Sentinel-6 Level-2P skewness products (LR & HR)

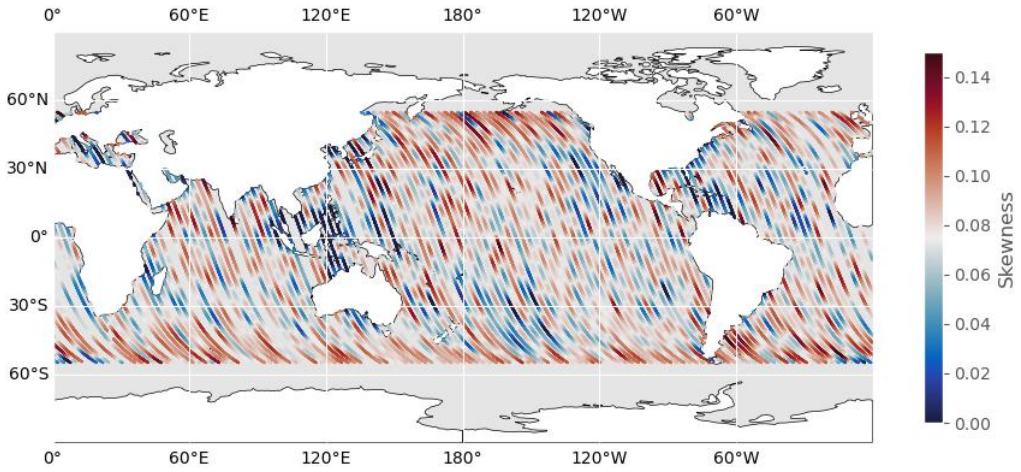

Figure 1. Averaged skewness pattern from ascending tracks

Nomenclature: SALP-MU-P-EA-23676-CLS

Issue: 1 rev 0

Date: 10/12/2024

Chronology Issues:			
Issue:	Date:	Validated by	Reason for change:
1.0	2024/12/10		Initial release – creation of the document

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List of Acronyms:

AVISO+	Archiving, Validation and Interpretation of Satellite Oceanographic data
CF	Climate and Forecast
CLS	Collecte Localisation Satellites
CMEMS	Copernicus Marine Environment Monitoring Service
CNES	Centre National d'Etudes Spatiales
COARDS	Cooperative Ocean/Atmopshere Reasearch Data Service
ECMWF	European Centre for Medium-range Weather Forecasting
FROGS	Frogs Oceanographic Ground Segment
SWH	Significant wave height
TAC	Thematic Assembly Centre
UTC	Universal Time Coordinated

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[1] C. Buchhaupt et al., “A Fast Convolution Based Waveform Model for Conventional and Unfocused SAR Altimetry”, *Advances in Space Research* 62, n°6 (2018): 1445–1463.

[2] S. Dinardo et al., “Sentinel-6 MF Poseidon-4 Radar Altimeter: Main Scientific Results from S6PP LRM and UF-SAR Chains in the First Year of the Mission”, *Advances in Space Research* 73, n°1 (2024): 337–375.

[3] C. Buchhaupt et al., “Impact of Vertical Water Particle Motions on Focused SAR Altimetry”, Advances in Space Research 68, n°2 (2020): 853-874.

[4] L. Rodet et al., “New processing capabilities in the SPP chain for improving the Sentinel-3 and Sentinel-6 altimetric parameter estimates”, *Ocean Surface Topography Science Team Meeting* (2023): 121.

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1. Introduction: Context and product objectives

High accuracy sea level measurements are becoming increasingly important in many diverse fields of research and application. Amongst the several factors that can degrade that measure, the sea state bias is probably predominant. It manifests itself in biasing the range reference below the actual mean sea level by several centimeters. In general terms this bias can be attributed to the difference in electromagnetic backscattering from surface waves that have flat troughs and sharp crest. Indeed, skewness represents that waves have rounder through and peakier crest and is expected to be positive.

The Sentinel-6 Level-2P skewness products was developed to estimate the skewness from Sentinel-6 LR and HR acquisitions. That demonstration product is generated by different retracking processes, provides an initial estimation of such a phenomenon and allows a finer description of the sea state.

