Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters Product Handbook

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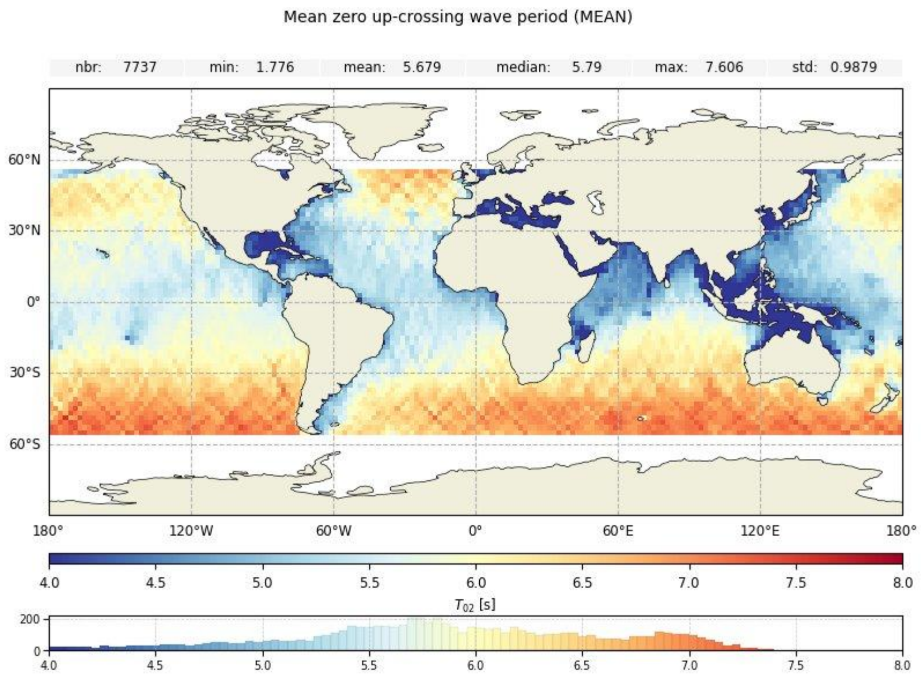

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List of Acronyms

Aviso+	Archiving, Validation and Interpretation of Satellite Oceanographic data
CLS	Collecte, Localisation, Satellites
CNES	Centre National d'Etudes Spatiales
DDA	Delay Doppler Altimetry
HR	High Resolution
L1B	Level-1B product
L2	Level-2 product
L2P	Level-2+ product
LR	Low Resolution
PDAP	Payload Data Acquisition and Processing
PTR	Point Target Response
SAR	Synthetic Aperture Radar
SPP	Sentinel Processing Prototype
SSH	Sea Surface Height
STC	Short-Time Critical
SWH	Significant Wave Height

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1 Introduction

Operational altimetry processing traditionally relies on a “frozen sea” assumption, neglecting the influence of ocean dynamics on Doppler frequencies and introducing biases in estimated sea-state parameters. The Sentinel-6 Deplay-Doppler retracking 5 parameters product is based on an advanced SAR (Delay-Doppler) processing approach that overcomes this limitation by explicitly accounting for ocean surface dynamics. Besides the standard variables—Sea Surface Height (SSH), backscatter coefficient (σ_0), and Significant Wave Height (SWH)—this retracker also enables the estimation of:

- the **wave vertical velocity dispersion** $\boldsymbol{\sigma_v}$, from which the **mean up-crossing wave period** $\boldsymbol{T_{02}}$ can be derived.
- the **projected geophysical doppler** $\boldsymbol{u_x}$;

The dataset presented here covers cycles 42 to 60 (January-June 2022) and cycles 116 to 134 (January-June 2024). It constitutes a demonstration product designed for the scientific community, showcasing the potential of advanced SAR retracking techniques. It delivers enhanced-resolution altimetry measurements together with improved SSH and SWH estimates, wave-period-related diagnostics derived from vertical velocity, and geophysical Doppler information. These features open new perspectives for coastal ocean applications, surface current studies, and swell characterization.

EUMETSAT is responsible for the Sentinel-6 operations and oversees broadcasting the Sentinel-6 products. The following demonstration product (L2P skewness) is built by CLS and CNES from official Sentinel-6 products and is available on the CNES Aviso+ web site thanks to a CNES/CLS cooperation and CNES funding.

Dedicated to users unfamiliar with the mission, L2P products are added value products giving access to the largest community of users, including model assimilation actors etc and is provided by CNES/CLS cooperation.

The purpose of this document is to describe briefly the Sentinel-6 Delay-Doppler retracking 5 parameters product and the process employed to obtain them.

After a short overview of the processing steps complete information about user products is provided, giving nomenclature, format description, and software routines.

1.1 Data Policy and conditions of use

The use of the Sentinel-6 Delay-Doppler retracking 5 parameters product (DOI: 10.24400/527896/AVISO-2026.008) is described in the AVISO+ License Agreement.

2 Overview of the Sentinel-6 mission

Sentinel-6 is a collaborative Copernicus mission, implemented and co-founded by the European Commission, ESA, EUMETSAT and the USA through NASA and NOAA. EUMETSAT is responsible for the Sentinel-6 operations as part of the Copernicus component of the EU Space Program Sentinel-6 MF satellite was successfully launched on the 21th of November 2020. On November 30th, its Poseidon-4 altimeter was switched on, and since December 17th 2020, Sentinel-6 MF is on its operational orbit to continue the long term climate data record on the primary TOPEX, Jason-1, Jason-2 and Jason-3 ground track. By succeeding to TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 on their primary ground track, Sentinel-6 MF has extended the high-precision ocean altimetry data record. Its onboard altimeter (POS4) operates simultaneously in two acquisition modes in a so-called interleaved mode (see below).

During Sentinel-6 MF tandem phase with Jason-3 (2020/12/17 to 2022/04/07), both satellites were on the same ground-track (with only 30 seconds delay), which was a unique opportunity to precisely assess parameter discrepancies between both missions and detect geographically correlated biases, jumps or drifts. Thanks to this tandem phase, Sentinel-6 MF has been precisely calibrated leading to a seamless transition between Jason-3 and Sentinel-6 MF LR as reference mission in the DUACS system.

2.1 Sentinel-6 tracking and acquisition mode

Sentinel-6 MF altimeter, Poseidon-4, always operates in interleaved mode, which enables simultaneous measurements in:

• Low Resolution Mode, hereafter "LR", which is the historical mode used by previous altimeters in the Topex/Jason satellites. Please note that while Topex/Jason altimeters were acquiring data with a 2kHz PRF, Sentinel-6 LR mode uses a 9kHz PRF.

• High Resolution Mode, hereafter "HR", commonly called Synthetic Aperture Radar (SAR) or Delay Doppler Altimetry (DDA), already used on Cryosat-2 and on the Sentinel-3 satellites

2.2 Orbits, Passes and Repeat cycle

'Orbit' is one revolution around the Earth by the satellite.

'Repeat Cycle' is the time period that elapses until the satellite flies over the same location again.

