NASA SDS Product Specification

Level-1 Range Doppler Pixel Offsets

L1_ROFF

Rev B

JPL D-105009

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Rev A (R4.0)	February 07, 2024	Cover page, Sec. 1.3, Figure 2-1, Table 2-1, Table 2-2, Sec. 2-2, Table 3-5; Sec. 3.7, Sec. 4.3, Sec. 4.4.2.2; Sec. 4.4.3	N/A	Added version number to cover page; Updated AD and AR; Updated Fig. 2-1; Revised RIFG, RUNW, GUNW description in Table 2-1; Revised product level description in Table 2-2; Clarified use of offset blending algorithm in Sec. 2.2; Removed unused attributes in Table 3-5; Updated product output grid features in Sec. 3.7; Revised and improved readability of Sec. 4.3; Added subsection on attitude state vectors; Improved description of geolocation grid Datasets in Sec. 4.4.3.
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** Include the JPL Limited Release System (LRS) clearance number for each revision to be shared with foreign partners.*

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1 INTRODUCTION

1.1 Purpose of Description

This document provides a specification of the NASA-ISRO Synthetic Aperture Radar (NISAR) L-SAR Level-1 (L1) Range Doppler Pixel Offsets product to be generated by the NASA Science Data System (SDS) and provided to the Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC). This data product is referenced by the short name ROFF.

1.2 Document Organization

Section 2 provides an overview 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.

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

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

Section 6 provides a description of the metadata cube representation.

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

1.3 Applicable and Reference Documents

Applicable documents levy requirements on areas addressed in this document. Reference documents are cited to provide additional information to readers. In case of conflict between the applicable documents and this document, the Project shall review the conflict to find the most effective resolution.

Applicable Documents

[AD1] NISAR NASA SDS Level 4 Requirements, JPL D-95655, Rev A, February 06, 2024

[AD2] NISAR NASA SDS Algorithm Development Plan, JPL D-95678, Initial, September 12, 2019

[AD3] NISAR Science Data Management and Archive Plan, JPL D-80828, June 1, 2016

[AD4] NISAR Science Management Plan, JPL D-76340, Rev A, August 14, 2018

[AD5] NISAR SDS ADT Calibration and Validation Plan, JPL D-102256, Rev A, November 20, 2023

[AD6] NISAR NASA SDS L4 Software Management Plan (SMP), JPL D-95656, Rev A, September 19, 2019

[AD7] ISO-19115-2, https://www.iso.org/obp/ui/#iso:std:iso:19115:-2:ed-2:v1:en

Reference Documents

[RD1] NISAR NASA SDS Algorithm Theoretical Basis Document, JPL D-95677, Rev. A, November 12, 2023

[RD2] EOSDIS Handbook, July 2016, retrieved from https://cdn.earthdata.nasa.gov/conduit/upload/5980/EOSDISHandbookWebFinaL2.pdf

[RD3] NISAR SDS L-SAR File Naming Conventions, JPL D-102255, Rev B, April 28, 2023

[RD4] NISAR L1_RSLC Product Specification Document, JPL D-102268, Rev C, February 07, 2024

[RD5] HDF5 documentation at https://portal.hdfgroup.org/display/HDF5/HDF5

[RD6] Eineder, M. (2003), Efficient simulation of SAR interferograms of large areas and of rugged terrain, IEEE Transactions on Geoscience and Remote Sensing, 41(6), 1415-1427

2 PRODUCT OVERVIEW

2.1 Product Background

Each NASA SDS L0B-L2 LSAR product (Figure 2-1 and Table 2-1 Product dependency) is distributed as a single Hierarchical Data Format version 5 (HDF5) [RD5] granule. All the metadata and imagery data are packaged in clearly defined sub-groups within the granule in compliance with the HDF5 specification. The NISAR product level definitions are given in **Error! Reference source not found.**.

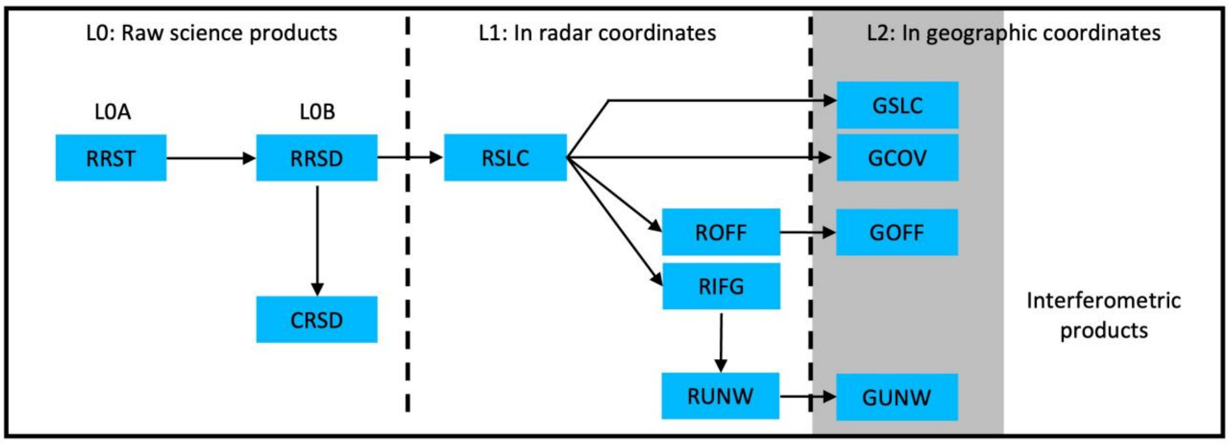

Figure 2-1 Product dependency.

Table 2-1 Key to product dependency diagram

L0 Product	Scope	Description	Granule Size
Radar Raw Science Telemetry (RRST)	Global	This L0A product contains the raw downlinked data delivered to SDS	By downlinked files
Radar Raw Signal Data (RRSD)	Global	This L0B product is corrected, aligned radar pulse data derived from the RRST products and used for further processing	By radar observation, i.e., continuous data collected in a single radar mode
Calibration Raw Signal Data (CRSD)	Global	This L0B product contains instrument calibration data	By radar data take, i.e., a sequence of observations for one radar-on period

L1 Product	Scope	Description	Granule Size
Range-Doppler Single Look Complex (RSLC)	Global	The L1 RSLC product contains focused SAR images in range-Doppler coordinates. The RSLC is input to other L1 and L2 products	On pre-defined track/frame. High-resolution modes will have a high-res RSLC product and a background resolution RSLC product
Range-Doppler Nearest-Time Interferogram (RIFG)	Antarctica, Greenland, and selected mountain glaciers. Nearest pair in time and co-pol channels only	Multi-looked interferogram in range-Doppler coordinates, ellipsoid and topographic phase flattened and formed with precise coregistration using geometrical offsets and high-resolution pixel offsets obtained from incoherent cross-correlation	On pre-defined track/frame
Range-Doppler Nearest-Time Pixel Offsets (ROFF)	Antarctica, Greenland, and selected mountain glaciers. Nearest pair in time and co-pol channels only	Unfiltered and unculled layers of pixel offsets in range-Doppler coordinates with different resolutions obtained from incoherent cross-correlation	On pre-defined track/frame
Range-Doppler Nearest-Time Unwrapped Interferogram (RUNW)	Antarctica, Greenland, and selected mountain glaciers. Nearest pair in time and co-pol channels only	Multi-looked unwrapped interferogram in range-Doppler coordinates, ellipsoid- and topography-flattened	On pre-defined track/frame

L2 Product	Scope	Description	Granule Size
Geocoded SLC (GSLC)	Global and all channels	Single Look Complex SAR image on geocoded map coordinate system	On pre-defined track/frame
Geocoded Nearest-Time Pixel Offsets (GOFF)	Antarctica, Greenland, and selected mountain glaciers. Nearest pair in time and co-pol channels only	Unfiltered and unculled layers of pixel offsets with different resolutions obtained from incoherent cross-correlation and geocoded on map coordinate system	On pre-defined track/frame
Geocoded Nearest-Time Unwrapped Interferogram (GUNW)	Global. Nearest pair in time and co-pol channels only	Geocoded, multi-looked, ellipsoid and topography flattened unwrapped interferogram	On pre-defined track/frame

L2 Product	Scope	Description	Granule Size
Geocoded Polarimetric Covariance Matrix (GCOV)	Global and all channels. Single/Dual/Quad pol	Geocoded, multi-looked polarimetric covariance matrix	On pre-defined track/frame

Table 2-2 NISAR product level descriptions defined by Science.

