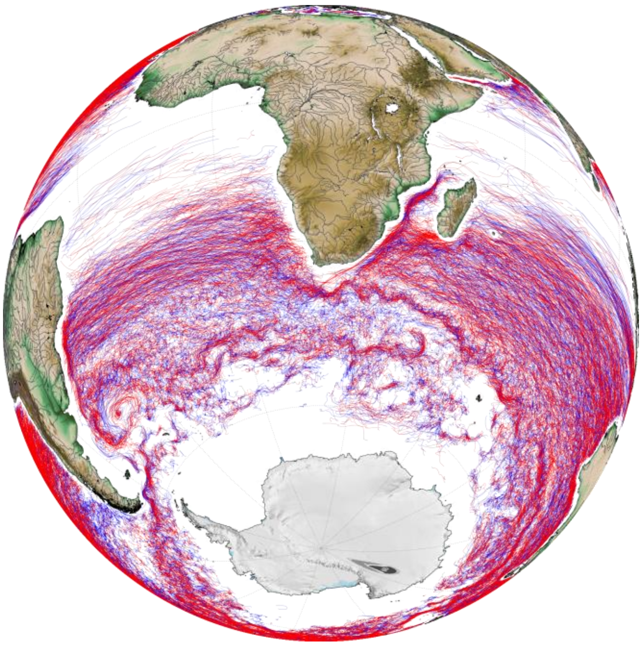
MESOSCALE EDDY TRAJECTORIES ATLAS PRODUCT HANDBOOK
META2.0 Delayed Time



Reference: SALP-MU-P-EA-23126-CLS

Issue: 3 rev 4

Date: March 2021

Aviso+ Altimetry
11 rue Hermès, 31520 Ramonville St Agne, France – aviso@altimetry.fr

Chronology Issues:		
Issue:	Date:	Reason for change:
1.0	2017/06/29	1st issue
2.0	2018/09/20	New version META2018_exp (2.0exp)
3.0	2019/09/20	Addition of NRT experimental products (3.0exp)
3.1	2020/06/11	Minor corrections
3.2	2020/08/17	META2.0exp DT update : extension of the period with changes in the format
3.3	2021/02/23	META2.0exp DT update : extension of the period and renaming into META2.0 DT
3.4	2021/03/24	Restructuring handbook for META2.0 DT only

List of Acronyms:

AVISO+	Archivage, Validation et Interprétation des données des Satellites Océanographiques
C3S	Copernicus Climate Change Service http://climate.copernicus.eu/
CLS	Collecte Localisation Satellites
CMEMS	Copernicus Marine Environment Monitoring Service
CNES	Centre National d'Etudes Spatiales
DUACS	Data Unification and Altimeter Combination System
FTP	File Transfer Protocol
NetCDF	Network Common Data Format
OSU	Oregon State University
SLA	Sea Level Anomaly (a.k.a. sea surface height with respect to a mean sea surface)

List of figures

Figure 1: Left, initial sea level anomaly product. Right, the high-filtered version used for the DT 2.0 eddy detection. 3

Figure 2: Eddy detections: black dots are eddies observation centers 4

Figure 3: Eddy tracking; each color corresponds to a different day 5

Figure 4: The radius is varying with the latitude 6

Figure 5: Tracking procedure : the eddy number 1 is kept because an association is found on map D+3, contrary to the eddy number 2 where no association is found on the last map. 6

Figure 6: The association of two consecutive observations takes into account the contamination by land in the trajectory: if the land is inside the defined area A, the tracking is stopped 7

Reference documents

Chelton, D.B., Schlax, M.G., Samelson, R.M., 2011. Global observations of nonlinear mesoscale eddies. Prog. Oceanogr. 91, 167–216. https://doi.org/10.1016/j.pocean.2011.01.002

Schlax, M.G., Chelton, D.B., 2016. The “Growing Method” of Eddy Identification and Tracking in Two and Three Dimensions. College of Earth, Ocean and Atmospheric, Oregon State University Sciences, Corvallis, Oregon.

