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Product Specification Document for the OPERA Radiometric Terrain-Corrected SAR Backscatter from Sentinel-1

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Observational Products for End-Users from Remote Sensing Analysis (OPERA) Project

Product Specification Document for the OPERA Radiometric Terrain-Corrected SAR Backscatter from Sentinel-1

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1 INTRODUCTION

1.1 Document Purpose

This document provides a specification of the OPERA (Observational Products for End-users from Remote-sensing Analysis) Level-2 Radiometric Terrain-Corrected SAR backscatter from Sentinel-1 (RTC-S1) product to be generated by the OPERA Science Data System and provided to the NASA's Alaska Satellite Facility (ASF) Distributed Active Archive Center (ASF.DAAC).

1.2 Document Organization

Section 2 provides an overview of the product, including its purpose.

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's GeoTIFF layers.

Section 5 provides qualitative descriptions of the information provided in the product's HDF5 metadata.

Section 6 provides a detailed identification of the individual fields within the RTC-S1 product HDF5 metadata, including for example their units, size, and coordinates.

Appendix A provides a description of geolocation grids and projection systems used for the product.

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

1.3 Applicable and Reference Documents

The product described in this document responds to requirements imposed by applicable documents indicated below. In case of conflict between the applicable documents and this one, the OPERA Project shall review the conflict to find the most effective resolution.

Applicable Documents

[AD1] NASA SNWG Cycle 2 – OPERA Program Level (Level 1) Requirements Document, Oct. 15, 2021

[AD2] OPERA Level 2 Requirements, JPL D-107391, Rev A, Dec. 16, 2021

[AD3] OPERA Product Description, JPL D-107389, Rev A, Dec. 14, 2021

Reference Documents

[RD1] Product Specification Document for the OPERA Radiometric Terrain-Corrected SAR Backscatter from Sentinel-1 Static Layers, JPL D-108764 Rev A, November 6, 2023.

[RD2] Shiroma, Gustavo H. X. and Lavalle, Marco and Buckley, Sean M., "An Area-Based Projection Algorithm for SAR Radiometric Terrain Correction and Geocoding." IEEE Transactions on Geoscience and Remote Sensing 60 (2022): 1–23. [link]

[RD3] OPERA Algorithm Theoretical Basis Document for Radiometric Terrain-Corrected SAR Backscatter from Sentinel-1, JPL D-107393, Rev Preliminary, September 31, 2022.

[RD4] Earth Science Data and Information System (ESDIS) Standards Office (ESO). "GeoTIFF File Format, ESDS-RFC-040v1.1." Earthdata, 16 September. 2019. https://www.earthdata.nasa.gov/esdis/esco/standards-and-practices/geotiff. Accessed 24 September 2023.

[RD5] Cloud Optimized GeoTIFF: An imagery format for cloud-native geospatial processing. www.cogeo.org/. Accessed 24 September 2023.

[RD6] "TIFF/IT for Image Technology." *The National Digital Information Infrastructure and Preservation Program at the Library of Congress*, 3 Oct. 2006, www.loc.gov/preservation/digital/formats/fdd/fdd000072.shtml. Accessed 21 June 2022.

[RD7] HDF5 documentation at https://portal.hdfgroup.org/display/HDF5/HDF5.

The latest official versions of OPERA documents should be obtained from https://www.jpl.nasa.gov/go/opera/about-opera. This document is a 'live' one with the primary purpose of developing and describing the RTC-S1 product for the OPERA Algorithm Development Team's (ADT) Calibration/Validation delivery to the OPERA SDS.

1.4 Applicable Software

This document is being released with the Calibration/Validation delivery of the RTC-S1 Science Application Software (SAS) at this GitHub repository: https://github.com/opera-adt/RTC version 1.0.2 (v1.0.2). The products generated by this version of the SAS are consistent with this document.

2 PRODUCT OVERVIEW

2.1 Product Background

The OPERA RTC-S1 product is derived from the original Copernicus Sentinel-1 (S1) interferometric wide (IW) single-look complex (SLC) data, provided by the European Space Agency (ESA), with a near global scope (land masses excluding Antarctica) and temporal sampling coincident with the availability of S1 A/B SLC data.

Each OPERA RTC-S1 product corresponds to a single S1 burst. The workflow for generating the RTC-S1 requires a run configuration (runconfig) file that contains the parameters for the RTC-S1 Science Application Software (SAS), three input products (Table 2-1), namely the S-1 SAFE file containing the burst to process, the associated S1 orbit ephemerides, and a reference DEM; an optional input consisting of a burst database provided by the OPERA ADT that is used to make sure that all RTC-S1 products with the same burst identification (burst ID) are projected over the same geographic grid. The DEM used for generating the standard OPERA RTC-S1 product is based on the Copernicus DEM 30m (GLO-30) and Copernicus DEM 90 (GLO-90) models.

Radar-geometry layers such as incidence angle, local incidence angle, number of looks, etc., vary slightly over time for each position on the ground, and therefore are considered static for the project. These static layers are packaged into an RTC-S1-STATIC product for each burst ID, and are provided separately from the OPERA RTC-S1 product, as they are produced only once or a limited number of times, to account for changes in the DEM, in the S1 orbit, or in the static-layers generation algorithm [RD1].

The processing for generating OPERA RTC-S1 and RTC-S1-STATIC product follows a similar workflow consisting of six blocks B1-B6 (Figure 2-1). The field “product_type” in the runconfig selects the type of the output product “RTC_S1” (RTC-S1) or “RTC_S1_STATIC” (RTC-S1-STATIC). The steps that are disabled in the processing of RTC-S1-STATIC products are shown in dark blue color in the diagram.

In block B1, the workflow inputs, i.e., S1 SLCs (SAFE file), S1 orbit, and burst DB (optional), are loaded into memory. The SLCs and burst metadata are then passed to block B2, where the radiometric calibration converts the input S1 SLC represented as digital numbers (DNs) into beta-naught backscattering β_0 (beta naught) by radiometric calibration and thermal noise correction. In block B3, the layover/shadow mask is computed over the range-Doppler geometry and the shadow pixels are dilated by pre-defined window size (if not set by the user). Also, in B3, the azimuth and range shifts due to bistatic and static-troposphere delays are computed as look-up tables (LUTs). The layover/shadow mask, range and azimuth LUTs, along with the reference DEM are passed to ISCE3 for radiometric terrain correction (RTC) and geocoding [RD2][RD3]. Resulting layers are saved as cloud optimized GeoTIFFs (COGs) in block B5, and the full product metadata is saved in the HDF5 format in block B6.

