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NEW APPROACH TO UNDERWATER TECHNOLOGIES FOR INNOVATIVE, LOW-COST OCEAN OBSERVATION (NAUTILOS): operational field primary capture system

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Abstract—**The large variety of platforms and sensors globally deployed and available, allows access to a conspicuous quantity of data and variables with heterogeneous formats and scales. In the last decades governments and the scientific world have encouraged standardizations and best practices for data collection, elaboration and distribution. Several initiatives had led the bases for globally shared practices and quality indexes. This paper aims at giving a state of the art concerning the existing best practices and quality indices of the most important platforms, initiatives and projects for the scope of NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation – H2020 project (www.nautilos-h2020.eu; ct. 101000825)**

Keywords—EOV, interoperability, standards

I. INTRODUCTION (*HEADING 1*)

The value of any system is contingent on its relationship to its user community and scaled by the degree of its adoption. To this end, during the last decades the International Organization for Data Exchange (IODE), the Framework for Ocean Observing (FOO), the Global Ocean Observing System (GOOS), as well as European initiatives (Copernicus Marine Service, European Marine Observations and Data network, SeaDataNet networks of National Oceanographic Data Centers), etc. have encouraged standardizations and best practices for data collection, elaboration and distribution [1]. More recently, the Ocean Best Practices System (OBPS) supports the objective of fostering and making available best practices across the value chain, from observations to data management and applications for understanding the state and potential of our ocean. To gain maximum value from this vital information we need to use commonly accepted methods, 'best practices', across our ocean observing system, in order to deliver data that is interoperable, re-usable, of high quality and with consistent latency.

The OBPS workflow put the users at the center of the process. They may be able to access best practice from running networks, training to learn about best practices, have the possibility to develop, publish and let other users to adopt best practices[1].

NAUTILOS has the strategic objective of filling in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas [2]. This paper recalls the technologies and sensors that NAUTILOS is developing, then lists the running international initiatives also included in the OBPS, describes the approach to facilitate NAUTILOS data flow into European Marine depositories and initiatives.

[1]https://eurosea.eu/ocean-best-practices/

II. NAUTILOS TECHNOLOGIES AND REFERENCE NETWORKS

NAUTILOS is focusing on 17 instrumentation/tools that can operate from shallow coastal waters to open and deep-sea sites, providing complete datasets for studying the marine ecosystem functions and advanced data products and tools.

NAUTILOS is developing sensors to match and fit needs of operational oceanography platforms, more specifically it is targeting the following integrating platforms:

- Fisheries Observing Systems (Opportunity ships);
- Aquaculture Observing Systems (Ferrybox)
- Acoustic Marine Mammal Monitoring System (fixed point observation);
- Autonomous vehicles and Lander missions (Gliders/AUV)
- ARGO floats
- Animal- borne instrumentation
- Mooring buoys and fixed observatories

These platforms already fall into or can be associated to one of the GOOS platforms networks (Data Buoy Cooperation Panel (DBCP)[2], Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP)[3], Ship Observations Team (SOT)[4], ARGO[5], OceanSITES[6], OceanGliders[7], Animal-Borne Ocean Sensors (AniBOS)) that organize the standards and best practices for the platform stakeholders.

[2]https://www.ocean-ops.org/dbcp/; [3]https://www.go-ship.org/;
[4]https://www.ocean-ops.org/sot/; [5]https://argo.ucsd.edu/;
[6]http://www.oceansites.org/; [7] https://www.oceangliders.org

At European level, EuroGOOS that has established Task Teams, and TT members collaborate in the areas of shared priorities, exchange best practices, and feed data to the EuroGOOS ROOS regional portals, and European Marine data programs and initiatives: EMODnet, and Copernicus Marine Service and SeaDataNet. The European Marine Data programs and initiatives largely contribute to standards and best practices definition and in this framework most of the parameters and platforms have a precise and well consolidated policy of quality and data/metadata codification and format. Some of these initiatives also deal with the long-term preservation and legacy of (some) data and in particular the IODE network of National Oceanographic Data Centers, and well-established international repositories (ICES DB, PANGAEA, …) were designed and are evolving to support researchers with these crucial topics of the ocean data research activities. To maximize the value and impact data collection, NAUTILOS strategy has to consider these end-points, the retrieval process for data and/or metadata production, and to apply these standards/requirements backwards toward the data dissemination/production.

