Essential Ocean Variable (EOV): Particulate Matter

Background and Justification

Particulate matter includes a number of variables that describe the suspended particulates (total suspended matter; TSM) and particulate matter transport in the ocean, both organic and inorganic fractions. Particulate Organic Matter (POM) includes Particulate Organic Carbon (POC) and Particulate Organic Nitrogen (PON). 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. 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. Measurements of the inorganic fraction include Particulate Inorganic Carbon (PIC), which primarily represents calcareous shells of calcifying organisms, as well as biogenic silica (BSi). 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.

Apart from aeolian deposition, particulate matter transport 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.

For the glossary of terms and list of abbreviations please see the back of the document.

Table 1: EOV Information	
Name of EOV	Particulate Matter
Sub-Variables	Particulate Organic Matter (POM), Particulate Organic Carbon (POC), Particulate Organic Nitrogen (PON), Particulate Organic Phosphorus (POP), Particulate Inorganic Carbon (PIC), Total Suspended Matter (TSM), POC flux, Calcium Carbonate ($CaCO_3$) flux, Biogenic Silica (BSi) flux
Derived Products	
Supporting variables	Beam attenuation, backscatter, Surface and subsurface temperature , Surface and subsurface salinity, Nutrients, Ocean colour (chlorophyll-a concentration), Phytoplankton biomass and diversity (gross and net primary production, Oxygen (excess), Inorganic carbon (total alkalinity), Ocean surface stress (wind speed), mixed layer depth, Diapycnal eddy diffusion across the mixed layer
Responsible GOOS Panel	GOOS Biogeochemistry Panel Contact: ioccp@ioccp.org

Table 2: Requirements Setting					
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 *[as defined in the FOO]*	Concept to Mature (depending on the Scientific Application)				
Phenomena to Capture	**1 Eutrophication**	**2 Primary production**	**3 Calcification**	**4 Export fluxes**	**5 Remineralization**
Temporal Scales of the Phenomena	Coastal Daily to weekly Open Ocean Weekly to monthly	Coastal Daily to weekly Open Ocean Weekly to monthly	Monthly	Monthly to annual	
Spatial Scales of the Phenomena	Coastal 1-100 km Open Ocean 100-1000 km	Coastal 1-100 km Open Ocean 100-1000 km	1-250 km	Coastal 1-100 km Open Ocean 25-500 km	
Magnitudes/Range of the Signal to Capture	0.5 mmol C m^{-3}			POC: 0.5 Pg C yr^{-1} $decade^{-1}$ $CaCO_3$: 0.05 Pg C yr^{-1} $decade^{-1}$ BSi: 10 Tmol Si yr^{-1} $decade^{-1}$	
Current Uncertainty					