Product Level	Description
Level 0A	Unprocessed instrument data with all communications artifacts removed, but without reconstruction of missing data and sorting of samples from the instrument. May still contain bit errors and missing data that needs reconstruction
Level 0B	Reconstructed, time ordered, unprocessed instrument data at original resolution
Level 1	Processed instrument data, focused to full resolution complex images or derived radar parameters including interferometric phase and pixel offsets, in native radar coordinate system
Level 2	Focused radar imagery or derived radar parameters projected to a map coordinate system
Level 3	Derived geophysical parameters on a geocoded grids with the same or coarser posting as the Level 1 or Level 2 products

2.2 ROFF Product Overview

The ROFF product contains a collection of dense pixel offsets layers obtained from applying incoherent cross-correlation on a pair of coarsely coregistered L1 Range Doppler Single Look Complex (RSLC) products in the range-Doppler geometry of the earlier (i.e., “reference”) RSLC product. The pair of RSLCs used to produce ROFF is first coarsely aligned with geometrical coregistration using the best available sensor orbit ephemeris and a Digital Elevation Model (DEM) [RD1].

The spacing, the window size, and the search radius used to generate the ROFF offsets layers for L-SAR data are summarized in Table 2-3 to Table 2-6 and organized by sensor mode (e.g., 40 MHz single-pol) and area of observation (i.e., ice sheets or mountain glaciers). Irrespective of the mode, the pixel offsets layers are provided with a nominal posting of 90 m on the ground. It is assumed that pixel offsets layers within ROFF share the same spacing and the same starting pixel along slant range and azimuth directions. Each pixel offset layer is distributed without performing any conventional post-processing operation i.e., layers might contain offset outliers, and are not low-pass filtered to reduce noise in the data [RD1].

The ROFF product is primarily meant for cryosphere applications, and it is only generated for LSAR acquisitions over Antarctica, Greenland, and selected mountain glaciers.

Table 2-2-3 Pixel offset parameter: 80 MHz, Antarctica and Greenland.

Layer	Range Bandwidth (MHz)	Sample spacing in slant range (pixels)	Sample spacing in along-track (pixels)	Window size in slant-range (pixels)	Window size in along-track (pixels)	Search radius in slant range (pixels)	Search radius in along-track (pixels)
IL1_80IS	80	30	15	64	32	64	33
IL2_80IS	80	30	15	96	64	64	33
IL3_80IS	80	30	15	196	128	8	8

Table 2-2-4 Pixel offset parameters: 40 MHz, Antarctica and Greenland.

Layer	Range Bandwidth (MHz)	Sample spacing in slant range (pixels)	Sample spacing in along-track (pixels)	Window size in slant range(pixels)	Window size in along-track (pixels)	Search radius in slant range (pixels)	Search radius in along-track (pixels)
IL1_40IS	40	15	15	32	32	8	8
IL2_40IS	40	15	15	64	64	8	8
IL3_40IS	40	15	15	128	128	8	8

Table 2-2-5 Pixel offset parameters: 20 MHz, mountain glaciers.

Layer	Range Bandwidth (MHz)	Sample spacing in slant range (pixels)	Sample spacing along-track (pixels)	Window size in slant range (pixels)	Window size in along-track (pixels)	Search radius in slant range (pixels)	Search radius in along-track (pixels)
IL1_20MG	20	8	15	32	32	16	32
IL2_20MG	20	8	15	32	64	16	32
IL3_20MG	20	8	15	64	128	16	32

Table 2-2-6 Pixel offset parameters: 40 MHz, mountain glaciers.

Layer	Range Bandwidth (MHz)	Sample spacing in slant range (pixels)	Sample spacing along-track (pixels)	Window size in slant range (pixels)	Window size in along-track (pixels)	Search radius in slant range (pixels)	Search radius in along-track (pixels)
IL1_40MG	40	15	15	32	32	32	32
IL2_40MG	40	15	15	64	64	32	32
IL3_40MG	40	15	15	128	128	32	32

The structure of the ROFF product is described in Section 4. The details of the data elements are given in Section 5. Metadata cubes are discussed in Section 6.

3 PRODUCT ORGANIZATION

3.1 File Format

All NISAR standard products are in the HDF5 [RD5]. 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, MATLAB or Python.

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 [RD5] 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.

3.1.1 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 named Datatypes.

3.1.2 HDF5 Group

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

Groups and their nested objects can be accessed using a path-like notation, akin to the notation employed for accessing Unix directories. The root Group is “/”. A Group contained in root might be called “/myGroup”.

3.1.3 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.

3.1.4 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 3-1 lists the Atomic Datatypes that are used in NISAR data products.

Table 3-1 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
H5T_IEEE_F64LE	64-bit, little-endian, IEEE floating point
H5T_C_S1	character string made up of one or more bytes

Derived Datatypes are user-defined variants of predefined Atomic Datatypes where the data organization has been modified at the bit-level. Derived data types are particularly useful for representing custom N-bit integers and floating-point numbers.

Composite Datatypes incorporate sets of Atomic datatypes. Composite Datatypes include Array, Enumeration, Variable Length and Compound.

- The Array Datatype defines a multi-dimensional array that can be accessed atomically.

- Variable Length presents a 1-D array element of variable length. Variable Length Datatypes are useful as building blocks of ragged arrays.
- Compound Datatypes are composed of named fields, each of which may be dissimilar Datatypes. Compound Datatypes are conceptually equivalent to structures in the C programming language.

Named Datatypes are explicitly stored as Objects within an HDF5 File. Named Datatypes provide a means to share Datatypes among Objects. Datatypes that are not explicitly stored as Named Datatypes are stored implicitly. They are stored separately for each Dataset or Attribute they describe.

The Derived and Compound Datatypes used in NISAR products are reported in Table 3-2.

Table 3-2 NISAR HDF5 Derived and Compound Datatypes

Description	Comments
16-bit little-endian floating point	"binary16" half precision type in IEEE 754-2008 standard. Matches numpy.float16 type in Python. We will refer to this type as H5T_IEEE_F16LE or Float16 in our documents

H5T_COMPOUND
{
16-bit little-endian floating-point "r";
16-bit little-endian floating-point "i";
}
	Complex numbers made up of two half precision floating point numbers

H5T_COMPOUND
{
32-bit little-endian floating-point "r";
32-bit little-endian floating-point "i";
}
	Complex numbers made of two single precision floating point numbers

H5T_COMPOUND
{
64-bit little-endian floating-point "r";
64-bit little-endian floating-point "i";
}
	Complex numbers made of two double precision floating point numbers

3.1.5 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.

3.2 NISAR File Organization

3.2.1 Groups

All NISAR HDF5 files are organized within a hierarchy of Groups, with no actual data at the root("/") level. Table 3-3 shows the general layout of the HDF5 files that are generated by the NISAR SDS.

Table 3-3 Group organization at the top level of a NISAR HDF5 File.

Group Name	Description
/science/LSAR/	All science data from the L-SAR instrument is organized under this group
/science/SSAR/	All science data from the S-SAR instrument is organized under this group
/science/[L/S]SAR/identification /	File level metadata for cataloging, archiving the granule

In the nominal baseline, L-SAR and S-SAR data will not appear in the same granule, even if they cover the same geographic area. Data structure described below the primary groups ("/science/LSAR/" for L-SAR and "/science/SSAR/" for S-SAR) will be the same for L-SAR and S-SAR products. The rest of the document from this point on describes the layout of the product containing L-SAR data. The specification for equivalent S-SAR data products will be the same except for the substitution of "LSAR" by "SSAR" in the dataset paths in the HDF5 granule.

3.2.2 File Level Metadata

Global metadata at the file level are currently given as Global Attributes shown in Table 3-4.

Metadata regarding the data in the particular granule are given in "/science/LSAR/identification/". These data are described further in Section 4.2 and Section 5.2.

Table 3-4 Global attributes of ROFF.

Attribute	Format	Description	Value
Conventions	string	NetCDF-4 conventions adopted in this product	CF-1.7
title	string	Product title	NISAR L1_ROFF Product
institution	string	Name of producing agency	NASA JPL
mission_name	string	Mission name	NISAR
reference_document	string	Name and version of Product Description Document to use as reference for product	D-105009 NISAR NASA SDS Product Specification L1 Range Doppler Pixel Offsets

contact	string	Contact information for producer of product	nisar-sds-ops@jpl.nasa.gov

3.2.3 Variable Metadata (HDF5 Attributes)

NISAR 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. Wherever possible, these HDF5 Attributes employ names that conform to the Climate and Forecast (CF) conventions.

Table 3-5 lists the CF names for the HDF5 Attributes that NISAR products typically employ.

Table 3-5 Common variable attributes in HDF5 File.

Attribute	Description
_FillValue	The value used to represent missing or undefined data
description	Miscellaneous information about the data or the methods to generate it
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
units	Unit of data
valid_max	Maximum theoretical value of the variable
valid_min	Minimum theoretical value of the variable

Some HDF5 Datasets are populates with statistical Attributes. Table 3-6 and Table 3-7 describe the statistical Attributes added to real- and complex-valued HDF5 datasets, respectively. The list of real-valued HDF5 Datasets for the standard ROFF product is given in Table 3-8.

