|  |  |  |
| --- | --- | --- |
|  | **Analysis Ready Data**  ***For Land*** | **Product Family Specification:**  **Normalised Radar Backscatter** |

# Document Status

**For Adoption as: Product Family Specification, Normalised Radar Backscatter**

This Specification should next be reviewed on: Q1/2022

Proposed revisions may be provided to: [lsi@lists.ceos.org](mailto:lsi@lists.ceos.org)

# Document History

|  |  |  |  |
| --- | --- | --- | --- |
| **Version** | **Date** | **Description of Change** | **Author** |
| 0.0.2 | 23.03.2017 | Zero Draft based on materials discussed in and | Lewis |
|  |  | leading up to LSI-VC-3, provided by SEO and others |  |
| 0.1.0 | 18.04.2017 | Various revisions to structure. | Lewis |
| 1.0.0 | 18.04.2017 | Included material provided by Brian Killough/SEO | Lewis |
|  |  | reflecting input from a range of SAR experts/users. |  |
| 1.0.1 | 20.04.2017 | Edits reflecting feedback from SEO, change to the | Lewis, Killough |
|  |  | figure/table in ‘guidance’; removed item 4.2, which |  |
|  |  | appeared redundant; moved reference to definitive |  |
|  |  | ephemeris to a note under item 4.1; added reference to speckle under table 3 (radiometric corrections). |  |
| 2.0.0 | 30.08.2017 | Feedback incorporated, circulated to LSI-VC. | Lewis |
| 2.1.0 | 06.09.2017 | Feedback from ESA included. | Lewis |
| 2.1.1 | 06.09.2017 | Edits rolled in. | Lewis |
| 3.0 | 02.02.2018 | Feedback from the teleconference | Siqueira |
|  |  | (06/12/2018) and post teleconf (emails) Included. |  |
| 3.1 | 03.04.2018 | Nuno Miranda (ESA) comments addressed | Siqueira, Miranda |
|  |  | (uncertainty information to be required at the |  |
|  |  | threshold level – 3.4 Radiometric corrections |  |
|  |  | (Accuracy), split sensor acquisition mode). |  |
| 3.1.1 | 12.04.2018 | Ake Rosenqvist (JAXA) comments (split sensor | Siqueira |
|  |  | acquisition mode into acquisition and processing |  |
|  | 04.06.2018 | parameters, include “global incidence angle”).  Feedback from Ben Lewis, GA (process table update) | Siqueira |
| 3.2 | 07.08.2018  21.08.2018 | Feedback from the “SAR ARD definition Team” before and at IGARSS 2018. Feedback on the 2nd SAR ARD definition Team teleconference (20/08/2018):  add a sentence on 1.19 that the radiometric performance metadata should be provided for each of the polarization channel when available | Siqueira  Rosenqvist |
| 3.2.1 | 14.12.2018 | Clarification about per pixel NESZ provision for each channel when noise removal is implemented. | Chapman |
| 3.2.2 | 05.02.2019 | Abstract updated, metadata definition added and v3.2.2 shared with LSI-VC list and LSI-VC-7 participants. | Rosenqvist, Charbonneau & Siqueira |
| 3.2.3 | 27.05.2019 | Formatting and verbiage updated for consistency. | Metzger |
| 4.0 | 02.03.2019 | Version endorsed at LSI-VC7 meeting (14Feb 2019) with minor amendments to address feedback from the SAR Definition Team. | LSI-VC-7 |
| 4.1 | 06.26.2019 | Added self-assessment columns | Bontje |
| 4.2 | 20.12.2019 | Integrated review at ESRIN CEOS WGCV SAR meeting. | Rosenqvist, Small, Chapman, Meyer, Lavalle, Miranda, Thankappan, Tadono, Zhou |
| 4.3 | 11.01.2020 | Integrated experiences with polarimetric document and clarified metadata descriptions for source data and products. Metadata specifications as separate document. | Small, Rosenqvist, Charbonneau & Zhou |
| 4.4 | 12.01.2020 | Single-source and Multi-source cases tentatively as separate documents. | Small & Rosenqvist |
| 4.5 | 06.02.2020 | 2.3 Scattering Area Image added | Small, Rosenqvist Charbonneau, Yuan, Dadamia, Zhou & Kellndorfer |
| 4.6 | 18.02.2020 | Simple mosaic multi-source case tentatively added to single document. Separate multi-source case still in development and alignment with POL v.2.7 | Rosenqvist |
| 4.7 | 13.03.2020 | Update to 4.4 Gridding Convention | Small, Kellndorfer, Rosenqvist & Charbonneau |
| 4.8 | 23.04.2020  10.05.2020 | * Definitions: Revised CEOS-ARD Acronym for Interferometric Radar from “IR” to “InSAR” * Item 3.2. Name change from “Backscatter conversion” to “Scaling conversion” | Thankappan,  Rosenqvist, Small, Charbonneau |
| 4.9 | 12.05.2020 | * Items 1.2 & 2.1: Aligned Target requirements with the SR 4.2 PFS and added NRB Metadata Specification as Target * Document history editorial | Rosenqvist, Labahn  Rosenqvist, Chapman, Labahn |
| 5.0 | 12.05.2020 | PFS endorsed at LSI-VC-9, meeting #3 | LSI-VC-9 |
| 5.1 | 03.03.2021 | Proposed changes after Feb. 2021 telecon | Small, Charbonneau |
| 5.2 | 14.04.2021 | * Item 1.7.7: Text clarification * Item 2.3: Move to Target * Item 2.9: Added new per-pixel metadata: Resampled DEM (Target) | Rosenqvist, Logan, Charbonneau, Zhou, Small, Chapman, Kellndorfer, Yuan, Repse, Truckenbrodt, Tadono, Albinet |
| 5.3 | 03.05.2021 | * Item 1.6.6: Move source data looks to Target * Item 1.7.1: Product Level and Product ID information requirement removed * Item 1.7.5: Two corners sufficient * Item 2.3, 2.4: move proposed new descriptive text to forthcoming “Educational resources” document | Rosenqvist, Logan, Charbonneau, Zhou, Small, Chapman, Kellndorfer, Yuan, Repse, Truckenbrodt, Tadono, Albinet |
| 5.4 | 20.05.2021  08.08.2021 | * Item 4.3: Geolocation accuracy requirement (Threshold) relaxed as per LSI-VC-10 discussions * Editorial | Rosenqvist |
| 5.5.01 | 31.08.2021  09.09.2021  29.09.2021  30.09.2024 | * Items 1.6.3, 1.6.5, 1.6.9, 1.7.1, 1.7.6, 2.8, 4.3: Text clarifications * Item 1.6.9: Allowing for provision of mean and/or max/min noise level values * Item 1.7: Name change “Product Attributes” to “CEOS-ARD Product Attributes” * Item 1.7.5: Require same CRS as in 1.7.9 * Item: 1.7.6: Format requirement * Item 1.7.9: Move EPSG code requirement to Threshold * Item 1.7.10: Removed (redundant) * Item 2.8: Name change “Acquisition Day” to “Acquisition ID” image. * Item 2.9: Name change “Resampled DEM” to “Per-pixel DEM” * 4.2: Added specifications of EGM used (Threshold) and methods for resampling of DEM and EGM (Target) * 4.3: Absolute localisation error given as bias and standard deviation (Threshold) * Item 1.6.7 (Source Data Image Attributes):   Azimuth Pixel Spacing can be provided in units  of metres or seconds. | Repse, Zhou,  Rosenqvist, Yuan,  Charbonneau,  Truckenbrodt, Small |
| 5.5 | 04.10.2021  14.10.2021 | Editorial check | Bontje,  Rosenqvist |

