Advancement of the Biogeochemistry (BGC) Essential Ocean Variables (EOVs)

Rik Wanninkhof, NOAA/AOML, Miami

With input from:
Toste Tanhua, GEOMAR, Kiel
Maciej Telszewski and Artur Palacs, International Carbon Coordination Project (IOCCP) and GOOS BCG Panel
• NOAA (OGP, OCO, CPO, COD, OOMD,...) has been the leader in implementing the GOOS framework for sustained ocean observations (FOO)
• Building is more fun than maintaining
Essential Ocean Variables

**Essential Ocean variables are part of the Framework of Ocean Observations (FOO)**

The Framework is designed to approach ocean observations with a focus on Essential Ocean Variables, ensuring assessments that cut across platforms and recommend the best, most cost effective plan to provide an optimal global view for each theme.

**Criteria for EOVs:**

**Relevance**  The variable is effective in addressing the overall GOOS Themes – Climate, Real-Time Services, and Ocean Health.

**Feasibility**  Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.

**Cost effectiveness**  Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology.

Expert Panels recommend what measurements are to be made needed to address key scientific/societal issues, various observing options, and data management practices and documented in EOV's specification sheets.

“Variables that need to be measured everywhere, all the time”
REPORT

First Technical Experts Workshop of the GOOS Biogeochemistry Panel:
Defining Essential Ocean Variables for Biogeochemistry

13-16 November 2013
Townsville, Australia

<table>
<thead>
<tr>
<th>Name (Gender)</th>
<th>Home Institution</th>
<th>Country of residence</th>
<th>Main Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr Matthew Church (M)</td>
<td>University of Hawaii</td>
<td>USA</td>
<td>Defining how ocean biology couples or decouples carbon and nitrogen cycles in the ocean.</td>
</tr>
<tr>
<td>Dr Katja Fennel (F)</td>
<td>Dalhousie University</td>
<td>Canada</td>
<td>Development of coupled physical-biogeochemical models.</td>
</tr>
<tr>
<td>Prof. Christoph Heinze (M)</td>
<td>University of Bergen</td>
<td>Norway</td>
<td>Three-dimensional modelling and quantification of marine biogeochemical cycles.</td>
</tr>
<tr>
<td>Dr Masao Ishii (M)</td>
<td>JMA-MRI</td>
<td>Japan</td>
<td>Understanding of the natural and anthropogenic changes in ocean carbon and oxygen cycles based on observations.</td>
</tr>
<tr>
<td>Dr Iris Kiest (F)</td>
<td>GEOMAR</td>
<td>Germany</td>
<td>Parameterization of marine biogeochemical processes in local and large-scale models.</td>
</tr>
<tr>
<td>Dr Andrew Lenton (M)</td>
<td>CSIRO</td>
<td>Australia</td>
<td>Reanalysis and parameterization of carbon and biogeochemistry variables. Data-model fusion.</td>
</tr>
<tr>
<td>Dr Keith Rodgers (M)</td>
<td>Princeton University</td>
<td>USA</td>
<td>Using models to identify and understand dynamical controls on seasonal to interannual to decadal variability in the marine carbon cycle.</td>
</tr>
<tr>
<td>Dr Toste Tanhua (M)</td>
<td>GEOMAR</td>
<td>Germany</td>
<td>Cycling and transport of biogeochemical properties within the ocean interior. Measurements of transient tracers, such as CFC-12 and SF6, in the interior ocean and deliberate tracer release experiments.</td>
</tr>
<tr>
<td>Dr Bronte Tillbrook (M)</td>
<td>CSIRO</td>
<td>Australia</td>
<td>Observationalist binding the physical, chemical and biological processes that drive the carbon cycle.</td>
</tr>
<tr>
<td>Dr Rik Wanninhof (M)</td>
<td>NOAA - AOML</td>
<td>USA</td>
<td>Ocean biogeochemistry observations and parameterization of ocean carbon variables.</td>
</tr>
<tr>
<td>Dr Maciej Telszewski (M)</td>
<td>IOCCP</td>
<td>Poland</td>
<td>Ocean biogeochemistry observations and parameterization of ocean carbon variables.</td>
</tr>
</tbody>
</table>
1. The role of ocean biogeochemistry in climate
   1.1. How is the ocean carbon content changing?
   1.2. How does the ocean influence cycles of non-CO₂ greenhouse gases?

