CEOS-ARD Product Family Specification

Synthetic Aperture Radar

Normalised Radar Backscatter [NRB]
Polarimetric Radar [POL]
Ocean Radar Backscatter [ORB]
Geocoded Single-Look Complex [GSLC]
Interferometric Radar [INSAR]
Composite Backscatter [CB]

Version 1.3
May 2026

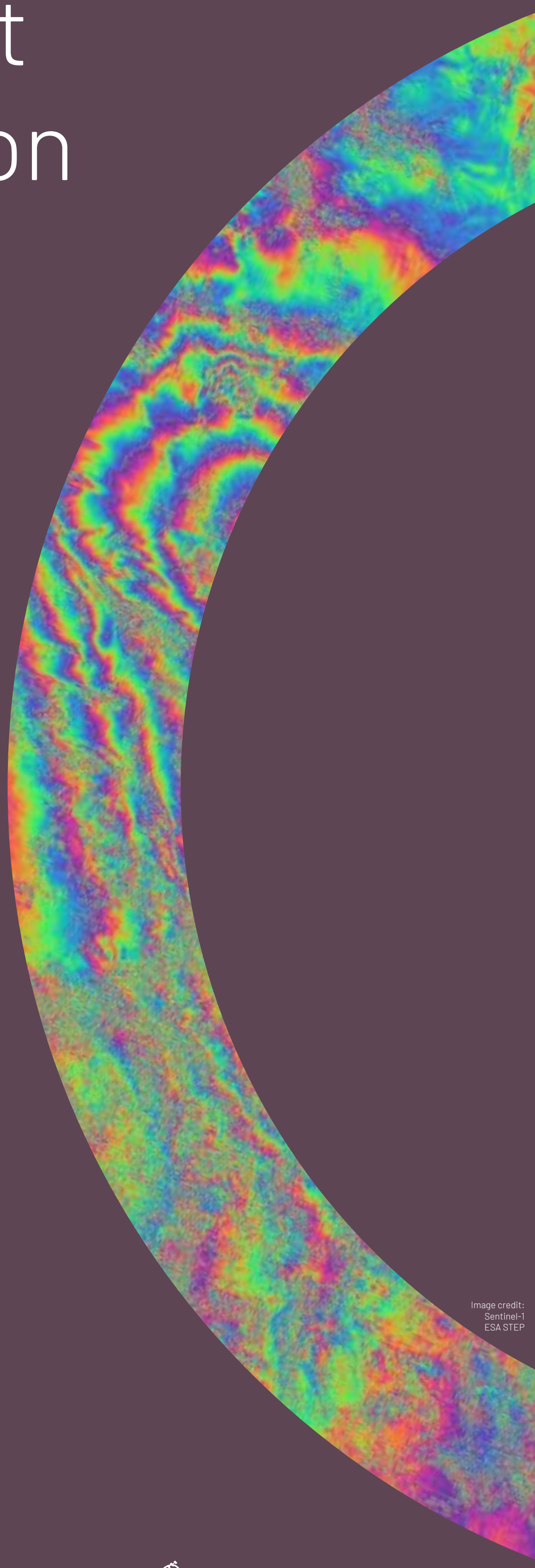


Image credit: Sentinel-1 ESA STEP

CEOS Committee on Earth Observation Satellites

Committee on Earth Observation Satellites	**Analysis Ready Data**	**Product Family Specification:** **Synthetic Aperture Radar**

Document Status

Product Family Specification, Synthetic Aperture Radar

Proposed revisions may be provided to: ard-contact@lists.ceos.org

Document History

Version	Date	Description of change	Affected CEOS-ARD product	Author
0.1	14-12-2022	Zero Draft based on the CARD4L NRB PFS v5.5, POL PFS 3.5, ORB PFS v1.0 and draft GSLC v0.1	-	Charbonneau Rosenqvist, Truckenbrodt, Small, Zhou, Albinet, Tadono, Chapman, Logan, Yuan, Repse, Dadamia, Lavalle, Miranda, Mayer, Kellndorfer, Valentino, Lewis, Pinheiro, Siqueira, Deschamps, Hajduch
0.2	13-02-2023	Reformat to CEOS-ARD PFS template. Change “CARD4L” to “CEOS-ARD” Change “Target” to “Goal”	-	Rosenqvist
0.3	29-07-2023	Refinement of GSLC specifications and alignment with NRB, POL and ORB parameters. New items: 1.7.13 (Radar Unit Look Vector) , 1.7.14 (Slant Range Sensor to Surface), 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	[GSLC]	Charbonneau, Zebker, Rosenqvist, Albinet, Small, Truckenbrodt

Version	Date	Description of change	Affected CEOS-ARD product	Author
		Correction image), 2.16 (Ionospheric Phase Correction Image). Annex reorganisation and ORB and GSLC examples added		
0.3.1	26-09-2023	New items 1.7.15 (Reference orbit) and 3.7 (Flattened Phase) 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
0.4.1	11-10-2023	Add product code in summary table		Rosenqvist
1.0	11-10-2023	CEOS-ARD for SAR PFS – including Geocoded Single-Look Complex v1.0 – endorsed at LSI-VC-14		LSI-VC
1.0.1	07-12-2023	Drafting InSAR product addition to PFS	[InSAR]	Charbonneau
1.0.2	17-05-2024	Item 1.6.7 (Source Data Image Attributes): Azimuth Pixel Spacing can be provided in units of metres or seconds. Item 1.7.9 (Product Image Size): Text clarification of Number of pixels per line Item 2.1 (Metadata Machine Readability): Alignment of with description in Item 1.2. Items 2.2–2.16, 3.1, 3.6, 3.7: RAW removed and HDF5 added to suggested data formats. New items: 1.7.16 (InSAR Pair), 1.7.17 (InSAR Pair Co-Registration), 1.7.18 (Local In SAR Phase Quality, 1.7.19 (Interferogram Filtering), 1.7.20 (Phase Unwrapping). Items 1.6.4 (Source Data Orbit Information/Relative orbit number) and 2.5 (Ellipsoid Incidence Angle Image) moved from Goal to Threshold for [GSLC].	[NRB] [POL] [ORB] [GSLC]	Charbonneau, Small, Chapman, Logan, Shiroma, Brancato

