Mesoscale Eddy Trajectory Atlas Product Handbook

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)

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
CNES	Centre National d'Etudes Spatiales
DUACS	Data Unification and Altimeter Combination System
FTP	File Transfer Protocol
META2018	Mesoscale Eddy Trajectory Atlas - 2018 version
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

Mesoscale Eddies in Altimeter Observations of SSH web site at OSU, http://wombat.coas.oregonstate.edu/eddies/

Dudley B. Chelton, Michael G. Schlax, Roger M. Samelson, 2011: Global observations of nonlinear mesoscale eddies, Progr. Oceanogr., 91 (2011) 167–216, doi:10.1016/j.pocean.2011.01.002

Michael G. Schlax and Dudley B. Chelton, 2016: The "Growing Method" of Eddy Identification and Tracking in Two and Three Dimensions, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, July 8, 2016

Mesoscale Eddy Trajectory Atlas Product Handbook, SALP-MU-P-EA-23126-CLS, issue 1.0 https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_eddytrajectory.pdf

Contents

1. Overview of this document

This document is the user manual for the Mesoscale Eddy Trajectory Atlas product, processed by CNES/CLS in the DUACS system. This product is generated and quality-controlled following the methodology developed by D. Chelton and M. Schlax at the Oregon State University (USA). The algorithm benefits from upgrades added through this collaboration, and the Mesoscale Eddy Trajectory Atlas dataset is now distributed by AVISO+.

This document describes the version 2.0 Experimental (2.0exp) of this product (versioning for AVISO+ distributed product), released in September 2018. It 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 trajectory atlas

2.1.1. Rationale

The mesoscale circulation is defined like a class of energetic phenomena of spatial scales ranging from about ten to several hundred kilometers and time scales ranging from a few days to several months. Its forcing mechanisms are mainly instabilities from the large-scale circulation and interactions between currents and bathymetry and the direct forcing by the wind.

Altimetry enables observations of such phenomena by measuring the sea surface topography around which currents swirl by the geostrophic balance between the pressure gradient force and the Coriolis acceleration. A best resolution is obtained with several satellites to study and understand eddies, with diameters ranging from 100 to 300 km (when the ground track separation at equator is about 315 km for Jason). The existence of at least two satellites operating simultaneously is therefore necessary for this type of research.

Analysis of Sea Level Anomalies from merged satellite data reveals the areas of high eddy activity, the number of eddies during those years, their horizontal scale and height. 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, nearly all of those eddies can transport heat, salts and nutrients trapped within them -- also as opposed to planetary waves that would not transport water parcels. Some regions see more anticyclonic eddies (positive sea level anomalies), 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+ Eddy Atlas

- A dedicated dataset has been produced, for the 16-year period October 1992 - December 2008 by Chelton et al. in 2011 at Oregon State University [Chelton et al., 2011] with a weekly time step, thus enabling easy statistics and long-term studies. Each eddy was defined on the basis of connected pixels that satisfy specified criteria. The procedure was a 2-dimensional version of the method presented by Williams et al. [2011], modified as described by Schlax and Chelton (2016).
- In the version 1.0exp delivered on AVISO+ in July 2017, some upgrades had been added to the algorithm previously used (e.g. upgrades from the Version 4 eddy dataset, 2014),. an improved version of the eddy identification and tracking procedure was developed in collaboration between D. Chelton and CLS/DUACS. The details are in the Mesoscale Eddy Trajectory Atlas product handbook, version 1.0, June 2017.
- For the last delivery of version 2.0 experimental detailed in this handbook, the new version of input data has been taken into account (see section 0) and the tracking process has been improved and is detailed in section 3.2.4.

The eddy atlas is now routinely generated and quality-controlled by the DUACS team and distributed by AVISO+. The objective is to streamline the generation process and to reduce the latency of this product.

2.2. Acknowledgments

When using the **Mesoscale Eddy Trajectory Atlas product**, please cite: "The altimeter the Mesoscale Eddy Trajectory Atlas products were produced by SSALTO/DUACS and distributed by AVISO+ (http://www.aviso.altimetry.fr/) with support from CNES, in collaboration with Oregon State University with support from NASA".

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

To produce the eddy tracking product, the processing uses DUACS "two-satellite" daily Delayed Time Gridded Sea Level Anomalies product. In version 1.0, the data were the DUACS2014 distributed by AVISO+. In version 2.0exp, the reprocessed DUACS2018 version distributed by the Copernicus Climate Change Service (C3S http://climate.copernicus.eu/) has been used. This global product gives a full earth coverage of ocean height variations with stable sampling, which allows computing an eddy daily global product.

