Essential Ocean Variable (EOV): Nitrous Oxide (N_2O)

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 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 oceans - including its coastal areas such as continental shelves, estuaries and upwelling areas - are a major source of N_2O and contribute 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.

Table 1: EOV Information	
Name of EOV	Nitrous Oxide (N_2O)
Sub-Variables	Not applicable
Derived Products	Global N_2O concentration fields, Global Ocean N_2O emission estimates
Supporting variables	Temperature (T), Salinity (S), Atmospheric pressure
Contact/Lead Expert(s)	Hermann Bange (GEOMAR, Germany) and Sam Wilson (University of Hawaii, USA) are Co-chairs of 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'

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 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	Mature			
Phenomena to Capture	**1** **Changes in storage of O_2**	**2** **Eutrophication**	**3** **Upwelling**	**4** **Flux of N_2O to the atmosphere**
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	Decrease of ~1 µM O_2 $year^{-1}$	Increase of ~1 µM N $year^{-1}$	Change in SST of >2°C	
Desired Detection Limit Relative to the Signal	?	?	?	

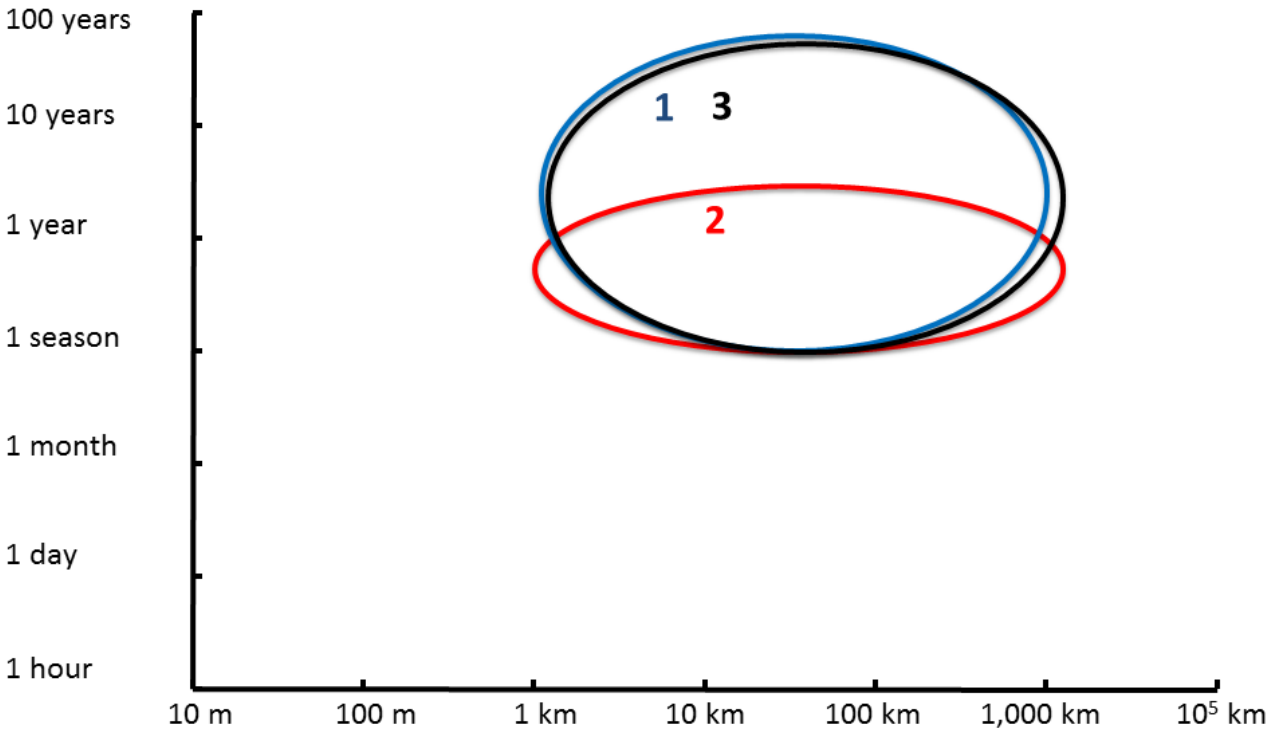

Figure 1: Spatial and temporal scales of phenomena (as color-coded and listed in Table 2 above) to be addressed.

