Essential Ocean Variable (EOV): Inorganic Carbon

Background and Justification

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 Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), partial pressure of carbon dioxide (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.

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

Table 1: EOV Information	
Name of EOV	Inorganic Carbon
Sub-Variables	Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial pressure of carbon dioxide (pCO_2) and pH. *[At least two of the four Sub-Variables are needed.]*
Derived Products	Saturation state (aragonite, calcite), Dissolved carbonate ion concentration, Air-sea flux of CO_2, Anthropogenic carbon, Change in total carbon
Supporting Variables	Surface and subsurface Temperature, Surface and subsurface Salinity, Ocean vector stress (wind speed), Atmospheric column-averaged dry-air mole fraction of CO2 (xCO_2), Barometric pressure, Oxygen, Calcium concentration, Transient tracers, Oxygen to argon ratio (O_2/Ar)
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 2.1. How large are the ocean's dead zones and how fast are they growing? Q 2.2. What are rates and impacts of ocean acidification? Q 3.1. Is the biomass of the oceans changing?				
Readiness Level *[as defined in the FOO]*	Mature				
Phenomena to Capture	**1 Air-Sea Fluxes**	**2 Storage / inventory**	**3 Ocean Acidification**	**4 Primary production**	**5 Export fluxes**
Temporal Scales of the Phenomena	Monthly	Annual	Coastal Daily Open Ocean Seasonal	Seasonal to decadal	Seasonal to decadal
Spatial Scales of the Phenomena	1-250 km	100-1000 km	Coastal 0.1-100 km Open Ocean 100-1000km	Coastal 1-100 km Open Ocean 100-1000 km	Coastal 1-100 km Open Ocean 100-1000 km
Magnitudes/Range of the Signal to Capture	2 Pg C yr^{-1}	20 Pg C $decade^{-1}$	Saturation states 0.1 $decade^{-1}$ pH 0.01 $decade^{-1}$	0.5 Pg C yr^{-1} $decade^{-1}$ (net community production)	1 Pg C yr^{-1} $decade^{-1}$
Current Uncertainty Relative to the Signal					
Target Uncertainty Relative to the Signal	±10%	±10%	±20%		