Version	Date	Description of change	Affected CEOS-ARD product	Author
1.0.3	10-07-2024	Completion of the InSAR addition	[InSAR]	Charbonneau, Rosenqvist, Small, De Zan, Brancato, Shiroma
1.1	23-07-2024	CEOS-ARD for SAR PFS, update v1.1 endorsed at LSI-VC teleconference		LSI-VC
1.1.1	05-09-2024	New Item: 1.7.23 (Displacement Modelling) and addition and [InSAR] refinement to Item 1.7.16 (InSAR Pair).	[InSAR]	Charbonneau, Garthwaite, Rosenqvist, De Zan, Hawkins, Chapman, Zhou, Staniewicz, Shiroma, Jayasri, Truckenbrodt, Valentino
1.2	14-04-2025	CEOS-ARD for SAR PFS, update v1.2 endorsed at LSI-VC-17		LSI-VC
1.2.1	04-03-2026	Items 1.2 and 2.1 (Metadata Machine Readability). Changed to reference "the latest corresponding" PFS rather than version number. Added CB product description in PFS background section. New Items: 1.7.24 (Composite Backscatter Processing), 2.21 (Contributing Observation Image), 2.22 (Composite Quality Map Image)	All [CB]	Small, Rosenqvist, Charbonneau, Valentino, Zhou, Albinet, Jayasri, Truckenbrodt, Shiroma, Sundari, Tadono, Baldry, Chapman, Kennedy
1.2.2	16-04-2026	1.6.5 (Source Data Orbit Information). Separating Goal requirements for GSLC and InSAR. 4.3 (Geometric Accuracy). InSAR Threshold requirement to specify SAR acquisition used for geocoding moved to Goal.	[GSLC] [InSAR]	Small, Rosenqvist, Charbonneau, Mohr
1.2.3	24-04-2026	4.2 (Digital Elevation Model). Added description to clarify case where more than one DEM or EGM have been used to generate a mosaic or composite product.	All	Rosenqvist, Charbonneau, Small, Mohr
1.3	24-04-2026	CEOS-ARD for SAR PFS v1.3 endorsed at LSI-VC-19	[CB] All	LSI-VC

Contributing Authors

François Charbonneau, Natural Resources Canada, Canada
Ake Rosenqvist, soloEO / Japan Aerospace Exploration Agency, Japan
John Truckenbrodt, German Aerospace Centre (DLR), Germany
Clément Albinet, European Space Agency (ESA), Italy
David Small, University of Zurich, Switzerland
Bruce Chapman, Jet Propulsion Laboratory, USA
Howard Zebker, Stanford University, USA
Zheng-Shu Zhou, CSIRO, Australia
Kimberlee Baldry, Geoscience Australia, Australia
David Bekaert, Jet Propulsion Laboratory, USA
Virginia Brancato, Jet Propulsion Laboratory, USA
Danilo Dadamia, CONAE, Argentina
Benjamin Deschamps, Environment and Climate Change, Canada
Matt Garthwaite, CSIRO, Australia
Guillaume Hajduch, Collecte Localisation Satellites, France
Jayasri Poludasu, ISRO, India
Josef Kellndorfer, Earth Big Data, USA
Joseph Kennedy, Alaska Satellite Facility, USA
Marco Lavalle, Jet Propulsion Laboratory, USA
Thomas Logan, Alaska Satellite Facility, USA
Franz Meyer, Alaska Satellite Facility, USA
Nuno Miranda, European Space Agency (ESA), Italy
Matthias Mohr, Radiant Earth Foundation, Germany
Muriel Pinheiro, European Space Agency (ESA), Italy
Marko Repse, Sinergise, Slovenia
HariPriya Sakethapuram, ISRO, India
Gustavo H. X. Shiroma, Jet Propulsion Laboratory, USA
Usha Sundari, ISRO, India
Andreia Siqueira, Geoscience Australia, Australia
Scott Staniewicz, Jet Propulsion Laboratory, USA
Takeo Tadono, Japan Aerospace Exploration Agency, Japan
Medhavy Thankappan, Geoscience Australia, Australia
Antonio Valentino, Starion *for* European Space Agency (ESA), Italy
Anna Wendleder, German Aerospace Centre (DLR), Germany
Fang Yuan, Digital Earth Africa, Australia
Francesco De Zan, Delta-Phi Remote Sensing GmbH, Germany

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 organised into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets."

Description

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 five CEOS-ARD SAR specifications endorsed by CEOS Land Surface Imaging-Virtual Constellation (CEOS LSI-VC):

- Normalised Radar Backscatter [version 5.5]
- Polarimetric Radar [version 3.5]
- Ocean Radar Backscatter [version 1.0]
- Geocoded Single-Look Complex [SAR version 1.1]
- Interferometric SAR [SAR version 1.2]
- Composite Backscatter [SAR version 1.3]

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. However, 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 digital elevation model (DEM), for which the topographic phase contribution is removed.

The **[NRB]** specification accommodates basic mosaic products generated from more than one input data source, where each pixel value in the **[NRB]** product uniquely corresponds to the pixel value of *one* of its input data sources, indicated in the Acquisition ID per-pixel metadata. For products where the pixel value is dependent on multiple input sources, see the Composite backscatter **[CB]** product below.

The **CEOS-ARD Composite Backscatter [CB]** product is a composite backscatter product generated from a set of SAR images acquired over a time-window, and where each pixel value is derived from two or more of the input data sources (e.g. by local resolution weighting [Small et al., 2022]). (Note the difference with respect to the basic mosaic products accommodated by **[NRB]** above). **[CB]** datasets can be derived from a set of **[NRB] or [POL] or [GSLC]** inputs, making further use of those products' backscatter estimates and scattering area per-pixel metadata that were used to normalise them. The **[CB]** source image layers are arranged in a set of input products acquired within a defined time-window, and a single composite backscatter product is the output. It may contain multiple channels (wavelengths, polarisations). It is generally assumed that a single composite backscatter image layer will be generated from a set of inputs sharing a common polarisation and wavelength. The set of input products can be either from a single satellite or mission, or even from multiple missions, given a high standard of geometric and radiometric calibration in all contributing missions. Further quality per-pixel metadata may also be provided, such as (a) the Contributing Observations image (2.21) or (b) Composite Quality Map (2.22).

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.

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 nearest neighbour method is recommended for resampling the data to the geocoded format. 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 Sinc interpolation may be 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).

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.

The **CEOS-ARD Interferometric SAR [InSAR]** product format specification describes products resulting from InSAR processing steps. Two levels of product categories are supported: 1) The first level includes InSAR coherence and wrapped interferogram images derived from a pair (or several pairs) of SLC or GSLC source data listed in the product metadata file. The product metadata file reports the processing information (parameters and methods) used to produce them. The PFS also supports unwrapped interferograms, but their inclusion is not a threshold requirement for this product level. An InSAR pair identification label allows support of InSAR time series products derived from several repeated pass SAR source combinations. A Boolean flag is used to indicate whether the interferometric phases due to Earth curvature and to the surface topography are removed from interferograms. This **[InSAR]** product level can then serve as input in temporal coherence analysis techniques or as input in production of time series displacement products by distributed target approaches like Small BAseline Subset (SBAS) technique [Lanari *et al.* 2004]. 2) InSAR displacement belongs to the second level of **[InSAR]** products. Displacement products can be expressed as InSAR displacement from a pair of SAR acquisitions and/or from a time series of SAR acquisitions, as a displacement and/or as displacement rate products over a time period. Since several different InSAR displacement approaches exist in the literature for which, each have their own criteria and parameters, it is not possible to prescribe specific metadata details. Nonetheless, it is required that main processing steps (with reference to methodologies), with their chosen parameters (criteria like statistical thresholds and estimation window sizes) are well defined in the displacement product metadata, in order to preserve traceability for the end users. For [InSAR] displacement products generated from first level CEOS-ARD **[InSAR]**, listed "source" products in the metadata can refer to those first level CEOS-ARD **[InSAR]** described above. In accordance with other CEOS-ARD products, per-pixel metadata and data are terrain geocoded products.