Table 3-6 Statistical attributes for real-valued HDF5 Datasets.

Attribute	Description
min_value	Minimum value of real-valued HDF5 Dataset
mean_value	Mean value of real-valued HDF5 Dataset
max_value	Maximum value of real-valued HDF5 Dataset
sample_stddev	Sample standard deviation of real-valued HDF5 Dataset

Table 3-7 Statistical attributes for complex valued HDF5 Datasets.

Attribute	Description
min_real_value	Minimum value of the real part of a complex-valued HDF5 Dataset
mean_real_value	Mean value of the real part of a complex-valued dataset HDF5 Dataset
max_real_value	Maximum value of the real part of a complex-valued HDF5 Dataset
sample_stddev_real	Sample standard deviation of the real part of a complex-valued HDF5 Dataset

min_imag_value	Minimum value of the imaginary part of a complex-valued HDF5 Dataset
mean_imag_value	Mean value of the imaginary part of a complex-valued HDF5 Dataset
max_image_value	Max value of the imaginary part of a complex-valued HDF5 Dataset
sample_stddev_imag	Sample standard deviation of the imaginary part of a complex-valued HDF5 Dataset

Table 3-8 ROFF HDF5 Datasets populated with statistical Attributes.

Attribute	HDF5 Datasets	Dataset type
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/[HH/VV]/[layer1/layer2/layer3]/	slantRangeOffset alongTrackOffset correlationSurfacePeak crossOffsetVariance alongTrackOffsetVariance slantRangeOffsetVariance snr	Real-valued

3.3 Cloud Optimization

NISAR science data products utilize several special features of the HDF5 format to optimize file sizes and enable high-performance read access in a cloud environment. A key challenge of cloud data access is the latency associated with calls to the cloud storage Application Programming Interface (API), so the following strategies are used to minimize the number of cloud API calls needed per byte of data read:

- Chunks: Large datasets within the products use chunked storage. Every read operation thus fetches at least one entire chunk of data. The chunk size is nominally 512x512 pixels, though the precise chunk dimensions should be obtained using the H5Pget_chunk method of the HDF5 C API (or its equivalent in other language bindings).
- Compression: Data are written using a compression filter, minimizing the amount of data stored and hence transferred over the network. The HDF5 API handles decompression automatically.
- Paging: Files are created with the "paged" file space strategy (H5F_FSPACE_STRATEGY_PAGE in the HDF5 C API). These pages serve as the basic unit of allocation within the file. The page size is chosen larger than the chunk size so that both a chunk of data and its HDF5-internal metadata can be read in a single cloud API call. This parameter may be queried using the H5Pget_file_space_page_size method of the HDF5 C API.

Software that reads NISAR products stored on the cloud should take heed of the following recommendations:

- Set the page buffer size to a multiple of the file space page size using H5Pset_page_buffer_size in the HDF5 C API. This enables caching logic that reduces the number of cloud API calls in the file driver.
- Implement chunk-aligned data access patterns. Reads in multiples of the chunk size (and aligned with chunk boundaries) are most efficient.
- If other access patterns are desired, try setting the read cache large enough to hold all the chunks that may be re-read. For example, line-by-line access can still be efficient if the read cache is large enough to hold N lines, where N is the chunk dimension. That way lines can be read from the cache instead of fetching the same set of chunks N times over the network. The cache size may be set globally using the H5Pset_cache or locally with the H5Pset_chunk_cache methods of the HDF5 C API.

Note that, in general, these optimizations require knowledge of the file contents. Therefore, the most robust approach is to open the file, inspect the contents (e.g., chunk size, page size, and dataset dimensions) and then re-open the file with optimal parameters.

3.4 Granule Definition

NISAR ROFF granules will conform to the Tiling Scheme being developed for the mission and are expected to have a ground footprint of 240 km x 240 km.

3.5 File Naming Convention

NISAR ROFF Granule names will conform to the Standard Product File Naming Scheme [RD3].

3.6 Temporal Organization

The ROFF data are arranged on a uniformly spaced, increasing zero-Doppler azimuth time grid. Using row-major order convention of representing 2D raster arrays, zero-Doppler azimuth time is represented by the row direction or the slowest changing dimension.

3.7 Spatial Organization

The ROFF data are arranged on a uniformly spaced, increasing zero-Doppler azimuth time in the row direction and increasing slant range grid in the column direction following the row-major order convention of representing 2D raster arrays.

3.8 Spatial Sampling and Resolution

NISAR mission uses a non-uniformly spaced sequence of pulses in SweepSAR mode to collect radar data, to overcome the limitations imposed by transmit gaps affecting the wide imaging swath [RD1]**Error! Reference source not found.**. Processing software accounts for the non-uniform sampling to generate the final ROFF product on a uniform grid. Some salient features of the output grid for the ROFF product are:

1. The center of the top-left pixel will correspond to the same zero-Doppler azimuth time and slant range for all imagery layers in an L-SAR ROFF product.
2. The main imaging band (“frequencyA”) is spatially averaged to the same posting, irrespective of the imaging mode (Table 2-3 to Table 2-6). This allows for spatial mosaicking operations across instrument mode changes.

3.8.1 Along Track Mosaicking

The spatial sampling of the output grid has also been designed to facilitate along-track mosaicking of contiguous ROFF product granules if the user desires. The following features simplify the implementation of along-track mosaicking

1. The slow time sampling frequency (inverse of the zero Doppler time spacing between consecutive lines) will be chosen to be an integer, to allow synchronization between adjacent granules at integer second boundaries without the need for resampling in the azimuth time direction.
2. The slant range to the first pixel will be a multiple of the lowest sampling frequency (corresponding to 5MHz) to enable concatenation of adjacent granules with simple integer shifts of imagery in the slant range direction.

Currently, it is not possible to mosaic products generated using data acquired with different bandwidths in the along-track direction.

3.8.2 Partially compressed SLC data

Partially compressed data in RSLC files will not be used to produce ROFF products. Spatially averaged pixels with any partially compressed or missing data in SLCs will be set to the value specified by _FillValue attribute.

4 LEVEL 1 RADAR PIXEL OFFSET PRODUCT

In this section, we briefly describe the layout of ROFF data and associated metadata within the NISAR HDF5 file. Detailed description of Group and Dataset names can be found in Section 5. In this section, we focus on the organization of L-SAR instrument data within the file under the Group name "/science/LSAR/".

4.1 Shapes and Dimensions of Data

Information on the shapes and dimensions of the data items in various data tables are described as part of the metadata (Section **Error! Reference source not found.**). This information is useful both as part of the product identification and for setting up further processing, i.e., dimensioning arrays.

4.2 Product Identification

Information needed to identify this product is given under the Group "/science/LSAR/identification/" (Section **Error! Reference source not found.**). This includes information such as orbit, cycle, track, and frame numbers, acquisition times, a polygon representing the bounding box of the included imagery in geographic coordinates, product version, and product specification version (i.e., the version number of this document).

4.2.1 Composite Release Identifier

The Composite Release Identifier (CRID) is a global version identifier documenting the algorithms and the overall status of the science data system used to generate the product. The CRID follows the format *EPMMmp* where:

- **E (Environment)**: a single character representing the environment or the venue where the product was generated. It can assume the values:
  - *A*: if the product was generated in the Algorithm Development environment
  - *D*: if the product was generated in the Development environment
  - *P*: if the product was generated in the Production environment
  - *T*: if the product was generated in the Integration and Test (I&T) environment
- **P (Mission Phase)**: a single numerical digit indicating the mission phase in which the product was generated. It can assume the following values:
  - *0*: for pre-launch (Phase D)
  - *1*: for primary science phase operations (Phase E)
  - *2*: extended mission (Phase E)
  - *3*: post-operations (Phase F), decommissioning, end of mission processing
- **MM (Major Release)**: two numeric digits monotonically increasing between 0 and 99. The Major Release resets to zero upon a change in the Mission Phase identifier. A change

in the Major Release indicates a major change in the products i.e., a change to one or more algorithms or to the processing rules having a significant impact on the science content of the product. The Major Release stands as a composite of the versions of all the algorithms used in the science data production systems. Individual algorithm versions are allocated in the product metadata.

- **m (Minor Release):** a single numeric digit increasing monotonically between 0 and 1 indicating a minor update to the product and/or the data system. A change in the Minor Release identifier indicates minor algorithm changes (e.g., bug fixes, small functional updates) that do not have a significant impact on the product. The Minor Release identifier resets to zero upon every update to the Major Release identifier
- **P (Patch Release)**: a single numerical digit monotonically increasing between 0 and 1. A change in the Patch Release identifier indicates an update to the science data system software that has undergone the System Deployment Review to fix a critical bug. The Patch Release resets to zero upon updates to the Major Release or Minor Release identifiers.

