Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Level 2 Radiometer Geophysical Data Record
Short Name: L2_RAD_GDR

Revision B

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1 Introduction

1.1 Purpose

The purpose of this Product Description Document is to describe the Level 2 Radiometer (Operational/Interim) Geophysical Data Record (GDR) science data product from the Surface Water Ocean Topography (SWOT) mission. Three versions of this product are generated depending on latency:

- Operational Geophysical Data Record (OGDR) available at latencies of < 7 hours.
- Interim Geophysical Data Record (IGDR) available at latencies of < 3 days.
- Geophysical Data Record (GDR) available at latencies of < 60 days.

These data products are also referenced by the short names L2_RAD_OGDR, L2_RAD_IGDR, and L2_RAD_GDR, respectively. This product description applies to all three versions of the data product as they have identical format.

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 L2_RAD_(O/I)GDR product, including 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

This product is generated in response to SWOT project science requirements described in [1]. A description of the algorithms that are used to generate the L2_RAD_(O/I)GDR product are provided by Algorithm Theoretical Basis Documents (ATBDs) in [2]. The primary objective of the L2_RAD_(O/I)GDR product is to provide measurements of the range delay corrections due to the wet troposphere content, and the two-way atmospheric attenuation to sigma0 at the Ku-, C-, and Ka-band frequencies from each of the two simultaneously active radiometers onboard SWOT.

The two SWOT radiometers are named the "+y" and "–y" strings and operate independently from each other. Each radiometer has a single feed that illuminates the 1-meter primary reflector to produce two beams on the ground. The names of the two strings are a reference to the location (+y or -y) of the two beams relative to the y-axis of the spacecraft body-fixed frame. Each of the radiometers operate at three frequencies, 18.7, 23.8, and 34.0 GHz. Each radiometer has a linear polarization vector fixed in the instrument coordinate frame, and they are orthogonal to each other. The vectors are rotated approximately 45 degrees relative to the vertical and horizontal polarization components at the Earth intercept. The radiometer processing algorithms use independent calibration coefficients for each radiometer to account for the polarization and emission angle differences between the two beams. The three operating frequencies of 18.7, 23.8, and 34.0 GHz are primarily aimed towards recovery of atmospheric attenuation to sigma0, water vapor, and cloud liquid burden, respectively.

The L2_RAD_(O/I)GDR product provides Level 1B and Level 2 measurements from each of the two SWOT radiometers. In particular, this product provides the following for each radiometer:

1. Level 1B measurements of radiometer antenna temperatures at three frequencies.
2. Level 1B measurements of radiometer main beam and equalized brightness temperatures at three frequencies.
3. Level 2 measurements of wet troposphere range corrections in support of sea surface height measurements performed by the Ka-band Radar Interferometer (KaRIn) and nadir altimeter instruments.
4. Level 2 measurements of two-way atmospheric attenuation to sigma0 measurements at the Ku-, C-, and Ka-band frequencies.
5. Level 2 measurements of cloud liquid water, water vapor content, and wind speed.

For a given time span, the L2_RAD_(O/I)GDR product is provided as a single file that contains data from both radiometers. The data from each radiometer are provided as two separate groups of data structures within each file, one group for each radiometer, that are generated independently. The L2_RAD_(O/I)GDR product serves as an input to low-rate (LR) KaRIn and nadir altimeter processing. The Level 2 measurements listed above are primarily aimed towards the respective over-ocean data from those instruments, as they are subject to land contamination. However, the radiometer measurements may also be valid over large inland waters such as lakes, depending on their size, where land contamination effects are not significant. The L2_RAD_(O/I)GDR product is not used as an input to high-rate (HR) KaRIn processing since the KaRIn HR data are primarily over land . Applications using the L2_RAD_(O/I)GDR product, for example the KaRIn LR and nadir altimeter products, perform interpolation of the measurements from the two radiometers in time and space (e.g., across the KaRIn swath and along-track) to the KaRIn and nadir altimeter measurement times and locations. Note that the radiometers on SWOT are not intended or capable of meeting performance requirements over land and therefore do not contribute to the hydrology error budget. Furthermore, the radiometers are not intended to support climatology. For example, cold-sky maneuvers are not performed by SWOT to monitor the calibration of the radiometers.

2.2 Latency

The three latencies of the L2_RAD_(O/I)GDR product allow for consolidation of instrument calibrations and the required auxiliary data that are needed to generate this product. The latency of these products is primarily linked to the availability of radiometer calibration coefficients for the provided data period and the orbit ephemeris used to geolocate the measurements. The radiometer calibration coefficients are expected to be available within 35 days after measurement time.

The L2_RAD_GDR product is generated with a latency of < 60 days using the using the Precise Orbit Ephemeris (POE) [3] to geolocate the measurements. The POE is available with a latency of <= 35 days. Accurate geolocation of the measurements from the two radiometers also requires availability of ground reconstructed satellite attitude products (ATTD_RECONST [4]) which provide the orientation of the spacecraft platform. The ATTD_RECONST products are available with a latency of less than 1.5 days after data collection. The calibration coefficients may be refined before generating reprocessed versions of the L2_RAD_GDR product.

The L2_RAD_IGDR product is generated with a latency of < 3 days using the Medium-accuracy Orbit Ephemeris (MOE) [3] to geolocate the measurements, the best available calibration coefficients from ~35 days before measurement time, and the ATTD_RECONST products. The MOE and ATTD_RECONST products are both available with a latency of less than 1.5 days after data collection, and the L2_RAD_IGDR product will become available soon after.