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]** (given that terrain-flattening was applied, a goal-requirement for GSLC), the inverse conversion can be made true by including the optional topographically flattened phase. In this way a **[NRB]** or **[POL]** product can be used like a **[GSLC]** for InSAR applications. Consequently, it becomes obvious that they all can follow a common approach, in terms of content and structure, in order to optimize their interoperability.

For this combined **CEOS-ARD for Synthetic Aperture Radar** PFS, as for the individual **[NRB]**, **[CB], [POL]**, **[ORB]**, **[GSLC]**, and **[InSAR]** PFSs, metadata requirements are defined under two categories: Threshold and Goal. **Threshold requirements** refer to metadata parameters or data files which are mandatorily required in a product in order to be CEOS-ARD compliant. **Goal requirements** (formerly referred to as Target) 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 constraints. 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 applications/environment of the CEOS-ARD product. Exceptions are identified in the tables by specifying the usage.

Definitions and Abbreviations

ALE	Absolute Localisation Error
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.
CB	Composite Backscatter
CEOS-ARD	Committee on Earth Observation Satellites - Analysis Ready Data
Composite Product	Product where samples (or pixels) are generated from more than one input data source, e.g. by local resolution weighting or by backscatter averaging.
CovMat	Normalised Radar Covariance Matrix
DOI	Digital Object Identifier
GSLC	Geocoded Single-Look Complex
InSAR	Interferometric Synthetic Aperture Radar
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.
Mosaic Product	Product generated from more than one input data source and where a pixel value in the product uniquely corresponds to the pixel value of one of its input data sources.
NRB	Normalised Radar Backscatter
Pixel Spacing	Processed sample distance
POL	Polarimetric Radar
PRD	Polarimetric Radar Decomposition
RTC	Radiometrically Terrain Corrected
Spatial Resolution	The smallest size objects that can be distinguished by the sensor at the ground surface.
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.

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] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Data must be traceable to SI reference standard. *Note 1: Relationship to 3.5. Traceability requires an estimate of measurement uncertainty.* *Note 2: Information on traceability should be available in the metadata as a single DOI landing page.*	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.2	**Metadata Machine Readability**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component/variable for further use. **Goal (Desired) Requirements** As threshold, but metadata is formatted in accordance with the latest corresponding CEOS-ARD SAR Metadata Specifications, 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.3	**Product Type**	[NRB] [CB] [POL]	**Threshold (Minimum) Requirements** CEOS-ARD product type name – or names in case of compliance with more than one product type – and, if required by the data provider, copyright.	Achieved level: Threshold / Goal

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
		[ORB] [GSLC] [InSAR]	**Goal (Desired) Requirements** As threshold.	Explanation / Justification: … Other feedback: …
1.4	**Document Identifier**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Reference to CEOS-ARD for Synthetic Aperture Radar PFS document as URL. **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.5	**Data Collection Time**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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 the case of composite or mosaic products, the dates/times of the first and last data takes is provided with the product. **Goal (Desired) Requirements** As threshold, but using ISO 8601 time format.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6	**Source Data Attributes**		Subsection describing (detailing) each SAR acquisition used to generate the ARD product. *Note 1: Source data attribute information are described for each acquisition and sequentially identified e.g. as acqID= 1, 2, 3, …* *Note 2: Source data attribute information can refer to [NRB], [POL], [ORB], [InSAR] or [GSLC] products for higher level ARD derived from those, under the condition of their availability (item 1.6.1).*	

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.6.1	**Source Data Access**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** The metadata identifies the location from where the source data can be retrieved, expressed as a URL or DOI. **Goal (Desired) Requirements** 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.2	**Instrument**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** The instrument used to collect the data is identified in the metadata: - Satellite name - Instrument name **Goal (Desired) Requirements** As threshold, but using CEOS Mission-Instruments-Measurements (MIM) database (https://ceos.org/mim-database) as reference .	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.3	**Source Data Acquisition Time**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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. **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.4	**Source Data Acquisition Parameters**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Acquisition parameters related to the SAR antenna: - 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) **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.6.5	**Source Data Orbit Information**	[NRB] [CB] [POL] [ORB] [GSLC]	**Threshold (Minimum) Requirements** Information related to the platform orbit used for data processing: - Pass direction [asc/desc] * - Orbit data source [e.g., predicted/ definite/ precise/ downlinked, etc.] ** 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.* **Goal (Desired) Requirements** 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. - Absolute orbit number - Relative orbit number	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
		[InSAR] [GSLC]	**Threshold (Minimum) Requirements** Information related to the platform orbit used for data processing: - Relative orbit number, if defined **Goal (Desired) Requirements** As threshold, plus for [GSLC], perpendicular baseline to virtual orbit or reference orbit used for phase correction	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">1.6.6</td><td rowspan="2">Source Data Processing Parameters</td><td rowspan="2">[NRB]
[CB]
[POL]
[ORB]
[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Processing parameters details of the source data:
- 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)

Note: Azimuth and Range number of looks are not required when sources are CEOS-ARD or any other geocoded products</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
As threshold, plus additional relevant processing parameters, e.g., range- and azimuth look bandwidth and LUT applied.</td></tr>
<tr><td rowspan="2">1.6.7</td><td rowspan="2">Source Data Image Attributes</td><td rowspan="2">[NRB]
[CB]
[POL]
[ORB]
[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Image attributes related to the source data:
- Source Data geometry (slant range/ground range/geocoded)
- 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
Note: For geocoded sources ([GSLC] and [InSAR]), Azimuth and Range pixel spacing are replaced by line (row) and pixel (column) spacing information. Spatial resolution information is not required for geocoded sources.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Geometry of the image footprint expressed in WGS84 in a standardised format (e.g., WKT).

