Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Precise and Medium-accuracy Orbit Ephemeris data product
Short Name: POE and MOE

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National Aeronautics and Space Administration
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cnes

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE

Baseline	2018-12-06	ALL	Initial Release
Initial Release	2019-02-06	ALL	Initial Release
V1.1	2020-09-15	2.1, 2.2	Add processing standard information. Provide POE latency information.
V1.2	2021-05-27	§5.2.1	Add “Orbit” in Title Change “mission_name” in “platform” Change “first_measurement_time” in “time_coverage_start” Change “last_measurement_time” in “time_coverage_end” Add “Z” at the end of the creation date Modify the list of xref_* global attributes

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1 Introduction

1.1 Purpose

The purpose of this Product Description Document is to describe the Precise and Medium-accuracy Orbit Ephemeris data products from the Surface Water Ocean Topography (SWOT) mission. These data products are also referenced by the short names POE and MOE, respectively. These products provide high-accuracy estimates of the position and velocity vectors (i.e., orbit ephemeris) of the center of mass of the SWOT spacecraft in the Earth-Centered Earth-Fixed (ECEF) International Terrestrial Reference Frame (ITRF). The POE and MOE have identical format. They differ primarily in the latency at which they are available, and consequently in the accuracy of the estimates of the satellite orbit ephemeris.

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 POE and MOE products, 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 POE and MOE products are generated in response to SWOT project science requirements described in (SWOT Science Requirements Document, JPL D-61923, 2018). They are aimed towards providing accurate estimates of the position and velocity vectors of the center of mass of the SWOT spacecraft, namely the SWOT orbit ephemeris. The orbit ephemeris provided on both products are computed using precise orbit determination (POD) techniques with tracking data from the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) and Global Positioning System (GPS) instruments onboard SWOT. The two tracking systems complement each other to enable estimates of the satellite's radial position to within 2-3 cm (RMS).

The POE and MOE are generated by the CNES SSALTO processing center. A general description of the processing standards (satellite force models, measurement models, spacecraft attitude) that are used for currently flying missions can be found on the International DORIS Service (IDS) website: https://ids-doris.org/doris-system/satellites.html. Detailed descriptions of the actual POD algorithms are also available in the published literature. Information on the SWOT mission will be added to the IDS website when available, e.g., from launch preparation onward.

2.2 Latency

The MOE product is generated with a latency of less than 1.5 days from data collection. Typically, the SWOT reconstructed attitude product (ATTD_RECONST (Raffier, 2021)) that provides the orientation of the spacecraft body-fixed frame with respect to the inertial frame, and the DORIS and GPS tracking data from day D will be available early on day D+1.

The POE product is expected to have better accuracy than the MOE with the longer latency allowing for the use of more accurate inputs to the POD computations. POEs are available less than 28 days after the MOE, assuming a 7-day arc length; POEs are generated once per week, or by batches. Reprocessed versions of the POE product may be generated through the life of the SWOT mission with evolving models of the satellite forces and tracking data measurements.

3 Product Structure

3.1 Granule Definition

The POE and MOE products are both 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).

Each POE and MOE file provides orbit ephemeris state vectors at intervals of 10 seconds along the satellite orbit. Each file therefore contains 9361 state vectors.

3.2 File Organization

The SWOT POE and MOE products adopt 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 satellite position and velocity vectors with an associated quality flag at each epoch.

Table 1. Description of file comprising the POE and MOE products.

File	Name	Description
1	POE and MOE Product	Provides Earth-Centered Earth-Fixed (ECEF) position and velocity vectors of the center of mass of the SWOT spacecraft in the International Terrestrial Reference Frame (ITRF) with an associated quality flag at each epoch.

3.3 File Naming Convention

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

POE:
SWOT_VOR_AXVCNE<CreationDateTime>_<ValidityBeginningDateTime>_<ValidityEndingDateTime>.nc

MOE:
SWOT_POR_AXVCNE<CreationDateTime>_<ValidityBeginningDateTime>_<ValidityEndingDateTime>.nc

where CreationDateTime, ValidityBeginningDateTime, and ValidityEndingDateTime follow the format YYYYMMDD_hhmmss and are all provided in UTC. They reflect the creation time of the file, and the range of times for which the file is valid.

An example of an MOE 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 4.1.1)

SWOT_POR_AXVCNE20190613_120000_20190611_225923_20190613_005923.nc

3.4 Spatial Sampling and Resolution

The time series of satellite position and velocity vectors provided in the POE and MOE products have no spatial dependencies.

3.5 Temporal Organization

The sequential time series of position and velocity vectors are typically provided with a sampling interval of 10 seconds. Orbit interpolation methods are used to compute the position and velocity vectors of the satellite center of mass at a desired time. This is typically performed with classical Everett interpolation techniques. A single time tag is associated with each record of the data product.

3.6 Spatial Organization

The POE and MOE products do not have any spatial dependencies.

3.7 Volume

Table 2 provides the expected volume of each daily POE and MOE 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 65 bytes and 9361 data records are expected in each daily file.

Table 2. Description of Data Volume of Each File of POE and MOE products.

