Mesoscale Eddy Trajectories Atlas Product Handbook

META3.0exp Near-Real-Time
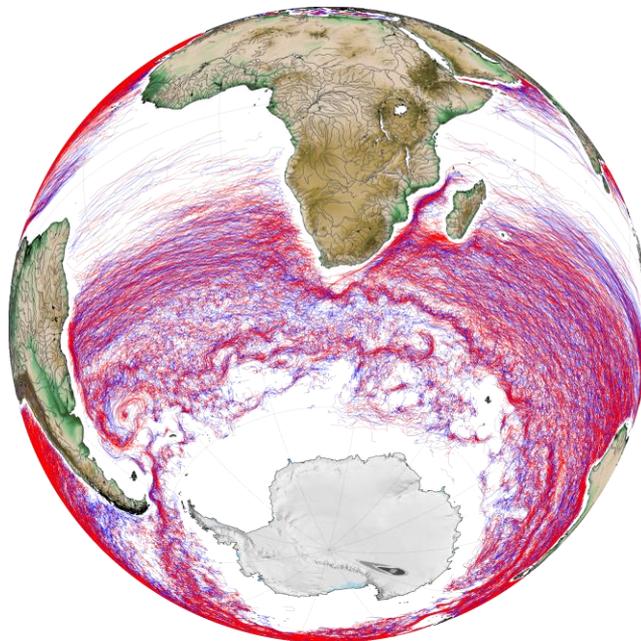
Chronology Issues:		
Issue:	Date:	Reason for change:
1.0	2021/03/24	1st issue from former User Manual

List of Acronyms:

ADT	Absolute Dynamic Topography (=SLA+MDT)
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
MDT	Mean Dynamic Topography (difference between Mean Sea Surface (MSS) and Geoid)
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

Reference documents

Mason, E., Pascual, A., McWilliams, J.C., 2014. A New Sea Surface Height–Based Code for Oceanic Mesoscale Eddy Tracking. J. Atmospheric Ocean. Technol. 31, 1181–1188. https://doi.org/10.1175/JTECH-D-14-00019.1

<div style="background:#001a8c;color:#fff;">**Contents**</div>

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1. Overview of this document

This document is the user manual for the Mesoscale Eddy Trajectories Atlas NRT (**META3.0exp**) product, processed by CNES/CLS in the DUACS system.

2.1.2This version is generated and quality-controlled following the methodology developed by E. Mason at the Instituto Mediterráneo de Estudios Avanzados (IMEDEA, Spain The algorithm benefits from upgrades added through this collaboration, and the META3.0exp dataset is distributed by AVISO+.

This document describes

the near-real-time version 3.0 Experimental (NRT META3.0exp) product, released since September 2019

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 the product.

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.

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2.1.2. Versioning of the AVISO+ Mesoscale Eddy Trajectories Atlas

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 product:

Mesoscale Eddy Trajectories Atlas product in near-real-time 3.0exp, please cite: "The altimetric Mesoscale Eddy Trajectories Atlas (META3.0exp NRT) is produced by SSALTO/DUACS and distributed by AVISO+ (https://www.aviso.altimetry.fr/) with support from CNES, in collaboration with IMEDEA".

2.3. User's feedback

The product is an **experimental** product.

Therefore, 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: Input product used .

Eddy product	Input data	Variable	Origin
Near-real-time version 3.0exp	**"all-satellite"** daily **Near Real Time** DUACS2018 version	Gridded Global **Absolute Dynamic Topographies** (ADT)	Copernicus Marine Service (CMEMS) http://marine.copernicus.eu/

Table 1: Input product used

The NRT product is based on "all-satellite" input products, that allows a better sampling of the ocean at a given time. Indeed the focus on short period of time with a best sampling is in the interest of using a NRT product.

The eddy detection is made on ADT maps to avoid a) misinterpreting eddies with a permanent signature and b) that the displacement of large currents creates anomalies similar to eddies.

3.2. Algorithm

The algorithm used for this product is derived from the one described in (Mason et al., 2014).

