Essential Ocean Variable (EOV): Nitrous Oxide

Background and Justification

Nitrous oxide (N_2O) is an important climate-relevant trace gas in the Earth's atmosphere. In the troposphere it acts as a strong greenhouse gas and in the stratosphere it acts as an ozone depleting substance because it is the precursor of ozone depleting nitric oxide radicals. Because of the on-going decline of chlorofluorocarbons and the continuous increase of N_2O in the atmosphere, the contributions of N_2O to both the greenhouse effect and ozone depletion will be even more pronounced in the 21st century. The ocean - including its coastal areas such as continental shelves, estuaries and upwelling areas - is a major source of N_2O and contributes about 30% to the atmospheric N_2O budget. Oceanic N_2O is mainly produced as a by-product during archaeal nitrification (i.e. ammonium oxidation to nitrate) whereas bacterial nitrification seems to be of minor importance as source of oceanic N_2O. N_2O occurs also as an intermediate during microbial denitrification (nitrate reduction via N_2O to dinitrogen, N_2). Nitrification is the dominating N_2O production process, whereas denitrification contributes only 7-35% to the overall N_2O water column budget in the ocean. The amount of N_2O produced during both nitrification and denitrification strongly depends on the prevailing dissolved oxygen (O_2) concentrations and is significantly enhanced under low (i.e. suboxic) O_2 conditions. N_2O is usually not detectable in anoxic waters because of its reduction to N_2 during denitrification. Thus, significantly enhanced N_2O concentrations are generally found at oxic/suboxic or oxic/anoxic boundaries. The strong O_2 sensitivity of N_2O production is also observed in coastal characterised by seasonal shifts in the O_2 regime. A biological source of N_2O in the well-oxygenated mixed layer/euphotic zone seems to be unlikely. Global maps of N_2O in the surface ocean show enhanced N_2O anomalies (i.e. supersaturation of N_2O) in equatorial upwelling regions as well as N_2O anomalies close to zero (i.e. near equilibrium) in large parts of the open ocean. The MEMENTO (The MarinE MethanE and NiTrous Oxide database: https://memento.geomar.de) project has been launched with the aim to collect and archive N_2O data sets and to provide actual fields of surface N_2O for emission estimates.

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

Table 1: EOV Information	
Name of EOV	Nitrous Oxide
Sub-Variables	Nitrous Oxide (N_2O)
Derived Products	Global N_2O concentration fields, Global Ocean N_2O emission estimates
Supporting variables	Surface and subsurface temperature, Surface and subsurface salinity, Atmospheric pressure
Responsible GOOS Panel	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 1.2. How does the ocean influence cycles of non-CO_2 greenhouse gases? Q 2.1. How large are the ocean's "dead zones" and how fast are they changing? Q 3.2. How do the eutrophication and pollution impact ocean productivity and water quality?			
Readiness Level *[as defined in the FOO]*	Mature			
Phenomena to Capture	**1** **Deoxygenation**	**2** **Eutrophication**	**3** **Upwelling**	**4** **Air-sea Fluxes**
Temporal Scales of the Phenomena	Seasonal to decadal	Seasonal to decadal	Seasonal to perennial	
Spatial Scales of the Phenomena	Coastal 1-500 km Open Ocean <2000 km	Coastal 1-500 km Open Ocean <2000 km	Coastal 1-500 km Open Ocean <2000 km	
Magnitudes/Range of the signal to Capture	*[range in nM-N]*	~1 µM N year^{-1} (increase of nitrogen)	*[range in nM-N]*	
Current Uncertainty Relative to the Signal				
Target Uncertainty Relative to the Signal				