[CB]</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.6.8	**Sensor Calibration**	[NRB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.9	**Performance Indicators**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Provide performance indicators on data intensity noise level (NEσ^0 and/or NEβ^0 and/or NEγ^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. **Goal (Desired) Requirements** Provide additional relevant performance indicators (e.g., ENL, PSLR, ISLR, and performance reference DOI or URL).	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.10	**Source Data Polarimetric Calibration Matrices**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** The complex-valued polarimetric distortion matrices with the channel imbalance and the cross-talk applied for the polarimetric calibration.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.6.11	**Mean Faraday Rotation Angle**	[NRB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.6.12	**Ionosphere Indicator**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
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] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Processing parameters details of the CEOS-ARD product: - Processing facility - Processing date - Software version - Location from where CEOS-ARD product can be retrieved, expressed as a URL or DOI. **Goal (Desired) Requirements** 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.2	**Auxiliary Data**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as DOIs. *Note: Auxiliary data includes DEMs, etc., and any additional data sources used in the generation of the product.*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.3	**Product Sample Spacing**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** CEOS-ARD product processing parameters details: - Pixel (column) spacing - Line (row) spacing **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.4	**Product Equivalent Number of Looks**	[NRB] [CB] [POL] [ORB] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Equivalent Number of Looks (ENL)	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.5	**Product Resolution**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Average spatial resolution of the CEOS-ARD product along: - Columns - Rows	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment

1.7.6	**Product Filtering**	[NRB]
		[CB]
		[POL]
		[ORB]
			Threshold (Minimum) Requirements
			Flag if speckle filter has been applied [True/False].
			Metadata should include:
			- Reference to algorithm as DOI or URL
			- Input filtering parameters
			  ○ Type
			  ○ Window size in pixel units
			  ○ Any other parameters defining the speckle filter used
			
			Mandatory for [POL]: Advanced polarimetric filter preserving covariance matrix properties shall be applied.
			Goal (Desired) Requirements
			As threshold.
				Achieved level: Threshold / Goal
				Explanation / Justification: …
				Other feedback: …

1.7.7	**Product Bounding Box**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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. Four corners of the product file are recommended for scenes crossing the Antemeridian, or the North or the South Pole. **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.7.8	**Product Geographical Extent**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** The geometry of the SAR image footprint expressed in longitude/latitude based on WGS84 (EPSG 4326), in a standardised format (e.g., WKT Polygon). **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.9	**Product Image Size**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Image attributes of the CEOS-ARD product: - Number of lines - Number of pixels per line - File header size (if applicable) - Number of no-data border pixels (if appl.) **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.7.10	**Product Pixel Coordinate Convention**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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]. **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
1.7.11	**Product Coordinate Reference System**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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. **Goal (Desired) Requirements** As threshold.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.12	**Look Direction Polynomials**	[ORB]	**<u>Threshold (Minimum) Requirements</u>** 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. Example polynomial: $LookDir = a_1Lat^2 + a_2Lon^2 + a_3LatLon + a_4Lat + a_5Lon + a_6$ where: a_i = polynomial coefficients Lat = latitude Lon = longitude Lat and Lon are the related coordinates in the product map units [‘m’, ‘deg’, ‘arcsec’] ** 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.* **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.13	**Radar Unit Look Vector**	[GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** 3-D components radar unit look vector, specified at centre of scene, in an Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centred Rotating - ECR) is provided. It consists of unit vectors from antenna to surface pixel (i.e., positive Z component). Only required if per-pixel metadata 2.12 (Radar Unit Look Vector Grid Image) is not provided. **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.14	**Slant Range Sensor to Surface**	[GSLC]	**<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. **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.15	**Reference Orbit**	[NRB] [POL] [GSLC]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Usage: For [NRB] & [POL] only when per-pixel metadata 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.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">1.7.16</td><td rowspan="2">InSAR Pair</td><td rowspan="2">[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
InSAR baseline criteria information
● Baseline type: Single Reference, Multi-baseline or All
● Minimal and maximal perpendicular baselines (not required when type = “All”)
● Minimal and maximal temporal baselines (not required when type = “All”)

When [InSAR] product contains image data derived from InSAR pairs, as defined under items 3.8, 3.9, and 3.10, provide list of source acquisition ID (e.g. as per item 1.6 acqID) for the InSAR pair (primary and secondary acquisitions). Repeat for multiple InSAR pair products and assign/specify InSAR pair ID number (e.g. insarID = 1,2,3 …). For multi-polarisation source acquisition, specify the polarisation used for the InSAR pair.

Provide Perpendicular and Parallel orbit baseline information estimated at scene centre. In addition, orbital baseline information can be provided as per pixel metadata 2.18 and 2.19.

Flag if orbital baseline refinement has been applied [true/false]. If true, specify refinement method (ex.: GCPs, FFT, …).

Azimuth common band filtering and range spectral shift filtering flags.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>

Source type format with value ”GSLC” should be provided when InSAR analysis is performed from [GSLC] products generated from SLC source acquisitions listed under item 1.6. If GSLC data aren’t provided with the InSAR product, provide the [GSLC] URL link(s) if it is available. If source acquisitions listed under 1.6 are [GSLC], discard this note.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.17	**InSAR Pair Co-registration**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** Co-registration information of source acquisitions with a reference source. Provide reference source ID (or filename if different from source list) and for each co-registered source, report the azimuth and range standard deviation error in metre or sample fraction. <u>Not required when the InSAR product is generated from [GSLC] products (see product level in requirement 1.6.6).</u> **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.18	**Local InSAR Phase Quality**	[InSAR]	<u>**Threshold (Minimum) Requirements**</u> Local InSAR phase quality estimation information ● Methodology name [ex.: Coherence, DespecKS, Persistent Scatterers [Temporal variability of intensity and/or Spectral diversity correlation], …) ● Reference to methodology [text or DOI] ● Estimation parameters and selection criteria used, as for examples: 1. For coherence ▪ Window size ▪ Weighting shape ▪ Coherence threshold for selection 2. For DespecKS [Ferretti *et al.* 2011] or similar statistical approach ▪ Window size ▪ Statistical test function (Kolmogorov-Smirnov, Anderson-Darling, …) ▪ Number of statistically homogeneous pixels (SHP) threshold for selection ▪ Phase triangulation coherence (γ_{PTA}) threshold 3. For Persistent Scatterers ▪ Temporal variability of intensity - Intensity mean/std ratio threshold - Relative intensity threshold - Spectral diversity correlation - Line and column spectral looks - Intensity minimal threshold - Spectral correlation threshold - Intensity mean/std ratio threshold All phase quality estimation techniques used shall be listed. <u>**Goal (Desired) Requirements**</u> As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.19	**Interferogram Filtering**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** If applied, interferogram filtering information ● Methodology name ● Reference to methodology [text or DOI] ● Filtering parameters used. **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.20	**Phase Unwrapping**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** If 3.10-Unwrapped Interferogram Image is provided, technique used for InSAR phase unwrapping ● Methodology name ● Reference to methodology [text or DOI] ● Unwrapping parameters 1. Coherence threshold 2. Number of iterations 3. Stable reference point coordinates or multi-point approach information **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.21	**Atmospheric Phase Correction**	[GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** If applied, reference to atmospheric phase correction technique and parameters used. ● Methodology name ● Reference to methodology [text or DOI] **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.22	**Ionospheric Phase Correction**	[GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** If applied, reference to ionospheric phase correction technique and parameters used. ● Methodology name ● Reference to methodology [text or DOI] **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
1.7.23	**Displacement Modelling**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Reference to displacement modelling technique used ● Methodology name ● Reference to methodology [text or DOI] ● Specific input parameters used If a temperature refinement model is used, indicate model and temperature data source.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
1.7.24	**CB Processing**	[CB]	**<u>Threshold (Minimum) Requirements</u>** Reference to composite backscatter generation method used ● Methodology name ● Reference to methodology [DOI] ● Specific input parameters used **<u>Goal (Desired) Requirements</u>** As threshold	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

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.