# Contributing authors (in alphabetical order)

Clément Albinet, ESA, Italy

Darcie Bontje, USGS, USA

Bruce Chapman, Jet Propulsion Laboratory, USA

François Charbonneau, Natural Resources Canada, Canada

Danilo Dadamia, CONAE, Argentina

Josef Kellndorfer, Earth Big Data, USA

Brian Killough, NASA, USA

Steven Labahn, USGS, USA

Marco Lavalle, Jet Propulsion Laboratory, USA

Adam Lewis, Geoscience Australia, Australia

Thomas Logan, Alaska Satellite Facility, USA

Mary Metzger, USGS, USA

Franz Meyer, Alaska Satellite Facility, USA

Nuno Miranda, European Space Agency, Italy

Marko Repse, Sinergise, Slovenia

Ake Rosenqvist, soloEO *for* Japan Aerospace Exploration Agency, Japan

Andreia Siqueira, Geoscience Australia, Australia

David Small, University of Zurich, Switzerland

Takeo Tadono, Japan Aerospace Exploration Agency, Japan

Medhavy Thankappan, Geoscience Australia, Australia

John Truckenbrodt, Friedrich Schiller University Jena, Germany

Fang Yuan, Digital Earth Africa, Australia

Zheng-Shu Zhou, CSIRO, Australia

**Description**

**Product Family Title:** **Normalised Radar Backscatter (CEOS-ARD -NRB)**

**Applies to***:* Data collected by Synthetic Aperture Radar sensors.

The CEOS-ARD Product Family Specifications for Synthetic Aperture Radar (SAR) data are specifically aimed at users interested in exploring the potential of SAR but who may lack the expertise or facilities for SAR processing. There are (as of September 2021) two CEOS-ARD SAR products endorsed by CEOS LSI-VC, and two under development:

• Normalised Radar Backscatter [endorsed]

• Polarimetric Radar [endorsed]

• Geocoded Single-Look Complex [under development]

• Interferometric Products [under development]

The CEOS-ARD Normalised Radar Backscatter product specification described below has been subject to Radiometric Terrain Correction (RTC) and is provided in the gamma-0 (0) backscatter convention, which mitigates the variations from diverse observation geometries. It is recommended for most land applications. As the NRB product contains backscatter values only, it cannot be directly used for SAR polarimetry or interferometric applications that require local phase estimates.

It should be noted that while speckle is inherent in SAR acquisitions, speckle filtering has not been applied to the Normalised Radar Backscatter product in order to preserve spatial resolution and user freedom. Some applications (or processing methods) may require spatial or temporal filtering for stationary backscatter estimates.

# Definitions

|  |  |
| --- | --- |
| CEOS-ARD | CEOS Analysis Ready Data |
| NRB | Normalised Radar Backscatter |
| POL | Polarimetric Radar |
| GSLC | Geocoded Single-Look Complex |
| InSAR | Interferometric Radar |
| RTC | Radiometric Terrain Correction |
| Ancillary Data | Data other than instrument measurements, originating in the instrument itself or from the satellite, required to perform processing of the data. They include orbit data, attitude data, time information, spacecraft engineering data, calibration data, data quality information, and data from other instruments. |
| Auxiliary Data | The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources. |
| Metadata | Structured information that describes other information or information services. With well-defined metadata, users should be able to get basic information about data, without the need to have knowledge about its entire content. |
| Spatial Resolution | The highest magnification of the sensor at the ground surface. |
| Spatial Sampling Distance | Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface. |