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

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 various Level-2P Skewness products and the process employed to obtain them. Note that the L2P skewness product is a different product from L2P which handbook can be found here :

https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_L2P_S3_S6.pdf

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

2. Overview

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. These modes are:

• Low Resolution Mode, hereafter "LR".

• High Resolution Mode, hereafter "HR", a.k.a. Synthetic Aperture Radar (SAR) or Delay Doppler Altimetry (DDA).

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.

In July 2023, Sentinel-6 full mission reprocessing was distributed. LR and HR data were reprocessed using Processing Baseline F08 (see F08 product notice for details).

The demonstration products described hereafter use official F08 L1A and L1B Sentinel-6 products (for HR and LR processing) as inputs.

2.1. S6 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. L2P files production

3.1. L1B

The impact of ocean dynamics on SAR data has been well documented in the past years (e.g. [3]). To mitigate this effect, we perform a custom L1b processing from the L1a products, with only 40 looks (compared to 322 looks in the operational products). The processing otherwise follows the same approach as in the operational chain, with the so-called approximate processing described in [2].

3.2. Retracking process

The retracking process must be adapted to enable the retrieving of the skewness parameter. For both LR and HR mode, this process relies on the physics-based (frequency domain) waveform model described in [1] and implemented in the Sentinel Processing Prototype [2]. Since the skewness is highly correlated to the SWH, we adopt a two-step retracking, whose main steps are summarized below:

3.2.1. Low Resolution Mode

Table 1. LR retracking processing steps

Input:	20 Hz L1b ntc PDAP F08 data
1 Hz L2 Processing:	• 4-parameter 20 Hz retracking of epoch, σ_0, ξ^2 and SWH of 40 individual waveforms • Alignment of the waveforms on gate 50 (using retracked epoch) • 2-sec average of the aligned waveforms • 3-parameter retracking of epoch, σ_0 and skewness of the averaged waveform (using as input, previous averaged retracked SWH and ξ^2)
1 Hz L2 output:	1 Hz L2 with 4 parameters: • σ_0 (retracking of 2-sec average waveform) • ξ^2 (average from 40 waveform) • SWH (average from 40 waveform retracking) • skewness (retracking of 2-sec average waveform)

3.2.2. High Resolution Mode

Table 2. HR retracking processing steps

Input:	20 Hz L1b new processed data (see section 3.1) from L1a official product
1 Hz L2 Processing:	• Alignment of the waveforms (using tracker) • 2-sec average of the (40) aligned waveforms • 3-parameter 20 Hz retracking of epoch, σ_0 and SWH of the averaged waveform 3-parameter retracking of epoch, σ_0 and skewness of the averaged waveform (using retracked SWH)

1 Hz L2 output:	1 Hz L2 with 3 parameters: • σ_0 (from 2nd retracking of the average waveform) • SWH (from 1st retracking of the average waveform) • skewness (from 2nd retracking of the average waveform)

3.3. Geographical selection

The skewness characterizes the sea state, and the waves included in the targeted footprint. For that reason, all the values that do not respect the following criteria are set to NaN.

Parameter (x)	Units	Method	Criterion or valid values
surface_classification_flag	-	Threshold	x=0 (ocean)

Table 3. Flag and threshold for geographical selection

4. Product Presentation

4.1. Validation and use

The skewness parameter obtained by the various retrackers still shows a high residual noise. An additional averaging step is recommended over large windows (250-points~1500 km) to obtain reliable patterns and be comparable to the ECMWF ERA-5 model [4], Figure 2.

