REPORT

First Technical Experts Workshop of the GOOS Biogeochemistry Panel:

Defining Essential Ocean Variables for Biogeochemistry

13-16 November 2013
Townsville, Australia

Contents

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Participants List

Name (Gender)	Home Institution	Country of residence	Main Expertize
Dr Matthew Church (M)	University of Hawaii	USA	Defining how ocean biology couples or decouples carbon and nitrogen cycles in the ocean
Dr Katja Fennel (F)	Dalhousie University	Canada	Development of coupled physical-biogeochemical models
Prof. Christoph Heinze (M)	University of Bergen	Norway	Three-dimensional modelling and quantification of marine biogeochemical cycles
Dr Masao Ishii (M)	JMA-MRI	Japan	Understanding of the natural and anthropogenic changes in ocean carbon and oxygen cycles based on observations
Dr Iris Kriest (F)	GEOMAR	Germany	Parameterization of marine biogeochemical processes in local and large-scale models
Dr Andrew Lenton (M)	CSIRO	Australia	Reanalysis and parameterization of carbon and biogeochemistry variables. Data-model fusion.
Dr Keith Rodgers (M)	Princeton University	USA	Using models to identify and understand dynamical controls on seasonal to inter-annual to decadal variability in the marine carbon cycle
Dr Toste Tanhua (M)	GEOMAR	Germany	Cycling and transport of biogeochemical properties within the ocean interior. Measurements of transient tracers, such as CFC-12 and SF_6, in the interior ocean and deliberate tracer release experiments.
Dr Bronte Tillbrook (M)	CSIRO	Australia	Observationalist binding the physical, chemical and biological processes that drive the carbon cycle
Dr Rik Wanninhof (M)	NOAA - AOML	USA	Ocean biogeochemistry observations and parameterization of ocean carbon variables
Dr Maciej Telszewski (M)	IOCCP	Poland	Ocean biogeochemistry observations and parameterization of ocean carbon variables

Report

1. Background and rationale

The ocean observing community has realized that quantifying the simultaneous impacts of multiple stressors on ocean ecosystems and biogeochemistry cannot be achieved without a truly multidisciplinary approach to observing. This requires a re-thinking of many observing strategies, and some compromises (within and across-disciplines) will have to be made in order to achieve a fit-for-purpose global ocean observing system.

A key recommendation from the OceanObs'09 Conference held in Venice in September 2009 (www.oceanobs09.net) was for international integration and coordination of interdisciplinary ocean observations. The Conference was sponsored by many international and national ocean agencies, and attended by representatives of ocean observation programs worldwide. Based on impressive agreement among the many groups present and their strong desire to work collectively, the sponsors commissioned a Task Team to develop an Integrated Framework for Sustained Ocean Observing (hereafter referred to as the FOO).

One of the initial tasks set by the FOO (published in May 2012) is for the three Ocean Observing System Panels (Physics, Biology/Ecology and Carbon/Biogeochemistry), interacting through virtual and in-person meetings and workshops, to propose a set of Essential Ocean Variables (EOVs) which would then be promoted as fundamental measurements needed to address the current scientific and societal ocean/climate-related issues. This list would enable funding of the interdisciplinary, integrated global ocean observing network (the improved, multidisciplinary GOOS). Each panel has a lead organization, which is tentatively tasked to consult the community and create a loose consortium of relevant and interested experts and/or organizations, helping to justify and negotiate the inclusion of certain parameters in the final list of EOVs.

The IOCCP was asked by the Task Team to lead the Biogeochemistry Panel. The IOCCP SSG agreed to follow a 4-step work plan leading to the initial assessment of the existing observing network. This work plan includes the following: (i) compile (and update as needed) the available information on societal and scientific requirements regarding marine biogeochemistry parameters necessary for inclusion into the FOO as EOVs; (ii) consult with programmatic and institutional partners on their requirements for the multidimensional feasibility assessment of the proposed parameters. It is important that observing, modeling and sensor/instrument developing communities are involved; (iii) lead a multidimensional feasibility assessment of the proposed parameters built on the FOO recommendations and summarize the results for inclusion into the Global Climate Observing System; (iv) produce a summary publication of the multidimensional feasibility assessment of the marine biogeochemistry parameters necessary for inclusion into the FOO as EOVs.

To kick-start the process and aid steps (ii) and (iii) of the work plan, the Global Ocean Observing System (GOOS) sponsored, through IOCCP, an expert meeting which was carried out side by side with the Biology and Ecosystem Panel meeting.

The First Technical Workshop for Biology and Ecosystem and Biogeochemistry Panels was held in Townsville, Australia 13-16 November 2013. During this workshop the GOOS Biogeochemistry Panel sought advice from technical experts to assist with:

- identification of major scientific and societal challenges that require sustained observations of ocean biogeochemistry variables;
- identification of candidate biogeochemical Essential Ocean Variables (EOVs);
- defining the state of readiness of set requirements, existing observing system elements and existing data streams for all proposed EOVs on the various frequency and resolution levels
- clarification of the role of GOOS, IOCCP, OOPC and the biology panel in developing consensus requirements, coordinating observing networks, and promoting development of a data management system;
- identifying monitoring activities and projects to practically implement the biogeochemistry recommendations in the GOOS Framework for Ocean Observing (FOO), the Panel for Integrated Coastal Observation (PICO) Plan and the upcoming update of the Global Climate Observing System's Implementation Plan.

