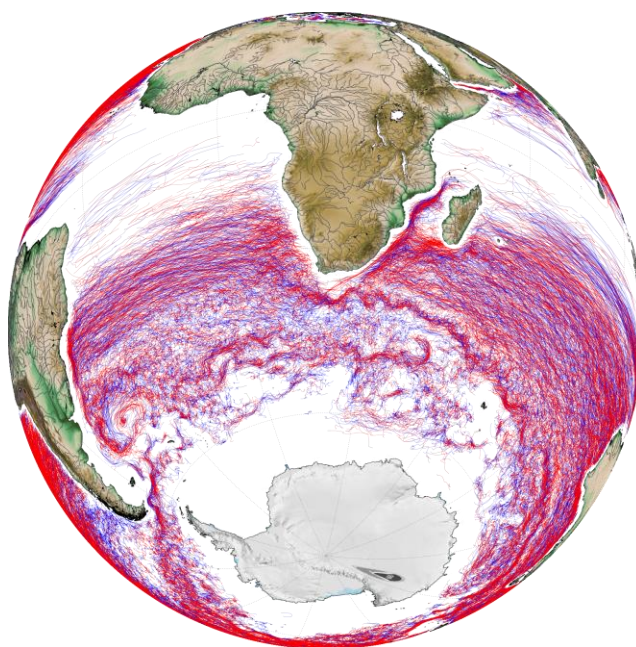




Mesoscale Eddy Trajectory Atlas Product Handbook



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Chronology Issues:

Issue:	Date:	Reason for change:
1.0	2017/06/29	1 st issue

D : page deleted

I : page inserted

M : page modified

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
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)

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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](https://doi.org/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

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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 1.0 of this product (versioning for AVISO+-distributed product), released in May 2016. 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. The AVISO+ Eddy Atlas in a few words

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).

Some upgrades have been added to the algorithm previously used (e.g. upgrades from the Version 4 eddy dataset, 2014). Previous versions of the eddy datasets were based on weekly

sampling of the DUACS SLA fields. Changing to daily sampling for Version 4 resulted in occasional very large jumps in eddy locations using the original algorithm. The reason for the problem has been identified and an improved version of the eddy identification and tracking procedure has been developed in collaboration between D. Chelton and CLS/DUACS.

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, originally distributed by AVISO+ Note that from July 2017 this product will be distributed by the Copernicus Climate Change Service (C3S <http://climate.copernicus.eu/>). 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 and in section 3.3. 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.