For Sentinel-6:

- The orbit is circular with an orbital period of 112 min and 26 s;
- The inclinaison is 66 deg;

- The passes are numbered from 1 to 254 representing a full ‘repeat cycle’ for the repetitive orbit;
- The repeat cycle is 10 days, meaning that the same path is covered every 10 days.

The localisation of orbits (for realised and extrapolated cycles) can be found on the AVISO+ web site:

https://www.aviso.altimetry.fr/en/data/tools/pass-locator.html

3 Description of the processing

For the Level 1B (L1B) and Level 2 (L2) processing, we make use of the Sentinel Processing Prototype (SPP) [2].

3.1 Level 1B: Unfocused-SAR (UFSAR) processing

We retrieve the Level 1A Short-Time Critical (STC) data from EUMETSAT, and then mostly follow the approach of the Payload Data Acquisition and Processing (PDAP) component of the Sentinel-6 ground segment by processing Level-1A data with an UFSAR approximate beam steering algorithm. However, a few changes are made to enable the retracking of the ocean dynamics, in particular:

- The number of Doppler looks is increased to 448 instead of 322, which corresponds to a longer illumination time (3.2 s instead of 2.3 s). To avoid the Doppler aliasing due to the low pulse repetition frequency (PRF), we mask the range gates impacted by the replicas in the higher frequencies (see Figure 1);

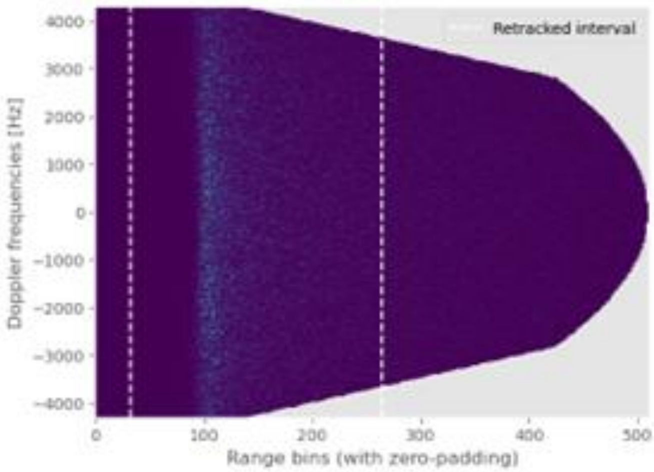


Figure 1: Example of 2-dimensional stack after the UFSAR L1B processing. Range gates at the extreme Doppler frequencies have been masked to prevent Doppler aliasing

- We kept the entire 2D stack instead of summing the Doppler looks to obtain the 1D multilooked waveform, as prescribed in [3].

3.2 Level 2: Numerical 5-parameter retracking of the stack

We retrack the L1B 2D stack with a model computed using a numerical Point Target Response (PTR) [1] as well as five parameters:

- Sea Surface Height (SSH);
- Radiometry σ_0 ;
- Significant Wave Height (SWH);
- Wave vertical velocity dispersion σ_v [3] (see Figure 3);
- Projected geophysical Doppler u_x [4, 5] (see Figure 5).

Figure 2 shows the impact of the new parameters on a theoretical stack. To increase the speed computation, we retrack only 192 looks, that we build by averaging the 2—3 closest looks (i.e. the so-called beam sampling factor is set to 3). The skewness is set to 0.1 and the mean square slope to infinity.

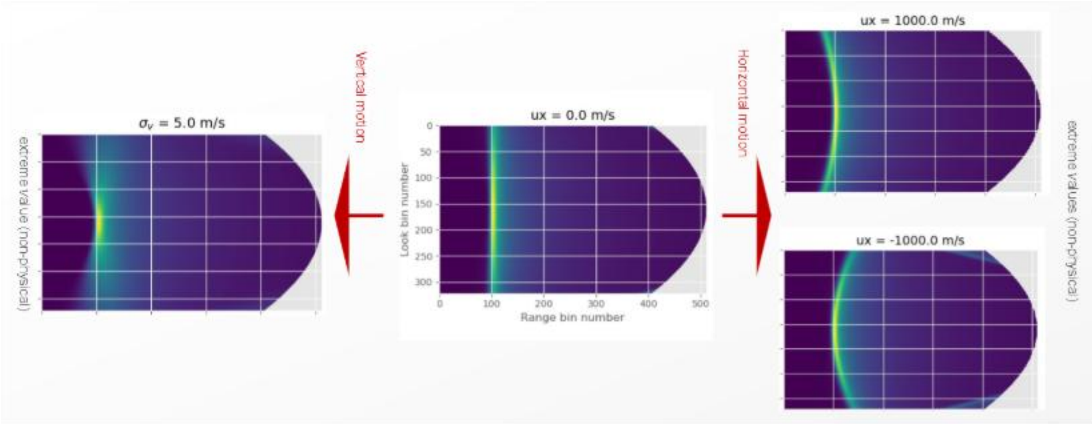


Figure 2: Impact of the new variables on a theoretical stack with 322 looks and zero-padding of 2 The values of the new parameters are typically much smaller, high non-physical values are used so that their effect can be grasped with the naked eye.

3.3 Post-processing: Computing the variables of interest

We edited the variables with the following prescriptions:

- -55 < latitude < 55 [deg] ;
- 0 < SWH < 20 [m] ;
- -130 < SSH < 100 [m] ;
- 0 < σ_v < 2 [m/s] ;
- -60 < u_x < 60 [m/s].

Moreover, we computed new variables:

- We corrected the wave vertical velocity dispersion to account for the velocity-slope correlation, using the iterative approach introduced in Section 5.3 of [3].

- We computed the mean up-crossing wave period from the SWH and the wave vertical velocity dispersion using their theoretical relation: $T_{02} = \frac{\pi}{2}\frac{SWH}{\sigma_v}$.

- We interpolated the ERA5 wave model to compute the wind velocity in the eastern and northern directions (u10 and v10).

- We interpolated the PDAP 20 Hz L2 LRM product to compute the altitude from the precise orbit ephemeris (POE) and the three parameters from the numerical retracker: SSH, SWH and σ0.

4 Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters product

4.1 Temporal availability

Sentinel-6 Delay-Doppler retracking 5 parameters product cover cycles 42 to 60 (January to June 2022) and cycles 116 to 134 (January to June 2024).

4.2 Product content

Figure 3 and Figure 5 provide an overall view of the along-track variables σ_v and u_x available in the product, computed over one complete data cycle. Figure 4 and Figure 6 present the same quantities after spatial averaging onto a 4°×4° latitude-longitude grid, also computed over a full cycle.

These averaged maps facilitate the visualization of the large-scale spatial patterns and regional variability of the retrieved parameters. As illustrated in Figure 6, the projected geophysical Doppler velocity u_x, derived from Sentinel-6 Cycle 45 data at 1 Hz resolution, has a mean value of 2.6 m/s and a standard deviation of 2.5 m/s. Its geographical distribution reveals large-scale patterns that are strongly correlated with the wind field, as will be discussed in the next section.