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 Surface Height 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 the ADT field with a third order Lanczos filter with a half-power cutoff wavelength of 500 km. The result was subtracted from the original ADT data to produce a high-pass filtered grid which contains only mesoscale variability (Figure 1).
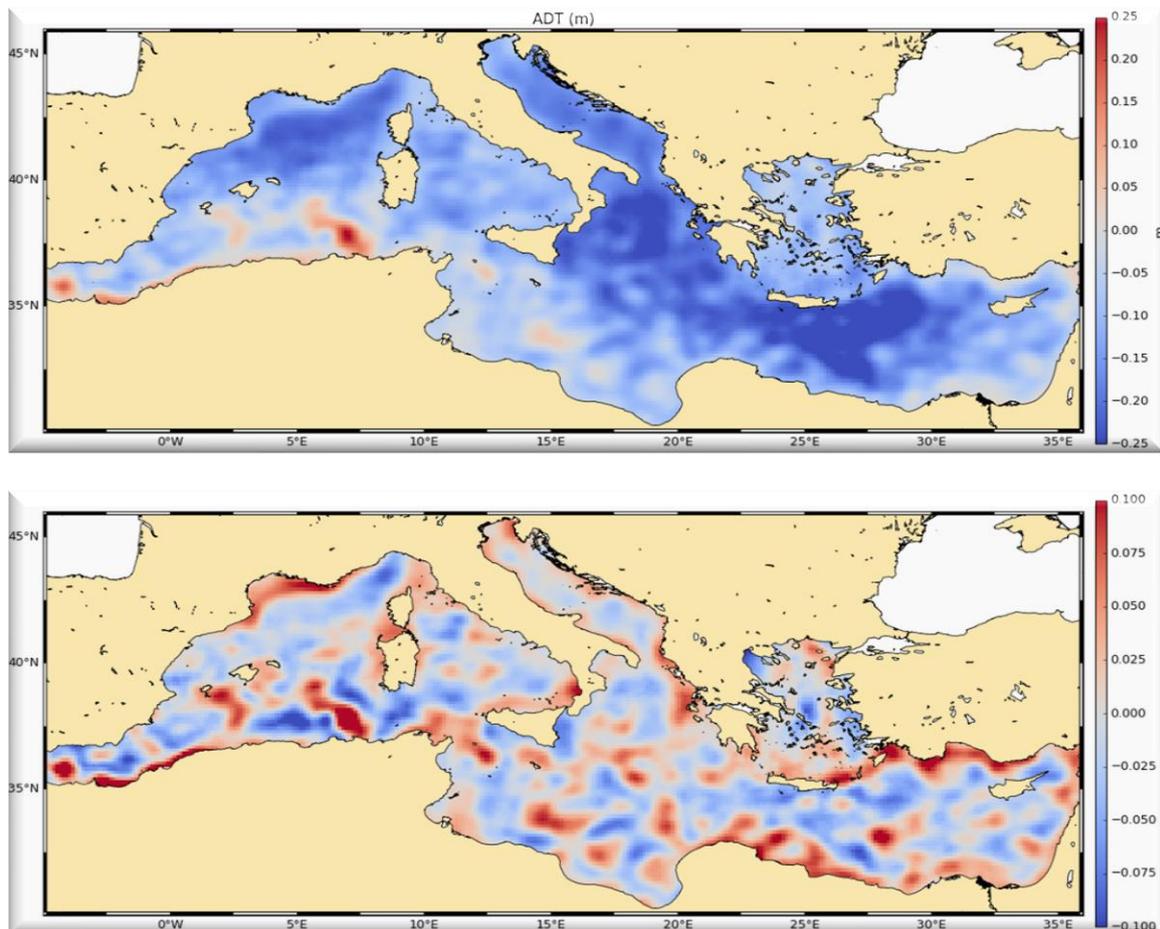
Figure 1: Top, initial ADT variable. Bottom, after the filter is applied as an input for NRT3.0exp eddy detection.

3.2.2. Detection

The detection is made in two steps

1/ By the identification of ADT closed contours between -100/100 cm and at each 0.25 cm interval, closed contours are identified and analyzed (see Figure 2 top). An eddy is identified if some characteristics follow some criteria.

The full explanation can be found in (Mason et al., 2014).