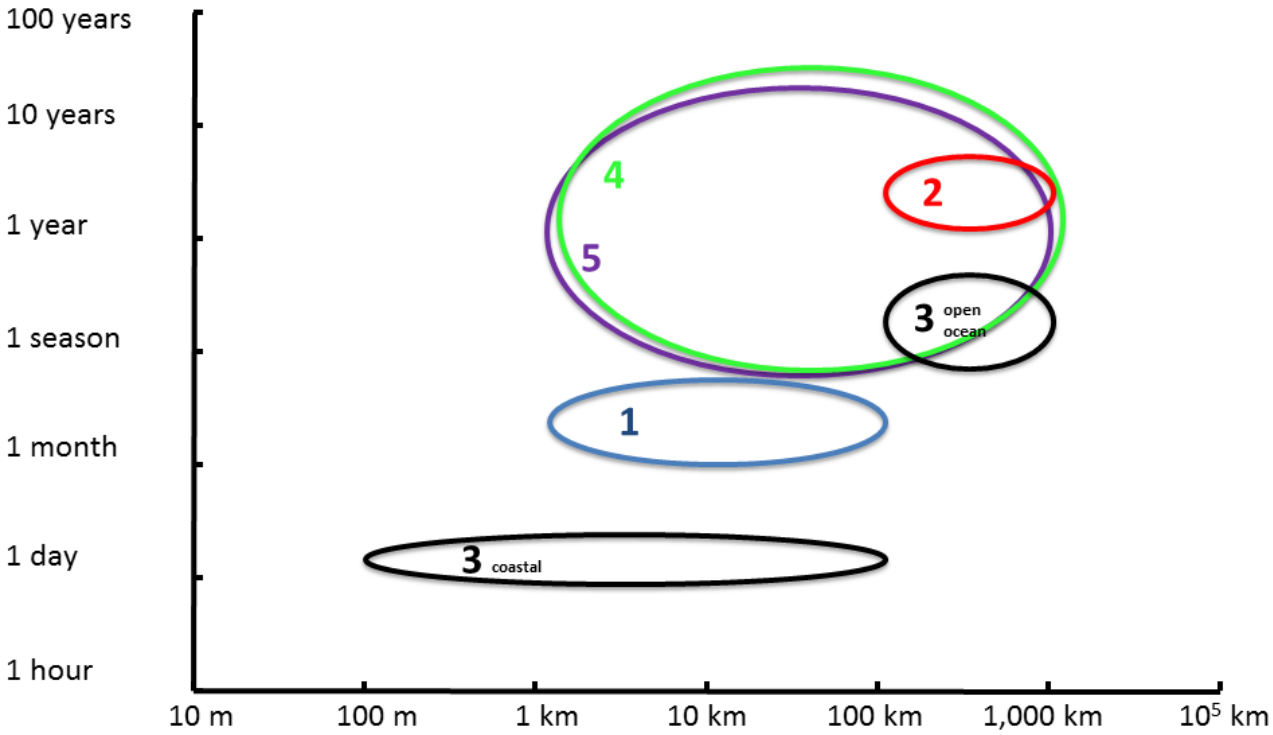

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks						
Observing Approach	**Ship-based Underway Observations**	**Ship-based Repeat Hydrography**	**Moored Fixed-Point Observatories**	**Drifters**	**Ship-based Fixed-Point Observatories**	**Profiling floats**
Readiness Level of the Observing Approach for this EOV	Mature	Mature	Mature	Mature	Mature	pH Pilot pCO_2 Concept DIC Concept TA Concept
Leading Observing Network	SOOP-CO_2	GO-SHIP	OceanSITES			Biogeochemical Argo
Readiness Level of the Network	Concept	Mature	Pilot			Pilot
Phenomena Addressed	**1,3**	**2,3**	**1,3,4**	**1,3**	**1,3,4,5**	**2,3,4,5**
Spatial Scales Currently Captured by the Observing Network	Horizontal coverage: global, every 10°, denser in the coastal domain Vertical coverage: surface Footprint:	Horizontal coverage: global, every 20° Vertical coverage: full depth Footprint:	Horizontal coverage: Vertical coverage: Footprint: local (sub-basin scale)	Horizontal coverage: Vertical coverage: Footprint: regional (basin-scale)	Horizontal coverage: Vertical coverage: Footprint: local (sub-basin scale)	Horizontal coverage: every 10°, denser in the coastal domain Vertical coverage: Footprint:
Typical Observing	Weekly to decadal	Decadal	Sub-daily to seasonal and	Hourly to annual	Weekly to decadal	Weekly to annual

Frequency			annual			
Supporting Variables Measured	Atmospheric / ocean pCO_2, Surface temperature and salinity,		Surface and subsurface temperature and salinity, Wind speed, Atmospheric CO_2	Surface and subsurface temperature	Wind speed, Atmospheric and ocean pCO_2	
Sensor(s)/Technique	Equilibrator, Permeable membrane, Infra-red, CRDS	Benchtop instruments	Equilibrator, Permeable membrane	Spectro-photometric	Titration, equilibrator	Spectro-photometry Variety of sensors are being developed
Accuracy/Uncertainty Estimate (units)	$\underline{pCO_2}$ ±2 µatm	$\underline{TA/DIC}$ ±2 µmol kg^{-1} $\underline{pH}$ ±0.005 $\underline{pCO_2}$ ±2 µatm	$\underline{pCO_2}$ ±5 µatm	$\underline{pCO_2}$ ±5 µatm $\underline{pH}$ ±0.005	$\underline{TA/DIC}$ ±2 µmol kg^{-1} $\underline{pH}$ ±0.005 $\underline{pCO_2}$ ±2 µatm	$\underline{pCO_2}$ ±5 µatm $\underline{pH}$ ±0.005
Reporting Mechanisms(s)	Individual Networks Annual Reports IOCCP Annual Report					