4.3 Radar Imagery

The ROFF product's imagery layers and associated datasets are initially organized based on the center frequency within the Group "/science/LSAR/ROFF/swaths/frequencyA/". Only the main NISAR imaging band ("frequencyA") will be processed for ROFF products. The pixel offset layers and associated Datasets are situated under the Group "/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/". This group is further organized by polarization (TxRx). For example, the Pixel Offsets Group could contain the Group "/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/". Each polarization Group is further organized in distinct Groups, one for each generated offset layer, and by a final grouping. These Pixel Offset Layers Groups are assigned monotonically increasing numbers, where the minimum index number (i.e., "layer1") contains the pixel offset layers and associated datasets at the finest resolution while the maximum index number (i.e., "layer3") contains the offset layers and associated datasets at the coarsest resolution. As an example, the Dataset "/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/slantRangeOffset" corresponds to the slant range sub-pixel offset estimate at the finest resolution derived from the "frequencyA" and "HH" polarization imagery layers within the reference and secondary input RSLCs.

The details of the data elements are given in Section **Error! Reference source not found.**. The resolution of data elements is discussed in Section 2.2.

4.4 Radar Metadata

The Group "/science/LSAR/ROFF/metadata/" includes a list of miscellaneous metadata needed to interpret the geolocation and the imagery (e.g., layers of slant range and along-track pixel offsets) included in the ROFF product.

4.4.1 Processing Information

The Group "/science/LSAR/ROFF/metadata/processingInformation/" includes the processing parameters, algorithms, and the inputs granules and files used to produce ROFF. For a complete description of this group, refer to Section 5.4.

4.4.1.1 Parameters

The Group "/science/LSAR/ROFF/metadata/processingInformation/parameters/" is further organized in four Groups:

1. *reference*: including the effective velocity and the reference terrain height of the reference RSLC. This Group is further organized by frequency and includes some relevant parameters of the reference RSLC such as the slant range and zero Doppler time, the slant range and the azimuth bandwidth, the azimuth FM rate, and the Doppler centroid
2. *secondary*: this Group follows the same organization of *reference* but includes the corresponding metadata for the secondary RSLC
3. *common*: organized by frequency, and including the parameters derived by combining the information from the reference and secondary RSLC such as common Doppler Centroid and the common Doppler bandwidth
4. *pixelOffsets*: including the parameters used to generate the individual layers of dense pixel offsets in the radar geometry. This group is further organized by frequency. The Group *frequencyA* contains the offsets parameter common to each layer of offsets i.e., the offset spacings in slant range and along-track directions, and the correlation surface oversampling factor. The offsets parameters specific for each offset layer are further organized in the *layer* Groups. Each *layer* Group contains the along-track and slant range window and search window sizes used to generate the pixel offsets for that specific layer

The Group *parameters* also contains the Dataset *runConfigurationContents* which includes a copy of the run configuration file used for processing populated with all the processing options, parameter values, and input files.

4.4.1.2 Algorithms

The Group *algorithms* "/science/LSAR/ROFF/metadata/processingInformation/algorithms/" includes the name and the version of the software used to generate the product. The Group is further organized by distinct Groups identifying the processing steps used to generate the ROFF product:

1. *coregistration*: including the algorithms used to perform the coarse and fine coregistration of the reference and secondary RSLCs (e.g., geometry coregistration, cross-correlation algorithm).
2. *crossCorrelation*: further organized by offset layer and including the cross-correlation algorithm used to generate each individual layer of pixel offset.

4.4.1.3 Input Files

The Group *inputs* "/science/LSAR/ROFF/metadata/processingInformation/inputs/" includes the filenames of the input RSLC granules, configuration files, orbit files, and a description of the DEM used for processing.

4.4.2 Other Radar Metadata

4.4.2.1 Orbit

The reference RSLC orbit ephemeris used for generating the ROFF product is provided under the Group "/science/LSAR/ROFF/metadata/orbit/" and further detailed in Section 5.5. This Group includes time-tagged antenna phase center position and velocity vectors in Earth Centered Earth Fixed (ECEF) Ccartesian coordinates and information on the used orbit fidelity.

4.4.2.2 Attitude

The attitude state vectors of the reference RSLC used for generating the ROFF product can be found under the Group "/science/LSAR/RIFG/metadata/attitude/". This Group includes time-tagged quaternions and Euler angles representing the slant range plane from the antenna phase center in an ECEF Cartesian system.

4.4.3 Geolocation Grid

The Group "/science/LSAR/ROFF/metadata/geolocationGrid/" contains information on the radar geometry of the reference RSLC. The Datasets within this Group (i.e., the geolocation grid cubes) are referenced over the radar-grid which is defined by the coordinate vectors "slantRange", "zeroDopplerTime", and "heightAboveEllipsoid". Normals are with respect to the WGS84 ellipsoid.

The "geolocationGrid" Group also include the Datasets:

1. "coordinateX" and "coordinateY" containing the mapping of the zero-Doppler grid to the geographic grid in the units defined by the Dataset "epsg" within the same Group
2. "losUnitVectorX" and "losUnitVectorY" identifying the East and North components of the Line-Of-Sight (LOS) unit vector (i.e., the vector from the target to the sensor) in the East-North-Up (ENU) coordinate system for each point of the geographic grid. The Up component of the LOS unit vector can be simply derived from the East and North components as:

$$losUnitVectorZ = \sqrt{1 - losUnitVectorX^2 - losUnitVectorY^2}$$

3. "alongTrackUnitVectorX" and "alongTrackUnitVectorY" containing the East and North components of the along-track unit vector (i.e., the projection of the along-track vector at the ground height) in UTM coordinates

4. “incidenceAngle containing the incidence angle, i.e., the angle between the LOS vector and the normal to the ellipsoid at the target height
5. “elevationAngle” containing the elevation angle i.e., the angle between the LOS vector and the normal to the ellipsoid at the sensor
6. “groundTrackVelocity” containing the ground track velocity i.e., the absolute value of the platform velocity scaled at the target height
7. “perpendicularBaseline” and “parallelBaseline” containing the perpendicular and parallel component of the baseline between the reference and secondary RSLCs. The baseline components are only computed for the bottom and top heights of the geolocation grid cubes

5 PRODUCT SPECIFICATION

5.1 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 5-1 Table of dimensions and shapes in ROFF product.

Name	Shape	Description
scalar	scalar	Scalar values
numberOfDatatakes	scalar	Number of datatakes in product
numberOfObservations	scalar	Number of observations in product
numberOfFrequencies	scalar	Number of L-SAR frequencies in product
numberOfFrequencyAPolarizations	scalar	Number of polarization layers associated with L-SAR frequencyA
numberOfFrequencyAOffsetLayers	scalar	Number of pixel offset layers associated with L-SAR frequencyA
offsetDataShape	(offsetZeroDopplerTimeLength, offsetSlantRangeWidth)	Shape associated with Pixel Offset layers
offsetSlantRangeWidth	scalar	Number of pixels in Pixel Offset layers
offsetZeroDopplerTimeLength	scalar	Number of lines in all L-SAR frequencyA imagery datasets
geolocationCubeShape	(geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)	Shape associated with metadata cubes
twoLayersCubeShape	(geolocationCubeWidth, geolocationCubeLength, twoLayersCubeHeight)	Shape associated with baseline metadata cubes
geolocationCubeHeight	scalar	Height dimension of the metadata cube
geolocationCubeLength	scalar	Length dimension of the metadata cube
geolocationCubeWidth	scalar	Width dimension of the metadata cube
twoLayersCubeHeight	scalar	Height dimension of the baseline metadata cube
dopplerCentroidTimeLength	scalar	Length dimension of Doppler centroid grid
dopplerCentroidSlantRangeWidth	scalar	Length dimension of Doppler centroid grid
dopplerCentroidShape	(dopplerCentroidTimeLength, dopplerCentroidSlantRangeWidth)	Shape of the Doppler centroid grid
orbitListLength	scalar	Number of orbit state vectors
orbitShape	(orbitListLength, 3)	Shape of orbit state vector triplets dataset
attitudeListLength	scalar	Number of attitude state vectors
attitudeQuaternionShape	(attitudeListLength, 4)	Shape of attitude quaternion dataset
attitudeShape	(attitudeListLength, 3)	Shape of attitude Euler angle triplets dataset
numberOfInputL1Files	scalar	Number of input L1 granules
numberOfInputConfigFiles	scalar	Number of input configuration files
numberOfInputOrbitFiles	scalar	Number of input orbit files

5.2 Product Identification

Table 5-2 NISAR HDF5 variables used for product identification.

