# Essential Ocean Variable (EOV): Dissolved 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 $CO_2$.

| **Table 1: EOV Information** | |
|---|---|
| **Name of EOV** | Dissolved Oxygen |
| **Sub-Variables** | |
| **Derived Products** | Net Community Production and Export production (NCP&E), Air-sea $O_2$ fluxes, Improved constraint on atmospheric $O_2/N_2$ ratio (partitioning of anthropogenic $CO_2$), Temporal and spatial extent of hypoxic/anoxic regions |
| **Supporting Variables** | Temperature (T), Salinity (S), Wind speed, Mixed Layer Depth (MLD), Stratification |
| **Contact/Lead Expert(s)** | Arne Körtzinger (GEOMAR, Germany), Richard Wanninkhof (NOAA AOML, USA) |

| Table 2: Requirements Setting | | | | |
|---|---|---|---|---|
| **Responsible GOOS Panel** | Biogeochemistry Panel | | | |
| **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** | Mature | | | |
| **Phenomena to Capture** | **1**<br>**Air-sea fluxes of $O_2$** | **2**<br>**Changes in storage of $O_2$** | **3**<br>**Extent of hypoxia*** | **4**<br>**Net Community Production & Export (NCP&E)** |
| **Temporal Scales of the Phenomena** | Monthly | Seasonal to decadal | <u>Coastal</u><br>Seasonal<br><br><u>Open Ocean</u><br>Annual | Weekly to monthly |
| **Spatial Scales of the Phenomena** | 1-250 km | 100-1000 km | <u>Coastal</u><br>0.1-100 km<br><br><u>Open Ocean</u><br>100-1000 km | <u>Coastal</u><br>1-100 km<br><br><u>Open Ocean</u><br>100-1000 km |
| **Magnitudes/Range of the Signal** | 100 Tmol $O_2$ year$^{-1}$ | 0.4 Pmol $O_2$ decade$^{-1}$ | <u>Coastal</u><br>400 hypoxic regions; 425,000 km$^2$<br><br><u>Open Ocean</u><br>?<br>Volume/area of hypoxic regions | 8 Pg C year$^{-1}$ |

| | | | | |
|---|---|---|---|---|
| **Desired Detection Limit Relative to the Signal** | ± 10 % | ± 10 % | ± 10 %<br><u>Coastal</u><br>?<br><u>Open Ocean</u><br>? | ± 25 %<br><u>Coastal</u><br>?<br><u>Open Ocean</u><br>? |

*Hypoxic = waters with Dissolved Oxygen below ≤2 ml of $O_2$ $l^{-1}$ (Diaz & Rosenberg, 1995)

