Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Reconstructed Attitude Product
Short Name: ATTD_RECONST

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March 30, 2022

Version 1.3
SWOT-IS-CDM-0684-CNES

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

CHANGE LOG

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE
Baseline	2018-12-06	ALL	Initial Release
1.1	2020-09-25	4.1.2 and 5.2.3 3.3	Modifications of “quaternion_qual” Product centered at 12h TAI Distribution update
1.2	2020-11-04	ALL	Make date fields consistent. Add some global attributes.
1.3	2022-03-30	4.1.2 4.1.3 5.2.1 5.2.3	Definition of the values of the quaternion_qual indicator. Update of the global attributes.

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1 Introduction

1.1 Purpose

The purpose of this Product Description Document is to describe the Reconstructed Attitude science data product from the Surface Water Ocean Topography (SWOT) mission. This data product is also referenced by the short name ATTD_RECONST. It is generated by blending data from the payload gyro and the spacecraft star tracker to provide an accurate measure of satellite attitude that will be used for KaRIn, Radiometer, and Precise Orbit Determination (POD) processing.

1.2 Document Organization

Section 2 provides a general description of the product, including its purpose, and latency.

Section 3 provides the structure of the product, including granule definition, file organization, spatial resolution, temporal and spatial organization of the content, the size and data volume.

Section 4 provides qualitative descriptions of the information provided in the product.

Section 5 provides a detailed identification of the individual fields within the ATTD_RECONST product, including for example their units, size, coordinates, etc.

Section 6 provides references for this product.

Appendix A provides a listing of the acronyms used in this document.

2 Product Description

2.1 Purpose

The ATTD_RECONST product is generated in response to SWOT project science requirements described in [1]. It is aimed towards providing an accurate measure of the SWOT spacecraft attitude. The product uses quaternions to represent the attitude of the spacecraft body-fixed KaRIn Metering Structure Reference Frame with respect to the inertial Geocentric Celestial Reference Frame. This product is used for processing of the KaRIn and radiometer science data, and to perform precise orbit determination of the spacecraft. The data in this product are generated by blending data from the onboard gyro and star tracker.

2.2 Latency

The ATTD_RECONST product is generated with a latency of less than 1.5 days from data collection. Typically, star tracker and gyro data from day D will be available early on day D+1. Reprocessed versions of this product may be generated through the life of the SWOT mission.

3 Product Structure

3.1 Granule Definition

The ATTD_RECONST product is organized into daily files, spanning 26 hours and centered at 12:00:00 (TAI) of each day (i.e. from day D-1 23:00 to day D+1 01:00 TAI time).

3.2 File Organization

The ATTD_RECONST product adopts the NetCDF file format. Each product granule is provided as a single file as shown in Table 1. Each file contains a time series of quaternions and associated quality flags.

Table 1. Description of file comprising the ATTD_RECONST product.

File	Name	Description
1	Reconstruct Attitude Product	Provides quaternions to represent the rotation between the spacecraft body-fixed KaRIn Metering Structure Reference Frame and the inertial Geocentric Celestial Reference Frame.

3.3 File Naming Convention

The name of each ATTD_RECONST product follows the general SWOT product naming convention and is as follows:

SWOT_ATTD_RECONST_<RangeBeginningDateTime>_<RangeEndingDateTime>_<CRID>_<ProductCounter>.nc

where:

- RangeBeginningDateTime and RangeEndingDateTime are, respectively, the UTC date and time of the first and last measurements in the file following the format YYYYMMDDThhmmss
- CRID is the Composite Release Identifier that denotes the version of the processing software.
- ProductCounter is the version number of the data product if it is generated multiple times.

An example of a file name with data centered on 2019-06-12 12:00:00 (TAI) is as follows (*tai_utc_difference* being equal to 37 seconds, refer to section 4.1.1):

SWOT_ATTD_RECONST_20190611T225923_20190613T005923_PGA000_01.nc

3.4 Spatial Sampling and Resolution

The time series of quaternions provided in the ATTD_RECONST product has no spatial dependencies.

3.5 Temporal Organization

The sequential time series of quaternions is typically provided with a sampling interval of 15.625 ms (i.e., 64 Hz).

3.6 Spatial Organization

The ATTD_RECONST product does not have any spatial dependencies.