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.1	**Metadata Machine Readability**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component/variable for further use. **Goal (Desired) Requirements** As threshold, but metadata is formatted in accordance with the latest corresponding CEOS-ARD SAR Metadata Specifications, 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.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">2.2</td><td rowspan="2">Data Mask Image</td><td rowspan="2">[NRB]
[CB]
[POL]
[ORB]
[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Mask image indicating:
- Valid data
- Invalid data
- No data

File format specifications/ contents provided in metadata:
- Sample Type [Mask]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int, ...]
- Bits per Sample
- Byte Order
- Bit Value Representation

Note 1: All bit value representations included in the Data Mask Image should be indicated in the metadata.
Note 2: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
As threshold, including additional bit value representations, e.g.:
- Layover (masked as invalid data in threshold)
- Radar shadow (masked as invalid data in threshold)
- Ocean water
- Land (recommended for [ORB])
- RTC applied (e.g., for maritime scenes with land samples for which RTC has been applied)
- DEM gap filling (i.e., interpolated DEM over gaps)
- [InSAR] Unwrapped interferogram phase quality flag/score</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.3	**Scattering Area Image**	[NRB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
			Goal (Desired) Requirements **Usage:** Recommended for scenes that include land areas. 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. File format specifications/ contents provided in metadata: - Sample Type [Scattering Area] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note 1: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file could be provided as a URL address of that unique metadata file. Note 2: Required for e.g. NRB/POL products if they are to be used as an input to production of composite backscatter (CB) when weighted averages based on the areas are used to generate composite backscatter.	

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">2.4</td><td rowspan="2">Local Incident Angle Image</td><td>[NRB]
[POL]
[ORB]</td><td><u>Threshold (Minimum) Requirements</u>
DEM-based Local Incident angle image is provided.

File format specifications/ contents provided in metadata:
- Sample Type [Angle]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order

Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.

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</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td>[GSLC]</td><td><u>Goal (Desired) Requirements</u>
As threshold.</td></tr>
</table>

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">2.5</td><td rowspan="2">Ellipsoidal Incident Angle Image</td><td>[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Ellipsoidal incident angle is provided.

File format specifications/ contents provided in metadata:
- Sample Type [Angle]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order
- Reference Ellipsoid Name

Required when 2.12 Radar Unit Look Vector Grid Image is not provided

Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td>[NRB]
[POL]
[ORB]</td><td><u>Goal (Desired) Requirements</u>
As threshold.

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.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.6	**Noise Power Image**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Estimated Noise Equivalent σ^0 (or β^0 or γ^0, as applicable) used for noise removal, if applied, for each channel. NEσ^0 and NEγ^0 are both based on either an ellipsoid Earth model or the local topography. File format specifications/ contents provided in metadata: - Sample Type [Gamma-Nought, Sigma-Nought, Beta-Nought] - Correction model type [Ellipsoid, Topography] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note: For [CB] the same compositing algorithm as for backscatter shall be used.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
2.7	**Gamma-to-Sigma Ratio Image**	[NRB] [POL] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<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^0 by this ratio results in an estimate of RTC σ_T^0. File format specifications/ contents provided in metadata: - Sample Type [Ratio] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="4">2.8</td><td rowspan="4">Acquisition ID Image</td><td rowspan="2">[NRB]
[POL]
[ORB]
[GSLC]</td><td><u>Threshold (Minimum) Requirements</u>
Note: Required for mosaic products 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 (integer or fractional) day offset to reference observation date [UTC]. Date used as reference (“Day 0”) is provided in the meta-data.

Pixels not representing a unique date or ID (e.g., pixels averaged in image overlap zones) are flagged with a pixel value referencing a date range that is provided in the metadata.

File format specifications/ contents provided in metadata:
- Sample Type [Day, Time, ID]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per sample
- Byte Order</td><td rowspan="4"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
As threshold.</td></tr>
<tr><td rowspan="2">[CB]</td><td><u>Threshold (Minimum) Requirements</u>
Not required.</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
The source IDs for each pixel are identified.

File format specifications/ contents provided in metadata:
- Sample Type [ID]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per sample
- Byte Order</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.9	**Per-pixel DEM**	[NRB] [CB] [POL] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** 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. File format specifications/ contents provided in metadata: - Sample Type [Height] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
2.10	**Per-pixel Geoid**	[ORB]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** 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. File format specifications/ contents provided in metadata: - Sample Type [Height] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order - Ground Sampling Distance	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.11	**Look Direction Image**	[ORB]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Look Direction Image is provided. It represents the planar angle between north and each range direction. File format specifications/ contents provided in metadata: - Sample Type [Angle] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.12	**Radar Unit Look Vector Grid Image**	[GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>Goal (Desired) Requirements</u> 3-D components radar unit look vector, specified at each pixel in an Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centred Rotating – ECR) is provided. It consists of unit vectors from the antenna to the surface pixel (i.e., positive Z component). In the case of [InSAR] product, 3-D components radar unit look vector of the reference acquisition. File format specifications/ contents provided in metadata: - Sample Type [3D unit vector] - Source acquisition ID (e.g. acqID) (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Double Float, ...] - Bits per Sample - Byte Order Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.	

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.13	**Slant Range Sensor to Surface Image**	[GSLC] [InSAR]	<u>**Threshold (Minimum) Requirements**</u> Not required.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>**Goal (Desired) Requirements**</u> Slant range distance from the sensor to the surface, specified at each pixel in an Earth-Centred Earth-Fixed (ECEF) coordinate system (also called Earth Centred Rotating – ECR) is provided. In the case of [InSAR] product, the slant range distance of the reference acquisition File format specifications/ contents provided in metadata: - Sample Type [Length] - Source acquisition ID (e.g. acqID) (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order Note: For CEOS-ARD products created from repeat-pass acquisitions, with narrow orbital tube radius, a single static per pixel metadata file can be provided as a URL address of that unique metadata file.	