The “Growing Method” is available on

https://www.aviso.altimetry.fr/fileadmin/documents/data/products/value-added/Schlax_Chelton_2016.pdf

Contents

1. Overview of this document 1
2. The Mesoscale Eddy Trajectories Atlas 1
2.1.1. Rationale 1
2.1.2. Versioning of the AVISO+ Mesoscale Eddy Trajectories Atlases 2
2.2. Acknowledgments 2
2.3. User's feedback 2
3. Processing 2
3.1. Input data 2
3.2. Algorithms 2
3.2.1. Filtering 2
3.2.2. Detection 3
3.2.3. Estimation of eddy characteristics 4
3.2.4. Tracking 5
3.3. Product Statistical analysis for DT 2.0 8
4. Description of the product 8
4.1. Product general content and specifications 8
4.2. Nomenclature of files 8
4.3. NetCDF 8
4.4. Structure and semantic of NetCDF files 10
5. How to download a product 11
5.1. Registration 11
5.2. Access Services 11
Appendix A - Product header 12

1. Overview of this document

This document is the user manual for the Mesoscale Eddy Trajectories Atlas product, processed by CNES/CLS in the DUACS system.

Several versions are distributed by AVISO+ (details in 2.1.2), this document focuses on the META2.0 version which is operational since December 2020.

All the versions are detailed on the AVISO+ Product page,

The Atlas in version META2.0 is generated and quality-controlled following the methodology developed by D. Chelton and M. Schlax at the Oregon State University (OSU) (Chelton et al., 2011; Schlax and Chelton, 2016). The algorithm benefits from upgrades added through these collaborations, and the Mesoscale Eddy Trajectories Atlas dataset is distributed by AVISO+.

This document describes the delayed-time version 2.0 (**META2.0 DT**) of this product (versioning for AVISO+ distributed product), released in December 2020 and updated as the number of input available maps increase with time.

The document is organized as follows:

- Chapter 2; presentation
- Chapter 3; processing: input data and method applied
- Chapter 4; the product description, with the different files provided, the nomenclature & the file format
- Chapter 5; how to download products.

2. The Mesoscale Eddy Trajectories Atlas

2.1.1. Rationale

The mesoscale circulation is defined as a class of energetic phenomena of spatial dimensions ranging from tens to hundreds of kilometers and spanning days to years. The mesoscale structures are mainly generated by currents instabilities, from the ocean large-scale circulation instabilities due to wind or topographic obstacles, creating variability around the ocean’s mean state.

Altimetry enables observations of such phenomena by measuring the sea surface height, where currents swirl around local highs and lows through the geostrophic balance between the pressure gradient force and the Coriolis acceleration. The best resolution is obtained with several satellites to study and understand eddies, whose diameters range from 100 to 300 km, when the ground track separation at the Equator is about 315 km for Jason. The existence of at least two satellites operating simultaneously is therefore necessary for research on mesoscale features.

The analysis of Sea Surface Height (starting with Sea Level Anomalies, now more with Absolute Dynamic Topography) from merged satellite data reveals the areas of high eddy activity, the number of eddies per year, their horizontal scale and amplitude. Such a census helps understand ocean dynamics due to eddies, and to discriminate eddies' effect from other processes (like the Rossby waves). This reveals that most of the mesoscale features are "non-linear", i.e. that these features are coherent structures (as opposed to planetary waves that would be linear). Moreover, eddies can transport heat, salts and nutrients trapped within them if they rotate faster than they move-- also as opposed to planetary waves that would not transport water parcels. Some regions see more anticyclonic eddies (highs in the Sea Surface Height), like the Tehuantepec and Papagayo eddy area, others more cyclonic eddies, such as seen in the Humboldt Current.

2.1.2. Versioning of the AVISO+ Mesoscale Eddy Trajectories Atlases

The versioning of the different Mesoscale Eddy Trajectories Atlas is detailed on the AVISO+ website:

https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-trajectory-product.html

2.2. Acknowledgments

When using the products **Mesoscale Eddy Trajectories Atlas product** in delayed-time 2.0, please cite: "The altimetric Mesoscale Eddy Trajectories Atlas (META2.0) product was produced by SSALTO/DUACS and distributed by AVISO+ (https://aviso.altimetry.fr) with support from CNES, in collaboration with Oregon State University with support from NASA".

2.3. User's feedback

Each and every question, comment, example of use, and suggestion will help us improve the product. You're welcome to ask or send them to aviso@altimetry.fr.