Table 4: Future Observing Capacity					
Observing Approach	**Surface Autonomous Vehicles**	**Moored Fixed-point Observatories**	**Autonomous Underwater Vehicles**	**Ship-based Underway Observations**	
Novel aspect of the observing approach	Novel observing approach and network (OceanGliders) for pH and pCO_2.	Resolving full water column measurement of pH and pCO_2.	Novel observing approach resolving water column measurements of pH and pCO_2.	New sub-variables measured (DIC/TA) using new sensors/techniques.	
How does this novel aspect impact our observing capacity?					
Readiness Level of the Observing Network	pH Pilot pCO_2 Concept DIC Concept TA Concept	pCO_2 (surface) Mature pCO_2 (interior) concept pH Concept	Concept	underway pCO_2 Mature underway DIC/TA underway pH	
Spatial Scales Captured by the Observing Network	20°, surface	1 km	10-1000 km, full depth	Every 10°, Denser in the coastal domain, Surface	
Typical Observing Frequency	Daily to monthly	Sub-daily to seasonal and annual	Daily to monthly	Weekly to annual	
Time-Scale Until Part of Observing System					
Supporting Variables Measured					

Sensor(s)/Technique	Spectro-photometry & Equilibrator Very dynamic field, variety of sensors are being developed	Permeable membrane Very dynamic field, variety of sensors are being developed	Spectro-photometry Very dynamic field, variety of sensors are being developed	DIC NDIR (?CRDS) pCO_2 Equilibrator pH Permeable membrane TA Titration	
Accuracy/Uncertainty Estimate (units)	pCO_2 ±5 µatm pH ±0.005	pCO_2 ±10 µatm pH ±0.005	pCO_2 ±5 µatm pH ±0.005	pH ±0.005 TA ±2 µatm DIC ±4 µatm	

