4DATLANTIC-OHC

Experimental Dataset Description (EDD)

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1	0	31/08/2022	Creation of document	
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2	0	15/12/2024	Modifications related to version 2.0 of the product	

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1. Introduction

1.1. Executive summary

Given the major role of the Atlantic Ocean in the climate system, it is essential to characterise the temporal and spatial variations of its heat content. The 4DAtlantic Project (https://eo4society.esa.int/projects/4datlantic-ohc/) aims at developing and testing space geodetic methods to estimate the regional **ocean heat content** (OHC) change over the Atlantic Ocean from satellite altimetry and gravimetry. The strategy developed in the frame of the ESA MOHeaCAN Project (https://eo4society.esa.int/projects/moheacan/) is pursued and refined at spatial regional scales both for the data generation and the uncertainty estimate. At two test sites, OHC change derived from in situ data (RAPID and OVIDE-AR7W) are used to evaluate the accuracy and reliability of the new space geodetic based OHC change. The Atlantic OHC product will be used to better understand the complexity of the Earth's climate system. In particular, the project aims at better understanding the role played by the Atlantic Meridional Overturning Circulation (AMOC) in regional and global climate change, and the variability of the Meridional Heat transport in the North Atlantic. In addition, improving our knowledge on the Atlantic OHC change will help to better assess the global ocean heat uptake and thus estimate the Earth's energy imbalance more accurately as the ocean absorbs about 90% of the excess energy stored by the Earth system.

In the 4DAtlantic project, the OHC change is estimated from the measurement of the thermal expansion of the ocean. The latter is obtained by removing the ocean mass change and the sea level change due to salinity (halosteric sea level changes) derived from gravimetry and in situ data respectively to the total sea-level change derived from altimetry measurements. This approach provides consistent spatial and temporal sampling of the ocean heat content change in the Atlantic Ocean.

4DAtlantic project's objectives are to develop novel algorithms, estimate realistic regional OHC uncertainties thanks to a rigorous error budget of the altimetric, gravimetric and in-situ instruments in order to reach the challenging target for the uncertainty quantification.

1.2. Purpose of the document

This document is the Experimental Dataset Description (EDD) of the 4DAtlantic-OHC project supported by ESA. The EDD is dedicated to the content and format description of the 4DAtlantic-OHC product. This product gathers estimates of the OHC at regional scales evolution over April 2002 - December 2022.

This is the primary document that users should read before handling the products. It provides an overview of processing algorithms, technical product content and format and main validation results. Details on the algorithms are given in the Algorithm theoretical basis document (ATBD) [AD2].

1.3. Document structure

In addition to this introduction, the document is organised as follows:

- Section 2 summarises the principle of the space geodetic approach to estimate the OHC.
- Section 3 presents 4DAtlantic-OHC product's content and specifications.
- Section 4 summarises the validation activities performed on the 4DAtlantic-OHC product.
- Section 5 presents data policy and product access.

1.4. Related documents

Id.	Ref.	Description
AD1	AO/1-10546/20/I-NB	Call to tender "4DAtlantic-OHC REGIONAL ACTIVITIES"
AD2	OHCATL-DT-020-MAG_ATBD	4DAtlantic - OHC Algorithm Theoretical Basis Document v2.0
AD3	OHCATL-DT-033-MAG_Product_Validation_Report	Product Validation Report of the 4DAtlantic-OHC product

Table 1 *List of applicable documents*

1.5. Abbreviations and Acronyms

Synonym	Description
AMOC	Atlantic Meridional Overturning Circulation
ATBD	Algorithm theoretical basis document
Argo	International program that uses profiling floats deployed worldwide to observe ocean properties such as temperature and salinity.
C3S	Copernicus Climate Change Service
COST-G	International Combination Service for Time-variable Gravity Fields
EDD	Experimental dataset description
EEH	Expansion efficiency of heat