3. Processing

3.1. Input data

The data used are described in Table 1.

Eddy product	Input data	Variable	Origin
Delayed-time version 2.0	**"two-satellite"** daily **Delayed Time** DUACS2018 version	Gridded Global **Sea Level Anomalies** (SLA)	Copernicus Climate Change Service (C3S) http://climate.copernicus.eu/

Table 1: Input product used

3.2. Algorithms

The algorithms used for this product are derived from the one implemented at Oregon State University and described in (Schlax and Chelton, 2016).

The main processing steps are described in this section. Some steps can vary from the paper cited above and some steps are the same (explicitly indicated).

This section highlights the improvements used for this version with respect to the previous one.

3.2.1. Filtering

The Sea Level Anomaly field includes a wide range of features, ranging from small to large-scale ones. Eddies are identified as features with diameters of 100-300 km, so the first step is to remove larger scale variability using a low pass filter. Large-scale variability was computed by smoothing using a Lanczos filter with a 1000 km half-power cutoff wavelength in latitude and longitude. The result was subtracted from the original SLA data to produce a high-pass filtered grid which contains only mesoscale variability (Figure 1).

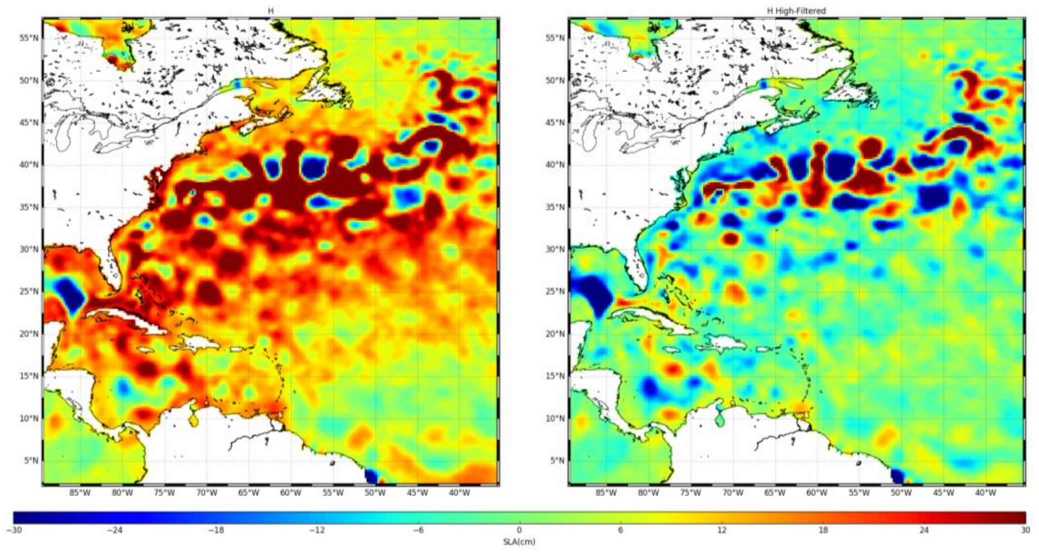


Figure 1: Left, initial sea level anomaly product. Right, the high-filtered version used for the DT 2.0 eddy detection.

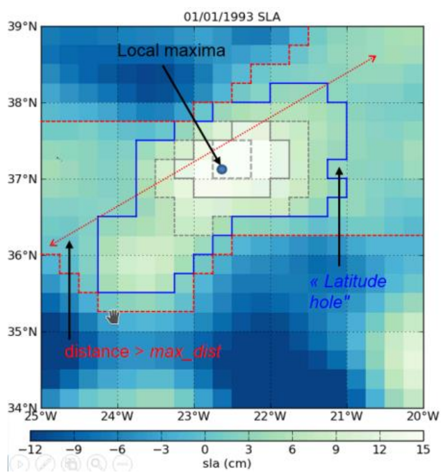
3.2.2. Detection

META2.0 (same as in v1.0exp) described in Schlax and Chelton (2016) and Chelton et al. (2011)

After filtering, extrema of the Sea Level Anomaly field are detected to estimate eddy locations and properties.