Product identification variables		
/science/LSAR/identification/absoluteOrbitNumber		
Type: UInt32	**Shape: scalar**	
Description: Absolute orbit number		
	units	1
/science/LSAR/identification/trackNumber		
Type: UByte	**Shape: scalar**	
Description: Track number		
	units	1
/science/LSAR/identification/frameNumber		
Type: UInt16	**Shape: scalar**	
Description: Frame number		
	units	1
/science/LSAR/identification/missionId		
Type: string	**Shape: scalar**	
Description: Mission identifier		
/science/LSAR/identification/processingCenter		
Type: string	**Shape: scalar**	
Description: Data processing center		
/science/LSAR/identification/productType		
Type: string	**Shape: scalar**	
Description: Product type		
/science/LSAR/identification/granuleId		
Type: string	**Shape: scalar**	
Description: Unique granule identification name		
/science/LSAR/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 parameters		
/science/LSAR/identification/productSpecificationVersion		
Type: string	**Shape: scalar**	
Description: Product specification version which represents the schema of this product		
/science/LSAR/identification/lookDirection		
Type: string	**Shape: scalar**	
Description: Look direction, either "Left" or "Right"		
/science/LSAR/identification/orbitPassDirection		
Type: string	**Shape: scalar**	
Description: Orbit direction, either "Ascending" or "Descending"		
/science/LSAR/identification/referenceZeroDopplerStartTime		
Type: string	**Shape: scalar**	
Description: Azimuth start time of reference RSLC product		
/science/LSAR/identification/referenceZeroDopplerEndTime		
Type: string	**Shape: scalar**	
Description: Azimuth stop time of reference RSLC product		
/science/LSAR/identification/secondaryZeroDopplerStartTime		

Type: string		**Shape: scalar**
Description: Azimuth start time of secondary RSLC product		
/science/LSAR/identification/secondaryZeroDopplerEndTime		
Type: string		**Shape: scalar**
Description: Azimuth stop time of secondary RSLC product		
/science/LSAR/identification/plannedDatatakeId		
Type: string		**Shape: (numberOfDatatakes)**
Description: List of planned datatakes included in the product		
/science/LSAR/identification/plannedObservationId		
Type: string		**Shape: (numberOfObservations)**
Description: List of planned observations included in the product		
/science/LSAR/identification/isUrgentObservation		
Type: string		**Shape: scalar**
Description: Flag indicating if observation is nominal ("False") or urgent ("True")		
/science/LSAR/identification/listOfFrequencies		
Type: string		**Shape: (numberOfFrequencies)**
Description: List of frequency layers available in the product		
/science/LSAR/identification/diagnosticModeFlag		
Type: UByte		**Shape: scalar**
Description: Indicates if the radar operation mode is a diagnostic mode (1-2) or DBFed science (0): 0, 1, or 2		
/science/LSAR/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		
/science/LSAR/identification/isGeocoded		
Type: string		**Shape: scalar**
Description: Flag to indicate if the product data is in the radar geometry ("False") or in the map geometry ("True")		
/science/LSAR/identification/boundingPolygon		
Type: string		**Shape: scalar**
Description: OGR compatible WKT representing the bounding polygon of the image. Horizontal coordinates are WGS84 longitude followed by latitude (both in degrees), and the vertical coordinate is the height above the WGS84 ellipsoid in meters. The first point corresponds to the start-time, near-range radar coordinate, and the perimeter is traversed in counterclockwise order on the map. This means the traversal order in radar coordinates differs for left-looking and right-looking sensors. The polygon includes the four corners of the radar grid, with equal numbers of points distributed evenly in radar coordinates along each edge		
	ogr_geometry	polygon
	epsg	4326
/science/LSAR/identification/processingDateTime		
Type: string		**Shape: scalar**
Description: Processing UTC date and time in the format YYYY-mm-ddTHH:MM:SS		
/science/LSAR/identification/radarBand		
Type: string		**Shape: scalar**
Description: Acquired frequency band, either "L" or "S"		
/science/LSAR/identification/instrumentName		
Type: string		**Shape: scalar**
Description: Name of the instrument used to collect the remote sensing data provided in this product		
/science/LSAR/identification/processingType		
Type: string		**Shape: scalar**
Description: Nominal (or) Urgent (or) Custom (or) Undefined		
/science/LSAR/identification/isDithered		
Type: string		**Shape: scalar**
Description: "True" if the pulse timing was varied (dithered) during acquisition, "False" otherwise		
/science/LSAR/identification/isMixedMode		
Type: string		**Shape: scalar**

Description: "True" if this product is generated from reference and secondary RSLCs with different range bandwidths, "False" otherwise	
/science/LSAR/identification/compositeReleaseId	
Type: string	**Shape: scalar**
Description: Unique version identifier of the science data production system	

5.3 Radar Imagery

Table 5-3 NISAR HDF5 variables related to SAR imagery.

Product imagery variables		
/science/LSAR/ROFF/swaths/frequencyA/listOfPolarizations		
Type: string		**Shape: (numberOfFrequencyAPolarizations)**
Description: List of processed polarization layers with frequency A		
/science/LSAR/ROFF/swaths/frequencyA/centerFrequency		
Type: Float64		**Shape: scalar**
Description: Center frequency of the processed image in hertz		
	units	hertz
/science/LSAR/ROFF/swaths/frequencyA/listOfLayers		
Type: string		**Shape: (numberOfFrequencyAOffsetLayers)**
Description: List of pixel offsets layers		
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/sceneCenterAlongTrackSpacing		
Type: Float64		**Shape: scalar**
Description: Nominal along-track spacing in meters between consecutive lines near mid-swath of the product images		
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/sceneCenterGroundRangeSpacing		
Type: Float64		**Shape: scalar**
Description: Nominal ground range spacing in meters between consecutive pixels near mid-swath of the product images		
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/slantRangeSpacing		
Type: Float64		**Shape: scalar**
Description: Slant range spacing of the offset grid		
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/zeroDopplerTimeSpacing		
Type: Float64		**Shape: scalar**
Description: Along-track spacing of the offset grid		
	units	seconds
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/slantRangeOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters

/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/snr		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Pixel offsets signal-to-noise ratio		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/correlationSurfacePeak		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Normalized correlation surface peak		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/slantRangeOffsetVariance		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/alongTrackOffsetVariance		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Along-track pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer1/crossOffsetVariance		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/slantRangeOffset		
Type: Float32	**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**	
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points

	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/snr		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Pixel offsets signal-to-noise ratio		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/correlationSurfacePeak		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Normalized correlation surface peak		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/slantRangeOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/alongTrackOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Along-track pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer2/crossOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points

	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/slantRangeOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/snr		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Pixel offsets signal-to-noise ratio		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/correlationSurfacePeak		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Normalized correlation surface peak		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/slantRangeOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/alongTrackOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Along-track pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points

	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/HH/layer3/crossOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/slantRangeOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/snr		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Pixel offsets signal-to-noise ratio		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/correlationSurfacePeak		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Normalized correlation surface peak		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/slantRangeOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points

	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/alongTrackOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Along-track pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer1/crossOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/slantRangeOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/snr		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Pixel offsets signal-to-noise ratio		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/correlationSurfacePeak		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Normalized correlation surface peak		
	_FillValue	nan

	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/slantRangeOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/alongTrackOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Along-track pixel offset variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer2/crossOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/slantRangeOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) slant range pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/alongTrackOffset		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Raw (unculled, unfiltered) along-track pixel offsets		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/snr		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Pixel offsets signal-to-noise ratio		

	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/correlationSurfacePeak		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Normalized correlation surface peak		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	1
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/slantRangeOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Slant range pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/alongTrackOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Along-track pixel offsets variance		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/VV/layer3/crossOffsetVariance		
Type: Float32		**Shape: (offsetZeroDopplerTimeLength, offsetSlantRangeWidth)**
Description: Off-diagonal term of the pixel offsets covariance matrix		
	_FillValue	nan
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	units	meters^2
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/slantRange		
Type: Float64		**Shape: (offsetSlantRangeWidth)**
Description: Slant range vector		
	units	meters
/science/LSAR/ROFF/swaths/frequencyA/pixelOffsets/zeroDopplerTime		
Type: Float64		**Shape: (offsetZeroDopplerTimeLength)**
Description: Zero Doppler azimuth time vector		
	units	seconds since YYYY-mm-ddTHH:MM:SS

5.4 Processing Information

Table 5-4 NISAR HDF5 variables related to processing parameters.