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.14	**InSAR Phase Uncertainty Image**	[GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired)l Requirements** Estimates of uncertainty in InSAR phase is provided, such as finite signal to noise ratio, quantization noise, platform state vector accuracy, 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. In case both the wrapped and unwrapped interferograms are supplied, specify which interferogram the uncertainty image corresponds to. File format specifications/ contents provided in metadata: - Sample Type [Angle] - insarID number (for [InSAR] product only) - Corresponding interferogram (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.15	**Atmospheric Phase Correction Image**	[GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Phase correction value at each pixel, if applied. File format specifications/ contents provided in metadata: - Sample Type [Angle] - insarID number (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
2.16	**Ionospheric Phase Correction Image**	[GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Phase correction value at each pixel, if applied. File format specifications/ contents provided in metadata: - Sample Type [Angle] - insarID number (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.17	**Simulated Topographic Phase Image**	[InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Simulated topographic phase image(s) used to remove topographic contribution to interferogram(s). File format specifications/ contents provided in metadata: - Sample Type [Angle] - insarID number (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
2.18	**InSAR Perpendicular Baseline Image**	**[InSAR]**	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Perpendicular orbital baseline between primary and secondary source acquisitions. File format specifications/ contents provided in metadata: - Sample Type [Length] - insarID number (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.19	**InSAR Parallel Baseline Image**	[InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Parallel orbital baseline between primary and secondary source acquisitions. File format specifications/ contents provided in metadata: - Sample Type [Length] - insarID number (for [InSAR] product only) - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Float, ...] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
2.20	**InSAR Displacement Model Point Image**	[InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Data file(s) identifying pixels used for InSAR displacement modeling (items 3.11 to 3.14). As a suggestion, this information can be provided as a single multi-layer file, where each 1bit layer, containing 0 (not used) and 1 (used) flags, refers to an insarID pair (for SBAS type InSAR) or Source ID (when insarIDs are not listed). Instead, a list of Dates identifying layers can be provided under this item. File format specifications/ contents provided in metadata: - Sample Type [Model Points] - Source ID or insarID number or Dates - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [1bit, 8bit, …] - Bits per Sample - Byte Order	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.21	**Contributing Observations Image**	[CB]	<u>**Threshold (Minimum) Requirements**</u> Not required. <u>**Goal (Desired) Requirements**</u> From the methodology defined in [Small et al. 2022] , the quality layer describing the [CB] composite's achieved local resolution is provided (see Annex 5). A separate Composite Quality Map Image is generated for each polarisation, as, in the general case, each may have a different number of inputs. File format specifications/ contents provided in metadata: - Quality Descriptor Type - dB-scaling Expression Convention [linear amplitude or linear power*] - Polarization [HH/HV/VV/VH/RR/…] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
2.22	**Composite Quality Map Image**	[CB]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** From the methodology defined in [Small et al. 2022] , the quality layer describing the [CB] composite's achieved local resolution is provided (see Annex 5). A separate Composite Quality Map Image is generated for each polarisation, as, in the general case, each may have a different number of inputs. File format specifications/ contents provided in metadata: - Quality Descriptor Type - dB-scaling Expression Convention [linear amplitude or linear power*] - Polarization [HH/HV/VV/VH/RR/…] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order **Note: Transformation to the logarithmic decibel scale is not required or desired as this step can be completed by the user if necessary.*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

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.

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.1	**Backscatter Measurements**	[NRB]	**<u>Threshold (Minimum) Requirements [NRB]</u>** "Terrain-flattened" Radiometrically Terrain Corrected (RTC) Gamma-Nought backscatter coefficient (γ_T^0) is provided for each polarization. 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 [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order **Note: Transformation to the logarithm decibel scale is not required or desired as this step can be completed by the user if necessary.* **<u>Goal (Desired) Requirements</u>** As threshold.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.1	**Backscatter Measurements**	[POL]	**<u>Threshold (Minimum) Requirements [POL]</u>** Measurements can be: <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. And/or <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. File format specifications/contents provided in metadata: - Measurement Type [CovMat/PRD] - Measurement convention unit [linear amplitude or linear power*, or phase angle] - Individual covariance matrix element or/and Individual component of the decomposition [C3m11, C3m12, … or H, A, alpha, or ...] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/ Float/Complex, etc.] - Bits per Sample - Byte Order **Note 1: Transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.* *Note 2: It is recommended to keep CovMat or PRD measurement files separated. Else, specify the multi-channel format order [BIP, BIL, BSQ].*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>Goal (Desired) Requirements</u> As threshold.	

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">3.1</td><td rowspan="2">Backscatter Measurements</td><td rowspan="2">[ORB]</td><td><u>Threshold (Minimum) Requirements [ORB]</u>
<u>Geoid-corrected Sigma-Nought backscatter coefficien</u>t (σ^0) is provided for each polarization.

File format specifications/contents provided in metadata:
- Measurement Type [Sigma-Nought]
- Backscatter Expression Convention [linear amplitude or linear power*]
- Polarization [HH/HV/VV/VH]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order

*Note: Transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Radiometrically Terrain-corrected Sigma-Nought backscatter coefficient (σ_T^0) is provided for each polarization.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.1	**Backscatter Measurements**	[GSLC]	**<u>Threshold (Minimum) Requirements [GSLC]</u>** Backscatter coefficient, in complex number format, is provided for each polarization (e.g., HH, HV, VV, VH). GSLC phase is terrain-flattened using Earth ellipsoid and digital elevation or surface models. File format specifications/contents provided in metadata: - Measurement Type [Gamma-Nought, Sigma-Nought or Beta-Nought] - Backscatter Expression Convention [linear amplitude] - Polarization [HH/HV/VV/VH] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order **Note: Transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>Goal (Desired) Requirements</u> **Radiometric and Phase Terrain-flattened** Gamma-Nought backscatter coefficient (γ_T^0), in complex number format, is provided for each polarization (e.g., HH, HV, VV, VH).	

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.1	**Backscatter Measurements**	[InSAR]	<u>**Threshold (Minimum) Requirements [InSAR]**</u> Not required. <u>**Goal (Desired) Requirements**</u> Terrain-flattened Radiometrically Terrain Corrected (RTC) Gamma-Nought backscatter coefficient (γ_T^0) is provided for each polarization. File format specifications/contents provided in metadata: - Measurement Type [Gamma-Nought] - Source ID (e.g. item 1.6 acqID) - Backscatter Expression Convention [linear amplitude or linear power*] - Polarization [HH/HV/VV/VH, …] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order *Note: Transformation to the logarithm decibel scale is not required or desired as this step can be completed by the user if necessary.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">3.1</td><td rowspan="2">Backscatter Measurements</td><td rowspan="2">[CB]</td><td><u>Threshold (Minimum) Requirements</u>
Composite Backscatter γ_c^0 calculated (e.g. via Local-Resolution-Weighting [Small et al., 2022]) from a set of Terrain-flattened” Radiometrically Terrain Corrected (RTC) Gamma-Nought backscatter coefficient (γ_T^0) image inputs (NRB, POL, or compliant (i.e. terrain-flattened) GSLC) is provided for each polarization.