On each local maximum or minimum, the algorithm searches the points around it to extend the area detected as an eddy, following some rules:

- The tested area must be equal or smaller in amplitude than the area already defined.
- The distance between the two remotest points must be less than a maximum diameter for an eddy: Distance max = 700 km for latitudes lower than +/-25° of latitude, or 400 km for latitudes higher than +/-25°.
- Maximum Area = 2000 pixels.
- No latitude holes on the edges and no hole within the interior of the area.



If the tested area is not already included in the detection region of another eddy, an eddy is considered as detected. Any further detection on this area is stopped.

Note that multiple extrema eddies are authorized.

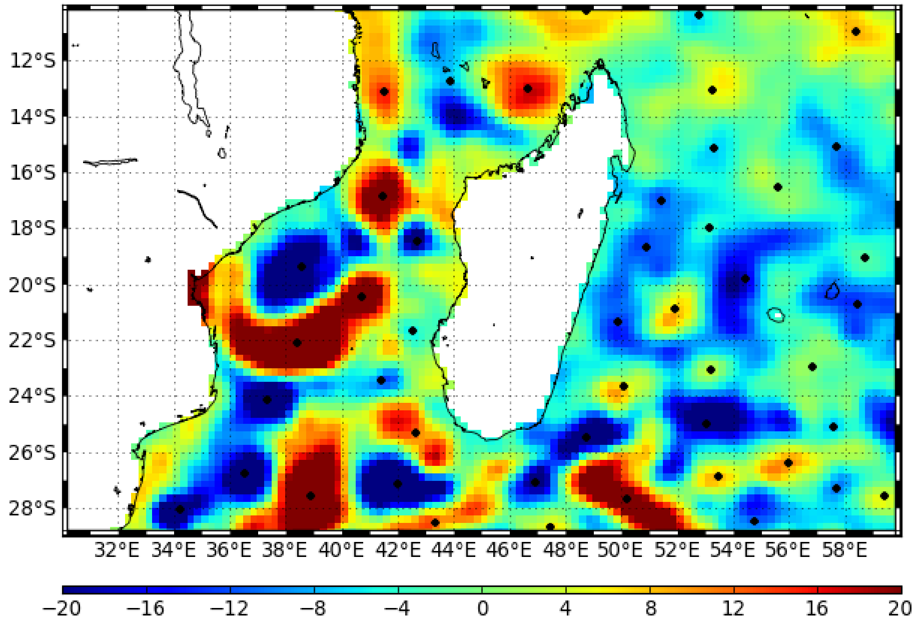


Figure 2: Eddy detections: black dots are eddies observation centers

3.2.3. Estimation of eddy characteristics

After the detection, we compute an estimate of different eddy characteristics, provided as variables within the dataset:

Characteristic	Value
Center position	Longitude and latitude of the center of the eddy (SLA centroid if multiple extrema)
Amplitude	|SSH(max_local) – SSH(edge_pix)|
Radius_speed	Radius of a circle whose area is equal to that enclosed by the contour of maximum circum-average geostrophic speed
Speed_average	Average geostrophic speed of the contour defining the speed radius

Table 2: Characteristics of eddies in DT META2.0 (the full variables are detailed in section 4)

3.2.4. Tracking

META2.0 DT (improved compared to META1.0exp)