# Requirements

## General Metadata

*These are metadata records describing a distributed collection of pixels. The collection of pixels referred to must be contiguous in space and time. General metadata should allow the user to assess the overall suitability of the dataset, and must meet the following requirements:*

| **#** | **Item** | **Threshold**  **(Minimum) Requirements** | **Goal**  **(Desired) Requirements** | **Threshold Self-Assessment** | **Goal**  **Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Recommended Requirement Modification** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1.1** | **Traceability** | Not required. | Data must be traceable to SI reference standard.  *Note 1. Relationship to 3.4. Traceability requires an estimate of measurement uncertainty.*  *Note 2: Information on traceability should be available in the metadata as a single DOI landing page.* | Not Required |  |  | **Not Required** |
| **1.2** | **Metadata Machine Readability** | Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use. | As threshold, but metadata is formatted in accordance with CEOS-ARD NRB Metadata Specifications, v.5.5, or a community endorsed standard that facilitates machine-readability, such as ISO 19115-2 | Met Requirement |  | **Metadata stored in HDF5 file** | **Verified at Threshold** |
| **1.3** | **Product type** | CEOS-ARD product type name and (if required by the data provider) Copyright. | As threshold. | Met Requirement |  | **identification/ceosAnalysisReadyDataProductType = "Normalised Radar Backscatter** | **Verified at Threshold** |
| **1.4** | **Document Identifier** | Reference to CEOS-ARD - Normalised Radar Backscatter document as URL or DOI. | As threshold. | Met Requirement |  | **identification/ceosAnalysisReadyDataDocumentIdentifier = "https://ceos.org/ard/files/PFS/NRB/v5.5/CARD4L-PFS\_NRB\_v5.5.pdf** | **Verified at Threshold** |
| **1.5** | **Data Collection Time** | Number of source data acquisitions of the data collection is identified. The start and stop time of data collection is identified in the metadata, expressed in date/time (UTC). In case of composite products, the dates/times of the first and last data takes. | As threshold. | Met Requirement |  | **identification/zeroDopplerStartTime = "2023-10-08T22:53:07.427341Z"8Z"**  **identification/zeroDopplerEndTime = "2023-10-08T22:53:10.50039** | **Verified at Threshold** |
| **1.6** | **Source Data Attributes** | Sub-section describing (detailing) the SAR acquisition used to generate the CEOS-ARD product.  *Note: Source data attribute information are described for each acquisition and sequentially identified as acqID= 1, 2, 3, …* | |  |  |  |  |
| **1.6.1** | **Source Data Access** | The metadata identifies the location from where the source data can be retrieved, expressed as a URL or DOI. | The metadata identifies an online location from where the data can be consistently and reliably retrieved by a computer algorithm without any manual intervention being required. | Met Requirement |  | **/metadata/sourceData/dataAccess = "https://search.asf.alaska.edu/#/?dataset=SENTINEL-1&productTypes=SLC"** | **Verified at Threshold** |
| **1.6.2** | **Instrument** | The instrument used to collect the data is identified in the metadata:   * Satellite name * Instrument name | As threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record. | Met Requirement |  | **identification/instrumentName = "Sentinel-1A CSAR" ;**  **identification/platform = "Sentinel-1A" ;** | **Verified at Threshold** |
| **1.6.3** | **Source Data Acquisition**  **Time** | The start date and time of source data is identified in the metadata, expressed in UTC in date and time, at least to the second. | As threshold. | Met Requirement |  | **identification/zeroDopplerStartTime = "2023-10-08T22:53:07.427341"** | **Verified at Threshold** |
| **1.6.4** | **Source Data Acquisition Parameters** | Acquisition parameters related to the SAR antenna:   * Radar band * Centre frequency Observation mode * Polarization(s) * Antenna pointing [Right/Left]   - Beam ID | As threshold. | Met Requirement |  | **identification/radarBand = "C"**  **metadata/sourceData/centerFrequency = 5405000454.33435**  **identification/acquisitionMode = "IW"**  **data/listOfPolarizations = "HH","HV"**  **identification/lookDirection = "right"**  **/identification/subSwathID = "IW1"** | **Verified at Threshold** |
| **1.6.5** | **Source Data Orbit Information** | Information related to the platform orbit used for data processing:   * Pass direction [asc/desc) * Orbit data source [e.g., predicted/definite/ precise/ downlinked etc.] | As threshold, including also:   * Platform heading angle expressed in degrees [0 360] from North * Orbit data file containing state vectors (minimum of 5 state vectors, from 10% of scene length *before* start time to 10% of scene length *after* stop time) * Platform (mean) altitude | Met Requirement |  | **identification/orbitPassDirection = "ascending"**  **metadata/orbit/orbitType = "RES restituted orbit"** | **Verified at Threshold**  **Goal Level not assessed** |
| **1.6.6** | **Source Data Processing Information** | Processing parameters details of the source data:   * Processing facility * Processing date * Software version * Product ID (file name) * Product level * Azimuth number of Looks * Range number of Looks (separate values for each beam, as necessary) | As threshold,  Plus additional relevant processing parameters, e.g., Range- and Azimuth Look Bandwidth and LUT applied | Met Requirement |  | **Facilities are from geoTIFFs**  **HH = SOURCE\_DATA\_PROCESSING\_CENTER=organization: "ESA", site: "Production Service-SERCO", country: "Italy"**  **HV = SOURCE\_DATA\_PROCESSING\_CENTER=organization: "ESA", site: "Production Service-SERCO", country: "Italy"**  **mask = SOURCE\_DATA\_PROCESSING\_CENTER=organization: "ESA", site: "Production Service-SERCO", country: "Italy"**  **incidence\_angle = SOURCE\_DATA\_PROCESSING\_CENTER=organization: "ESA", site: "DLR-Oberpfaffenhofen", country: "Germany"**  **metadata/sourceData/processingDateTime = "2023-10-10T23:31:20.653952Z"**  **metadata/sourceData/softwareVersion = "3.61"**  **l1SlcGranules = "S1A\_IW\_SLC\_\_1SDH\_20231008T225259\_20231008T225317\_050680\_061B41\_ADA9.zip"**  **metadata/sourceData/productLevel = "L1"**  **metadata/sourceData/azimuthLooks = 1**  **metadata/sourceData/slantRangeLooks = 1** | **Verified at Threshold** |
| **1.6.7** | **Source Data Image Attributes** | Image attributes related to the source data:   * Source Data geometry (slant range/ground range) * Azimuth pixel spacing [m] (alternatively, Azimuth pixel spacing can be provided in second [s], equivalent to the azimuth time sample interval) * Range pixel spacing * Azimuth resolution * Range resolution * Near range incident angle * Far range incident angle | The geometry of the image footprint expressed in WGS84 in a standardised format (e.g., WKT). | Met Requirement |  | **metadata/sourceData/productLevel = "L1"**  **{in metadata/sourceData/productLevel:description it states ‘L1: Processed instrument data in radar coordinates system’ which means slant range}**  **/metadata/sourceData/zeroDopplerTimeSpacing = 0.00205556**  **metadata/sourceData/slantRangeSpacing = 2.32956**  **metadata/sourceData/azimuthResolutionInMeters = 22.5  metadata/sourceData/slantRangeResolutionInMeters = 2.7**  **metadata/sourceData/nearRangeIncidenceAngle = 30.5947**  **metadata/sourceData/farRangeIncidenceAngle = 36.4203** | **Verified at Threshold** |
