Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Satellite Center of Mass data product
Short Name: SAT_COM

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June 4, 2019

Version 1.0
SWOT-IS-CDM-1073-CNES

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

CHANGE LOG

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE
Baseline	2019-06-04	ALL	Initial Release

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1 Introduction

1.1 Purpose

The purpose of this Product Description Document is to describe the satellite center of mass data product from the Surface Water Ocean Topography (SWOT) mission. This data product is also referenced by the short name SAT_COM. This product is a standard data product. The SAT_COM product is generated by the CNES multi-mission Precise Orbit Determination (POD) processing facility inside the SSALTO ground processing center, simultaneously with Medium-accuracy Orbit Ephemeris (MOE) processing.

This product is described separately from the MOE/POE product, described in [1], because the MOE/POE definition is common to many missions, whereas SAT_COM is a specific product defined for SWOT.

Note that there is also a recurrent interface for nadir altimeter processing, named CORPFALTI (for Platform Correction for altimetry), which is produced by POD and gives specifically the vector from satellite CoM to altimeter antenna reference point.

1.2 Document Organization

Section 2 provides a general description of the product, including its purpose, the relevant requirements, 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 SAT_COM product, including for example their units, size, coordinates, etc.

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

2 Product Description

2.1 Purpose

The SAT_COM product is generated in response to SWOT project science requirements described in [2]. The SAT_COM product is aimed toward providing accurate estimates of the vector from the origin of the spacecraft body-fixed KaRIn Metering Structure Frame (KMSF) (KMSF to CoM), in that satellite reference frame, to the satellite center of mass (CoM), and the satellite mass. The KMSF origin is a well-known fixed point on the SWOT payload, which can be physically related to reference points of the various payloads (see Figure 1 for illustration). Consequently, the SAT_COM product will provide the satellite center of mass position (X/Y/Z) with respect to KMSF origin.

The transformation to reference points for the various payload instrument will be performed by their respective processing software, given that the orbit ephemeris products typically provide the position of the satellite CoM.

This product is needed as satellite center of mass will vary significantly during the mission. If these variations were unknown, they would add some errors on Precise Orbit Determination (POD) accuracy, and then on the accuracy of the measurements from the nadir altimeter and Ka-Band Radar Interferometer (KaRIn).

There are several contributions to the SWOT CoM variations, mainly:

- CoM variations due to solar array rotations: up to several cm depending on the solar array angle. The solar array angle is provided to POD processing through spacecraft telemetry.
- Thermoelastic variations: negligible in satellite CoM variation budget, so not accounted for in the SAT_COM product.
- Ergol (propellant) consumption: correlated with satellite maneuvers. This contribution is expected to be small in comparison to the effects of the solar array rotations, but will reach a few mm at the end of the mission. The mass evolution will be reflected in the mass provided in the SAT_COM product

As a consequence, the SAT_COM product will be a historic file that will be continuously updated through the life of the SWOT mission. It provides the sum total of the CoM variations due to solar array orientation and the estimated propellant consumption. It records the satellite mass and center of mass coordinates in the KMSF reference frame, which is a spacecraft body-fixed reference frame, with a new entry for every event that causes the CoM to change (e.g., maneuver, solar panel orientation change). For COM variations due to ergol consumption (maneuvers), the COM will be based:

- on predicted maneuvers for a very recent update
- on restituted maneuvers if considering an older value

Specifically, this means that previously provided values may change with each update of the SAT_COM file. It is expected that the longer latency of the Precise Orbit Ephemeris (POE), with respect to the MOE, will allow the POE to be generated only from restituted information.

The SAT_COM product will be generated by the CNES SSALTO processing center.