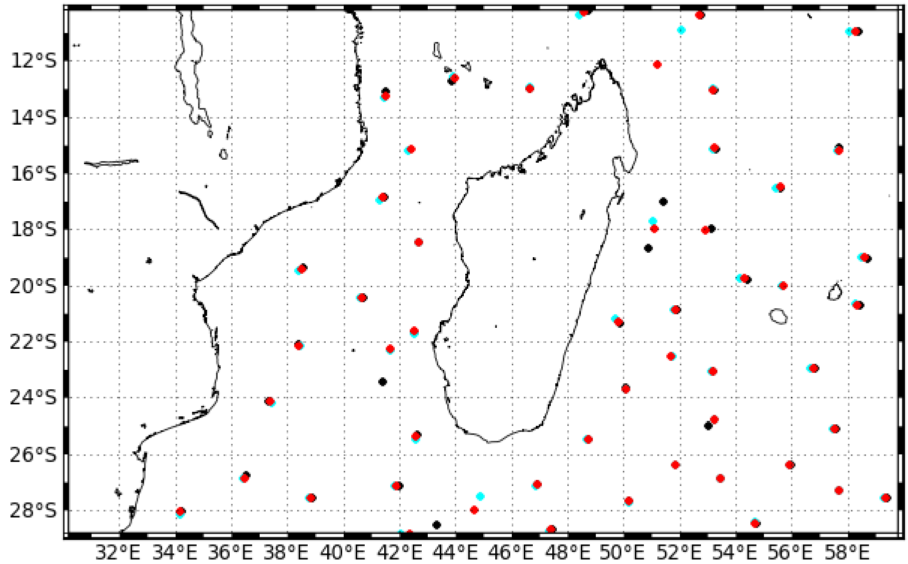
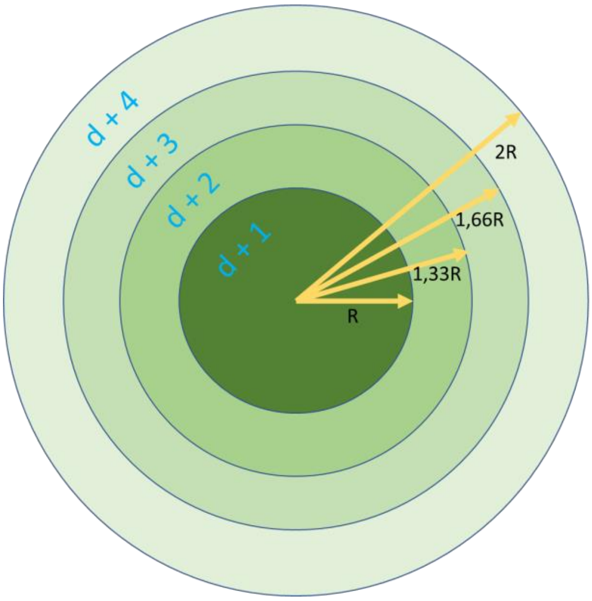


Figure 3: Eddy tracking; each color corresponds to a different day



After performing detection on several consecutive days, we apply a procedure to build the trajectories over time of the detected eddies.

To search for next observation on D+1, we build a circle of radius R that encompass an area to find linked observations. If several observations are found within this circle, a cost function is applied, which must be minimized to link two observations and consider they are two different positions of the same eddy.

The cost function depends on the amplitude and position (to compute distance) variables.

If no observation linked to the eddy is found in D+1 map, the research process is done on Day+2 and until D+4 maps with circles of growing radius as shown on the figure.

The radius R depends on the latitude (Figure 4)

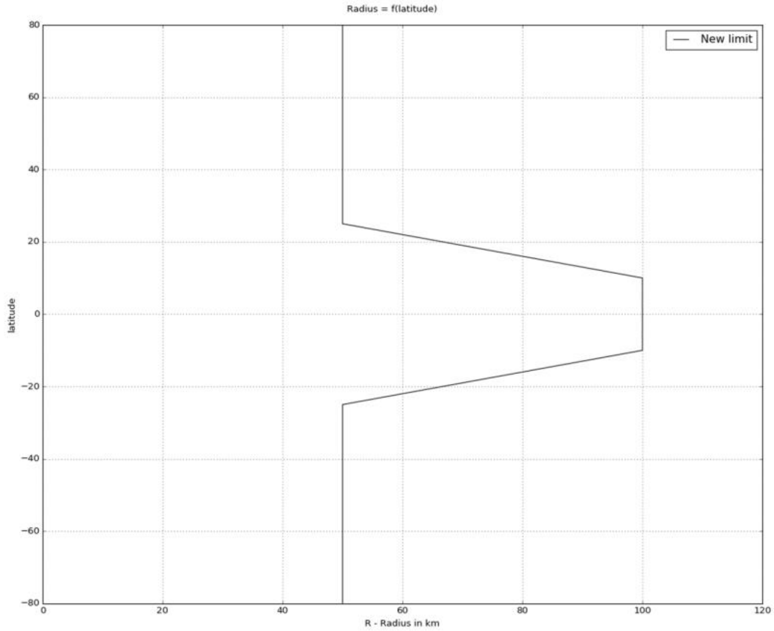


Figure 4: The radius is varying with the latitude

Loss of the eddy position on one map:

The tracking procedure allows the loss of one to three consecutive observations as illustrated in Figure 5: Tracking procedure : the eddy number 1 is kept because an association is found on map D+3, contrary to the eddy number 2 where no association is found on the last map.. This can happen sometimes due to identification thresholds criteria and/or map quality. Then, the lost eddy is reconstructed using interpolation. This information is given is the file in the variable 'observation_flag'.