| **1.6.8** | **Sensor Calibration** | Not required. | Sensor calibration parameters are identified in the metadata or can be accessed using details included in the metadata. Ideally this would support machine to machine access | Not Required |  |  | **Not Required** |
| **1.6.9** | **Performance Indicators** | Provide performance indicators on data intensity noise level (NE0 and/or NE0 and/or NE0 (noise equivalent sigma and/or beta and/or gamma naught)). Provided for each polarization channel when available.  Parameter may be expressed as the mean and/or minimum and maximum noise equivalent values of the source data.  Values do not need to be estimated individually for each product, but may be estimated once for each acquisition mode, and annotated on all products. | Provide additional relevant performance indicators (e.g., ENL, PSLR, ISLR etc.) | Met Requirement |  | **metadata/sourceData/maxNoiseEquivalentSigmaZero = -22**  **Units are dB** | **Verified at Threshold** |
| **1.6.10** | **Source Data Polarimetric Calibration Matrices** | Not Required. | The complex-valued polarimetric distortion matrices with the channel imbalance and the cross-talk applied for the polarimetric calibration. | Not Required |  |  | **Not Required** |
| **1.6.11** | **Mean Faraday Rotation Angle** | Not Required. | The mean Faraday rotation angle estimated from the polarimetric data and/or from models with reference to the method or paper used to derive the estimate. | Not Required |  |  | **Not Required** |
| **1.6.12** | **Ionosphere Indicator** | Not required. | Flag indicating whether the backscatter imagery is “significantly impacted” by the ionosphere (0- false, 1 – true). Significant impact would imply that the ionospheric impact on the backscatter exceeds the radiometric calibration requirement or goal for the imagery. | Not Required |  |  | **Not Required** |
| **1.7** | **CEOS-ARD Product Attributes** | Sub-section containing information related to the CEOS-ARD product generation procedure and parameters | |  |  |  |  |
| **1.7.1** | **Product Data Access** | Processing parameters details of the CEOS-ARD product:   * Processing facility * Processing date * Software version * Location from where the CEOS-ARD product can be retrieved, expressed as a URL or DOI. | The metadata identifies an online location from where the data can be consistently and reliably retrieved by a computer algorithm without any manual intervention being required. | Met Requirement |  | **identification/institution = "NASA JPL"**  **identification/processingDateTime = "2023-10-09T14:27:52.974847Z"**  **metadata/processingInformation/algorithms/softwareVersion = "1.0.1"** | **Verified at Threshold** |
| **1.7.2** | **Ancillary Data** | Not required. | The metadata identifies the sources of ancillary data used in the generation process, ideally expressed as DOIs.  *Note: Ancillary data includes DEMs and any additional data sources used in the generation of the product.* | Not Required |  |  | **Not Required** |
| **1.7.3** | **Product**  **Sample Spacing** | CEOS-ARD product processing parameters details:   * Pixel (column) spacing * Line (row) spacing | As threshold. | Met Requirement |  | **data/xCoordinateSpacing = 30**  **data/yCoordinateSpacing = -30** | **Verified at Threshold** |
| **1.7.4** | **Product**  **Filtering** | Flag if filter has been applied [true/false]  Metadata should include   * Reference to algorithm * Input filtering parameters   + Type   + Window size   + Other filter parameters | As threshold. | Met Requirement |  | **metadata/parameters/filteringApplied = false** | **Verified at Threshold** |
| **1.7.5** | **Product Bounding Box** | Two opposite corners of the product file (bounding box) are identified, expressed in the coordinate reference system defined in 1.7.9. | As threshold. | Met Requirement |  | **identification/boundingBox = 370140, 5061600, 469500, 5108700** | **Verified at Threshold** |
| **1.7.6** | **Product Image Extent** | The geometry of the image footprint expressed in WGS84, in a standardised format (e.g., WKT). | As threshold. | Met Requirement |  | **"POLYGON ((-76.55485553917953 45.74063060914809, -76.49537497589922 45.74873200533597, -76.43544828411001 45.75685970086086, -76.37796808315656 45.76462547306998, -76.31965908258196 45.77247037937519, -76.26249653075536 45.78013063325719, -76.20550868538898 45.78773670391862, -76.14941495802276 45.79519410935692, -76.09362335863473 45.80258199202877, -76.0394857016436 45.80972413161087, -75.98522257124735 45.81685482713208, -75.93065011887468 45.82399774202978, -75.87345608908285 45.83145106173516, -75.81993596436736 45.83840084934592, -75.76652015255573 45.84531017599898, -75.71426893056322 45.85204389019038, -75.66214916953464 45.85873508757528, -75.60975051425174 45.86543596384318, -75.55636307254063 45.87223564876741, -75.50461685913601 45.87880224003079, -75.45282280252157 45.88534926864657, -75.49666758402033 46.05066795590792, -75.54796316958462 46.04420072917706, -75.60055083409729 46.03754586169104, -75.65277628640337 46.03091059737488, -75.70566735485767 46.02416525629162, -75.75884567161565 46.01735693319529, -75.8120822589894 46.01051444621736, -75.866448702324 46.00350018349664, -75.92093601413588 45.99644238908459, -75.97528408741208 45.9893745105098, -76.0300214027111 45.98222811831616, -76.08479476383023 45.97504863070205, -76.14034443076127 45.96773906002456, -76.19565364089905 45.96043183361986, -76.25198720762945 45.95296036307637, -76.30885719749422 45.94538765593207, -76.36593628140706 45.93775638791998, -76.423128835367 45.93007897981063, -76.48146089205525 45.92221754123911, -76.5405948701911 45.91421564146805, -76.60034757943464 45.90609669290628, -76.55485553917953 45.74063060914809))"** | **Verified at Threshold** |
| **1.7.7** | **Product Image Size** | Image attributes of the CEOS-ARD product:   * Number of lines * Number of pixels/line * File header size (if applicable) * Number of no-data border pixels (if appl.) | As threshold. | Met Requirement |  | **data/xCoordinates = 3312**  **data/yCoordinates = 1570** | **Verified at Threshold** |
| **1.7.8** | **Product**  **Pixel Coordinate Convention** | Coordinate referring to the Centre, or the Upper Left Corner or the Lower Left Corner of a pixel.  Values are [pixel centre, pixel ULC or pixel LLC] | As threshold. | Met Requirement |  | **Value is ULC as given in the geoTIFF specification http://geotiff.maptools.org/spec/geotiff2.5.html** | **Verified at Threshold** |
| **1.7.9** | **Product Coordinate Reference System** | The metadata lists the map projection (or geographical coordinates, if applicable) that has been used and any relevant parameters required to use of data in that map projection, expressed in a standardised format (e.g., WKT).  Indicate EPSG code, if defined for the CRS. | As threshold. | Met Requirement |  | **data/projection = 32618** | **Verified at Threshold** |

