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 sea-water, 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.

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	Temperature (T), Salinity (S)
Contact/Lead Expert(s)	CFCs/SF_6: John L. Bullister (NOAA/PMEL, USA) or Toste Tanhua (GEOMAR, Germany); ^{3}He/tritium, ^{14}C: William J. Jenkins (WHOI, USA) and Robert Key (Princeton, USA); ^{39}Ar: William Smethie (LDEO, USA)

The Global Ocean Observing System

Table 2: Requirements Setting						
Responsible GOOS Panel	Biogeochemistry Panel					
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	Mature - 9					
Phenomena to Capture	**1 Ventilation/ transit time distribution**	**2 Transport times**	**3 Anthropogenic carbon storage**			
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	0-1000 years	0-100 years	~2 Pg C yr^{-1}			
Desired Detection Limit Relative to the Signal	±10%	±10%	±10%			

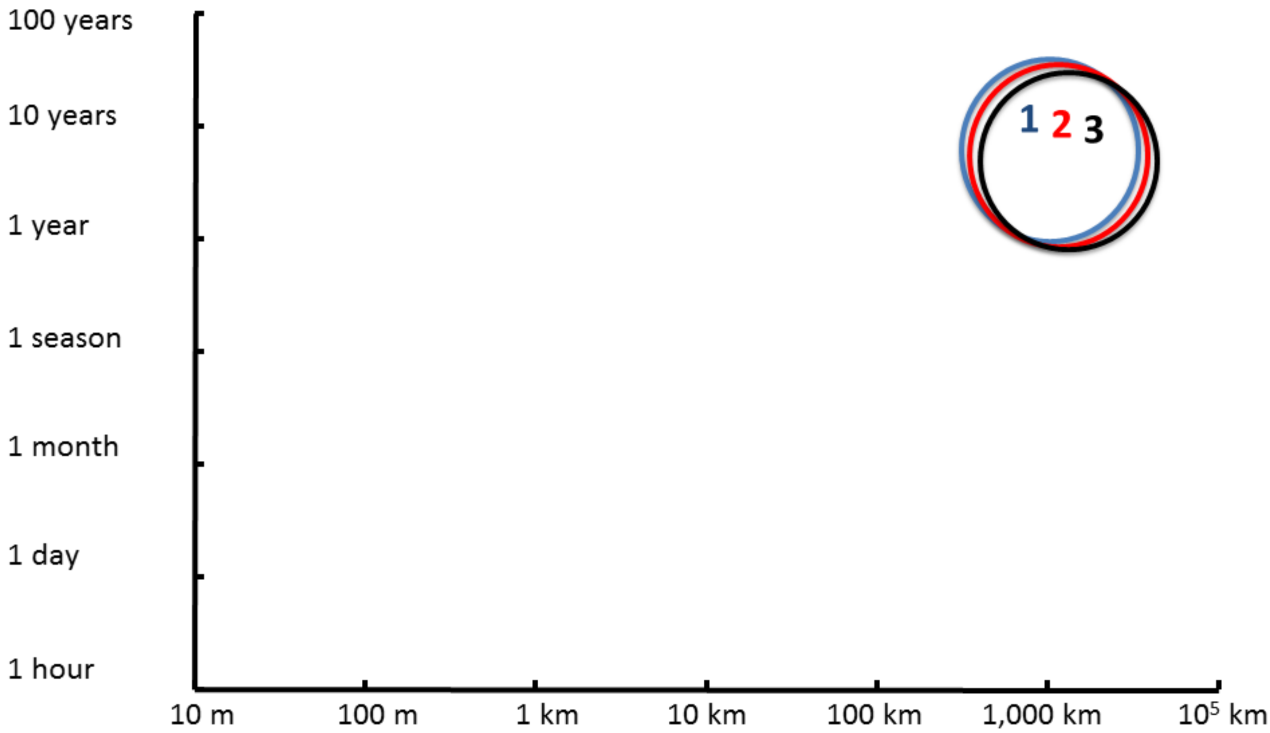

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks*			
Observing Network	**Ship-based Hydrography (SH)**		
Phenomena Addressed	**1,2,3**		
Readiness Level of the Observing Network (as defined in the FOO)	CFCs/SF_6, ^{3}He/tritium, ^{14}C Mature - 9		
Spatial Scales Currently Captured by the Observing Network	CFCs/SF_6 Typically every 30 nm Section spacing: 20°, coarser for the isotopes		
Typical Observing Frequency	Annual to decadal		
Supporting Variables Measured	S, T		
Sensor(s)/ Technique	CFCs/SF_6 Purge and trap GC with ECD Tritium/^{3}He & ^{14}C AMS/MS		
Accuracy/Uncertainty Estimate (units)	CFCs and SF_6 ±1% Tritium ±0.5%, 0.005 TU (precision/detection limit) ^{3}He ±0.15% in δ^3He ^{14}C ±0.4%		
Reporting Mechanism(s)	GOOS Implementation Plan 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-based Hydrography with ^{39}Ar measurements (SHAr)**		
Phenomena Addressed	**1,2,3**		
Readiness Level of the Observing Network (as defined in the FOO)	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, S		
Sensor(s)/Technique	ATTA (Atomic Trap Trace Analysis)		
Accuracy/Uncertainty Estimate (units)	$\pm 1\times10^{-16}$		