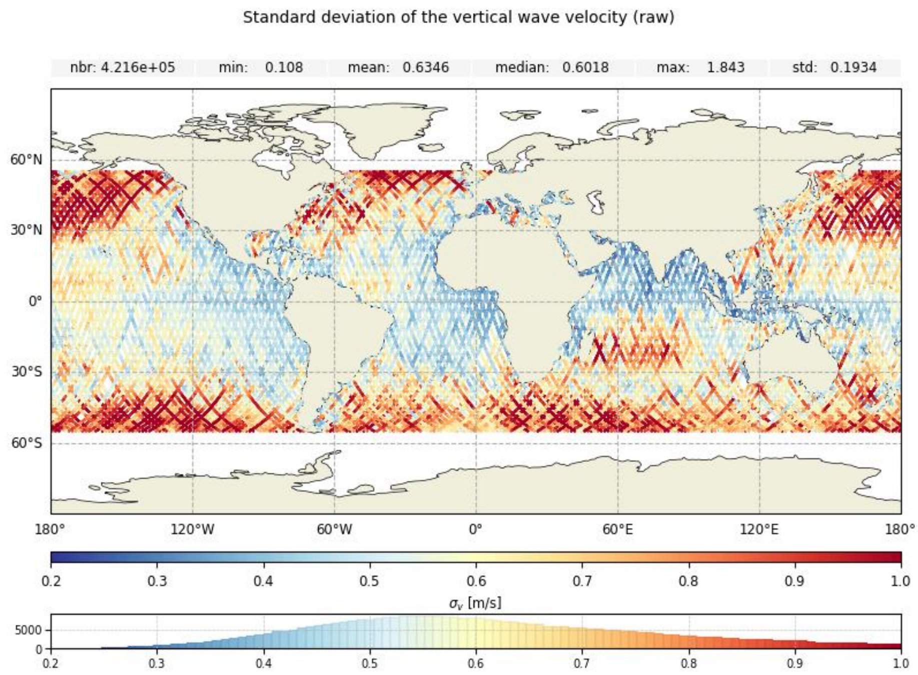


Figure 3: Along-track wave vertical velocity dispersion, σ_v [m/s], calculated from Sentinel-6 Cycle 45 measurements compressed to 1 Hz.

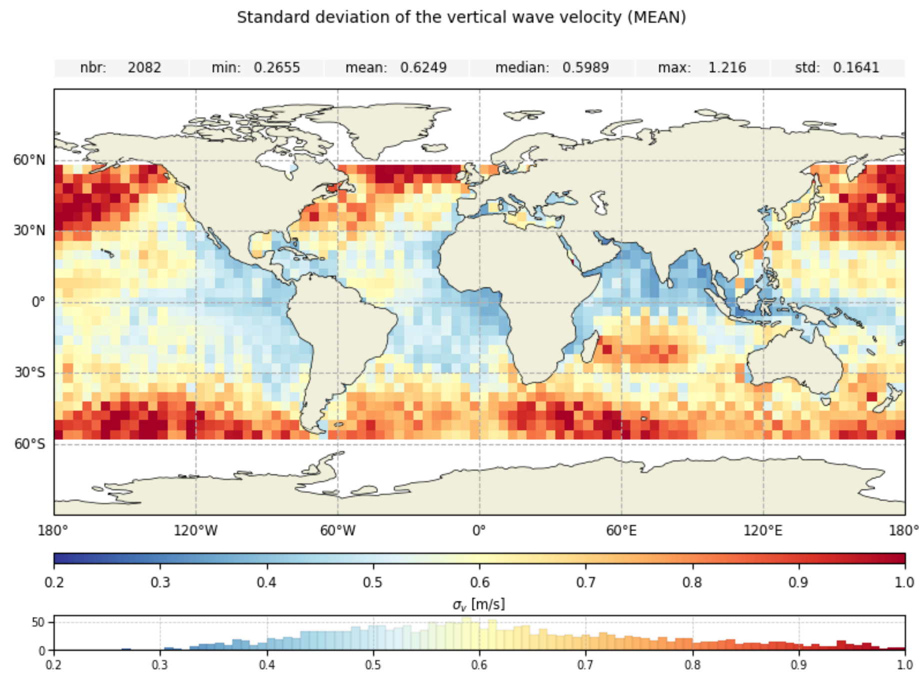


Figure 4: Mean wave vertical velocity dispersion, σ_v [m/s], calculated from Sentinel-6 Cycle 45 measurements compressed to 1 Hz and averaged within 4° × 4° latitude-longitude bins.

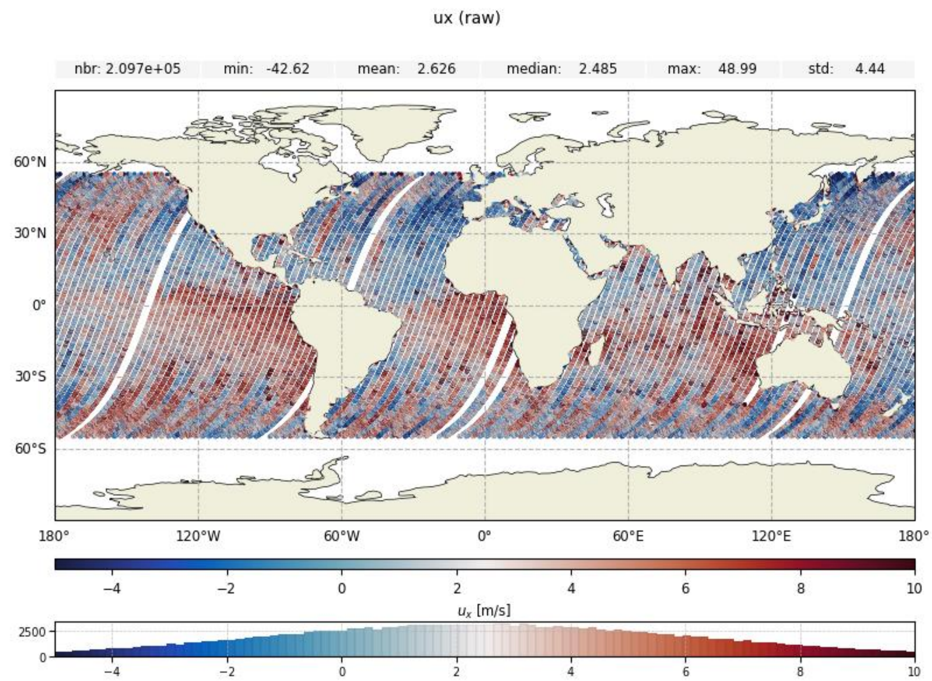


Figure 5: Along-track ascending projected geophysical Doppler velocity, u_x [m/s], calculated from Sentinel-6 Cycle 45 measurements compressed to 1 Hz.