3.7 Volume

Table 2 provides the expected volume of each daily ATTD_RECONST file granule. The provided data product volume is conservative since the NetCDF binary format that compresses the data is used for the product. Each data record is comprised of 52 bytes and 5990400 data records are expected in each daily file.

Table 2. Description of Data Volume of Each File of ATTD_RECONST product.

File	Name	Volume/Granule (GB/day)
1	Reconstructed Attitude Daily File	0.3115

4 Qualitative Description

Each ATTD_RECONST file contains global metadata, followed by the time series of time tags, quaternions, and associated quality flags.

4.1 Reconstructed Attitude File

4.1.1 Time and Location

Time tags for each measurement data record are provided in the UTC and TAI time scales using the variables *time* and *time_tai*, respectively.

- *time*: Time in UTC time scale (seconds since January 1, 2000 00:00:00 UTC which is equivalent to January 1, 2000 00:00:32 TAI)
- *time_tai*: Time in TAI time scale (seconds since January 1, 2000 00:00:00 TAI, which is equivalent to December 31, 1999 23:59:28 UTC)

The variable *time* has an attribute named *tai_utc_difference*, which represents the difference between TAI and UTC (i.e., total number of leap seconds) at the time of the first measurement record in the product granule.

- *time_tai[0] = time[0] + tai_utc_difference*

The above relationship holds true for all measurement records unless an additional leap second occurs within the time span of the product granule. To account for this, the variable *time* also has an attribute named *leap_second* which provides the date at which a leap second might have occurred within the time span of the product granule. The variable *time* will exhibit a jump when a leap second occurs. If no additional leap second occurs within the time span of the product granule *time:leap_second* is set to “0000-00-00 00:00:00”.

The table below provides some examples for the values of *time*, *time_tai*, and *tai_utc_difference*. With this approach, the value of *time* will have a 1 second regression during a leap second transition, while *time_tai* will be continuous. That is, when a positive leap second is inserted, two different instances will have the same value for the variable *time*, making time non-unique by itself; the difference between *time* and *time_tai*, or the *tai_utc_difference* and *leap_second* fields, can be used to resolve this. Some examples are provided in the table below.

UTC Date	TAI Date	time	time_tai	tai_utc_difference
January 1, 2000 00:00:00	January 1, 2000 00:00:32	0.0	32.0	32
December 31, 2016 23:59:59	January 1, 2017 00:00:35	536543999.0	536544035.0	36
December 31, 2016 23:59:59.5	January 1, 2017 00:00:35.5	536543999.5	536544035.5	36
December 31, 2016 23:59:60	January 1, 2017 00:00:36	536543999.0	536544036.0	37
January 1, 2017 00:00:00	January 1, 2017 00:00:37	536544000.0	536544037.0	37
January 1, 2017 12:00:00	January 1, 2017 12:00:37	536587200.0	536587237.0	37

Locations are not provided with each time tag.

4.1.2 Quality Flags

The following quality flag is provided for the quaternion at each epoch.

- *quaternion_qual*: quality flag for the quaternion.

This quality flag reflects issues that degrade the performance of the reported quaternions. These issues include:

- Missing input data
- Anomalous input data
- Algorithm issues

The detailed values of the *quaternion_qual* variable in the Attitude file are the following:

- 0 : good
- 1 : degraded due to anomalous gyro data
- 2 : bad

4.1.3 Attitude Measurements

Reconstructed attitude measurements are provided as quaternions at each time tag.

- *quaternion*: Four-dimensional variable that represents the attitude of the spacecraft body-fixed KaRIn Metering Structure Reference Frame (KMSF) with respect to the inertial Geocentric Celestial Reference Frame (GCRF).

The quaternion vector that relates the KMSF and GCRF is denoted $Q_{GCRF\to KMSF}$, where:

$$Q_{GCRF\to KMSF} = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \tag{1}$$

The four-dimensional variable *quaternion* that is provided at each time tag then represents q_0, q_1, q_2, and q_3, with q_0 being the real (scalar) part. These quaternions can then be used to construct the rotation matrix $M_{GCRF\to KMSF}$ as represented in equation (2) below.

$$M_{GCRF\to KMSF} = \begin{bmatrix} 2(q_0^2 + q_1^2) - 1 & 2(q_1 q_2 - q_0 q_3) & 2(q_1 q_3 + q_0 q_2) \\ 2(q_1 q_2 + q_0 q_3) & 2(q_0^2 + q_2^2) - 1 & 2(q_2 q_3 - q_0 q_1) \\ 2(q_1 q_3 - q_0 q_2) & 2(q_2 q_3 + q_0 q_1) & 2(q_0^2 + q_3^2) - 1 \end{bmatrix} \tag{2}$$