## Per-Pixel Metadata

*The following minimum metadata specifications apply to each pixel. Whether the metadata are provided in a single record relevant to all pixels, or separately for each pixel, is at the discretion of the data provider. Per-pixel metadata should allow users to discriminate between (choose) observations on the basis of their individual suitability for application*

| **#** | **Item** | **Threshold**  **(Minimum) Requirements** | **Target**  **(Desired) Requirements** | **Threshold Self-Assessment** | **Goal**  **Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Recommended Requirement Modification** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **2.1** | **Metadata Machine Readability** | Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use. | As threshold, but metadata is formatted in accordance with CEOS-ARD NRB Metadata Specifications, v.5.5 | Met Requirement |  | **Metadata is stored in HDF5 file** | **Verified at Threshold** |
| **2.2** | **Data Mask Image** | Mask image indicating:   * Valid data * Invalid data * No data   File format specifications/ contents provided in metadata:   * Sample Type [Mask] * Data Format [Raw/GeoTif/COG, …] * Data Type [Byte/Int/Float, ...] * Bits per sample * Byte order * Bit value representation | As threshold, including in addition e.g.   * Layover (masked as invalid data in Threshold) * Radar shadow (masked as invalid data in Threshold) * Ocean water, etc. | Met Requirement |  | **Filename = OPERA\_L2\_RTC-S1\_T033-069005-IW1\_20231008T225307Z\_20231009T142749Z\_S1A\_30\_v1.0\_mask.tif**  **Sample Type: Mask**  **File Format = GeoTIFF** [**http://geotiff.maptools.org/spec/geotiff2.5.html**](http://geotiff.maptools.org/spec/geotiff2.5.html)  **Data Type = UINT**  **BitsperSample = 8**  **ByteOrder = Little Endian**  **LAYER\_DESCRIPTION=Mask Layer. Values: 0: not masked; 1: shadow; 2: layover; 3: layover and shadow; 255: invalid/fill value**  **File Format is GeoTIFF** [**http://geotiff.maptools.org/spec/geotiff2.5.html**](http://geotiff.maptools.org/spec/geotiff2.5.html) | **Verified at Threshold** |
| **2.3** | **Scattering Area Image** | Not required. | DEM-based scattering area image used for terrain normalisation is provided.  File format specifications/ contents provided in metadata:   * Sample Type [Scattering Area] * Data Format * Data Type * Byte Order * Bits per sample | Not Required |  |  | **Not Required** |
| **2.4** | **Local Incident Angle Image** | DEM-based Local Incident angle image is provided.  File format specifications/ contents provided in metadata:   * Sample Type [Angle] * Data Format * Data Type * Byte Order * Bits per sample | As threshold. | Met Requirement |  | **Given as a static layer**  **File Name = OPERA\_L2\_RTC-S1-STATIC\_T033-069005-IW1\_20140403\_S1A\_30\_v1.0\_local\_incidence\_angle.tif**  **Layer\_Name=Local Incidence Angle**  **File Format is GeoTIFF http://geotiff.maptools.org/spec/geotiff2.5.html**  **Data Type = FLOAT**  **BitsperSample = 32**  **ByteOrder = Little Endian** | **Verified at Threshold** |
| **2.5** | **Ellipsoidal Incident Angle Image** | Not required. | Ellipsoidal incident angle is provided.  Indicate which ellipsoidal height was used.  File format specifications/ contents provided in metadata:   * Sample Type [Angle] * Data Format * Data Type * Byte Order * Bits per sample | Not Required |  |  | **Not Required** |
| **2.6** | **Noise Power Image** | Not required. | Estimated noise equivalent σo (or 0 or o, as applicable) used for Noise Removal, if applied, for each channel.  File format specifications/ contents provided in metadata:   * Sample Type [NESZ or NEBZ] * Data Format * Data Type * Byte Order * Bits per sample | Not Required |  |  | **Not Required** |
| **2.7** | **Gamma-to-**  **Sigma Ratio Image** | Not required. | Ratio of the integrated area in the Gamma projection over the integrated area in the Sigma projection (ground). Multiplying RTC o by this ratio results in an estimate of RTC o .  File format specifications/ contents provided in metadata:   * Sample Type [Ratio] * Data Format * Data Type * Byte Order * Bits per sample | Not required |  |  | **Not Required** |
| **2.8** | **Acquisition ID Image** | **Note: Required for multi-source product only.**  Acquisition ID, or acquisition date, for each pixel is identified.  In case of multi-temporal image stacks, use source acquisition ID (i.e., 1.6 acqID values) to list contributing images.  In case of Date, data represent day offset to reference observation date [UTC]. Date used as reference (“Day 0”) is provided in the metadata.  Pixels not representing a unique date (e.g., pixels averaged in image overlap zones) are flagged with a pre-set pixel value that is provided in the metadata.  File format specifications/ contents provided in metadata:   * Sample Type [Day, ID] * Data Format * Data Type * Byte Order * Bits per sample | In case of image composites, the sources for each pixel are uniquely identified. | Not required |  | **Only required for multi-source products** | **Verified at Threshold**  **Not required for NRB Product** |
| **2.9** | **Per-pixel DEM** | Not required. | Provide DEM as used during the geometric and radiometric processing of the SAR data, resampled to an exact geometric match in extent and resolution with the CEOS-ARD SAR image product.  File format specifications/ contents provided in metadata:   * Sample Type [Height] * Data Format * Data Type * Byte Order * Bits per sample | Not required |  |  | **Not Required** |