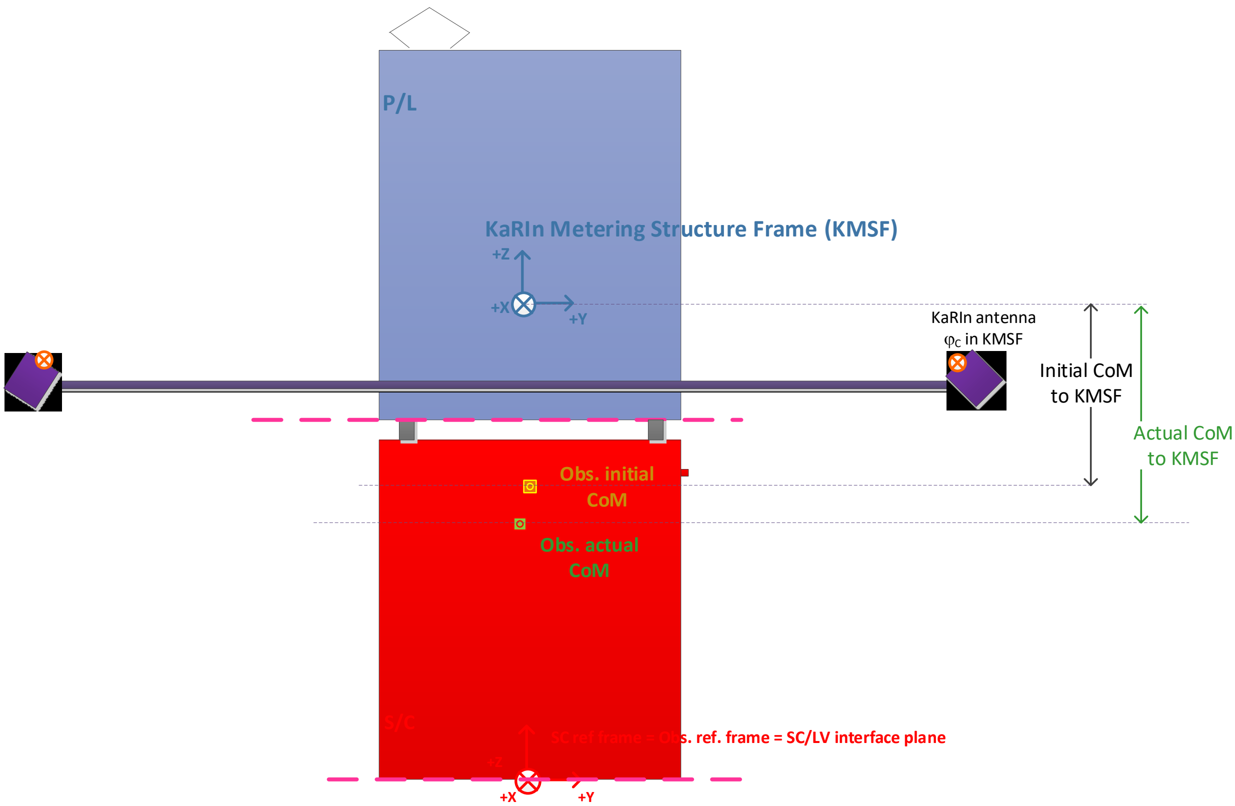

Figure 1 Illustration of KaRIn Metering Structure Frame (KMSF) and satellite center of mass (CoM)

2.2 Latency

The SAT_COM product is a historic file, distributed with the MOE product, with updated inputs as becomes available.

The SAT_COM product is generated with a latency of less than 1.5 days from data collection (same as MOE). Typically, CoM information for day D becomes available at day D+1, 12h TAI.

3 Product Structure

3.1 Granule Definition

The SAT_COM product file is organized as a historic file that contains the full time series of the CoM from launch to day D-1, where D is the current day.

CNES/SSALTO generates an updated SAT_COM file each day since the beginning of MOE products, even if there are no updates of the COM values. The sampling interval of the time series in the file is not constant, since new entries are only provided when there is a satellite event that causes the CoM to change.

This SAT_COM file will span the full mission life time:

- Production begins with the first MOE product, covering the same period as the first MOE
- The SAT_COM product will be updated with each daily MOE product: it will thus cover a duration from the first measurement date having be used for the first MOE to the last measurement of the most recent MOE file.
- Most of the time only the name of the file will be updated (creation date and end date)
- For each MOE product window that contains a COM variation (solar array rotation, maneuver), a new record will be added to the file.
- Only the most recent version of the SAT_COM product should be used as it will contain the best available past and present information
- The file size will increase during the mission life.
- The MOE file is organized into daily files, spanning 26 hours from day D-1 23:00 (TAI) to day D+1 01:00 (TAI), so the SAT_COM file will provide information up to day D+1 01:00 (TAI)

Note: this file will cover both the calibration and science orbit phases of the SWOT mission. Orbit change maneuvers will have a significant impact on radial COM position (about 1 cm).

3.2 File Organization

The SAT_COM product consists of one single file in NetCDF format.

Table 1. Description of file comprising the SAT_COM product.

File	Name	Description
1	SAT_COM Product	Provides - X/Y/Z coordinates of satellite Center of mass in KMSF reference frame (KaRIn metering and structure reference frame) with associated information of the origin of the variation - Satellite mass

3.3 File Naming Convention

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

SWOT_SAT_COM_<CreationDateTime>_<StartDateTime>_<EndDateTime>.nc

where Creation, Start, and End date times follows the format YYYYMMDD_hhmmss and are all provided in UTC.

