

	<h2>Analysis Ready Data</h2>	<p>Product Family Specification:</p> <p>Synthetic Aperture Radar</p>
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Document Status

For Adoption as: **Product Family Specification, Synthetic Aperture Radar**

Proposed revisions may be provided to: lsi@lists.ceos.org

Document History

Version	Date	Description of change	Affected CARD product	Author
0.1	14-12-2022	Zero Draft based on the CEOS ARD NRB PFS v5.5, POL PFS 3.5, ORB PFS v1.0 and draft GSLC v0.1	-	Charbonneau Truckenbrodt
0.2	13-02-2023	Reformat to CEOS ARD PFS template	-	Rosenqvist
0.3	29-07-2023	Refinement of GSLC specifications and alignment with NRB, POL and ORB parameters. Annex reorganization and ORB and GSLC examples added	[GSLC]	Charbonneau, Zebker, Rosenqvist, Albinet, Small, Truckenbrodt
0.31	xx	New items 1.7.15 (Reference orbit) and 3.7 (Flattened Phase) and added as Goal	[NRB] [POL]	Charbonneau
0.4	26-09-2023	Item 4.3 (Geometric accuracy). Clarification added to indicate whether absolute location accuracy (ALE) estimates refer to source data, ARD product, or both.	[NRB] [POL] [ORB] [GSLC]	Small, Chapman, Charbonneau, Rosenqvist, Albinet, Truckenbrodt

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CEOS Analysis Ready Data Definition

“CEOS Analysis Ready Data (CEOS ARD) are satellite data that 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 and interoperability both through time and with other datasets.”

Product Family Specification Title: Synthetic Aperture Radar (CEOS ARD SAR)

Applies to:

Data collected by Synthetic Aperture Radar sensors.

Background to CEOS ARD for Synthetic Aperture Radar:

The CEOS Analysis Ready Data (CEOS ARD) Product Family Specification (PFS) for Synthetic Aperture Radar (SAR) data is specifically aimed at users interested in exploring the potential of SAR but who may lack the expertise or facilities for SAR processing.

This CEOS ARD for Synthetic Aperture Radar PFS incorporates, into a single generic document, the following four CEOS ARD SAR specifications endorsed by CEOS Land Surface Imaging-Virtual Constellation (CEOS LSI-VC) (as of Oct. 2023):

- Normalised Radar Backscatter [version 5.5]
- Polarimetric Radar [version 3.5]
- Ocean Radar Backscatter [version 1.0]
- Geocoded Single-Look Complex [version 1.0]

The **CEOS ARD Normalised Radar Backscatter [NRB]** specification describes products that have been subject to Radiometric Terrain Correction (RTC) and are provided in the Gamma-Nought (γ_T^0) backscatter convention (Small, 2011), which mitigates the variations from diverse observation geometries and is recommended for most land applications. An additional metadata layer can be optionally provided for conversion of γ_T^0 to Sigma-Nought (σ_T^0) backscatter layer for compatibility with legacy software or numerical models. As the **[NRB]** product contains backscatter values only, it cannot be directly used for SAR polarimetry or interferometric applications that require relative polarization phase or local phase estimates respectively. Nonetheless, as an option, a “flattened” phase data layer can be provided with an **[NRB]** product for enabling InSAR analysis. The “flattened” phase is the interferometric phase, with respect to a reference orbit and to a DEM, for which the topographic phase contribution is removed.

The **CEOS ARD Polarimetric Radar [POL]** product format is an extension of the CEOS ARD Normalised Radar Backscatter format **[NRB]**. This extension is required in order to better support Level-1 SLC polarimetric data, including full-polarimetric modes (e.g., RADARSAT-2, ALOS-2/4, SAOCOM-1 and future missions), and hybrid or linear dual-polarimetric modes (i.e., Compact Polarimetric mode available on RCM, SAOCOM and the upcoming NISAR mission). The **[POL]** product can be defined in two processing levels:

- The normalised covariance matrix **[CovMat]** representation (C2 or C3) which preserves the inter-channel polarimetric phase(s) and maximizes the available information for users. Interoperability within current CEOS ARD-SAR backscatter definition is preserved, since diagonal elements of the covariance matrix are backscatter intensities. Scattering information enhancement can be achieved by applying incoherent polarimetric decomposition techniques (e.g., Freeman-Durden, van Zyl, Cloude-Pottier, Yamaguchi-based) directly on the C2 or C3 matrix.
- Polarimetric Radar Decomposition **[PRD]** refers to ARD products where polarimetric information is broken down into simplified parameters to facilitate user interpretation of the data. They are derived from coherent or incoherent polarimetric decomposition techniques.

The **CEOS ARD Ocean Radar Backscatter [ORB]** product specification describes products that have been projected on a geoid and are provided in the Sigma-Nought (σ^0) backscatter convention, which is recommended for most ocean applications. Backscatter may be calibrated to the ellipsoid (σ_E^0) or radiometrically terrain corrected (σ_T^0) prior to geometric terrain correction. As the basic **[ORB]** product contains backscatter values only, it *cannot* be directly used for SAR polarimetry or interferometric applications that require local phase estimates. Nonetheless, an advanced **[ORB]** product could include the upper diagonal of the polarimetric σ^0 covariance matrix for enabling advanced polarimetric analysis (similar to the **[POL]** product).