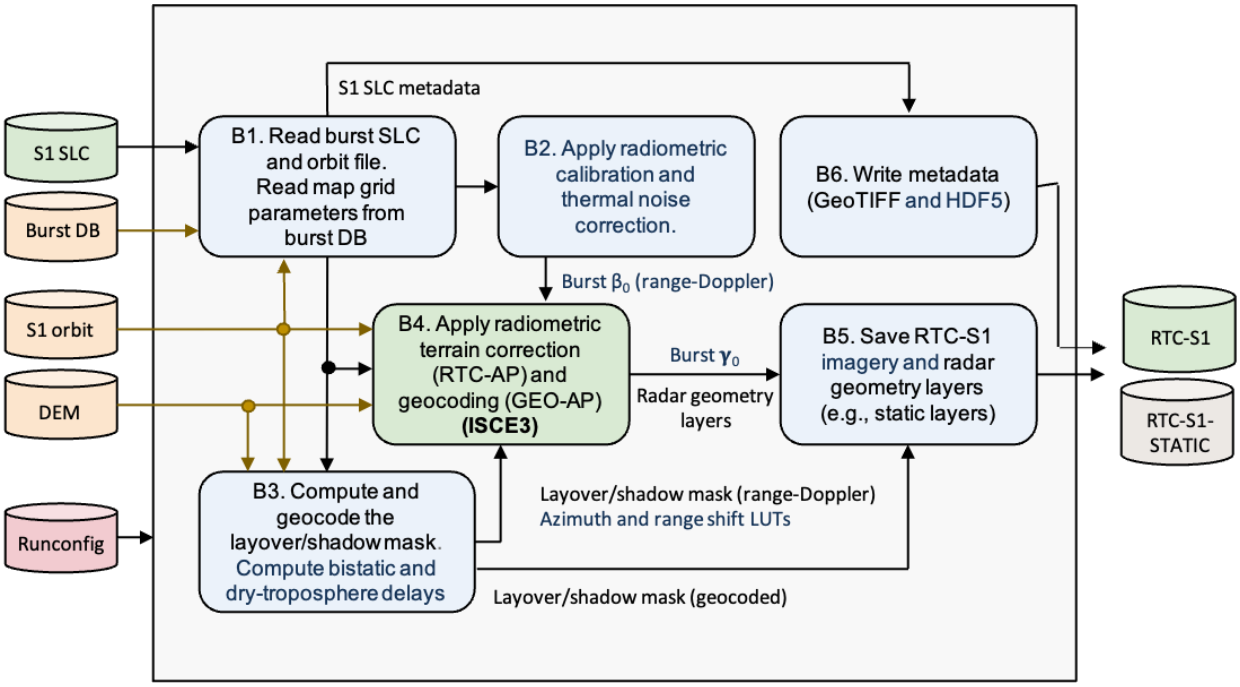

Figure 2-1 Diagram illustrating the OPERA RTC-S1 and RTC-S1-STATIC products' workflow. The steps shown in dark blue color are only enabled in the production of OPERA RTC-S1 products.

Table 2-1 Input products and files for RTC-S1 product.

Product	Description	Granule Size
S1 SAFE file	The input S1 SAFE file	Variable
S1 orbit ephemerides	The input S1 orbit ephemerides	Variable
DEM	Reference DEM	Variable
Burst DB (optional)	Burst database in SQLite format	Fixed

2.2 RTC-S1 Product Overview

The RTC-S1 product is a Level 2 product that contains S1 backscatter normalized with respect to the topography and projected onto pre-defined UTM/ Polar stereographic system map grid (Appendix A: Geocoded Product Grids) with a 30-meter spacing (Table 2-2).

RTC-S1 images are normalized to the backscatter coefficient gamma0 γ_0 obtained from the original radar brightness β_0 through radiometric terrain correction. The RTC-S1 product includes an RTC area normalization factor (ANF) layer, provided with the same dimensions as the RTC imagery, that can be used to approximate the images to the β_0 convention. The RTC-S1 polarimetric imagery is distributed in a lexicographic polarimetric basis as individual cloud-optimized GeoTIFFs (COGs) [RD4][RD5], i.e., one GeoTIFF file per processed polarization.

Due to the S1 mission narrow orbital tube, radar-geometry layers such as incidence angle, local incidence angle, number of looks, and RTC ANF vary slightly over time for each position on the ground, and therefore are considered static for the project. These *static layers* are provided separately from the OPERA RTC-S1 product, as they are produced only once or a limited number of times, to account for changes in the DEM, in the S1 orbit, or in the static-layers generation algorithm. Static layers will also be provided as single-band COG files, with map grid matching RTC-S1 products with the same burst ID.

The RTC-S1 metadata is provided in the Hierarchical Data Format version 5 (HDF5) format [RD7]. All relevant data and lookup tables are converted to map coordinates. The HDF5 file also include RTC-S1 product metadata including the input S1 SLC metadata (e.g., processing parameters and orbit metadata); sensor information (left/right-looking, sensor name, wavelength, polarization, radar frequency); RTC processing information (algorithms and parameters); and product geolocation grid (including coordinate reference system and map projection).

Table 2-2 Pixel spacing of the RTC-S1 product.

Product	Pixel spacing in Northing (m)	Pixel spacing in Easting (m)
RTC-S1	30	30
RTC-S1-STATIC	30	30

3 PRODUCT ORGANIZATION

The RTC-S1 product is distributed as cloud-optimized GeoTIFF files (COGs) containing the RTC-S1 polarimetric imagery, i.e., the normalized SAR backscatter for each polarization channel (usually two for VV and VH polarizations) and a mask file. It also includes an HDF5 file containing the RTC-S1 product metadata and a browse image in the Portable Network Graphic (PNG) format.

The associated RTC-S1-STATIC product contains additional layer provided as cloud-optimized GeoTIFF files (COGs): local incidence angle, incidence angle, mas, number of looks, and RTC area normalization factor (ANF) gamma0 to beta0 and RTC ANF gamma0 to sigma0.

3.1 File Naming Convention

OPERA RTC-S1 granule names are designed to ensure unique and descriptive identification for the OPERA RTC-S1 products. The following file-naming convention is used:

OPERA_L2_RTC-S1_[BurstID]_[StartDateTime]_[ProductGenerationDateTime]_[Sensor]_[PixelSpacing]_[ProductVersion]{_[LayerName]}.Ext

- BurstID: Unique burst identification string consistent with ESA burst map convention in the form of T[TrackNumber]-[ID]-[SubSwath] (e.g, T069-147170-IW1)
- StartDateTime: The acquisition start date and time (Greenwich Mean Time or GMT) of the S1 SAFE file that was used as an input to the RTC-S1 SAS (e.g., burst SLCs) (format: YYYYMMDDTHHMMSSZ)
- ProductGenerationDateTime: The date and time (GMT) at which the product was generated by OPERA (format: YYYYMMDDTHHMMSSZ)
- Sensor: The input product sensor, e.g., “S1A” representing Sentinel-1A
- PixelSpacing: Pixel spacing in meters
- ProductVersion: OPERA RTC-S1 product version number with four characters, including the letter “v” and two digits indicating the major and minor versions, which are delimited by a period
- LayerName: Name of the RTC-S1 product layer (e.g., “VV”), if applicable.
- Ext: File extension: “tif”, “h5”, or “png”.

Example:
OPERA_L2_RTC-S1_T069-147170-IW1_20210205T163901Z_20220101T140222Z_S1A_30_v1.0.h5
OPERA_L2_RTC-S1_T069-147170-IW1_20210205T163901Z_20220101T140222Z_S1A_30_v1.0_VV.tif
OPERA_L2_RTC-S1_T069-147170-IW1_20210205T163901Z_20220101T140222Z_S1A_30_v1.0_VH.tif
OPERA_L2_RTC-S1_T069-147170-IW1_20210205T163901Z_20220101T140222Z_S1A_30_v1.0_mask.tif

3.2 Temporal Organization

The OPERA RTC-S1 temporal sampling of RTC data matches available Sentinel-1 A/B SLCs.

3.3 Spatial Organization

The OPERA RTC-S1 data are arranged on a uniformly spaced, North-up and West-left grid – i.e., decreasing North or Y coordinate in the row direction and increasing East or X coordinate in the column direction following the row-major order convention of representing 2D raster arrays. Pixel-is-area convention (see Appendix A: Geocoded Product Grids) is used to tag the raster layers with coordinate information.

3.4 Spatial Sampling and Resolution

Some salient features of the output grid for the RTC-S1 product are:

1. All imagery layers of the RTC-S1 product will be located over the same geographical grid.
2. The geographical grid coordinates will be a multiple of the pixel spacing for easy comparison with other RTC-S1 products of same burst ID.

3.4.1 Mosaicking

The spatial sampling of the output grid has been designed to facilitate the mosaicking of contiguous RTC-S1 product granules if the user desires. See Appendix A: Geocoded Product Grids for details on the common output grid used for all L2 products.

4 THE OPERA RTC-S1 PRODUCT

OPERA RTC-S1 layers are generated over UTM/ Polar Stereographic coordinates (see Appendix A: Geocoded Product Grids). The RTC-S1 product can be directly overlaid on a map or combined with other similar RTC-S1 products to create change maps, for example.

In this section, we briefly describe the layout of RTC-S1 data packaged into GeoTIFF files and associated metadata. The RTC-S1 product represents radar backscattering in γ_0. Conversion to β_0 is accomplished using the area normalization factor provided at the same posting as the imagery layers.

4.1 File format - GeoTIFF

OPERA RTC-S1 polarimetric imagery and static layers such as layover/shadow mask, RTC ANF, number of looks, and local-incidence angle are distributed as single-band cloud optimized GeoTIFFs (COGs) [RD4] [RD5].