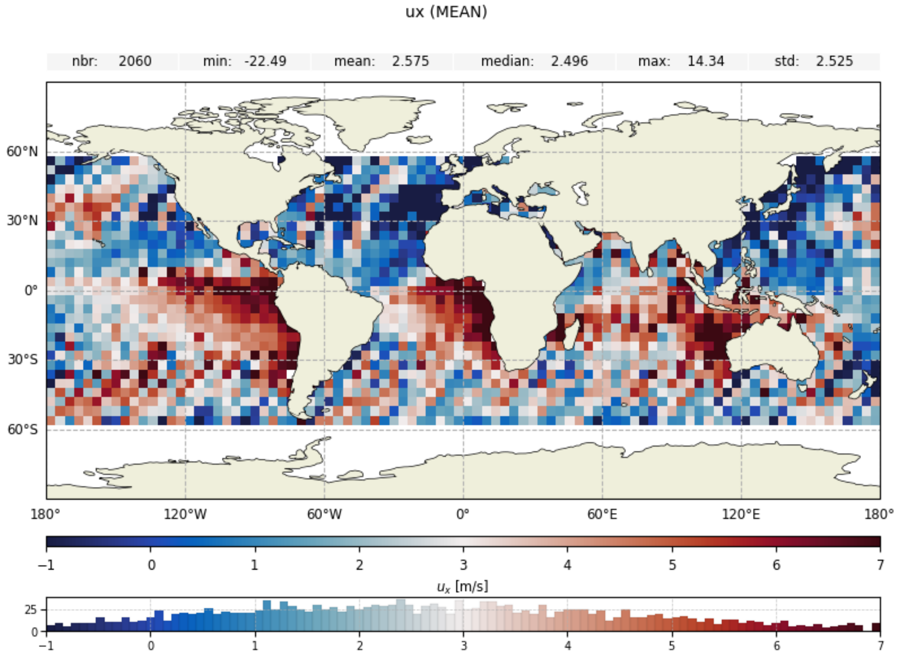


Figure 6: Mean projected geophysical Doppler velocity, u_x [m/s], calculated from Sentinel-6 Cycle 45 measurements compressed to 1 Hz and averaged within 4° × 4° latitude-longitude bins.

4.3 Validation and use

A first validation step was carried out to assess the consistency of the newly retrieved variables—namely the along-track Doppler velocity (u_x), the vertical wave velocity dispersion (σ_v), and the wave period (T_{02}), derived from SWH and σ_v—with their corresponding ERA5 model variables at the global scale. An example of such comparisons, for the variable σ_v, is presented in Figure 7 and Figure 8.

The differences between observations and model outputs may be explained by the occurrence of more extreme σ_v values (both smaller and larger) in the measurements.

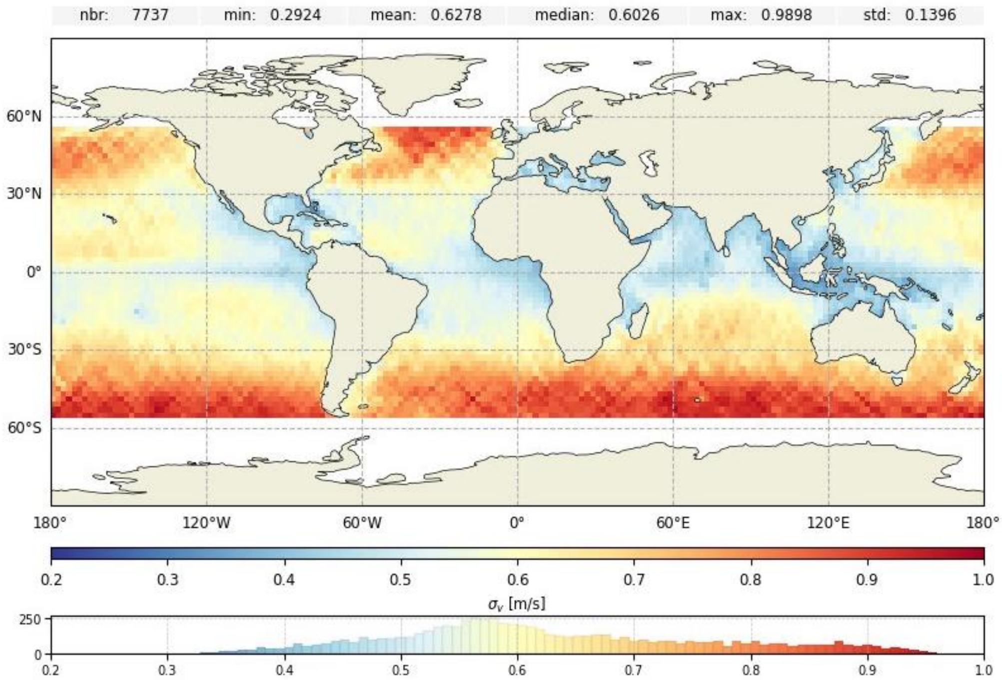


Figure 7: Observed vertical wave velocity dispersion σ_v retrieved from the 5-parameter retracking over multiple Sentinel-6 data cycles between +/-55˚Lat (January to June 2022).

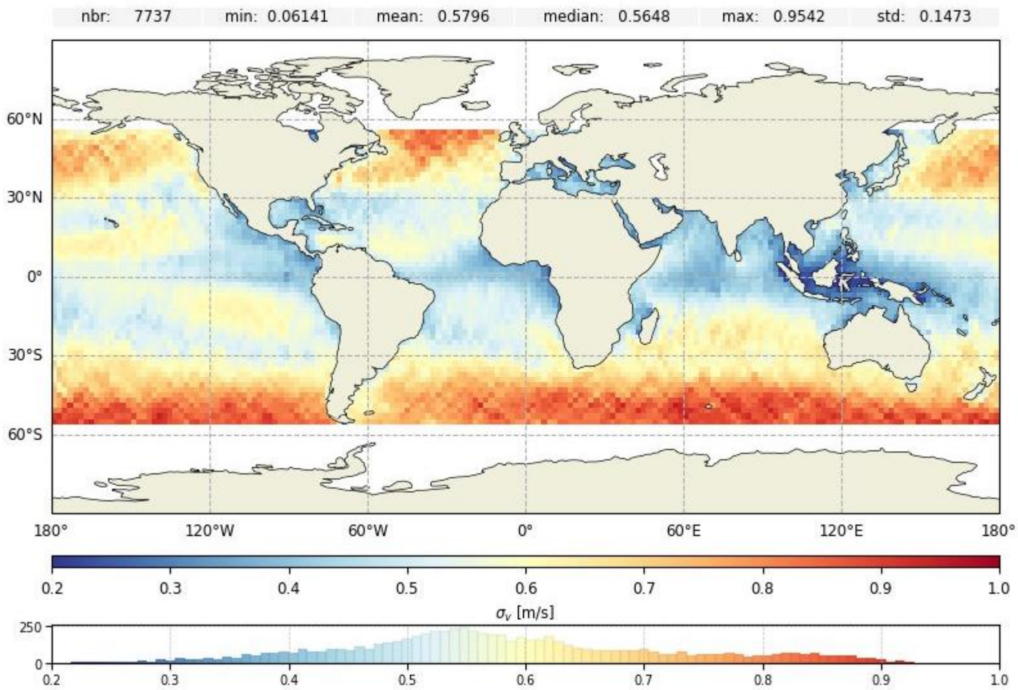
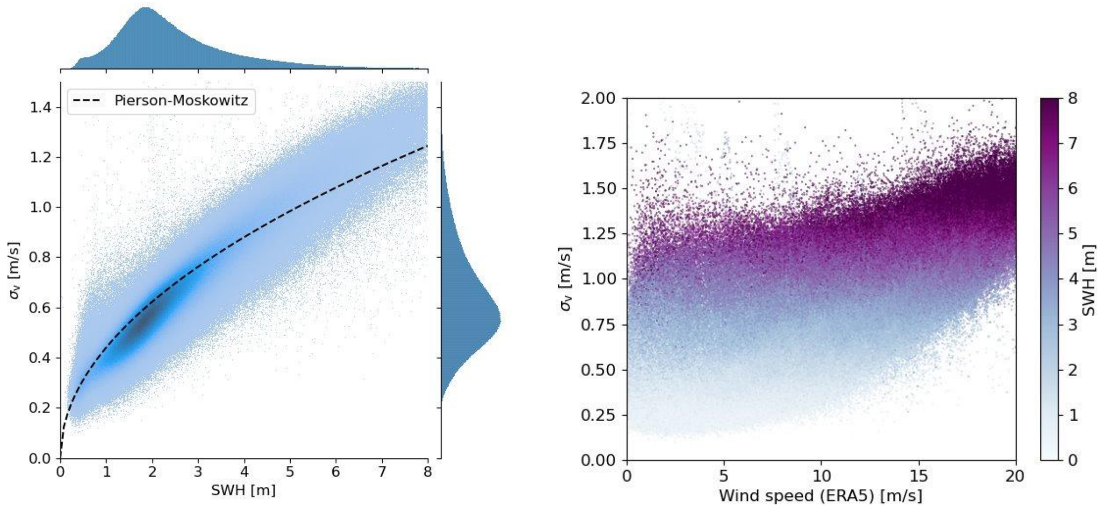