ESA	European Space Agency
EWH	Equivalent water height
FTP	File transfer protocol
GFZ	Deutsches GeoForschungsZentrum or German research center for geosciences
GIA	Glacial isostatic adjustment
GMWTC	Global mean wet tropospheric correction
GRACE(-FO)	Gravity recovery and climate experiment (-Follow on)
GRD	Changes in Earth Gravity, Earth Rotation and viscoelastic solid-Earth Deformation
GSFC	Goddard Space Flight Center
$(SL_{halosteric})$	Halosteric sea level
IEEH	Integrated expansion efficiency of heat
JPL	Nasa's jet propulsion laboratory
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiale
MASL	Manometric Sea Level
MSS	Mean sea surface
MWR	Microwave radiometer
OHC	Ocean heat content
OHU	Ocean heat uptake
OLS	Ordinary least square
RD	Reference document
SL	Absolute Sea level
SLA	Absolute Sea level anomaly
(SL_{steric})	Steric sea level
(SL_{thermo})	Thermosteric sea level

Table 2 *List of Abbreviations and acronyms*

1.6. Bibliography

- Lozier, M. S., Li, F., Bacon, S., Bahr, F., Bower, A. S., Cunningham, S. A., de Jong, M. F., de Steur, L., deYoung, B., Fischer, J., Gary, S. F., Greenan, B. J. W., Holliday, N. P., Houk, A., Houpert, L., Inall, M. E., Johns, W. E., Johnson, H. L., Johnson, C., Karstensen, J., Koman, G., Le Bras, I. A., Lin, X., Mackay, N., Marshall, D. P., Mercier, H., Oltmanns, M., Pickart, R. S., Ramsey, A. L., Rayner, D., Straneo, F., Thierry, V., Torres, D. J., Williams, R. G., Wilson, C., Yang, J., Yashayaev, I., and Zhao, J.: A sea change in our view of

overturning in the subpolar North Atlantic, Science, 363, 516–521, https://doi.org/10.1126/science.aau6592, 2019.

- Marti, F., Blazquez, A., Meyssignac, B., Ablain, M., Barnoud, A., Fraudeau, R., Jugier, R., Chenal, J., Larnicol, G., Pfeffer, J., Restano, M., and Benveniste, J.: Monitoring the ocean heat content change and the Earth energy imbalance from space altimetry and space gravimetry, Earth Syst. Sci. Data, 14, 229–249, https://doi.org/10.5194/essd-14-229-2022, 2022.
- Russell, G. L., Gornitz, V., and Miller, J. R.: Regional sea level changes projected by the NASA/GISS Atmosphere-Ocean Model, Clim. Dyn., 16, 789–797, https://doi.org/10.1007/s003820000090, 2000.

2. Physical principle

In the framework of the MOHeaCAN project, the OHC product is calculated from regional **OHC change.**

In this document, the word "change" refers to the difference between any two states - it refers to the difference between the present state (t) and the state to a given date (t_{ref}) or time period.

This regional OHC change is derived from the **Steric Sea Level (SSL) change**. For this purpose, a coefficient of expansion efficiency of heat is needed to do the conversion of thermal expansion into OHC change.

2.1. The (Integrated) Expansion Efficiency of Heat

The expansion efficiency of heat (EEH) expresses the change in ocean density due to heat uptake. As a matter of fact it represents the ratio of the temporal derivative of thermosteric sea level over the temporal derivative of the heat content under a given heat uptake. The EEH is dependent on temperature, salinity and pressure (Russell et al., 2000). Thus, integrated over the total water column, the EEH is supposed to vary with latitude along with the variations of integrated salinity, temperature and pressure. At a regional scale, the EEH has never been calculated. To explain this, it occurs that the OHC change over an entire water column can be null whilst the thermal expansion is not. In such a situation, the EEH is not defined and cannot be calculated. A way to avoid this issue is to consider the **integrated expansion efficiency of heat (IEEH)** instead of the EEH (Marti et al., 2022).. The IEEH must reflect the variation in sea level due to a change in its heat content. The idea is to use in-situ products to calculate the IEEH (see section 3), which is assumed to be a characteristic of the water column, allowing a variation in steric level to be converted into a variation in OHC thanks to this proportionality coefficient. It is important to note that the IEEH is independent of the measurement system used.

$$IEEH = \frac{\delta SL_{thermo}}{\delta OHC}$$ Eq. 1

2.2. OHC calculation

The OHC estimated from satellite measurement of steric sea level can therefore be deduced from the in-situ OHC by doing the following. :

$$(\Delta OHC)_{sat} = (\Delta OHC)_{in\ situ} + \frac{(\Delta SL_{thermo})_{sat} - (\Delta SL_{thermo})_{in\ situ}}{(IEEH)_{in\ situ}}$$ Eq. 2

The absolute height of the thermosteric sea level is not accessible by satellite; only its steric variations are available.