The **CEOS ARD Geocoded Single-Look Complex (GSLC)** product is relevant to interferometric studies. The **[GSLC]** product is derived from the range-Doppler (i.e. slant range) Single-Look Complex (SLC) product using a DEM and the orbital state vectors and output in the map projected system. The phase of a geocoded SLC is “flattened” with respect to a reference orbit and to a DEM, to eliminate topographic phase contributions [Zebker et al., 2017 and Zheng and Zebker, 2017]. The sample spacing of the **[GSLC]** product in the map coordinate directions is comparable to the full resolution original SLC product. The **[GSLC]** product can be directly overlaid on a map or combined with other similar **[GSLC]** products to derive interferograms and create change maps, for example. Since the **[GSLC]** phase is flattened, the phase difference between two **[GSLC]** products acquired on a same relative orbit produces an interferogram referring only to surface displacement and noise (i.e., no

topographic fringes). The **[GSLC]** product may optionally be radiometrically terrain corrected such that the squared amplitude yields γ_T^0 .

As can be seen from the above PFS descriptions, only a few minor details in terms of generated parameters and/or the addition of supplemental data distinguish these CEOS ARD products. In part, they are to a large extent all backward-compatible. For example, **[POL]** products implicitly include **[NRB]** products, while a coastal **[NRB]** or **[POL]** product can simply be made compatible with other **[ORB]** products by applying gamma-to-sigma conversion. Just as **[GSLC]** can be converted to **[NRB]**, the inverse conversion can be made true by including the optional topographic flatten phase. In this way a **[NRB]** or **[POL]** product can be used like a **[GSLC]** for InSAR applications. Consequently, it becomes obvious that they should all need to follow a common approach, in terms of content and structure, in order to optimize their interoperability.

For this generic *CEOS ARD for Synthetic Aperture Radar* PFS, as for the individual **[NRB]**, **[POL]**, **[ORB]**, and **[GSLC]** PFSs, metadata requirements are defined under two categories: Threshold and Goal. **Threshold requirements** refers to metadata parameters or data files which are mandatorily required in a product in order to be CEOS ARD compliant. **Goal requirements** are complementary metadata parameters or data files that are desirable or more accurate but more constraining/challenging to achieve depending on the SAR missions and the data provider constraint. Since this document integrates four CEOS ARD PFSs, it is worth noting that some requirements have been “relaxed” for a few Threshold parameters, depending on the target applications/environment of a CEOS ARD product. Exceptions are identified in the tables by specifying the usage.

Notice and Limitations [POL]

For Polarimetric Radar **[POL]** products, optimal incoherent Polarimetric Radar Decomposition **[PRD]** should be performed under the slant range projection (Gens et al., 2013, Toutin et al., 2013). In order to minimise bias in the CEOS ARD-SAR Level-2a covariance matrix product, speckle filtering and averaging of the covariance matrix should be applied in the slant range projection, and geocoding should be performed using nearest-neighbour resampling. Specifically, nearest-neighbour resampling ensures that the averaged covariance matrix elements in slant range and in geocoded ground projection are exactly the same. Consequently, the polarimetrically derived parameters are exactly equal in both approaches (assuming that no further averaging is performed on the ARD product for decomposing the polarimetric information). Bilinear and average resampling methods are also suitable for resampling the covariance matrix, but some differences with polarimetric parameters generated in slant range and then resampled (bilinear) might be observed on sloped terrains. Even if the Sinc method is more robust for spatial resampling, it does not preserve covariance matrix integrity, and should consequently not be used for this ARD product.

It is recommended that ARD providers who desire to distribute **[PRD]** products decompose the polarimetric information starting from Level-1 SLC data and then geocode the derived parameters rather than use the **[CovMat]** ARD product. Resampling can be performed using any of the supported methods (nearest-neighbour, bilinear, average, bi-cubic spline or Lanczos are recommended), which need to be indicated in the product metadata. Note that coherent decomposition techniques cannot be performed on **[CovMat]** ARD products.

Covariance matrix products contain a variable number of layers (or bands) with different data types depending on the polarimetric mode (full or dual) and decomposition technique. The **[CovMat]** products for the C2 matrix have 3 layers (2 real-valued diagonal elements and 1 complex-valued off-diagonal element). **[CovMat]** products for the C3 matrix have 6 layers (3 real-valued diagonal elements and 3 complex-valued off-diagonal elements). Layers that can be obtained via a complex conjugation of other layers are not provided within the product. Polarimetric Decomposition products contain typically 2 to 4 (or more) real-valued layers depending on the particular decomposition algorithm. Within the **[CovMat]** product files, ARD layers are organized in order to reduce access delays and maximize efficiency in extracting the desired information. In **[CovMat]** products, geographically contiguous samples for each layer may be stored next to each other and organized “layer by layer”. Alternatively, samples belonging to the same covariance matrix might be stored next to each other and organized “matrix by matrix”. **[PRD]** products are organized “layer by layer”, i.e., with bands corresponding to the output of the polarimetric decomposition stored next to each other.

Definitions

CEOS ARD	Committee on Earth Observation Satellites - Analysis Ready Data
NRB	Normalised Radar Backscatter
RTC	Radiometrically Terrain Corrected
POL	Polarimetric Radar
CovMat	Normalised Radar Covariance Matrix
PRD	Polarimetric Radar Decomposition
GSLC	Geocoded Single-Look Complex
InSAR	Interferometric Radar
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 a need to have knowledge about its entire content.
Spatial Resolution	The smallest size objects that can be distinguished by the sensor at the ground surface.
Pixel Spacing	The processed sample distance.
Spatial Sampling Distance	Spatial sampling distance is the great circle distance on the reference surface distance between adjacent spatial samples on the Earth's surface.
DOI	Digital Object Identifier

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 requirements listed below. The column “CEOS ARD product” indicates to which CEOS ARD SAR product (NRB, POL, ORB, GSLC) the parameter refers.