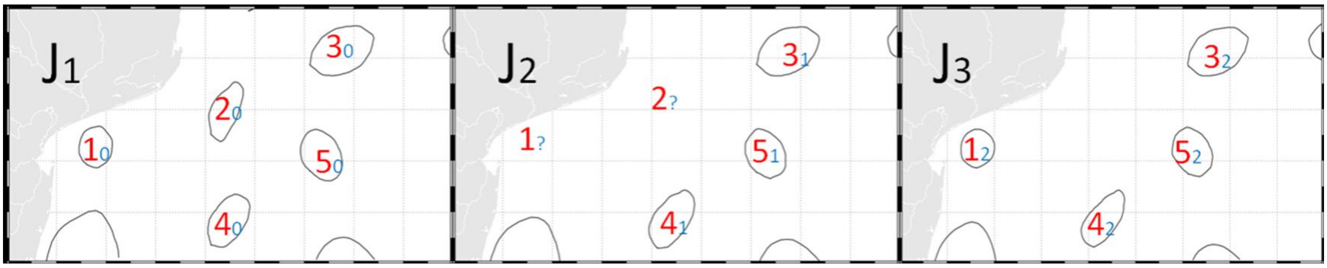


Figure 5: Tracking procedure : the eddy number 1 is kept because an association is found on map D+3, contrary to the eddy number 2 where no association is found on the last map.

Contamination by land:

The tracking process takes into account the proximity of the land in the trajectory of the eddy. When the two positions are defined at D0 and D+1 or more, an area A is defined as a function of the radius r of the eddy. The trajectory is stopped if some land is found in the area A.

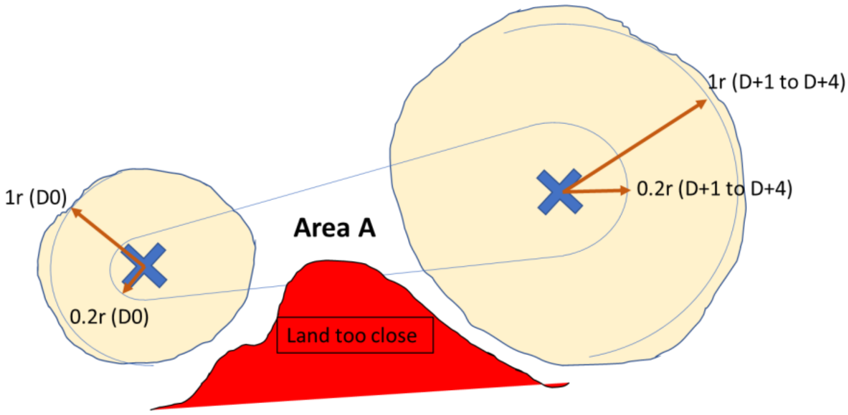


Figure 6: The association of two consecutive observations takes into account the contamination by land in the trajectory: if the land is inside the defined area A, the tracking is stopped

After the tracking, only trajectories lasting at least 28 days are selected and delivered.

3.3. Product Statistical analysis for DT 2.0

A series of plots is provided for comparison with the plots available in Chelton et al. [2011], but based on the new DUACS SLA product distributed by C3S from 2018:

https://www.aviso.altimetry.fr/fileadmin/documents/data/products/value-added/aviso_validation_report_eddy_tracking_2.0.pdf

4. Description of the product

4.1. Product general content and specifications

Eddy product	Covered period	Spatial coverage	Delivery format	Update
Delayed-time version 2.0exp	01/01/1993 – 0703/2020, the end date is updated every year	-46 to 373°E* - 77°S to 80°N	One NetCDF file (cyclonic and anticyclonic eddies in the same file)	Each year

Table 3: Characteristics of the product delivery

*The negative longitudes maintain continuity in longitude for the trajectories crossing the Prime Meridian to the West, the longitudes above 360°E are for the trajectories crossing the Prime Meridian to the East.