The L2_RAD_OGDR product is generated with a latency of < 7 hours using the onboard DORIS DIODE navigator orbit ephemeris to geolocate the measurements, and the best available calibration coefficients from ~35 days before measurement time. Knowledge of the spacecraft platform orientation from the ATTD_RECONST products are not available with sufficient latency for the L2_RAD_OGDR products. As such, the L2_RAD_OGDR product geolocates the measurements from the two radiometers to nadir at measurement time instead of the actual off-nadir beam locations described in section 3.4 below. This approach is taken because the L2_RAD_OGDR products are only expected to be used for the corresponding < 7-hour latency nadir altimeter OGDR science data products, and not for any KaRIn science data products.

3 Structure

3.1 Granule Definition

The L2_RAD_GDR and L2_RAD_IGDR products are organized into pass files based upon the location of the satellite center of mass from the satellite orbit ephemeris, and not the radiometer beam locations. There is no overlap of data from one pass file to the next. A single pass is a half revolution of the Earth by the satellite from pole to pole (extreme south to north latitudes for ascending passes, and north to south latitudes for descending passes). The L2_RAD_OGDR product is organized by data telemetry downloads from the instruments (~1.5-2 hours in duration or less), much like the nadir altimeter OGDR.

3.2 File Organization

The L2_RAD_(O/I)GDR science data product adopts the NetCDF-4 file format. Each product granule is provided as a single file as shown in Table 1. The data from the two radiometers are provided as two separate NetCDF-4 groups of data structures, one group for each radiometer, within each file. The names of the two NetCDF groups are provided in Table 2. Each group has attributes to identify the radiometer (+y or -y) from which the data were generated.

Table 1. Description of file comprising the L2_RAD_(O/I)GDR product.

File	Name	Description
1	Level 2 Radiometer (Operational/Interim) Geophysical Data Record	Provides Level 1B and 2 measurements from each of two active radiometers in separate NetCDF groups.

Table 2. Names of two NetCDF data groups within L2_RAD_(O/I)GDR product.

Name	Description
AMR_Side_1	Provides measurements from first radiometer. Refer to the group attribute *radiometer_sensor_name* to identify the radiometer that is applicable to this group.
AMR_Side_2	Provides measurements from second radiometer. Refer to the group attribute *radiometer_sensor_name* to identify the radiometer that is applicable to this group.

3.3 File Naming Convention

The L2_RAD_(O/I)GDR products adopts the following file naming convention:

SWOT_(O/I/G)PRAD_2Pv(S/P/P)<StartCycleID>_<StartPassID>_<StartDate>_<StartTime>_<EndDate>_<EndTime>_<CRID>_<ProductCounter>.nc

where:

<StartCycleID> is the three-digit cycle number of the first measurement in the file.

<StartPassID> is the three-digit pass number of the first measurement in the file.

<StartDate> and <StartTime> reflect the UTC time of the first measurement in the file.

<EndDate> and <EndTime> reflect the UTC time of the last measurement in the file.

<CRID> reflect the software version used to create the product.

<ProductCounter> is a two-digit number reflecting the version of the product generated with the same software, starting with 01 for the first version.

Example product names for cycle 23 and pass 56 with assumed start and end measurement times is as follows:

OGDR: SWOT_OPRAD_2PaS023_056_20220704_070707_20220704_081707_POA2_03.nc

IGDR: SWOT_IPRAD_2PaP023_056_20220704_070707_20220704_075707_PIA2_03.nc

GDR: SWOT_GPRAD_2PaP023_056_20220704_070707_20220704_075707_PGA2_03.nc

3.4 Spatial Sampling and Resolution

The measurements from each radiometer are temporally organized along the satellite ground track. The temporal resolution of the radiometer measurements is 16 Hz. The two radiometers facilitate measurements on the left and right sides of the satellite nadir point, approximately half-way across each of the two KaRIn swaths, as shown in Figures 1 and 2. The beam of one radiometer is aligned approximately 4.5 degrees (~70 km) fore and the other is 4.5 degrees (~70 km) aft of the satellite nadir point. The time tags of the radiometer measurements are independent of the KaRIn and nadir altimeter measurements. The time tags of the measurements from each radiometer are also independent of each other. Note that when the satellite is flying "forward", the spacecraft body-fixed X-axis is approximately in the same direction as the velocity vector, and the +y and -y radiometers are providing measurement on the right and left swaths, respectively. When flying "backward", the spacecraft body-fixed axis is approximately in the opposite direction to the velocity vector, and the +y and -y radiometers are providing measurements on the left and right swaths, respectively.

The reported time tags of the measurements correspond to the middle of the measurement integration period. The latitude and longitude of the measurements reported in the L2_RAD_IGDR and L2_RAD_GDR products correspond to the radiometer boresight location for each horn projected onto the Earth (i.e. 4.5 degrees fore and aft of nadir point, half-way across the KaRIn swath). Values reported in the L2_RAD_OGDR product correspond to nadir locations, for reasons described in section 2.2. Each radiometer horn has three frequencies which are co-aligned. The reported geophysical estimates (e.g., wet troposphere correction) correspond to the vertical atmospheric column directly above the reported locations by accounting for obliquity factors for the slant-path observations. As such, spatial and temporal interpolation of the measurements from the two radiometers is required for application to the nadir altimeter or KaRIn swath measurements. Furthermore, the reported values should then be scaled by an appropriate obliquity factor for non-vertical signal paths.