NAUTILOS is covering 14 Biology and Ecosystem and Biogeochemical EOVs (inorganic carbon, stable carbon isotopes, dissolved oxygen, inorganic macronutrients, suspended particulates, ocean color, ocean sound, phytoplankton biomass and diversity, zooplankton biomass and diversity, marine turtles, birds, mammals, abundance and distribution, live coral, sea grass cover, microbe biomass and diversity (emerging) and invertebrate abundance and distribution (emerging), 2 DOOS specific EOVs (litter including microplastics, seafloor sponge habitat cover) and 9 MSFD Descriptors (D1, D3, D4, D5, D6, D7, D9, D10, D11) and the Table I presents the mapping of a such multitude of capabilities.

As anticipated the goal of OBPS is to implement procedures for NAUTILOS EOVs, including in information about the sensors and procedures used to measure the variables. For the new sensors, if needed, NAUTILOS has to include the publication of written manuals for the QA/QC procedures, otherwise NAUTILOS has to refer to common standards and procedures. The Table II collects the key reference recommendations.

Further to these recommendations, for implementing easy data interoperability the project has to adopt and refer to common vocabularies. The Table III lists the adopted standards.

TABLE I. METADATA VOCABULARIES

Metadata field	**Vocs exists**	**Link to vocabulary**	**Vocabulary governance**
Platform type	Yes	http://vocab.nerc.ac.uk/collection/L06/current/	BODC
Platform type bigram	Yes	CMEMS INSTAC	EuroGOOS DATAMEQ
sensor_model	Yes	http://vocab.nerc.ac.uk/collection/L22/current/	BODC -NVS
ICES_code	Yes	https://ocean.ices.dk/codes/ShipCodes.aspx	ICES
contributors_role			NAUTILOS
naming_authority	Yes	https://edmo.seadatanet.org/	SeaDataNet
Institution	Yes	https://edmo.seadatanet.org/	SeaDataNet
qc_method	*	doi	
data_mode	Yes	RT/DM/REP	EuroGOOS DATAMEQ
Phase	No		NAUTILOS
variable names	Yes	http://vocab.nerc.ac.uk/collection/P02/current/ http://vocab.nerc.ac.uk/collection/P01/current/ http://vocab.nerc.ac.uk/collection/P07/current/	BODC - NVS
Time	yes	ISO8601	ISO
Datum	Yes	WGS84	ISO
Taxon	Yes	LSID	WoRMS
Country	yes	ISO3166	ISO
Licence	Yes	https://creativecommons.org/	CC
INSPIRE	Yes	ISO 19115	ISO/INSPIRE

III. PROMOTING THE USE OF NAUTILOS DATA

There are two categories of data to be used within NAUTILOS:

- internal project data, i.e., data outputs from the project itself;
- externally valuable environmental data, i.e., real-world application data.

The data consists of a combination of numeric data (i.e., parameters measured by sensors), images and sounds from in situ fixed and moving platforms (time series, profiles, trajectories), and from model outputs (gridded data) that use collected data. While the data flow for classical ocean physical parameters such as temperature and salinity, as described in the previous section, is well-defined, some of the NAUTILOS variables, such as digital images, microplastic observations, and acoustic data, are part of new data flows and while the endpoint may be already defined, the in-between data standards are still under discussion.

One example to present the general case is “Marine litter”.

Marine Litter has been added to the EMODnet Chemistry scope since 2017. It is an important subject on the international political agendas such as of G7 and G20. It is very relevant for the MSFD agenda and is managed under the descriptor D10. This aims to provide instruments to assess, monitor, set targets and finally reach a good environmental status (GES) with regard to marine litter. GES should be achieved only when “properties and quantities of marine litter do not cause harm to the coastal and marine environment”.