Relative to the Signal					
Target Uncertainty Relative to the Signal				± 10 %	

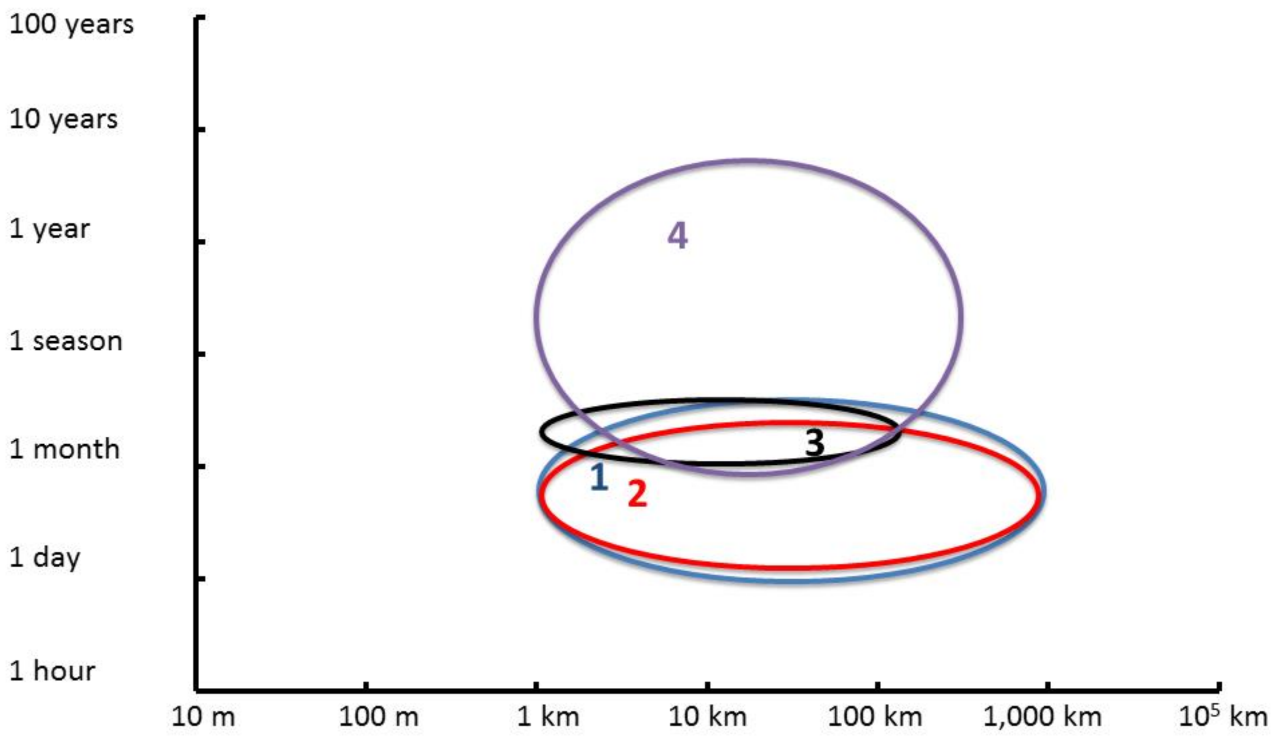

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks (Part 1)						
Observing Approach	**Ship-based Underway Observations**	**Gliders**	**Moored Fixed-point Observatories**	**Profiling floats**	**Satellite Remote Sensing**	
Readiness Level of the Observing Approach	Pilot	Mature	Mature	Mature	Mature	
Leading Observing Network		OceanGliders		Biogeochemical (BGC) Argo	Ocean Colour Radiometry – Virtual Constellation (OCR-VC)	
Readiness Level of the Observing Network	Concept	Pilot	Concept	Pilot	Mature	
Phenomena Addressed	**1**,**2** & possibly **3**	**1**,**2**	**1**,**2** & possibly **3**	**1**,**2**	**1**,**2**,**3**,**4**	
Spatial Scales Currently Captured by the Observing Network	Horizontal Coverage: Every 10°, denser near the coast Vertical Coverage: Footprint: *[to be defined for various oceanographic regimes]*	Horizontal Coverage: Every 10°, denser near the coast Vertical Coverage: Footprint: *[to be defined for various oceanographic regimes]*	Horizontal Coverage: Every 1-5° in coastal domain Vertical Coverage: Footprint: *[to be defined for various oceanographic regimes]*	Horizontal Coverage: Every 5° in open ocean Vertical Coverage: Footprint: *[to be defined for various oceanographic regimes]*	Horizontal Coverage: Global Vertical Coverage: Surface only Footprint: *[to be defined for various oceanographic regimes]*	
Typical Observing Frequency	Monthly	Monthly	Daily to annual	Daily to weekly	Daily	

Supporting Variables Measured	Beam-c, backscatter	Beam-c, backscatter	Oxygen, Nitrate, pH	Beam-c, backscatter	Reflectance	
Sensor(s)/ Technique	in line optics	Optical	Optical	Optical	Optical	
Accuracy/ Uncertainty Estimate (units)	See review: Boss et al., (2015).					
Reporting Mechanism(s)	Individual Networks Annual Reports					