3.2. Algorithm

The algorithms used for this product are derived from the one implemented at Oregon State University and described in [Schlax & Chelton, 2016]. The main processing steps are described in this section. 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 second order Lanczos filter. The result was subtracted from the original SLA data to produce a grid which contains only mesoscale variability.
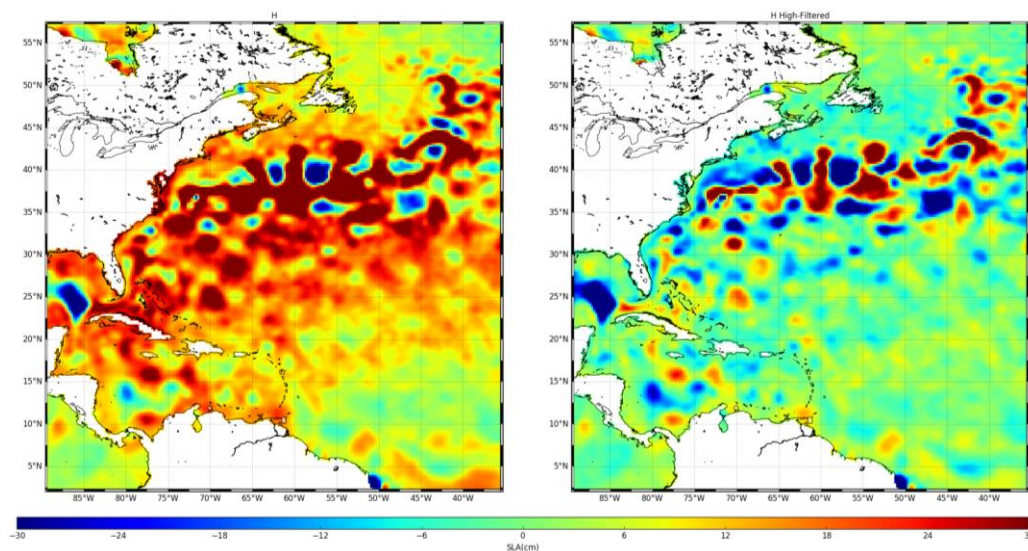

Figure 1: Left, initial sea level anomaly product. Right, the high-filtered version used for the eddy detection.

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3.2.2. Detection (same as in v1.0exp)

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

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

- tested area must be equal or smaller in amplitude than the area already defined,
- distance between the two remotest points must be less than a maximum likely 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.
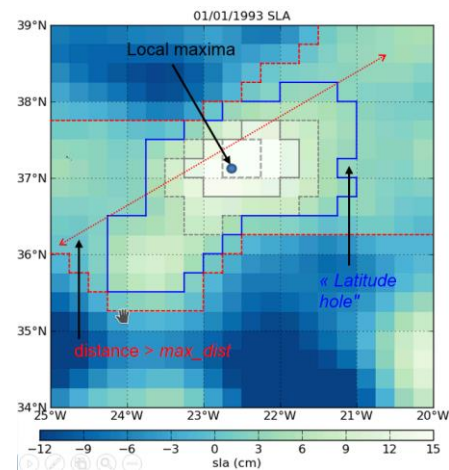
If the tested area isn't already included in the detection region of another eddy, an eddy is considered to be detected. Any further detection on this area is stopped.
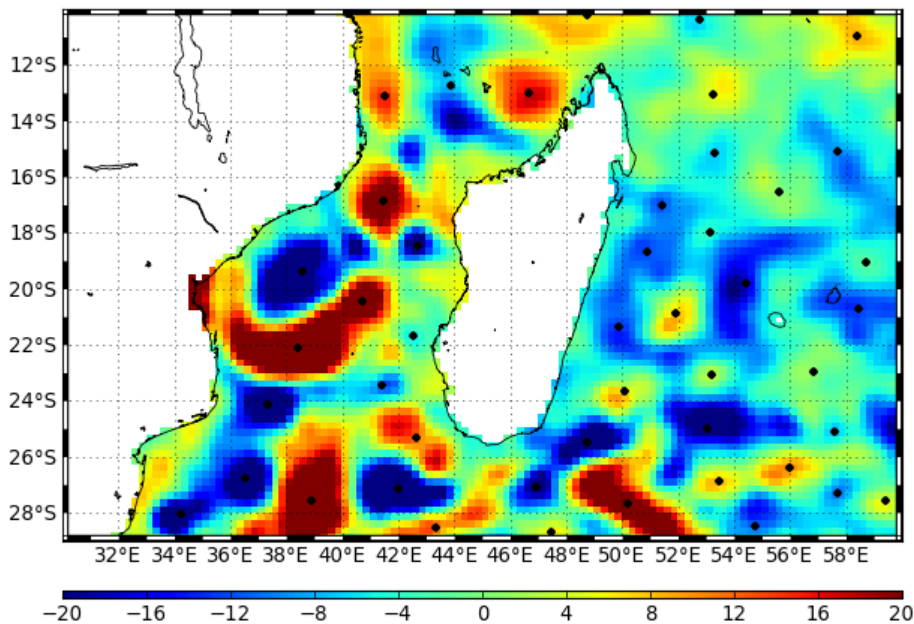
Figure 2: Eddy detections: black dots are eddies observation centers