This report summarizes the work accomplished in Townsville by the experts of the Biogeochemistry Panel. A parallel document describes the work of Biology and Ecosystem Panel experts.

2. Societal needs and scientific requirements for the global ocean observing system.

Authors of the FOO specifically point out to the fact that a large part of the current global ocean observing system is driven by climate observing requirements. The reality is that there are more societal and scientific drivers for ocean observations than climate (and weather).

Guided by the FOO, discussions about additional scientific questions and societal benefits that require sustained ocean observations were the first step in the EOV defining process. The following three overarching requirements, each divided into two main questions were agreed upon and became the baseline for further considerations.

1. The role of ocean biogeochemistry in climate

The oceans play a critical role in the cycling of many greenhouse gases. Most notably the ocean is responsible for taking up and storing about 50% of the anthropogenic emissions of carbon dioxide since the pre-industrial, thereby buffering (or mitigating) the rate of climate change.

Key Questions:

1.1. How is the ocean carbon content changing?

As the biggest mobile reservoir of carbon in the earth system, any change in the oceans ability to take up and store anthropogenic carbon will have a direct impact on rates of atmospheric CO_2 concentrations, and hence on climate. Therefore an observing framework that allows quantification and detection of change of both anthropogenic and total ocean carbon storage and uptake is critical (e.g. for setting emission targets, carbon accounting, model predictions, etc.). Additionally, understanding ocean oxygen fluxes and inventories are important indicators of ocean ventilation and respiration, which are needed for more accurate carbon budgets.

1.2. How does the ocean influence cycles of non-CO_2 greenhouse gases?

The ocean is a key unknown in the cycling of many other non-CO_2 greenhouse gases, such as ozone depleting e.g. halocarbons (e.g. methyl bromide, bromoform etc.), CH_4, N_2O, and DMS. Ocean measurements are essential for closing the budgets of these gases, which are potentially strong amplifiers of climate change. Furthermore, an ocean observing system that allows for early detection would serve as a warning system alerting us to the risk of passing key tipping points in the climate system.

2. Human impacts on ocean biogeochemistry

Human activities like fossil fuel burning and industrial fertilizer production have perturbed the global elemental cycles of carbon and nitrogen and significantly impact ocean chemistry. For example, shifts in the carbon chemistry of seawater have been widely recorded, as well as changes in nitrogen and oxygen in both coastal and open ocean waters. These induce a variety of shifts in marine resources of which we still don’t understand the full impact. The rates at which these changes occur often exceed the recent geological record, and highlight the need for a more comprehensive, multivariable approach to ocean biogeochemical analyses in order to better track and predict changes and impacts on marine ecosystems.

Key Questions:

2.1. How large are the ocean’s “dead zones” and how fast are they changing?

The oxygen content of the ocean is decreasing in many areas and in particular oxygen minimum zones (OMZ) are growing, likely due to combined effects of changes in circulation and rates of biological oxygen consumption. Oxygen is a strong habitat constraint for most marine animals, and OMZs are areas of highly reduced animal diversity. Low oxygen concentration leads to significant changes in biogeochemistry such as reduction of available nitrate, which can impact ocean productivity.

2.2. What are rates and impacts of ocean acidification?

Ocean acidity (i.e. the activity of protons, H^+) has increased by 30% since the pre-industrial period. This acidification will likely have significant effects on all levels of the trophic chain (e.g. reproduction, ecosystem structure, physiology) directly impacting future food security. Changes and impacts are expected to be heterogeneous and more severe in the coastal ocean.

3. Ocean ecosystem health

Changes in ocean chemistry will directly impact the health of marine ecosystems and in consequence affect humans that rely on marine resources for ecosystem services (e.g. food security, aquaculture).

Key Questions:

3.1. Is the biomass of the ocean changing?

Quantifying the magnitude of changes in ocean biomass and productivity and separating natural variability and secular trends is crucial for understanding and mitigating future impacts on fisheries. Changes in nutrient supply and distribution of macro- and micronutrients are key drivers of primary productivity, which will be impacted by changes in the nitrogen cycle (e.g. N_2 fixation, denitrification). Understanding biogeochemistry changes is key to predicting potential impacts on food webs.

3.2. How does eutrophication and pollution impact ocean productivity and water quality?

Land-based sources of nutrients (macro and micro) and carbon (organic and inorganic) into the coastal ocean increasingly lead to eutrophication and hypoxia directly impacting productivity and leading to deleterious effects such as harmful algal blooms (HAB). Furthermore, human pollution (POPs, Plastics, dioxins) can adversely impact ecosystem health.

3. Observable variables – information needed to answer societal and scientific questions

In the second step, the workshop participants focused on listing the necessary measurements needed to address each question. Unless specifically mentioned, during this phase the attention focused on the variable itseld and not as much on the required frequency or resolution of the measurement..The readiness of the measurement was also taken into account The FOO specifically requires to include all measurements considered critical, even those that are not feasible for implementation at the moment due to technical obstacles. By doing so, the FOO process seeks to trigger innovation by advocating development of technologies needed for the fit-for-purpose observing system. Also, no division between coastal and open ocean was made.

Experts from modelling and observing communities were equally active during this phase of the workshop. It is envisaged that future EOV consultation process will also include both communities.

Following this phase of the workshop the following measurements needed to answer each question (section 2 of this report) were identified.