The GeoTIFF is a format to store georeferenced raster images and is widely used by remote-sensing communities. The GeoTIFF format is defined in the public domain as Tagged Image File Format (TIFF) [RD6] It enables the storage of compressed images with associated metadata that can be easily read by Geographic Information System (GIS) software, including the open Geospatial Data Abstraction Library (GDAL) and Quantum GIS (QGIS).

To save storage space, each GeoTIFF file is compressed using the DEFLATE algorithm.

4.2 Radar Imagery

The RTC-S1 radar imagery is saved as individual COG files, one for each polarization. The radar backscatter is normalized to gamma0 γ_0 to reduce the dependence of the radar backscatter with the topography.

4.3 Mask

The mask layer contains the valid/invalid, layover, and shadow classification computed using the RTC-S1 burst orbit, and it is provided over the same geographic grid as the associated geocoded imagery. The mask layer contains 5 classes represented by an unsigned byte data type:

- Class 0: Valid sample not affected by layover or shadow
- Class 1: Valid sample affected by shadow
- Class 2 - Valid sample affected by layover
- Class 3: Valid sample affected by layover and shadow
- Class 255: Invalid sample (fill value)

4.4 Static layers (RTC-S1-STATIC product)

Static layers are identified by the burst ID and they are provided in the same map grid as the RTC-S1 product. Since static layers are produced only once or a limited number of times, to account for changes in the DEM, in the S1 orbit, or in the static-layers generation algorithm, they are provided separately from the RTC-S1 product. Static layers include the RTC ANF, number of looks, layover/shadow mask, incidence angle, and local-incidence angle.

4.4.1 Local-incidence angle

Local-incidence angle is defined as angle between LOS vector and terrain normal vector at the target provided in the same geographic grid as the geocoded imagery.

4.4.2 Incidence angle

Incidence angle is defined as angle between LOS vector and the ellipsoid normal at the target provided in the same geographic grid as the geocoded imagery.

4.4.3 Mask

The mask layer contains the valid/invalid, layover, and shadow classification computed over the reference RTC-S1-STATIC burst orbit, and it is provided over the same geographic grid as the associated geocoded imagery. The mask layer contains 5 classes represented by an unsigned byte data type:

- Class 0: Valid sample not affected by layover or shadow
- Class 1: Valid sample affected by shadow
- Class 2 - Valid sample affected by layover
- Class 3: Valid sample affected by layover and shadow
- Class 255: Invalid sample (fill value)

4.4.4 Number of Looks

The radar imagery is obtained from the geocoding of S1 SLCs using an adaptive multi-looking algorithm. The algorithm uses an area-based projection approach to multi-look radar samples that intersect completely or partially with each geographical grid pixel according to topography and radar geometry. The number of looks layer indicates the number of radar samples used to compute each RTC-S1 imagery pixel and it is provided in the same geographic grid as the RTC-S1 product imagery.

4.4.5 Radiometric Terrain Correction (RTC) Area Normalization Factor (ANF) Gamma0 to Beta0

The radar backscatter is normalized to gamma0 γ_0 to reduce the dependence of the radar backscatter with the topography. The radiometric terrain correction (RTC) normalizes the original S1 backscatter from beta0 to gamma0. The RTC area normalization factor (ANF) gamma0 to beta0 provides the factors to normalize the gamma0 backscatter to beta0. This layer is provided in the same grid as the corresponding RTC-S1 imagery.

4.4.6 Radiometric Terrain Correction (RTC) Area Normalization Factor (ANF) Gamma0 to Sigma0

The RTC area normalization factor (ANF) gamma0 to sigma0 provides the factors to normalize the gamma0 backscatter to sigma0. This layer is provided in the same grid as the associated RTC-S1 imagery.

4.5 GeoTIFF metadata

All RTC-S1 product layers (GeoTIFF files) are saved with the same metadata, divided into four sections: 1) Product Identification, 2) Input Datasets, 3) Sentinel-1 IW SLC parameters, 4) RTC-S1 Processing Information, and 5) Radio Frequency Interference (RFI) information.

4.5.1 Product Identification

Table 4-1 lists the product identification fields of the GeoTIFF metadata. The attribute PRODUCT_VERSION informs the version of the RTC-S1 product (structure and metadata), whereas the attribute SOFTWARE_VERSION describes the version of the software that generated the RTC-S1 product.

Table 4-1. GeoTIFF metadata: product identification.

Attribute	Description
LAYER_NAME	Product layer name
LAYER_DESCRIPTION	Product layer description
ABSOLUTE_ORBIT_NUMBER	Absolute orbit number
TRACK_NUMBER	Track number
PLATFORM	Name of the sensor platform (e.g., “Sentinel-1A”)
INSTRUMENT_NAME	Name of the instrument used to collect the remote sensing data provided in this product (e.g., “Sentinel-1A CSAR”)
PRODUCT_TYPE	The product type: “RTC-S1”
PROJECT	The project name: “OPERA”
INSTITUTION	Institution that created this product: “NASA JPL”
CONTACT_INFORMATION	Contact information for producer of the product: "operasds@jpl.nasa.gov"

PRODUCT_VERSION	The product version (same as in the product filename): “1.0”
PRODUCT_SPECIFICATION_VERSION	Product specification version which represents the schema of this product: “1.0”
ACQUISITION_MODE	Acquisition mode: “IW”
CEOS_ANALYSIS_READY_DATA_PRODUCT_TYPE	CEOS Analysis Ready Data (CARD) product type
LOOK_DIRECTION	Look direction: “right”
ORBIT_PASS_DIRECTION	Orbit direction can be ascending or descending
PRODUCT_LEVEL	The product level: “L2”. Product levels: - L0A: Unprocessed instrument data; - L0B: Reformatted, unprocessed instrument data; - L1: Processed instrument data in radar coordinates system; - L2: Processed instrument data in geocoded coordinates system
PROCESSING_TYPE	Processing type: “NOMINAL” or “URGENT” or “CUSTOM” or “UNDEFINED”
PROCESSING_DATETIME	RTC-S1 product processing date. Format: YYYY-MM-DDTHH:MM:SSZ.
RADAR_BAND	Acquired frequency band: “C”
CEOS_ANALYSIS_READY_DATA_DOCUMENT_IDENTIFIER	CEOS Analysis Ready Data (CARD) document identifier
PRODUCT_DATA_ACCESS	Location from where this product can be retrieved (URL or DOI)
STATIC_LAYERS_DATA_ACCESS	Location of the static layers product associated with this product (URL or DOI)

BOUNDING_BOX	Bounding box of the product, in order of xmin, ymin, xmax, ymax
BOUNDING_BOX_EPSG_CODE	EPSG code used to represent BOUNDING_BOX coordinates
BOUNDING_BOX_PIXEL_COORDINATE_CONVENTION	Pixel coordinate convention used to represent BOUNDING_BOX coordinates: “edges/corners”
BOUNDING_POLYGON	OGR compatible WKT representation of the RTC-S1 product bounding polygon
BOUNDING_POLYGON_EPSG_CODE	EPSG code used to represent BOUNDING_POLYGON coordinates
BURST_ID	Burst identification (burst ID)
SUB_SWATH_ID	Sub-swath identification
ZERO_DOPPLER_START_TIME	Azimuth start time of the product in the format YYYY-MM-DDThh:mm:ss.sZ
ZERO_DOPPLER_END_TIME	Azimuth stop time of the product in the format YYYY-MM-DDThh:mm:ss.sZ

4.5.2 Input Datasets

Table 4-2 describes the metadata fields that list the input datasets used to generate the RTC-S1 product.

Table 4-2 GeoTIFF metadata: input datasets.

Attribute	Description
INPUT_L1_SLC_GRANULES	List of input L1 SLC products used
INPUT_ORBIT_FILES	List of input orbit files used
INPUT_DEM_SOURCE	Description of the input DEM
INPUT_ANNOTATION_FILES	List of input annotation files used

4.5.3 Sentinel-1 IW SLC Parameters

Table 4-3 describes the metadata fields describing the input Sentinel-1 SLC parameters.