Processing-related variables		
/science/LSAR/ROFF/metadata/processingInformation/parameters/runConfigurationContents		
Type: string	**Shape: scalar**	
Description: Contents of the run configuration file with parameters used for processing		
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/referenceTerrainHeight		
Type: Float32	**Shape: (dopplerCentroidTimeLength)**	
Description: Reference Terrain Height as a function of time for reference RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/isMixedMode		
Type: string	**Shape: scalar**	
Description: "True" if reference RSLC is a composite of data collected in multiple radar modes, "False" otherwise		
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/rfiCorrectionApplied		
Type: string	**Shape: scalar**	
Description: Flag to indicate if RFI correction has been applied to reference RSLC		
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/slantRangeStart		
Type: Float64	**Shape: scalar**	
Description: Slant range start distance for the reference RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/numberOfRangeSamples		
Type: UInt64	**Shape: scalar**	
Description: Number of slant range samples for each azimuth line within the reference RSLC		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/numberOfAzimuthLines		
Type: UInt64	**Shape: scalar**	
Description: Number of azimuth lines within the reference RSLC		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/slantRangeSpacing		
Type: Float64	**Shape: scalar**	
Description: Slant range spacing of reference RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/zeroDopplerTimeSpacing		
Type: Float64	**Shape: scalar**	
Description: Time interval in the along-track direction for reference RSLC raster layers		
	units	seconds
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/zeroDopplerStartTime		
Type: string	**Shape: scalar**	
Description: Azimuth start time of the reference RSLC product		
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/rangeBandwidth		
Type: Float64	**Shape: scalar**	
Description: Processed slant range bandwidth for reference RSLC		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/azimuthBandwidth		
Type: Float64	**Shape: scalar**	
Description: Processed azimuth bandwidth for reference RSLC		
	units	hertz

/science/LSAR/ROFF/metadata/processingInformation/parameters/reference/frequencyA/dopplerCentroid		
Type: Float64		**Shape: (dopplerCentroidTimeLength, dopplerCentroidSlantRangeWidth)**
Description: 2D LUT of Doppler centroid for frequency A		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/referenceTerrainHeight		
Type: Float32		**Shape: (dopplerCentroidTimeLength)**
Description: Reference Terrain Height as a function of time for secondary RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/rfiCorrectionApplied		
Type: string		**Shape: scalar**
Description: Flag to indicate if RFI correction has been applied to secondary RSLC		
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/isMixedMode		
Type: string		**Shape: scalar**
Description: "True" if secondary RSLC is a composite of data collected in multiple radar modes, "False" otherwise		
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/slantRangeStart		
Type: Float64		**Shape: scalar**
Description: Slant range start distance for the secondary RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/numberOfRangeSamples		
Type: UInt64		**Shape: scalar**
Description: Number of slant range samples for each azimuth line within the secondary RSLC		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/numberOfAzimuthLines		
Type: UInt64		**Shape: scalar**
Description: Number of azimuth lines within the secondary RSLC		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/slantRangeSpacing		
Type: Float64		**Shape: scalar**
Description: Slant range spacing of secondary RSLC		
	units	meters
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/zeroDopplerStartTime		
Type: string		**Shape: scalar**
Description: Azimuth start time of the secondary RSLC product		
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/zeroDopplerTimeSpacing		
Type: Float64		**Shape: scalar**
Description: Time interval in the along-track direction for secondary RSLC raster layers		
	units	seconds
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/rangeBandwidth		
Type: Float64		**Shape: scalar**
Description: Processed slant range bandwidth for secondary RSLC		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/azimuthBandwidth		
Type: Float64		**Shape: scalar**
Description: Processed azimuth bandwidth for secondary RSLC		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/secondary/frequencyA/dopplerCentroid		
Type: Float64		**Shape: (dopplerCentroidTimeLength, dopplerCentroidSlantRangeWidth)**
Description: 2D LUT of Doppler centroid for frequency A		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/common/frequencyA/dopplerCentroid		
Type: Float64		**Shape: (dopplerCentroidTimeLength, dopplerCentroidSlantRangeWidth)**
Description: Common Doppler centroid used for processing interferogram		
	units	hertz

/science/LSAR/ROFF/metadata/processingInformation/parameters/common/frequencyA/dopplerBandwidth		
Type: Float64		**Shape: scalar**
Description: Common Doppler Bandwidth used for processing interferogram		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/rangeBandwidth		
Type: Float64		**Shape: scalar**
Description: Processed slant range bandwidth for frequency A pixel offsets layers		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/azimuthBandwidth		
Type: Float64		**Shape: scalar**
Description: Processed azimuth bandwidth for frequency A pixel offsets layers		
	units	hertz
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/correlationSurfaceOversampling		
Type: UInt32		**Shape: scalar**
Description: Oversampling factor of the cross-correlation surface		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/margin		
Type: UInt32		**Shape: scalar**
Description: Margin in pixels around reference RSLC edges excluded during cross-correlation computation		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/slantRangeStartPixel		
Type: UInt32		**Shape: scalar**
Description: Reference RSLC start pixel in slant range		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/alongTrackStartPixel		
Type: UInt32		**Shape: scalar**
Description: Reference RSLC start pixel in along-track		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/slantRangeSkipWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation skip window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/alongTrackSkipWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation skip window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer1/alongTrackWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer1/slantRangeWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer1/alongTrackSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer1/slantRangeSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer2/alongTrackWindowSize		

Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer2/slantRangeWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer2/alongTrackSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer2/slantRangeSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer3/alongTrackWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer3/slantRangeWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer3/alongTrackSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Along-track cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/parameters/pixelOffsets/frequencyA/layer3/slantRangeSearchWindowSize		
Type: UInt32		**Shape: scalar**
Description: Slant range cross-correlation search window size in pixels		
	units	1
/science/LSAR/ROFF/metadata/processingInformation/algorithms/softwareVersion		
Type: string		**Shape: scalar**
Description: Software version used for processing		
/science/LSAR/ROFF/metadata/processingInformation/algorithms/coregistration/coregistrationMethod		
Type: string		**Shape: scalar**
Description: RSLC coregistration method		
	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/algorithms/coregistration/geometryCoregistration		
Type: string		**Shape: scalar**
Description: Geometry coregistration algorithm		
	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/algorithms/coregistration/resampling		
Type: string		**Shape: scalar**
Description: Secondary RSLC resampling algorithm		
	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/algorithms/crossCorrelation/layer1/crossCorrelationAlgorithm		
Type: string		**Shape: scalar**
Description: Cross-correlation algorithm for layer 1		
	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/algorithms/crossCorrelation/layer2/crossCorrelationAlgorithm		
Type: string		**Shape: scalar**
Description: Cross-correlation algorithm for layer 2		

	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/algorithms/crossCorrelation/layer3/crossCorrelationAlgorithm		
Type: string	**Shape: scalar**	
Description: Cross-correlation algorithm for layer 3		
	algorithm_type	RSLC coregistration
/science/LSAR/ROFF/metadata/processingInformation/inputs/l1ReferenceSlcGranules		
Type: string	**Shape: (numberOfInputL1Files)**	
Description: List of input reference L1 RSLC products used		
/science/LSAR/ROFF/metadata/processingInformation/inputs/l1SecondarySlcGranules		
Type: string	**Shape: (numberOfInputL1Files)**	
Description: List of input secondary L1 RSLC products used		
/science/LSAR/ROFF/metadata/processingInformation/inputs/configFiles		
Type: string	**Shape: (numberOfInputConfigFiles)**	
Description: List of input config files used		
/science/LSAR/ROFF/metadata/processingInformation/inputs/demSource		
Type: string	**Shape: scalar**	
Description: Description of the input digital elevation model (DEM)		
/science/LSAR/ROFF/metadata/processingInformation/inputs/orbitFiles		
Type: string	**Shape: (numberOfInputOrbitFiles)**	
Description: List of input orbit files used		

5.5 Other Radar Metadata

Table 5-5 NISAR HDF5 variables related to useful radar metadata.