We need to define a reference date where we assume that $(\Delta OHC)_{sat} = (\Delta OHC)_{in\ situ}$ and $(\Delta SL_{steric})_{sat} = (\Delta SL_{steric})_{in\ situ} = (\Delta SL_{steric})_{ref}$

$$(\Delta OHC)_{sat} - (\Delta OHC)_{in\ situ} =$$ Eq. 3

$$\frac{((\Delta SL_{thermo})_{sat} + (\Delta SL_{halo}) - (\Delta SL_{steric})_{ref}) - ((\Delta SL_{thermo})_{in\ situ} + (\Delta SL_{halo}) - (\Delta SL_{steric})_{ref})}{IEEH_{insitu}} =$$

$$\frac{(\Delta SL_{steric})_{sat} - (\Delta SL_{steric})_{in\ situ}}{(IEEH)_{in\ situ}}$$

2.2.1. Constancy of the IEEH

The IEEH shows regional variations due to ocean temperature and volume changes which may be induced by factors such as ocean currents and atmospheric circulation patterns. However, at the global scale the IEEH can be considered as constant (Eq. 4), with typical trends being less than 0.03% per decade. This means that at the global scale, the ocean is considered a large and well mixed body of water.

$$(IEEH)_{in\ situ}(t) = (IEEH)_{in\ situ}(t_0) \quad \text{Eq. 4}$$

3. Product specification

3.1. File format

The product is delivered as Network Common Data Form version 4 (netCDF4) file with metadata attributes compliant with version 1.7 of the Climate & Forecast conventions (CF V1.7).

3.2. Spatial information

All 2-D fields of the product are displayed on a 1° longitude-latitude grid (WGS84). As the product is focused on the Atlantic Ocean, the spatial coverage is restricted between 100°W to 25°E longitude and 90°S to 90°N latitude.

3.3. Temporal information

Time dependent fields are displayed at monthly resolution for OHC grids and at yearly resolution for local error variance-covariance matrices.

3.4. File naming convention

The product follows this naming standard:

OHC_4DATLANTIC_<START_DATE>_<END_DATE>_<VERSION>.nc

where:

- <START_DATE> and <END_DATE> give the UTC start and end date of the total data coverage in the form YYYYMM with Y, M as year and month respectively.
- <VERSION> is the four-digit version number, starting with 'V1-0' for the first major version. The first digit changes each time a major version is released ('V2-0', 'V3-0'), while changes in the second digit indicate reprocessing versions or minor versions ('V1-2', 'V1-3').
- .nc: standard NetCDF filename extension.

3.5. Dimensions

4 dimensions are defined:

- latitude
- longitude
- time
- time_covar: time dimension for error variance-covariance matrices (defined at annual resolution)
- time_covar_2: time dimension for error variance-covariance matrices (defined at annual resolution)

3.6. Metadata

The netCDF file contains some metadata at the file-level, at the layer-level and at the level of the dimensions. These metadata inform for example about the variable units, the variable ranges, etc…

3.7. Variables

Variables (dimensions)	Description	Units	Data Type
time(time)	Time (monthly timestep)	days since 1950-01-01 00:00:00 UTC	double
time_covar(time_covar)	Time vector of regional covariance matrices (annual timestep)	days since 1950-01-01 00:00:00 UTC	double
time_covar_2(time_covar)	Time vector of regional covariance matrices (annual timestep)	days since 1950-01-01 00:00:00 UTC	double
latitude(latitude)	Latitude of data	degrees_north	double
longitude(longitude)	Longitude of data	degrees_east	double
crs	Describes the grid_mapping used by the 2-D variables of the file	none	int
cell_surface(latitude, longitude)	Surface of the grid cell	square meter (m^2)	double
ohc(time, latitude, longitude)	regional ocean heat content from the space geodetic approach - derived from the regional thermosteric sea level change using a regional expansion efficiency of heat coefficients	joules per square meter (J/m^2) (the m^2 refers to the cell_surface of each cell)	double
ohc_mask(time)	OHC mask to apply on OHC grids for masking interpolated data (1 for observed data and 0 for extrapolated data)	none	int
ohc_var_covar_matrix_local(time_covar, time_covar_2, latitude, longitude)	Variance covariance matrix of errors on OHC change time-series	square joules per meter to the power of 4 (J^2/m^4)	double