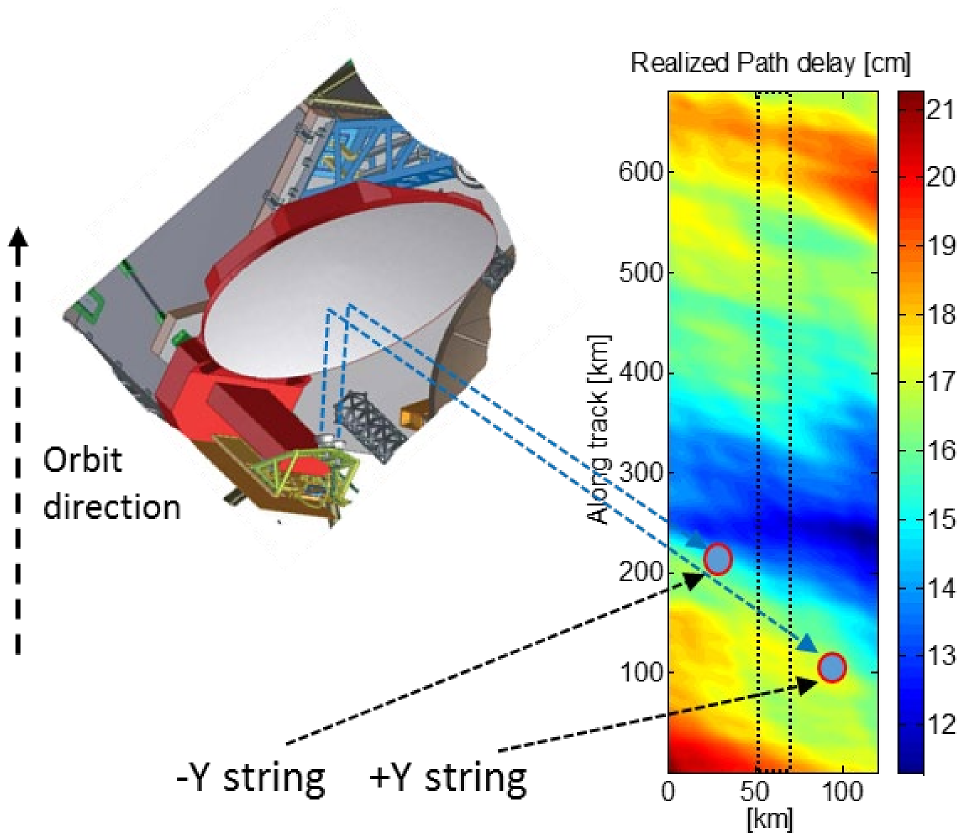

Figure 1. Spatial sampling from two SWOT radiometers when the satellite is flying "forward" with spacecraft X-axis closely aligned with the velocity vector. In this case +y is on the right swath and -y is on the left swath.

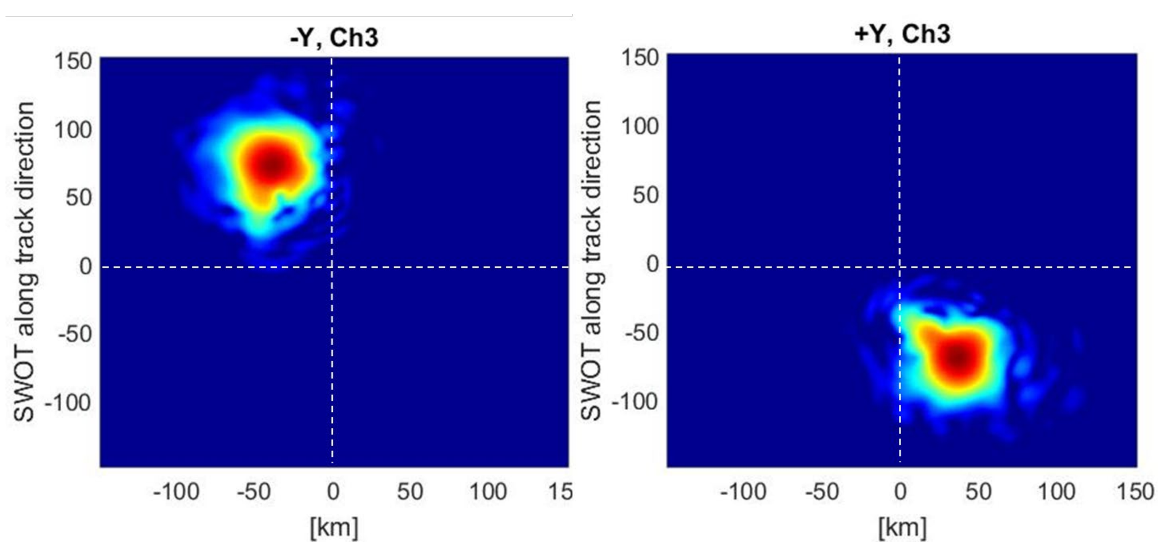

Figure 2. SWOT radiometer antenna patterns projected onto the ground when satellite is flying "forward".

It should be noted that while each radiometer is operating at 16 Hz, the 16 Hz measurements are composed of measurements of the antenna temperature, instrument reference load, and noise diodes. As such, and depending on the instrument configuration, only 12-13 antenna temperature (i.e. science) measurements are available in each second and reported on this L2_RAD_(O/I)GDR science data product. Not reported on this product are the remaining 3-4 instrument measurements in each second that are of the reference load and noise diodes. The reference load and noise diode measurements are used to generate the antenna temperature measurements themselves. As a result, the 12-13 radiometer measurements per second of the antenna temperatures, corresponding brightness temperatures, and geophysical parameters on this product are not necessarily equally spaced within each second.

The spatial resolution of each of the individual 12-13 AMR main beam brightness temperature measurements per second at the 3dB antenna pattern contour is 31 km at 18.7 GHz, 27 km at 23.8 GHz and 19 km at 34.0 GHz. The equalized brightness temperatures and corresponding geophysical measurements then have a spatial resolution of 27 km, namely the same resolution as the 23.8 GHz main beam brightness temperatures. Figure 3 below shows the -30, -20 and -3dB beam contours for each frequency for two radiometers.

