4DATLANTIC-OHC

EXPERIMENTAL DATASET DESCRIPTION (EDD)

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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 2020.

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	Algorithm theoretical basis document of the 4DAtlantic-OHC product
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 Documents
BSC	Barcelona Supercomputing Centre
CCI	Climate Change Initiative program (supported by ESA)
CMEMS	Copernicus Marine Environment and Monitoring Service
DA	Applicable document
DOI	Digital Object Identifier
DR	Reference document
ED(D)	Experimental Dataset (Description)
EEH	Expansion Efficiency of Heat

EEA	European Environment Agency
EEI	Earth Energy Imbalance
ESA	European Space Agency
EO	Earth Observations
GMSL	Global Mean Sea Level
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	GRACE Follow-On
HSSL	Halosteric Sea Level
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LOPS	Laboratoire d'Océanographie Physique et Spatiale
MHT	Meridional Heat Transport
MOi	Mercator-Ocean International
NOC	National Oceanography Centre
ODATIS	Ocean Data and Services portal
OHC	Ocean Heat Content
OM	Ocean mass
OMI	Ocean Monitoring Indicator
OSNAP	Overturning in the Subpolar North Atlantic Program
PVR	Product Validation report
RMSD	Root-mean-square deviation
SL	Sea Level
SSL	Steric Sea Level
TOA	Top Of Atmosphere
WMO	World Meteorological Organization

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.

2. Physical principle

In the framework of the 4DAtlantic-OHC project, the regional **Ocean Heat Content** (**OHC) change** is calculated from the sea water thermal expansion change derived from satellite observations. The approach relies on the sea level budget equation,

$$\Delta SL = \Delta OM + \Delta TSSL + \Delta HSSL \qquad \text{Equation 1}$$

whose terms are:

- Total Sea Level (SL) change
- Ocean Mass (OM) change
- ThermoSteric Sea Level (TSSL) change (or thermal expansion change)
- HaloSteric Sea level (HSSL) change

The thermosteric sea level change can be derived from this equation with SL change, OM change and HSSL change respectively estimated from altimetry, space gravimetry and in situ data.

Then, a coefficient of expansion efficiency of heat is needed to do the conversion of thermal expansion change into OHC change. The diagram below presents the relationship between the main variables that are used to calculate the OHC change and its time derivative from the TSSL change and applying the Integrated Expansion Efficiency of Heat (IEEH) coefficient.

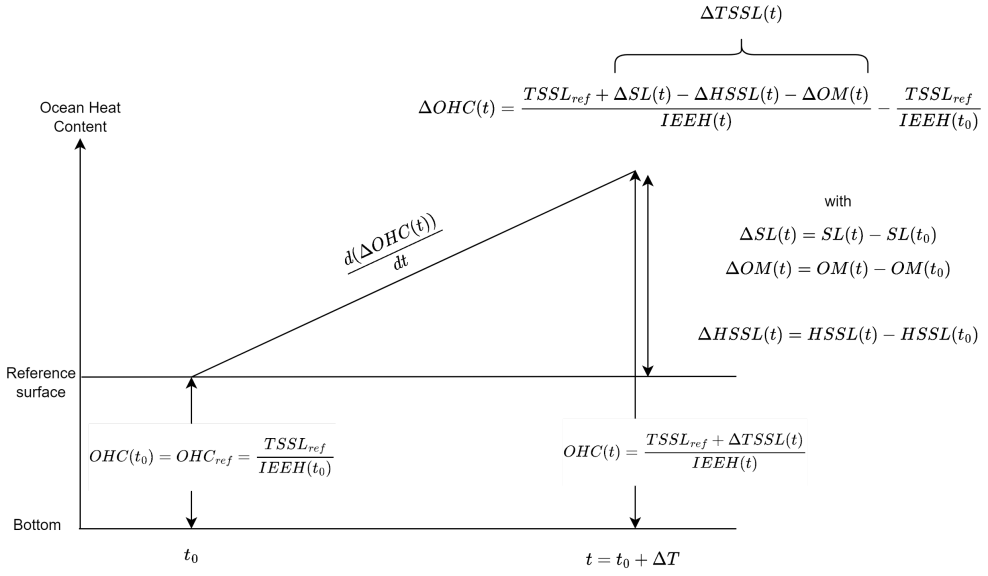

Figure 1: *diagram of OHC change and its time derivative calculation with IEEH approach*

OHC change ($\Delta OHC(t)$) is defined by the difference between OHC at t and t_0 , and can be written as follow:

$$\Delta OHC(t) = \frac{TSSL_{ref} + \Delta TSSL(t)}{IEEH(t)} - \frac{TSSL_{ref}}{IEEH(t_0)}$$ Equation 2

Where $\Delta TSSL$ is the TSSL change, $IEEH$ the integrated expansion efficiency of heat and $TSSL_{ref}$ is the reference of the $TSSL$ at $t = t_0$.
Users are invited to consult the ATBD [AD2] for details on the algorithm.

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)

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 (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 (m²)	double
ohc(time, latitude,	Ocean heat content change	joules per square	double

longitude)		meter (J/m²)	
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(latitude, longitude, time_covar, time_covar)	Variance covariance matrix of errors on OHC change time-series	square joules per meter to the power of 4 (J²/m⁴)	double
ohc_trends(latitude, longitude)	Trend of the OHC change timeseries	watt per square meter (W/m²)	double
ohc_trends_uncertainties(latitude, longitude)	Trend uncertainty of the OHC change timeseries (1-σ)	watt per square meter (W/m²)	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

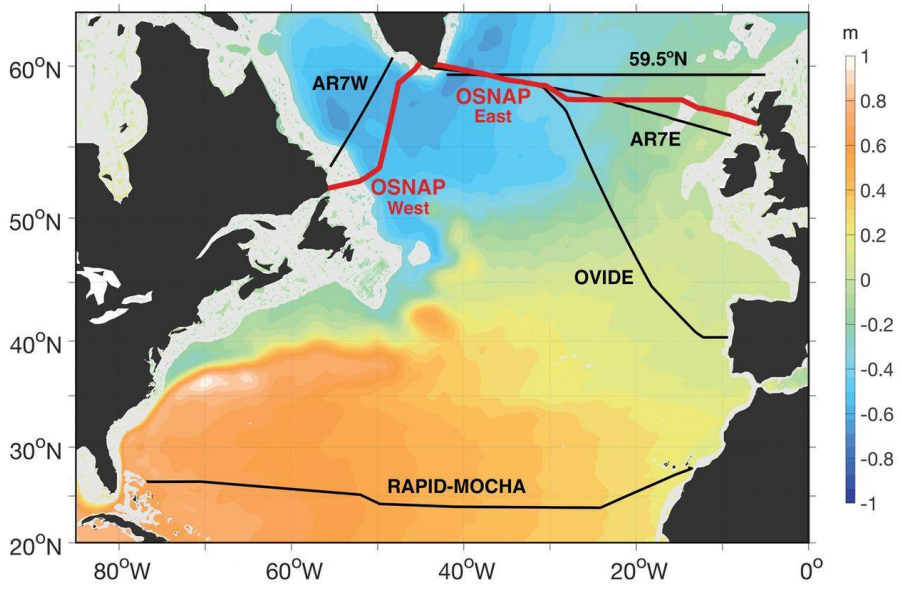

Figure 2 *:* Location of the RAPID-MOCHA (at 26.5°N) and the French OVIDE line across the North Atlantic superposed on a map of mean dynamic topography (Lozier et al., 2019)

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 1.0)".

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:

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