Essential Ocean Variable (EOV): Transient Tracers

Background and Justification

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 seawater, 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 have been measured. More recently also the related compound sulphur hexafluoride (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 argon isotope ^{39}Ar has a half-life in the right order of magnitude to characterize global ocean ventilation and have an impeccable inertness. Difficult measurement techniques have hampered its use, but recently new technologies are emerging that might allow for a global survey of ^{39}Ar in the near future.

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

Table 1: EOV Information	
Name of EOV	Transient Tracers
Sub-Variables	Chlorofluorocarbons (CFC-12, CFC-11, CFC-113, CCl_4), Sulphur hexafluoride (SF_6), tritium, ^{3}He, ^{14}C, ^{39}Ar
Derived Products	Tracer ages, Age and transit time distribution (TTD) of water masses, Anthropogenic carbon concentration
Supporting Variables	Surface and subsurface temperature, Surface and subsurface salinity
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		
Scientific Application(s)	Q1.1. How is the ocean carbon content changing? Q2.1. How large are the ocean's dead zones and how fast are they growing? Q2.2. What are rates and impacts of ocean acidification?		
Readiness Level *[as defined in the FOO]*	Mature – Level 9 (out of 9) – ''Sustained"		
Phenomena to Capture	**1** **Ventilation**	**2** **Circulation**	**3** **Anthropogenic carbon sequestration**
Temporal Scales of the Phenomena	Annual to decadal	Annual to decadal	Annual to decadal
Spatial Scales of the Phenomena	Open Ocean 500-10,000 km	Open Ocean 500-10,000 km	Open Ocean 500–10,000 km
Magnitudes/Range of the Signal to Capture	0-1000 years (water mass age)	0-100 years (transport times)	~2 Pg C yr^{-1}
Current Uncertainty Relative to the Signal			
Target Uncertainty Relative to the Signal	±10%	±10%	±10%