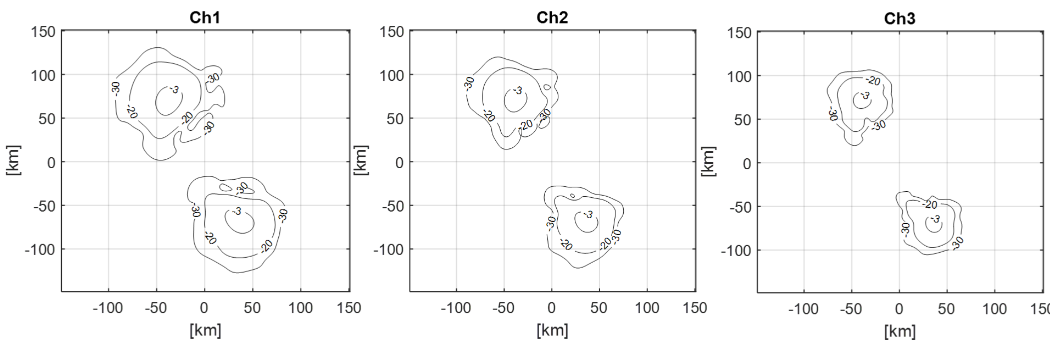

Figure 3. Antenna pattern contours projected onto the Earth's surface for each AMR channel.

3.5 Temporal Organization

Each of the two data groups that comprise the L2_RAD_(O/I)GDR data product consists of time-ordered records that are sequential along the satellite ground track. Each record within each group has an associated measurement time tag. There is no relationship between the records from the two groups given that the two radiometers are operating independently. In particular, each record of the two data groups may not have the same time tag, and may not be synchronized. Each record consists of the parameters that are described below.

3.6 Spatial Organization

Each record corresponds to one 16 Hz measurement along the satellite ground track, with only 12-13 16 Hz measurements per second (refer to section 3.3). The measurement in each record has an associated time tag, latitude, and longitude. The latitude and longitude reported in the L2_RAD_IGDR and L2_RAD_OGDR products correspond to the radiometer boresight location projected onto the Earth at the time of the measurement. As described earlier, values reported in the L2_RAD_OGDR product correspond to nadir locations.

3.7 Volume

Table 3 provides the expected volume of the individual file granule that comprises the L2_RAD_(I)GDR product. The provided data product volume is conservative as it does not account for any NetCDF internal compression. Each data record is comprised of 103 bytes. For SWOT, we expect two groups, each with up to 13 data records per second, 3087 seconds per pass, and approximately 28 passes per day. Each of the L2_RAD_OGDR files will likely have a larger size than the L2_RAD_(I)GDR files since they are organized by telemetry data downloads, which will typically be approximately 1.5-2 hours in duration. An L2_RAD_OGDR file spanning 1.5 hours will have a size of 0.0144 GB without NetCDF compression.

Table 3. Description of data volume of each file of the L2_RAD_(I)GDR product.

File	Name	Volume/Pass (GB/pass)	Volume/Day (GB/day)
1	Radiometer Measurements Pass File	0.0083	0.231

4 Qualitative Description

The following descriptions apply to each of the two groups that comprise the SWOT L2_RAD_(O/I)GDR science data product, with one group for each of the two active radiometers. Each of the two radiometers onboard SWOT provide antenna and main beam brightness temperature measurements at 18.7, 23.8, and 34.0 GHz. The geophysical measurements of troposphere content, atmospheric attenuation, and radiometer wind speed are then derived from equalized brightness temperature measurements. Equalized brightness temperatures are derived from along-track averaging of the 18.7, 23.8, and 34.0 GHz main beam brightness temperatures to provide footprint sizes equal to the footprint size of the 23.8 GHz channel along the spacecraft track.

4.1 Level 2 Radiometer Measurement Files

4.1.1 Time and Location

A single time tag applies to each data record within each group. The time tag corresponds to the middle of the integration period of the measurement.

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 *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 group.

- *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 group. 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 “0000-00-00T00:00:00Z”.

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

The location of the measurement is provided for each time tag, and corresponds to the boresight location projected onto the Earth's surface. The latitude and longitude are computed using the reference ellipsoid as defined in the global attributes *ellipsoid_semi_major_axis* and *ellipsoid_flattening*.

- *latitude*: Latitude (degrees)
- *longitude*: Longitude (degrees)

4.1.2 Quality Flags

Quality flags are provided for each of the following parameters at every data record. Each of these quality flags have a value of 0 for "good" and 1 for "bad".

- *rad_coordinates_qual*: the quality flags for the provided latitude and longitude. A value of 0 indicates that the latitude and longitude coordinates are computed using orbit and attitude information, a value of 1 indicates they are computed without attitude information and reflect nadir coordinates, and a value of 2 indicates that they are not computed because orbit information is not available. Typically, attitude information is not available at the very short latencies of L2_RAD_OGDR product generation, but is available for L2_RAD_IGDR and L2_RAD_GDR product generation. As such, this flag will typically have a value of 1 for the L2_RAD_OGDR products, and 0 for L2_RAD_IGDR and L2_RAD_GDR products.
- *rad_ta_187_qual, rad_ta_238_qual, rad_ta_340_qual*: the antenna temperature measurement quality flags at the three operating frequencies (18.7, 23.8, and 34.0 GHz).
- *rad_tmb_187_qual, rad_tmb_238_qual,* and *rad_tmb_340_qual*: the main beam brightness temperature measurement quality flags at the three operating frequencies (18.7, 23.8, and 34.0 GHz).
- *rad_tb_187_qual, rad_tb_238_qual,* and *rad_tb_340_qual*: the equalized brightness temperature measurement quality flags at the three operating frequencies (18.7, 23.8, and 34.0 GHz).
- *rad_water_vapor_qual, rad_cloud_liquid_water_qual, rad_wind_speed_qual, rad_wet_tropo_cor_qual, rad_atm_cor_sig0_ku_qual, rad_atm_cor_sig0_c_qual, and rad_atm_cor_sig0_ka_qual*: the quality flags for the geophysical measurements of water vapor, cloud liquid water, wind speed, wet troposphere correction, and two-way Ku, C, and Ka- band atmospheric attenuations, respectively.