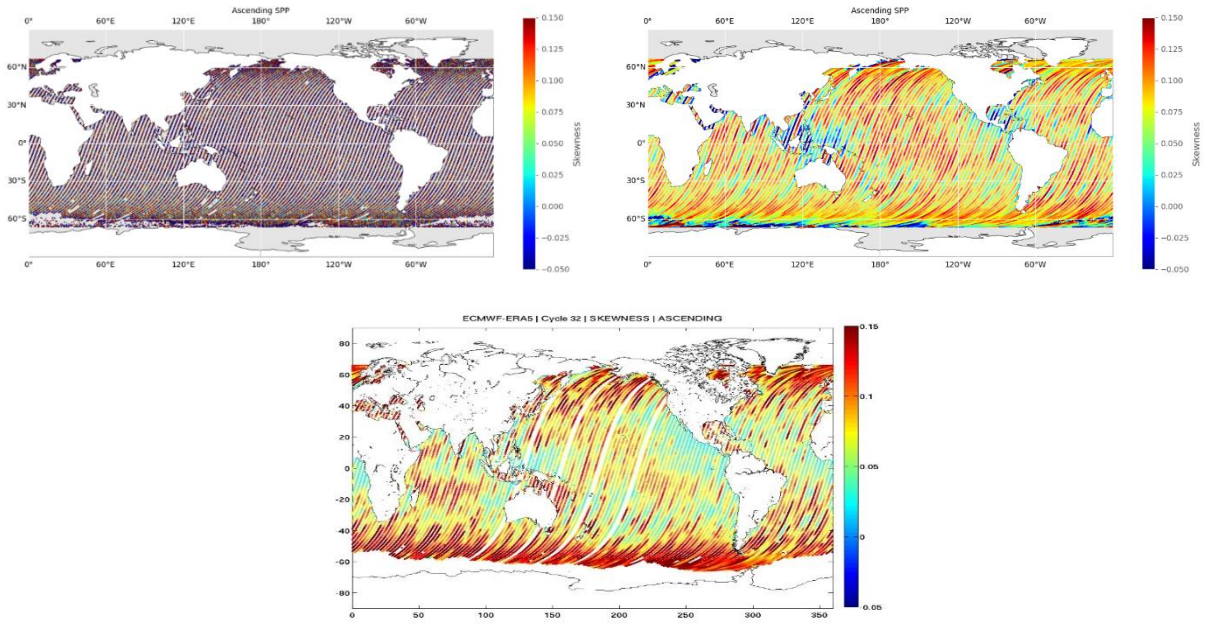

Figure 2. Skewness pattern from ascending tracks: Sentinel-6 raw data (top left), Sentinel-6 averaged data (top right) and ECMWF ERA-5 model (bottom, center).

4.2. Temporal Availability

L2P skewness products from Sentinel-6 are available from September 30th, 2021, to October 2nd, 2022, for both processing (LRM & HRM). It corresponds to all passes from cycle 33 to cycle 69 (included)

4.3. Nomenclature

Sentinel-6 L2P skewness filenames use the following nomenclature:

S6A_CYCLENB_PASSNB_l2p_skewness.nc

Where the name components are:

- CYCLENB: cycle number
- PASSNB: pass number

This is a filename example corresponding to the current Sentinel-6 L2P skewness products:

S6A_033_001_l2p_skewness.nc

5. Data Format

This chapter presents the data storage format and convention used for S6 L2P products. 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.

Each NetCDF file contains two groups, LR and HR, with variables described below.

5.1. L2P Product Format

5.1.1. Dimensions

One dimension is defined in the products:

- time: number of point along track

5.1.2. Data Handling Variables

The variables defined in the product are listed and described inTable 4, where XX corresponds to either the LR or HR (SAR) retracker.

Name of variable	Type	Content	Unit	Dimensions
time	double	UTC time XX	datetime64	time
latitude	double	Latitude	degrees_north	time
longitude	double	Longitude	degrees_east	time
surface_classification_flag	int	Flag indicating the surface type : 0, 1, 2, 3, 4, 5, 6 for open_ocean, land, continental_water, aquatic_vegetation, continental_ice_snow, floating_ice, salted_basin	-	time
sig0	double	Sigma0 from XX ocean retracker	dB	time
swh	double	Significant wave height from XX ocean retracker	meters	time
skewness	double	Skewness from XX ocean retracker	-	time

ksi2	double	Estimated epointing (only LR)	Degrees square	time

Table 4. Product variable descriptions

Additional attributes may be available in L2 files (see Appendix 8.1). They provide information about the type of product or the processing and parameter used.