#	Parameter	CEOS ARD product	Requirements	Self Assessment
1.1	Traceability	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> Data must be traceable to SI reference standard. <i>Note 1: Relationship to 3.5. Traceability requires an estimate of measurement uncertainty.</i> <i>Note 2: Information on traceability should be available in the metadata as a single DOI landing page.</i>	
1.2	Metadata Machine Readability	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Metadata is provided in a structure that enables a computer algorithm to be used consistently and to automatically identify and extract each component part for further use.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As threshold, but metadata is formatted in accordance with CEOS ARD SAR Metadata Specifications, v.1.0, or in a community endorsed standard that facilitates machine-readability, such as ISO 19115-2, Climate and Forecast (CF) convention and the Attribute Convention for Data Discovery (ACDD), etc.	

1.3	Product Type	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> CEOS ARD product type name and copyright (if copyright is required by the data provider). Product type name should be NRB, POL, ORB and/or GSLC.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	
1.4	Document Identifier	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Reference to CEOS ARD Synthetic Aperture Radar document as URL or DOI.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	
1.5	Data Collection Time	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Number of source data acquisitions of the data collection is identified. The start and stop UTC time of data collection is identified in the metadata, expressed in date/time. In case of composite products, the dates/times of the first and last data takes and the per-pixel metadata “2.8 Acquisition ID Image” is provided with the product.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	
1.6	Source Data Attributes		Subsection describing (detailing) <u>each SAR acquisition</u> used to generate the ARD product. <i>Note: Source data attribute information are described for each acquisition and sequentially identified as acqID= 1, 2, 3, ...</i>	

1.6.1	Source Data Access	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> The metadata identifies the location from where the source data can be retrieved, expressed as a URL or DOI.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> 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.	<u>Other feedback on requirements:</u> ...
1.6.2	Instrument	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> The instrument used to collect the data is identified in the metadata: <ul style="list-style-type: none"> - Satellite name - Instrument name 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.	
1.6.3	Source Data Acquisition Time	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> 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.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	<u>Other feedback on requirements:</u> ...
1.6.4	Source Data Acquisition Parameters	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Acquisition parameters related to the SAR antenna: <ul style="list-style-type: none"> - Radar band - Centre frequency - Observation mode (i.e., Beam mode name) - Polarization(s) (listed as in original product) - Antenna pointing [Right/Left] - Beam ID (i.e., Beam mode Mnemonic) 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	

1.6.5	Source Data Orbit Information	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Information related to the platform orbit used for data processing:</p> <ul style="list-style-type: none"> - Pass direction [asc/desc] * - Orbit data source [e.g., predicted/definite/ precise/ downlinked, etc.] <p><i>* For source data crossing the North or South Pole, it is recommended to produce two distinct CEOS ARD products and to use the appropriate "Pass direction" in each.</i></p> <p><u>Goal (Desired) Requirements</u> As threshold, including also:</p> <ul style="list-style-type: none"> - 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 <i>before</i> start time to 10% of scene length <i>after</i> stop time) - Platform (mean) altitude. 	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
1.6.6	Source Data Processing Parameters	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Processing parameters details of the source data:</p> <ul style="list-style-type: none"> - Processing facility - Processing date - Software version - Product level - Product ID (file name) - Azimuth number of looks - Range number of looks (separate values for each beam, as necessary) <p><u>Goal (Desired) Requirements</u> As Threshold, plus additional relevant processing parameters, e.g., range- and azimuth look bandwidth and LUT applied.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

1.6.7	Source Data Image Attributes	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Image attributes related to the source data: <ul style="list-style-type: none"> - Source Data geometry (slant range/ground range) - Azimuth pixel spacing - Range pixel spacing - Azimuth resolution - Range resolution - Near range incident angle - Far range incident angle 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> The geometry of the image footprint expressed in WGS84 in a standardised format (e.g., WKT).	
1.6.8	Sensor Calibration	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> 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.	
1.6.9	Performance Indicators	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Provide performance indicators on data intensity noise level ($NE\sigma^0$ and/or $NE\beta^0$ and/or $NE\gamma^0$ (noise equivalent sigma and/or beta and/or gamma-nought)). 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.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> Provide additional relevant performance indicators (e.g., ENL, PSLR, ISLR, and performance reference DOI or URL).	
1.6.10	Source Data Polarimetric	[NRB] [POL]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal

	Calibration Matrices	[ORB] [GSLC]	<p><u>Goal (Desired) Requirements</u> The complex-valued polarimetric distortion matrices with the channel imbalance and the cross-talk applied for the polarimetric calibration.</p>	<p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
1.6.11	Mean Faraday Rotation Angle	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> 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.</p>	<p><u>Other feedback on requirements:</u> ...</p>
1.6.12	Ionosphere Indicator	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> 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.</p>	<p><u>Other feedback on requirements:</u> ...</p>
1.7	CEOS ARD Product Attributes		Subsection containing information related to the CEOS ARD product generation procedure and geographic parameters.	
1.7.1	Product Data Access	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Processing parameters details of the CEOS ARD product:</p> <ul style="list-style-type: none"> - Processing facility - Processing date - Software version - Location from where the CEOS ARD product can be retrieved, expressed as a URL or DOI. 	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> 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.</p>	

1.7.2	Auxiliary Data	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> The metadata identifies the sources of ancillary data used in the generation process, ideally expressed as DOIs. <i>Note: Ancillary data includes DEMs, etc., and any additional data sources used in the generation of the product.</i>	<u>Other feedback on requirements:</u> ...
1.7.3	Product Sample Spacing	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> CEOS ARD product processing parameters details: <ul style="list-style-type: none"> - Pixel (column) spacing - Line (row) spacing 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	<u>Other feedback on requirements:</u> ...
1.7.4	Product Equivalent Number of Looks	[NRB] [POL] [ORB]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> Equivalent Number of Looks (ENL)	<u>Other feedback on requirements:</u> ...
1.7.5	Product Resolution	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ...
			<u>Goal (Desired) Requirements</u> Average spatial resolution of the CEOS ARD product along: <ul style="list-style-type: none"> - Columns - Rows 	<u>Other feedback on requirements:</u> ...