File	Name	Volume/Granule (MB/day)
1	POE and MOE Daily File	0.6085

4 Qualitative Description

Each POE and MOE file contains global metadata, followed by the time series of time tags, satellite position and velocity vectors, and an associated quality flag.

4.1 MOE/POE 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

4.1.2 Quality Flags

The following quality flag is provided for each time tag.

- *orbit_qual*: orbit quality flag.

This quality flag reflects issues that degrade the performance of the reported satellite orbit ephemeris. The values of this flag and meanings are as follows. Valid values range from 3-8, and the nominal value of this flag is 3.

- 3: Adjusted on actual tracking data.
- 4: Estimated during a maneuver.
- 5: Interpolated (over data gaps).
- 6: Extrapolated for a duration less than 1 day.
- 7: Extrapolated for a duration between 1 and 2 days.
- 8: Extrapolated for a duration greater than 2 days.

4.1.3 Satellite ECEF Position and Velocity

Estimates of the position and velocity vectors of the satellite center of mass are provided in the Earth-Centered Earth-Fixed (ECEF) International Terrestrial Reference Frame (ITRF). When Cartesian coordinates are expressed in ECEF coordinates, the $+z$ axis of the ECEF frame goes through the north pole, and the $+x$ axis goes through both the equator (zero latitude) and the prime meridian (zero longitude). The $+y$ axis completes the right-handed coordinate system. The version of the ITRF used to defined the position and velocity vectors is indicated as a global attribute. The position and velocity vectors are provided by the variables named *position* and *velocity*.

- *position*: Three-dimensional variable that represents the x, y, and z components of the ECEF position vector of the satellite center of mass.
- *velocity*: Three-dimensional variable that represents the x, y, and z components of the ECEF velocity vector of the satellite center of mass.

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 POE and MOE Files

5.2.1 Global Attributes

Global attributes for the POE and MOE products are provided in Table 5 below.

Table 5. Global attributes of POE and MOE products.

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	A descriptive title for the data product, e.g., "SWOT Precise Orbit Ephemeris Product" or "SWOT Medium-accuracy Orbit Ephemeris 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 DORIS and GPS Tracking Data").
history	string	UTC time when file generated. Format is: "YYYY-MM-DD hh:mm:ssZ : Creation"
platform	string	"SWOT"
references	string	Published or web-based references that describe the data or methods used to product it. 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	Short name of product, e.g., "MOE" or "POE"
time_coverage_start	string	UTC time of first position and velocity within the product. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
time_coverage_end	string	UTC time of last position and velocity within the product. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
reference_frame	string	The version of the reference frame, e.g., ITRF14.
xref_doris_files	string	List of input DORIS measurement files.
xref_gps_files	string	List of input GPS measurement files.
xref_attd_reconst_files	string	List of input spacecraft attitude files.
xref_solarpanel_orientation_files	string	List of input solar panel orientation files.
xref_sat_com_file	string	Input center of mass history file.
xref_histo_oef	string	Input orbit events file.
xref_pole_location	string	Input Earth orientation parameters file.

xref_leapsec_file	string	Input leap second history file.

5.2.2 Dimensions

The dimensions that are used for the variables in the POE and MOE products are provided in Table 6 below.

Table 6. Dimensions used in POE and MOE products.

Dimension Name	Value
time	Number of measurement records in product.
statedim	Dimension of each of the position and velocity vectors at each epoch. Should always have a value of 3.

5.2.3 Variables

Variables in the POE and MOE products with their respective attributes are provided in Table 7 below.

Table 7. Variables in POE and MOE products.

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-DD hh:mm:ss
	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 position(time, statedim)		
	_FillValue	9.9692099683868690e+36
	long_name	ECEF position vector of satellite center of mass
	units	m
	scale_factor	1.0e0
	quality_flag	orbit_qual

	comment	Earth-Centered Earth-Fixed (ECEF) position vector of the satellite center of mass.
double velocity(time, statedim)		
	_FillValue	9.9692099683868690e+36
	long_name	ECEF velocity vector of satellite center of mass
	units	m/s
	scale_factor	1.0e0
	quality_flag	orbit_qual
	comment	Earth-Centered Earth-Fixed (ECEF) velocity vector of the satellite center of mass.
byte orbit_qual(time)		
	_FillValue	127
	long_name	orbit quality flag
	standard_name	status_flag
	flag_meanings	adjusted_on_actual_tracking_data estimated_during_a_maneuver interpolated_over_data_gap extrapolated_for_a_duration_less_than_1_day extrapolated_for_a_duration_between_1_and_2 days extrapolated_for_a_duration_greater_than_2_days
	flag_values	3 4 5 6 7 8
	valid_min	3
	valid_max	8
	comment	Quality flag for position and velocity vectors.

6 References

Raffier, B. (2021). *SWOT Product Description Document: Reconstructed Attitude Product, SWOT-IS-CDM-0684-CNES.* Toulouse: CNES.

(2018). *SWOT Science Requirements Document, JPL D-61923.* Jet Propulsion Laboratory.

Appendix A. **Acronyms**

CNES	Centre National d'Études Spatiales
DORIS	Doppler Orbitography Radiopositioning Integrated by Satellite
ECEF	Earth-Centered Earth-Fixed
GPS	Global Positioning System
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
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