Table 3 *: Description of the content and format of 4DAtlantic-OHC product (NetCDF file)*

4. Product validation

The 4DAtlantic OHC product has been validated on the northern part of the Atlantic Ocean with independent data from 2 test sites:

- The RAPID-MOCHA section
- The OVIDE section

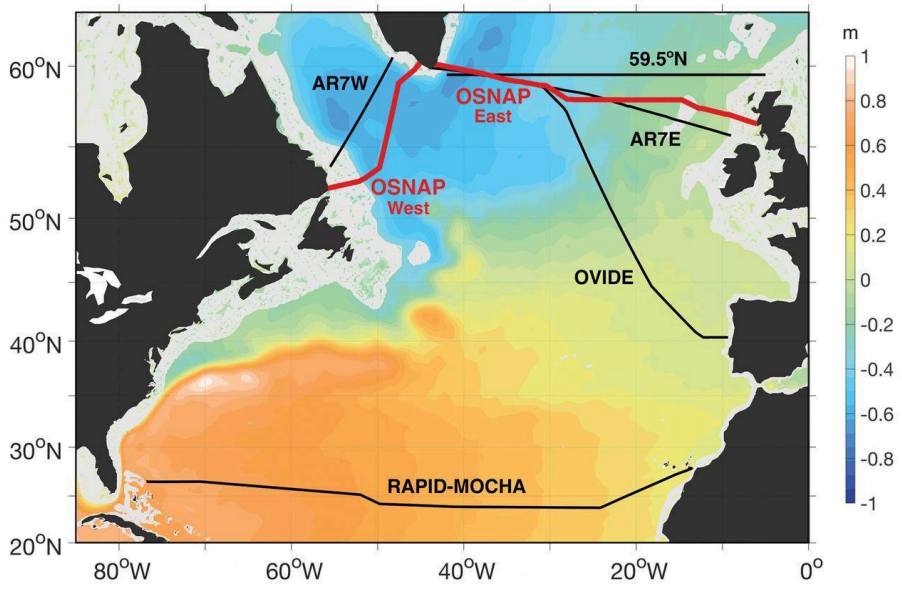

Figure 2 *:* Location of the RAPID-MOCHA (at 26.5°N) and the French OVIDE line across the North Atlantic superposed on a map of mean dynamic topography (Lozier et al., 2019)

These sites are representative of different oceanic processes that depend on latitude: sub-tropical areas for RAPID and sub-polar gyre for OVIDE-AR7W.

Gridded OHC datasets computed from the in situ Argo network measurements - partly integrating Deep Argo measurements (down to 2000 m depth) - were also used for the comparison. In particular on latitudinal bands in the subtropical north Atlantic area (20-40°N) and with a focus on the Irminger basin.

Comparison of OHC datasets was made in terms of regional trend, annual cycle and inter-annual variations. For more details, users are invited to consult the Product Validation Report document [AD3].

5. How to access the 4DAtlantic-OHC product?

5.1. Downloading

The data product (NetCDF file), together with the algorithm description document (ATBD [AD2]), can be found and downloaded on the AVISO webpage:

https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/ocean-heat-content-and-earth-energy-imbalance/atlantic-ocean-heat-content-change.html

Once downloaded, NetCDF data can be browsed and used through a number of software, like:

- ncBrowse: https://www.pmel.noaa.gov/epic/java/ncBrowse/
- NetCDF Operator (NCO): http://nco.sourceforge.net/
- Panoply: https://www.giss.nasa.gov/tools/panoply/
- IDL, Matlab, GMT, Python…

Useful information on UNIDATA: http://www.unidata.ucar.edu/software/netcdf/

5.2. Dataset reference

When using the 4DAtlantic-OHC dataset in a publication or study, please cite: "The 4DAtlantic-OHC product from space altimetry and space gravimetry was produced by Magellium/LEGOS and distributed by AVISO+ (*https://aviso.altimetry.fr*) with support from ESA (*https://doi.org/*10.24400/527896/A01-2022.012 version 2.0)".

All the information about the project are available on the project website: https://www.4datlantic-ohc.org/

5.3. Support

For any technical issues or additional information related to the 4DAtlantic-OHC product, users are advised to contact the project team:

- Robin Fraudeau (technical coordinator) : robin.fraudeau@magellium.fr
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- Michaël Ablain (project manager) : michael.ablain@magellium.fr

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