Note that the numbering of the eddies may differ from one day to another one so this variable should not be taken as the basis for comparison between files.

4.2. Nomenclature of files

META2.0 DT

META2.0_19930101_20200307.nc includes the whole time series of the data processed for the version META2.0

4.3. NetCDF

The product is stored using the NetCDF CF format. NetCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The NetCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. The NetCDF software was developed at the Unidata Program Center in Boulder, Colorado. The NetCDF libraries define a machine-independent format for representing scientific data. Please see Unidata NetCDF pages for more information on the NetCDF software package: http://www.unidata.ucar.edu/packages/netcdf/

NetCDF data is:

- Self-Describing. A NetCDF file includes information about the data it contains.
- Architecture-independent. A NetCDF file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers.
- Direct-access. A small subset of a large dataset may be accessed efficiently, without first reading through all of the preceding data.
- Appendable. Data can be appended to a NetCDF dataset along one dimension without copying the dataset or redefining its structure. The structure of a NetCDF dataset can be changed, though this sometimes causes the dataset to be copied.
- Sharable. One writer and multiple readers may simultaneously access the same NetCDF file.

The NetCDF version provided here is version 4 “classic”.

4.4. Structure and semantic of NetCDF files

META2.0 DT

All the eddies detected are stored in a unique file.

Each detected track is stored end-to-end on one dimension "obs" (an index). The "track" variable numbers the eddy track, and thus allows to separate tracks.

Variable name	Description	Standard _name	Dimensions	Units
META2.0exp_%Y%m%d_%Y%m%d.nc				
NetCDF-CF **Obs : Each detected track is stored end-to-end on one dimension "obs" (an index). The "track" variable numbers the eddy trajectory, and thus allows to separate tracks.**				
amplitude	magnitude of the height difference between the extremum of SLA within the eddy and the SLA of the contour defining the eddy perimeter		(Obs)	m
cyclonic_type	rotating sense of the eddy : -1 is Cyclonic and 1 is Anticyclonic		(Obs)	-1 or 1
latitude	eddy center latitude	latitude	(Obs)	Degrees _north
longitude	eddy center longitude	longitude	(Obs)	Degrees _east
observation_number	observation sequence number, days from eddy first detection		(Obs)	ordinal
observation_flag	flag indicating if the value is interpolated between two observations or not (0: observed, 1: interpolated)		(Obs)	boolean
speed_average	average speed of the contour defining the radius scale "speed_radius"		(Obs)	m/s
speed_radius	radius of a circle whose area is equal to that enclosed by the contour of maximum circum-average speed		(Obs)	m
time	days since 1950-01-01 00:00:00 UTC	time	(Obs)	Days
track	trajectory identification number		(Obs)	ordinal

5. How to download a product

5.1. Registration

To access data, registration is required. During the registration process, the user shall accept using licenses for the use of AVISO+ products and services. This product is available for non-commercial uses only.

Register at:

http://www.aviso.altimetry.fr/en/data/data-access/registration-form.html

or, if already registered on AVISO+, request the addition of this product on your personal account on https://www.aviso.altimetry.fr/no_cache/en/my-aviso-plus.html

and select the product:

"**Mesoscale eddy trajectory atlas product (restricted licence)**"

5.2. Access Services

Note that once your registration is processed (see above), AVISO+ will validate your registration by e-mail as soon as possible (within 5 working days during working hours, Central European Time). The access information will be available in your personal account on https://www.aviso.altimetry.fr/en/my-aviso-plus.html .