Figure 8: ERA5 model-derived vertical wave velocity dispersion σ_v interpolated over multiple Sentinel-6 data cycles (January to June 2022).

The vertical velocity variance is correlated with both the significant wave height (SWH) and wind speed, as shown in Figure 9. This behavior is broadly consistent with theoretical wave spectrum models for a fully developed sea.



(a) (b)

Figure 9 : correlation between the observed vertical wave velocity dispersion σ_v retrieved from the 5-parameter retracking and the measured significant wave height (a) / the wind speed from ERA5 (b)

T_{02} is an integrated parameter that gives more weight to the higher frequencies of the wave spectrum i.e. wind waves. It is used to estimate the average period of the zero-crossing waves in sea state. Figure 10 presents the global distribution of the mean zero up-crossing wave period, derived from six months of Sentinel-6 observations.

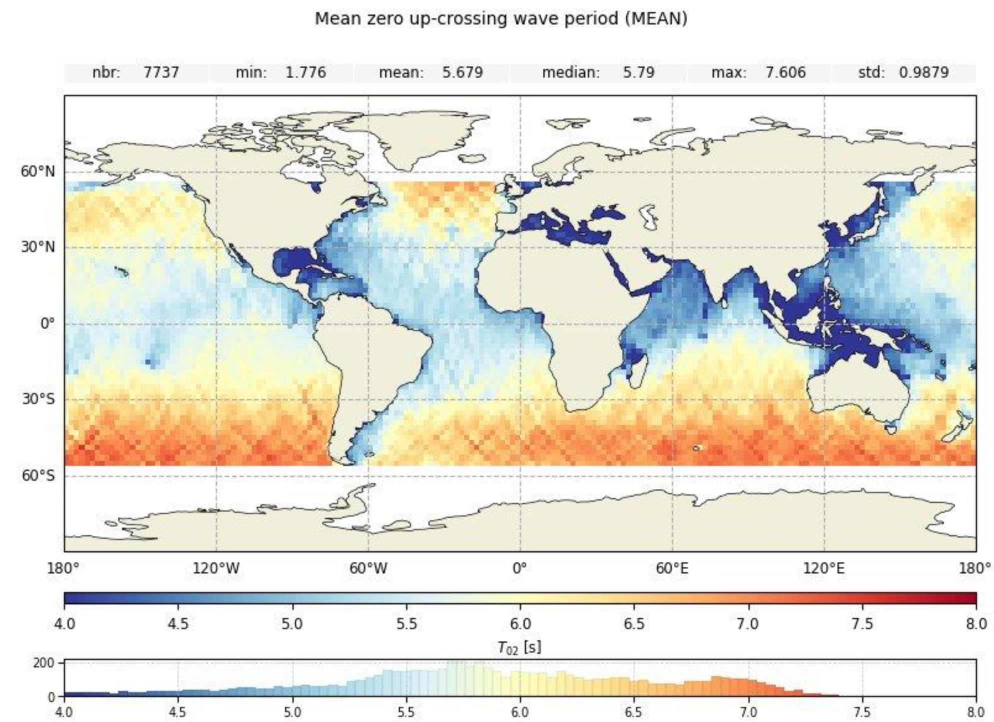
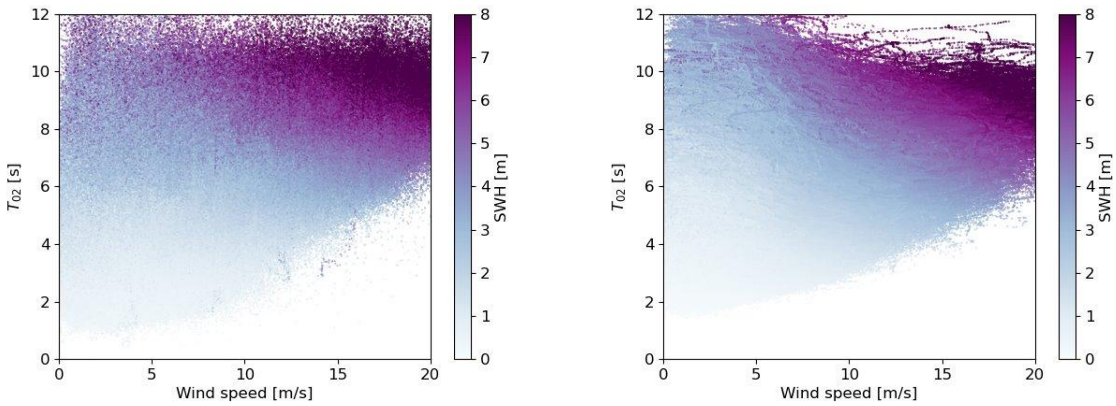


Figure 10: Observed mean zero up-crossing wave period T_{02} retrieved from the 5-parameter retracking over multiple Sentinel-6 data cycles (January to June 2022).