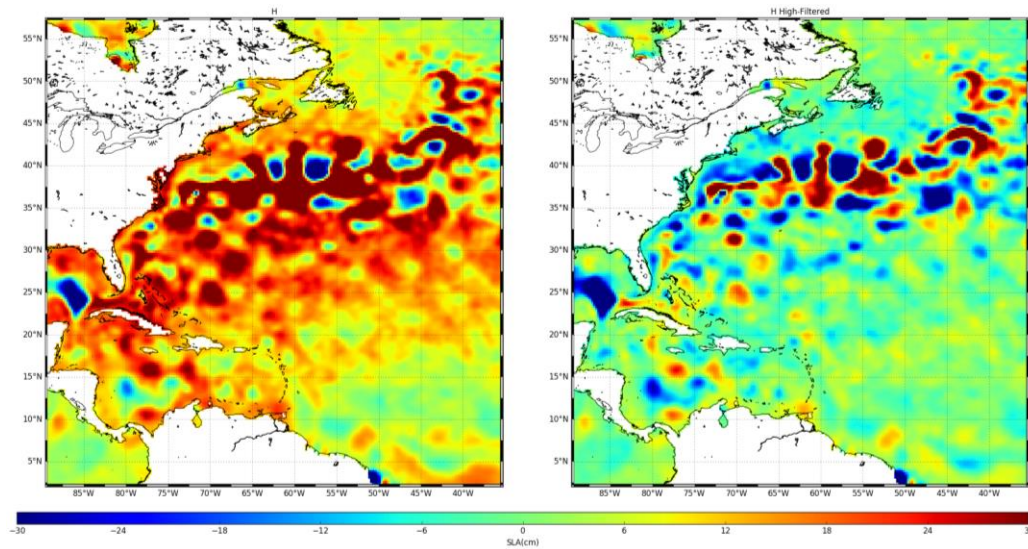


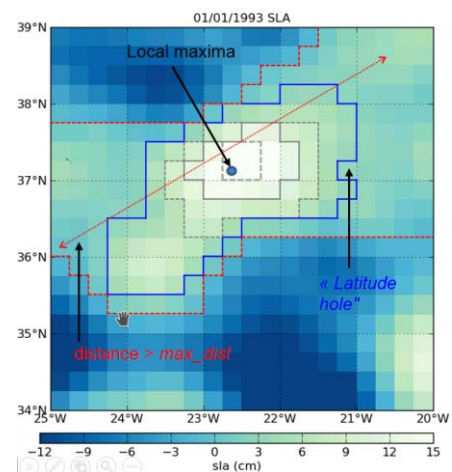
Figure 1: Left, initial sea level anomaly product. Right, the high-filtered version used for the eddy detection.

3.2.2. Detection

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.

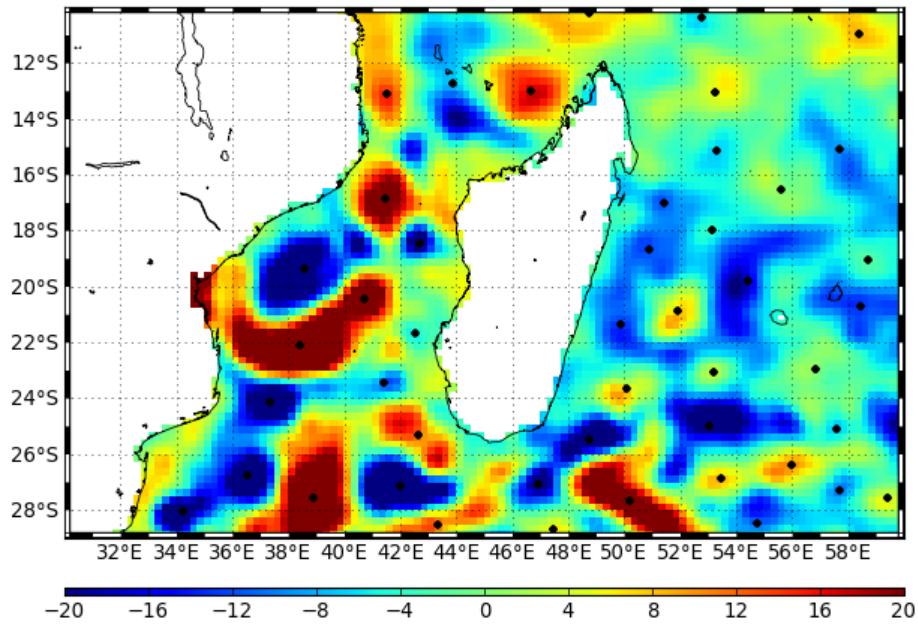


Figure 2: Eddy detections: black dots are eddies observation centers

3.2.3. Estimation of eddy characterization

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

- Amplitude = $|\text{sla}(\text{max_local}) - \text{mean}(\text{sla}(\text{edge_pix}))|$
- 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