Table 3: Current Observing Networks (Part 2)			
Observing Approach	**Moored Fixed-point Observatories (shallow sediment traps)**	**Optical Imaging Systems**	
Readiness Level of the Observing Approach	Mature	Mature	
Leading Observing Network			
Readiness Level of the Observing Network	Concept	Concept	
Phenomena Addressed	**4**	**4**	
Spatial Scales Currently 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			
Sensor(s)/ Technique		LOPC, UVP, transmissiometer, and many other – *see review by Boss et al., 2015*	
Accuracy/ Uncertainty Estimate (units)			
Reporting Mechanism(s)	Individual Networks Annual Reports		

Table 4: Future Observing Capacity				
Observing Approach	**Profiling floats**	**Moored Fixed-point Observatories**	**Ship-based Repeat Hydrography**	
What is the novel aspect of this observing approach?	New sub-variables measured (vertical particle flux of POC)	New sub-variables measured (vertical particle flux of POC)	A new observing network available (GO-SHIP)	
Phenomena Addressed	4	4	1,2,3,4	
Readiness Level of the Observing Network	Concept	Concept	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				
Sensor(s)/ Technique	LOPC, transmission meter, (UVP?)	LOPC, transmission meter, (UVP?)		
Accuracy/ Uncertainty Estimate (units)				

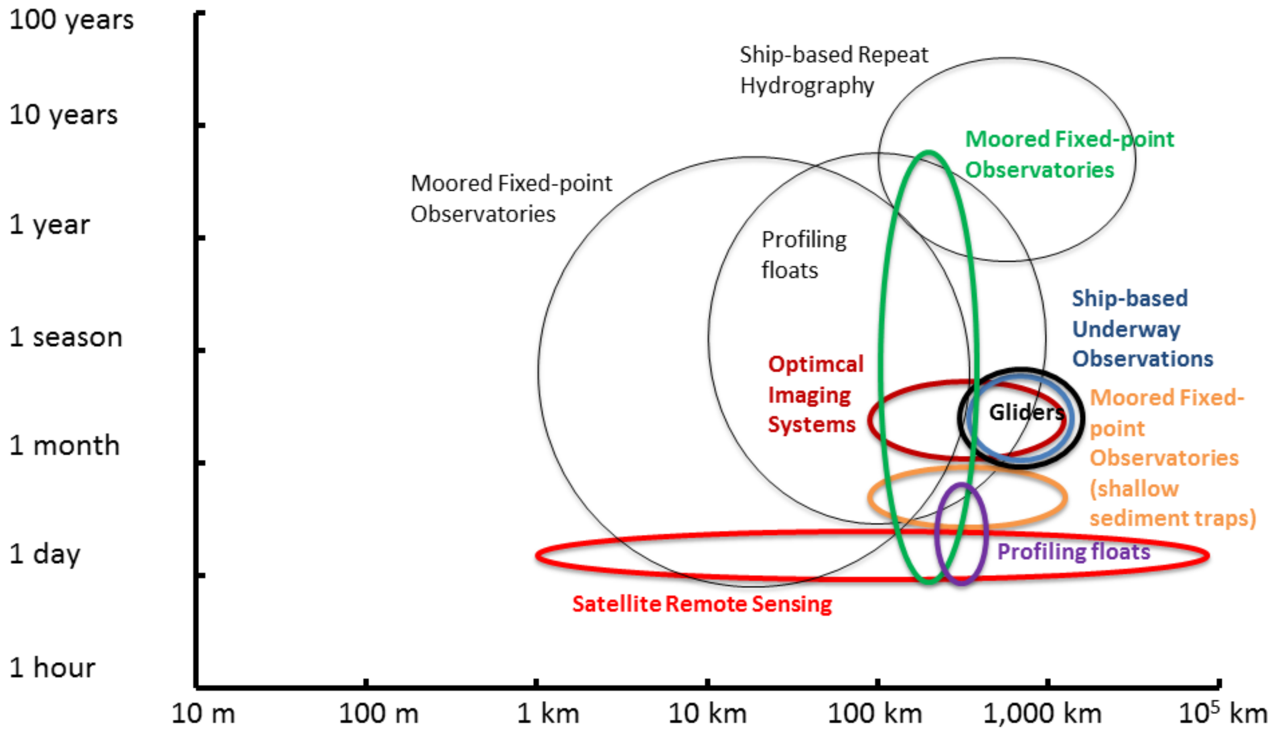

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles). SS not visualized because no temporal or spatial scale was provided.