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 [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order

*Note: Transformation to the logarithmic decibel scale is not required or desired as this step can be completed by the user if necessary.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
As threshold.</td></tr>
<tr><td rowspan="2">3.2</td><td rowspan="2">Scaling Conversion</td><td rowspan="2">[NRB]
[CB]
[POL]
[ORB]
[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
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.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
As threshold, but use of float32.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.3	**Noise Removal**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<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. **Note: Thermal noise removal and image border noise removal to remove overall scene noise and scene edge artefacts, respectively.*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>Goal (Desired) Requirements</u> As threshold.	
3.4	**Radiometric Terrain Correction Algorithm**	[NRB] [CB] [POL]	**<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. Metadata references, e.g.: - 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 auxiliary data used to make corrections *Note: Examples of technical documentation include an Algorithm, Theoretical Basis Document, product user guide, etc.*	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …
			<u>Goal (Desired) Requirements</u> As threshold.	
		[InSAR] [GSLC]	**<u>Threshold (Minimum) Requirements</u>** Not required.	
			<u>Goal (Desired) Requirements</u> Require resolution of DEM better than the output product resolution when applying terrain corrections.	

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.5	**Radiometric Accuracy**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Uncertainty (e.g., bounds on γ^0 or σ^0) information is provided as document referenced as URL or DOI. SI traceability is achieved.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
3.6	**Mean Wind-Normalised Backscatter Measurements**	[ORB]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** **Usage:** Only for Maritime scenes 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. File format specifications/contents provided in metadata: - Measurement Type [Wind-Normalised Backscatter] - Backscatter Expression Convention [intensity ratio] - Polarization [HH/HV/VV/VH] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order Note: Reference wind model, wind speed and direction used for reference backscattering coefficient should be provided.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">3.7</td><td rowspan="2">Flattened Phase</td><td rowspan="2">[NRB]
[POL]</td><td><u>Threshold (Minimum) Requirements</u>
Not required.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Usage: Alternative to [GSLC] product for [NRB] and [POL] products

The Flattened Phase is the interferometric phase for which the topographic phase contribution is removed. It 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 Phase with the [NRB] or [POL] intensity (3.1 Backscatter measurement) provides the [GSLC] equivalent, as follows:

GSLC = sqrt(NRB) x exp(j FlattenPhase)

File format specifications/contents provided in metadata:

- Measurement Type [Flattened Phase]
- Reference Polarization [HH/HV/VV/VH]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order

In case of polarimetric data, indicate the reference polarization.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.8	**Coherence Image**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** InSAR coherence image for each InSAR pair defined under 1.7.16 File format specifications/contents provided in metadata: - Measurement Type [Coherence] - insarID number - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, Complex Float ...] - Bits per Sample - Byte Order Coherence image statistics - Average - Standard deviation	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">3.9</td><td rowspan="2">Interferogram Image</td><td rowspan="2">[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Not required.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Interferogram image for each InSAR pair defined under 1.7.16.. Indicate if the InSAR simulated ellipsoid and topographic phases have been subtracted.

File format specifications/contents provided in metadata:
- Measurement Type [Interferogram]
- insarID number
- Subtracted Earth curvature phase flag [True/False]
- Subtracted topographic phase flag [True/False]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order</td></tr>
<tr><td rowspan="2">3.10</td><td rowspan="2">Unwrapped Interferogram Image</td><td rowspan="2">[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Not required.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Unwrapped interferogram image for each InSAR pair defined under 1.7.16..

File format specifications/contents provided in metadata:
- Measurement Type [Unwrapped Interferogram]
- insarID number
- Component [Line of Sight, Vertical, East, North]
- Data Format [GeoTIFF/HDF5/NetCDF, …]
- Data Type [Int/Float, ...]
- Bits per Sample
- Byte Order</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.11	**InSAR Displacement Image**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Displacement map image(s) could be expressed as a single cumulative displacement map or a temporal series of incremental displacement maps. File format specifications/contents provided in metadata: - Measurement Type [InSAR Cumulative Displacement or InSAR Incremental Displacement] - Measurement projection [Line of Sight, Vertical, Horizontal, East, North] - Interval start time - Interval end time - Reference Polarization* [HH/HV/VV/VH/RH/RL/...] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order *In case of polarimetric data, indicate the reference polarization.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.12	**InSAR Displacement Residue Image**	[InSAR]	<u>**Threshold (Minimum) Requirements**</u> Not required. <u>**Goal (Desired) Requirements**</u> Displacement residue map images for each source acquisition generated from displacement model. File format specifications/contents provided in metadata: - Measurement Type [Displacement residues] - Measurement projection [Line of Sight, Vertical, Horizontal, East, North] - Source ID - Reference Polarization* [HH/HV/VV/VH/RH/RL/…] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order *In case of polarimetric data, indicate the reference polarization.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.13	**InSAR Displacement Rate Image**	[InSAR]	<u>**Threshold (Minimum) Requirements**</u> Not required. <u>**Goal (Desired) Requirements**</u> Mean linear displacement rate (velocity) estimate. File format specifications/contents provided in metadata: - Measurement Type [Displacement rate] - Measurement projection [Line of Sight, Vertical, Horizontal, East, North] - Interval start time - Interval end time - Rate (velocity) units [mm/year, cm/year, mm/month, …] - Reference Polarization* [HH/HV/VV/VH/RH/RL/…] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order *In case of polarimetric data, indicate the reference polarization.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
3.14	**InSAR Displacement Rate Model Fit Image**	[InSAR]	**<u>Threshold (Minimum) Requirements</u>** Not required. **<u>Goal (Desired) Requirements</u>** Goodness of fit for model defined in 3.13 File format specifications/contents provided in metadata: - Measurement Type [Model standard deviation, R-squared, RMSE …] - Measurement projection [Line of Sight, Vertical, Horizontal, East, North] - Interval start time - Interval end time - Reference Polarization* [HH/HV/VV/VH/RH/RL/…] - Data Format [GeoTIFF/HDF5/NetCDF, …] - Data Type [Int/Float, ...] - Bits per Sample - Byte Order *In case of polarimetric data, indicate the reference polarization.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

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.

<table>
<tr><th>#</th><th>Parameter</th><th>CEOS-ARD product</th><th>Requirements</th><th>Self-Assessment</th></tr>
<tr><td rowspan="2">4.1</td><td rowspan="2">Geometric Correction Algorithm</td><td rowspan="2">[NRB]
[CB]
[POL]
[ORB]
[GSLC]
[InSAR]</td><td><u>Threshold (Minimum) Requirements</u>
Not required.</td><td rowspan="2"><u>Achieved level:</u> Threshold / Goal

<u>Explanation / Justification:</u> …

<u>Other feedback:</u> …</td></tr>
<tr><td><u>Goal (Desired) Requirements</u>
Metadata references, e.g.:
- A metadata citable peer-reviewed algorithm,
- Technical documentation regarding the implementation of that algorithm expressed as URLs or DOIs
- The sources of auxiliary data used to make corrections.
- Resampling method used for geometric processing of the source data.

