DUACS

GRIDDED SEA LEVEL HEIGHTS AND GEOSTROPHIC VELOCITIES COMPUTED WITH SWOT LEVEL-3 PRODUCTS (USING BOTH KARIN AND NADIR INSTRUMENTS) WITH MIOST/4DVARNET/VARDYN PRODUCT USER MANUAL

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1 Introduction

For 20 years, the DUACS system has been producing, as part of the CNES/SALP project, the Copernicus Marine Environment and Monitoring Service (CMEMS) and the Copernicus Climate Change Service (C3S), high quality multimission altimetry Sea Level products for oceanographic applications, climate forecasting centers, geophysical and biology communities... While the operational production of the Sea Level along track and maps is now generated as part as CMEMS and C3S, the development of new experimental DUACS products started mid-2016 at CNES aiming at improving the resolution of the current products and designing new products.

Using the global Synthetic Aperture Radar mode (SAR) coverage of Sentinel-3A/B and optimizing the LRM altimeter processing (retracking, editing, ...) will notably allow us to fully exploit the fine-scale content of the altimetric missions. The recent launch of SWOT offers an excellent opportunity to enhance the spatial resolution of the products and paves the way for new challenges in the utilization, validation, and integration of these data into mapping systems.

Thanks to this increase of real time altimetry observations, we will also be able to improve Level-4 products by combining these new Level-3 products and new mapping methodology, such as dynamic interpolation, data-driven interpolation approaches or multiscale and multivariate interpolation. Finally, these improvements will benefit to downstream products: geostrophic currents, Lagrangian products, eddy atlas…

This document describes the Gridded (level4) Sea Level Heights and geostrophic velocities computed with Multiscale & Multivariate interpolation (Ubelmann et al., 2021), the VarDyn (Le Guillou et al., 2025) and the 4DvarNET (Fablet et al., 2021, Beauchamp et al., 2023) mapping methods for the global ocean. This product takes input data from along-track and wide-swath SWOT remote sensing measurements, which are summarized in Table 1.

2 Processing

2.1 Input data

The input data used to compute the gridded products are the

- for satellites SARAL/AltiKa, Cryosat-2, HaiYang-2B, Jason-3, Copernicus Sentinel-3A&B, Sentinel 6A, SWOT Nadir
    - NRT (Near-Real-Time) Nadir along-track (or Level-3) SEA LEVEL products (DOI: https://doi.org/10.48670/moi-00147) delivered by the Copernicus Marine Service (CMEMS, http://marine.copernicus.eu/). The gridded product is based on NRT L3 Nadir datasets for the period from July 7, 2025, to December 31, 2025.
    - MY (Multi-Year) Nadir along-track (or Level-3) SEA LEVEL products (DOI: https://doi.org/10.48670/moi-00146) delivered by the Copernicus Marine Service (CMEMS, http://marine.copernicus.eu/). The gridded product is based on MY L3 Nadir datasets for the period from March 28, 2023, to July 6, 2025.
- for SWOT KaRIn : the SEA LEVEL products L3_LR_SSH (V3.0) delivered by AVISO for Expert SWOT L3 SSH KaRin (DOI: https://doi.org/10.24400/527896/A01-2023.018) for the period from March 28, 2023 to December 31, 2025.