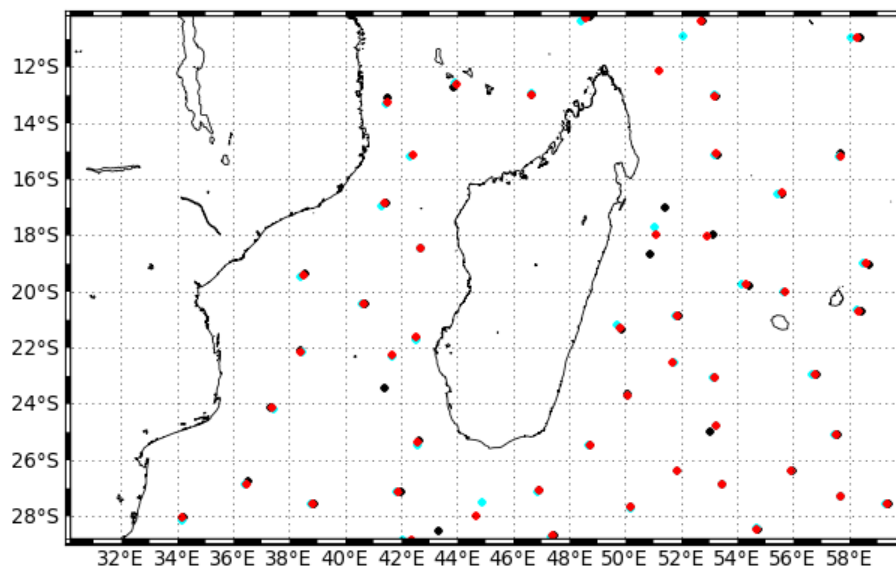
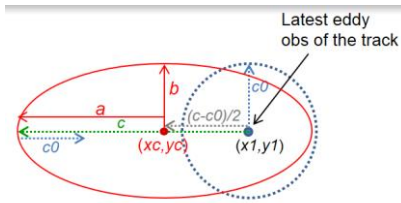


Figure 3: Eddy tracking; each color corresponds to a different day



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, we build an ellipse that encompasses an area to find likely linked observations. If several observations are found within this ellipse, 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.

Each equation is computed in degrees.

Ellipse features use the following:

- $b=c0 = 1.05$ degrees
- $c = f(\text{lat})$:
 - o $\text{abs}(\text{lat}) > 23$, $c = c0$
 - o $\text{abs}(\text{lat}) < 5$, $c = c_{\text{max}} = 1.55$ degrees
 - o $5 < \text{abs}(\text{lat}) < 23$, $c = (\text{abs}(\text{lat}) - 23) * (c_{\text{max}} - c0) / 18 + c0$

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

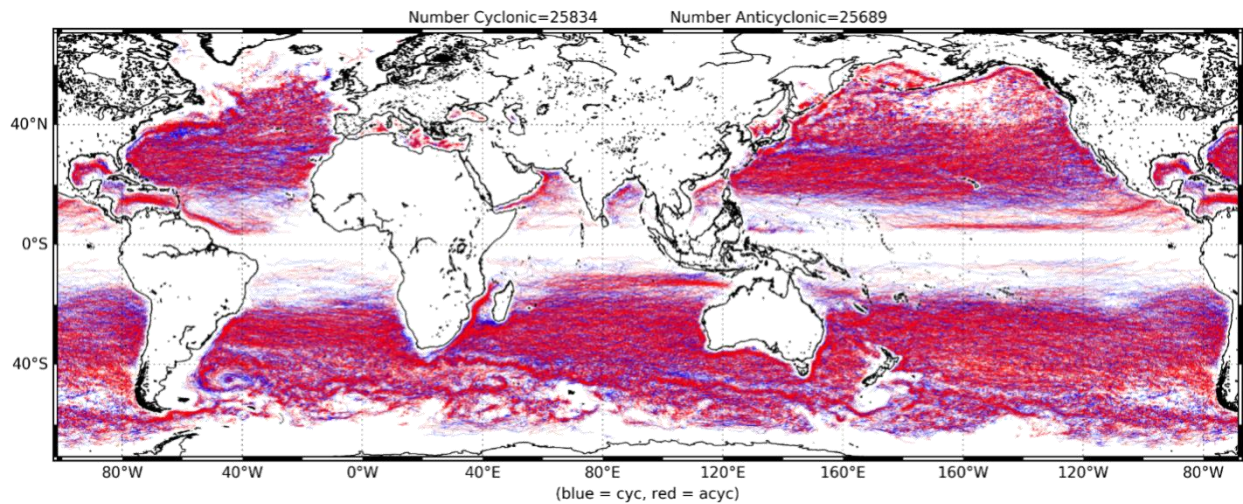


Figure 4: All tracks longer than 16 weeks for the whole available period

3.3. Algorithm changes

3.3.1. Version 1.0

This chapter describes the algorithm improvements of this new version with respect to previous datasets [Chelton et al., 2016].