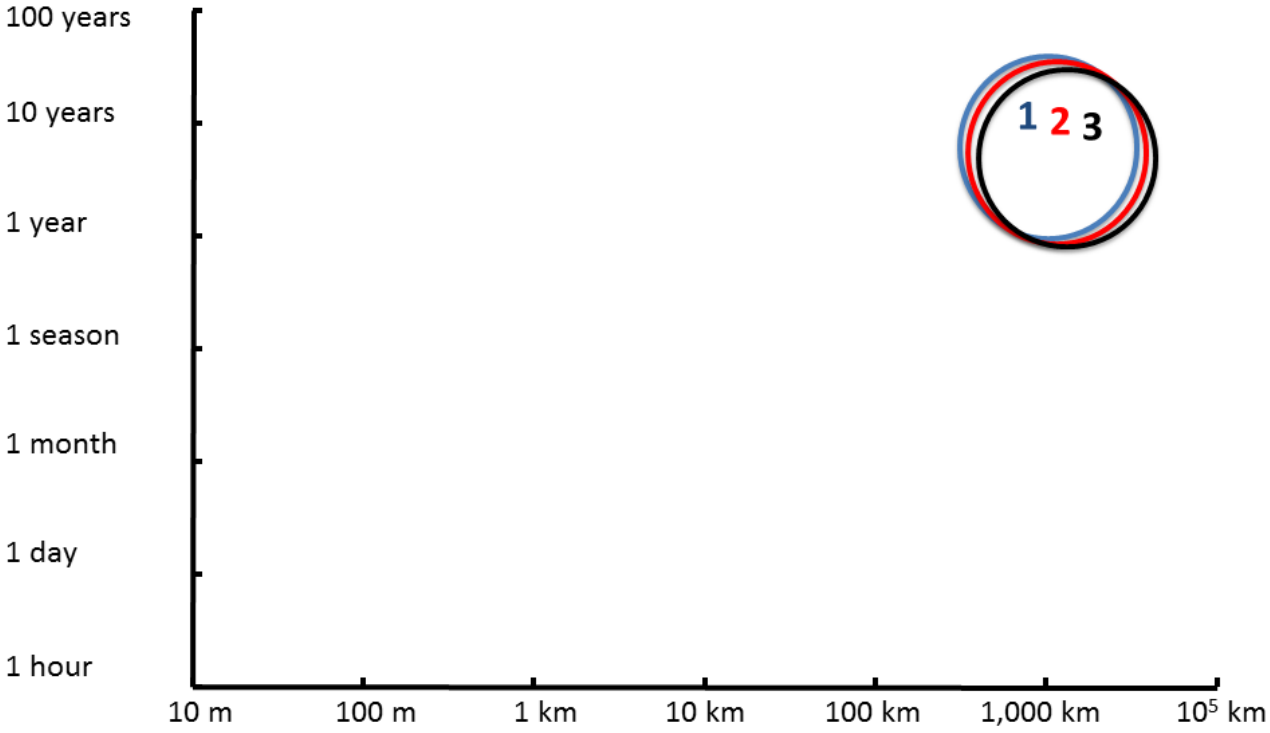

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks		
Observing Approach	**Ship-based Repeat Hydrography**	
Readiness Level of the Observing Approach for this EOV	Mature - 9	
Leading Observing Network	GO-SHIP	
Readiness Level of the Observing Network	$CFCs/SF_6$, ^3He/tritium, ^{14}C Mature - 9	
Phenomena Addressed	**1,2,3**	
Spatial Scales Currently Captured by the Observing Network	Horizontal coverage: $CFCs/SF_6$ global, typically every 30 nm; section spacing of 20°, coarser for the isotopes Vertical coverage: Footprint: *[to be defined for various oceanographic regimes]*	
Typical Observing Frequency	Annual to decadal	
Supporting Variables Measured	Surface and subsurface temperature and salinity	
Sensor(s)/ Technique	$CFCs/SF_6$: Purge and trap GC with ECD Tritium/^3He & ^{14}C: AMS/MS	
Accuracy/Uncertainty Estimate (units)	$CFCs$ and SF_6: ±1% Tritium: ±0.5%, 0.005 TU (precision/detection limit) ^3He: ±0.15% in δ^3He ^{14}C: ±0.4%	
Reporting Mechanism(s)	Individual Networks Annual Reports	

Table 4: Future Observing Capacity			
Observing Approach	**Ship-based Repeat Hydrography**		
Novel aspect of the Observing Approach	^{39}Ar measurements using ATTA (Atomic Trap Trace Analysis)		
How does the novel aspect impact our observing capacity?	It allows for better quantification of phenomena 1,2 and 3 in "old" waters		
Readiness Level of the Observing Network	Concept - 3		
Spatial Scales Captured by the Observing Network	100-10,000 km		
Typical Observing Frequency	Decadal or one-time survey		
Time-Scale Until Part of Observing System	5-10 years		
Supporting Variables Measured	T Surface and subsurface temperature and salinity		
Sensor(s)/Technique	ATTA (Atomic Trap Trace Analysis)		
Accuracy/Uncertainty Estimate (units)	$\pm 1 \times 10^{-16}$		