The rotation matrix $M_{GCRF\to KMSF}$ represents the rotation that transforms the GCRF to the KMSF. As such, a vector with coordinates x^{GCRF} in the GCRF, and x^{KMSF} in the KMSF, are then related as shown in equations (3) and (4) below.

$$x^{GCRF} = M_{GCRF\to KMSF} \cdot x^{KMSF} \tag{3}$$

$$x^{KMSF} = M_{GCRF\to KMSF}^{T} \cdot x^{GCRF} \tag{4}$$

The KMSF is illustrated in Figure 1 below and defined in [2]. The KMSF is a spacecraft body-fixed coordinate system that is defined from the physical SWOT hardware on the KaRIn Metering Structure. This coordinate system has its Z axis oriented towards nadir, Y axis along the KaRIn mast, and X axis completing the right-handed coordinate system.

Also shown in Figure 1 is the KaRIn Baseline Frame (KBF). The KBF is the frame that the SWOT spacecraft intends to align with the local nadir track compensation target, with its Y axis aligned with the actual baseline (between the centers of phase of the KaRIn antenns). The offset and rotation between the KMSF and KBF are measured before launch and updated once during the KaRIn checkout phase soon after launch. This transformation is used by KaRIn science data processing.

The KMSF serves as the reference body-fixed fixed frame for various ground processing as follows.

- The origin of the KMSF serves as the reference to define the various reference points that are required for precise orbit determination (POD) processing (e.g., antenna phase center, satellite center of mass, etc).
- The orientation of the body-fixed frame (e.g., KMSF) with respect to the inertial frame (e.g., GCRF) is required for POD processing.
- The orientation of the body-fixed frame (e.g., KMSF) with respect to the International Terrestrial Reference Frame (ITRF) is required for KaRIn and radiometer processing to correctly orient their respective measurements. This orientation is construct by using the combination of the quaternions provided in this product that relate the KMSF and GCRF together with knowledge of the orientation of the ITRF with respect to the GCRF. Knowledge of the orientation of the ITRF with respect to the GCRF is computed during POD processing of the Medium-Accuracy Orbit Ephemeris (MOE) and Precise Orbit Ephemeris ([3]).

Note concerning the quality flag: If the time epoch is associated with a “bad” quality flag (*quaternion_qua*l = 2, see §4.1.2), the corresponding quaternion is set to [0 0 0 0].