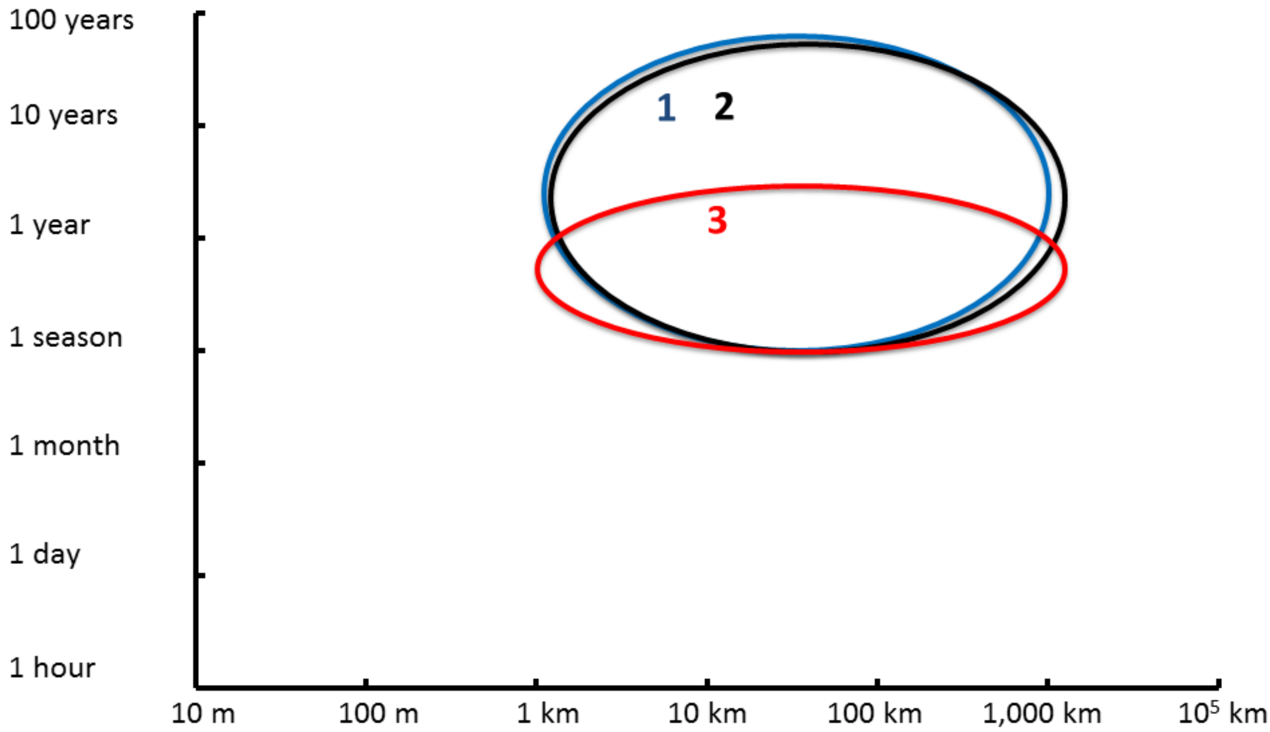

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks		
Observing Approach	**Ship-based Repeat Hydrography**	**Ship-based Fixed-point Observatories**
Readiness Level of the Observing Approach for this EOV	Mature	Mature
Leading Observing Network	GO-SHIP	
Readiness Level of the Observing Network	Mature	
Phenomena Addressed	**1,2,3,4**	**1,2,3,4**
Spatial Scales Currently Captured by the Observing Network	Horizontal coverage: 1-5000 km Vertical coverage: Footprint: *[to be defined for various oceanographic regimes]*	Horizontal coverage: Vertical coverage: Footprint: *[to be defined for various oceanographic regimes]*
Typical Observing Frequency	Annual to decadal	Monthly to decadal
Supporting Variables Measured	Surface and subsurface temperature, Surface and subsurface salinity, Atmospheric pressure	Surface and subsurface temperature, Surface and subsurface salinity, Atmospheric pressure
Sensor(s)/ Technique	Static/cont. equilibration + GC/ECD; static/cont. equilibration + cavity ringdown N_2O analyzer	Static/cont. equilibration + GC/ECD; static/cont. equilibration + cavity ringdown N_2O analyzer
Accuracy/Uncertainty Estimate (units)	Accuracy calibrated against NOAA standards Uncertainty discrete samples: ~±5%; cont. sampling: <±1%	Accuracy calibrated against NOAA standards Uncertainty discrete samples: ~±5%; cont. sampling: <±1%
Reporting Mechanism(s)	Individual Networks Annual Reports	

Table 4: Future Observing Capacity		
Observing approach	**Ship-based Underway Observations**	
What is the novel aspect of this observing approach?	New observing platform	
How does this novel aspect impact our observing capacity?		
Phenomena Addressed		
Readiness Level of the Observing Network	Pilot	
Spatial Scales Captured by the Observing Network	1-10,000 km	
Typical Observing Frequency	Daily to monthly	
Time-Scale until Part of Observing System	5-10 years	
Supporting Variables Measured		
Sensor(s)/Technique	Cavity-ringdown N_2O analyzer coupled to equilibrator	
Accuracy/Uncertainty Estimate (units)	Accuracy: calibrated against NOAA standards Uncertainty <±1%	