1.1. How is the ocean carbon content changing?

- Carbonate system
- Transient Tracers
- O_2
- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- ^{13}DIC, ^{14}DIC

1.2. How does the ocean influence cycles of non-CO_2 greenhouse gases?

- CH_4 (regional)
- DMS
- N_2O
- Halocarbons/O_3-depleting substances
- O_2

2.1. How large are the ocean's dead zones and how fast are they growing?

- O_2
- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- Transient Tracers
- Material Export and/or Ar/O_2
- Carbonate system

2.2. What are rates and impacts of ocean acidification?

Question 2.2a: Detection

- Carbonate system (saturation state as derived variable)
- O_2
- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- Atmospheric deposition of anthropogenic sulfates
- Transient Tracers
- ^{13}DIC
- PON, POP, DON, DOP
- Ra isotopes (coastal)

Question 2.2b: Impact

- Carbonate System (saturation state as derived variable)
- Dissolution Rates
- PIC, POC
- Phytoplankton Functional Groups

- Benthic and Pelagic Species
- ^{231}Pa, ^{230}Th

3.1. Is the biomass of the ocean changing?

Question 3.1a: Is production changing

- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- Micronutrients (eg. Fe)
- O_2
- Carbonate System
- O_2/Ar
- O_2 isotopes
- Opal, POC, $CaCO_3$

Question 3.1b: Is biomass changing

- POM (POC, PON, POP) (turbidity & beam attenuation)
- Chlorophyll from remote sensing products
- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- Particle size spectra

3.2. How does eutrophication and pollution impact ocean productivity and water quality?

Question 3.2a: Eutrophication

- Macronutrients (NO_3, PO_4, Si, NH_4, NO_2)
- O_2
- POC, DOC
- $^{18}O/^{16}O$
- Ra isotopes (coastal)

Question 3.2b: Pollution

Although the importance of this issue is recognized, this panel defers to the expertize of specialized communities, for example toxicologists, to suggest relevant related variables for implementation into the sustained global observing system. Some suggestions that arose were:

- Dioxin
- POPs (particulate organic pollutants)
- Plastics
- Heavy Metals

In addition to the above measurements, a whole suite of physical and biological climate variables need to be measured in parallel to put biogeochemical observations into context. These additional observations are at times fundamental measurements needed to address questions listed in section 2 of this report. As efforts of three Ocean Observing System Panels of GOOS will converge, the biogeochemistry community will be an eager consumer of (list definitely not exhaustive):

Physical Climate

- Temperature and salinity along with isopycnal and diapycnal mixing rates
- Mixed Layer Depth and stratification as derived variables from temperature and salinity
- Sea Surface Height
- Light (3D)

Biology

- Chlorophyll, ocean color (perhaps bio-optics rather than biology), and associated derived variables

4. Essential Ocean Variables for Biogeochemistry – the core set of observations.

The group proposed Essential Ocean Variables (EOVs) from all variables listed in section 3, based on expert discussions and as a results of a scoring exercise. Two scoring methods were exercised and the nine highest scoring variables are proposed in section 5.

First, each of the variables listed in each separate question from section 3 obtained a ranking on a scale from 5 (most effective variables) to 1 (less efffective variable) points. In those cases where more than 5 variables were listed for a given question, no points were assigned to variable that ranked sixth and under. The points were then summed over the various questions, leading to a quantification of the priority of the variables.

Next, each variable was discussed and ranked in terms of its impact (how many questions can this EOV provide information for?) and feasibility (how easy or difficult is it to obtain this data?) with (1,1) assigned to variable with lowest impact and feasibility and (10,10) assigned to variables with highest impact and feasibility. Important discussions among the participants were held during this phase of the meeting until consensus amongst experts was reached.

Figure 1 summarizes these efforts. Most of the proposed EOV's fall into the high-feasibility high-impact quarter. Material export with high assessed impact and relatively high score on "responsiveness" to set requirements was accepted as a proposed EOV. On the other hand ^{14}C was not accepted by the group despite its relatively high impact assessment, mainly due to it's very low responsiveness to set requirements.