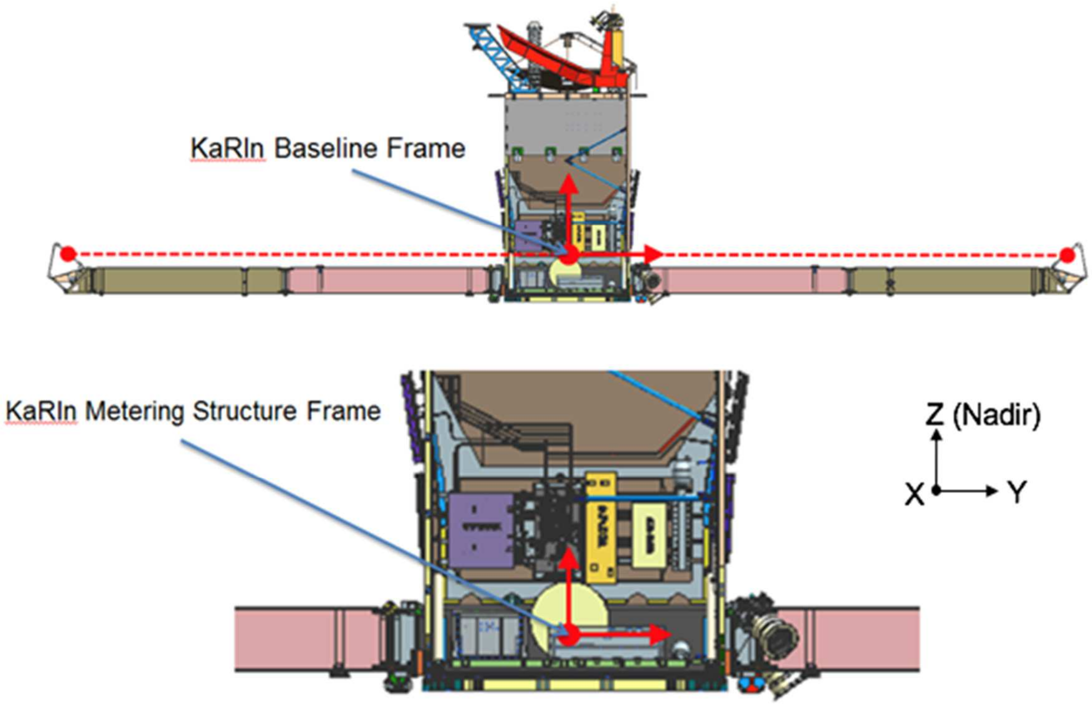

Figure 1. Illustration of the SWOT body-fixed reference frames.

5 Detailed Product Description

5.1 NetCDF Variables

Variables are used to store the various measurements. Each variable is assigned a name and a particular data type. Variables can be scalar values (i.e. 0 dimension), or can have one or more dimensions. Each variable then has attributes that provide additional information about the variable. Descriptions of variables data types and variable attributes are provided in Table 3 and Table 4 below, respectively.

Table 3. Variable data types in NetCDF product.

Data Type	Description
char	characters
byte	8-bit signed integer
unsigned byte	8-bit unsigned integer
short	16-bit signed integer
unsigned short	16-bit unsigned integer
int	32-bit signed integer
unsigned int	32-bit unsigned integer
long	64-bit signed integer
unsigned long	64-bit unsigned integer
float	IEEE single precision floating point (32 bits)
double	IEEE double precision floating point (64 bits)

Table 4. Common variable attributes in NetCDF file.

Attribute	Description
_FillValue	The value used to represent missing or undefined data. (Before applying add_offset and scale_factor).
add_offset	If present this value should be added to each data element after it is read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
calendar	Reference time calendar
comment	Miscellaneous information about the data or the methods to generate it.
coordinates	Coordinate variables associated with the variable
flag_meanings	Used in conjunction with flag_values. Describes the meanings of each of the elements of flag_values.
flag_values.	Used in conjunction with flag_meanings. Posssible values of the flag variable.
institution	Institution which generates the source data for the variable, if applicable.
leap_second	UTC time at which a leap second occurs within the time span of data within the file.
long_name	A descriptive variable name that indicates its content.
quality_flag	Names of variable quality flag(s) that are associated with this variable to indicate its quality.
scale_factor	If present, the data are to be multiplied by the value after they are read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
source	Data source (model, author, or instrument)
standard_name	A standard variable name that indicates its content.
tai_utc_difference	Difference between TAI and UTC reference time.
units	Unit of data after applying offset (add_offset) and scale_factor.

valid_max	Maximum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as maximum value of actual data)
valid_min	Minimum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as minimum value of actual data)

5.2 Reconstructed Attitude File

5.2.1 Global Attributes

Global attributes for the ATTD_RECONST product are provided in Table 5 below.

Table 5. Global attributes of ATTD_RECONST product.

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this product. This attribute should be set to CF-1.7 to indicate that the group is compliant with the Climate and Forecast NetCDF conventions.
title	string	SWOT Reconstructed Attitude Product
institution	string	Name of producing agency, e.g., “CNES”.
source	string	The method of production of the original data. If it was model-generated, source should name the model and its version, as specifically as could be useful. If it is observational, source should characterize it (e.g., "SWOT Payload Gyro and Star Trackers").
history	string	UTC time when file generated. Format is: "YYYY-MM-DDThh:mm:ssZ : Creation"
platform	string	“SWOT”
references	string	Provides version number of software generating product.
reference_document	string	Name and version of Product Description Document to use as reference for product.
contact	string	Contact information for producer of product. (e.g., "ops@cnes.fr").
short_name	string	ATTD_RECONST
product_file_id	string	Identifier of the product file : ATTD_RECONST, ATTD_CONTEXT
crid	string	Composite release identifier (CRID) of the data system used to generate this file
product_version	string	Version identifier of this data file
pge_name	string	PGE_ATTD_RECONST
pge_version	string	Version identifier of the product generation executable (PGE) that created this file
time_coverage_start	string	UTC time of first quaternion within the product. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
time_coverage_end	string	UTC time of last quaternion within the product. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
ref_frame_A	string	The name of the reference frame specifying the first frame of the transformation, e.g., GCRF.