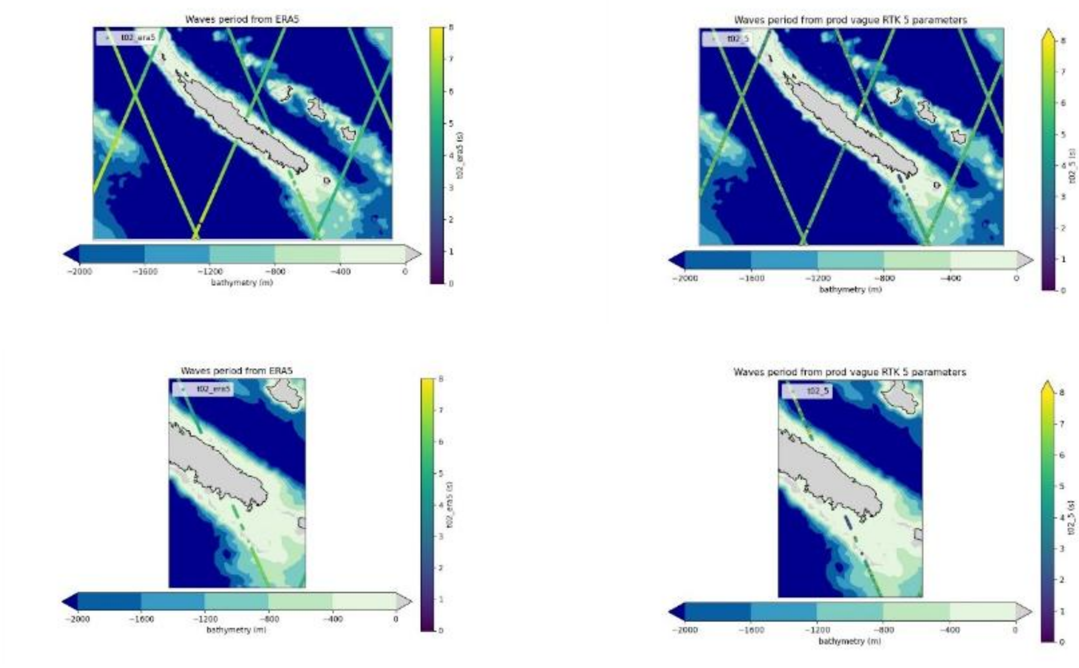


(a) (b)

Figure 11: Distribution of T02 values (in seconds) derived from the 5-parameter retracking (a) and from the ERA5 model (b) as a function of wind speed. The color scale represents significant wave height (SWH).

Figure 11 indicates that the T02 values retrieved from observations can exceed those from ERA5, particularly for wind speeds above 7 m/s. This is likely linked to the higher frequency of extreme σ_v values observed in the measurements than in the ERA5 model.

The high along-track resolution can be used to study coastal areas, extreme events or wave-topography disentanglement.
A regional analysis carried out over the New Caledonia area highlights the added value of the observations. In this region, the measurements provide wave period values that are more consistent with the underlying physical processes than those estimated by the model. As illustrated in Figure 12, and supported by bathymetric information, New Caledonia is surrounded by a lagoon bounded by a coral reef barrier, which significantly alters wave dynamics. This feature is not captured by the ERA5 model through the wave period T_{02}. In contrast, the period derived from SWH and σ_v reveals a clear decrease within the lagoon.



(a) (b)

Figure 12: Comparison between the wave period (T_{02}) from the ERA5 model (a) and that derived from the 5-parameter retracking over the New Caledonia region (b). Bathymetry is also shown to highlight the location of the lagoon.

A sensitivity analysis with respect to wind forcing was conducted on the σ_v parameter by computing power spectra for different ranges of ERA5 wind speed values. The presence of a spectral peak between 10 and 100 km, as shown in Figure 13, indicates a dependence on wind conditions. The removal of low winds area reduces the spectral slope, illustrating the impact of **wind/waves interactions or uncertainty** to be studied with such products.

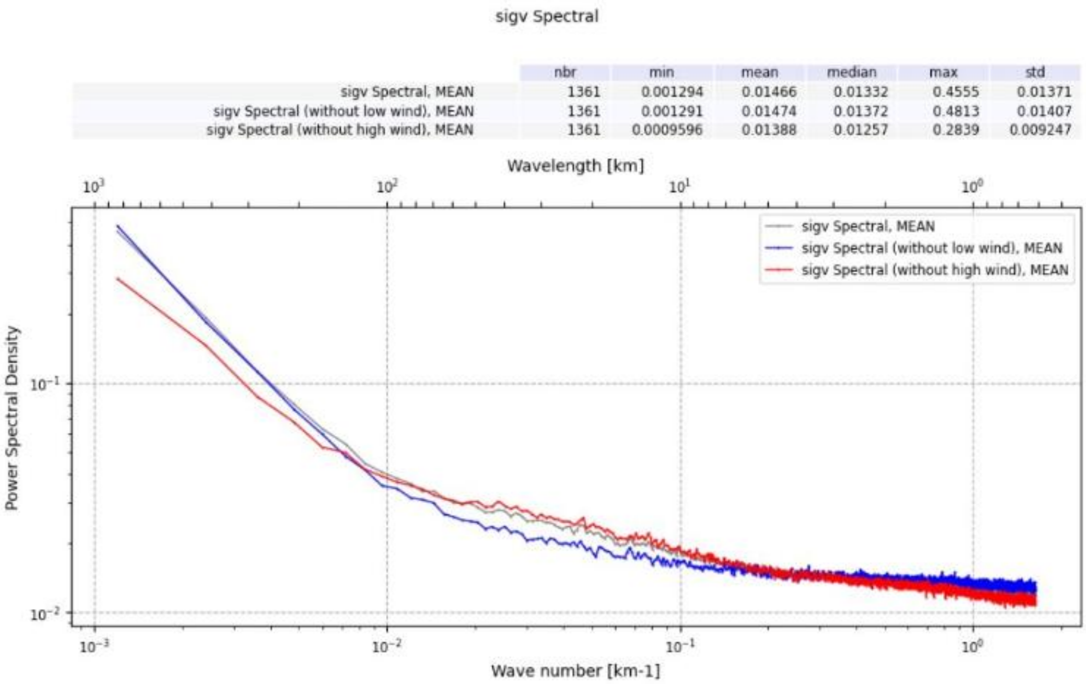


Figure 13: Spectral analysis of σ_v for different ranges of ERA5 wind speed.

Over the New Caledonia region, CFOSAT SWIM data were used to derive a two-dimensional directional spectrum. Figure 14 clearly shows the presence of circumpolar swell and trade-wind-driven wave systems in this area. In connection with the wave period analysis presented for this region, these results confirm the capability of the measurements to capture the local wave dynamics.