To this end EMODnet Chemistry has developed products for these three main categories: Beach litter (nets, bottles etc.), Seafloor Litter (i.e. litter collected by fish trawl surveys), Micro-litter (micro plastics). Starting from the outcomes of already ongoing initiatives (Technical Support Group – Marine Litter (TSG ML), JRC Project on Marine Litter baselines, Regional Sea Conventions (OSPAR, HELCOM, UNEP/MAP, BSCS), ICES, MEDITS, etc.), EMODnet Chemistry implemented two main databases - one for beach litter, modelled after the OSPAR-MCS approach, and one for seafloor litter, modelled after the ICES-DATRAS approach – and they collect a description of the detected elements, i.e. standardized description of the sampled element by using common terms from a standardized vocabulary.

In other terms, whatever is the methodology to collect the sample (manual annotation, taking a picture, taking a sample and processing it in the lab, etc.) the outcome of the procedure is a collection of information describing the litter. To describe the litter, EMODnet Chemistry has developed a document about "Guidelines and formats for gathering and management of micro-litter data sets on a European scale". Eventually, whatever is the methodology to collect the information, to be immediately consumable by EMODnet Chemistry litter registry, the information has to be described in a standard metadata format, i.e. Common Data Index (CDI) [3]

IV. IMPROVING GLOBAL ATTRIBUTES IN MARINE DATA EXCHANGE

As described in the previous sections, according the parameter and the recording platform, NAUTILOS can refer to and adapt already widely adopted standards and best practices. The same analysis highlighted that a key element in the ocean best practice is the proper compilation of metadata.

Usually, this information is reported in the global attributes, but it may not be valid for all the parameters in the data model. Hence here NAUTILOS propose to move this information at the level of the parameter where it will be possible to refer to different QC/QF for different parameters.

The Table IV shows an example of the attributes for a CTD parameter (i.e. TEMP) and in yellow the (new position of the) reference to the QC/QF methodology.

According the conducted analysis, NAUTILOS recommend to move the reference of the applied QC/QF best practice at the level of the parameter attributes e.g.:

Attribute – TEMP_QC – QC_method – String - https://repository.oceanbestpractices.org/handle/11329/656

This would improve the quality metadata and usability of the data.

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REFERENCES

[1] T. Tanhua, et al., Ocean FAIR data services. Frontiers in Marine Science,6, 440J, 2019.

[2] G. Pieri, et al., NEW TECHNOLOGY IMPROVES OUR UNDERSTANDING OF CHANGES IN THE MARINE ENVIRONMENT. 9th EuroGOOS International conference, Shom; Ifremer; EuroGOOS AISBL, May 2021, Brest, France. pp.500-508.

[3] https://www.emodnet-chemistry.eu/repository/Proposal-EMODnet-TG-ML-Micro-Litter-Data-Gathering-03062020.pdf

