than "video"; also includes laser beam att.

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Table 4: Future Observing Networks*					
Observing Network	**Profiling Floats (PF)**	**Moorings (M)**			
Phenomena Addressed	**5,6,7**	**5,6,7**			
Readiness Level of the Observing Network (as defined in the FOO)	Concept (Pilot?)	Concept			
Spatial Scales Captured by the Observing Network	10-1000 km	1-500 km			
Typical Observing Frequency	Weekly to annual	Daily to annual			
Time-scale until part of observing system	?	?			
Supporting Variables Measured#	Vertical particle flux of POC ($CaCO_3$, and BSi?)	Vertical particle flux of POC ($CaCO_3$, and BSi?)			
Sensor(s)/ Technique	LOPC, transmission meter, (UVP?)	LOPC, transmission meter, (UVP?)			
Accuracy/ Uncertainty Estimate (units)	?	?			

*By an Observing Network we understand a number of reasonably well coordinated observing platforms equipped with technology allowing measurements of this particular EOV.
#We only include Supporting Variables listed in Table 1 as Supporting Variables Measured for this particular EOV.

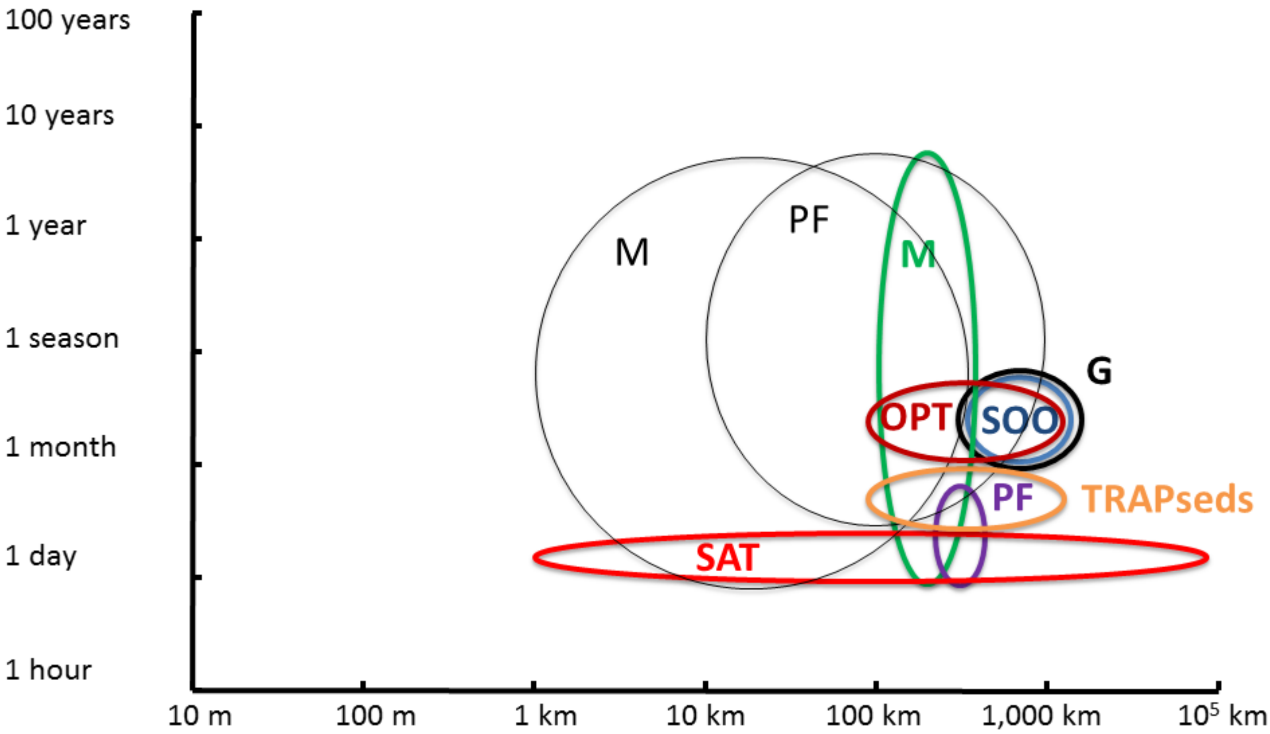

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles). SS not visualized because no temporal or spatial scale was provided.