Table 1: *List of input data and their definition.*

Input product	Altimeter mission	Name of product	Name of dataset	DOI	Variable used
DT Nadir Altimetry global products	SARAL/ AltiKa	CMEMS products: SEALEVEL_ GLO_PHY_L3 _NRT_ 008_044	cmems_obs-sl_glo_phy-ssh_my_al-l3-duacs_PT1S	10.48670/moi-00146	sla_unfiltered
	Cryosat-2		cmems_obs-sl_glo_phy-ssh_my_c2n-l3-duacs_PT1S		
	HaiYang-2B		cmems_obs-sl_glo_phy-ssh_my_h2b-l3-duacs_PT1S		
	Jason-3		cmems_obs-sl_glo_phy-ssh_my_j3n-l3-duacs_PT1S		
	Copernicus Sentinel-3A		cmems_obs-sl_glo_phy-ssh_my_s3a-l3-duacs_PT1S		
	Copernicus Sentinel-3B		cmems_obs-sl_glo_phy-ssh_my_s3b-l3-duacs_PT1S		
	Copernicus Sentinel-6A		cmems_obs-sl_glo_phy-ssh_my_s6a-hr-l3-duacs_PT1S		
	SWOT Nadir		cmems_obs-sl_glo_phy-ssh_my_swon-l3-duacs_PT1S & cmems_obs-sl_glo_phy-ssh_my_swonc-l3-duacs_PT1S		
NRT Nadir Altimetry global products	SARAL/ AltiKa	CMEMS products: SEALEVEL_ GLO_PHY_L3 _NRT_ 008_044	cmems_obs-sl_glo_phy-ssh_nrt_al-l3-duacs_PT1S	10.48670/moi-00147	sla_unfiltered
	Cryosat-2		cmems_obs-sl_glo_phy-ssh_nrt_c2n-l3-duacs_PT1S		
	HaiYang-2B		cmems_obs-sl_glo_phy-ssh_nrt_h2b-l3-duacs_PT1S		
	Jason-3		cmems_obs-sl_glo_phy-ssh_nrt_j3n-l3-duacs_PT1S		
	Copernicus Sentinel-3A		cmems_obs-sl_glo_phy-ssh_nrt_s3a-l3-duacs_PT1S		
	Copernicus Sentinel-3B		cmems_obs-sl_glo_phy-ssh_nrt_s3b-l3-duacs_PT1S		
	Copernicus Sentinel-6A		cmems_obs-sl_glo_phy-ssh_nrt_s6a-hr-l3-duacs_PT1S		
	SWOT Nadir		cmems_obs-sl_glo_phy-ssh_nrt_swon-l3-duacs_PT1S		

Wide swath Altimetry global products	SWOT KaRIn	AVISO product: SWOT_L3_LR_SSH in v3.0	-	10.24400/527896/A01-2023.018	ssha_unfiltered

2.2 Methodology

2.2.1 MIOST products

The global maps produced here are based on the multiscale and multivariate MIOST (Multiscale Inversion of Ocean Surface Topography) mapping approach, as described in Ubelmann et al. (2021, 2022). This method is able of accounting for various modes of variability of the ocean surface topography (e.g., geostrophic, barotrope, equatorial waves dynamic …) by constructing several independent components within an assumed covariance model. Here, we used the geostrophic mode to depict the geostrophically balanced evolution of sea surface height (SSH) as well as the barotrope and equatorial wave mode to capture residual high frequency signal (e.g., Tropical Instability Waves and Poincaré Waves) withing the 10°S and 10°N band from the altimetry constellation. Unlike the previous release, since the v2.0.1 version the new versions include an additional mode to represent coherent internal tides over a six-month period, aiming to absorb residual internal tide signals in the L3 dataset. This enhancement has proven effective within the mapping protocol, significantly reducing mapping errors compared to earlier versions. Furthermore, since the v2.0.1 release introduces a new a priori noise estimation for SWOT KaRIn measurements, which contributes to improved accuracy, particularly in the intertropical region.

Similar to the optimal interpolation techniques used in operational context (e.g., Le Traon et al, 1998, 2003; Ducet et al., 2000; Pujol et al., 2016), MIOST operates within a linear and gaussian framework. To address practical considerations, the inversion problem is formulated within a reduced subcomponent space, allowing the accommodation of numerous observations in extensive spatio-temporal windows. This is beneficial for handling multiple signals of varying scales in both time and space. This mapping method has already been tested in both idealized (Ubelmann et al., 2021) and real observational systems (Ubelmann et al., 2022, Ballarotta et al., 2023), demonstrating its capability to map the surface topography and currents at global scale. It is noteworthy that in generating the SSH maps for this study, a Delayed-Time (DT) mode processing was adopted. This mode incorporates both past and future observations for a specific date to constrain the interpolation process.

More information about the method and assessment results for the experimental gridded products presented here are described in Ballarotta et al. (2025).