2. Human impacts on ocean biogeochemistry
   2.1. How large are the ocean’s “dead zones” and how fast are they changing?
   2.2. What are rates and impacts of ocean acidification?

3. Ocean ecosystem health
   3.1. Is the biomass of the ocean changing?
   3.2. How does eutrophication and pollution impact ocean productivity and water quality?

Excluded direct input of manmade materials (pollutants & plastics) [Under IMO purview]
EOVs for Biogeochemistry

Developed by a panel of experts based on:

1. Addressing global biogeochemical issues (Key themes)
2. Impact and feasibility

Examples of OVs that did not make the cut:
Trace metals, noble gases, methane lipids, organic nutrients, radioisotopes
The separation of EOVs is merely for [management] convenience

<table>
<thead>
<tr>
<th>PHYSICS</th>
<th>BIOGEOCHEMISTRY</th>
<th>BIOLOGY AND ECOSYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea state</td>
<td>Oxygen</td>
<td>Phytoplankton biomass and diversity</td>
</tr>
<tr>
<td>Ocean surface stress</td>
<td>Nutrients</td>
<td>Zooplankton biomass and diversity</td>
</tr>
<tr>
<td>Sea ice</td>
<td>Inorganic carbon</td>
<td>Fish abundance and distribution</td>
</tr>
<tr>
<td>Sea surface height</td>
<td>Transient tracers</td>
<td>Marine turtles, birds, mammals abundance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and distribution</td>
</tr>
<tr>
<td>Sea surface temperature</td>
<td>Suspended particulates</td>
<td>Live coral</td>
</tr>
<tr>
<td>Subsurface temperature</td>
<td>Nitrous oxide</td>
<td>Seagrass cover</td>
</tr>
<tr>
<td>Surface currents</td>
<td>Stable carbon isotopes</td>
<td>Macroalgal canopy</td>
</tr>
<tr>
<td>Subsurface currents</td>
<td>Dissolved organic carbon</td>
<td>Mangrove cover</td>
</tr>
<tr>
<td>Sea surface salinity</td>
<td>Ocean colour (Spec Sheet under development)</td>
<td></td>
</tr>
<tr>
<td>Subsurface salinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean surface heat flux</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Essential Biodiversity Variables

---

http://goosocean.org/
The Global Ocean Observation System (GOOS) is a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans and continuous forecasts of the future conditions of the sea.
EOVs applied to Ocean Ecosystem Health

Hot, Sour & Breathless - Ocean under stress

How is the biggest ecosystem on Earth faring?

Ocean and coastal regions under stress

1. CO₂
2. Heat
3. Oxygen

And others: eutrophication (nutrient cycle), pollutants, plastics
Mapping of EOVs to addressing ocean health

EOVs cover:
- measured
- derived parameters (e.g. rates (Fluxes))