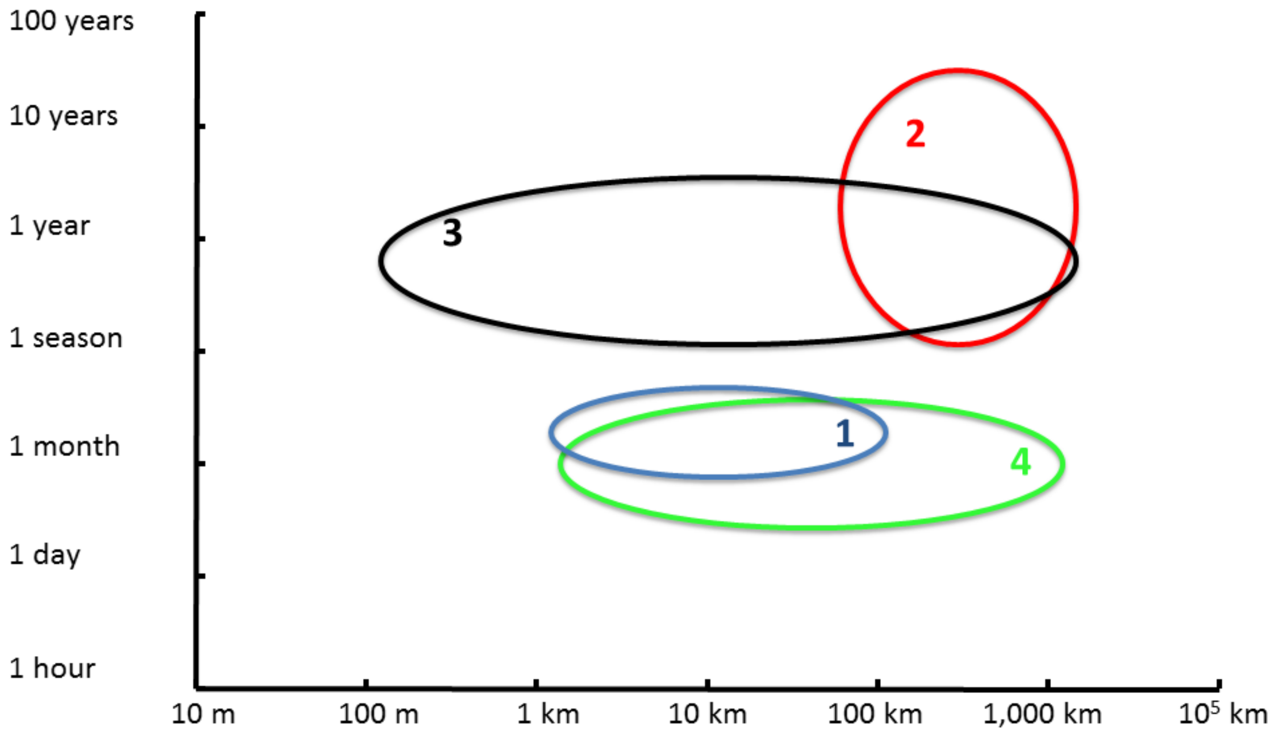


**Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.**

| Table 3: Current Observing Networks* | | | | | | |
|---|---|---|---|---|---|---|
| **Observing Network** | **Profiling Floats (PF)** | **Repeat Hydrography (RH)** | **Moorings (M)** | **Gliders (G)** | **Ship-based Time-Series (STS)** | **Ship Of Opportunity (SOO)** |
| **Phenomena Addressed** | **1,2,3,4** | **2** | **1,4** | **1,3,4** | **3,4** | **1,4** |
| **Readiness Level of the Observing Network** (as defined in the FOO) | Pilot/ Mature | Mature | Mature | Mature | Mature | Mature |
| **Spatial Scales Currently Captured by the Observing Network** | Global every 3° | Global along section: 30 nm<br><br>Section spacing: 20° | Local | Coastal 10-100 km | Local | 10-100 km |
| **Typical Observing Frequency** | Bi-weekly to annual | Decadal | Hourly | Hourly | Monthly | Sub-weekly to monthly |
| **Supporting Variables Measured** | T, S, MLD, Stratification | T, S, MLD, Stratification | T, S | T, S, MLD, Stratification | T, S, MLD, Stratification | T, S, MLD, Stratification |
| **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)** | GOOS Implementation Plan<br>IOCCP Report | | | | | |

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

| Table 4: Future Observing Networks | | | | | |
|---|---|---|---|---|---|
| **Observing Network** | **Ship Of Opportunity (SOO)** | | | | |
| **Phenomena Addressed** | **1,4** | | | | |
| **Readiness Level of the Observing Network** (as defined in the FOO) | Pilot | | | | |
| **Spatial Scales Captured by the Observing Network** | Coastal<br>10-100 km<br><br>Open Ocean<br>10-1000 km | | | | |
| **Typical Observing Frequency** | Monthly | | | | |
| **Time-Scale Until Part of Observing System** | 5-10 years | | | | |
| **Supporting Variables Measured** | $O_2$, S, T, Wind speed | | | | |
| **Sensor(s)/Technique** | Equilibrator inlet mass spectrometry | | | | |
| **Accuracy/Uncertainty Estimate (units)** | ± 1% | | | | |