Table 5a: Data & Information Creation – Beam-c and Backscatter					
Responsible entity and readiness level in each category per observing network	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream Delivery**	**Data Repository**	**Data Product**
SOO	Non-existent	Non-existent	Non-existent	Non-existent	Non-existent
	Concept				
G					
M					
PF					
SAT					
SS					

Table 5b: Data & Information Creation – Ship-based PON, POC, POP, PIC					
Responsible entity and readiness level in each category per observing network	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream Delivery**	**Data Repository**	**Data Product**
SOO	Non-existent	PIs deliver to national data centres	PIs deliver to national data centres	National data centres	None
	Mature				

Table 5c: Data & Information Creation – Particulate Matter Transport					
Responsible entity and readiness level in each category per observing network	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream Delivery**	**Data Repository**	**Data Product**
SAT	MODIS/SeaWiFS	NASA/NASA (Goddard)	NASA/NASA (Goddard)	NASA/NASA (Goddard)	
	Mature				
TRAPseds	Diverse	Diverse	Diverse	WHOI, PANGAEA, etc.	
	Pilot to mature				
OPT	Individual	Individual	Individual	Individual	
	Pilot				
PF	Individual	Individual	Individual	Individual	
	Pilot				

Table 6: Links & References	
Links* (especially regarding Background & Justification)	Use of float-based bio-optics for model validation and assimilation: Bagniewski, W., Fennel, K., Perry, M.J., D'Asaro, E.A., Optimizing models of the North Atlantic spring bloom using physical, chemical and bio-optical observations from a Lagrangian float, *Biogeosciences* **8**, 1291-1307, doi:10.5194/bg-8-1291-2011 (2011) Estimation of PIC from acid-labile backscatter: Balch WM, Drapeau DT, Bowler BC, Booth ES, Lyczskowski E, Alley D The contribution of coccolithophores to the optical and inorganic carbon budgets during the Southern Ocean Gas Experiment: New evidence in support of the "Great Calcite Belt" hypothesis. *Journal of Geophysical Research-Oceans* Special Issue. **116**, C00F06, doi:10.1029/2011JC006941 (2011) Demonstration of POC measurements from floats: Boss, E., D. Swift, L. Taylor, P. Brickley, R. Zaneveld, S. Riser, M.J. Perry, and P.G. Strutton. Observations of pigment and particle distributions in the western North Atlantic from an autonomous float and ocean color satellite. *Limnol. Oceanogr*. **53**, 2112-2122 (2008) Use of backscatter observations for vertical particle flux estimates: Briggs, N., Perry, M.J., Cetinic, I., Lee, C., D'Asaro, E., High-resolution observations of aggregate flux during a sub-polar North Atlantic spring bloom, *Deep-Sea Research* **58**, 1031-1039, (2011) General motivation for autonomous observations of bio-optics: Claustre, H., Antoine, D., Boehme, L., Boss, E., D'Ortenzio, F., Fanton D'Andon, O., Guinet, C., Gruber, N., Handegard, N. O., Hood, M., Johnson, K., Körtzinger, A, Lampitt, R., LeTraon, P.-Y., Lequéré, C., Lewis, M., Perry, M.-J., Platt, T., Roemmich, D., Sathyendranath, S., Testor, P., Send, U. and J. Yoder. Guidelines towards an integrated ocean observation system for ecosystems and biogeochemical cycles, 2010. *in* Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306. (2010) Motivation for use of autonomous data for model validation: Fennel, K., Cetinic, I., D'Asaro, E., Lee, C., Perry, M.J., Autonomous data describe North Atlantic spring bloom, *EOS Transactions AGU*, Vol. **92**, No. 50, 465-466, doi:10.1029/2011EO500002 (2011)
Links for Contributing Networks	No unified network; National Data Centres (e.g. NODC); individual projects (e.g. HOT, BATS)
Data References	

List of abbreviations

EOV – Essential Ocean Variable
GOOS – Global Ocean Observing System
IOCCP – International Ocean Carbon Coordination Project
FOO – Framework for Ocean Observing
POC – Particulate Organic Carbon
POM – Particulate Organic Matter
PON – Particulate Organic Nitrogen
POP – Particulate Organic Phosphorus
PIC – Particulate Inorganic Carbon
$CaCO_3$ – Calcium carbonate
BSi – Biogenic silica
T – Temperature
S – Salinity
NCP – Net Community Production
NOC – National Oceanography Centre
WHOI – Woods Hole Oceanographic Institute
UTAS – University of Tasmania
IUEM – Institut Universitaire Européen de la Mer
LOV – Laboratoire d'Océanographie de Villefranche-sur-Mer
SOO – Ships Of Opportunity
G – Gliders
M – Moorings
PF – Profiling Floats
SAT – Satellites
SS – Ship-based Sampling
TRAPseds – Shallow sediment traps
OPTM – Optical Methods
LOPC – Laser-Optical Plankton Counter
UVP – Underwater Vision Profiler
PI – Principal Investigator
NODC – National Oceanographic Data Center
HOT – the Hawaii Ocean Time-Series
BATS – Bermuda Atlantic Time-Series Study
MODIS – Moderate Resolution Imaging Spectroradiometer
SeaWiFS – Sea-Viewing Wide Field-of-View Sensor
NASA – National Aeronautics and Space Administration