3.2.3. Estimation of eddy characterization (same as in v1.0exp)

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

- *Amplitude* = |sla(max_local) – mean(sla(edge_pix))|

- *Radius_speed* = Radius of a circle with 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

3.2.4. Tracking (new in version 2.0exp)
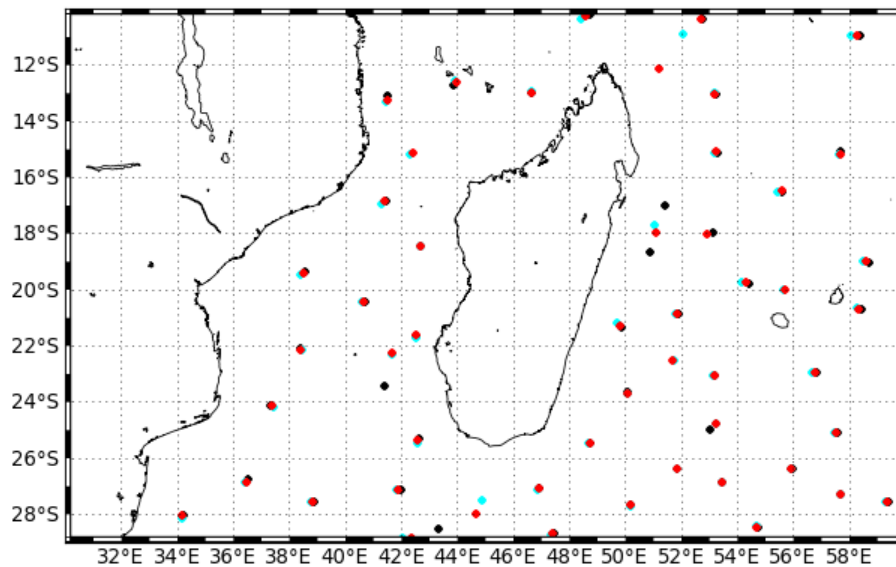
Figure 3: Eddy tracking; each color corresponds to a different day

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)
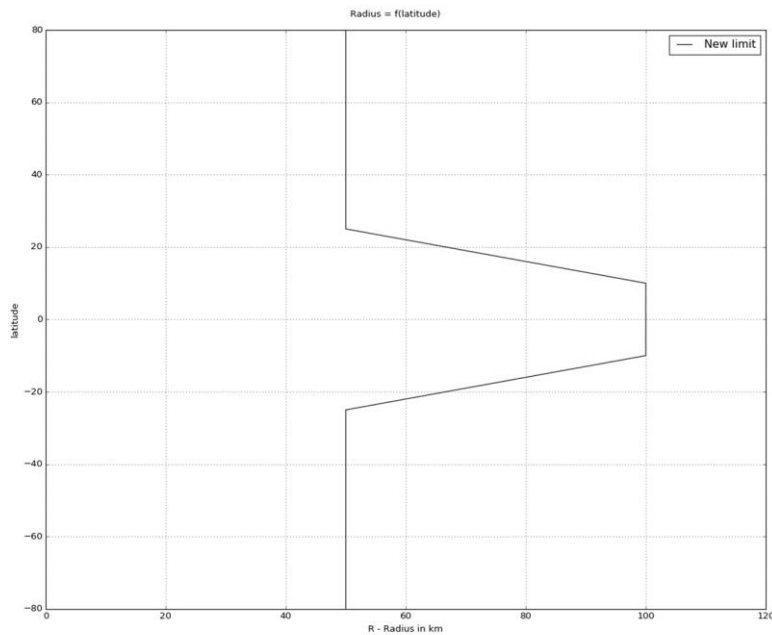
Figure 4: The radius is varying with the latitude