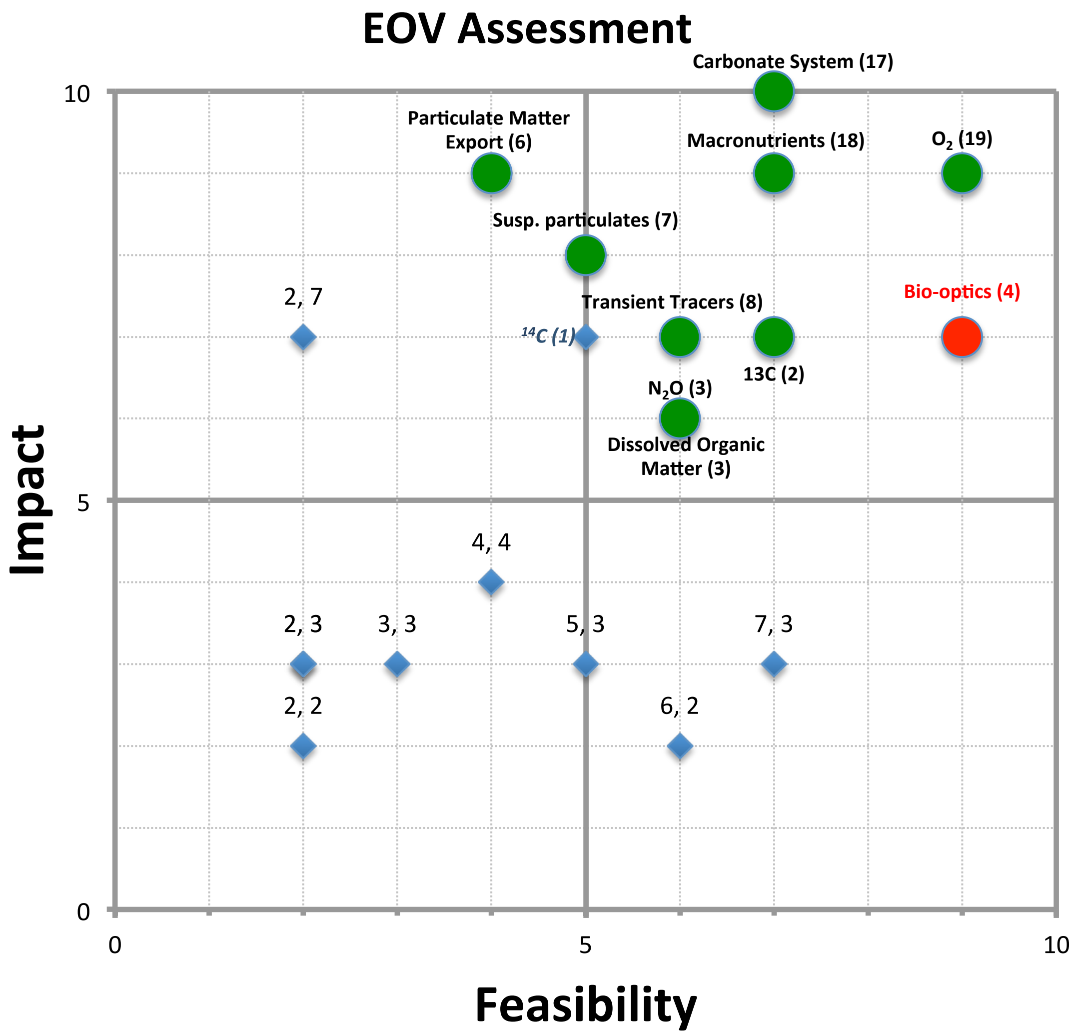

Figure 1. Multi-dimensional assessment of proposed variables leading to selection of Essential Ocean Variables for Biogeochemistry. Feasibility assessment on x axis and impact assessment on y axis. In brackets, number of points summed over 9 ranked questions is given for 11 highest ranked variables. Based on our assessment EOVs plotted in green are proposed as 1st tier EOVs. Bio-optics are no longer an EOV for Biogeochemistry. This EOV is not anymore on our list. During the post-meeting discussions and work on Specification Sheets it became clear that it really provides the information for suspended particles and perhaps particulate matter export. Discussions will be held to include pigments in work done by the Biology and Ecosystem Panel.

5. Proposed Essential Ocean Variables for Biogeochemistry

The FOO proposes assessing each EOV according to its readiness level in three categories: Requirements Processes, Coordination of Observational Elements and Data Management and Information Products. All these, plus some more meta-data type of information divided into several subcategories, are included in the newly developed EOV Specification Sheet. Specification sheets for each Biogeochemical

EOV described in this report are attached as annexes.

In this chapter we provide a short justification for each proposed EOV. Additional comments and discussions related to technicalities and measurements' logistics for each EOV are (supposed to be) presented at the beginning of relevant Specification Sheet.

i. Oxygen (Rik Wanninkhof, Bronte Tilbrook)

Oceanic measurements of dissolved oxygen have a long history, and oxygen is the third-most oft-measured water quantity after temperature and salinity. The implementation of a full-fledged observatory of oxygen in the ocean is critical to measure and understand the large (mostly) decreasing trends in the concentrations of dissolved oxygen in the ocean over the last few decades. These trends have important implications for our understanding of anthropogenic climate change. Sub-surface oxygen concentrations in the ocean everywhere reflect a balance between supply through circulation and ventilation and consumption by respiratory processes, the absolute amount of oxygen in a given location is therefore very sensitive to changes in either process.

ii. Macro Nutrients (Masao Ishii, Iris Kriest)

iii. Carbonate System (Andrew Lenton, Keith Rodgers)

The ocean is a major component of the global carbon cycle, exchanging massive quantities of carbon in natural cycles driven by the ocean circulation and biogeochemistry. Since seawater has a high capacity for absorbing carbon, the ocean also is a significant modulator of the rate of accumulation of carbon in the atmosphere, and thus slows the rate of global warming. The net carbon uptake of the ocean is approximately 25% of each year's anthropogenic emissions. Due to the chemistry of carbon in water, this uptake is causing a decline in ocean pH, also known as ocean acidification. The ecological consequences of ocean acidification are a focus for much of the present research. Understanding current carbon uptake by the ocean is critical for understanding how the carbon cycle and climate are evolving under the impact of human activities, and the mechanistic understanding developed is needed in the interest of improved prediction of the state of the climate system. Understanding and predicting rates of ocean acidification are also fundamental to understanding the ocean's biogeochemical evolution. The observations required to constrain the carbon system at a point in space and time are any two of DIC, Total Alkalinity, pCO_2 and pH, and associated physical variables (temperature and salinity). The carbon system is in a delicate balance such that high quality observations will continue to be required.