TABLE II. NAUTILOS TECHNOLOGIES

	NAUTILOS Marine Technologies	Variables targeted	Target disciplinary groups	MSFD Descriptor	EMODnet theme	Copernicus Marine Service	EuroGOOS TT	GOOS - International Network
1	Dissolved Oxygen Sensors	Dissolved oxygen	Marine biogeochemistry	D3 - Population of commercial fish/shell	Chemistry	yes	Argo	ARGO
			Regulatory environmental monitoring	D4 - Elements of Marine food webs	Physics		Fixed Platforms	OceanSites
				D5 - Eutrophication			Gliders	OceanGliders
							FerryBox	Go-SHIP
2	Fluorescence Sensor	Chlorophyll-a fluorescence	Marine biology/ecology	D5 - Eutrophication	Chemistry	yes	Argo	ARGO
			Regulatory environmental monitoring		Physics		Fixed Platforms	OceanSites
							Gliders	OceanGliders
							FerryBox	Go-SHIP
3	Ocean surface multi/hyperspectral and laser induced chlorophyll-a fluorescence sensors and cameras	Sea surface temperature, Laser induced chlorophyll-a fluorescence, Ocean color	Marine biology/ecology	D4 - Elements of Marine food webs	Physics	yes	FerryBox	Go-SHIP
			Regulatory environmental monitoring Ocean colour community	D5 - Eutrophication	Chemistry			
4	Passive broadband acoustic recording sensor	Marine noise (anthropogenic and natural sources, including marine mammals, sea ice cracking, seismic activity, meteorological sources)	Marine biology/ecology	D11 - Energy and Water noise	Physics		Fixed Platforms	OceanSites
			Regulatory environmental monitoring	D1 - Biological diversity	Biology			OBIS
5	Passive acoustic event recorder	Marine mammal sound detection (porpoise & dolphin clicks for abundance estimation)	Marine biology/ecology	D1 - Biological diversity	Biology			OBIS
			Regulatory environmental monitoring					
6	Active Acoustic Profiling Sensor	Suspended particle concentration / distribution (zooplankton, microplastics, organic and inorganic sediment)	Marine biology/ecology Marine pollution	D10 - Marine litter	Chemistry			
				D1 - Biological diversity	Physics			OceanSites
					Biology			OBIS
7	Sampler for phytoplankton and other suspended matter	Concentrated suspended matter samplers for analyses of phyto-pigments, particulate organic matter, microbe biomass and diversity	Marine biology	D1 - Biological diversity	Biology		Gliders	OBIS
			Marine ecological monitoring Climate research	D5 - Eutrophication	Chemistry		FerryBox	GO-SHIP
			Marine pollution		Physics			
8	Carbonate system/ocean acidification sensors	pH, pCO2,Total Alkalinity	Marine biogeochemistry Climate research	D1 - Biological diversity	Chemistry	yes		GOA-ON/SOCAT
9	Silicate Electrochemical Sensor	Silicate concentration (Si)	Marine biogeochemistry	D5 - Eutrophication	Chemistry		FerryBox	
10	Submersible Nano- and Microplastics Sampler	Concentrated suspended matter samples	Marine ecology Marine pollution	D10 - Marine litter	Physics		FerryBox	
11	Low-cost Microplastic sensors	Concentration and characterisation of microplastics	Marine ecology Marine pollution	D10 - Marine litter	Chemistry		FerryBox	
12	Deep Ocean CTD	Conductivity, Temperature, Pressure (Salinity and Density derived)	Physical oceanography	D7 - Alteration of hydrographical	Physics	yes	Fixed Platforms	DOOS
								Go-SHIP
13	Deep ocean low-level radioactivity sensor	Radon gas, potassium 40K, radium 226Ra and 228Ra, and other natural isotopes	Environmental monitoring	D9 - Contaminants in fish and seafood	-		Fixed Platforms	DOOS
14	Integration of existing technologies in animal tagging systems	Temperature, Salinity, Chlorophyll-a fluorescence,	Physical oceanography Marine biology/ecology	D7 - Alteration of hydrographical	Physics	yes	AnimalBourne Instrument	AniBOS

		Dissolved oxygen						
15	Demonstration of novel equipment for key seabed habitat mapping	Live corals, hard corals, seafloor sponges	Marine biology	D6 - Seafloor integrity	Seabed habitats			
16	Smartphone NIR Scanner	Plastics	Marine pollution	D10 - Marine litter	Chemistry		FerryBox	
17	Visual marine image annotation	Macroplastics, Sponge and cold-water coral cover, major seafloor organism types.	Marine pollution Marine biology/ecology	D10 - Marine litter	Chemistry		FerryBox	