Radar metadata-related variables		
/science/LSAR/ROFF/metadata/orbit/reference/interpMethod		
Type: string	**Shape: scalar**	
Description: Orbit interpolation method, either "Hermite" or "Legendre"		
/science/LSAR/ROFF/metadata/orbit/reference/time		
Type: Float64	**Shape: (orbitListLength)**	
Description: Time vector record. This record contains the time corresponding to position and velocity records		
	units	seconds since YYYY-mm-ddTHH:MM:SS
/science/LSAR/ROFF/metadata/orbit/reference/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
/science/LSAR/ROFF/metadata/orbit/reference/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 / second
/science/LSAR/ROFF/metadata/orbit/reference/orbitType		
Type: string	**Shape: scalar**	
Description: Orbit product type, either "FOE", "NOE", "MOE", "POE", or "Custom", where "FOE" stands for Forecast Orbit Ephemeris, "NOE" is Near real-time Orbit Ephemeris, "MOE" is Medium precision Orbit Ephemeris, and "POE" is Precise Orbit Ephemeris		
/science/LSAR/ROFF/metadata/orbit/secondary/interpMethod		
Type: string	**Shape: scalar**	
Description: Orbit interpolation method, either "Hermite" or "Legendre"		
/science/LSAR/ROFF/metadata/orbit/secondary/time		
Type: Float64	**Shape: (orbitListLength)**	
Description: Time vector record. This record contains the time corresponding to position and velocity records		
	units	seconds since YYYY-mm-ddTHH:MM:SS
/science/LSAR/ROFF/metadata/orbit/secondary/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
/science/LSAR/ROFF/metadata/orbit/secondary/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 / second
/science/LSAR/ROFF/metadata/orbit/secondary/orbitType		
Type: string	**Shape: scalar**	
Description: Orbit product type, either "FOE", "NOE", "MOE", "POE", or "Custom", where "FOE" stands for Forecast Orbit Ephemeris, "NOE" is Near real-time Orbit Ephemeris, "MOE" is Medium precision Orbit Ephemeris, and "POE" is Precise Orbit Ephemeris		
/science/LSAR/ROFF/metadata/attitude/reference/time		
Type: Float64	**Shape: (orbitListLength)**	
Description: Time vector record. This record contains the time corresponding to attitude and quaternion records		
	units	seconds since YYYY-mm-ddTHH:MM:SS
/science/LSAR/ROFF/metadata/attitude/reference/quaternions		

Type: Float64	**Shape: (attitudeListLength, quaternions)**	
Description: Attitude quaternions (q0, q1, q2, q3)		
	units	1
/science/LSAR/ROFF/metadata/attitude/reference/eulerAngles		
Type: Float64	**Shape: (attitudeListLength, tripletxyz)**	
Description: Attitude Euler angles (roll, pitch, yaw)		
	units	degrees
/science/LSAR/ROFF/metadata/attitude/reference/attitudeType		
Type: string	**Shape: scalar**	
Description: Attitude type, either "FRP", "NRP", "PRP, or "Custom", where "FRP" stands for Forecast Radar Pointing, "NRP" is Near Real-time Pointing, and "PRP" is Precise Radar Pointing		
/science/LSAR/ROFF/metadata/attitude/secondary/time		
Type: Float64	**Shape: (orbitListLength)**	
Description: Time vector record. This record contains the time corresponding to attitude and quaternion records		
	units	seconds since YYYY-mm-ddTHH:MM:SS
/science/LSAR/ROFF/metadata/attitude/secondary/quaternions		
Type: Float64	**Shape: (attitudeListLength, quaternions)**	
Description: Attitude quaternions (q0, q1, q2, q3)		
	units	1
/science/LSAR/ROFF/metadata/attitude/secondary/eulerAngles		
Type: Float64	**Shape: (attitudeListLength, tripletxyz)**	
Description: Attitude Euler angles (roll, pitch, yaw)		
	units	degrees
/science/LSAR/ROFF/metadata/attitude/secondary/attitudeType		
Type: string	**Shape: scalar**	
Description: Attitude type, either "FRP", "NRP", "PRP, or "Custom", where "FRP" stands for Forecast Radar Pointing, "NRP" is Near Real-time Pointing, and "PRP" is Precise Radar Pointing		

5.6 Geolocation Grid

Table 5-6 NISAR HDF5 variables related to metadata cube.

Metadata cube-related variables		
/science/LSAR/ROFF/metadata/geolocationGrid/epsg		
Type: Int32	**Shape: scalar**	
Description: EPSG code corresponding to the coordinate system used for representing the geolocation grid		
	long_name	EPSG code
	units	1
/science/LSAR/ROFF/metadata/geolocationGrid/coordinateY		
Type: Float64	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: Y coordinates in specified EPSG code		
	_FillValue	nan
	grid_mapping	projection
	long_name	Coordinate Y
	units	meters
/science/LSAR/ROFF/metadata/geolocationGrid/coordinateX		
Type: Float64	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: X coordinates in specified EPSG code		
	_FillValue	nan
	grid_mapping	projection
	long_name	Coordinate X
	units	meters
/science/LSAR/ROFF/metadata/geolocationGrid/incidenceAngle		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: Incidence angle is defined as the angle between the LOS vector and the normal to the ellipsoid at the target height		
	valid_max	90.0
	valid_min	0.0
	_FillValue	nan
	grid_mapping	projection
	long_name	Incidence angle
	units	degrees
/science/LSAR/ROFF/metadata/geolocationGrid/losUnitVectorX		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: East component of unit vector of LOS from target to sensor		
	valid_max	1.0
	valid_min	-1.0
	_FillValue	nan
	grid_mapping	projection
	long_name	LOS unit vector X
	units	1
/science/LSAR/ROFF/metadata/geolocationGrid/losUnitVectorY		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	

Description: North component of unit vector of LOS from target to sensor		
	valid_max	1.0
	valid_min	-1.0
	_FillValue	nan
	grid_mapping	projection
	long_name	LOS unit vector Y
	units	1
/science/LSAR/ROFF/metadata/geolocationGrid/alongTrackUnitVectorX		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: East component of unit vector along ground track		
	valid_max	1.0
	valid_min	-1.0
	_FillValue	nan
	grid_mapping	projection
	long_name	Along-track unit vector X
	units	1
/science/LSAR/ROFF/metadata/geolocationGrid/alongTrackUnitVectorY		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: North component of unit vector along ground track		
	valid_max	1.0
	valid_min	-1.0
	_FillValue	nan
	grid_mapping	projection
	long_name	Along-track unit vector Y
	units	1
/science/LSAR/ROFF/metadata/geolocationGrid/elevationAngle		
Type: Float32	**Shape: (geolocationCubeHeight, geolocationCubeLength, geolocationCubeWidth)**	
Description: Elevation angle is defined as the angle between the LOS vector and the normal to the ellipsoid at the sensor		
	valid_max	90.0
	valid_min	0.0
	_FillValue	nan
	grid_mapping	projection
	long_name	Elevation angle
	units	degrees
/science/LSAR/ROFF/metadata/geolocationGrid/parallelBaseline		
Type: Float32	**Shape: (geolocationCubeWidth, geolocationCubeLength, twoLayersCubeHeight)**	
Description: Parallel component of the InSAR baseline		
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points
	long_name	Parallel baseline
	units	meters
/science/LSAR/ROFF/metadata/geolocationGrid/perpendicularBaseline		
Type: Float32	**Shape: (geolocationCubeWidth, geolocationCubeLength, twoLayersCubeHeight)**	
Description: Perpendicular component of the InSAR baseline		
	mean_value	Arithmetic average of the numeric data points
	min_value	Minimum value of the numeric data points
	max_value	Maximum value of the numeric data points
	sample_stddev	Standard deviation of the numeric data points

	long_name	Perpendicular baseline
	units	meters
/science/LSAR/ROFF/metadata/geolocationGrid/slantRange		
Type: Float64	**Shape: (geolocationCubeWidth)**	
Description: Slant range values corresponding to the geolocation grid		
	units	meters
/science/LSAR/ROFF/metadata/geolocationGrid/zeroDopplerTime		
Type: Float64	**Shape: (geolocationCubeWidth)**	
Description: Zero Doppler time values corresponding to the geolocation grid		
	units	seconds since YYYY-mm-ddTHH:MM:SS
/science/LSAR/ROFF/metadata/geolocationGrid/groundTrackVelocity		
Type: Float64	**Shape: (geolocationCubeWidth)**	
Description: Absolute value of the platform velocity scaled at the target height		
	_FillValue	nan
	grid_mapping	projection
	long_name	Ground-track velocity
	units	meters / second
/science/LSAR/ROFF/metadata/geolocationGrid/heightAboveEllipsoid		
Type: Float64	**Shape: (geolocationCubeHeight)**	
Description: Height values above WGS84 Ellipsoid corresponding to the location grid		
	standard_name	height_above_reference_ellipsoid
	units	meters

6 METADATA CUBE

In this section, we provide an overview of the metadata cubes used to store spatially-varying ancillary data in the secondary layers of the NISAR L-SAR product HDF5 granules. Note that this sparse representation is to assist users in ingesting and analyzing NISAR products within existing GIS software and is not meant to replace traditional representations of SAR data within the product granules or traditional processing approaches with radar geometry-aware software.

Metadata cubes are represented as three-dimensional arrays in the NISAR product HDF5 modules (Figure 6-1). The axes of the array are interpreted as (height, increasing azimuth time, and increasing slant range) in case of radar geometry products and as (height, decreasing northing, and increasing easting) in case of geocoded products. The data is organized with height as the first axis, as this allows one to directly ingest data as GCPs or rasters into existing GIS software. Each height layer is the same size. Metadata cubes will have fixed grid spacing (3 km in azimuth/northing x 1 km in slant range/easting x 0.5 km in height and will allow for easy merging when multiple products along the same imaging track are to be concatenated. The metadata fields on this coarse resolution grid will be evaluated using traditional radar processing approaches without approximations. The metadata cube will also span a field slightly larger than the original image product to allow users to interpolate data without introducing edge effects. Such low-resolution representation of slowly varying parameters has been demonstrated for InSAR products and processing **Error! Reference source not found.**.