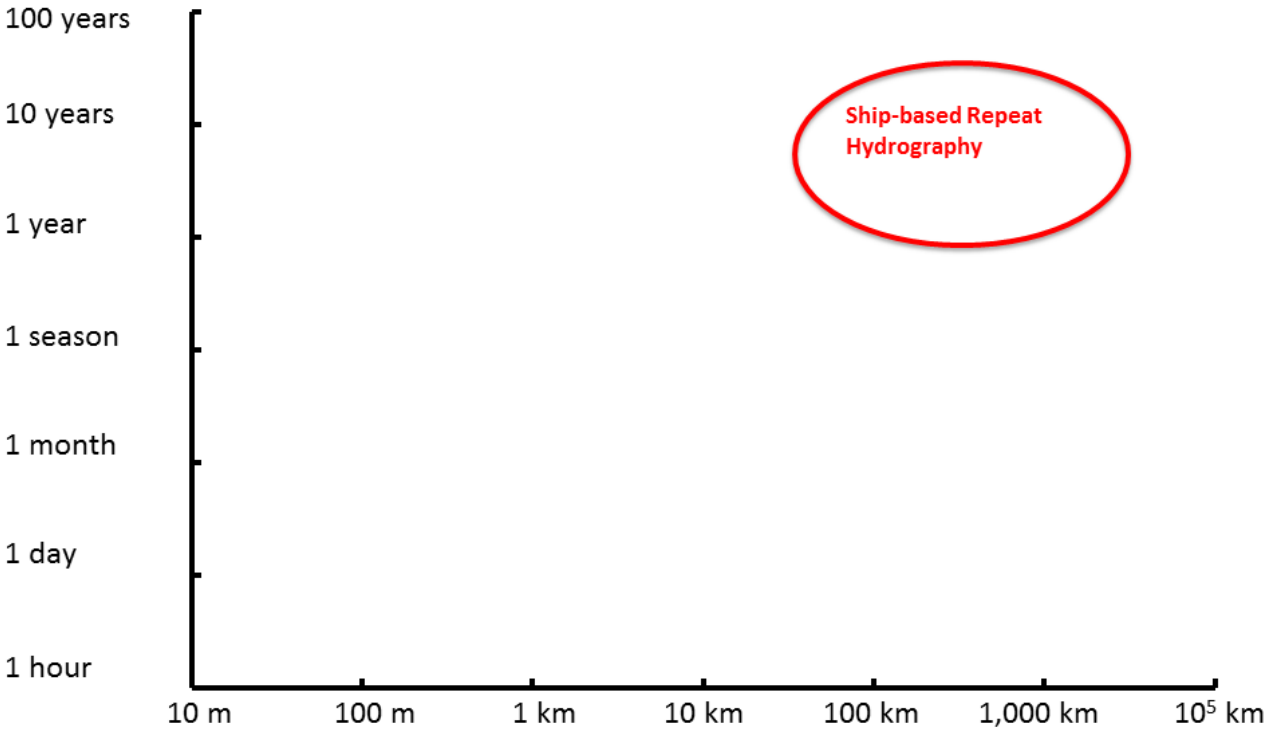

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).

Table 5: Data & Information Creation					
Observing Approach	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream delivery**	**Data Repository**	**Data Products**
Ship-based Hydrography	GO-SHIP	CCHDO		NCEI OCADS CCHDO PANGAEA	GLODAPv2
	Mature				

Table 6: Links & References	
Best Practices, Guides and Other Background Documentation	A. P. McNichol et al. (2010). Collection and measurement of carbon isotopes in seawater DIC. 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. J. L. Bullister and T. Tanhua. (2010). Sampling and Measurement of Chlorofluorocarbon and Sulfur Hexafluoride in Seawater. 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.
Links for Contributing Networks	GO-SHIP: http://www.go-ship.org/index.html
Links for Near-Real Time Data Stream Delivery	
Links to Data Repositories	NCEI OCADS: https://www.nodc.noaa.gov/ocads/ CCHDO: http://cchdo.ucsd.edu/ PANGAEA: https://www.pangaea.de/
Data Product Links and References	GLODAPv2: http://glodap.info/ 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
CFCs – Chlorofluorocarbons
TTD – Transit Time Distribution
GC – Gas Chromatograph
ECD – Electron Capture Detector
MS – Mass Spectrometer
AMS – Accelerator Mass Spectrometer
TU – Tritium Units
ATTA - Atomic Trap Trace Analysis
nm – nautical mile = 1.852 km
GO-SHIP – Global Ocean Ship-based Hydrographic Investigations Program
CCHDO – CLIVAR and Carbon Hydrographic Data Office
GLODAP – Global Ocean Data Analysis Project
NCEI OCADS – National Centers for Environmental Information Ocean CArbon Data System

List of References

Z.-T. Lu, P. Schlosser, W.M. Smethie Jr., N.C. Sturchio, T.P. Fischer, B.M. Kennedy, R. Purtschert, J.P. Severinghaus, D.K. Solomon, T. Tanhua, R. Yokochi, 2014. Tracer Applications of Noble Gas Radionuclides in the Geoscience, Earth Science Reviews, doi.org/10.1016/j.earscirev.2013.09.002.

Fine, R. A.: Observations of CFCs and SF(6) as Ocean Tracers, Annual Review of Marine Science, Vol 3, 3, 173-195, 10.1146/annurev.marine.010908.163933, 2011.