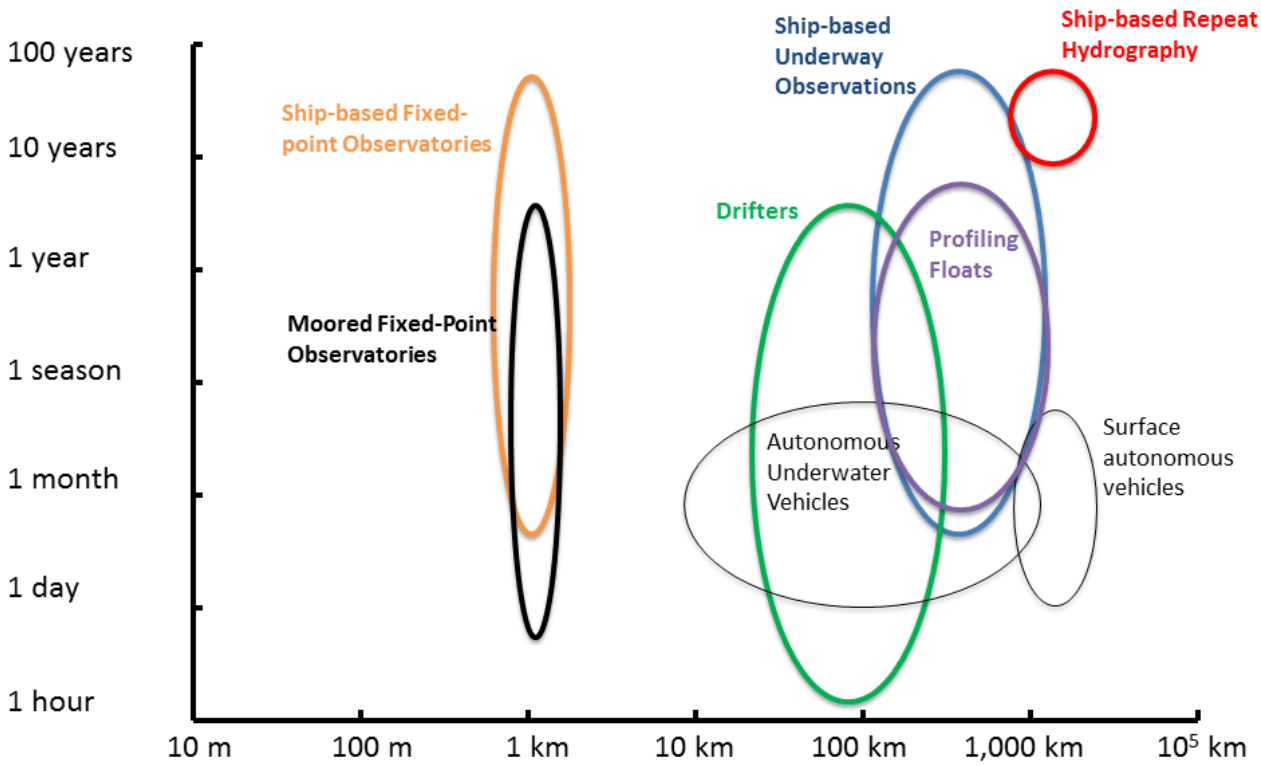

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).

Table 5: Data & Information Creation					
Observing Approach	**Oversight & Coordination**	**Data Quality Control**	**Near Real-time Data Stream Delivery**	**Data Repository**	**Data Products**
Ship-based Underway Observations	IOCCP	Level 1: PIs Level 2: SOCAT		NCEI OCADS SOCAT PANGAEA	SOCATv4 LDEO Climatology GLODAPv2 SOCOM
	Mature	Mature		Mature	
Ship-based Repeat Hydrography	Surface IOCCP Interior GO-SHIP, IOCCP	Surface Level 1: PIs Level 2: SOCAT Interior Level 1: PIs Level 2: GLODAP RG		Surface NCEI OCADS SOCAT PANGAEA Interior NCEI OCADS	
Moored Fixed-Point Observatories	OceanSITES, IOCCP			OceanSITES GDACs (US NDBC, Ifremer Coriolis)	
Drifters					
Ship-based Fixed-point Observatories	OceanSITES, IOCCP				

Table 6: Links & References	
Best Practices, Guides and Other Background Documentation	Dickson, A.G., C.L. Sabine, and J.R. Christian, eds. (2007), Guide to best practices for ocean CO_2 measurements, PICES Special Publication 3, 191 pp., Guide to Best Practices in Ocean Acidification Research and Data Reporting (Eds: Riebesell U., Fabry V. J., Hansson L. & Gattuso J.-P., 2010. 260 p. Luxembourg: Publications Office of the European Union). Addendum, 2015-11-13 Certified Reference Materials (CRMs): https://www.nodc.noaa.gov/ocads/oceans/Dickson_CRM/batches.html
Links for Contributing Networks	GO-SHIP: http://www.go-ship.org OceanSITES: http://www.oceansites.org/index.html
Links for Near-Real Time Data Stream Delivery	
Links to Data Repositories	NCEI OCADS: https://www.nodc.noaa.gov/ocads/ SOCAT: http://www.socat.info PANGAEA: https://www.pangaea.de/
Data Product Links and References	SOCATv4: http://www.socat.info GLODAPv2: http://glodap.info/ LDEO Climatology: https://www.nodc.noaa.gov/ocads/oceans/LDEO_Underway_Database/ SOCOM: http://www.bgc-jena.mpg.de/SOCOM/

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
pCO_2 – Partial pressure of carbon dioxide
DIC – Dissolved Inorganic Carbon
TA – Total Alkalinity
nm – nautical mile = 1.852 km
µatm – 10^{-6} atmospheres (pressure)
PI – Principal Investigator
CCHDO – CLIVAR and Carbon Hydrographic Data Office
GO-SHIP – Global Ocean Ship-based Hydrographic Investigations Program
GODAE – Global Ocean Data Assimilation Experiment
GLODAP - Global Ocean Data Analysis Project
RG – Reference Group
SOCAT – Surface Ocean CO_2 Atlas
CARINA - CARbon dioxide IN the Atlantic Ocean database
LDEO – Lamont-Doherty Earth Observatory
NDIR - Nondispersive Infrared Detector
CRDS - Cavity Ring-Down Spectroscopy
NCEI OCADS – National Centers for Environmental Information Ocean CArbon Data System
SOCOM - Surface Ocean pCO_2 Mapping intercomparison
US NDBC – United States National Data Buoy Center -

List of References