EOVs cover:
Stressor
Causes
Result
Direct effects
Impacts
Feedback to climate

<table>
<thead>
<tr>
<th>Stressor</th>
<th>Causes</th>
<th>Result</th>
<th>Direct effects</th>
<th>Impacts</th>
<th>Feedback to climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warming</td>
<td>A relatively mature study area in terms of physical changes and physiology but poorly studied at ecosystem and biogeochemical level</td>
<td>Increased greenhouse gas emissions to the atmosphere</td>
<td>Temperature increase, particularly in near-surface waters</td>
<td>Decreased carbon dioxide solubility</td>
<td>Reduced ocean uptake of carbon dioxide due to solubility effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Less ocean mixing due to increased stratification</td>
<td>Increased speed of chemical and biological processes</td>
<td>Increased oxygen consumption, carbon dioxide production and decrease in oxygen transfer to the deep ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Increased run-off and sea-ice melt will also contribute to stratification in Arctic waters</td>
<td>Reduced natural nutrient re-supply in more stratified waters</td>
<td>Potential decrease in the export of carbon to the ocean's interior</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stress to organism physiology, including coral bleaching</td>
<td>Decreasing primary production except in the Arctic where sea-ice loss may result in an increase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Extensive migration of species</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More rapid turnover of organic matter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nutrient stress for phytoplankton, particularly in warm waters</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Changes to diversify, food webs and productivity, with potential consequences for fisheries, coastal protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidification</td>
<td>Developed as a research topic in past decade</td>
<td>Increasing atmospheric carbon dioxide emissions</td>
<td>Unprecedented rapid change to ocean carbonate chemistry</td>
<td>Reduced calcification, growth and reproduction rates in many species</td>
<td>Reduced ocean uptake of carbon dioxide due to chemical effects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coastal nutrient enrichment, methane hydrates and acid gases from industrial emissions may also contribute locally</td>
<td>Much of the ocean will become corrosive to shelled animals and corals, with effects starting in the Arctic by 2030</td>
<td>Changes to the carbon and nitrogen composition of organic material</td>
<td>Changes to the export of carbon to the ocean's interior</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Increased oxygen use throughout the water column due to changing composition of organic material</td>
</tr>
<tr>
<td>Deoxygenation</td>
<td>Emerging issue, poorly studied</td>
<td>Reduced oxygen solubility due to warming</td>
<td>Less oxygen available for respiration especially in productive regions, and in the ocean interior</td>
<td>Reduced growth and activity of zooplankton, fish and other oxygen-using organisms</td>
<td>Enhanced production of the two greenhouse gases methane and nitrous oxide</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased oxygen supply to the ocean interior due to less mixing</td>
<td>Extended areas of low and very low oxygen</td>
<td>Endocrine disruption</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nutrient rich land run-off stimulating oxygen removal locally</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All three together</td>
<td>Few studies</td>
<td>Increasing greenhouse gas emissions, especially carbon dioxide, to the atmosphere</td>
<td>More frequent occurrence of waters that will not only be warmer but also have higher acidity and less oxygen content</td>
<td>Damage to organism physiology, energy balance, shell formation: e.g. coral reef degradation</td>
<td>Major change to ocean physics, chemistry and ecosystems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ocean acidification can reduce organisms' thermal tolerance, increasing the impact of warming</td>
<td>Risk of multiple positive feedbacks to atmosphere, increasing the rate of future climate change</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Combined effects further increase risk to food security and industries depending on healthy and productive marine ecosystems</td>
<td></td>
</tr>
</tbody>
</table>
Highlights of implementation of the GOOS EOV concept

STATE OF THE CLIMATE IN 2015

3. GLOBAL OCEANS—G. C. Johnson and A. R. Parsons

Special Supplement to the Bulletin of the American Meteorological Society Vol. 97, No. 8, August 2016

2016 is in the works!
EOVs facilitate systematic reporting of changes over time of key climate variables: SST

Climate modes and natural variability

2015 – (1981-2010)

2015-2014

Anthropogenic warming \( \approx 0.1 \, ^\circ\text{C}/\text{decade} \)

Sea surface temperatures—B. Huang, J. Kennedy, Y. Xue, and H.-M. Zhang
EOVs facilitate systematic reporting of changes over time of key climate variables: $O_2$

Causes:
- Ocean warming (Small contribution)
- Increase AOU (respiration + change in ventilation)

A systematic reporting of changes over time of key climate products: 

Air-sea $\text{CO}_2$ Flux $f(\text{CO}_2, \text{SST}, \text{stress})$


Anthropogenic $\text{CO}_2$ uptake
$\approx 0.5$ mol C m$^{-2}$ yr$^{-1}$

2016-2015

Global ocean carbon cycle—R. A. Feely, R. Wanninkhof, P. Landschützer, B. R. Carter, and J. A. Triñanes
Utilization of EOVs to create products: Aragonite saturation State $f(T, S, C)$

Jiang et al., GBC, 2015
Utilization of EOVs to elucidate causes and processes: Chlorophyll (Ocean Color and SST)

Strong coherence in biogeographical provinces

Global ocean phytoplankton—B. A. Franz, M. J. Behrenfeld, D. A. Siegel, and S. R. Signorini
Utilization of EOVs to guide new platform and sensor development “fit for purpose”

Autonomous platforms and sensors

12388 profile data near 60 °S, 170°W 4/21/201707.