Table 4-3 GeoTIFF metadata: Sentinel-1 SLC parameters.

Attribute	Description
CENTER_FREQUENCY	Center frequency of the processed image in Hz
SOURCE_DATA_ACCESS	Location from where the source data can be retrieved (URL or DOI)
SOURCE_DATA_NUMBER_OF_ACQUISITIONS	Number of source data acquisitions: “1”
SOURCE_DATA_INSTITUTION	Institution that created input product: “ESA”
SOURCE_DATA_PROCESSING_CENTER	Source data processing center

SOURCE_DATA_PROCESSING_DATETIME	Processing date and time of the source data
SOURCE_DATA_SOFTWARE_VERSION	Version of the software used to create the source data (IPF version)
SOURCE_DATA_PRODUCT_LEVEL	Product level of the source data: “L1”. Product levels: - L0A: Unprocessed instrument data; - L0B: Reformatted, unprocessed instrument data; - L1: Processed instrument data in radar coordinates system; - L2: Processed instrument data in geocoded coordinates system
SOURCE_DATA_RANGE_BANDWIDTH	Processed range bandwidth in Hz
SOURCE_DATA _AVERAGE_ZERO_DOPPLER_SPACING_IN_METERS	Average pixel spacing in meters between consecutive lines in the along-track direction of the source data
SOURCE_DATA_SLANT_RANGE_SPACING	Distance in meters between consecutive range samples of the source data
SOURCE_DATA _SLANT_RANGE_RESOLUTION_IN_METERS	Slant-range resolution of the source data in meters
SOURCE_DATA_SLANT_RANGE_START	Slant-range start distance of the source data
SOURCE_DATA_NUMBER_OF_RANGE_SAMPLES	Number of slant range samples for each azimuth line within the source data
SOURCE_DATA_ZERO_DOPPLER_TIME_SPACING	Time interval in the along-track direction of the source data
SOURCE_DATA _AZIMUTH_RESOLUTION_IN_METERS	Azimuth resolution of the source data in meters
SOURCE_DATA_ZERO_DOPPLER_START_TIME	Azimuth start time of the input product in the format YYYY-MM-DDThh:mm:ss.sZ

SOURCE_DATA_ZERO_DOPPLER_END_TIME	Azimuth stop time of the input product in the format YYYY-MM-DDThh:mm:ss.sZ
SOURCE_DATA_NUMBER_OF_AZIMUTH_LINES	Number of azimuth lines within the source data product

4.5.4 Processing Information

Table 4-4 lists processing and other product parameters associated with the RTC-S1 product.

Table 4-4 GeoTIFF metadata: RTC-S1 processing parameters.

Attribute	**Description**
SOFTWARE_VERSION	The algorithm software version used to generate the RTC-S1 product. This document is consistent with SOFTWARE_VERSION 1.0.2
ISCE3_VERSION	Version of the ISCE3 framework used for processing
S1_READER_VERSION	Version of the OPERA s1-reader
AREA_OR_POINT	Indicates that pixel values are assumed to represent an area rather than points: “Area”
PROCESSING_INFORMATION_MULTILOOKING_APPLIED	Flag to indicate if pre-processing multilooking has been applied
PROCESSING_INFORMATION_FILTERING_APPLIED	Flag to indicate if post-processing filtering has been applied
PROCESSING_INFORMATION_NOISE_CORRECTION_APPLIED	Flag to indicate if noise removal has been applied
PROCESSING_INFORMATION _RADIOMETRIC_TERRAIN_CORRECTION_APPLIED	Flag to indicate if radiometric terrain correction (RTC) has been applied

PROCESSING_INFORMATION _STATIC_TROPOSPHERIC_GEOLOCATION_CORRECTION_APPLIED	Flag to indicate if the static tropospheric correction has been applied
PROCESSING_INFORMATION _WET_TROPOSPHERIC_GEOLOCATION_CORRECTION_APPLIED	Flag to indicate if the wet tropospheric correction has been applied
PROCESSING_INFORMATION _BISTATIC_DELAY_CORRECTION_APPLIED	Flag to indicate if the bistatic delay correction has been applied
PROCESSING_INFORMATION_DEM_INTERPOLATION_ALGORITHM	DEM interpolation method
PROCESSING_INFORMATION_DEM_EGM_MODEL	Earth Gravitational Model associated with the DEM
PROCESSING_INFORMATION_GEOCODING_ALGORITHM	Geocoding algorithm
PROCESSING_INFORMATION _RADIOMETRIC_TERRAIN_CORRECTION_ALGORITHM	Radiometric terrain correction (RTC) algorithm
PROCESSING_INFORMATION _NOISE_REMOVAL_ALGORITHM_REFERENCE	A reference to the noise removal algorithm applied
PROCESSING_INFORMATION _RADIOMETRIC_TERRAIN_CORRECTION_ALGORITHM_REFERENCE	A reference to the radiometric terrain correction (RTC) algorithm applied
PROCESSING_INFORMATION _GEOCODING_ALGORITHM_REFERENCE	A reference to the geocoding algorithm applied
PROCESSING_INFORMATION _INPUT_BACKSCATTER_NORMALIZATION_CONVENTION	Backscatter normalization convention of the source data
PROCESSING_INFORMATION _OUTPUT_BACKSCATTER_NORMALIZATION_CONVENTION	Backscatter normalization convention of the radar imagery associated with this product
PROCESSING_INFORMATION	Backscatter expression convention

_OUTPUT_BACKSCATTER_EXPRESSION_CONVENTION	
PROCESSING_INFORMATION _OUTPUT_BACKSCATTER_DECIBEL_CONVERSION_EQUATION	Equation to convert provided backscatter to decibel (dB)
PROCESSING_INFORMATION_BURST_GEOGRID_SNAP_X	Burst geogrid snap for Coordinate X (W/E)
PROCESSING_INFORMATION_BURST_GEOGRID_SNAP_Y	Burst geogrid snap for Coordinate Y (S/N)

4.5.5 Quality Assurance Information

Table 4-5 lists the QA metadata fields including geolocation accuracy and radio frequency interference (RFI) that may be provided in the RTC-S1 product if RFI is detected. The flag QA_RFI_INFO_AVAILABLE indicates if the RFI information is available.

Table 4-5. GeoTIFF metadata: RTC-S1 RFI information.

Attribute	**Description**
QA_GEOMETRIC_ACCURACY_BIAS_X	An estimate of the localization error bias in the easting direction
QA_GEOMETRIC_ACCURACY_BIAS_Y	An estimate of the localization error bias in the northing direction
QA_GEOMETRIC_ACCURACY_STDDEV_X	An estimate of the localization error standard deviation in the easting direction
QA_GEOMETRIC_ACCURACY_STDDEV_Y	An estimate of the localization error standard deviation in the northing direction
QA_RFI_INFO_AVAILABLE	A flag to indicate whether RFI information is available in the source data

QA_RFI_MITIGATION_PERFORMED*	RFI detection and mitigation strategy
QA_RFI_MITIGATION_DOMAIN*	Domain in which the RFI mitigation was performed
QA_RFI_BURST_REPORT_SWATH*	Swath associated with the IW RFI burst report list
QA_RFI_BURST_REPORT_AZIMUTH_TIME*	Sensing start time of the burst that corresponds to the RFI report in the format YYYY-MM-DDThh:mm:ss.sZ
QA_RFI_IN_BAND_OUT_BAND_POWER_RATIO*	Ratio between the in-band and out-of-band power of the burst
QA_RFI_TIME_DOMAIN_REPORT_PERCENTAGE_AFFECTED_LINES*	Percentage of level-0 lines affected by RFI
QA_RFI_TIME_DOMAIN_REPORT_AVG_PERCENTAGE_AFFECTED_SAMPLES*	Average percentage of affected level-0 samples in the lines containing RFI
QA_RFI_TIME_DOMAIN_REPORT_MAX_PERCENTAGE_AFFECTED_SAMPLES*	Maximum percentage of level-0 samples affected by RFI in the same line
QA_RFI_FREQUENCY_DOMAIN_REPORT_NUM_SUB_BLOCKS*	Number of sub-blocks in the current burst
QA_RFI_FREQUENCY_DOMAIN_REPORT_SUB_BLOCK_SIZE*	Number of lines in each sub-block
QA_RFI_FREQUENCY_DOMAIN_REPORT_ISOLATED _PERCENTAGE_AFFECTED_LINES*	Percentage of level-0 lines affected by RFI
QA_RFI_FREQUENCY_DOMAIN_REPORT_ISOLATED _MAX_BANDWIDTH_PERCENTAGE_AFFECTED_LINES*	Maximum percentage of bandwidth affected by isolated RFI in a single line
QA_RFI_FREQUENCY_DOMAIN_REPORT _PERCENTAGE_BLOCKS_PERSISTENT_RFI*	Percentage of processing blocks affected by persistent RFI. In this case the RFI detection is performed on the

	mean power spectrum density (PSD) of each processing block.
QA_RFI_FREQUENCY_DOMAIN_REPORT _MAX_PERCENTAGE_BW_AFFECTED_PERSISTENT_RFI*	Maximum percentage of the bandwidth affected by persistent RFI in a single processing block

* Fields that may or may not be available depending on the availability of RFI information from the input S1 IW SLC dataset.