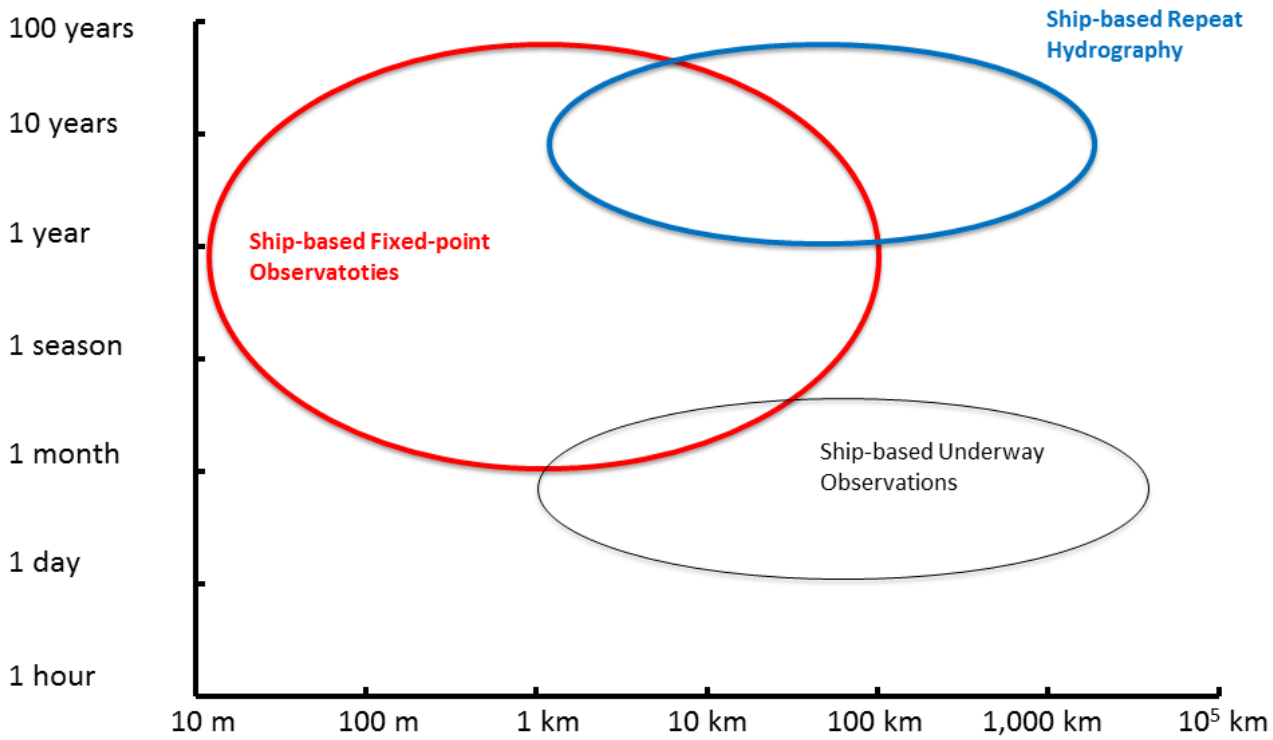

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).

Table 5: Data & Information Creation

Observing Approach	Oversight & Coordination	Data Quality Control	Near Real-Time Data Stream Delivery	Data Repository	Data Products
Ship-based Hydrography	SCOR WG #143	MEMENTO		MEMENTO *(available only upon free registration)*	MEMENTO global N_2O concentration and emission fields *(available only upon free registration)* GLODAPv2
	Pilot				
Ship-based Fixed-Point Observatories	SCOR WG #143	MEMENTO		MEMENTO *(available only upon free registration)*	
	Pilot				

Table 6: Links & References	
Best Practices, Guides and Other Background Documentation	
Links for Contributing Networks	SCOR WG143: Dissolved N_2O and CH_4 measurements: Working towards a global network of ocean time series measurements of N_2O and CH_4 https://portal.geomar.de/web/scor-wg-143/home GO-SHIP: http://www.go-ship.org/index.html
Links to Near-Real Time Data Stream Delivery	
Links to Data Repositories	MEMENTO: https://memento.geomar.de *(available only upon free registration)*
Data Product Links and References	MEMENTO: https://memento.geomar.de *(available only upon free registration)* 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.

The Global Ocean Observing System

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
MEMENTO – The MarinE MethanE and NiTrous Oxide
SCOR – Scientific Committee on Oceanic Research
WG – Working Group
SST – Sea Surface Temperature
GC – Gas chromatography
ECD – Electron capture detector
NOAA – National Oceanic and Atmospheric Administration
GLODAP – Global Ocean Data Analysis Project

The Global Ocean Observing System

List of References

Arévalo-Martínez, D. L., M. Beyer, M. Krumbholz, I. Piller, A. Kock, T. Steinhoff, A. Körtzinger, and H. W. Bange (2013), A new method for continuous measurements of oceanic and atmospheric N_2O, CO and CO_2: performance of off-axis integrated cavity output spectroscopy (OA-ICOS) coupled to non-dispersive infrared detection (NDIR), Ocean Science, 9(6), 1071-1087; http://www.ocean-sci.net/9/1071/2013/os-9-1071-2013.html.

Bakker, D. C. E., H. W. Bange et al. (2014), Air-sea interactions of natural long-lived greenhouse gases (CO_2, N_2O, CH_4) in a changing climate, in Ocean-Atmosphere Interactions of Gases and Particles, edited by P. S. Liss and M. T. Johnson, pp. 113-169, Springer Verlag, Heidelberg; http://link.springer.com/book/10.1007/978-3-642-25643-1