# Essential Ocean Variable (EOV): Oxygen

## Background and Justification

Oceanic measurements of dissolved oxygen have a long history, and oxygen ($O_2$) is the third-most oft-measured water quantity after temperature and salinity. Because of technological advances in the last decade oxygen observations are poised to make the same breakthrough regarding frequency and depth of measurements that temperature and salinity observations made in this decade by utilizing profiling floats and other autonomous platforms. 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. Oceanic oxygen has therefore been proposed as a bellwether indicator of climate change. Moreover, a global ocean $O_2$ observing network can improve the atmospheric oxygen to nitrogen ratio ($O_2/N_2$) constraint on the ocean-land-partitioning of anthropogenic carbon dioxide ($CO_2$). Annual cycles in oxygen concentration that are observed below the euphotic zone will also allow determination of the seasonal to interannual net remineralization rates as a proxy for export production. It will help interpretation of variations in water mass ventilation rates and will provide crucial data (initial conditions, evaluation) for ocean biogeochemistry models. It will aid interpretation of sparse data from repeat hydrographic surveys that are needed, for example, to constrain the oceanic inventory of anthropogenic $CO_2$.

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

| **Table 1: EOV Information** | |
|---|---|
| **Name of EOV** | Oxygen |
| **Sub-Variables** | Dissolved Oxygen ($O_2$) |
| **Derived Products** | Apparent Oxygen Utilization, Air-sea $O_2$ fluxes, Net Community Production (NCP), Net carbon export flux, Ocean oxygen inventories |
| **Supporting Variables** | Surface and subsurface temperature, Surface and subsurface salinity, Ocean surface vector stress (wind speed) |
| **Responsible GOOS Panel** | GOOS Biogeochemistry Panel<br>Contact: ioccp@ioccp.org |

| Table 2: Requirements Setting | | | | |
|---|---|---|---|---|
| **Societal Drivers** | 1. The role of ocean biogeochemistry in climate<br>2. Human impacts on ocean biogeochemistry<br>3. Ocean ecosystem health | | | |
| **Scientific Application(s)** | Q 1.1. How is the ocean carbon content changing?<br>Q 2.1. How large are the ocean's "dead zones" and how fast are they changing?<br>Q 3.1. Is the biomass of the ocean changing?<br>Q 3.2. How do the eutrophication and pollution impact ocean productivity and water quality? | | | |
| **Readiness Level** (as defined in the FOO) | Mature – Level 8 (out of 9) – "Mission Qualified" | | | |
| **Phenomena to Capture** | **1 Air-sea fluxes** | **2 Deoxygenation** | **3 Primary Production** | **4 Eutrophication** |
| **Temporal Scales of the Phenomena** | Monthly | Coastal<br>Seasonal<br><br>Open Ocean<br>Annual to decadal | Weekly to monthly | |
| **Spatial Scales of the Phenomena** | 1-250 km | Coastal<br>0.1-100 km<br><br>Open Ocean<br>100-1000 km | Coastal<br>1-100 km<br><br>Open Ocean<br>100-1000 km | |
| **Magnitudes/Range of the Signal to Capture** | 100 Tmol $O_2$ year$^{-1}$ | Coastal<br># hypoxic regions: 400<br>Volume/area of hypoxic regions: 425,000 km$^2$<br><br>Open Ocean<br>$O_2$ storage: 0.4 Pmol $O_2$ decade$^{-1}$ | 8 Pg C year$^{-1}$ (Net Community Production) | |

| | | | | |
|---|---|---|---|---|
| | | Volume/area of hypoxic regions: | | |
| **Current Uncertainty Relative to the Signal** | | | | |
| **Target Uncertainty Relative to the Signal** | ± 10 % | ± 10 % | ± 25 % | |