<table>
<thead>
<tr>
<th>Inorganic carbon</th>
<th>Color</th>
<th>O₂</th>
<th>T</th>
<th>Nutrients</th>
</tr>
</thead>
</table>

K. Johnson, MBARI
Summary

- EOVs are a useful approach to fully utilize the platform-based observing approach of GOOS FOO and JCOMM.
- EOVs are critical for systematic observations of key parameters, processes, and interconnectivity between processes and properties.
- (BGC) EOVs (and their specification sheets) will be critical in incorporating new platform designs and instruments.

Milestones:
90% BGC EOV
Closing thought regarding performance based frameworks

*The problem with the bean counters is what’s being counted. It’s a focus on solely counting things, rather than the scientific products and advances in understanding*”
Highlights of products and required EOVs

Global air-sea CO$_2$ fluxes: from climatology to pCO$_2$ data-based near real time flux maps

EOVs: Seastate, Surface stress sea ices, SSH, SST, Currents, SSS CO$_2$

Significant improvements in estimates of global climatological CO$_2$ uptake:

- Current estimate (2006-2015) 2.6 Pg C y$^{-1}$ (26%)
- Decrease in uncertainty from ± 1 to 0.5 Pg C y$^{-1}$
- Advances in near real-time fluxes

(Takahashi et al., 1997; 1999; 2002; 2006; 2007; 2009; 2014)

Rödenbeck et al. (2015)
A systematic reporting of changes over time of key climate product: Ocean heat content
Fig. 3.6. (a) Time series of annual average global integrals of in situ estimates of upper (0–700 m) OHC A
Challenges

- Implementation
- Expansion to other key interlinking areas (operational oceanography, commerce, ocean health)
- Maintaining climate quality data
- Instrumentation/platforms

- EOVs lead the way
Societal Benefits: Applications: Phenomena

- Tsunami/Storm Surge
- Sea Level Monitoring
- Ocean Circulation
- Climate Models
- Ocean heat content
- Air-sea fluxes
- Mixed Layer
- Upwelling, Convection, Ventilation
- Land-Sea fluxes
- Wave Processes
- Se Ice Processes
- Coastal and Boundary Processes
- Ocean-Atmosphere phenomena
- Ocean Carbon Cycle
- non-CO2 greenhouse gas cycles
- Eutrophication hypoxia
- Ocean productivity
- Particulate concentrations
- Particulate Matter Transport
- Habitat modification
- Food webs
- Contaminants Sources/Transport
- Contaminant sinks/ transformation
- Pollution Impacts

- Climate Mitigation
- Climate Adaptation
- Climate Services
- Tsunami and Inundation Risk
- Marine Services
- Efficient Maritime Economy
- Coastal Protection
- Human Health
- Sustainable Management
- Pollution Assessment
- Habitat modification
- Food webs
- Contaminants Sources/Transport
- Contaminant sinks/ transformation
- Pollution Impacts

- Climate Forecasting and Projection
- Climate analysis and assessment
- Climate Cycles
- Weather forecasting
- Ocean forecasting
- Ecosystem Assessment
- Biodiversity Assessment
- Marine Hazard Response
- Assessing Human Impact on Ocean

- Ocean Health
- Operational ocean services
- Coastline
- Efficient Coastal Economies
- Coastal Living
- Sustainable Ocean Health
- Biodiversity
- Tourism and Culture
- Clean Waters
- Human Impacts
What’s wrong with bean counting?
It’s important to note what’s wrong with bean counting. It’s not that counting is wrong. Counting is good. We desperately need to know what’s working and what isn’t.

The problem with the bean counters is what’s being counted. It’s a focus on solely counting things, rather than dimensions of life related to people.