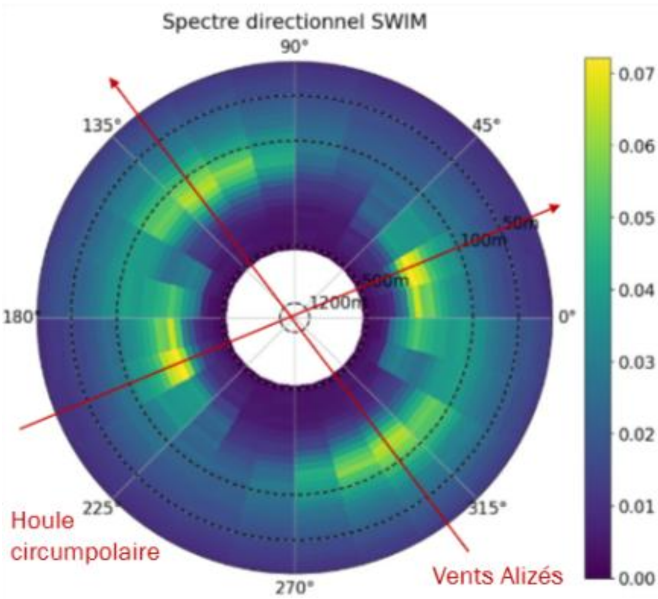
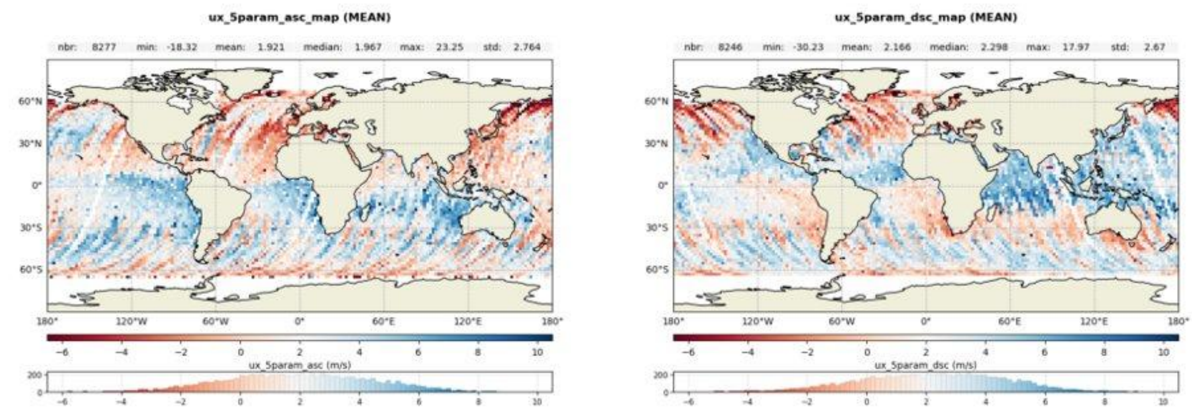


Figure 14: Two-dimensional directional spectrum from CFOSAT SWIM over the New Caledonia region.

The parameter u_x, representing the along-track surface velocity, was also plotted as a 6-month average derived from retracking data for ascending and descending passes (see Figure 15). It was subsequently analyzed in relation to ERA5 wind speed (Figure 16) and wind direction (Figure 17). These comparisons show promising potential for retrieving wind direction.



(a) (b)

Figure 15: Effective along-track surface velocity u_x retrieved from ascending (a) and descending (b) passes computed over 6 months (January-June 2026)

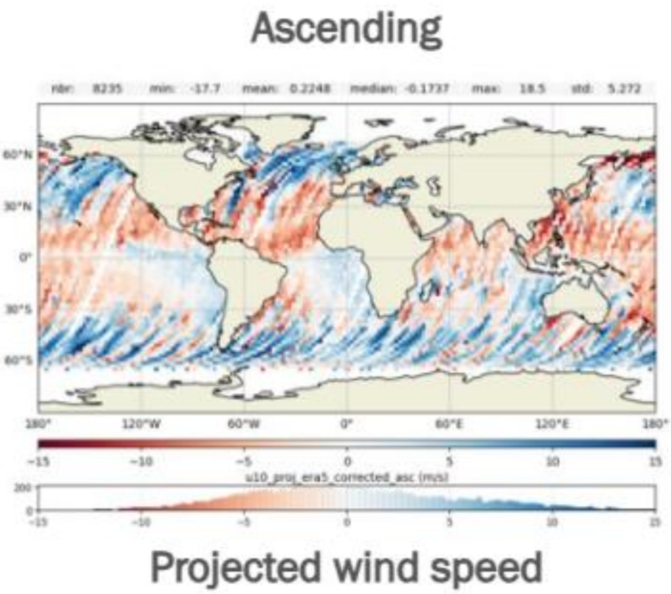


Figure 16: Projected wind speed from ERA5 model retrieved from ascending passes computed over 6 months (January-June 2026)

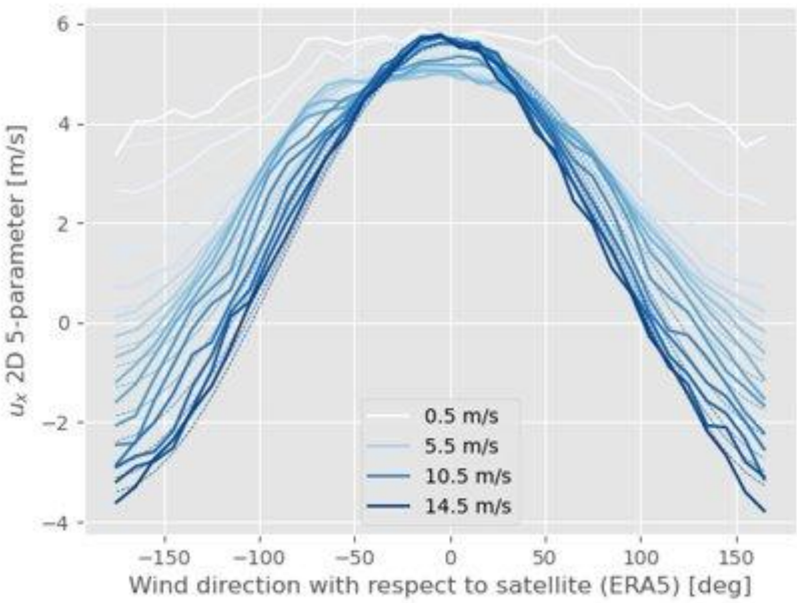


Figure 17: Dependence of retrieved along-track surface velocity u_x on ERA5 wind direction, shown for multiple wind speed bins

4.4 Nomenclature

Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters filenames are named under the following convention:

S6A_<cycle_number>_<pass_number>_l2p_ddoppler_rtk5params.nc

This is a filename example corresponding to the product:

S6A_043_254_l2p_ddoppler_rtk5params.nc

5 Data Format

This chapter presents the data storage format and convention used for Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters product. All products are distributed in NetCDF-4 with norm CF. NetCDF (Network Common Data Form) is an open source, generic and multi-platform format developed by Unidata. An exhaustive presentation of NetCDF and additional conventions is available on the following web site:

https://www.unidata.ucar.edu/software/netcdf/

All basic NetCDF conventions are applied to files. Additionally, the files are based on the attribute data tags defined by the Cooperative Ocean/Atmopshere Reasearch Data Service (COARDS) and Climate Forecast (CF) metadata conventions. The CF convention generalises and extends the COARDS convention but relaxes the COARDS constraints on dimension and order and specifies methods for reducing the size of datasets. A wide range of software is available to write or read NetCDF/CF files. API made available by UNIDATA:

- C/C++/Fortran;
- Java;
- MATLAB, Objective-C, Perl, Python, R, Ruby, Tcl/Tk.

5.1 Dimensions

One dimension is defined in the Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters product:

- time: UTC time SAR [seconds since 2000-01-01]

5.2 Data Handling Variables

The variables defined in the product are listed and described in Table 1.