iv. Transient tracers (Toste Tanhua)

Transient tracers are a group of (chemical) compounds that can be used in the ocean to quantify ventilation, transit time distribution and transport time-scales. These compounds are all conservative in sea-water, or have well-defined decay-functions, and a well-established source function over time at the ocean surface. Measurement of transient tracers in the interior ocean thus provides information on the time-scales since the ocean was ventilated, i.e. in contact with the atmosphere. Knowledge of the transit time distribution (TTD) of a water-mass allows for inference of the concentrations or fates of other transient compounds, such as anthropogenic carbon or nitrous oxide. Commonly measured transient tracers are the chlorofluorocarbons (CFCs) 11 and 12, although in the past also CFC-113 and CCl_4 has been measured. More recently also the related compound SF_6 is regularly measured since it provides information on ventilation of the fast ventilated parts of the ocean. The radioactive isotopes ^{14}C and tritium (that decays to the stable ^{3}He) are commonly used, and have a natural decay time in addition to anthropogenic input during the 1950s. The tritium-^{3}He couple adds unique, additional information in that whereas the other transient tracers trace pathways into the ocean from the surface, tritiugenic-^{3}He traces the reverse pathway back out. That is, it is a nutrient-like tracer, being generated at a known rate by tritium decay and escaping to the surface ocean where it is “zeroed out” by gas exchange with the atmosphere. Although strictly not a transient tracer, since it is produced naturally by cosmic rays in the atmosphere. The isotope ^{39}Ar has a half-life in the right order of magnitude to characterize global ocean ventilation and have an impeccable inertness. However difficult measurement techniques have hampered its use. Recently new technologies are emerging that might allow for a global survey of ^{39}Ar in the near future.

v. Suspended particulates (Katja Fennel, Matt Church, Masao Ishii)

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.

vi. Particulate Matter Export (Matt Church, Christoph Heinze, Iris Kriest)

This EOV constitutes fluxes of particulate organic as well as inorganic matter (particulate organic carbon POC, calcium carbonate $CaCO_3$, particulate organic nitrogen PON, particulate organic phosphorus POP, biogenic silica BSi, and fairly inert clay minerals of continental origin) sinking out of the ocean surface layer. Surface layer is primarily defined here as the euphotic zone, where photosynthetic activity is possible. Plant production comes first in the food chain, and all subsequent trophic levels depend mostly on this primary production. Export supplies the deep aphotic ocean with carbon and other elements, while removing these from immediate contact with the atmosphere and the seasonal cycle. On its way downwards, particulate organic matter will be consumed and remineralised through heterotrophic activity by bacteria and animals, while particulate inorganic carbon and biogenic silica partially dissolve, depending on the respective saturation levels of ambient seawater. The reminder of the particle flux is deposited onto the ocean floor. The degradation of POC and $CaCO_3$ change the CO_2 partial pressure, the pH value, and the alkalinity in seawater. Remineralisation of organic matter reduces the oxygen content and releases inorganic nutrients back to the water column.

Variations in the export of POC and $CaCO_3$ contribute critically to changes in atmospheric CO_2 concentration as these export fluxes are key for the functioning of the biological carbon pumps. For quantifying correct transient and steady state budgets of CO_2 in the climate system, knowledge of the export fluxes of POC and $CaCO_3$ is key, though the uptake of anthropogenic carbon from the atmosphere is dominated by inorganic buffering. From process studies, clear indications have been derived which suggest a change in the export rain ratio $CaCO_3$:POC in a high CO_2 world with progressing ocean acidification. It is expected that the kinetics of POC production increase, and that the formation of $CaCO_3$ decreases under low pH/high CO_2 partial pressure. So far, we have no valid reference export map especially for $CaCO_3$. Hence, without producing such a map based on high quality measurements it will be impossible to track changes in global marine biocalcification rates over the coming decades.

Recording changes in BSi export would be needed to filter out what part of alteration in $CaCO_3$ export may be due to changes in BSi production or silicic acid availability for diatoms and radiolarians. As BSi export is an excellent proxy for upwelling strength, BSi export can also be used to underpin changes in overturning strength as expected under global warming trends. Changes in overturning, in general would lead to a decrease in export rates of biogenic particulate matter. These combined processes presumably also lead to a decrease in new production, i.e., nutrient supply to the surface ocean for producing new biomass. A tracking of trends in export rates, therefore, is vital for identifying the cause for changes in marine biomass production, also for food supply. Organic matter export is the foundation for subsequent degradation of organic matter *in situ* and respective oxygen consumption. Quantification of the organic matter export is therefore important for explaining trends in regional changes of dissolved oxygen in the water column within the context of widespread de-oxygenation and potential changes in greenhouse gas sources of N_2O and CH_4. Export of mostly inert clay material of continental origin can constrain marine dust deposition fields and shed important information of trends of micronutrient supply to the ocean surface layer (the mobilisation of trace metals from continental inputs would not change the mass flux significantly).

vii. Nitrous Oxide (Hermann Bange)