ref_frame_B	string	The name of the reference frame specifying the second frame of the transformation, e.g., KMSF.
attitude_direction	string	Direction of rotation from provided quaternions, e.g., A2B as indicated in equations (1) and (2). • A2B indicates a rotation from ref_frame_A to ref_frame_B • B2A indicates a rotation from ref_frame_B to ref_frame_A.
xref_gyro_files	string	List of input GYRO measurement files.
xref_star_tracker_files	string	List of input star tracker files
xref_histo_oef_file	string	Name of input satellite event file.
xref_eclipse_files	string	Names of input satellite eclipse files.
xref_events_param_file	string	Name of input parameter file for satellite event processing.
xref_param_attd_reconst	string	Name of input processor configuration parameters file.
xref_leapsec_file	string	Name of input leap seconds file.

5.2.2 Dimensions

The dimensions that are used for the variables in the ATTD_RECONST product are provided in Table 6 below.

Table 6. Dimensions used in ATTD_RECONST product.

Dimension Name	Value
time	Number of measurement records in product.
quatdim	Dimension of quaternion vector at each epoch. Should always have a value of 4.

5.2.3 Variables

Variables in the ATTD_RECONST product with their respective attributes are provided in Table 7 below.

Table 7. Variables in ATTD_RECONST product.

Global Variables		
double time(time)		
	_FillValue	9.9692099683868690e+36
	long_name	time in UTC
	standard_name	time
	calendar	gregorian
	tai_utc_difference	[Value of TAI-UTC at time of first record]
	leap_second	YYYY-MM-DDThh:mm:ssZ
	units	seconds since 2000-01-01 00:00:00.0
	comment	time of measurement in seconds in the UTC time scale since 1 Jan 2000 00:00:00 UTC. [tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set. If a leap second occurs within the data set, the attribute leap_second is set to the UTC time at which the leap second occurs.
double time_tai(time)		
	_FillValue	9.9692099683868690e+36

	long_name	time in TAI
	standard_name	time
	calendar	gregorian
	units	seconds since 2000-01-01 00:00:00.0
	comment	time of measurement in seconds in the TAI time scale since 1 Jan 2000 00:00:00 TAI. This time scale contains no leap seconds. The difference (in seconds) with time in UTC is given by the attribute [time:tai_utc_difference].
double quaternion(time, quatdim)		
	_FillValue	9.9692099683868690e+36
	long_name	quaternion
	units	1
	scale_factor	1.0e0
	quality_flag	quaternion_qual
	valid_max	1.0
	valid_min	-1.0
	comment	Four elements of quaternion that is used to construct the rotation matrix with direction indicated by global attribute attitude_direction. Index 0 corresponds to real (scalar) component. For “bad” quaternion_qual time stamps, the quaternion is set to [0 0 0 0].
byte quaternion_qual(time)		
	_FillValue	127
	long_name	quality flag for quaternion
	standard_name	status_flag
	flag_meanings	good degraded bad
	flag_values	0 1 2
	valid_min	0
	valid_max	2
	comment	Quality flag for the quaternion. A value of 0 indicates good, a value of 1 indicates degraded, and any other values indicate bad.

6 References

[1] "SWOT Science Requirements Document, JPL D-61923," Jet Propulsion Laboratory, 2018.

[2] N. Tchintcharadze, "SWOT Level 2 coordinate systems and conventions specification, SWOT-TS-SYS-434-CNES," CNES, Toulouse, 2017.

[3] N. Picot, "SWOT Product Description Document: Precision and Medium-accuracy Orbit Ephemeris Data Product, SWOT-IS-CDM-0658-CNES," CNES, Toulouse, 2020.

Appendix A. Acronyms

ATBD	Algorithm Theoretical Basis Document
CNES	Centre National d’Études Spatiales
GCRF	Geocentric Celestial Reference Frame
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
KBF	KaRIn Baseline Frame
KMSF	KaRIn Metering Structure Reference Frame
MOE	Medium-Accuracy Orbit Ephemeris
NASA	National Aeronautics and Space Administration
POD	Precise Orbit Determination
POE	Precise Orbit Ephemeris
SWOT	Surface Water Ocean Topography
TBC	To Be Confirmed
TBD	To Be Determined

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