4.1.3 Geophysical Flags

The following geophysical flags are provided for each record. The geophysical estimates of wet troposphere correction, cloud liquid water, water vapor content, and wind speed should be considered as invalid with any one of the following values of these flags: *rad_surface_type_flag* = 2, *rad_rain_flag* = 1, *rad_sea_ice_flag* = 1.

- *rad_surface_type_flag*: Surface type (0 = open ocean, 1 = coastal ocean, and 2 = land) applied for the generation of the wet troposphere correction as derived from a static surface type database. The surface type database accounts for the antenna patterns of each radiometer, and is therefore unique to each radiometer. A nominal open ocean retrieval algorithm is used to determine the wet troposphere correction when *rad_surface_type_flag* = 0, while a coastal retrieval algorithm is used when *rad_surface_type_flag* = 1. Wet troposphere corrections are invalid when *rad_surface_type_flag* = 2.
- *rad_rain_flag*: Rain flag (0 = no rain, 1 = rain) based upon brightness temperature measurements.
- *rad_sea_ice_flag*: Sea ice flag (0 = no sea ice, 1 = sea ice) based upon brightness temperature measurements.

4.1.4 Sensor Measurements

The following Level 1B sensor measurements are provided for each record:

- *rad_ta_187, rad_ta_238,* and *rad_ta_340*: Antenna temperature measurements at each of the three operating frequencies (18.7, 23.8, and 34.0 GHz).
- *rad_tmb_187, rad_tmb_238,* and *rad_tmb_340*: Main beam brightness temperature measurements at each of the three operating frequencies (18.7, 23.8, and 34.0 GHz).
- *rad_tb_187, rad_tb_238,* and *rad_tb_340*: Equalized brightness temperature measurements at each of the three operating frequencies (18.7, 23.8, and 34.0 GHz).

4.1.5 Geophysical Information

The following geophysical information is provided for each record:

- *rad_distance_to_land*: Radiometer radial distance to land.
- *rad_land_frac_187, rad_land_frac_238,* and *rad_land_frac_340*: Radiometer land fraction: this parameter indicates the fraction of the radiometer 18.7, 23.8, and 34.0 GHz footprints that contains land. Values range from 0 for no land within footprint, and 1 for entire footprint covered by land.

4.1.6 Geophysical Estimates

The following Level 2 geophysical estimates are provided for each record. Although each radiometer is pointed off-nadir and hence measures along a non-vertical path through the atmosphere, the geophysical estimates correspond to the equivalent vertical atmospheric column directly above the reported latitude and longitude. As such, they should be scaled by an appropriate obliquity factor for non-vertical signal paths.

- *rad_cloud_liquid_water*: Cloud liquid water content.
- *rad_water_vapor*: Water vapor content.
- *rad_wet_tropo_cor*: Wet troposphere correction. Values are typically negative so that they should be added to the KaRIn and nadir altimeter range measurements).
- *rad_wind_speed*: Wind speed.
- *rad_atm_cor_sig0_ku, rad_atm_cor_sig0_c,* and *rad_atm_cor_sig0_ka*: Two-way atmospheric attenuation to backscatter coefficients (Sigma0) at Ku-, C-, and Ka-band frequencies. Values should be added to respective backscatter coefficient measurements from nadir altimeter and KaRIn to correct for atmospheric attenuation.

5 Detailed Product Description

The L2_RAD_(O/I)GDR product adopts the NetCDF-4 file format and conventions. This is a self-documenting format that contains metadata as global attributes, group attributes, dimensions, variables, and attributes for variables. Global attributes apply to all of the data within the file. Each file contains two NetCDF groups of data, one for each radiometer. Group attributes are defined uniquely for each data group and only apply to the data within that individual group. Variable attributes only apply to the associated variable. The NetCDF command "ncdump –h l2_rad_gdr.nc" can be used to view the header of the product, which describes the content of the product.

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 4 and Table 5 below, respectively.

Table 4. 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 5. 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 date 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 Level 2 Radiometer Product File

5.2.1 Global Attributes

Global attributes for the L2_RAD_(O/I)GDR product are provided in Table 6 below. These attributes are applicable to all of the contents in each file.