Nitrous oxide (N_2O) is an important climate-relevant trace gas in the Earth's atmosphere. In the troposphere it acts as a strong greenhouse gas and in the stratosphere it acts an ozone depleting substance because it is the precursor of ozone depleting nitric oxide radicals. Because of the on-going decline of chlorofluorocarbons and the continuous increase of N_2O in the atmosphere the contributions of N_2O to both the greenhouse effect and ozone depletion will be even more pronounced in the 21st century. The oceans - including its coastal areas such as continental shelves, estuaries and upwelling areas - are a major source of N_2O and contribute about 30% to the atmospheric N_2O budget. Oceanic N_2O is mainly produced as a by-product during archaeal nitrification (i.e. ammonium oxidation to nitrate) whereas bacterial nitrification seems to be of minor importance as source of oceanic N_2O. N_2O occurs also as an intermediate during microbial denitrification (nitrate reduction via N_2O to dinitrogen, N_2). Nitrification is the dominating N_2O production process, whereas denitrification contributes only 7-35% to the overall N_2O water column budget in the ocean. The amount of N_2O produced during both nitrification and denitrification strongly depends on the prevailing dissolved oxygen (O_2) concentrations and is significantly enhanced under low (i.e. suboxic) O_2 conditions. N_2O is usually not detectable in anoxic waters because of its reduction to N_2 during denitrification. Thus, significantly enhanced N_2O concentrations are generally found at oxic/suboxic or oxic/anoxic boundaries. The strong O_2 sensitivity of N_2O production is also observed in coastal characterised by seasonal shifts in the O_2 regime. A biological source of N_2O in the well-oxygenated mixed layer/euphotic zone seems to be unlikely. Global maps of N_2O in the surface ocean show enhanced N_2O anomalies (i.e. supersaturation of N_2O) in equatorial upwelling regions as well as N_2O anomalies close to zero (i.e. near equilibrium) in large parts of the open ocean. The MEMENTO (The MarinE MethanE and NiTrous Oxide database: https://memento.geomar.de) project has been launched with the aim to collect and archive N_2O data sets and to provide actual fields of surface N_2O for emission estimates.

viii. Carbon-13 (Bronte Tilbrook)

Oceanic measurements of the $^{13}C/^{12}C$ of dissolved inorganic carbon (DIC), referred to as $\delta^{13}C$, serve two main purposes. First, seasonal $\delta^{13}C$ changes in the surface ocean indicate the magnitude of organic matter (OM) export rate, the foundation of the ocean's biological pump. Second, decadal changes in ocean $\delta^{13}C$ depend on the accumulation rate of anthropogenic CO_2 in the ocean. The ratio of anthropogenic signal to background variability for $\delta^{13}C$ is four times that for DIC, making anthropogenic $\delta^{13}C$ change in the ocean easier to detect than the associated DIC change. Thus, measured $\delta^{13}C$ inventory changes over time can be used to estimate anthropogenic CO_2 uptake in the ocean. The ratio of decadal changes in the concentration and $\delta^{13}C$ of CO_2 in the atmosphere, coupled with the air-sea gradients in pCO_2 and $\delta^{13}C$ of dissolved CO_2, yield estimates of the fraction of anthropogenic CO_2 taken up the ocean and terrestrial biota.

ix. Dissolved Organic Matter (Craig Carson, Dennis Hansell)

Dissolved organic matter (DOM) represents one of the largest exchangeable reservoirs of organic material on earth. At ~662 ±32 Pg (10^{15} g) C, dissolved organic carbon (DOC) exceeds the inventory of organic particles in the oceans by 200 fold, making it one of the largest of the bioreactive pools of carbon in the ocean, second only to dissolved inorganic carbon (38,100 Pg C) (Hansell et al. 2009). The size of the reservoir (comparable to that of atmospheric CO_2), as well as its role as a sink for autotrophically fixed carbon (Hansell and Carlson, 1998), as a substrate to heterotrophic microbes (Carlson and Hansell 2014), and as a sink/source of carbon involved in climate variations over long time scales (Sexton et al. 2011), highlights its importance in the ocean carbon and nitrogen cycles. DOC is exported from the epipelagic zone at 1.9 PgC yr^{-1}, contributing ~20% to the biological pump via meridional overturning circulation (Hansell et al. 2009). The allochthonous supply of dissolved organic nitrogen (DON) from gyre margins into the interior of the ocean's oligotrophic subtropical gyres provides an important source of new N to gyre surface waters (Letscher et al., 2013). The flux of dissolved organic phosphorus (DOP) can support up to 25% of annual primary production and up to 100% of phosphorous export in some oceanic systems (Lomas et al., 2010).

6. Pilot projects – testing field

One session of the workshop was devoted to developing ideas for potential pilot projects. Based on preliminary pre-meeting suggestions from GOOS SC on pilot project characteristics, a couple of pilot projects were relatively briefly discussed. Their overall aim would be to allow for a better-informed and fit-for-purpose future development of two elements of the observing system.

Pilot Project: Global O_2 profiling array

This project aims at determining the feasibility of a full-scale ARGO array equipped with O_2 sensors by using data already available on profiling floats with O_2 to formulate a modelling effort (approximately 200 floats with O_2 sensors). Also, work on quality controlling of these measurements and advancing the data stream would have to be incorporated in the project. Several working questions could be addressed under this initiative:

- Based on model state, what level of change can you detect using float measurements?
- What percentage of the ARGO network would you need O_2 sensors to constrain fluxes with sufficient precision to observe decadal scale trends and annual fluctuations?
- Can you use a model to optimize the appropriate scales of sampling for a distributed network?
- What can these existing data tell us about short-term variability in O_2?
- Can you use the other floats to inform our understanding of the O_2 floats?
- How can we make the float data ARGO compliant?