An example of a SAT_COM file name produced simultaneously with an MOE file that is 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_ SAT_COM_20190613_120000_20190112_225923_20190613_005923.nc

where 20190112_225923 is an example of the start date time of the very first produced MOE file.

3.4 Spatial Sampling and Resolution

The time series of mass and center of mass positions provided in the SAT_COM products have no spatial dependencies.

3.5 Temporal Organization

A single time tag is associated with each record of the data product. The sampling interval between records will vary to represent actual satellite events that result in a change to the CoM.

The time series in the file should be considered to be piecewise continuous. Specifically, interpolation between records should not be used. That is, for an arbitrary time *t*, the COM position in KMSF is given by the last (latest in time) vector in the file whose time stamp is less than or equal to *t*.

For solar array rotations, the record will provide the value of the COM position at the end of the rotation.

Note that there is a specific interface for mission center with a time slot around each event defining the period over which the performance is not guaranteed (event duration plus tranquilization period if any).

3.6 Spatial Organization

The SAT_COM product does not have any spatial dependencies.

3.7 Volume

Table 2 provides the expected volume of each daily SAT_COM file granule.

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

File	Name	Total Volume (MB)
1	SAT_COM Daily File	< 1 (at the end of the mission)

4 Qualitative Description

The SAT_COM product file contains global metadata, followed by the time series of time tags, the CoM vector, the satellite mass and an associated event flag.

4.1 SAT_COM 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 Flags

The following flag is provided for each time tag.

- *event_flag*: flag indicating the origin of the satellite COM variation

This flag will indicate the origin of the change to the CoM :

- 1: predicted orbit control maneuver
- 2: restituted orbit control maneuver
- 3: solar array rotation
- 8: miscellaneous (e.g., POD adjustment to optimize performance)

4.1.3 Satellite COM Position

Updates to the position of the satellite center of mass are provided in the KMSF reference frame.

- *com_coordinates*: Three-dimensional variable that represents the *x, y,* and *z* components of the satellite center of mass position in the KMSF reference frame.

4.1.4 Satellite mass

Updates to the total mass of the satellite is provided:

- *sat_mass*: variable that represents the satellite 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 SAT_COM Files

5.2.1 Global Attributes

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

Table 5. Global attributes of the SAT_COM 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	A descriptive title for the data product, e.g., "SWOT Center of Mass data 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:ss : Creation"
mission_name	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").
first_measurement_time	string	UTC time of first date of COM variation spanning period. Format is: YYYY-MM-DDThh:mm:ss.ssssss
last_measurement_time	string	UTC time of last date of COM variation spanning period. Format is: YYYY-MM-DDThh:mm:ss.ssssss

5.2.2 Dimensions

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

Table 6. Dimensions used in SAT_COM product.

Dimension Name	Value
time	Number of measurement records in product.
coord_dim	Dimension of each of the COM coordinates at each

	epoch [X/Y/Z]. Should always have a value of 3.

5.2.3 Variables

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

Table 7. Variables in SAT_COM 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-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 com_coordinates(time, coord_dim)		
	_FillValue	9.9692099683868690e+36
	long_name	Satellite center of mass coordinates in the KaRIn Metering Structure reference frame
	units	m
	scale_factor	1.0e0
	comment	Satellite center of mass position in KaRIn Metering Structure reference frame
double sat_mass(time)		
	_FillValue	9.9692099683868690e+36
	long_name	Satellite mass
	units	kg
	scale_factor	1.0e0
	comment	Satellite total mass
byte event_flag(time)		
	_FillValue	127
	long_name	event flag to describe source of satellite COM change
	standard_name	status_flag
	flag_meanings	predicted / restituted / solar_array_rotation / miscellaneous
	flag_values	1 2 3 8
	valid_min	1
	valid_max	8
	comment	Flag to describe source of change to satellite COM. “predicted” refers to predicted change from a satellite maneuver; “restituted” refers to computed change from a

		satellite maneuver; “solar_array_rotation” refers to change resulting from change in solar panel orientation; “miscellaneous” refers to miscellaneous event such as an orbit determination adjustment to optimize performance.

6 References

[1] N. Picot, "SWOT Product Description Document: Precise and Medium-accuracy Orbit Ephemeris data product, SWOT-IS-CDM-0658-CNES," CNES, 2019.

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

Appendix A. **Acronyms**

CNES	Centre National d'Études Spatiales
COM	Center Of Mass
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
KMSF	KaRIn Metering Structure 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