Appendix A - Product header

META2.0 DT

```
dimensions:
  obs = 27880804 ;
variables:
  ushort amplitude(obs) ;
    amplitude:description = "magnitude of the height difference between the extremum of SLA within the eddy and the SLA of the contour defining the eddy perimeter" ;
    amplitude:longname = "amplitude" ;
    amplitude:units = "m" ;
    amplitude:min = 0.01 ;
    amplitude:max = 0.486 ;
    amplitude:add_offset = 0LL ;
    amplitude:scale_factor = 0.001 ;
  byte cyclonic_type(obs) ;
    cyclonic_type:description = "Cyclonic : -1; Anticyclonic : +1" ;
    cyclonic_type:longname = "rotating sense of the eddy" ;
    cyclonic_type:units = "boolean" ;
    cyclonic_type:min = -1b ;
    cyclonic_type:max = 1b ;
  float latitude(obs) ;
    latitude:_FillValue = NaNf ;
    latitude:axis = "Y" ;
    latitude:description = "Eddy center latitude" ;
    latitude:longname = "eddy center latitude" ;
    latitude:standard_name = "latitude" ;
    latitude:units = "degrees_north" ;
    latitude:min = -77.3222f ;
    latitude:max = 79.7605f ;
  float longitude(obs) ;
    longitude:_FillValue = NaNf ;
    longitude:axis = "X" ;
    longitude:description = "Eddy center longitude" ;
    longitude:longname = "eddy center longitude" ;
    longitude:standard_name = "longitude" ;
    longitude:units = "degrees_east" ;
    longitude:min = -47.548f ;
    longitude:max = 372.9487f ;
  byte observation_flag(obs) ;
    observation_flag:description = "Flag indicating if the value is interpolated between two observations or not (0: observed, 1: interpolated)" ;
    observation_flag:longname = "virtual_position" ;
    observation_flag:units = "boolean" ;
    observation_flag:min = 0b ;
    observation_flag:max = 1b ;
  ushort observation_number(obs) ;
    observation_number:description = "Observation sequence number, days from eddy first detection" ;
```

```
        observation_number:longname = "observation number" ;
        observation_number:units = "ordinal" ;
        observation_number:min = 0US ;
        observation_number:max = 1848US ;
    ushort speed_average(obs) ;
        string speed_average:description = "Average speed of the contour defining the radius scale
“speed_radius”" ;
        speed_average:longname = "maximum circum-averaged speed" ;
        speed_average:units = "m/s" ;
        speed_average:min = 0.0097 ;
        speed_average:max = 3.0876 ;
        speed_average:add_offset = 0LL ;
        speed_average:scale_factor = 0.0001 ;
    ushort speed_radius(obs) ;
        speed_radius:description = "Radius of a circle whose area is equal to that enclosed by the
contour of maximum circum-average speed" ;
        speed_radius:longname = "speed radius scale" ;
        speed_radius:units = "m" ;
        speed_radius:min = 7050. ;
        speed_radius:max = 403200. ;
        speed_radius:add_offset = 0LL ;
        speed_radius:scale_factor = 50. ;
    int time(obs) ;
        time:axis = "T" ;
        time:description = "Date of this observation" ;
        time:longname = "Time" ;
        time:standard_name = "time" ;
        time:min = 15706 ;
        time:max = 25633 ;
        time:units = "days since 1950-01-01" ;
        time:calendar = "proleptic_gregorian" ;
    uint track(obs) ;
        track:description = "Trajectory identification number" ;
        track:longname = "Trajectory number" ;
        track:units = "ordinal" ;
        track:min = 0U ;
        track:max = 379974U ;

// global attributes:
        :title = "Mesoscale Eddy Trajectories Atlas in Altimeter Observations of SLA" ;
        :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
        :comment = "Surface product; mesoscale eddies" ;
        :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention
Standard Name Table" ;
        :date_created = "2020-07-09T16:26:15Z" ;
        :time_coverage_duration = "P9784D" ;
        :time_coverage_start = "1993-01-01T00:00:00Z" ;
        :time_coverage_end = "2020-03-07T00:00:00Z" ;
        :institution = "CNES/CLS in collaboration with Oregon State University" ;
        :project = "SSALTO/DUACS" ;
```

:creator_url = "http://www.aviso.altimetry.fr" ;
:creator_email = "aviso@altimetry.fr" ;
:license = "http://www.aviso.altimetry.fr/fileadmin/documents/data/License_Aviso.pdf" ;
:summary = "This dataset contains mesoscale eddy trajectories atlas from two-satellite C3S SLA maps over the global ocean" ;
:input_product_reference = "https://www.aviso.altimetry.fr/en/data/product-information/updates-and-reprocessing/ssaltoduacs-delayed-time-reprocessing.html" ;
:product_version = "2.0" ;

SALP

SERVICE
ALTIMETRIE
&
LOCALISATION
PRECISE