2/ Next, the center of the eddy is defined as the center of the circle which fits best with the contour of the maximum speed. The corresponding radius is then calculated as the radius of this best fit circle.

3/ Characteristics are calculated as described in Table 2.

Figure 2: Top) ADT contours analysed for the NRT META3.0exp product; middle) final eddies detected; bottom) mask of the eddies in the ADT.

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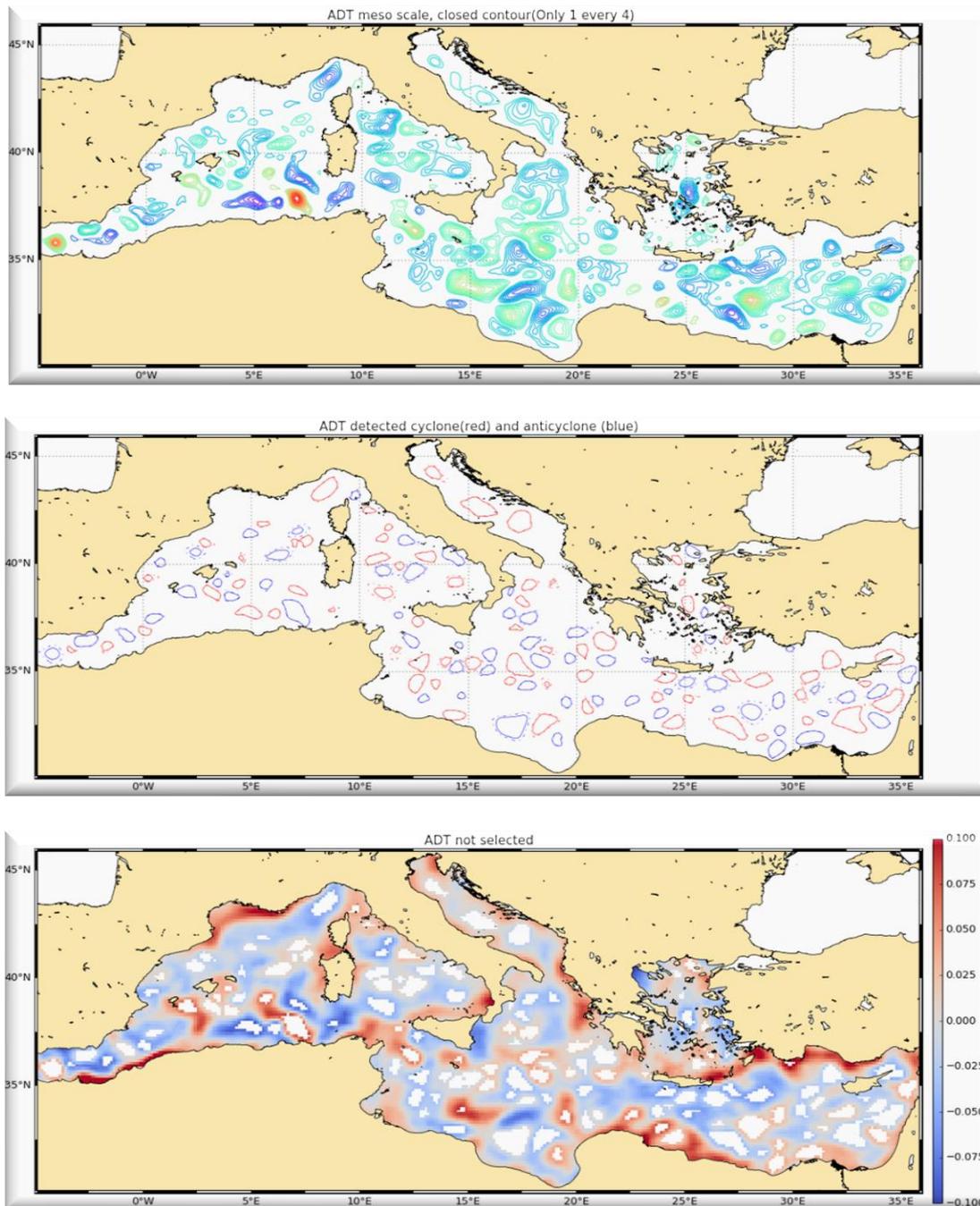
After the detection, we compute an estimate of different eddy characteristics, provided as variables within the dataset:

Characteristic	Value
Center position	Longitude and latitude of the center of the best fit circle with the contour of maximum circum-average geostrophic speed
Amplitude	|SSH(local_extremum) – SSH(outermost_contour)|
Radius_speed	Radius of the best fit circle with the contour of maximum circum-average geostrophic speed
Speed_average	Average geostrophic speed of the contour defining the speed radius
Speed profile	Profile speed average values from effective contour inwards to smallest inner contour
Effective contour	Largest contour of the detected eddy
Speed contour	Speed contour of the detected eddy

Table 2: Characteristics of eddies for NRT META3.0exp (the full variables are detailed in section 4)

3.2.4. Tracking

NRT 3.0exp (Different from Mason et al., 2014)
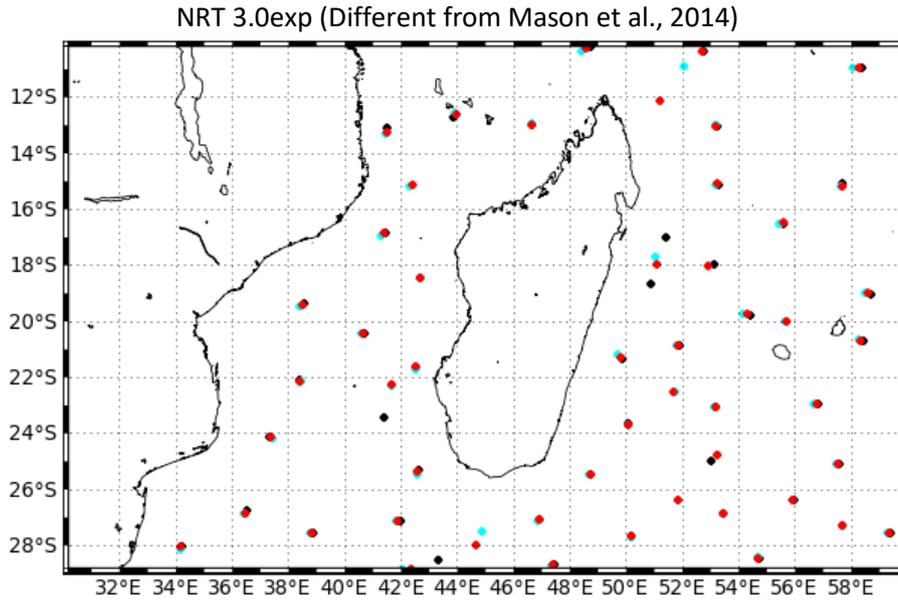
Figure 3 : Eddy tracking; each color corresponds to a different day
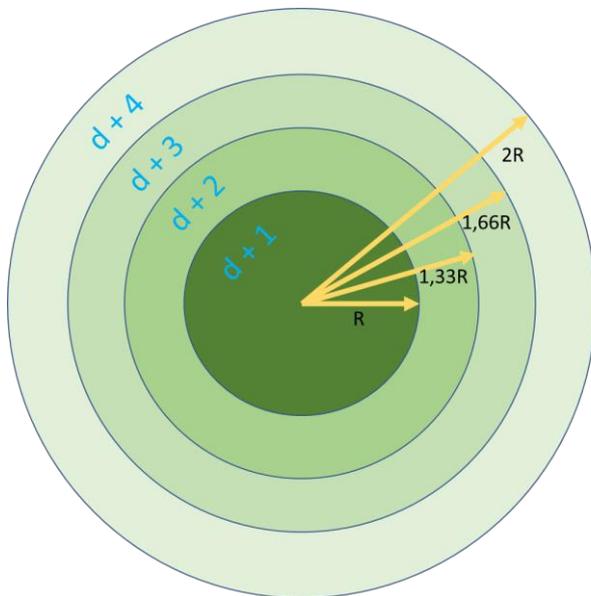
After performing detection on several consecutive days, we apply a procedure to build the trajectories over time of the detected eddies.