## Radiometric Terrain Corrected Measurements

*The following requirements must be met for all pixels in a collection. The requirements indicate the necessary outcomes and to some degree the minimum steps*

*necessary to be deemed to have achieved those outcomes. Radiometric corrections must lead to normalised measurement(s) of backscatter intensity.*

| **#** | **Item** | **Threshold**  **(Minimum) Requirements** | **Target**  **(Desired) Requirements** | **Threshold Self-Assessment** | **Goal**  **Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Recommended Requirement Modification** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **3.1** | **Backscatter Measurements** | Terrain-flattened Gamma-Nought backscatter coefficient () is provided for each polarization (e.g., HH, HV, VV, VH).  File format specifications/contents provided in metadata:   * Measurement Type [Gamma-Nought] * Backscatter Expression Convention [linear amplitude or linear power\*] * Polarization [HH/HV/VV/VH] * Data Format [Raw/GeoTif/COG, …] * Data Type [Byte/Int/Float, ...] * Byte order * Bits per sample   *\*Note: transformation to the logarithm decibel scale is not required or* desired *as this step can be easily completed by the user if necessary.* | As threshold. | Met Requirement |  | **File Name =**  **OPERA\_L2\_RTC-S1\_T033-069005-IW1\_20231008T225307Z\_20231009T142749Z\_S1A\_30\_v1.0\_HH.tif**  **/metadata/processingInformation/parameters/outputBackscatterNormalizationConvention = “gamma0”**  **/metadata/processingInformation/parameters/outputBackscatterExpressionConvention = “linear backscatter intensity”**  **From geoTIFF file LAYER\_NAME=RTC-S1 HH Backscatter**  **Data format is geoTIFF as described in** [**http://geotiff.maptools.org/spec/geotiff2.5.html**](http://geotiff.maptools.org/spec/geotiff2.5.html)  **Data Type = FLOAT**  **ByteOrder = 32**  **ByteOrder = Little Endian**  **File Name =**  **OPERA\_L2\_RTC-S1\_T033-069005-IW1\_20231008T225307Z\_20231009T142749Z\_S1A\_30\_v1.0\_HV.tif**  **/metadata/processingInformation/parameters/outputBackscatterNormalizationConvention = “gamma0”**  **/metadata/processingInformation/parameters/outputBackscatterExpressionConvention = “linear backscatter intensity”**  **From geoTIFF file LAYER\_NAME=RTC-S1 HV Backscatter**  **Data format is geoTIFF as described in** [**http://geotiff.maptools.org/spec/geotiff2.5.html**](http://geotiff.maptools.org/spec/geotiff2.5.html)  **Data Type = FLOAT**  **ByteOrder = 32**  **ByteOrder = Little Endian** | **Verified at Threshold** |
| **3.2** | **Scaling Conversion** | Indicate equation to convert from pixel linear amplitude/power to logarithmic decibel scale, including, if applicable, associated calibration (dB offset) factor. | As threshold. | Met Requirement |  | **/metadata/processingInformation/parameters/outputBackscatterDecibelConversionEquation = "10\*log10(backscatter\_linear)"** | **Verified at Threshold** |
| **3.3** | **Noise Removal** | Flag if noise removal\* has been applied (Y/N). Metadata should include reference to algorithm as URL or DOI  \* *Note: Thermal noise removal and image border noise removal to remove overall scene noise and scene edge artefacts, respectively.* | As threshold. | Met Requirement |  | **metadata/processingInformation/parameters/noiseCorrectionApplied = TRUE**  **/metadata/processingInformation/algorithms/noiseCorrectionAlgorithmReference = "Thermal Denoising of Products Generated by the S-1 IPF. ESA document. Accessed: May 29, 2023. [Online]. Available: https://sentinels.copernicus.eu/documents/247904/2142675/Thermal-Denoising-of-Products-Generated-by-Sentinel-1-IPF.pdf"** | **Verified at Threshold** |
| **3.4** | **Radiometric Terrain Correction Algorithms** | Adjustments are made for terrain by modelling the local illuminated reference area using the preferred choice of a traceable published peer reviewed algorithm to produce a radiometrically terrain corrected (RTC) Gamma-Nought ().  Metadata references:   * a citable peer-reviewed algorithm * technical documentation regarding the implementation of that algorithm expressed as URLs or DOIs * the sources of ancillary data used to make corrections.   *Note 1: Examples of technical*  *documentation include an Algorithm, Theoretical Basis Document, product user guide, etc.* | Require resolution of DEM better than the output product resolution when applying terrain corrections. | Met Requirement |  | **/metadata/processingInformation/algorithms/radiometricTerrainCorrection = "Area-Based SAR Radiometric Terrain Correction (RTC-AP)"**  **/metadata/processingInformation/algorithms/radiometricTerrainCorrectionAlgorithmReference = "Gustavo H. X. Shiroma, Marco Lavalle, and Sean M. Buckley, "An Area-Based Projection Algorithm for SAR Radiometric Terrain Correction and Geocoding," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-23, 2022, Art no. 5222723, doi: 10.1109/TGRS.2022.3147472."** | **Verified at Threshold** |
| **3.5** | **Radiometric Accuracy** | Not required. | Uncertainty (e.g., bounds on *ϒ*0) information is provided as document referenced as URL or DOI. SI traceability is achieved. | Not required |  |  | **Not Required** |