6. Products policy and accessibility

Sentinel-6 L2P skewness products (DOI: 10.24400/527896/a01-2024.012) are available via authenticated servers **on demand only**. Please contact aviso@altimetry.fr if you are interested.

News, updates and reprocessing

6.1. Updates and reprocessing

6.1.1. Product version

The product versions are listed hereafter:

Version	Delivery date	Period	FA	Evolution with respect to previous version
v1.0	2024-12-10	2021/10/25 to 2022/10/25		• Datasets creation

6.2. Citation

Recommendations to Sentinel-6 users on publication policy :

Any use of this dataset must be verified in the AVISO+ license and must cite its DOI 10.24400/527896/a01-2024.012 as well as the following sentence: "This product "L2P skewness demonstration products (CLS/CNES) was produced by CNES/CLS cooperation and distributed by AVISO+ with the support from CNES."

7. Contacts

For more information, please contact:

Aviso+ User Services
CLS
11 rue Hermès
Parc Technologique du canal
F-31520 Ramonville Cedex
France
E-mail: aviso@altimetry.fr
On Internet: https://www.aviso.altimetry.fr/

The user service is also interested in user feedback; questions, comments, proposals, requests are much welcome.

8. Appendix

8.1. Example of Sentinel-6 L2P skewness product File

```
netcdf S6A_033_001_l2p_skewness {

// global attributes:
                :altimeter_sensor_name = "Poseidon-4B" ;
                :creation_time = "2024-12-02T18:38:14Z" ;
                :mission_name = "Sentinel-6A" ;
                :institution = "CLS/CNES" ;
                :cycle_number = 33LL ;
                :contact = "aviso@altimetry.fr" ;
                :title = "L2P skewness demonstration products (CLS/CNES)" ;
                :pass_number = 1LL ;
                :funding = "This work was supported by CNES under contract SALP 2024 221-332" ;
                :doi = "10.24400/527896/a01-2024.012" ;

group: LR {
  dimensions:
        time = 3349 ;
  variables:
        float surface_classification_flag(time) ;
                surface_classification_flag:_FillValue = NaNf ;
                surface_classification_flag:comment = "7-state surface type classification from MODIS
and GlobCover" ;
                surface_classification_flag:flag_meanings = "open_ocean land continental_water
aquatic_vegetation continental_ice_snow floating_ice salted_basin" ;
                surface_classification_flag:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b ;
                surface_classification_flag:long_name = "flag indicating the surface type" ;
                surface_classification_flag:source = "xref_surface_classification" ;
                surface_classification_flag:standard_name = "status_flag" ;
                surface_classification_flag:valid_range = 0b, 6b ;
                surface_classification_flag:coordinates = "latitude longitude" ;
        double sig0(time) ;
                sig0:_FillValue = NaN ;
                sig0:units = "dB" ;
```

sig0:long_name = "Sigma0 from LRM processing" ;

sig0:coordinates = "latitude longitude" ;

double ksi2(time) ;

ksi2:_FillValue = NaN ;

ksi2:units = "deg^2" ;

ksi2:long_name = "ksi^2 from LRM processing" ;

ksi2:coordinates = "latitude longitude" ;

double swh(time) ;

swh:_FillValue = NaN ;

swh:units = "m" ;

swh:long_name = "SWH from LRM processing" ;

swh:coordinates = "latitude longitude" ;

double skewness (time) ;

skewness:_FillValue = NaN ;

skewness:units = "m" ;

skewness:long_name = "Skewness of wave height from LRM processing" ;

skewness:coordinates = "latitude longitude" ;

int latitude(time) ;

latitude:_FillValue = -2147483647 ;

latitude:comment = "Latitude of measurement [-90, +90]. Positive latitude is North latitude, negative latitude is South latitude" ;

latitude:long_name = "latitude" ;

latitude:standard_name = "latitude" ;

latitude:units = "degrees_north" ;

latitude:coordinates = "longitude latitude" ;

latitude:scale_factor = 1.e-06 ;

int longitude(time) ;

longitude:_FillValue = -2147483647 ;

longitude:comment = "Longitude of measurement [0, 360). East longitude relative to Greenwich meridian" ;

longitude:long_name = "longitude" ;

longitude:standard_name = "longitude" ;

longitude:units = "degrees_east" ;

longitude:coordinates = "longitude latitude" ;

longitude:scale_factor = 1.e-06 ;

double time(time) ;

time:_FillValue = NaN ;

time:comment = "Time refers to the instant the L1B waveform (which is a combination of pulses for both LR and HR) touches the surface. [tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set.