Name of variable	Content	Unit	Dimensions
time	UTC time SAR of the measurement	seconds since 2000-01-01 00:00:00 UTC	time
latitude	Latitude of the satellite	degrees_north	time
longitude	Longitude of the satellite	degrees_east	time
ssh	Sea surface height from SAR ocean retracker 5 parameters	m	time

ssh_lr	Nearest sea surface height from PDAP LR NR processing	m	time
swh	Significant wave height from SAR ocean retracker 5 parameters	m	time
swh_lr	Nearest significant wave height from PDAP LR NR processing	m	time
sig0	Sigma0 from SAR ocean retracker 5 parameters	dB	time
sig0_lr	Nearest sigma0 from PDAP LR NR processing	dB	time
ux	Horizontal velocity from SAR ocean retracker	m/s	time
sigmav	Corrected orbital velocity from SAR ocean retracker 5 parameters	m/s	time
t02	Wave period computed from SAR ocean retracker 5 parameters	s	time
u10_era5	ERA5 U10 interpolated to the coordinates of the 5-parameter retracking measurement	m/s	time
v10_era5	ERA5 V10 interpolated to the coordinates of the 5-parameter retracking measurement	m/s	time
phi_10_era5	ERA5 wind direction interpolated to the coordinates of the 5-parameter retracking measurement	degrees	time

Table 1 : Sentinel-6 Delay-Doppler Altimetry retracking 5 parameters product variables

The SSH values provided in the product are not corrected; users are therefore expected to apply their own corrections.

6 Products policy and accessibility

The use of the Sentinel-6 Delay-Doppler retracking 5 parameters products is described in the AVISO+ License Agreement.

Sentinel-6 Delay-Doppler retracking 5 parameters products are available via authenticated servers:

- CNES AVISO FTP/SFTP access (with AVISO+ credentials):
  - ftp://ftp-access.aviso.altimetry.fr:21
  - ftp://ftp-access.aviso.altimetry.fr:2122
    - /auxiliary/S6A_l2p_ddoppler_rtk5params/

- CNES AVISO THREDDS Data Server access (with AVISO+ credentials): https://tds-odatis.aviso.altimetry.fr/thredds/catalog/auxiliary/dataset-auxiliary-s6a-l2p-ddoppler-rtk5params.html

7 Contact

For further information on the AVISO product “Sentinel-6 Delay-Doppler Retracking 5 parameters” please contact the AVISO user helpdesk at:

aviso@altimetry.fr

Note that the AVISO user’s support team is also interested in user feedback, and requests are much welcome.

8 Appendix

8.1 Example of Sentinel-6 Delay-Doppler retracking 5 parameters product file

```
netcdf S6A_043_254_l2p_ddoppler_rtk5params {
dimensions:
	time = 16673 ;
variables:
	double ssh(time) ;
		ssh:_FillValue = NaN ;
		ssh:units = "m" ;
		ssh:long_name = "Sea surface height from SAR ocean retracker 5 parameters" ;
		ssh:coordinates = "latitude longitude" ;
	double ssh_lr(time) ;
		ssh_lr:_FillValue = NaN ;
		ssh_lr:long_name = "Nearest sea surface height from PDAP LR NR processing" ;
		ssh_lr:units = "m" ;
		ssh_lr:coordinates = "latitude longitude" ;
	double swh(time) ;
		swh:_FillValue = NaN ;
		swh:units = "m" ;
		swh:long_name = "Significant wave height from SAR ocean retracker 5 parameters" ;
		swh:coordinates = "latitude longitude" ;
	double swh_lr(time) ;
		swh_lr:_FillValue = NaN ;
		swh_lr:long_name = "Nearest significant wave height from PDAP LR NR processing" ;
		swh_lr:units = "m" ;
		swh_lr:coordinates = "latitude longitude" ;
	double sig0(time) ;
		sig0:_FillValue = NaN ;
		sig0:units = "dB" ;
		sig0:long_name = "Sigma0 from SAR ocean retracker 5 parameters" ;
		sig0:coordinates = "latitude longitude" ;
```

```
        double sig0_lr(time) ;
                sig0_lr:_FillValue = NaN ;
                sig0_lr:long_name = "Nearest sigma0 from PDAP LR NR processing" ;
                sig0_lr:units = "dB" ;
                sig0_lr:coordinates = "latitude longitude" ;
        double ux(time) ;
                ux:_FillValue = NaN ;
                ux:units = "m/s" ;
                ux:long_name = "Horizontal velocity from SAR ocean retracker" ;
                ux:coordinates = "latitude longitude" ;
        double sigmav(time) ;
                sigmav:_FillValue = NaN ;
                sigmav:long_name = "Corrected orbital velocity from SAR ocean retracker
5 parameters" ;
                sigmav:units = "m/s" ;
                sigmav:coordinates = "latitude longitude" ;
        double t02(time) ;
                t02:_FillValue = NaN ;
                t02:units = "s" ;
                t02:long_name = "Wave period computed from SAR ocean retracker 5
parameters" ;
                t02:coordinates = "latitude longitude" ;
        double u10_era5(time) ;
                u10_era5:_FillValue = NaN ;
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5-parameter retracking measurement" ;
                u10_era5:units = "m/s" ;
                u10_era5:coordinates = "latitude longitude" ;
        double v10_era5(time) ;
                v10_era5:_FillValue = NaN ;
                v10_era5:long_name = "ERA5 V10 interpolated to the coordinates of the
5-parameter retracking measurement" ;
                v10_era5:units = "m/s" ;
                v10_era5:coordinates = "latitude longitude" ;
        double phi_10_era5(time) ;
                phi_10_era5:_FillValue = NaN ;
```

```
		phi_10_era5:long_name = "ERA5 wind direction interpolated to the coordinates of the 5-parameter retracking measurement" ;
		phi_10_era5:units = "degrees" ;
		phi_10_era5:coordinates = "latitude longitude" ;
	double time(time) ;
		time:_FillValue = NaN ;
		time:long_name = "UTC time SAR" ;
		time:units = "seconds since 2000-01-01" ;
		time:calendar = "proleptic_gregorian" ;
	double latitude(time) ;
		latitude:_FillValue = NaN ;
		latitude:units = "degrees_north" ;
		latitude:long_name = "Latitude" ;
	double longitude(time) ;
		longitude:_FillValue = NaN ;
		longitude:units = "degrees_east" ;
		longitude:long_name = "Longitude" ;

// global attributes:
		:altimeter_sensor_name = "Poseidon-4B" ;
		:creation_time = "2026-06-10T18:38:14Z" ;
		:mission_name = "Sentinel-6A" ;
		:title = "ddoppler retracking 5 parameters demonstration products (CLS/CNES)" ;
		:cycle_number = 43LL ;
		:pass_number = 254LL ;
		:institution = "CLS/CNES" ;
		:funding = "This work was supported by CNES under contract SALP (250176)" ;
		:contact = "aviso@altimetry.fr" ;
		:doi = "10.24400/527896/AVISO-2026.008" ;
		:l1a_name_hr = "S6A_P4_1A_HR______20220118T001140_20220118T010757_20220118T165822_3377_043_254_127_EUM__OPE_ST_F04.SEN6" ;
		:PDAP_L2_LR_version = "F08" ;
}
```

9 Bibliography

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