3.3.1.1. Jumps

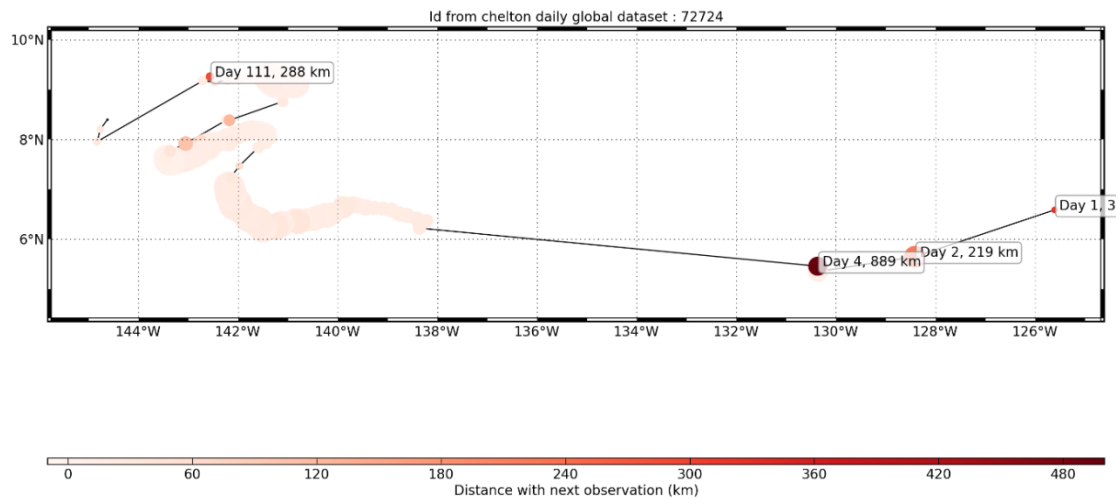


Figure 5: an example of a track with a gap in the version 4 OSU dataset.

In the last eddy dataset generated by OSU (referred to on the OSU website as “version 4”), the tracking process sometimes linked two observations obviously unrelated in view of the distance between them, and also of the incoherence with previous and following eddy movements. There are thus sometimes big distances between two consecutive observations. To reduce this behavior, we modified the ellipse to be smaller, commensurate with the daily sampling rather than weekly sampling in the earlier versions of the SLA datasets.

3.3.1.2. Drake Passage

In the last eddy dataset generated by OSU, no eddy trajectory could cross Drake Passage between South America and Antarctica. We modified the detection process to be able to accurately identify eddies in this area, and also the tracking routine, to be able to link observations on both sides of this Passage, thus allowing eddy trajectories to span between the Pacific and Atlantic.