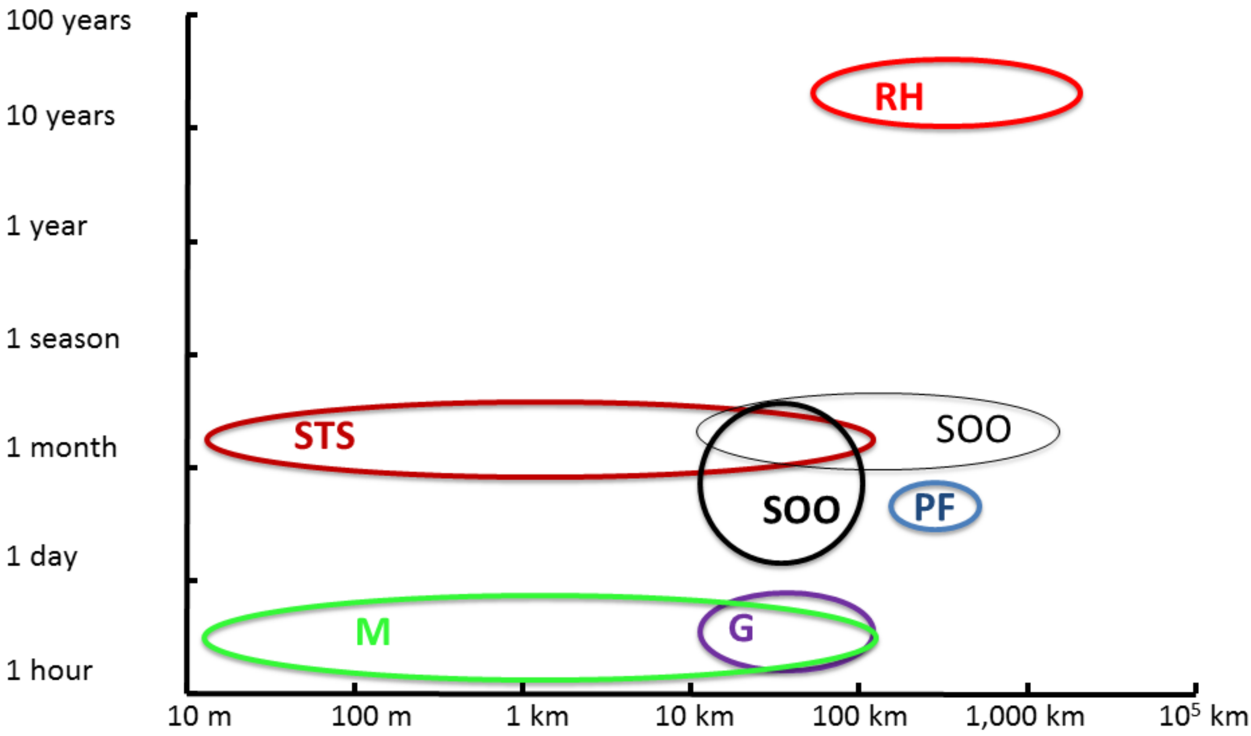


**Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).**

| Table 5: Data & Information Creation | | | | | |
|---|---|---|---|---|---|
| *Responsible entity and readiness level in each category per observing network* | **Oversight & Coordination** | **Data Quality Control** | **Near Real-Time Data Stream Delivery** | **Data Repository** | **Data Product** |
| **Profiling Floats** | Bio-Argo | | CORIOLIS | | Global NCP maps, Global $O_2$ flux maps, Global eutrophication maps |
| | Pilot | | Pilot | | |
| **Repeat Hydrography** | GO-SHIP | National programs | National data centres | CCHDO | |
| | Mature | Mature | | | |
| **Moorings** | | PIs | National data centres, CORIOLIS/GODAE | | |
| | | | | | |
| **Gliders** | | | | | |
| | | | | | |
| **Ship-based Time-Series** | | | | | |
| | | | | | |
| **Ship Of Opportunity** | | | | | |
| | | | | | |

| **Table 6: Links & References** | |
|---|---|
| **Links** (especially regarding Background and Justification) | http://www.solas-int.org/files/solas-int/content/downloads/pdf/reports/SOLAS-IMBER/o2_argo_whitepaper.pdf<br>http://www.oceanobs09.net/proceedings/cwp/cwp39/<br>http://www.oceanobs09.net/plenary/files/draft%20papers/Gruber_Koertzinger_Draft_Plenary_18JAN.pdf<br><br>Diaz, R. J. & Rosenberg, R. (2008), 'Spreading Dead Zones and Consequences for Marine Ecosystems', *Science* **321**(5891), 926--929. |
| **Links for Contributing Networks** | http://www.coriolis.eu.org/ (ARGO/PF)<br>http://cchdo.ucsd.edu/ (RH)<br>http://www.bco-dmo.org/ (STS) |
| **Data References** | http://www.coriolis.eu.org/ (ARGO/PF)<br>http://cchdo.ucsd.edu/ (RH)<br>http://www.bco-dmo.org/ (STS) |

**List of abbreviations**

EOV – Essential Ocean Variable
GOOS – Global Ocean Observing System
IOCCP – International Ocean Carbon Coordination Project
FOO – Framework for Ocean Observing
$O_2$ – Oxygen
C – Carbon
T – Temperature
S – Salinity
MLD – Mixed Layer Depth
NOAA – National Oceanic and Atmospheric Administration
OAML – Atlantic Oceanographic and Meteorological Laboratory
GEOMAR – Research Center for Marine Geosciences
NCP&E – Net Community Production and Export production
PF – Profiling Floats
RH – Repeat Hydrography
STS – Ship-based Time-Series
SOO – Ship Of Opportunity
G – Gliders
M – Moorings
nm – nautical mile = 1.852 km
Pmol = $10^{15}$ moles
Tmol = $10^{12}$ moles
µmol = $10^{-6}$ moles

CCHDO – CLIVAR and Carbon Hydrographic Data Office
GO-SHIP – Global Ocean Ship-based Hydrographic Investigations Program
GODAE – Global Ocean Data Assimilation Experiment
PI – Principal Investigator