1.7.6	Product Filtering	[NRB] [POL] [ORB]	<p><u>Threshold (Minimum) Requirements</u> Flag if speckle filter has been applied [true/false].</p> <p>Metadata should include:</p> <ul style="list-style-type: none"> - Reference to algorithm as DOI or URL - Input filtering parameters <ul style="list-style-type: none"> - Type - Window size in pixel units - Any other parameters defining the speckle filter used <p>Mandatory for [POL]: Advanced polarimetric filter preserving covariance matrix properties should be applied.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> As Threshold.</p>	
1.7.7	Product Bounding Box	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Two opposite corners of the product file (bounding box, including any zero-fill values) are identified, expressed in the coordinate reference system defined in 1.7.11.</p> <p>Four corners of the product file are recommended for scenes crossing the International Date Line, or the North or the South Pole.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> As Threshold.</p>	
1.7.8	Product Geographical Extent	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> The geometry of the SAR image footprint expressed in WGS84, in a standardised format (e.g., WKT Polygon).</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> As Threshold.</p>	

1.7.9	Product Image Size	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Image attributes of the CEOS ARD product: <ul style="list-style-type: none"> - Number of lines - Number of pixels/lines - File header size (if applicable) - Number of no-data border pixels (if appl.) 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	
1.7.10	Product Pixel Coordinate Convention	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> 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].	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	
1.7.11	Product Coordinate Reference System	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> The metadata lists the map projection (or geographical coordinates, if applicable) that was used and any relevant parameters required to geolocate data in that map projection, expressed in a standardised format (e.g., WKT). Indicate EPSG code, if defined for the CRS.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold.	

1.7.12	Look Direction Polynomials	[ORB]	<p>Threshold (Minimum) Requirements</p> <p>In case the per-pixel item 2.11 (Look Direction Image) is not provided, then a list of the polynomial coefficients a_i necessary to reconstruct the look direction angle*, together with an estimate of the added error from use of polynomial vs. per-pixel more accurate values, shall be provided.</p> <p>Example polynomial: $LookDir = a_1Lat^2 + a_2Lon^2 + a_3LatLon + a_4Lat + a_5Lon + a_6$</p> <p>where: a_i = polynomial coefficients Lat = latitude Lon = longitude Lat and Lon are the related coordinates in the product map units ['m', 'deg', 'arcsec']</p> <p><i>* The look direction angle represents the planar angle between north and each range direction. It is not constant in range, especially close to the poles.</i></p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
<p>Goal (Desired) Requirements</p> <p>As Threshold.</p>				
1.7.13	Radar Unit Look Vector	[GSLC]	<p>Threshold (Minimum) Requirements</p> <p>3-D components radar unit look vector, specified at centre of scene, in a Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centered Rotating - ECR) is provided. It consists of unit vectors from antenna to surface pixel (i.e. positive Z component).</p> <p>Only required If Per-Pixel metadata 2.12 (Radar Unit Look Vector Grid Image) is not provided</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
<p>Goal (Desired) Requirements</p> <p>As Threshold.</p>				

1.7.14	Slant Range Sensor to Surface	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Slant range distance from the sensor to the surface, specified at centre of scene Only required If Per-Pixel metadata 2.13 (Slant Range Sensor to Surface Image) is not provided</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> As Threshold.</p>	
1.7.15	Absolute Reference Orbit Number	[NRB] [POL] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> Usage: For [NRB] & [POL] only when 3.7 Flattened phase is provided. For [GSLC] when a reference orbit is used instead of a virtual orbit (see Annex A 1.2). Provide the absolute orbit number used as reference for topographic phase flattening. In case a virtual orbit has been used, provide orbit parameters or orbit state vectors as DOI or URL. Provide scene-centred perpendicular baseline for the for the source data relative to the reference orbit used (for approximate use only).</p>	

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 applications. Cloud optimized file formats are recommended.

The column "CEOS ARD product" indicates which CEOS ARD SAR product(s) (NRB, POL, ORB, GSLC) the parameter refers to.

#	Parameter	CEOS ARD product	Requirements	Self Assessment
2.1	Metadata Machine Readability	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component/variable/layer for further use.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...
			<u>Goal (Desired) Requirements</u> As Threshold, but metadata is formatted in accordance with CEOS ARD SAR Metadata Specifications, v.1.0.	
2.2	Data Mask Image	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Mask image indicating: <ul style="list-style-type: none"> - Valid data - Invalid data - No data File format specifications/ contents provided in metadata: <ul style="list-style-type: none"> - Sample Type [Mask] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int, ...] - Bits per Sample - Byte Order - Bit Value Representation 	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> ... <u>Other feedback on requirements:</u> ...