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. 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'.
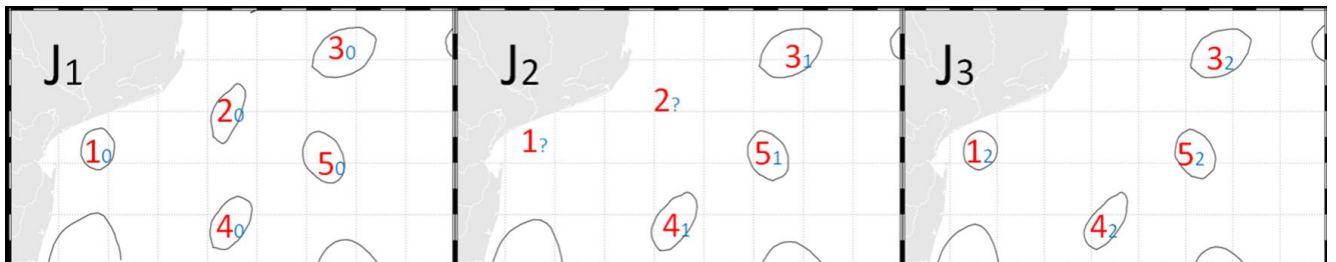
Figure 5: procedure to detect a tracking on a particular eddy: the eddy number 1 is kept because an association has been found on map D+3, contrary to the eddy number 2 where no association is found on the last map.

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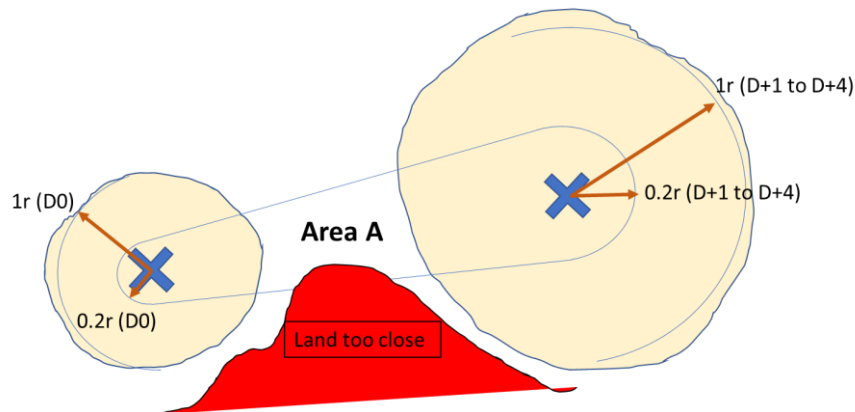
Figure 6: The association of two consecutive observations takes into account the contamination by land in the trajectory: if the land is inside the defined area A, the tracking is stopped

After this tracking, a filter is applied to remove short tracks (shorter than 28 days, i.e. 4 weeks).

3.3. Product Statistical analysis

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/statistical_analysis_aviso_eddy_dataset.pdf

4. Description of the product

4.1. Product general content and specifications

All results of eddy tracking are stored in one unique NetCDF file.

Another file will enable users that have downloaded the complete time series previously to only download the update. Note that eddy track numbering will be kept homogeneous with each update of the eddy dataset.

The detection and tracking are applied over the whole period indicated in the file name, covering from 0 to 360°E, and -82.5 to 82.5°N.

This product is a delayed time product, updated approximately annually.

4.2. Nomenclature of files

eddy_trajectory_1.0exp_%Y%m%d_%Y%m%d.nc   includes the whole time series of the data processed

eddy_trajectory_1.0exp_update_%Y%m%d_%Y%m%d.nc   includes the eddy tracks for which at least one detection was made during the period of the update (note that if the eddy was detected previously, the full track will be included from its beginning)

eddy_trajectory_2.0exp_%Y%m%d_%Y%m%d.nc   includes the whole time series of the data processed for the version 2.0exp

eddy_trajectory_2.0exp_update_%Y%m%d_%Y%m%d.nc   includes the eddy tracks for which at least one detection was made during the period of the update (note that if the eddy was detected previously, the full track will be included from its beginning) for the version 2.0exp

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.