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:
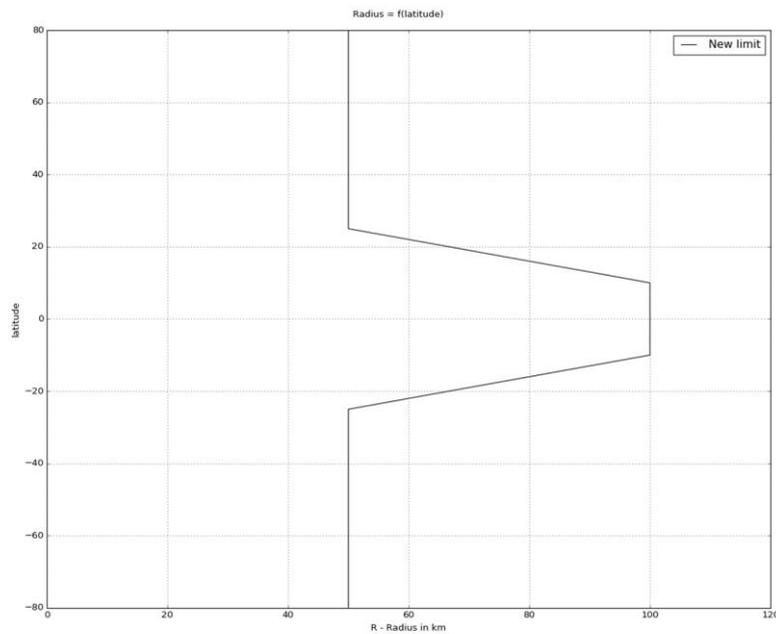
Figure 4: The radius is varying with the latitude

<u>Loss of the eddy position on one or several maps:</u>

The tracking procedure allows the loss of one to three consecutive observations as illustrated in Figure 5. 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'.
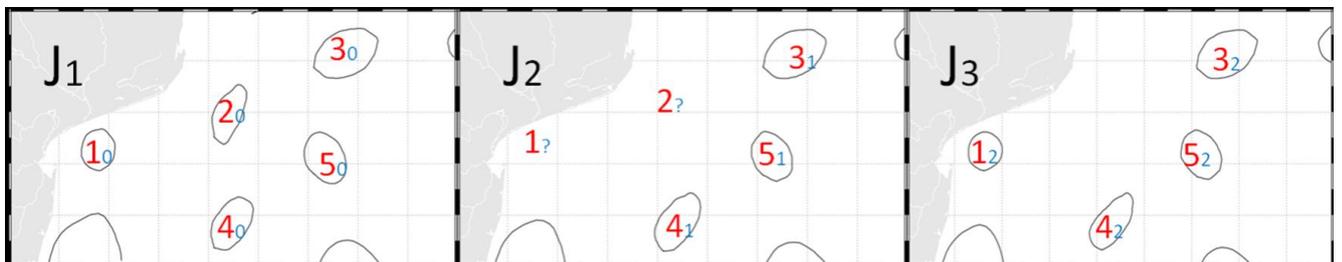
Figure 5: Tracking procedure : the eddy number 1 is kept because an association is found on map J3, contrary to the eddy number 2 where no association is found on the last map.

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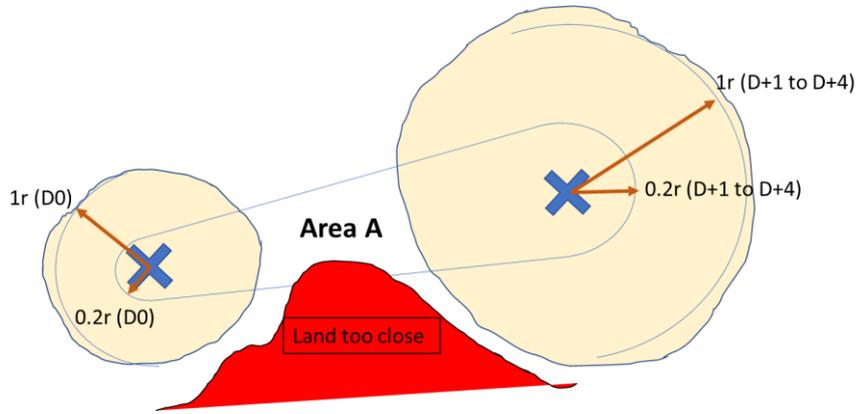
Figure 6: The association of two consecutive observations takes into account the contamination by land in the trajectory: if the land is inside the defined area A, the tracking is stopped

After the tracking, only trajectories lasting at least 10 days are selected and delivered.