			<p><u>Goal (Desired) Requirements</u> As threshold, including additional bit value representations, e.g.:</p> <ul style="list-style-type: none"> - Layover (masked as invalid data in Threshold) - Radar shadow (masked as invalid data in Threshold) - Ocean water, etc. - Land (recommended for [ORB]) - RTC applied (for Maritime scenes with land samples for which RTC is applied) - DEM gap filling (i.e., interpolated DEM over gaps) 	
2.3	Scattering Area Image	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u> Usage: Recommended for scenes that include land areas.</p> <p>DEM-based scattering area image used for Gamma-Nought terrain normalisation is provided. This quantifies the local scattering area used to normalise for radiometric distortions induced by terrain to the measured β^0 backscatter. The terrain-flattened γ_T^0 is best understood as β^0 divided by the local scattering area.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Scattering Area] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order 	<p><u>Other feedback on requirements:</u> ...</p>

2.4	Local Incident Angle Image	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> DEM-based Local Incident angle image is provided.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p><i>Note: For maritime [ORB] scenes when no land areas are covered, a geoid model could be used for the calculation of the local incident angle</i></p> <p><u>Goal (Desired) Requirements</u> As Threshold.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
2.5	Ellipsoidal Incident Angle Image	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Ellipsoidal incident angle is provided.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order - Reference Ellipsoid Name <p><i>Note: For maritime [ORB] scenes when no land areas are covered, the ellipsoidal incident angle is nearly identical to the geoid based local incident angle.</i></p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

2.6	Noise Power Image	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Estimated noise equivalent σ^o (or β^o or γ^o, as applicable) used for Noise Removal, if applied, for each channel. NESZ and NEGZ are both based on a simplified ellipsoid Earth model.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Gamma-Nought, Sigma-Nought, Beta-Nought] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
2.7	Gamma-to-Sigma Ratio Image	[NRB] [POL] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Ratio of the integrated area in the Gamma projection over the integrated area in the Sigma projection (ground). Multiplying RTC γ_T^o by this ratio results in an estimate of RTC σ_T^o</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Ratio] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

2.8	Acquisition ID Image	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Note: Required for multi-source product only.</p> <p>Acquisition ID, or acquisition date, for each pixel is identified.</p> <p>In case of multi-temporal image stacks, use source acquisition ID (i.e., 1.6 acqID values) to list contributing images.</p> <p>In case of Date, data represent (integer or fractional) day offset to reference observation date [UTC]. Date used as reference (“Day 0”) is provided in the metadata.</p> <p>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.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Day, Time, ID] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
			<p><u>Goal (Desired) Requirements</u></p> <p>In case of image composites, the sources for each pixel are uniquely identified.</p>	

2.9	Per-pixel DEM	[NRB] [POL] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u></p> <p>Provide DEM or DSM 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. Can also be provided with [ORB] products containing land areas.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Height] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
2.10	Per-pixel Geoid	[ORB]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u></p> <p>Provide Geoid 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 ORB image product.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Height] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order - Ground Sampling Distance 	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

2.11	Look Direction Image	[ORB]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Look Direction Image is provided. It represents the planar angle between north and each range direction.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
2.12	Radar Unit Look Vector Grid Image	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> 3-D components radar unit look vector, specified at each pixel in a Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centered Rotating - ECR) is provided. It consists of unit vectors from the antenna to the surface pixel (i.e. positive Z component).</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [3D unit vector] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

2.13	Slant Range Sensor to Surface Image	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Slant range distance from the sensor to the surface, specified at each pixel in a Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centred Rotating - ECR) is provided.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Distance] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
2.14	InSAR Phase Uncertainty Image	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required.</p> <p><u>Goal (Desired) Requirements</u> Estimate of uncertainty in InSAR phase is provided, such as finite signal to noise ratio, quantization noise, or DEM error. Identification of which error sources are included will be provided as DOI/URL reference or brief description. It represents statistical variation from known noise sources only.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

2.15	Atmospheric Phase Correction Image	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <p><u>Goal (Desired) Requirements</u> Phase correction value at each pixel, if applied. DOI/URL reference to algorithm or brief description is provided.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
2.16	Ionospheric Phase Correction Image	[GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <p><u>Goal (Desired) Requirements</u> Phase correction value at each pixel, if applied. DOI/URL reference to algorithm or brief description is provided.</p> <p>File format specifications/ contents provided in metadata:</p> <ul style="list-style-type: none"> - Sample Type [Angle] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Float, ...] - Bits per Sample - Byte Order 	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

Radiometrically Corrected Measurements

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 and/or decomposed polarimetric parameters. As for the per-pixel metadata, information regarding data format specification needs to be provided for each record. The requirements below must be met for all pixels/samples/observations in a collection. Cloud optimized file formats are recommended.

The column “CEOS ARD product” indicates which CEOS ARD SAR product (NRB, POL, ORB, GSLC) the parameter refers to.