5 OPERA RTC-S1 PRODUCT METADATA (HDF5 FILE)

5.1 File format – Metadata (HDF5)

The RTC-S1 product metadata is provided in Hierarchical Data Format version 5 (HDF5, [RD7]). HDF5 is a general-purpose file format and programming library for storing scientific data. The National Center for Supercomputing Applications (NCSA) at the University of Illinois developed HDF to help scientists share data more easily. Use of the HDF library enables users to read HDF files regardless of the underlying computing environments. HDF files are equally accessible in Fortran, C/C++, and other high-level computation packages such as IDL or MATLAB.

The HDF Group, a spin-off organization of the NCSA, is responsible for development and maintenance of HDF. Users should reference The HDF Group website at https://portal.hdfgroup.org/display/HDF5/HDF5 [RD7] to download HDF software and documentation.

HDF5 represents a significant departure from the conventions of previous versions of HDF. The changes that appear in HDF5 provide flexibility to overcome many of the limitations of previous releases. The basic building blocks have been largely redefined, and are more powerful but less numerous. The key concepts of the HDF5 Abstract Data Model are Files, Groups, Datasets, Datatypes, Attributes and Property Lists. The following sections provide a brief description of each of these key HDF5 concepts.

5.1.1 HDF5 File

A File is the abstract representation of a physical data file. Files are containers for HDF5 Objects. These Objects include Groups, Datasets, and Datatypes.

5.1.2 HDF5 Group

Groups provide a means to organize the HDF5 Objects in HDF5 Files. Groups are containers for other Objects, including Datasets, named Datatypes and other Groups. In that sense, groups are analogous to directories that are used to categorize and classify files in standard operating systems.

The notation for files is identical to the notation used for Unix directories. The root Group is “/”. A Group contained in root might be called “/myGroup.” Like Unix directories, Objects appear in Groups through “links”. Thus, the same Object can simultaneously be in multiple Groups.

5.1.3 HDF5 Dataset

The Dataset is the HDF5 component that stores user data. Each Dataset associates with a Dataspace that describes the data dimensions, as well as a Datatype that describes the basic unit of storage element. A Dataset can also have Attributes.

5.1.4 HDF5 Datatype

A Datatype describes a unit of data storage for Datasets and Attributes. Datatypes are subdivided into Atomic and Composite Types.

Atomic Datatypes are analogous to simple basic types in most programming languages. HDF5 Atomic Datatypes include Time, Bitfield, String, Reference, Opaque, Integer, and Float. Each atomic type has a specific set of properties. Examples of the properties associated with Atomic Datatypes are:

- Integers are assigned size, precision, offset, pad byte order, and are designated as signed or unsigned.
- Strings can be fixed or variable length, and may or may not be null-terminated.
- References are constructs within HDF5 Files that point to other HDF5 Objects in the same file.

HDF5 provides a large set of predefined Atomic Datatypes. Table 5-1 lists the Atomic Datatypes that are used in OPERA RTC-S1 products.

Table 5-1. HDF5 Atomic Datatypes

HDF5 Atomic Datatypes	Description
H5T_STD_U8LE	unsigned, 8-bit, little-endian integer
H5T_STD_U16LE	unsigned, 16-bit, little-endian integer
H5T_STD_U32LE	unsigned, 32-bit, little-endian integer
H5T_STD_U64LE	unsigned, 64-bit, little-endian integer
H5T_STD_I8LE	signed, 8-bit, little-endian integer
H5T_STD_I16LE	signed, 16-bit, little-endian integer
H5T_STD_I32LE	signed, 32-bit, little-endian integer
H5T_STD_I64LE	Signed, 64-bit, little-endian integer
H5T_IEEE_F32LE	32-bit, little-endian, IEEE floating point

HDF5 Atomic Datatypes	Description
H5T_IEEE_F64LE	64-bit, little-endian, IEEE floating point
H5T_C_S1	character string made up of one or more bytes

5.1.5 HDF5 Attribute

An Attribute is a small aggregate of data that describes Groups or Datasets. Like Datasets, Attributes are also associated with a particular Dataspace and Datatype. Attributes cannot be subsetted or extended. Attributes themselves cannot have Attributes.

5.2 OPERA RTC-S1 HDF5 File Organization

5.2.1 Groups

All OPERA RTC-S1 HDF5 files are organized as groups with no actual data at the root("/") level. Table 5-2 shows the general layout of the HDF5 files that are generated by the OPERA Science Data System.

Table 5-2 Group organization at the top level of a OPERA RTC-S1 HDF5 File

Group Name	Description
/identification	Product identification
/data	Since RTC-S1 images and static layers are provide outside of the HDF5 file, this group contains only the information about the data geographic grid.
/metadata	Product metadata

5.2.2 File Level Metadata

Global metadata at the file level are currently given as Global Attributes shown in Table 5-3.

Metadata regarding the data in the particular granule are given in "/identification". These data are described further in Sec 5.4 and Sec 6.2.

Table 5-3 Global Attributes of RTC-S1

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this product. This attribute should be set to CF-1.8 to indicate that the group is compliant with the Climate and Forecast NetCDF conventions.
title	string	OPERA RTC-S1 Product
institution	string	Name of producing agency.
project	string	"OPERA"
reference_document	string	Name and version of Product Description Document to use as reference for product.
contact	string	Contact information for producer of the product: "operasds@jpl.nasa.gov".

5.2.3 Variable Metadata (HDF5 Attributes)

OPERA standards incorporate additional metadata that describe each HDF5 Dataset within the HDF5 file. Each of these metadata elements appear in an HDF5 Attribute that is directly associated with the HDF5 Dataset.

5.3 Dimensions and Shapes of Data

Information on the dimensions and shapes of the data items in various data tables is described as part of the metadata (Sec 6.1). This information is useful both as part of the product identification and for setting up further processing, i.e., dimensioning arrays.

5.4 Product Identification

Information needed to identify this particular product is given under the Group "/identification" (Sec 6.2). This includes information such as orbit number, track-frame number, acquisition times, a polygon representing the bounding box of the included imagery in geographic coordinates, and product version.

5.5 Radar Metadata

The Group "/metadata" provides information about the source data ("metadata/sourceData"), processing workflow inputs, algorithms, and parameters ("processingInformation"), satellite orbit ("metadata/orbit"), and quality assurance (QA).

5.5.1 Source Data

Section 6.4 includes the input S1 SLC dataset metadata, mostly parsed from the annotation files provided along the S1 SLC dataset provided by ESA.

5.5.2 Processing Information

Metadata giving processing parameters, algorithms, and inputs used are given under in Section 6.5.

5.5.2.1 Parameters

Processing parameters are organized by frequency under the subgroup "processingInformation/parameters".

5.5.2.2 Processing Version Information

The RTC-S1 SAS and ISCE3 version and the names and types of the ISCE3 algorithms used in the processing are given under the subgroup "processingInformation/algorithms".