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- 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 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
eddy_trajectory_2.0exp_%Y%m%d_%Y%m%d.nc				
NetCDF-CF				
Dimension: Obs=25871877				
amplitude	magnitude of the height difference between the extremum of SLA within the eddy and the SLA around the contour defining the eddy perimeter		(Obs)	cm
cyclonic_type	flow orientation of eddies -1 is Cyclonic and 1 is Anticyclonic		(Obs)	1
latitude	observation latitude	latitude	(Obs)	Degrees_north
longitude	observation longitude	longitude	(Obs)	Degrees_east
observation_number	observation sequence number, days from eddy start		(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 L		(Obs)	cm/s
speed_radius	radius of a circle whose area is equal to that enclosed by the contour of maximum circum-average speed		(Obs)	km
time	days since 1950-01-01 00:00:00 UTC	time	(Obs)	Days
track	eddy 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

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 .

Appendix A - Product header

```
dimensions:
    obs = 25871877 ;
variables:
    float amplitude(obs) ;
        amplitude:Longname = "amplitude" ;
        amplitude:description = "magnitude of the height difference between the extremum of SLA within the eddy
and the SLA around the contour defining the eddy perimeter" ;
        amplitude:units = "cm" ;
        amplitude:min = 1.f ;
        amplitude:max = 48.6011f ;
    byte cyclonic_type(obs) ;
        cyclonic_type:Longname = "flow orientation" ;
        cyclonic_type:description = "cyclonic -1; anti-cyclonic +1" ;
        cyclonic_type:units = "1" ;
        cyclonic_type:min = -1b ;
        cyclonic_type:max = 1b ;
    float latitude(obs) ;
        latitude:Longname = "latitude of measurement" ;
        latitude:description = "observation latitude" ;
        latitude:standard_name = "latitude" ;
        latitude:units = "degrees_north" ;
        latitude:min = -77.3222f ;
        latitude:max = 79.7773f ;
    float longitude(obs) ;
        longitude:Longname = "longitude of measurement" ;
        longitude:description = "observation longitude" ;
        longitude:standard_name = "longitude" ;
        longitude:units = "degrees_east" ;
        longitude:min = 0.f ;
        longitude:max = 359.9994f ;
    ushort observation_number(obs) ;
        observation_number:Longname = "observation_number" ;
        observation_number:description = "observation sequence number, days from eddy start" ;
        observation_number:units = "ordinal" ;
        observation_number:min = 0US ;
        observation_number:max = 1848US ;
    byte observed_flag(obs) ;
        observed_flag:Longname = "observed value flag" ;
        observed_flag:description = "observed 0; interpolated +1" ;
        observed_flag:units = "1" ;
        observed_flag:min = 0b ;
        observed_flag:max = 1b ;
    float speed_average(obs) ;
        speed_average:Longname = "maximum circum-averaged speed" ;
        speed_average:description = "average speed of the contour defining the speed radius" ;
        speed_average:units = "cm/s" ;
        speed_average:min = 1.01865f ;
        speed_average:max = 308.764f ;
    ushort speed_radius(obs) ;
        speed_radius:Longname = "radius_scale" ;
        speed_radius:description = "radius of a circle whose area is equal to that enclosed by the contour of
maximum circum-average speed" ;
        speed_radius:units = "km" ;
        speed_radius:min = 7US ;
        speed_radius:max = 403US ;
    int time(obs) ;
        time:Longname = "Time" ;
        time:axis = "T" ;
        time:calendar = "julian" ;
        time:standard_name = "time" ;
```

```
        time:units = "days since 1950-01-01 00:00:00 UTC" ;
        time:min = 15706 ;
        time:max = 24854 ;
    uint track(obs) ;
        track:Longname = "track_number" ;
        track:description = "eddy identification number" ;
        track:units = "ordinal" ;
        track:min = 0U ;
        track:max = 352416U ;

// global attributes:
        :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
        :title = "Mesoscale Eddies in Altimeter Observations of SLA" ;
        :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 eddy atlas from two-satellite AVISO maps over global ocean" ;
        :comment = "Surface product; mesoscale eddies" ;
        :input_product_reference = "https://www.aviso.altimetry.fr/en/data/product-information/updates-and-
reprocessing/ssaltoduacs-delayed-time-reprocessing.html" ;
        :date_created = "2018-09-19T15:34:04Z" ;
        :time_coverage_duration = "P9148D" ;
        :time_coverage_start = "1993-01-01T00:00:00Z" ;
        :time_coverage_end = "2018-01-18T00:00:00Z" ;
        :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention Standard Name
Table v37" ;
        :product_version = "2.0.exp" ;
```

SALP

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