#	Parameter	CEOS ARD product	Requirements	Self Assessment
3.1	Backscatter Measurements	[NRB]	<p><u>Threshold (Minimum) Requirements [NRB]</u></p> <p>“Terrain-flattened” Radiometrically Terrain Corrected (RTC) Gamma-Nought backscatter coefficient (γ_T^0) is provided for each polarization.</p> <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [Gamma-Nought] - Backscatter Expression Convention [linear amplitude or linear power*] - Polarization [HH/HV/VV/VH] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p><i>*Note: transformation to the logarithm decibel scale is not required or desired as this step can be completed by the user if necessary.</i></p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
			<p><u>Goal (Desired) Requirements</u></p> <p>As Threshold.</p>	

3.1	Backscatter Measurements	[POL]	<p><u>Threshold (Minimum) Requirements [POL]</u></p> <p>Measurements can be:</p> <p><u>Normalised Radar Covariance Matrix (CovMat)</u> Diagonal (equivalent to [NRB]) and upper diagonal elements of the terrain-flattened_Gamma-Nought (γ_T^0) Covariance Matrix are provided for coherent dual (e.g., HH-HV, VV-VH, or ...) and fully polarimetric (e.g., HH-HV-VH-VV) acquisitions.</p> <p>And/or</p> <p><u>Polarimetric Radar Decomposition (PRD)</u> The individual components of the polarimetric decomposition obtained from the terrain-flattened (Gamma-Nought (γ_T^0)) covariance matrix.</p> <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [CovMat/PRD] - Measurement convention unit [linear amplitude, linear power, angle] - Individual covariance matrix element or/and Individual component of the decomposition [C3m11, C3m12, ... or H, A, alpha, or ...] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/ Float/Complex, etc.] - Bits per Sample - Byte Order <p><i>Note: It is recommended to keep CovMat or PRD measurement files separated. Otherwise, specify the multi-channel format order [BIP, BIL, BSQ]</i></p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
			<p><u>Goal (Desired) Requirements</u></p> <p>As Threshold.</p>	

3.1	Backscatter Measurements	[ORB]	<p><u>Threshold (Minimum) Requirements [ORB]</u></p> <p><u>Geoid-corrected Sigma-Nought backscatter coefficient (σ^0)</u> is provided for each polarization.</p> <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [Sigma-Nought] - Backscatter Expression Convention [linear amplitude or linear power*] - Backscatter Conversion Equation - Polarization [HH/HV/VV/VH] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p><i>*Note: transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.</i></p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
			<p><u>Goal (Desired) Requirements</u></p> <p>Radiometrically Terrain-corrected Sigma-Nought backscatter coefficient (σ_T^0) is provided for each polarization.</p>	

3.1	Backscatter Measurements	[GSLC]	<p><u>Threshold (Minimum) Requirements</u></p> <p><u>Radiometric and Phase</u> Terrain-flattened Gamma-Nought backscatter coefficient (γ_T^0), in complex number format, is provided for each polarization (e.g., HH, HV, VV, VH).</p> <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [Gamma-Nought] - Backscatter Expression Convention [linear amplitude or linear power*] - Polarization [HH/HV/VV/VH] - Data Format [Raw/GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p><i>*Note: transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.</i></p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u></p> <p>As Threshold.</p>	
3.2	Scaling Conversion	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u></p> <p>If applicable, indicate the equation to convert pixel linear amplitude/power to logarithmic decibel scale, including, if applicable, the associated calibration (dB offset) factor, and/or the equation used to convert compressed data (int8/int16/float16) to float32.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p><u>Goal (Desired) Requirements</u></p> <p>As Threshold, but use of float32.</p>	

3.3	Noise Removal	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Flag if noise removal* has been applied (Y/N). Metadata should include the noise removal algorithm and reference to the algorithm as URL or DOI.</p> <p><i>*Note: Thermal noise removal and image border noise removal to remove overall scene noise and scene edge artefacts, respectively.</i></p> <hr/> <p><u>Goal (Desired) Requirements</u> As Threshold.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
3.4	Radiometric Terrain Correction Algorithm	[NRB] [POL] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Adjustments were made for terrain by modelling the local contributing scattering area using the preferred choice of a published peer-reviewed algorithm to produce radiometrically terrain corrected (RTC) γ_T^0 backscatter estimates.</p> <p>Metadata references, e.g.:</p> <ul style="list-style-type: none"> - a citable peer-reviewed algorithm - technical documentation regarding the algorithm used to generate the backscatter estimates is expressed as URLs or DOIs - the sources of ancillary data used to make corrections <p>Goal for [GSLC] product type</p> <p><i>Note: Examples of technical documentation include an Algorithm, Theoretical Basis Document, product user guide, etc.</i></p> <hr/> <p><u>Goal (Desired) Requirements</u></p> <p>Goal for [GSLC] product type</p> <p>Require resolution of DEM better than the output product resolution when applying terrain corrections.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

3.5	Radiometric Accuracy	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <hr/> <p><u>Goal (Desired) Requirements</u> Uncertainty (e.g., bounds on γ^0 or σ^0) information is provided as document referenced as URL or DOI. SI traceability is achieved.</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
3.6	Mean Wind-Normalised Backscatter Measurements	[ORB]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <hr/> <p><u>Goal (Desired) Requirements</u> Usage: Only for Maritime scene</p> <p>Mean wind-normalised (over ocean) backscatter coefficient is provided for each available polarization. It is calculated as the ratio between the backscatter intensity and a simulated backscatter intensity image generated using an ocean surface wind model such as, e.g., Quilfen et al. (1998) or Vachon and Dobson (2000) for VV and HH polarization respectively.</p> <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [Wind-Normalised Backscatter] - Backscatter Expression Convention [intensity ratio] - Polarization [HH/HV/VV/VH] - Data Format [GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p><i>Note: Reference wind model, wind speed and direction used for reference backscattering coefficient should be provided.</i></p>	<p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