5.5.2.3 Input Files

All the mission input files – S1 SLC, orbit, calibration, DEM and configuration files are tracked and listed under the subgroup "processingInformation/inputs".

5.5.3 Orbit

Section 6.66.4 describes the orbit ephemeris used for generating the RTC-S1 under a subgroup named "metadata/orbit". This group includes time-tagged antenna phase center position and velocity vectors in Earth Centered Earth Fixed (ECEF) cartesian coordinates.

5.5.4 Quality Assurance

Section 6.7 provides quality assurance (QA) metadata containing radio frequency interference (RFI) information under a subgroup named "metadata/QA". The RFI-related variables are only included in the RTC-S1 product when RFI is detected and its associated information is available through the input S1 dataset annotation files. The presence of RFI metadata is indicated by the HDF5 Dataset "/metadata/QA/rfiInformation/isRfiInfoAvailable"

6 PRODUCT SPECIFICATION

6.1 Dimensions and Shapes

To simplify the description of the layout of data within the HDF5 file, we will use a table of dimensions and shapes to represent the relationship between similarly sized datasets. The entries in this table do not present actual datasets in the HDF5. This table is meant to be a guide to interpreting the shapes of the datasets in subsequent subsections.

Table 6-1 Table of dimensions and shapes in RTC-S1 product

Name	Shape	Description
scalar	scalar	None
numberOfObservations	scalar	number of observations in product
numberOfPolarizations	scalar	Number of polarization layers associated with the product
width	scalar	Number of pixels in all imagery datasets
length	scalar	Number of lines in all imagery datasets
productShape	(length, width)	Shape associated with imagery datasets
orbitListlength	scalar	description="Number of orbit state vectors
orbitShape	(orbitListlength, 3)	Shape of orbit state vector triplets dataset
numberOfInputL1Files	scalar	Number of input L1 granules
numberOfInputOrbitFiles	scalar	Number of input orbit files
numberOfInputAnnotationFiles	scalar	Number of input calibration files
numberOfInputConfigFiles	scalar	Number of input configuration files

6.2 Product Identification

Table 6-2 OPERA RTC-S1 HDF5 variables used for product identification

Product Identification Variables		
/identification/absoluteOrbitNumber		
Type: UInt64	**Shape: scalar**	
Description: Absolute orbit number		
	units	unitless
/identification/trackNumber		
Type: UByte	**Shape: scalar**	
Description: Track number		
	units	unitless
/identification/burstID		
Type: string	**Shape: scalar**	
Description: Burst identification (burst ID)		
/identification/subSwathID		
Type: string	**Shape: scalar**	
Description: Sub-swath identification		
/identification/platform		
Type: string	**Shape: scalar**	
Description: Platform name		
/identification/instrumentName		
Type: string	**Shape: scalar**	
Description: Name of the instrument used to collect the remote sensing data provided in this product		
/identification/productType		
Type: string	**Shape: scalar**	
Description: Product type		
/identification/project		
Type: string	**Shape: scalar**	
Description: Project name		
/identification/institution		
Type: string	**Shape: scalar**	
Description: Institution name		
/identification/contactInformation		
Type: string	**Shape: scalar**	
Description: Contact information for producer of this product		
/identification/productVersion		
Type: string	**Shape: scalar**	
Description: Product version which represents the structure of the product and the science content governed by the algorithm, input data, and processing parameter		
/identification/productSpecificationVersion		
Type: string	**Shape: scalar**	
Description: Product specification version which represents the schema of this product		
/identification/acquisitionMode		
Type: string	**Shape: scalar**	
Description: Acquisition mode		
/identification/ceosAnalysisReadyDataProductType		
Type: string	**Shape: scalar**	
Description: CEOS Analysis Ready Data (CARD) product type		

/identification/lookDirection		
Type: string		**Shape: scalar**
Description: Look direction can be left or right		
/identification/orbitPassDirection		
Type: string		**Shape: scalar**
Description: Orbit direction can be ascending or descending		
/identification/zeroDopplerStartTime		
Type: string		**Shape: scalar**
Description: Azimuth start time of the product in the format YYYY-MM-DDThh:mm:ss.sZ		
/identification/zeroDopplerEndTime		
Type: string		**Shape: scalar**
Description: Azimuth stop time of the product in the format YYYY-MM-DDThh:mm:ss.sZ		
/identification/isGeocoded		
Type: boolean		**Shape: scalar**
Description: Flag to indicate whether the primary product data is in radar geometry ("False") or map geometry ("True")		
/identification/productLevel		
Type: string		**Shape: scalar**
Description: Product level. L0A: Unprocessed instrument data; L0B: Reformatted, unprocessed instrument data; L1: Processed instrument data in radar coordinates system; and L2: Processed instrument data in geocoded coordinates system		
/identification/boundingPolygon		
Type: string		**Shape: scalar**
Description: OGR compatible WKT representation of the product bounding polygon		
/identification/boundingBox		
Type: Float64		**Shape: scalar**
Description: Bounding box of the product, in order of xmin, ymin, xmax, ymax		
	epsg	4326
	pixel_coordinate_convention	Upper left corner (ULC)
/identification/processingType		
Type: string		**Shape: scalar**
Description: Processing type: "NOMINAL", "STATIC_LAYERS", "URGENT", "CUSTOM", or "UNDEFINED"'		
/identification/processingDateTime		
Type: string		**Shape: scalar**
Description: Processing UTC date and time in the format YYYY-MM-DDThh:mm:ss.sZ		
/identification/radarBand		
Type: string		**Shape: scalar**
Description: Acquired frequency band		
/identification/ceosAnalysisReadyDataDocumentIdentifier		
Type: string		**Shape: scalar**
Description: CEOS Analysis Ready Data (CARD) document identifier		
/identification/dataAccess		
Type: string		**Shape: scalar**
Description: Location from where this product can be retrieved (URL or DOI)		
/identification/staticLayersDataAccess		
Type: string		**Shape: scalar**
Description: Location of the static layers product associated with this product (URL or DOI)		

6.3 Radar Imagery

Table 6-3 OPERA RTC-S1 HDF5 variables related to SAR imagery

Product Imagery Variables		
/data/listOfPolarizations		
Type: string		**Shape: (numberOfPolarizations)**
Description: List of processed polarization layers		
/data/projection		
Type: Int32		**Shape: scalar**
Description: Product map grid projection: EPSG code (HDF5 dataset) with other projection information (HDF5 attributes)		
	ellipsoid	Projection ellipsoid
	epsg_code	Projection EPSG code
	false_easting	The value added to all abscissa values in the rectangular coordinates for a map projection.
	false_northing	The value added to all ordinate values in the rectangular coordinates for a map projection.
	grid_mapping_name	Grid mapping variable name
	inverse_flattening	Inverse flattening of the ellipsoidal figure
	latitude_of_projection_origin	The latitude chosen as the origin of rectangular coordinates for a map projection.
	longitude_of_projection_origin	The longitude, with respect to Greenwich, of the prime meridian associated with the geodetic datum.
	semi_major_axis	Semi-major axis
	spatial_ref	Spatial reference
	utm_zone_number	UTM zone number
/data/yCoordinateSpacing		
Type: Float64		**Shape: scalar**
Description: Nominal spacing in meters between consecutive lines		
	units	meters
/data/xCoordinateSpacing		
Type: Float64		**Shape: scalar**
Description: Nominal spacing in meters between consecutive pixels		
	units	meters
/data/xCoordinates		
Type: Float64		**Shape: (width)**
Description: CF compliant dimension associated with the X coordinates		
	units	meters
/data/yCoordinates		
Type: Float64		**Shape: (length)**
Description: CF compliant dimension associated with the Y coordinates		
	units	meters