2.2.2 VarDyn products

The VarDyn mapping technique (Le Guillou et al., 2025, https://github.com/leguillf/MASSH) integrates a 4-Dimensional variational (4DVAR) scheme with a Quasi-Geostrophic (QG) model. It works by minimizing the discrepancy between the QG model and observational data. To ensure convergence during the minimization process, the method represents model error using a reduced wavelet basis.

2.2.3 4DVarNET products

The 4DvarNET mapping algorithm (Fablet et al., 2021, Beauchamp et al., 2023, https://github.com/CIA-Oceanix/4dvarnet-core) is a data-driven approach combining a data assimilation scheme associated with a deep learning framework. This neural network framework involves the joint training of the representation of the ocean dynamic, as well as of the solver of the data assimilation problem. The 4DvarNET algorithm is trained using a supervised learning strategy in an OSSE context, taking the SSH variable of an ocean model as ground truth. Once trained in OSSE, the 4DvarNET algorithm is ready to perform SSH reconstructions with real altimetric data as input. Here, 4DvarNET was trained on the GLORYS12 realistic high-resolution simulation (2021). Pseudo-observations were generated from this numerical simulation to represent the present-day nadir altimeter constellation as well as KaRIn swath.

2.2.4 Sea Ice mask

Additionally, a sea-ice mask has been implemented in polar regions to exclude sea-level values resulting from extrapolation by the MIOST system. This mask is derived from OSI SAF CDR V3.0 products (OSI-450_a) up to 2020, and from OSI SAF ICDR V3.0 interim products (OSI-430-a) from 2021 onwards (Lavergne et al., 2019). The masking is based on a 15% sea-ice concentration threshold.

3 PRODUCT DESCRIPTION

This new product corresponds to version 3.0 and is derived from the nadir along-track NRT and DT/MY datasets available through CMEMS, as well as the SWOT Level-3 Ocean product v3.0 (specifically, SWOT_L3_LR_SSH). It covers both the 1-day (CalVal) and 21-day (Science) mission phases. The SWOT_L3_SSH product integrates ocean surface topography measurements from the SWOT KaRIn and nadir altimeter instruments, combining them into a single variable mapped onto a 2 km spatial grid.

Thus, the gridded product versions presented here are consistent with the SWOT Karin L3 reprocessed versions. It is foreseen to deliver new versions of some products: for any new future version delivered, you will be informed via the AVISO User Helpdesk, and on the AVISO website. The version number is indicated in the file ('product_version' attribute).

3.1 Spatial information

The MIOST gridded products cover the entire global ocean (e.g., Figure 1a). Boundaries have been defined as 90°S-180°W/90°N-180°E and the spatial resolution is 1/8° for MIOST and 4DVARNET products, and 1/10° for VARDYN.