Pilot Project: Net community production and material export

This pilot project aims at evaluating relationships and limitations in methodologies for estimating net community production (NCP) and material export to the ocean's interior. A global array of sensors measuring oxygen, carbon, and nitrogen will provide measurements useful for estimating NCP. At the moment, we do not have sufficient understanding of limitations inherent to different approaches. Also there is no agreement on suitable models (e.g. mixed layer oxygen and carbon exchange, entrainment from base of mixed layer, etc.) needed for specific methodologies. A general three-step approach was drafted during the Panel discussions:

- Gather data based on different measurements of export (O_2, C, traps, etc.) to constrain NCP and methodologies for assessing NCP.
- Agreement on best practices, comparison of models required to constrain NCP.
- Evaluate relationships between particle fluxes and NCP. Convergence of global estimates of NCP.

Meeting Agenda

Wednesday, 13 November

08:00 – 10:30 Opening - Joint Session

- **INTRODUCTION/ WELCOME / EXPECTATIONS** [Albert Fischer (GOOS Secretariat/GEOWOW); Toste Tanhua (Chair, GOOS Biogeochem Panel) and, Ian Poiner (Chair GOOS Biology and Ecosystems)]
- **CONTEXT** - **SETTING THE SCENE** [John Gunn – Co-Chair, GOOS Steering Committee; and Albert Fischer] :
    - GOOS/ FOO/ OOPC/ EOVs/ Readiness/ New GOOS Biology and Biogeochemistry Panels / Pilot Projects + GOOS Regional Alliances / Coastal and Open Ocean/ PICO Plan /International Conventions and Assessments needing sustained ocean observations/ Modelling Needs / GEOWOW, GEO and GEOSS.
- **INTRODUCTION FROM EACH PARTICIPANT** – their role, their research and how it may fit in

10:30 – 11:00 Coffee Break

11:00 – 12:30 Joint Discussion Items

- **CONTEXT – INTRODUCING THE KEY CONCEPTS UNDERPINNING THE WORKSHOP** (which will be explored further in separate Panel sessions)
    - Essential Climate Variables/ Essential Biodiversity Variables – Introduce the concept of requirement driven design of the observing system, guiding the selection of EOVs. [John Gunn / OOPC?]
    - Biology Ecosystem Synthesis Report – brief summary of findings [Dave McKinnon, AIMS]
    - Biogeochemistry Synthesis Report – brief summary of findings [Maciej Telszewski, IOCCP]
    - What are the main scientific questions (or answers) that will provide significant scientific benefit / address societal challenges (that require sustained global ocean observations of biogeochemical and biological variables?) [As background for each Panel to devise a list of requirements eg societal or science driven questions that need sustained monitoring of EOVs to answer].
    - What long term global biology, biogeochemistry and observation systems are already in place, what variables do they measure and why do we need these variables? [keeping in mind the question – **why do we need a time series on EOVs ?**]
    - Global, regional and local existing data systems and information products.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 1)]

13:30 – 15.30 BGC Panel Separate Session 1 - Defining Requirements / Needs

- Define the **societal needs** for ocean biogeochemical observations (motivate why we should spend time and money on measuring these variables for decades), e.g. climate change, fisheries , health of ecosystems, healthy ocean, tourism, transport etc.
- Define the **science needs** for ocean biogeochemical observations.

- Define requirements for EOVs based on societal and science needs. Come up with a list of requirements, i.e. societal or science driven questions that needs sustained monitoring of biogeochemical variables to answer.

13:30 – 15.30 Biology Panel Separate Session 1 - Defining Requirements / Needs

- Understanding what we are trying to achieve – planned outcomes from the Workshop:
    - List of major societal challenges and scientific questions requiring sustained global observations of ocean biological variables.
    - Define and prioritise EOVs including measurement requirements (frequency and resolution)
    - Evaluation of 'readiness' of observation systems.
    - For each EOV – what is required to improve current observations?
    - Priority list of potential observation systems for ecosystem EOVs.
    - Candidate pilot projects.

Requirements:

- State of knowledge - Biology Ecosystem Synthesis Report – presentation of findings [Dave McKinnon]
- Define the societal needs for biology/ecosystem observations (why we should spend time and money on measuring these variables for decades), e.g. climate change, fisheries, health of ecosystems, healthy ocean, industry (e.g. tourism, transport etc).
- Define requirements for EOVs based on societal and science needs. Come up with a list of requirements, i.e. societal or science driven questions that needs sustained monitoring of biogeochemical variables to answer.
- What are the types of variables needed for modelling [Andrew Constable ACE CRC]
- What long term global/regional biology observation systems are already in place, what variables do they measure and why?

15:30 – 16:00 Coffee break

16:00 – 18:00 BGC Panel Separate Session 2 - Defining Requirements / Needs - Continued….

16:00 – 18:00 Biology Panel Separate Session 2 - Defining Requirements / Needs - Continued….

- Including initial prioritisation of requirements and define the EOVs that are needed (1st cut)

19:00 Group Dinner – On-site provided by AIMS

Thursday, 14 November 2013

08:00 – 8.30 Recap of Day 1 - Joint Discussion/ Cross-Fertilization

08.30 - 10:30 BGC Panel Separate Session 3 - Defining EOVs 1st Take

- What are the types of variables needed for modelling [Modellers to lead a discussion].
- Go through the requirements and define EOVs that are needed for those.