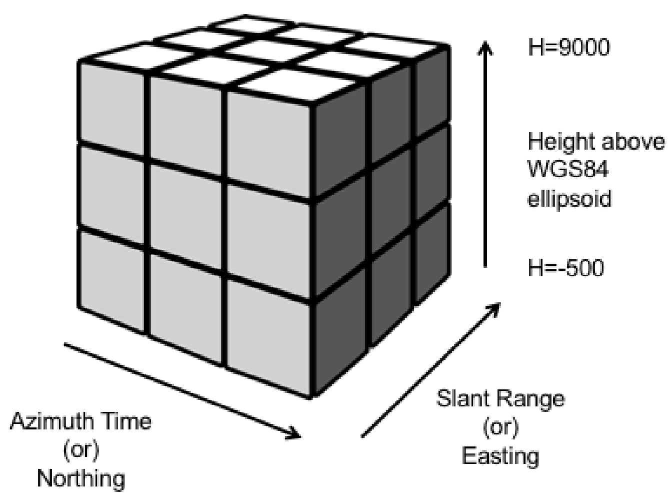

Figure 6-1. Metadata cube layer schematic

6.1 Metadata Cube Interpolation Example

We provide here a conceptual example of how these metadata cubes can be used within an existing GIS framework. Let us consider a GUNW product on a UTM Zone 10 grid (**Error!**

Reference source not found.). We use a geocoded product for the demonstration but the presented approach can be easily extended to radar coordinate products by replacing northing axis by azimuth time and easting axis by slant range.

Table 6-1 Example metadata cube properties.

Name	Value	Description
Primary layer properties		
xmin	100000.0	Easting of the first column (m)
xmax	340000.0	Easting of the last column (m)
dx	30.0	Column spacing in Easting (m)
Nx	8001	Number of columns
ymax	570000.0	Northing of first row (m)
ymin	330000.0	Northing of last row (m)
dy	-30.0	Row spacing in Northing (m). Negative to emphasize North-up imagery in geocoded products
Ny	8001	Number of rows
Metadata cube properties		
Cxmin	97000.0	Easting of first column (m)
Cxmax	343000.0	Easting of last column (m)
Cdx	1000.0	Column spacing in Easting (m)
CNx	247	Number of columns
Cymax	579000.0	Northing of first row (m)
Cymin	321000.0	Northing of last row(m)
Cdy	-3000.0	Row spacing in Northing (m). Negative to emphasize North-up imagery in geocoded products
CNy	87	Number of rows
Czmin	-1500	Height of the first layer (m)
Czmax	9000	Height of the last layer (m)
Cdz	1500	Layer spacing in height (m)
CNz	8	Number of height layers

Suppose we are interested in computing the Perpendicular Baseline (Bperp) at a pixel of interest located at UTM coordinates point (Px,Py). Since these are coordinates on a map domain, we can look up a DEM to get the height at this point. The three-dimensional point of interest then becomes (Px, Py, h(Px,Py)).

The metadata cube for Perpendicular baseline can be thought of as a three-dimensional field Bperp(x,y,z) – even though it is oriented as (Nz,Ny,Nx) in the HDF5 file for ease of use with a GIS. The user can use standard built-in regular grid three-dimensional interpolation routines in languages like MATLAB (e.g, interp3), IDL or Python (e.g, RegularGridInterpolator) to interpolate the Bperp array. We recommend cubic interpolation for best results. If a three-dimensional interpolator is not available, one could use two-dimensional cubic interpolation for each height layer followed by a one-dimensional cubic interpolation in the following manner:

1. Populate f(i), i=0,…Nz-1 by two-dimensional cubic interpolation of each height layer:

$$f(i) = Bperp\left[i, \frac{Py - Cymax}{Cdy}, \frac{Px - Cxmax}{Cdx}\right]$$

   where the numbers in the square brackets indicate indices into the three-dimensional cube. For example, if we are interested in the point (107590.0 East, 555870.0 North, 300.0 Height), we would interpolate at Row 7.71 and Column 10.59 for each height layer.

2. Interpolate f(i) using one-dimensional cubic interpolation:

$$Bperp\big(Px, Py, h(Px, Py)\big) = f\left[\frac{h(Px, Py) - Czmin}{Cdz}\right]$$

   where the number in the square bracket indicates an index into a one-dimensional array. For example, for a height value of 200.0, we would interpolate at an index of 1.2.

6.2 Metadata Cube Usage Note

Note that the metadata cubes are designed to accommodate one double-precision cube within 1 MB of memory, allowing for information to be easily stored in memory for on-the-fly computation within GIS frameworks or software without much overhead. The metadata cubes are not a replacement for traditional SAR processing approaches or very high-resolution analyses. They are meant to facilitate rapid processing and analysis by non-experts and will serve the needs for most SAR applications. Analyses show that the geolocation error is on the order of 1.5 cm due to interpolation which is significantly smaller than errors from sources such as DEM, orbits, and atmospheric path delay. Interpolation errors for each of the metadata layers will be reported after additional study.

7 APPENDIX A: ACRONYMS

ADT	Algorithm Development Team
AT	Along Track
AWS	Amazon Web Services
BFPQ	Block adaptive Floating-Point Quantization
Cal/Val	Calibration and Validation (also sometimes cal/val)
CDR	Critical Design Review
CF	Climate and Forecast
CPU	Central Processing Unit
CRSD	Calibration Raw Signal Data
CSV	Comma-separated values
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
DN	Digital Number
EAR	Export Administration Regulations
ECMWF	European Centre for Medium-Range Weather Forecasts
ECEF	Earth Centered Earth Fixed
EPSG	European Petroleum Survey Group
ESA	European Space Agency
FM	Frequency Modulation
FOP	Forecast Orbit Ephemeris
FOV	Field of View
GCOV	Geocoded Polarimetric Covariance (also as L2_GCOV)
GCP	Ground Control Point
GDAL	Geospatial Data Abstraction Library
GDS	Ground Data System
GIS	Geographic Information System
GMTED	Global Multi-resolution Terrain Elevation Data
GOFF	Geocoded Pixel Offsets (also as L2_GOFF)
GPU	Graphics Processing Unit
GSLC	Geocoded Single Look Complex (also as L2_GSLC)
GUNW	Geocoded Unwrapped Interferogram (also as L2_GUNW)
HDF5	Hierarchical Data Format version 5
HK, HKTM	Housekeeping Telemetry
InSAR	Interferometric Synthetic Aperture Radar
ISCE	InSAR Scientific Computing Environment
ISCE3	InSAR Scientific Computing Environment Enhanced Edition (for NISAR)
ISO	International Organization for Standardization

ISRO	Indian Space Research Organisation (British spelling)
L0B	Level-0B (data)
L1	Level-1 (data)
L2	Level-2 (data)
LOS	Line-Of-Sight
LUT	Lookup Table
Mbps	Megabits per second
MHz	Megahertz
MOE	Medium-precision Orbit Ephemeris
NCSA	National Center for Supercomputing Applications
NetCDF4	Network Common Data Form version 4
NISAR	NASA-ISRO Synthetic Aperture Radar
NOE	Near-Realtime Orbit Ephemeris
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
POD	Precision Orbit Determination
POE	Precision Orbit Ephemeris
PRF	Pulse Repetition Frequency
QA	Quality Assurance
REE	Radar Echo Emulator
RFI	Radio Frequency Interference
RIFG	Range-Doppler Interferogram (also as L1_RIFG)
ROFF	Range-Doppler Pixel Offsets (also as L1_ROFF)
RRSD	Radar Raw Signal Data
RRST	Radar Raw Science Telemetry
RSLC	Range-Doppler Single Look Complex (also as L1_RSLC)
RUNW	Range-Doppler UnWrapped Interferogram (also as L1_RUNW)
SAR	Synthetic Aperture Radar
SAS	Science Algorithm Software
SDS	Science Data System
SDT	Science Definition Team
SIS	Software Interface Specification
SLC	Single Look Complex
SNAPHU	Statistical-cost, Network-flow Algorithm for Phase Unwrapping
SRTM	Shuttle Radar Topography Mission
ST	Science Team
TAI	International Atomic Time (Temps Atomique International)
TCF	Terrain Correction Factor
TEC	Total Electron Content
TFdb	Track-frame Database
SWST	Sampling Window Start Time

UR	Urgent Response
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 84
XML	eXtensible Markup Language (xml in code)
YAML	YAML Ain't Markup Language