4. Description of the product

4.1. Product general content and specifications

Eddy product	Covered period	Spatial coverage	Delivery format	Update
Near-real-time version 3.0exp	01/01/2018 – ongoing with 15 days of latency	0 to 360°E - 82.5°S to 82.5°N	Two Netcdf files (one for cyclonic eddies and one for anticylonic eddies).	Daily

Table 3: Characteristics of the product delivery

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

eddy_trajectory_cyclonic_nrt_3.0exp_%Y%m%d_%Y%m%d.nc and

eddy_trajectory_anticyclonic_nrt_3.0exp_%Y%m%d_%Y%m%d.nc

include the whole time series of the data processed for the version META3.0exp. Each day, the second date increments to update the period of coverage.

4.3. NetCDF

The products are 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

All the eddies detected are stored in two files: cyclonic and anticyclonic.

Variable name	Description	Standard_name	Dimensions	Units
eddy_trajectory_nrt_3.0exp_cyclonic_%Y%m%d_%Y%m%d.nc eddy_trajectory_nrt_3.0exp_anticyclonic_%Y%m%d_%Y%m%d.nc				
NetCDF-CF **Dimensions:** **Obs : 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.** **Nbsamples : 50** **It is the number of points to store information**: if there is more or less than 50 points constituting a contour or the uavg_profile, the information is interpolated to be stored in the file				
latitude	observation latitude	latitude	(Obs)	Degrees_north
longitude	observation longitude	longitude	(Obs)	Degrees_east
time	days since 1950-01-01 00:00:00 UTC	time	(Obs)	Days
track	trajectory identification number		(Obs)	ordinal
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
amplitude	magnitude of the height difference between the extremum of ADT within the eddy and the ADT around the contour defining the eddy perimeter		(Obs)	meters
num_contours	number of contours selected for this eddy		(Obs)	ordinal
effective_contour_latitude	Latitudes of effective contour		(Obs, Nbsamples)	Degrees_north
effective_contour_longitude	Longitudes of effective contour		(Obs, Nbsamples)	Degrees_east
effective_contour_height	ADT filtered height for effective contour		(Obs)	meters

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effective_contour_ shape_error	Error criterion of fit on effective contour	(Obs)	%
effective_radius	radius of a circle whose area is equal to that enclosed by the effective contour	(Obs)	meters
speed_contour_ latitude	Latitudes of speed contour	(Obs, Nbsamples)	Degrees _north
speed_contour_ longitude	Longitudes of speed contour	(Obs, Nbsamples)	Degrees _north
speed_contour_ height	ADT filtered height for speed contour	(Obs)	meters
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)	km
speed_contour_ shape_error	Error criterion of fit on speed contour	(Obs)	%
inner_contour_height	ADT filtered height for inner contour	(Obs)	meters
uavg_profile	speed average values from effective contour inwards to smallest inner contour	(Obs, Nbsamples)	m/s
latitude_max	latitude of amplitude max	(Obs)	
longitude_max	longitude of amplitude max	(Obs)	

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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**"

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/no_cache/en/my-aviso-plus.html .