Table 3: Current Observing Networks*					
Observing Network	**Ship-based Hydrography (SH)**	**Ship-based Time-Series (STS)**			
Phenomena Addressed	**1,2,3,4**	**1,2,3,4**			
Readiness Level of the Observing Network (as defined in the FOO)	Mature	Mature			
Spatial Scales Currently Captured by the Observing Network	1-5000 km	Local			
Typical Observing Frequency	Annual to decadal	Monthly to decadal			
Supporting Variables Measured	N_2O, T, S, Atmospheric pressure	N_2O, T, S, 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)	GOOS Implementation Plan				

*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	**?**				
Readiness Level of the Observing Network (as defined in the FOO)	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	N_2O				
Sensor(s)/Technique	Cavity-ringdown N_2O analyzer coupled to equilibrator				
Accuracy/Uncertainty Estimate (units)	Accuracy calibrated against NOAA standards Uncertainty <±1%				

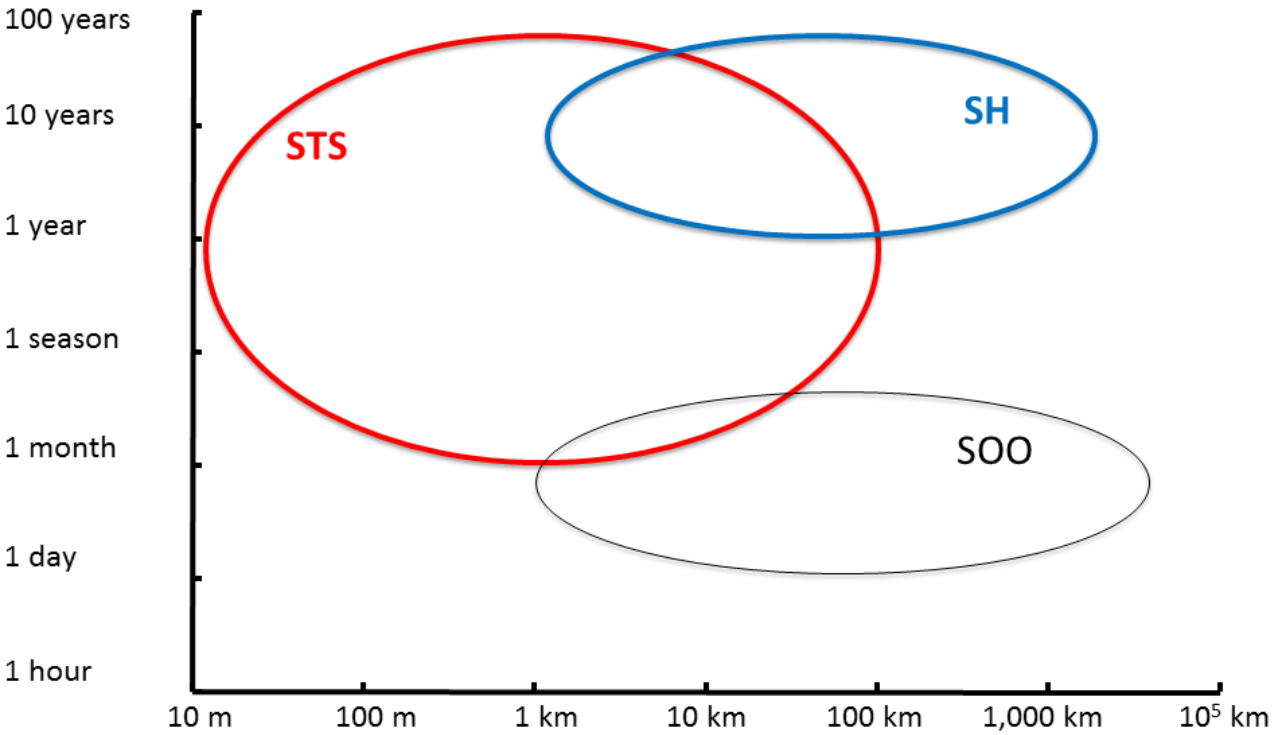

Figure 2. Spatial and temporal observation scales of component networks listed in Table 3 (thick coloured circles) and in Table 4 (thin black circles).

Table 5: Data & Information Creation					
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**
Ship-based Hydrography	SCOR WG143	MEMENTO	MEMENTO	MEMENTO	N_2O conc. data sets; global N_2O concentration and emission fields
	Pilot				
Ship-based Time-Series	SCOR WG143	MEMENTO	MEMENTO	MEMENTO	N_2O conc. data sets; global N_2O concentration and emission fields
	Pilot				

Table 6: Links & References	
Links (especially regarding Background & Justification)	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
Links for Contributing Networks	SCOR WG143 *Dissolved N2O and CH4 measurements: Working towards a global network of ocean time series measurements of N2O and CH4* https://portal.geomar.de/web/scor-wg-143/home
Data References	MEMENTO: https://memento.geomar.de

List of abbreviations

EOV – Essential Ocean Variable
GOOS – Global Ocean Observing System
IOCCP – International Ocean Carbon Coordination Project
FOO – Framework for Ocean Observing
N_2O – Nitrous Oxide
CH_4 – Methane
MEMENTO – The MarinE MethanE and NiTrous Oxide
SCOR – Scientific Committee on Oceanic Research
WG – Working Group
T – Temperature
S – Salinity
SST – Sea Surface Temperature
GC – Gas chromatography
ECD – Electron capture detector
NOAA – National Oceanic and Atmospheric Administration
SH – Ship-based Hydrography
STS – Ship-based Time-Series
SOO – Ship Of Opportunity