Table 6. Global attributes of the L2_RAD_(O/I)GDR data 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, built as follows: "Radiometer Level 2 Data Product: " + XXX Where XXX = “OGDR”, “IGDR” or “GDR”.
institution	string	Name of producing agency.
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., "radiometer").
history	string	UTC time when file generated. Format is: "YYYY-MM-DDThh: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@jpl.nasa.gov").
cycle_number	short	Cycle number of first radiometer measurement within product.
pass_number	short	Pass number of first radiometer measurement within product.
equator_time	string	UTC time of the first equator crossing in product. Format is YYYY-MM-DDThh:mm:ss.ssssssZ.
equator_longitude	double	Longitude of the first equator crossing in product (degrees)
short_name	string	Short name of the product
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	Name of the product generation executable (PGE) that created this file
pge_version	string	Version identifier of the product generation executable (PGE) that

		created this file
xref_dynamic_radiometer_coefficient_file	string	Name of dynamic radiometer coefficient file used to generate data in product.
xref_static_radiometer_coefficient_file	string	Name of static radiometer coefficient file used to generate data in product.
xref_static_radiometer_map_file	string	Name of static radiometer surface type map used to generate data in product.
xref_radiometer_level0_files	string	List of Level 0 radiometer files used to generate data spanning first_measurement_time and last_measurement_time.
xref_orbit_ephemeris_files	string	List of orbit ephemeris files used to generate data in product.
xref_attd_reconst_files	string	List of quaternion files used to generate data in product that represent the rotation between the spacecraft body-fixed reference frame and Geocentric Celestial Reference Frame (GCRF). Empty list if none used.
xref_q_gcrf_itrf_files	string	List of quaternion files used to generate data in product that represent the rotation between the Geocentric Celestial Reference Frame (GCRF) and International Terrestrial Reference Frame (ITRF). Empty list if none used.
xref_leapsec_file	string	Name of input leap second file.
ellipsoid_semi_major_axis	double	Semi-major axis of reference ellipsoid in meters.
ellipsoid_flattening	double	Flattening of reference ellipsoid.

5.2.2 Group Names, Attributes, and Dimensions

The L2_RAD_(O/I)GDR product contains two NetCDF data groups, one for each of the two radiometers. The names of the two NetCDF groups are provided in Table 2. Each of these two data groups have the group attributes shown in Table 7, with values that are applicable to the individual groups. Most importantly, the *radiometer_sensor_name* group attribute identifies which of the two radiometers, +y or -y, is providing the measurements within each group. Each of the two NetCDF data groups uses the dimensions attribute to identify the physical dimension of the variables within that individual group. The L2_RAD_(O/I)GDR product uses the dimension shown in Table 8 for each group to indicate the number of measurements within each group. Since each radiometer operates independently the value of this dimension is expected to be different for each of the two groups.

Table 7. Attributes of each of two data groups in the L2_RAD_(O/I)GDR product.

Attribute	**Format**	**Description**
radiometer_sensor_name	string	"AMR plus_y" or "AMR minus_y" corresponding to the side of the radiometer for which data within group are provided.
time_coverage_start	string	UTC time of first radiometer measurement within the data group. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ.
time_coverage_end	string	UTC time of last radiometer measurement within the data group. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ.
geospatial_lon_min	double	Westernmost longitude of granule bounding box (degrees)(1)
geospatial_lon_max	double	Easternmost longitude of granule bounding box (degrees)(1)
geospatial_lat_min	double	Southernmost latitude of granule bounding box (degrees)
geospatial_lat_max	double	Northernmost longitude of granule bounding box (degrees)
first_measurement_longitude	double	Longitude of first radiometer measurement in group (degrees).
first_measurement_latitude	double	Latitude of first radiometer measurement in group (degrees).
last_measurement_longitude	double	Longitude of last radiometer measurement in group (degrees).

last_measurement_latitude	double	Latitude of last radiometer measurement in group (degrees).
number_open_ocean_measurements	int	Number of open ocean measurements
percent_valid_open_ocean_measurements	double	Percent of open ocean measurements with wet troposphere correction quality flag set to good.

(1)Note, where geospatial_lon_min is greater than geospatial_lon_max the bounding box of the dataset extends from geospatial_lon_min through the Prime Meridian (0 degrees longitude) to geospatial_lon_max; for example, geospatial_lon_min = 350 degrees and geospatial_lon_max = 10 degrees incorporates 20 degrees of longitude (ranges 350 to 360, and 0 to 10).

Table 8. Dimensions of variables within each of two NetCDF data groups.

Name	Description
time	Number of measurements in group.

5.2.3 Detailed NetCDF Format Description

Table 9 provides a listing of the variables in each of the two NetCDF group in the L2_RAD_(O/I)GDR product and their associated variable attributes.

Table 9. Variables in each of the two NetCDF data groups (AMR_Side_1 and AMR_Side_2).

Group AMR_Side_1 or AMR_Side_2 Variables		
double time(time)		
	_FillValue	9.969209968386869e+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	9.969209968386869e+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].
int latitude(time)		
	_FillValue	2147483647
	long_name	latitude (positive N, negative S)
	standard_name	latitude
	units	degrees_north
	scale_factor	1e-06
	quality_flag	rad_coordinates_qual
	valid_min	-80000000
	valid_max	80000000

	comment	Latitude of measurement [-90, 90]. Positive latitude is North latitude, negative latitude is South latitude.
Int longitude(time)		
	_FillValue	2147483647
	long_name	longitude (degrees East)
	standard_name	longitude
	units	degrees_east
	scale_factor	1e-06
	quality_flag	rad_coordinates_qual
	valid_min	0
	valid_max	359999999
	comment	Longitude of measurement [0,360]. East longitude relative to Greenwich meridian.
byte rad_coordinates_qual(time)		
	_FillValue	127
	long_name	quality flag for latitude and longitude coordinates
	standard_name	status_flag
	flag_meanings	good no_attitude bad
	flag_values	0 1 2
	valid_min	0
	valid_max	2
	comment	Quality flag for the latitude and longitude coordinates. A value of 0 indicates that the latitude and longitude coordinates are computed using orbit and attitude information, a value of 1 indicates they are computed without attitude information and reflect nadir coordinates, and a value of 2 indicates that they are not computed because orbit information is not available.
byte rad_ta_187_qual(time)		
	_FillValue	127
	long_name	quality flag for 18.7 GHz antenna temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 18.7 GHz antenna temperature.
byte rad_ta_238_qual(time)		
	_FillValue	127
	long_name	quality flag for 23.8 GHz antenna temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 23.8 GHz antenna temperature.
byte rad_ta_340_qual(time)		
	_FillValue	127
	long_name	quality flag for 34.0 GHz antenna temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 34.0 GHz antenna temperature.
byte rad_tmb_187_qual(time)		
	_FillValue	127