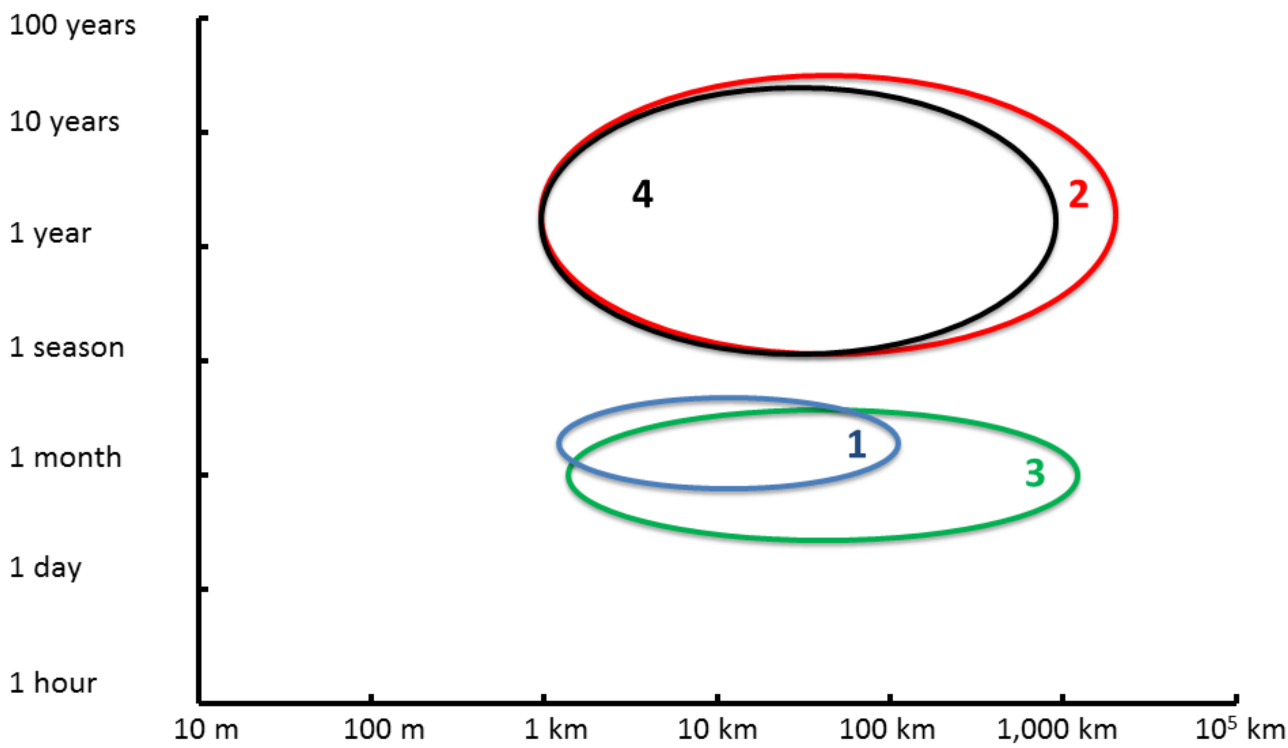


**Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.**

| Table 3: Current Observing Networks | | | | | | |
|---|---|---|---|---|---|---|
| **Observing Approach** | **Profiling Floats** | **Ship-based Repeat Hydrography** | **Moored Fixed-point Observatories** | **Gliders** | **Ship-based Fixed-point Observatories** | **Ship-based Underway Observations** |
| **Readiness Level of the Observing Approach for this EOV** | Mature | Mature | Mature | Mature | Mature | Mature |
| **Leading Observing Network** | Biogeochemical (BGC)-Argo | GO-SHIP | OceanSITES | OceanGliders | | |
| **Readiness Level of the Observing Network** | Pilot | Mature | Pilot | Concept | Concept | Concept |
| **Phenomena Addressed** | **1,2,3** | **2** | **1,3,4** | **1,2,3,4** | **2,3,4** | **1,3** |
| **Spatial Scales Currently Captured by the Observing Network** | Horizontal coverage: global, up to every 3°<br>Vertical coverage:<br>Footprint: | Horizontal coverage: global, along section 30 nm<br>Vertical coverage:<br>Footprint: 20° | Horizontal coverage: global<br>Vertical coverage:<br>Footprint: sub-basin scale (regional/biome scale) | Horizontal coverage: coastal ocean<br>Vertical coverage:<br>Footprint: 10-100 km | Horizontal coverage: regional /coastal<br>Vertical coverage:<br>Footprint: sub-basin scale (regional/biome scale) | Horizontal coverage: global<br>Vertical coverage:<br>Footprint: 10-100 km |
| **Typical Observing Frequency** | Bi-weekly to annual | Decadal | Hourly | Hourly | Monthly | Sub-weekly to monthly |
| **Supporting Variables Measured** | Surface and subsurface temperature, Surface and subsurface | Surface and subsurface temperature, Surface and subsurface | Surface and subsurface temperature, Surface and subsurface | Surface and subsurface temperature, Surface and subsurface | Surface and subsurface temperature, Surface and subsurface | Surface and subsurface temperature, Surface and subsurface |