## Geometric Terrain Corrections

*Geometric corrections must place the measurement accurately on the surface of the Earth (that is, geolocate the measurement) allowing measurements taken*

*through time to be compared.*

| **#** | **Item** | **Threshold**  **(Minimum) Requirements** | **Target**  **(Desired) Requirements** | **Threshold**  **Self-Assessment** | **Goal**  **Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Recommended Requirement Modification** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **4.1** | **Geometric Correction Algorithms** | Not required | Metadata references:   * A metadata citable peer-reviewed algorithm, * Technical documentation regarding the implementation of that algorithm expressed as URLs or DOIs * The sources of ancillary data used to make corrections. * Resampling method used for geometric processing of the source data.   *Note 1: Examples of technical*  *documentation can include e.g., an Algorithm, Theoretical Basis Document, a Product User Guide.* | Not required |  |  | **Not Required**  **Goal Level not assessed** |
| **4.2** | **Digital Elevation**  **Model** | 1. During ortho-rectification, the data provider shall use the same DEM that was used for the radiometric terrain flattening to ensure consistency of the data stack. 2. Provide reference to Digital Elevation Model used for Geometric Terrain Correction. 3. Provide reference to Earth Gravitational Model (EGM) used for Geometric Correction | 1. A DEM with comparable or better resolution to the resolution of the output CEOS-ARD product shall be used. 2. Resampling method used for preparation of the DEM. 3. Method used for resampling of EGM. 4. As threshold. | Met Requirement |  | **metadata/processingInformation/inputs/demSource = "Digital Elevation Model (DEM) for the NASA OPERA project version 1.1 (v1.1) based on the Copernicus DEM 30-m and Copernicus 90-m referenced to the WGS84 ellipsoid"**  **/metadata/processingInformation/algorithms/demEgmModel = "Earth Gravitational Model 2008 (EGM2008)"** | **Verified at Threshold** |
| **4.3** | **Geometric Accuracy** | An estimate of the absolute localisation error is provided as bias and standard deviation, provided in slant range/azimuth, or Northing/Easting.  *Note 1: Can be obtained from corner reflector measurements or mission calibration/ validation results.*  *Note 2: Accurate geolocation is a prerequisite to radar processing to correct for terrain. To enable interoperability between radar sensors, absolute accuracy is required.* | Output product sub-sample accuracy should be less than or equal to 0.1-pixel radial root mean square error (rRMSE).  Provide documentation of estimate of absolute localisation error as DOI or URL. | Met Requirement |  | **/metadata/qa/geometricAccuracy/bias/x = -0.72**  **/metadata/qa/geometricAccuracy/bias/y = -0.67**  **/metadata/qa/geometricAccuracy/stddev/x = 0.7**  **/metadata/qa/geometricAccuracy/stddev/y = 0.62** | **Verified at Threshold** |
| **4.4** | **Gridding Convention** | A consistent gridding/sampling frame is used. The origin is chosen to minimise any need for subsequent resampling between multiple products (be they from the same or different providers). This is typically accomplished via a “snap to grid” in relation to the most proximate grid tile in a global system.\*\*  \*\* If a product hierarchy of resolutions exists (or is planned), the multiple resolutions should nest within each other (e.g., 12.5m, 25m, 50m, 100m, etc.), and not be disjoint. | Provide DOI or URL to gridding convention used.  When multiple providers share a common map projection, providers are encouraged to standardise the origins of their products among each other.  In the case of UTM/UPS coordinates, the upper left corner coordinates should be set to an integer multiple of sample intervals from a 100 km by 100 km grid tile of the Military Grid Reference System's 100k coordinates (“snap to grid”).  For products presented in geographic coordinates (latitude and longitude), the origin should be set to an integer multiple of samples in relation to the closest integer degree. | Met Requirement |  | **/metadata/processingInformation/parameters/geocoding/burstGeogridSnapX = 30**  **/metadata/processingInformation/parameters/geocoding/burstGeogridSnapY = 30** | **Verified at Threshold** |