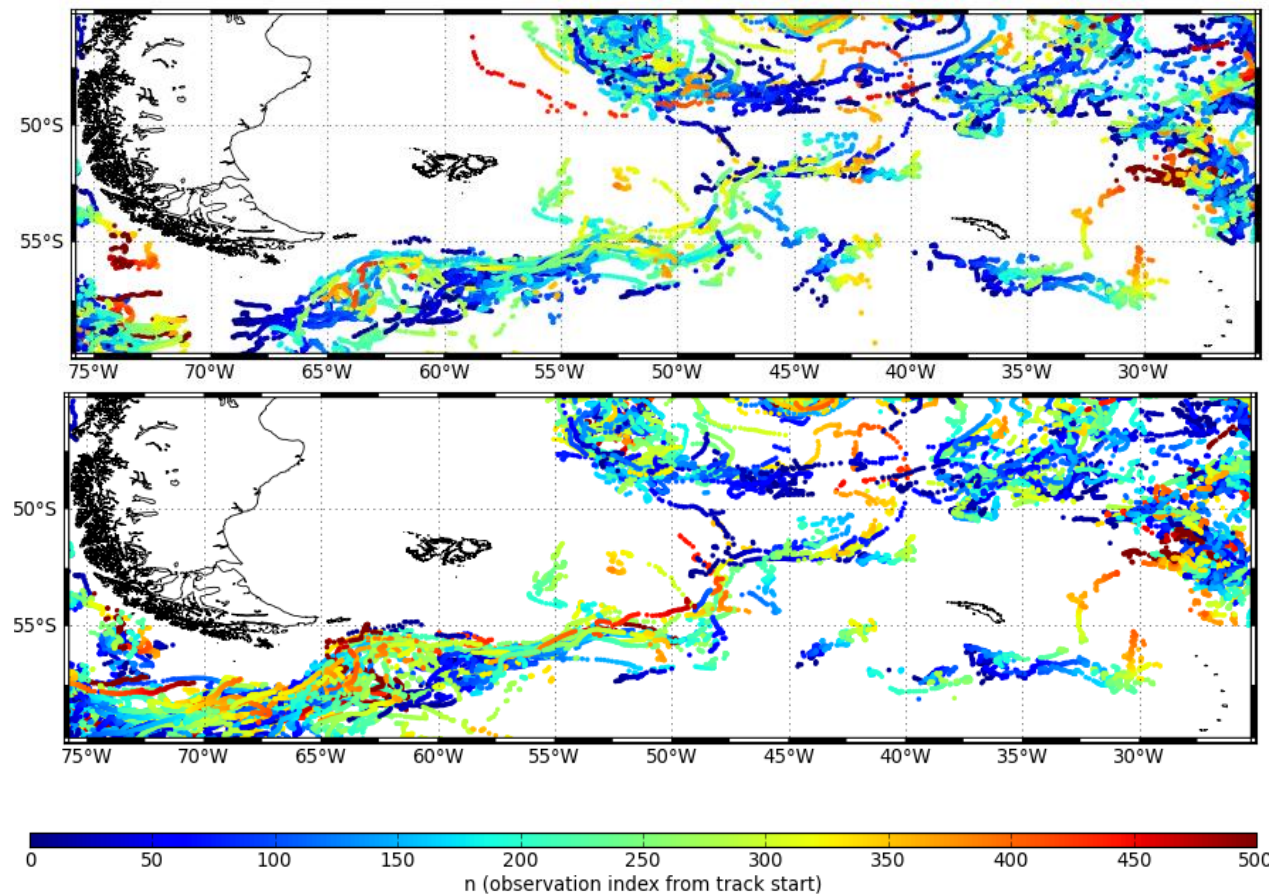


Figure 6: Eddy tracks around Drake Passage: top, 2014 version 4 eddy dataset generated by OSU; bottom, the current version. Where no eddy went through at 70°W, eddies are now more realistically crossing this longitude.

3.4. 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 AVISO+ from 2014:

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_%Y%m%d_%Y%m%d.nc includes the whole time series of the data processed

eddy_trajectory_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)

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 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_%Y%m%d_%Y%m%d.nc or eddy_trajectory_update_%Y%m%d_%Y%m%d.nc				
NetCDF-CF				
Dimension: Obs=22813018				
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
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 by contacting aviso@cls.fr

5.2. Access Services

The data access on the FTP server is authenticated on <ftp://ftp.aviso.altimetry.fr/>

Note that once your registration is processed (see above), AVISO+ will send you your own access (login/password) by e-mail as soon as possible (within 5 working days during working hours, Central European Time). If you don't enter your login/password, you will only be able to access to the anonymous FTP, where you will not find the data you're interested in.

Appendix A - Example of product header

```
netcdf aviso_atlas_19930101_20160925 {
dimensions:
    obs = 22813018 ;
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 = 48.362f ;
    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 = -76.9413f ;
        latitude:max = 79.6733f ;
    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 = 359.999f ;
    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 = 2196US ;
    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 = 1.1904f ;
        speed_average:max = 240.102f ;
    float 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 = 8.8154f ;
        speed_radius:max = 438.23f ;
    uint 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 = 15706U ;
time:max = 24374U ;
uint track(obs) ;
track:Longname = "track_number" ;
track:description = "eddy identification number" ;
track:units = "ordinal" ;
track:min = 0U ;
track:max = 268760U ;

// 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 = "2017-05-18T17:42:25Z" ;
:time_coverage_duration = "P8668D" ;
:time_coverage_start = "1993-01-01T00:00:00Z" ;
:time_coverage_end = "2016-09-25T00:00:00Z" ;
:standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention
Standard Name Table v37" ;
:product_version = "1.0" ;

```