Table 5: Data & Information Creation					
Observing Approach	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream Delivery**	**Data Repository**	**Data Products**
Ship-based Underway Observations		PIs deliver to national data centres	PIs deliver to national data centres	National data centres	Ocean Colour Climate Change Initiative (OC-CCI) data products NASA Ocean Colour Level 3 products
Satellite Remote Sensing	OCR-VC	NASA, ESA, JAXA	NASA's OceanColor Web	NASA's OceanColor Web	
Profiling Floats	BGC Argo	BGC Argo	Argo GDACs	Argo GDACs	
Moored Fixed-Point Observatories					
Gliders	OceanGliders				
Optical Imaging Systems					

Table 6: Links & References	
Best Practices, Guides and Other Background Documentation	
Links for Contributing Networks	BGC Argo: http://biogeochemical-argo.org/index.php OCR-VC: http://www.ioccg.org/groups/OCR-VC.html OceanGliders: http://www.ego-network.org/dokuwiki/doku.php?id=public:goosgstt
Links for Near-Real Time Data Stream Delivery	BGC Argo: http://biogeochemical-argo.org/data-access.php NASA's OceanColour Web: https://oceancolor.gsfc.nasa.gov/data/overview/
Links to Data Repositories	BGC Argo: http://biogeochemical-argo.org/data-access.php NASA's OceanColour Web: https://oceancolor.gsfc.nasa.gov/data/overview/
Data Product Links and References	Ocean Colour Climate Change Initiative (OC-CCI) data products NASA Ocean Colour Level 3 products

Glossary of terms

A **Framework for Ocean Observing (FOO)** is a guide for the ocean observing community to establish an integrated and sustained global observing system that addresses the variables to be measured, the approach to measuring them, and how their data and products will be managed and made widely available. FOO is available from: http://www.ioccp.org/index.php/foo

A **GOOS Essential Ocean Variable** is a sustained measurement or a group of measurements necessary to assess state and change at a global level, and to increase societal benefits from the ocean *[on scales from global to regional].*

Sub-variables are components of the EOV that may be measured, derived or inferred from other elements of the observing system and used to estimate the desired EOV.

Supporting variables are other EOVs or other measurements from the observing system that may be needed to deliver the sub-variables and/or derived products of the EOV.

Derived products are calculated from the EOV and other relevant information, in response to user needs.

A **phenomenon** is an observed process, event, or property, with characteristic spatial and time scale(s), measured or derived from one or a combination of EOVs, and needed to answer at least one of the GOOS Scientific Questions.

A **footprint** is here defined as the area over which given EOV measurements performed by a single observing element (as a transect, station, track, etc.) are representative of a broader region.

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
TSM – Total Suspended Matter
$CaCO_3$ – Calcium carbonate
BGC - Biogeochemical
BSi – Biogenic silica
T – Temperature
S – Salinity
LOPC – Laser-Optical Plankton Counter
UVP – Underwater Vision Profiler
PI – Principal Investigator
NODC – National Oceanographic Data Center
MODIS – Moderate Resolution Imaging Spectroradiometer
SeaWiFS – Sea-Viewing Wide Field-of-View Sensor
NASA – National Aeronautics and Space Administration
ESA – European Space Agency
JAXA – Japan Aerospace Exploration Agency
OC-CCI – Ocean Colour-Climate Change Initiative
OCR-VC – Ocean Colour Radiometry-Virtual Constellation
GDAC – Global Data Assembly Centre

List of References

Emmanuel Boss, Lionel Guidi, Mary Jo Richardson, Lars Stemmann, Wilford Gardner, James K.B. Bishop, Robert F. Anderson, Robert M. Sherrell, Optical techniques for remote and in-situ characterization of particles pertinent to GEOTRACES, Progress in Oceanography, Volume 133, April 2015, Pages 43-54, ISSN 0079-6611, http://dx.doi.org/10.1016/j.pocean.2014.09.007.

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)