3.7	Flattened Phase	[NRB] [POL]	<p>Threshold (Minimum) Requirements Not required</p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
			<p>Goal (Desired) Requirements Usage: Alternative to [GSLC] product for [NRB] and [POL] products</p> <p>Flattened SAR phase is derived from the range-Doppler SLC product using a DEM and the orbital state vectors with respect to a reference orbit (see Annex A1.2). The use of the Flattened SAR phase with the [NRB] or [POL] intensity (3.1 Backscatter measurement) provides the [GSLC] equivalent, as follows:</p> $\text{GSLC} = \text{sqrt}(\text{NRB}) \times \exp(j \text{ FlattenPhase})$ <p>File format specifications/contents provided in metadata:</p> <ul style="list-style-type: none"> - Measurement Type [Flattened Phase] - Reference Polarization [HH/HV/VV/VH] - Data Format [GeoTIFF/NetCDF, ...] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order <p>In case of polarimetric data, indicate the reference polarization.</p>	

Geometric Corrections

Geometric corrections are steps that are taken to place the measurement accurately on the surface of the Earth (that is, to geolocate the measurement) allowing measurements taken through time to be compared. This section specifies any geometric correction requirements that must be met in order for the data to be analysis ready.

The column “CEOS ARD product” indicates to which CEOS ARD SAR product (NRB, POL, ORB, GSLC) the parameter refers.

#	Parameter	CEOS ARD product	Requirements	Self Assessment
4.1	Geometric Correction Algorithm	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <p><u>Goal (Desired) Requirements</u> Metadata references, e.g.:</p> <ul style="list-style-type: none"> - 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. <p><i>Note: Examples of technical documentation can include e.g., an Algorithm Theoretical Basis Document (ATBD), a product user guide.</i></p>	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>
4.2	Digital Elevation Model	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Usage: For products including land areas</p> <ol style="list-style-type: none"> a) 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. b) Provide reference to Digital Elevation Model used for geometric terrain correction. c) Provide reference to Earth Gravitational Model (EGM) used for geometric correction 	<p><u>Achieved level:</u> Threshold / Goal</p> <p><u>Explanation / Justification:</u> ...</p> <p><u>Other feedback on requirements:</u> ...</p>

			<p><u>Goal (Desired) Requirements</u></p> <p>a) A DEM with comparable or better resolution to the resolution of the output CEOS ARD product shall be used if available. Else, the upsampled DEM is identified.</p> <p>b) Resampling method used for preparation of the DEM.</p> <p>c) Method used for resampling the EGM.</p>	
4.3	Geometric Accuracy	<p>[NRB] [POL] [ORB] [GSLC]</p>	<p><u>Threshold (Minimum) Requirements</u></p> <p>Accurate geolocation is a prerequisite to radar processing to correct for terrain and to enable interoperability between radar sensors.</p> <p>The absolute geolocation error (ALE) for a sensor is typically assessed through analysis of Single Look Complex (SLC) imagery and measured along the slant range and azimuth directions (case A: SLC ALE). The end-to-end “ARD” ALE of the final CARD product could be measured directly in the final image product in the chosen map projection, i.e. in the map coordinate directions: e.g. Northing and Easting (case B: ARD ALE). Providing accuracy estimates based on measurements following at least one scheme (A or B or both) meets the threshold requirement.</p> <p>Estimates of the ALE is provided as a bias and a standard deviation, with (Case A) SLC ALE expressed in slant range and azimuth, and (Case B) ARD ALE expressed in map projection dimensions.</p> <p><i>Note 1: This assessment is often made through comparison of measured corner reflector positions with their projected location in the imagery. In some cases, other mission calibration/validation results may be used.</i></p> <p><i>Note 2: The ALE is not typically assessed for every processed image, but through an ALE assessment by the data processing team characterizing all or (usually a subset) of the generated products.</i></p> <p><u>Goal (Desired) Requirements</u></p> <p>Output product sub-sample accuracy should be less than or equal to 0.1 (slant range) pixel radial root mean square error (rRMSE).</p> <p>Provide documentation of estimates of ALE as DOI or URL.</p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

4.4	Geometric Refined Accuracy	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> Not required</p> <p><u>Goal (Desired) Requirements</u> Values provided under 4.3 Geometric accuracy are provided by the SAR mission Cal/Val team.</p> <p>CEOS ARD processing steps could include method refining the geometric accuracy, such as cross-correlation of the SAR data in slant range with a SAR scene simulated from a DSM or DEM.</p> <p>Methodology used (name and reference), quality flag, geometric standard deviation values should be provided.</p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>
4.5	Gridding Convention	[NRB] [POL] [ORB] [GSLC]	<p><u>Threshold (Minimum) Requirements</u> 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.*</p> <p><i>* 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.</i></p> <p><u>Goal (Desired) Requirements</u> Provide DOI or URL to gridding convention used.</p> <p>When multiple providers share a common map projection, providers are encouraged to standardise the origins of their products among each other.</p> <p>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”).</p> <p>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.</p>	<p><u>Achieved level: Threshold / Goal</u></p> <p><u>Explanation / Justification: ...</u></p> <p><u>Other feedback on requirements: ...</u></p>

Self-Assessment Summary Table

		Threshold	Goal
1	General Metadata		
1.1	Traceability		
1.2	Metadata Machine Readability		
1.3	Product type		
1.4	Document Identifier		
1.5	Data Collection Time		
1.6	Source Data Attributes		
1.6.1	Source Data Access		
1.6.2	Instrument		
1.6.3	Source Data Acquisition Time		
1.6.4	Source Data Acquisition Parameters		
1.6.5	Source Data Orbit Information		
1.6.6	Source Data Processing Parameters		
1.6.7	Source Data Image Attributes		
1.6.8	Sensor Calibration		
1.6.9	Performance Indicators		
1.6.10	Source Data Polarimetric Calibration Matrices		
1.6.11	Mean Faraday Rotation Angle		
1.6.12	Ionosphere indicator		
1.7	CEOS ARD Product Attributes		
1.7.1	Product Data Access		
1.7.2	Ancillary Data		
1.7.3	Product Sample Spacing		
1.7.4	Product Equivalent Number of Looks		
1.7.5	Product Resolution		
1.7.6	Product Filtering		