6.4 Source Data Metadata

Table 6-4 OPERA RTC-S1 HDF5 variables related to the source data metadata

Source Data Variables		
/metadata/sourceData/numberOfAcquisitions		
Type: Int64	**Shape: scalar**	
Description: Number of source data acquisitions		
	units	unitless
/metadata/sourceData/dataAccess		
Type: string	**Shape: scalar**	
Description: Location from where this product can be retrieved (URL or DOI)		
/metadata/sourceData/institution		
Type: string	**Shape: scalar**	
Description: Location from where the source data can be retrieved (URL or DOI)		
/metadata/sourceData/processingCenter		
Type: string	**Shape: scalar**	
Description: Source data processing center		
/metadata/sourceData/rangeBandwidth		
Type: Float64	**Shape: scalar**	
Description: Processed range bandwidth in Hz		
	units	Hz
/metadata/sourceData/processingDateTime		
Type: string	**Shape: scalar**	
Description: Processing UTC date and time of the source data product (SLC Post processing date time) in the format YYYY-MM-DDThh:mm:ss.sZ		
/metadata/sourceData/softwareVersion		
Type: string	**Shape: scalar**	
Description: Version of the software used to create the source data (IPF version)		
/metadata/sourceData/azimuthLooks		
Type: Int64	**Shape: scalar**	
Description: Number of looks in azimuth used to generate source data		
	units	unitless
/metadata/sourceData/slantRangeLooks		
Type: Int64	**Shape: scalar**	
Description: Number of looks in slant range used to generate source data		
	units	unitless
/metadata/sourceData/productLevel		
Type: string	**Shape: scalar**	
Description: Product level of the source data. L0A: Unprocessed instrument data; L0B: Reformatted, unprocessed instrument data; L1: Processed instrument data in radar coordinates system; and L2: Processed instrument data in geocoded coordinates system		
/metadata/sourceData/centerFrequency		
Type: Float64	**Shape: scalar**	
Description: Center frequency of the processed image in Hz		
	units	Hz
/metadata/sourceData/numberOfRangeSamples		
Type: Int64	**Shape: scalar**	
Description: Number of slant range samples for each azimuth line within the source data		
	units	unitless

/metadata/sourceData/slantRangeStart		
Type: Float64	**Shape: scalar**	
Description: Slant-range start distance of the source data		
	units	meters
/metadata/sourceData/averageZeroDopplerSpacingInMeters		
Type: Float64	**Shape: scalar**	
Description: Average pixel spacing in meters between consecutive lines in the along-track direction of the source data		
	units	meters
/metadata/sourceData/zeroDopplerTimeSpacing		
Type: Float64	**Shape: scalar**	
Description: Time interval in the along-track direction of the source data		
	units	seconds
/metadata/sourceData/slantRangeSpacing		
Type: Float64	**Shape: scalar**	
Description: Distance in meters between consecutive range samples of the source data		
	units	meters
/metadata/sourceData/azimuthResolutionInMeters		
Type: Float64	**Shape: scalar**	
Description: Azimuth resolution of the source data in meters		
	units	meters
/metadata/sourceData/slantRangeResolutionInMeters		
Type: Float64	**Shape: scalar**	
Description: Slant-range resolution of the source data in meters		
	units	meters
/metadata/sourceData/nearRangeIncidenceAngle		
Type: Float64	**Shape: scalar**	
Description: Near range incidence angle in degrees		
	units	degrees
/metadata/sourceData/farRangeIncidenceAngle		
Type: Float64	**Shape: scalar**	
Description: Far range incidence angle in degrees		
	units	degrees
/metadata/sourceData/maxNoiseEquivalentSigmaZero		
Type: Float64	**Shape: scalar**	
Description: Maximum Noise equivalent sigma0 in dB		
	units	unitless
/metadata/sourceData/zeroDopplerStartTime		
Type: string	**Shape: scalar**	
Description: Azimuth start time of the input product in the format YYYY-MM-DDThh:mm:ss.sZ		
/metadata/sourceData/zeroDopplerEndTime		
Type: string	**Shape: scalar**	
Description: AAzimuth stop time of the input product in the format YYYY-MM-DDThh:mm:ss.sZ		
/metadata/sourceData/numberOfAzimuthLines		
Type: Int64	**Shape: scalar**	
Description: Number of azimuth lines within the source data product		
	units	

6.5 Processing Information

Table 6-5 OPERA RTC-S1 HDF5 variables related to processing information parameters

Processing Information Variables		
/metadata/processingInformation/parameters/preprocessingMultilookingApplied		
Type: boolean	**Shape: scalar**	
Description: 'Flag to indicate if a preprocessing multilooking has been applied		
/metadata/processingInformation/parameters/filteringApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if the post-processing filtering has been applied		
/metadata/processingInformation/parameters/noiseCorrectionApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if noise removal has been applied		
/metadata/processingInformation/parameters/radiometricTerrainCorrectionApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if radiometric terrain correction (RTC) has been applied		
/metadata/processingInformation/parameters/staticTroposphericGeolocationCorrectionApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if the static tropospheric correction has been applied		
/metadata/processingInformation/parameters/wetTroposphericGeolocationCorrectionApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if the wet tropospheric correction has been applied		
/metadata/processingInformation/parameters/bistaticDelayCorrectionApplied		
Type: boolean	**Shape: scalar**	
Description: Flag to indicate if the bistatic delay correction has been applied		
/metadata/processingInformation/parameters/inputBackscatterNormalizationConvention		
Type: string	**Shape: scalar**	
Description: Backscatter normalization convention of the source data		
/metadata/processingInformation/parameters/outputBackscatterNormalizationConvention		
Type: string	**Shape: scalar**	
Description: Backscatter normalization convention of the radar imagery associated with this product		
/metadata/processingInformation/parameters/outputBackscatterExpressionConvention		
Type: string	**Shape: scalar**	
Description: Backscatter expression convention		
/metadata/processingInformation/parameters/outputBackscatterDecibelConversionEquation		
Type: string	**Shape: scalar**	
Description: Equation to convert provided backscatter to decibel (dB)		
/metadata/processingInformation/parameters/geocoding/burstGeogridSnapX		
Type: Float64	**Shape: scalar**	
Description: Burst geogrid snap for Coordinate X (W/E)		
	units	meters
/metadata/processingInformation/parameters/geocoding/burstGeogridSnapY		
Type: Float64	**Shape: scalar**	
Description: Burst geogrid snap for Coordinate Y (S/N)		
	units	meters
/metadata/processingInformation/algorithms/softwareVersion		
Type: string	**Shape: scalar**	
Description: Software version		

/metadata/processingInformation/algorithms/demInterpolation	
Type: string	**Shape: scalar**
Description: DEM interpolation method	
/metadata/processingInformation/algorithms/demEgmModel	
Type: string	**Shape: scalar**
Description: Earth Gravitational Model associated with the DEM	
/metadata/processingInformation/algorithms/geocoding	
Type: string	**Shape: scalar**
Description: Geocoding algorithm	
/metadata/processingInformation/algorithms/radiometricTerrainCorrection	
Type: string	**Shape: scalar**
Description: Radiometric terrain correction (RTC) algorithm	
/metadata/processingInformation/algorithms/radiometricTerrainCorrectionAlgorithmReference	
Type: string	**Shape: scalar**
Description: A reference to the radiometric terrain correction (RTC) algorithm applied	
/metadata/processingInformation/algorithms/geocodingAlgorithmReference	
Type: string	**Shape: scalar**
Description: A reference to the geocoding algorithm applied	
/metadata/processingInformation/algorithms/noiseCorrectionAlgorithmReference	
Type: string	**Shape: scalar**
Description: A reference to the noise removal algorithm applied	
/metadata/processingInformation/algorithms/isce3Version	
Type: string	**Shape: scalar**
Description: Version of the ISCE3 framework used for processing	
/metadata/processingInformation/algorithms/s1ReaderVersion	
Type: string	**Shape: scalar**
Description: Version of the OPERA s1-reader used for processing	
/metadata/processingInformation/inputs/l1SlcGranules	
Type: string	**Shape: (numberOfInputL0BFiles)**
Description: List of input L1 SLC products used	
/metadata/processingInformation/inputs/orbitFiles	
Type: string	**Shape: (numberOfInputOrbitFiles)**
Description: List of input orbit files used	
/metadata/processingInformation/inputs/annotationFiles	
Type: string	**Shape: (numberOfInputAnnotationFiles)**
Description: List of input annotation files used	
/metadata/processingInformation/inputs/demSource	
Type: string	**Shape: scalar**
Description: Description of the input digital elevation model (DEM)	