| | | | | | | |
|---|---|---|---|---|---|---|
| | salinity | salinity, Surface ocean vector stress | salinity | salinity | salinity | salinity, Surface ocean vector stress |
| **Sensor(s)/ Technique** | Optical oxygen sensor | Wet chemistry (Winkler)/ Polarographic | Optical oxygen sensor | Optical oxygen sensor/ Polarographic | Wet chemistry (Winkler)/ Polarographic | Optical oxygen sensor |
| **Accuracy/Uncertainty Estimate (units)** | ±2.0 $\mu mol\ O_2\ kg^{-1}$ | ±0.5 $\mu mol\ O_2\ kg^{-1}$ | ±2.0 $\mu mol\ O_2\ kg^{-1}$ | ±2.0 $\mu mol\ O_2\ kg^{-1}$ | ±0.5 $\mu mol\ O_2\ kg^{-1}$ | ±2.0 $\mu mol\ O_2\ kg^{-1}$ |
| **Reporting Mechanism(s)** | Individual Networks Annual Reports | | | | | |

| Table 4: Future Observing Capacity | |
|---|---|
| **Observing approach** | |
| **What is the novel aspect of this observing approach?** | *none at the moment* |
| **How does this novel aspect impact our observing capacity?** | |

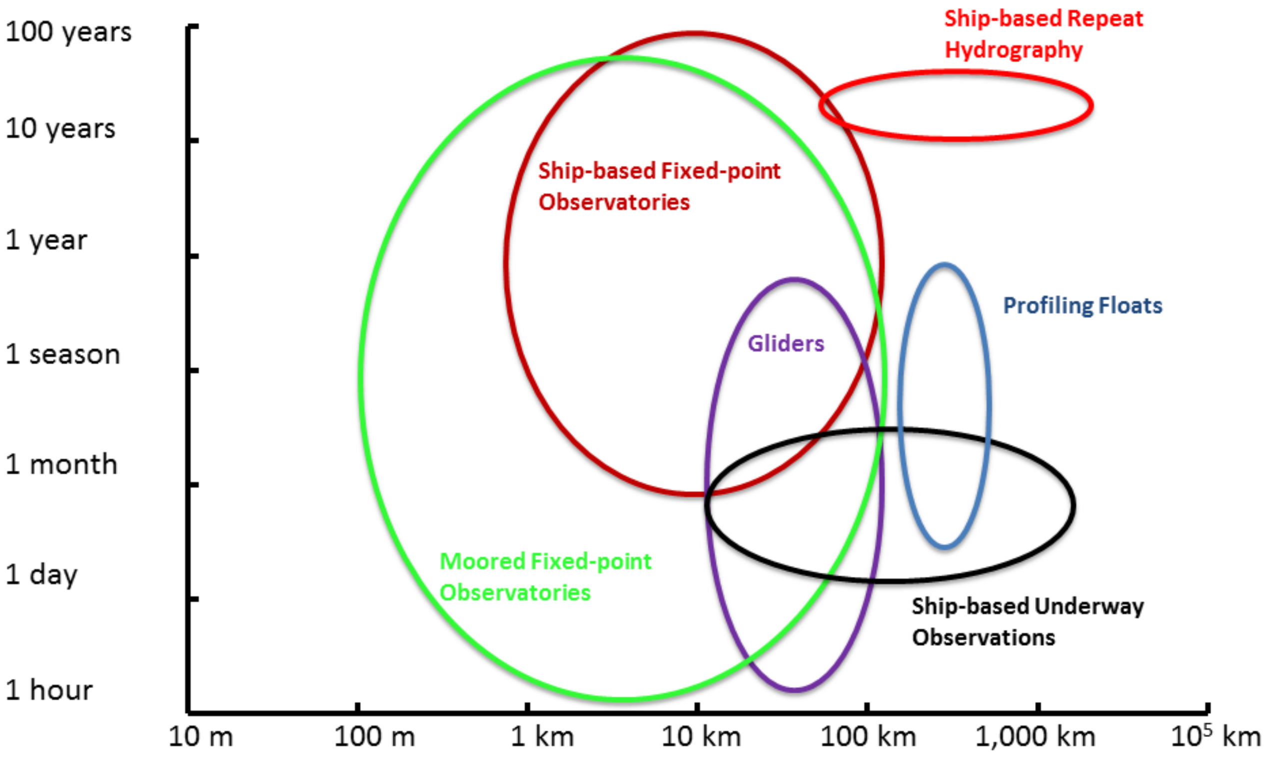


**Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).**

| Table 5: Data & Information Creation | | | | | |
|---|---|---|---|---|---|
| **Observing Approach** | **Oversight & Coordination** | **Data Quality Control** | **Near Real-Time Data Stream Delivery** | **Data Repository** | **Data Products** |
| **Profiling Floats** | BGC-Argo | | Argo GDACs | Argo GDACs | GLODAPv2 |
| | Pilot | | | | |
| **Ship-based Repeat Hydrography** | GO-SHIP | National programs | National data centres | CCHDO | |
| | Mature | | | | |
| **Moored Fixed-point Observatories** | OceanSITES | | | OceanSITES GDACs (US NDBC, Ifremer Coriolis) | |
| | | | | | |
| **Gliders** | OceanGliders | | | | |
| | | | | | |
| **Ship-based Fixed-point Observatories** | | | | | |
| | | | | | |
| **Ship-based Underway Observations** | | | | | |
| | | | | | |

| Table 6: Links & References | |
|---|---|
| **Best Practices, Guides and Other Background Documentation** | Best practices & guides:<br>C. Langdon (2010). Determination of Dissolved Oxygen in Seawater by Winkler Titration Using the Amperometric Technique. The GO-SHIP Repeat Hydrography Manual: A collection of Expert Reports and Guidelines, IOCCP Report No. 14, ICPO Publication Series No. 134, Version 1, 2010.