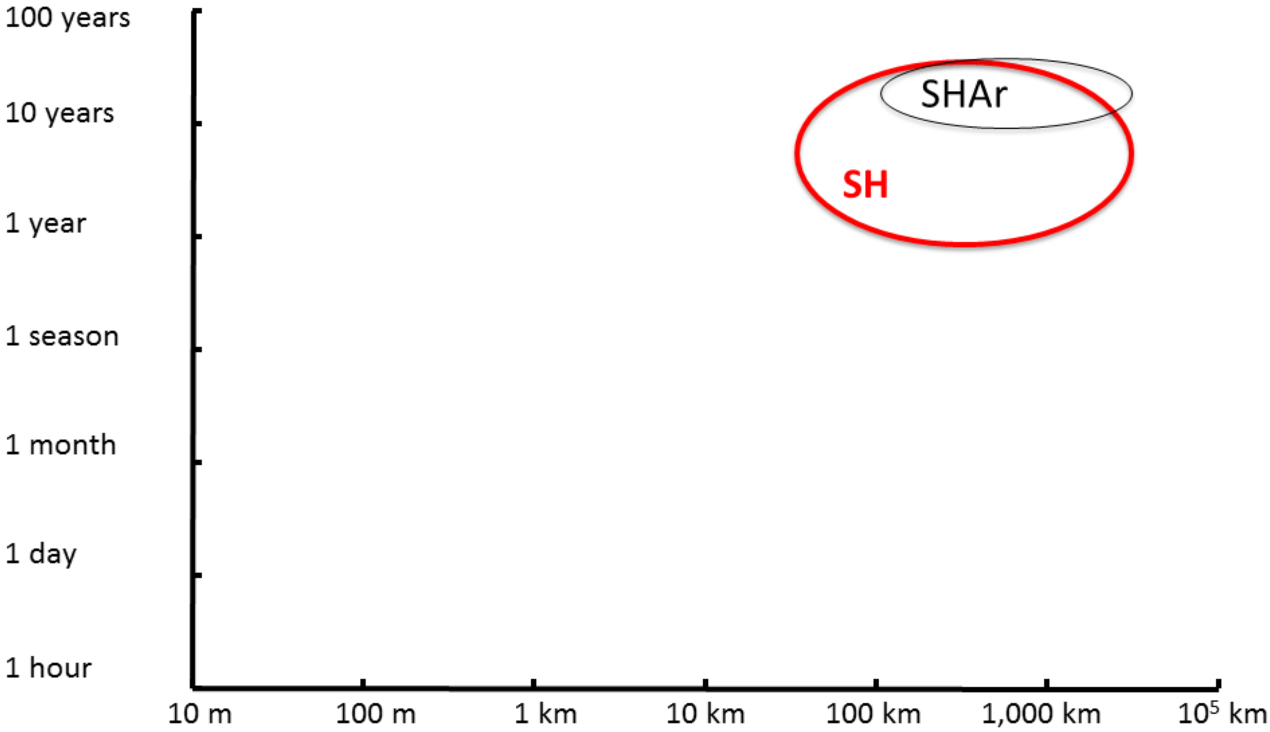

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).

Table 5: Data & Information Creation					
Responsible entity and readiness level in each category per observing element	**Oversight & Coordination**	**Data Quality Control**	**Near Real-Time Data Stream delivery**	**Data Repository**	**Data Product**
Ship-based Hydrography	No formal group established, but coordination provided through GO-SHIP	CCHDO	CCHDO for repeat hydrography	CCHDO	Global transit time distribution, or anthropogenic carbon content
	Mature				

Table 6: Links & References	
Links (especially regarding Background & Justification)	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. http://www.go-ship.org/Manual/McNichol_C1314.pdf http://www.go-ship.org/Manual/Bullister_Tanhua_CFCSF6.pdf
Links for Contributing Networks	http://www.go-ship.org/index.html
Data References	http://cchdo.ucsd.edu/

List of abbreviations

EOV – Essential Ocean Variable
GOOS – Global Ocean Observing System
IOCCP – International Ocean Carbon Coordination Project
CFCs – Chlorofluorocarbons
Ar – Argon
C – Carbon

He – Helium
SF_6 – Sulphur Hexafluoride
TTD – Transit Time Distribution
T – Temperature
S – Salinity
NOAA – National Oceanic and Atmospheric Administration
PMEL – Pacific Marine Environmental Laboratory
WHOI – Woods Hole Oceanographic Institute
LDEO – Lamont-Doherty Earth Observatory
GEOMAR – Research Center for Marine Geosciences
GC – Gas Chromatograph
ECD – Electron Capture Detector
MS – Mass Spectrometer
AMS – Accelerator Mass Spectrometer
TU – Tritium Units
SH – Ship based Hydrography
SHAr – Ship based Hydrography with ^{39}Ar measurements
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