	long_name	quality flag for 18.7 GHz main beam brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 18.7 GHz main beam brightness temperature.
byte rad_tmb_238_qual(time)		
	_FillValue	127
	long_name	quality flag for 23.8 GHz main beam brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 23.8 GHz main beam brightness temperature.
byte rad_tmb_340_qual(time)		
	_FillValue	127
	long_name	quality flag for 34.0 GHz main beam brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 34.0 GHz main beam brightness temperature.
byte rad_tb_187_qual(time)		
	_FillValue	127
	long_name	quality flag for 18.7 GHz equalized brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 18.7 GHz equalized brightness temperature.
byte rad_tb_238_qual(time)		
	_FillValue	127
	long_name	quality flag for 23.8 GHz equalized brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 23.8 GHz equalized brightness temperature.
byte rad_tb_340_qual(time)		
	_FillValue	127
	long_name	quality flag for 34.0 GHz equalized brightness temperature
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for 34.0 GHz equalized brightness temperature.
byte rad_cloud_liquid_water_qual(time)		

	_FillValue	127
	long_name	quality flag for radiometer cloud liquid water content
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer cloud liquid water content.
byte rad_wind_speed_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer wind speed
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer wind speed.
byte rad_water_vapor_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer water vapor content
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer water vapor content.
byte rad_wet_tropo_cor_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer wet troposphere correction
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer wet troposphere correction.
byte rad_atm_cor_sig0_ku_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer two-way atmospheric correction to Ku band backscatter coefficient
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer two-way atmospheric correction to Ku band backscatter coefficient.
byte rad_atm_cor_sig0_c_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer two-way atmospheric correction to C band backscatter coefficient
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer two-way atmospheric correction to C band backscatter coefficient.

byte rad_atm_cor_sig0_ka_qual(time)		
	_FillValue	127
	long_name	quality flag for radiometer two-way atmospheric correction to Ka band backscatter coefficient
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Quality flag for radiometer two-way atmospheric correction to Ka band backscatter coefficient.
byte rad_surface_type_flag(time)		
	_FillValue	127
	long_name	radiometer surface type
	standard_name	status_flag
	flag_meanings	open_ocean coastal_ocean land
	flag_values	0 1 2
	valid_min	0
	valid_max	2
	comment	Flag indicating the validity and type of processing applied to generate the wet troposphere correction (rad_wet_tropo_cor). A value of 0 indicates that open ocean processing is used, a value of 1 indicates coastal processing, and a value of 2 indicates that rad_wet_tropo_cor is invalid due to land contamination.
byte rad_rain_flag(time)		
	_FillValue	127
	long_name	radiometer rain flag
	standard_name	status_flag
	flag_meanings	no_rain rain
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Flag indicating if radiometer measurement is invalid due to rain contamination.
byte rad_sea_ice_flag(time)		
	_FillValue	127
	long_name	radiometer sea ice flag
	standard_name	status_flag
	flag_meanings	no_sea_ice sea_ice
	flag_values	0 1
	valid_min	0
	valid_max	1
	comment	Flag indicating if radiometer measurement is invalid due to sea ice contamination.
int rad_ta_187(time)		
	_FillValue	2147483647
	long_name	radiometer antenna temperature at 18.7 GHz
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_ta_187_qual
	valid_min	0
	valid_max	36000
	comment	Antenna temperature measurement at 18.7 GHz.
int rad_ta_238(time)		
	_FillValue	2147483647
	long_name	radiometer antenna temperature at 23.8 GHz
	units	K

	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_ta_238_qual
	valid_min	0
	valid_max	36000
	comment	Antenna temperature measurement at 23.8 GHz.
int rad_ta_340(time)		
	_FillValue	2147483647
	long_name	radiometer antenna temperature at 34.0 GHz
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_ta_340_qual
	valid_min	0
	valid_max	36000
	comment	Antenna temperature measurement at 34.0 GHz.
int rad_tmb_187(time)		
	_FillValue	2147483647
	long_name	radiometer main beam brightness temperature at 18.7 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tmb_187_qual
	valid_min	0
	valid_max	36000
	comment	Main beam brightness temperature measurement at 18.7 GHz. Value is unsmoothed (along-track averaging has not been performed).
int rad_tmb_238(time)		
	_FillValue	2147483647
	long_name	radiometer main beam brightness temperature at 23.8 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tmb_238_qual
	valid_min	0
	valid_max	36000
	comment	Main beam brightness temperature measurement at 23.8 GHz. Value is unsmoothed (along-track averaging has not been performed).
int rad_tmb_340(time)		
	_FillValue	2147483647
	long_name	radiometer main beam brightness temperature at 34.0 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tmb_340_qual
	valid_min	0
	valid_max	36000
	comment	Main beam brightness temperature measurement at 34.0 GHz. Value is unsmoothed (along-track averaging has not been performed).
int rad_tb_187(time)		