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Appendix A - Product header

netcdf eddy_trajectory_nrt_3.0exp_cyclonic_20180101_20190820 {
dimensions:
      obs = 1963946 ;
      NbSample = 50 ;
variables:
      ushort amplitude(obs) ;
            amplitude:description = "Magnitude of the height difference between the extremum of
ADT within the eddy and the ADT around the contour defining the eddy perimeter" ;
            amplitude:longname = "amplitude" ;
            amplitude:units = "m" ;
            amplitude:scale_factor = 0.001 ;
            amplitude:add_offset = 0LL ;
            amplitude:min = 0.004 ;
            amplitude:max = 1.239 ;
      float cost_association(obs) ;
            cost_association:description = "Cost value to associate with the next observation" ;
            cost_association:longname = "cost_value_to_associate_with_next_observation" ;
            cost_association:min = 0. ;
            cost_association:max = 0. ;
      float effective_contour_height(obs) ;
            effective_contour_height:description = "ADT filtered height for effective contour" ;
            effective_contour_height:longname = "effective contour height" ;
            effective_contour_height:units = "m" ;
            effective_contour_height:min = -0.706f ;
            effective_contour_height:max = 0.198f ;
      short effective_contour_latitude(obs, NbSample) ;
            effective_contour_latitude:axis = "X" ;
            effective_contour_latitude:description = "Latitudes of effective contour" ;
            effective_contour_latitude:longname = "effective contour latitudes" ;
            effective_contour_latitude:units = "degrees_east" ;
            effective_contour_latitude:scale_factor = 0.01 ;
            effective_contour_latitude:add_offset = 0LL ;
      short effective_contour_longitude(obs, NbSample) ;
            effective_contour_longitude:axis = "X" ;
            effective_contour_longitude:description = "Longitudes of effective contour" ;
            effective_contour_longitude:longname = "effective contour longitudes" ;
            effective_contour_longitude:units = "degrees_east" ;
            effective_contour_longitude:scale_factor = 0.01 ;
            effective_contour_longitude:add_offset = 180LL ;
      ubyte effective_contour_shape_error(obs) ;
            effective_contour_shape_error:description = "Error criterion of fit on effective
contour" ;
            effective_contour_shape_error:longname = "effective contour error" ;
            effective_contour_shape_error:units = "%" ;
            effective_contour_shape_error:scale_factor = 0.5 ;
            effective_contour_shape_error:add_offset = 0LL ;

```
        effective_contour_shape_error:min = 4.5 ;
        effective_contour_shape_error:max = 55. ;
    ushort effective_radius(obs) ;
        effective_radius:description = "Radius of a circle whose area is equal to that enclosed
by the effective contour" ;
        effective_radius:longname = "effective radius scale" ;
        effective_radius:units = "m" ;
        effective_radius:scale_factor = 50. ;
        effective_radius:add_offset = 0LL ;
        effective_radius:min = 9100. ;
        effective_radius:max = 248750. ;
    float inner_contour_height(obs) ;
        inner_contour_height:description = "ADT filtered height for inner contour" ;
        inner_contour_height:longname = "inner contour height" ;
        inner_contour_height:units = "m" ;
        inner_contour_height:min = -1.142f ;
        inner_contour_height:max = 0.176f ;
    float latitude(obs) ;
        latitude:axis = "Y" ;
        latitude:description = "Observation latitude" ;
        latitude:longname = "latitude of measurement" ;
        latitude:standard_name = "latitude" ;
        latitude:units = "degrees_north" ;
        latitude:min = -78.16272f ;
        latitude:max = 83.04803f ;
    float latitude_max(obs) ;
        latitude_max:axis = "Y" ;
        latitude_max:description = "Observation latitude" ;
        latitude_max:longname = "latitude of amplitude max" ;
        latitude_max:standard_name = "latitude" ;
        latitude_max:units = "degrees_north" ;
        latitude_max:min = -78.12547f ;
        latitude_max:max = 83.12267f ;
    float longitude(obs) ;
        longitude:axis = "X" ;
        longitude:description = "Observation longitude" ;
        longitude:longname = "longitude of measurement" ;
        longitude:standard_name = "longitude" ;
        longitude:units = "degrees_east" ;
        longitude:min = -11.32053f ;
        longitude:max = 362.679f ;
    float longitude_max(obs) ;
        longitude_max:axis = "X" ;
        longitude_max:description = "Observation longitude" ;