6.6 Orbit Metadata

Table 6-6 OPERA RTC-S1 HDF5 variables related to orbit metadata

Orbit Variables		
/metadata/orbit/referenceEpoch		
Type: string		**Shape: scalar**
Description: Reference epoch in the format YYYY-MM-DDTHH:MM:SS.SSS		
/metadata/orbit/interpMethod		
Type: string		**Shape: scalar**
Description: Orbit interpolation method		
/metadata/orbit/time		
Type: Float64		**Shape: (orbitListlength)**
Description: Time vector record. This record contains the time corresponding to position, velocity, acceleration records		
	units	seconds since YYYY-MM-DD HH:MM:SS
/metadata/orbit/position		
Type: Float64		**Shape: (orbitListlength, tripletxyz)**
Description: Position vector record. This record contains the platform position data with respect to WGS84 G1762 reference frame		
	units	meters
/metadata/orbit/velocity		
Type: Float64		**Shape: (orbitListlength, tripletxyz)**
Description: Velocity vector record. This record contains the platform velocity data with respect to WGS84 G1762 reference frame		
	units	meters per second
/metadata/orbit/orbitType		
Type: string		**Shape: scalar**
Description: Type of orbit file used in processing		

6.7 Quality Assurance Metadata

Table 6-7 OPERA RTC-S1 HDF5 variables related to quality assurance (QA) metadata

Quality Assurance Variables		
/metadata/qa/geometricAccuracy/bias/y		
Type: Float64	**Shape: scalar**	
Description: An estimate of the localization error bias in the northing direction		
	units	unitless
/metadata/qa/geometricAccuracy/bias/x		
Type: Float64	**Shape: scalar**	
Description: An estimate of the localization error bias in the easting direction		
	units	unitless
/metadata/qa/geometricAccuracy/stddev/y		
Type: Float64	**Shape: scalar**	
Description: An estimate of the localization error standard deviation in the northing direction		
	units	unitless
/metadata/qa/geometricAccuracy/stddev/x		
Type: Float64	**Shape: scalar**	
Description: An estimate of the localization error standard deviation in the easting direction		
	units	unitless
/metadata/qa/rfi/isRfiInfoAvailable		
Type: boolean	**Shape: scalar**	
Description: A flag to indicate whether RFI information is available in the source data		
/metadata/qa/rfi/rfiMitigationPerformed*		
Type: string	**Shape: scalar**	
Description: RFI detection and mitigation strategy		
/metadata/qa/rfi/rfiMitigationDomain*		
Type: string	**Shape: scalar**	
Description: Domain in which the RFI mitigation was performed		
/metadata/qa/rfi/rfiBurstReport/swath*		
Type: string	**Shape: scalar**	
Description: Swath associated with the IW RFI burst report list		
/metadata/qa/rfi/rfiBurstReport/azimuthTime*		
Type: string	**Shape: scalar**	
Description: Sensing start time of the burst that corresponds to the RFI report in the format YYYY-MM-DDThh:mm:ss.sZ		
/metadata/qa/rfi/rfiBurstReport/inBandOutBandPowerRatio*		
Type: Float64	**Shape: scalar**	
Description: Ratio between the in-band and out-of-band power of the burst		
	units	unitless
/metadata/qa/rfi/timeDomainRfiReport/percentageAffectedLines*		
Type: Float64	**Shape: scalar**	
Description: Percentage of level-0 lines affected by RFI		
	units	unitless
/metadata/qa/rfi/timeDomainRfiReport/avgPercentageAffectedSamples*		
Type: Float64	**Shape: scalar**	
Description: Average percentage of affected level-0 samples in the lines containing RFI		
	units	unitless
/metadata/qa/rfi/timeDomainRfiReport/maxPercentageAffectedSamples*		

Type: Float64		**Shape: scalar**
Description: Maximum percentage of level-0 samples affected by RFI in the same line		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/numSubBlocks*		
Type: Int64		**Shape: scalar**
Description: Number of sub-blocks in the current burst		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/subBlockSize*		
Type: Int64		**Shape: scalar**
Description: Number of lines in each sub-block		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/isolatedRfiReport/percentageAffectedLines*		
Type: Float64		**Shape: scalar**
Description: Percentage of level-0 lines affected by RFI		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/isolatedRfiReport/maxPercentageAffectedBW*		
Type: Float64		**Shape: scalar**
Description: Maximum percentage of bandwidth affected by isolated RFI in a single line		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/percentageBlocksPersistentRfi*		
Type: Float64		**Shape: scalar**
Description: Percentage of processing blocks affected by persistent RFI. In this case the RFI detection is performed on the mean power spectrum density (PSD) of each processing block		
	units	unitless
/metadata/qa/rfi/frequencyDomainRfiBurstReport/maxPercentageBWAffectedPersistentRfi*		
Type: Float64		**Shape: scalar**
Description: Maximum percentage of the bandwidth affected by persistent RFI in a single processing block		
	units	unitless

* Fields that may or may not be available depending on the availability of RFI information from the input S1 IW SLC dataset.

APPENDIX A: GEOCODED PRODUCT GRIDS

OPERA RTC-S1 products are generated on a pre-defined burst system. The projection system for a particular burst ID is held constant through the product lifetime. Each product layer includes information indicating the projection used for the product.

Map Projections

OPERA's SDS is able to ingest any Digital Elevation Model whose vertical datum represents height above the WGS84 Ellipsoid and the horizontal datum can be represented by a European Petroleum Standards Group (EPSG) code for generating geocoded product. Table B-00-1 lists the various projection systems used to output RTC-S1 products.

Table B-00-1. Projection Systems for L2 RTC-S1 Products

EPSG code	PROJ.4 string	Common Name	Geographical scope
3413	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs	NSIDC Sea Ice Polar Stereographic North	Greenland and Northern Hemisphere Sea Ice (products with center latitude greater than 75 degrees)
32601-32660	+proj=utm +zone=X-32600 +datum=WGS84 +units=m +no_defs	UTM Zone North	Northern Hemisphere Land except Greenland
32701-32760	+proj=utm +zone=X-32700 +south +datum=WGS84 +units=m +no_defs	UTM Zone South	Southern Hemisphere Land

Grid Alignment

OPERA RTC-S1 products will use a "pixel is area" convention. The "pixel is area" convention, which is the default, uses northing and easting coordinates Y and X, with (0,0) denoting the upper-left corner of the image, and increasing X to the east, increasing Y to the south. The first pixel value fills the grid cell with the top-left position (0,0) and bottom-right position (1,1).

APPENDIX B: ACRONYMS

ADT	Algorithm Development Team
ARD	Analysis Ready Data
ASF	Alaska Satellite Facility
ASF.DAAC	NASA's Alaska Satellite Facility Distributed Active Archive Center
CARD	CEOS Analysis Ready Data
CEOS	Committee on Earth Observation Satellites
CF	Climate and Forecast
COG	Cloud optimized GeoTIFF
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
ECEF	Earth Centered Earth Fixed
ESA	European Space Agency
Float32	Floating-point number of 32 bits
GDAL	Geospatial Data Abstraction Library
GeoTIFF	Georeferenced Tagged Image File Format
GIS	Geographic Information System
HDF5	Hierarchical Data Format version 5
InSAR	Interferometric Synthetic Aperture Radar
ISCE3	InSAR Scientific Computing Environment Enhanced Edition
OPERA	Observational Products for End-users from Remote-sensing Analysis
MHz	Mega-Hertz
MOE	Medium-precision Orbit Ephemeris
PNG	Portable Network Graphic
QA	Quality Assurance
RFI	Radio Frequency Interference
RTC	Radiometric Terrain Correction
RTC-S1	Radiometric Terrain Corrected SAR backscatter from Sentinel-1
SAR	Synthetic Aperture Radar
SAFE	Standard Archive Format for Europe
SAS	Science Application Software
SDS	Science Data System
SLC	Single Look Complex
UInt8	Unsigned Integers of 8 bits
UInt16	Unsigned Integers of 16 bits
UPS	Universal Polar Stereographic

URI	Uniform Resource Identifier
UTM	Universal Transverse Mercator
WRS	World Reference System