TABLE III. REFERENCE NETWORKS

Document Name	**Link**	**Applies to:**						
AtlantOS - Handbook for Data Management	https://archimer.ifremer.fr/doc/00370/48139/48242.pdf	yes	yes	yes	Yes	Yes	yes	Yes
ARGO User's Manual	https://archimer.ifremer.fr/doc/00187/29825/86414.pdf	-	-	-	-	-	yes	-
OceanSITES User's Manual	http://www.oceansites.org/docs/oceansites_user_manual_ver1_1.pdf	-	-	-	-	-	-	yes
EuroGOOS recommendations of In SITU data NRT QC	https://repository.oceanbestpractices.org/handle/11329/656	-	yes	yes	Yes	-	yes	yes
SeaDataCloud - Manual for Flow Cytometry Data ingestion, validation and long term storage	https://www.seadatanet.org/content/download/3721/file/SDC_WP9_D9.13_FlowCytometryDataManagement.pdf	yes	Yes	-	-	-	-	-
OceanGlider Data Format	https://github.com/OceanGlidersCommunity/OG-format-user-manual/blob/main/OG_Format.adoc	-	-	yes	Yes	-	-	-
OceanSITES Data Format	http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf	-	-	-	-	-	-	Yes
Ferrybox Data Format	https://www.ferrybox.com/imperia/md/content/ferryboxusergroup/ferrybox_d-3-3-b__data_management_guidelines__r_2-0.pdf	-	Yes	-	-	-	-	-
MEOP Data Format	https://www.meop.net/database/format/	-	-	-	-	yes	-	-
Marine Litter User	https://doi.org/10.13120/21addf37-7e82-4a55-b040-3d3d87115ac0	-	-	-	-	-	-	-
Guidelines and formats for gathering and management of micro-litter data sets on a European scale	https://doi.org/10.6092/d3e239ec-f790-4ee4-9bb4-c32ef39b426d	-	-	-	-	-	-	-
Marine Litter Technical Recommendations for the Implementation of MSFD Requirements	https://mcc.jrc.ec.europa.eu/documents/201702071118.pdf	Yes	Yes	-	-	-	-	-
Cruise Summary Report	https://www.seadatanet.org/content/download/7287/file/sdn_csr_backoffice_usermanual_V2.0.pdf	Yes	Yes	-	-	-	-	-
Animal Borne Instrument and Animal Telemetry	https://www.frontiersin.org/articles/10.3389/fmars.2019.00326/full	-	-	-	-	yes	-	-
Glider Community github	https://github.com/OceanGlidersCommunity	-	-	yes	yes	-	-	-

TABLE IV. PARAMETER METADATA

variable	TEMP		float	
attribute	TEMP	_ChunkSizes	int	570, 377
attribute	TEMP	_FillValue	float	NaN
attribute	TEMP	actual_range	float	-46.879, 815.861
attribute	TEMP	ancillary_variables	String	TEMP_QC TEMP_DM
attribute	TEMP	colorBarMaximum	double	32.0
attribute	TEMP	colorBarMinimum	double	0.0
attribute	TEMP	data_mode	String	R
attribute	TEMP	long_name	String	Sea temperature
attribute	TEMP	standard_name	String	sea_water_temperature
attribute	TEMP	units	String	degree_C
attribute	TEMP	sdn_parameter_urn	String	SDN:P01::TEMPST01
attribute	TEMP	valid_max	float	40.0
attribute	TEMP	valid_min	float	-2.5
variable	TEMP_QC		byte	
attribute	TEMP_QC	_ChunkSizes	int	570, 377
attribute	TEMP_QC	_FillValue	byte	127
attribute	TEMP_QC	actual_range	byte	0, 9
attribute	TEMP_QC	colorBarMaximum	double	10.0
attribute	TEMP_QC	colorBarMinimum	double	0.0
attribute	TEMP_QC	conventions	String	Copernicus Marine In Situ reference table 2
attribute	TEMP_QC	flag_meanings	String	no_qc_performed good_data probably_good_data bad_data_that_are_potentially_correctable bad_data value_changed value_below_detection nominal_value interpolated_value missing_value
attribute	TEMP_QC	flag_values	byte	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
attribute	TEMP_QC	long_name	String	Sea temperature quality flag
attribute	TEMP_QC	valid_max	byte	9
attribute	TEMP_QC	valid_min	byte	0
attribute	TEMP_QC	qc_manual	String	Recommendations for in-situ data Near Real Time Quality Control https://doi.org/10.13155/36230