# Summary Self-Assessment Table

|  |  | **Threshold** | **Goal** |
| --- | --- | --- | --- |
| **1** | **General Metadata** |  |  |
| 1.1 | Traceability | Not Required |  |
| 1.2 | Metadata Machine Readability | Met Requirement |  |
| 1.3 | Product type | Met Requirement |  |
| 1.4 | Document Identifier | Met Requirement |  |
| 1.5 | Data Collection Time | Met Requirement |  |
| **1.6** | **Source Data Attributes** |  |  |
| 1.6.1 | Source Data Access | Met Requirement |  |
| 1.6.2 | Instrument | Met Requirement |  |
| 1.6.3 | Source Data Acquisition Time | Met Requirement |  |
| 1.6.4 | Source Data Acquisition Parameters | Met Requirement |  |
| 1.6.5 | Source Data Orbit Information | Met Requirement |  |
| 1.6.6 | Source Data Processing Information | Met Requirement |  |
| 1.6.7 | Source Data Image Attributes | Met Requirement |  |
| 1.6.8 | Sensor Calibration | Not Required |  |
| 1.6.9 | Performance Indicators | Met Requirement |  |
| 1.6.10 | Source Data Polarimetric Calibration Matrices | Not Required |  |
| 1.6.11 | Mean Faraday Rotation Angle | Not Required |  |
| 1.6.12 | Ionosphere Indicator | Not Required |  |
| **1.7** | **CEOS-ARD Product Attributes** |  |  |
| 1.7.1 | Product Data Access | Met Requirement |  |
| 1.7.2 | Ancillary Data | Not Required |  |
| 1.7.3 | Product Sample Spacing | Met Requirement |  |
| 1.7.4 | Product Filtering | Met Requirement |  |
| 1.7.5 | Product Bounding Box | Met Requirement |  |
| 1.7.6 | Product Image Extent | Met Requirement |  |
| 1.7.7 | Product Image Size | Met Requirement |  |
| 1.7.8 | Product Pixel Coordinate Convention | Met Requirement |  |
| 1.7.9 | Product Coordinate Reference System | Met Requirement |  |
| **2** | **Per-Pixel Metadata** |  |  |
| 2.1 | Metadata Machine Readability | Met Requirement |  |
| 2.2 | Data Mask Image | Met Requirement |  |
| 2.3 | Scattering Area Image | Not Required |  |
| 2.4 | Local Incident Angle Image | Met Requirement |  |
| 2.5 | Ellipsoidal Incident Angle Image | Not Required |  |
| 2.6 | Noise Power Image | Not Required |  |
| 2.7 | Gamma-to-Sigma Ratio Image | Not Required |  |
| 2.8 | Acquisition ID Image | Not Required |  |
| 2.9 | Per-Pixel DEM | Not Required |  |
| **3** | **Radiometric Terrain Corrected Measurements** |  |  |
| 3.1 | Backscatter Measurements | Met Requirement |  |
| 3.2 | Scaling Conversion | Met Requirement |  |
| 3.3 | Noise Removal | Met Requirement |  |
| 3.4 | Radiometric Terrain Correction Algorithms | Met Requirement |  |
| 3.5 | Radiometric Accuracy | Not Required |  |
| **4** | **Geometric Terrain Corrections** |  |  |
| 4.1 | Geometric Correction Algorithms | Not Required |  |
| 4.2 | Digital Elevation Model | Met Requirement |  |
| 4.3 | Geometric Accuracy | Met Requirement |  |
| 4.4 | Gridding Convention | Met Requirement |  |

**Guidance**

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data. This Guidance material does not replace or over-ride the specifications.

# Introduction to CEOS-ARD

**What are CEOS Analysis Ready Data for Land (CEOS-ARD) products?**

CEOS-ARD products have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort. These products would be resampled onto a common geometric grid (for a given product) and would provide baseline data for further interoperability both through time and with other datasets.

CEOS-ARD products are intended to be flexible and accessible products suitable for a wide range of users for a wide variety of applications, including particularly time series analysis and multi-sensor application development. They are also intended to support rapid ingestion and exploitation via high-performance computing, cloud computing, and other future data architectures. They may not be suitable for all purposes and are not intended as a ‘replacement’ for other types of satellite products.

**When can a product be called CEOS-ARD?**

The CEOS-ARD branding is applied to a particular product once:

* The product has been assessed as meeting CEOS-ARD requirements by the agency responsible for production and distribution of the product.
* The assessment has been peer reviewed by the CEOS Land Surface Imaging Virtual Constellation in consultation with the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the co-leads of the [Land Surface Imaging Virtual Constellation.](http://ceos.org/ourwork/virtual-constellations/lsi/)

A product can continue to use CEOS-ARD branding as long as its generation and distribution remain consistent with the peer-reviewed assessment.

**What is the difference between Threshold and Target?**

Products that meet all threshold requirements should be immediately useful for scientific analysis or decision-making.

Products that meet target requirements will reduce the overall product uncertainties and enhance broad-scale applications. For example, the products may enhance interoperability or provide increased accuracy through additional corrections that are not reasonable at the *threshold* level.

Target requirements anticipate continuous improvement of methods and evolution of community expectations, which are both normal and inevitable in a developing field. Over time, *target* specifications may (as subject to due process) become accepted as *threshold* requirements.

# Reference Papers

The following papers provide scientific and technical guidance:

Hoekman D. and Reiche, J. Multi-model radiometric slope correction of SAR images of complex terrain using a two-stage semi-empirical approach. *Remote Sensing of Environment*, **156** (2015), pp. 1-10. https://doi.org/10.1016/j.rse.2014.08.037

Shimada, M., Itoh, T., Motohka, T., Watanabe, M., Shiraishi, T., Thapa, R., and Lucas, R. New global forest/non-forest maps from ALOS PALSAR data (2007–2010). *Remote Sensing of Environment* **155** (2014) pp. 13–31. https://doi.org/10.1016/j.rse.2014.04.014

Shimada, M. Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.* Dec. 2010, 3(4), pp 657-671. https://doi.org/10.1109/JSTARS.2010.2072984

Small, D., Rohner, C., Miranda, N., Ruetschi, M., & Schaepman, M. E., Wide-Area Analysis-Ready Radar Backscatter Composites, 2021. *IEEE Transactions on Geoscience and Remote Sensing*, *59*, 14p.

<https://doi.org/10.1109/TGRS.2021.3055562>

Small D. Flattening Gamma: Radiometric Terrain Correction for SAR Imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 2011, Vol. 49(8), pp. 3081-3093. https://doi.org/[10.1109/TGRS.2011.2120616](https://doi.org/10.1109/TGRS.2011.2120616)

Small D., Miranda N., Meier E. [2009] (presentation), Local Incidence Angle Considered Harmful, *Proc. of CEOS SAR 2009 Workshop,* Pasadena, California, USA, Nov. 17-19, 2009.

Small D., Miranda N. and Meier E., "A revised radiometric normalisation standard for SAR," *IEEE International Geoscience and Remote Sensing Symposium*, Cape Town, 2009, pp. 566-569. https//doi.org/10.1109/IGARSS.2009.5417439