1.7.7	Product Bounding Box		
1.7.8	Product Geographical Extent		
1.7.9	Product Image Size		
1.7.10	Product Pixel Coordinate Convention		
1.7.11	Product Coordinate Reference System		
1.7.12	Look Direction Polynomials		
1.7.13	Radar Unit Look Vector		
1.7.14	Slant Range Sensor to Surface		
1.7.15	Reference Orbit		
2	Per-Pixel Metadata		
2.1	Metadata Machine Readability		
2.2	Data Mask Image		
2.3	Scattering Area Image		
2.4	Local Incident Angle Image		
2.5	Ellipsoidal Incident Angle Image		
2.6	Noise Power Image		
2.7	Gamma-to- Sigma Ratio Image		
2.8	Acquisition ID Image		
2.9	Per-pixel DEM		
2.10	Per-pixel Geoid		
2.11	Look Direction Image		
2.12	Radar Unit Look Vector Grid Image		
2.13	Slant Range Sensor to Surface Image		
2.14	InSAR Phase Uncertainty Image		
2.15	Atmospheric Phase Correction Image		
2.16	Ionospheric Phase Correction Image		
3	Radiometrically Corrected Measurements		
3.1	Backscatter Measurements		
3.2	Scaling Conversion		

3.3	Noise Removal		
3.4	Radiometric Terrain Correction Algorithms		
3.5	Radiometric Accuracy		
3.6	Mean Wind- Normalised Backscatter Measurements		
3.7	Flattened Phase		
4	Geometric Corrections		
4.1	Geometric Correction Algorithms		
4.2	Digital Elevation Model		
4.3	Geometric Accuracy		
4.4	Geometric Refine Accuracy		
4.5	Gridding Convention		

Guidance

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data for a specific and well-developed Product Family Specification. This Guidance material does not replace or override the specifications.

Introduction to CEOS ARD

What is CEOS Analysis Ready Data?

CEOS ARD are products that 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. In general, 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:

- that product has been assessed as meeting CEOS ARD requirements by the agency responsible for production and distribution of the product, and
- that the assessment has been peer reviewed by the relevant CEOS team(s).

Agencies or other entities considering undertaking an assessment process should consult the CEOS ARD [Governance Framework](#).

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 Goal?

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

Products that meet goal 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.

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

Threshold (Minimum) Requirements

Threshold requirements are the MINIMUM that is needed for the data to be analysis ready. This must be practical and accepted by the data producers

Goal (Desired) Requirements

Goal requirements are the ideal; where we would like to be. Some providers may be able to meet these already.

Reference Papers [CEOS ARD for SAR]

ISO 19115-2 (2009) *Geographic information -- Metadata -- Part 2: Extensions for imagery and gridded data*, www.iso.org/standard/39229.html

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Shiroma, G.H.X., M. Lavalle and S. M. Buckley, *An Area-Based Projection Algorithm for SAR Radiometric Terrain Correction and Geocoding*. *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1-23, 2022, Art no. 5222723, doi: 10.1109/TGRS.2022.3147472.

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Polarimetric Radar [POL]

Cameron, W.L., N.N. Youssef, and L.K. Leung (1996) *Simulated polarimetric signatures of primitive geometrical shapes*, *IEEE Trans. Geosci. Remote Sens.*, vol. 34, no. 3, pp. 793–803.

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Krogager, E. (1993) *Aspects of polarimetric radar imaging*, Ph.D. dissertation, Tech. Univ. Denmark, Electromagn. Inst., Lyngby, Denmark

Lee, J.-S., J.-H. Wen, T.L. Ainsworth, K.-S. Chen, and A.J. Chen (2009) *Improved Sigma Filter for Speckle Filtering of SAR Imagery* *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 1, pp. 202-213.

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Toutin, T., H. Wang, P. Chomaz and E. Pottier (2013) *Orthorectification of Full-Polarimetric Radarsat-2 Data Using Accurate LIDAR DSM*, *IEEE Trans. Geosci. Remote Sens.*, vol. 51, no. 12, pp. 5252-5258.

Yamaguchi, Y., A. Sato, W.M. Boerner, R. Sato and H. Yamada (2011) *Four-Component Scattering Power Decomposition with Rotation of Coherency Matrix*, *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 6, pp. 2251-2258.

Ocean Radar Backscatter [ORB]

Quilfen, Y., Chapron, B., Elfouhaily, T., Katsaros, K., and Tournadre, J. (1998) Observation of tropical cyclones by high-resolution scatterometry, *J. Geophys. Res.*, 103(C4), 7767– 7786, doi:10.1029/97JC01911

Vachon, P.W. and F.W. Dobson (2000) Wind Retrieval from RADARSAT SAR Images: Selection of a Suitable C-Band HH Polarization Wind Retrieval Model, *Canadian Journal of Remote Sensing*, 26:4, 306-313, DOI: 10.1080/07038992.2000.10874781

Geocoded Single-Look Complex [GSLC]

Zebker, H. A., S. Hensley, P. Shanker and C. Wortham (2010) Geodetically Accurate InSAR Data Processor, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 48, no. 12, pp. 4309-4321, Dec. 2010, doi: 10.1109/TGRS.2010.2051333.

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