<br><br>V. Thierry, Gilbert Denis, Kobayashi Taiyo, Schmid Claudia, Kanako Sato (2016). Processing Argo oxygen data at the DAC level cookbook. http://doi.org/10.13155/39795<br><br>C. Schmechtig, Thierry Virginie, The Bio Argo Team (2016). Argo quality control manual for biogeochemical data. http://doi.org/10.13155/40879<br><br>Background documents:<br>Keeling, R. F., Kortzinger, A., & Gruber, N. (2010). Ocean Deoxygenation in a Warming World. Annual Reviews of Marine Science, 2, 199-229, doi: 10.1146/annurev.marine.010908.163855<br><br>Gruber, N. et al. (2010). "Adding Oxygen to Argo: Developing a Global In Situ Observatory for Ocean Deoxygenation and Biogeochemistry" in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.cwp.39 |
| **Links for Contributing Networks** | Biogeochemical Argo: www.biogeochemical-argo.com<br>GO-SHIP: http://www.go-ship.org/<br>OceanSITES: http://www.oceansites.org/<br>OceanGliders: http://www.ego-network.org/<br>$GO_2NE$: http://www.unesco.org/new/en/natural-sciences/ioc-oceans/sections-and-programmes/ocean-sciences/global-ocean-oxygen-network/ |
| **Links for Near-Real Time Data Stream Delivery** | BGC Argo GDACs: http://biogeochemical-argo.org/data-access.php |
| **Links to Data Repositories** | CCHDO: http://cchdo.ucsd.edu/<br>BGC Argo GDACs: http://biogeochemical-argo.org/data-access.php<br>OceanSITES GDACs: http://www.oceansites.org/data/index.html |
| **Data Product Links and References** | GLODAPv2: http://glodap.info/<br>Olsen, A., Key, R. M., van Heuven, S., Lauvset, S. K., Velo, A., Lin, X., Schirnick, C., Kozyr, A., Tanhua, T., Hoppema, M., Jutterström, S., Steinfeldt, R., Jeansson, E., Ishii, M., Pérez, F. F., and Suzuki, T.: The Global Ocean Data Analysis Project version 2 (GLODAPv2) – an internally consistent data product for the world ocean, Earth Syst. Sci. Data, 8, 297-323, doi:10.5194/essd-8-297-2016, 2016. |

## 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
nm – nautical mile = 1.852 km
Pmol = $10^{15}$ moles
Tmol = $10^{12}$ moles
µmol = $10^{-6}$ moles
BGC – Biogeochemical
CCHDO – CLIVAR and Carbon Hydrographic Data Office
GO-SHIP – Global Ocean Ship-based Hydrographic Investigations Program
GLODAP – Global Ocean Data Analysis Project
$GO_2NE$ – Global Ocean Oxygen Network
GDAC – Global Data Assembly Centre
NCP – Net Community Production
US NDBC – United States National Data Buoy Center

**List of references**

Diaz, R. J. & Rosenberg, R. (2008), 'Spreading Dead Zones and Consequences for Marine Ecosystems', *Science* **321**(5891), 926--929.