        longitude_max:longname = "longitude of amplitude max" ;
        longitude_max:standard_name = "longitude" ;
        longitude_max:units = "degrees_east" ;
        longitude_max:min = 4.272083e-05f ;
        longitude_max:max = 360.f ;
    ushort num_contours(obs) ;
```

```
        num_contours:description = "Number of contour selected for this eddy" ;
        num_contours:longname = "number of contour" ;
        num_contours:units = "ordinal" ;
        num_contours:min = 1US ;
        num_contours:max = 614US ;
    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 = 596US ;
    byte segment_size(obs) ;
        segment_size:min = 0b ;
        segment_size:max = 0b ;
    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:scale_factor = 0.0001 ;
        speed_average:add_offset = 0LL ;
        speed_average:min = 0. ;
        speed_average:max = 4.0077 ;
    float speed_contour_height(obs) ;
        speed_contour_height:description = "ADT filtered height for speed contour" ;
        speed_contour_height:longname = "speed contour height" ;
        speed_contour_height:units = "m" ;
        speed_contour_height:min = -0.706f ;
        speed_contour_height:max = 0.198f ;
    short speed_contour_latitude(obs, NbSample) ;
        speed_contour_latitude:axis = "X" ;
        speed_contour_latitude:description = "Latitudes of speed contour" ;
        speed_contour_latitude:longname = "speed contour latitudes" ;
        speed_contour_latitude:units = "degrees_east" ;
        speed_contour_latitude:scale_factor = 0.01 ;
        speed_contour_latitude:add_offset = 0LL ;
    short speed_contour_longitude(obs, NbSample) ;
        speed_contour_longitude:axis = "X" ;
        speed_contour_longitude:description = "Longitudes of speed contour" ;
        speed_contour_longitude:longname = "speed contour longitudes" ;
        speed_contour_longitude:units = "degrees_east" ;
        speed_contour_longitude:scale_factor = 0.01 ;
```

```
        speed_contour_longitude:add_offset = 180LL ;
    ubyte speed_contour_shape_error(obs) ;
        speed_contour_shape_error:description = "Error criterion of fit on speed contour" ;
        speed_contour_shape_error:longname = "speed contour error" ;
        speed_contour_shape_error:units = "%" ;
        speed_contour_shape_error:scale_factor = 0.5 ;
        speed_contour_shape_error:add_offset = 0LL ;
        speed_contour_shape_error:min = 3.5 ;
        speed_contour_shape_error:max = 88. ;
    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:scale_factor = 50. ;
        speed_radius:add_offset = 0LL ;
        speed_radius:min = 9100. ;
        speed_radius:max = 247250. ;
    int time(obs) ;
        time:axis = "T" ;
        time:calendar = "proleptic_gregorian" ;
        time:description = "Date of this observation" ;
        time:longname = "Time" ;
        time:standard_name = "time" ;
        time:units = "days since 1950-01-01 00:00:00" ;
        time:min = 24837 ;
        time:max = 25433 ;
    uint track(obs) ;
        track:description = "Eddy identification number" ;
        track:longname = "track number" ;
        track:units = "ordinal" ;
        track:min = 0U ;
        track:max = 60638U ;
    ushort uavg_profile(obs, NbSample) ;
        uavg_profile:description = "Speed average values from effective contour inwards to
smallest inner contour" ;
        uavg_profile:longname = "radial profile of uavg" ;
        uavg_profile:units = "m/s" ;
        uavg_profile:scale_factor = 0.0001 ;
        uavg_profile:add_offset = 0LL ;

// global attributes:
        :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
        :comment = "Surface product; mesoscale eddies" ;
        :creator_email = "aviso@altimetry.fr" ;
        :creator_url = "https://www.aviso.altimetry.fr" ;
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        :framework_used = "https://bitbucket.org/emason/py-eddy-tracker" ;
        :input_product_reference = "https://www.aviso.altimetry.fr/en/data/products/value-
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       :institution = "CLS/CNES in collaboration with IMEDEA" ;

       :license =
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       :product_version = "3.0.exp" ;

       :project = "SSALTO/DUACS" ;

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       :summary = "This dataset contains eddy atlas from all-satellite NRT CMEMS maps over
global ocean (SEALEVEL_GLO_PHY_L4_NRT_OBSERVATIONS*)" ;

       :time_coverage_duration = "P597D" ;

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       :title = "Mesoscale Cyclonic Eddies in Altimeter Observations of ADT" ;

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