[leap_second] is the UTC time at which a leap second occurs in the data set, if any. After this UTC time, the [tai_utc_difference] is increased by 1 second" ;

time:leap_second = "0000-00-00_00:00:00" ;

time:long_name = "time in UTC" ;

time:standard_name = "time" ;

time:tai_utc_difference = 37. ;

time:coordinates = "longitude latitude" ;

time:units = "seconds since 2000-01-01" ;

time:calendar = "Gregorian" ;

// group attributes:

:Conventions_lr = "CF-1.7" ;

:first_meas_time_lr = "2021-09-30T23:24:08.540522Z" ;

:last_meas_time_lr = "2021-10-01T00:20:21.462662Z" ;

:first_meas_lat_lr = -66.1459256852407 ;

:last_meas_lat_lr = 66.1448511315819 ;

:first_meas_lon_lr = 17.0599420765283 ;

:last_meas_lon_lr = 182.876850508501 ;

:semi_major_ellipsoid_axis_lr = 6378137. ;

:ellipsoid_flattening_lr = 0.003352810664747 ;

:l1b_processing_lr = "PDAP" ;

:l1b_name_lr = "S6A_P4_1B_LR_____20210930T232408_20211001T002021_20230307T144814_3373_033_001_127_EUM__REP_NT_F08.SEN6" ;

data:

} // group LR

group: HR {

dimensions:

time = 3173 ;

variables:

double surface_classification_flag(time) ;

surface_classification_flag:_FillValue = NaN ;

surface_classification_flag:long_name = "Flag indicating the surface type" ;

surface_classification_flag:flag_values = "0, 1, 2, 3, 4, 5, 6" ;

surface_classification_flag:flag_meanings = "open_ocean, land, continental_water, aquatic_vegetation, continental_ice_snow, floating_ice, salted_basin" ;

surface_classification_flag:coordinates = "latitude longitude" ;

double sig0(time) ;

sig0:_FillValue = NaN ;

sig0:units = "dB" ;
sig0:long_name = "Sigma0 from SAR processing" ;
sig0:coordinates = "latitude longitude" ;
double swh(time) ;
swh:_FillValue = NaN ;
swh:units = "m" ;
swh:long_name = "Significant wave height from SAR processing" ;
swh:coordinates = "latitude longitude" ;
double skewness(time) ;
skewness:_FillValue = NaN ;
skewness:units = "m" ;
skewness:long_name = "Skewness of wave height from SAR processing" ;
skewness:coordinates = "latitude longitude" ;
double time(time) ;
time:long_name = "UTC time SAR" ;
time:calendar = "proleptic_gregorian" ;
time:_FillValue = NaN ;
time:units = "seconds since 2000-01-01" ;
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" ;

// group attributes:
:first_meas_time_hr = "2021-09-30T23:24:06Z" ;
:ellipsoid_flattening_hr = 0.00335281066474748 ;
:l1b_processing_hr = "custom 40 looks" ;
:last_meas_time_hr = "2021-10-01T00:20:23Z" ;
:last_meas_lon_hr = -176.866461526697 ;
:semi_major_ellipsoid_axis_hr = 6378137. ;
:first_meas_lat_hr = -66.1457819066915 ;
:l1a_name_hr = "S6A_P4_1A_HR_____20210930T232406_20211001T002023_20211001T153446_3377_033_001_127_EUM__OPE_ST_F03.SEN6" ;
:last_meas_lat_hr = 66.1445536120941 ;

```
                    :Conventions_hr = "CF-1.6" ;
                    :first_meas_lon_hr = 16.8012869903732 ;
 data:
 } // group HR
}
```