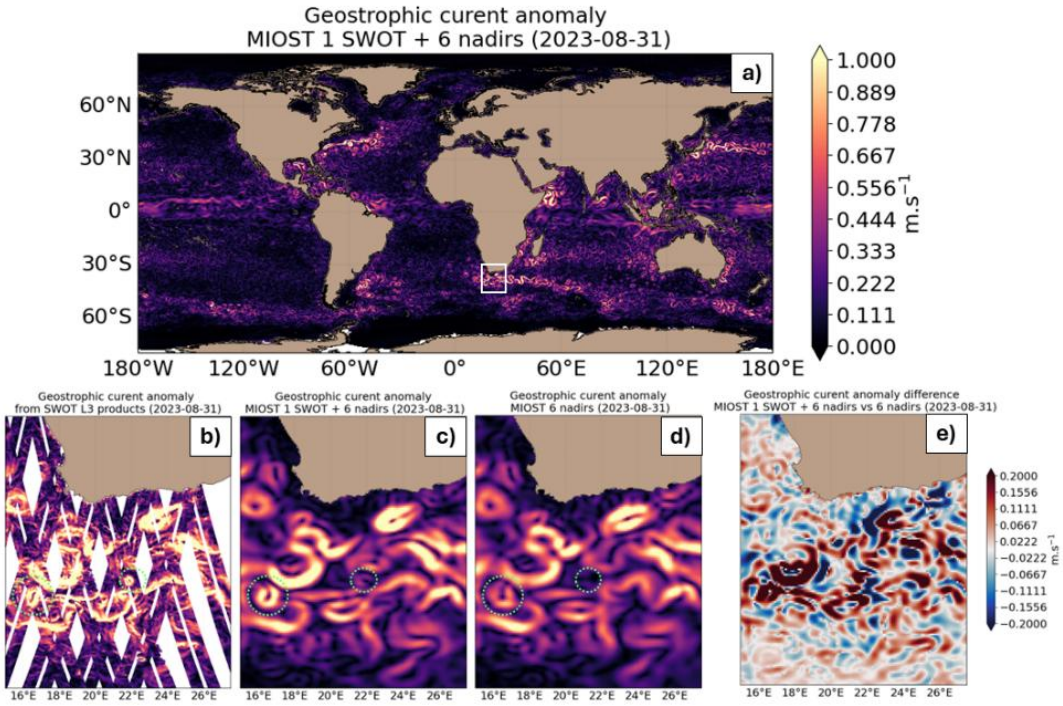


Figure 1: Example of geostrophic current reconstruction on 2023-08-31 with MIOST at a) global scale, b) view from Karin L3 products over the Agulhas region, c) from MIOST reconstruction integration 1SWOT and 6 nadirs, d) from MIOST reconstruction integration 6 nadirs and e) the difference in MIOST reconstructions between integration 1SWOT and 6 nadirs vs 6 nadirs only.

3.2 Temporal information

One file per day is delivered.

Two datasets are produced: one considering the CAVAL phase of SWOT and one considering the SCIENCE phase of SWOT

Table 2: *temporal information*

area	Start dates	End dates
Global CALVAL v3.0	2023/03/28	2023/07/10
Global SCIENCE v3.0	2023/07/11 (note that between 11 and 27 jul., the files contain only SWOT Nadir and other altimeters)	2025/12/31

3.3 File format

The product is delivered as a set of Network Common Data Form version 4 (netCDF4) files. Metadata attributes are compliant with version 1.7 of the Climate & Forecast conventions (https://cfconventions.org/Data/cf-conventions/cf-conventions-1.7/cf-conventions.html)

3.4 File naming convention

The product follows the naming standard:

dt_<zone>_allsat_phy_<date>_<prod_date>.nc

where:

- The type of data timeliness dt=delayed-time
- <zone>=area (global)
- allsat means that all the available missions are taken into account
- <date> is the date of the map
- <date_prod> is the date of the map's production
- .nc: standard NetCDF filename extension.

Example: dt_global_allsat_phy_20250902_20260202.nc

3.5 Product content

3.5.1 Dimensions

There are 3 dimensions present in every netCDF:

- **time:** number of grids in current file (one grid for one day).
- **Latitude:** number of grid points in latitude
- **Longitude:** number of grid points in longitude
- **bounds**: for graphical needs

3.5.2 Variables

The variables defined in the files referring to manometric measurements are the following:

Table 3: *Description of variables*

Name of variable	Type	Content	Unit
time	float	Time of measurements	days since 1950-01-01 00:00:00 UTC
latitude	float	Latitude value of measurements	degrees_north
longitude	float	Longitude value of measurements	degrees_east
latitude_bounds	double	latitude values at the north and south bounds of each pixel.	degrees_north
longitude_bounds	double	longitude values at the north and south bounds of each pixel.	degrees_east
sla	int	Sea Level Anomaly relative to a mean sea surface	Meters
adt	int	Absolute dynamic topography	meters
ugosa	int	Geostrophic velocity anomalies: zonal component	meters/second
vgosa	int	Geostrophic velocity anomalies: meridian component	meters/second
ugos	int	Absolute geostrophic velocity: zonal component	meters/second
vgos	int	Absolute geostrophic velocity: meridian component	meters/second

3.5.3 Metadata

Users will find a number of metadata attributes in the NetCDF file, at the file level, at the layer level, and at the level of the dimension variables.

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