08.30 - 10:30 Biology Panel Separate Session 3 - Defining EOVs 1st Take

- Priority list of requirements and define the EOVs that are needed taking into consideration:
  - Redundancies; and,
  - Likely spatial and temporal resolution.
- EOV observational requirements and an assessment of existing observing system.
- Review the agreed list of EOVs and define spatial and temporal resolution observational requirements.
  - E.g. Spatial resolution: Surface or interior ocean? Coastal or open ocean? At what spatial resolution in those realms?
  - Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
  - Accuracy and/or precision requirements.
- Ensure the temporal and spatial resolution needs to be tied to the requirements already defined.
- Existing long term global/regional biology observation systems – can they meet any of the identified requirements?
- Evaluate the 'readiness' to observe each EOV and recommendations for improvement and/or development.

10:30 – 11:00 Coffee Break

11:00 – 12:30 BGC Panel Separate Session 4 – Priority EOVs

- Assess the EOVs identified. Reduce redundant ones. Make sure EOV spatial and temporal resolution requirements are really needed. Produce a slim list of EOVs, without missing important variables capable of monitoring important processes or trends.

11:00 – 12:30 Biology Panel Separate Session 4 - Priority EOVs

- Priority list of requirements and define the EOVs that are needed taking into consideration:
  - Redundancies; and,
  - Likely spatial and temporal resolution.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 2)]

13:30 – 15:30 BGC Panel Separate Session 5 - EOV Observational Requirements, and assessment of existing observing systems

"Readiness table"

Go through the identified EOVs and define spatial and temporal resolution requirements.

- Spatial resolution: Surface or interior ocean? Coastal or open ocean. At what spatial resolution in those realms?
- Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
- Accuracy and/or precision requirements.

The temporal and spatial resolution needs to be tied to the requirements already defined.

Draw on already formulated resolution requirements from existing program plans, e.g. GO-SHIP, Oxygen on Argo, SOCAT

13:30 – 15:30 Biology Panel Separate Session 5 –'Readiness'

- EOV observational requirements and an assessment of existing observing system.
- Review the agreed list of EOVs and define spatial and temporal resolution observational requirements.
  - E.g. Spatial resolution: Surface or interior ocean? Coastal or open ocean. At what spatial resolution in those realms?
  - Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
  - Accuracy and/or precision requirements.
- Ensure the temporal and spatial resolution needs to be tied to the requirements already defined.
- Existing long term global/regional biology observation systems – can they meet any of the identified requirements?
- Evaluate the 'readiness' to observe each EOV and recommendations for improvement and/or development.

15:30 – 16:00 Coffee break

16:00 – 18:00 BGC Panel Separate Session 6 - EOV Observational Requirements, and assessment of existing observing systems – Continued…..

16:00 – 18:00 Biology Panel Separate Session 6 - Review of EOVs, Readiness and existing observing system.

- Finalise the "Readiness table" - for each EOV agree on:
  - the 'readiness' of observation systems
  - what is required to improve current observations.
  - priority list of potential observation systems for ecosystem EOVs

19:00 Group Dinner – On-site provided by AIMS

Friday, 15 November 2013

08:00 – 8.30 Recap of Day 2 - Joint Discussion / Cross-Fertilization

08:30 – 10:30 BGC Panel Separate Session 7 - Reduction of the number of EOVs

- Assess the EOVs identified. Reduce redundant ones. Make sure EOV spatial and temporal resolution requirements are really needed. We want to produce a slim list of EOVs, without missing important variables capable of monitoring important processes or trends.

08:30 – 10:30 Biology Panel Separate Session 7 – Review of EOVs, Readiness and existing observing systems – Continued….

10:30 – 11:00 Coffee Break

11:00 – 12:30 BGC Panel Separate Session 8 – Pilot Projects

- Potential pilot projects – based on the devised list of priority EOVs, what already exists (eg readiness of observation systems, GRA networks) and what monitoring systems could be established if there was funding?
- Selection of proposals based on the priority candidate EOVs and potential pilot projects.

11:00 – 12:30 Biology Panel Separate Session 8 – Pilot Projects

- Potential pilot projects – based on the devised list of priority EOVs, what already exists (eg readiness of observation systems, GRA networks) and what monitoring systems could be established if there was funding?
- Selection of proposals based on the priority candidate EOVs and potential pilot projects.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 3)]

13:30 – 15.30 Joint Discussions on Identified EOVS from each Panel

- Sharing the list of EOVs between Panels
- Sharing the ideas for Pilot Projects between Panels
- Discussion on overlap, synergy, redundancy etc.

15:30 – 16:00 Coffee break

16:00 – 18:00 Joint Session - Workshop Summary and Further Steps

- Discussion on overlap, synergy, redundancy, feasibility etc.
- Formulate a 10 year plan for the two GOOS Panels (envisioning a 70% cut in funding, or a 500% increase).
- Funding Discussion to implement the proposed Panel activities: what funding is available, and what are the potential funding bodies/rounds to approach for the funding of the potential proposals based on the list of Candidate EOVs and Pilot Projects.
- Writing the Workshop Report – next steps and due date.
- Next Panel Meetings?

19:00 Group Dinner – On-site provided by AIMS