	_FillValue	2147483647
	long_name	radiometer equalized brightness temperature at 18.7 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tb_187_qual
	valid_min	0
	valid_max	36000
	comment	Equalized brightness temperature measurement at 18.7 GHz. Value is smoothed (along-track averaging has been performed).
int rad_tb_238(time)		
	_FillValue	2147483647
	long_name	radiometer equalized brightness temperature at 23.8 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tb_238_qual
	valid_min	0
	valid_max	36000
	comment	Equalized brightness temperature measurement at 23.8 GHz. Value is smoothed (along-track averaging has been performed).
int rad_tb_340(time)		
	_FillValue	2147483647
	long_name	radiometer equalized brightness temperature at 34.0 GHz
	standard_name	toa_brightness_temperature
	units	K
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_tb_340_qual
	valid_min	0
	valid_max	36000
	comment	Equalized brightness temperature measurement at 34.0 GHz. Value is smoothed (along-track averaging has been performed).
int rad_distance_to_land(time)		
	_FillValue	2147483647
	long_name	radiometer main beam radial distance to land
	units	m
	scale_factor	100.0
	coordinates	longitude latitude
	valid_min	0
	valid_max	2147483646
	comment	Shortest distance between main beam measurement and land.
short rad_land_frac_187(time)		
	_FillValue	32767
	long_name	land fraction within main beam of 18.7 GHz channel
	units	1
	scale_factor	0.0001
	coordinates	longitude latitude
	valid_min	0
	valid_max	10000
	comment	Fraction of land within the 18.7 GHz main beam. Value is from 0 to 1.

short rad_land_frac_238(time)		
	_FillValue	32767
	long_name	land fraction within main beam of 23.8 GHz channel
	units	1
	scale_factor	0.0001
	coordinates	longitude latitude
	valid_min	0
	valid_max	10000
	comment	Fraction of land within the 23.8 GHz main beam. Value is from 0 to 1.
short rad_land_frac_340(time)		
	_FillValue	32767
	long_name	land fraction within main beam of 34.0 GHz channel
	units	1
	scale_factor	0.0001
	coordinates	longitude latitude
	valid_min	0
	valid_max	10000
	comment	Fraction of land within the 34.0 GHz main beam. Value is from 0 to 1.
short rad_cloud_liquid_water(time)		
	_FillValue	32767
	long_name	radiometer cloud liquid water content
	standard_name	atmosphere_cloud_liquid_water_content
	units	kg/m^2
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_cloud_liquid_water_qual
	valid_min	0
	valid_max	32766
	comment	Integrated cloud liquid water content.
short rad_wind_speed(time)		
	_FillValue	32767
	long_name	radiometer wind speed
	standard_name	wind_speed
	units	m/s
	scale_factor	0.01
	coordinates	longitude latitude
	quality_flag	rad_wind_speed_qual
	valid_min	0
	valid_max	32766
	comment	Sea surface wind speed.
short rad_water_vapor(time)		
	_FillValue	32767
	long_name	radiometer water vapor content
	standard_name	atmosphere_water_vapor_content
	units	kg/m^2
	scale_factor	0.1
	coordinates	longitude latitude
	quality_flag	rad_water_vapor_qual
	valid_min	0
	valid_max	32766
	comment	Integrated water vapor content.
short rad_wet_tropo_cor(time)		
	_FillValue	32767

	long_name	radiometer wet troposphere correction
	standard_name	altimeter_range_correction_due_to_wet_troposphere
	units	m
	scale_factor	0.0001
	coordinates	longitude latitude
	quality_flag	rad_wet_tropo_cor_qual
	valid_min	-10000
	valid_max	0
	comment	Value must be added to altimeter range to correct for delay due to the wet troposphere.
short rad_atm_cor_sig0_ku(time)		
	_FillValue	32767
	long_name	two-way atmospheric attenuation on Ku band altimeter backscatter coefficient
	units	dB
	scale_factor	0.001
	coordinates	longitude latitude
	quality_flag	rad_atm_cor_sig0_ku_qual
	valid_min	0
	valid_max	32766
	comment	Value must be added to altimeter backscatter coefficient to correct for atmospheric attenuation.
short rad_atm_cor_sig0_c(time)		
	_FillValue	32767
	long_name	two-way atmospheric attenuation on C band altimeter backscatter coefficient
	units	dB
	scale_factor	0.001
	coordinates	longitude latitude
	quality_flag	rad_atm_cor_sig0_c_qual
	valid_min	0
	valid_max	32766
	comment	Value must be added to altimeter backscatter coefficient to correct for atmospheric attenuation.
short rad_atm_cor_sig0_ka(time)		
	_FillValue	32767
	long_name	two-way atmospheric attenuation on Ka band altimeter backscatter coefficient
	units	dB
	scale_factor	0.001
	coordinates	longitude latitude
	quality_flag	rad_atm_cor_sig0_ka_qual
	valid_min	0
	valid_max	32766
	comment	Value must be added to altimeter backscatter coefficient to correct for atmospheric attenuation.

6 References

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

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[3] N. Picot, "SWOT Product Description Document: Precise and Medium-accuracy Orbit Ephemeris Data Product," SWOT-IS-CDM-0658-CNES, CNES, Toulouse, 2021.

[4] B. Raffier, "SWOT Product Description Document: Reconstructed Attitude Product," SWOT-IS-CDM-0684-CNES, CNES, Toulouse, 2022.

Appendix A. Acronyms

ATBD	Algorithm Theoretical Basis Document
CNES	Centre National d'Études Spatiales
GDR	Geophysical Data Record
HR	High Rate
IGDR	Interim Geophysical Data Record
JPL	Jet Propulsion Laboratory
KaRIn	Ka-band Radar Interferometer
LR	Low Rate
MOE	Medium-accuracy Orbit Ephemeris
NASA	National Aeronautics and Space Administration
OGDR	Operational Geophysical Data Record
POE	Precise Orbit Ephemeris
SWOT	Surface Water Ocean Topography
TBC	To Be Confirmed
TBD	To Be Determined