Note: Examples of technical documentation can include e.g., an Algorithm Theoretical Basis Document (ATBD), a product user guide.</td></tr>
</table>

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
4.2	**Digital Elevation Model**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**<u>Threshold (Minimum) Requirements</u>** **Usage:** For products including land areas 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 the Digital Elevation Model used for geometric terrain correction. For mosaic or composite products, specify the DEM used for each input data source, if different. c) Provide reference to Earth Gravitational Model (EGM) if used for geometric correction. For mosaic or composite products, specify the EGM used for each input data source, if different. **<u>Goal (Desired) Requirements</u>** 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. b) Resampling method used for preparation of the DEM. c) Method used for resampling the EGM.	<u>Achieved level:</u> Threshold / Goal <u>Explanation / Justification:</u> … <u>Other feedback:</u> …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
4.3	**Geometric Accuracy**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Accurate geolocation is a prerequisite to radar processing to correct for terrain and to enable interoperability between radar sensors. 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 CEOS-ARD 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. 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. For [CB] products, when sources come from different SAR platforms or different beam modes, provide averaged ALE or averaged ARD ALE. *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.* *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 suitably representative subset) of the generated products.* *Note 3: For new SAR missions, as long as calibration/validation reports are not available, values can be set to NaN and provide a DOI or URL link to pre-launch mission specification document.* **Goal (Desired) Requirements** Output product sub-sample accuracy should be less than or equal to 0.1 (slant range) pixel radial root mean square error (rRMSE). For [InSAR] products, specify the SAR acquisition used for geocoding. SAR acquisition could be different from the two source acquisitions of the product when a stack of acquisitions is processed simultaneously. Provide documentation of estimates of ALE as DOI or URL.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
4.4	**Geometric Refined Accuracy**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** Not required. **Goal (Desired) Requirements** Values provided under 4.3 Geometric accuracy are provided by the SAR mission Cal/Val team. 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. Methodology used (name and reference), quality flag, geometric standard deviation values should be provided. For [CB] products, provide averaged ALE or averaged ARD ALE estimated from all sources.	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …

#	Parameter	CEOS-ARD product	Requirements	Self-Assessment
4.5	**Gridding Convention**	[NRB] [CB] [POL] [ORB] [GSLC] [InSAR]	**Threshold (Minimum) Requirements** 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.*	Achieved level: Threshold / Goal Explanation / Justification: … Other feedback: …
			Goal (Desired) Requirements 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.	

Summary Self-Assessment Table

1	CEOS-ARD product	General Metadata	Threshold	Goal
1.1	[ALL]	Traceability		
1.2	[ALL]	Metadata Machine Readability		
1.3	[ALL]	Product Type		
1.4	[ALL]	Document Identifier		
1.5	[ALL]	Data Collection Time		
1.6		**Source Data Attributes**		
1.6.1	[ALL]	Source Data Access		
1.6.2	[ALL]	Instrument		
1.6.3	[ALL]	Source Data Acquisition Time		
1.6.4	[ALL]	Source Data Acquisition Parameters		
1.6.5	[ALL]	Source Data Orbit Information		
1.6.6	[ALL]	Source Data Processing Parameters		
1.6.7	[ALL]	Source Data Image Attributes		
1.6.8	[NRB] [POL] [ORB] [GSLC] [InSAR]	Sensor Calibration		
1.6.9	[ALL]	Performance Indicators		
1.6.10	[ALL]	Source Data Polarimetric Calibration Matrices		
1.6.11	[NRB] [POL] [ORB] [GSLC] [InSAR]	Mean Faraday Rotation Angle		
1.6.12	[ALL]	Ionosphere indicator		
1.7		**CEOS-ARD Product Attributes**		
1.7.1	[ALL]	Product Data Access		
1.7.2	[ALL]	Auxiliary Data		
1.7.3	[ALL]	Product Sample Spacing		
1.7.4	[NRB] [CB] [POL] [ORB] [InSAR]	Product Equivalent Number of Looks		
1.7.5	[ALL]	Product Resolution		
1.7.6	[NRB] [CB] [POL] [ORB]	Product Filtering		
1.7.7	[ALL]	Product Bounding Box		
1.7.8	[ALL]	Product Geographical Extent		
1.7.9	[ALL]	Product Image Size		
1.7.10	[ALL]	Product Pixel Coordinate Convention		
1.7.11	[ALL]	Product Coordinate Reference System		
1.7.12	[ORB]	Look Direction Polynomials		
1.7.13	[GSLC] [InSAR]	Radar Unit Look Vector		
1.7.14	[GSLC]	Slant Range Sensor to Surface		
1.7.15	[NRB] [POL] [GSLC]	Reference Orbit		

1.7.16	[InSAR]	InSAR Pair		
1.7.17	[InSAR]	InSAR Pair Co registration		
1.7.18	[InSAR]	Coherence		
1.7.19	[InSAR]	Interferogram Filtering		
1.7.20	[InSAR]	Phase Unwrapping		
1.7.21	[GSLC] [InSAR]	Atmospheric Phase Correction		
1.7.22	[GSLC] [InSAR]	Ionospheric Phase Correction		
1.7.23	[InSAR]	Displacement Modeling		
1.7.24	[CB]	CB Processing		
2	**CEOS-ARD product**	**Per-Pixel Metadata**	**Threshold**	**Goal**
2.1	[ALL]	Metadata Machine Readability		
2.2	[ALL]	Data Mask Image		
2.3	[NRB] [POL] [ORB] [GSLC] [InSAR]	Scattering Area Image		
2.4	[NRB] [POL] [ORB] [GSLC]	Local Incident Angle Image		
2.5	[NRB] [POL] [ORB] [GSLC] [InSAR]	Ellipsoidal Incident Angle Image		
2.6	[ALL]	Noise Power Image		
2.7	[NRB] [POL] [GSLC] [InSAR]	Gamma-to-Sigma Ratio Image		
2.8	[NRB] [CB] [POL] [ORB] [GSLC]	Acquisition ID Image		
2.9	[NRB] [CB] [POL] [GSLC] [InSAR]	Per-pixel DEM		
2.10	[ORB]	Per-pixel Geoid		
2.11	[ORB]	Look Direction Image		
2.12	[GSLC] [InSAR]	Radar Unit Look Vector Grid Image		
2.13	[GSLC] [InSAR]	Slant Range Sensor to Surface Image		
2.14	[GSLC] [InSAR]	InSAR Phase Uncertainty Image		
2.15	[GSLC] [InSAR]	Atmospheric Phase Correction Image		
2.16	[GSLC] [InSAR]	Ionospheric Phase Correction Image		
2.17	[InSAR]	Simulated Topographic Phase		
2.18	[InSAR]	InSAR Perpendicular Baseline		
2.19	[InSAR]	InSAR Parallel Baseline		
2.20	[InSAR]	InSAR Displacement Model Points		
2.21	[CB]	Contributing Observations Image		
2.22	[CB]	Composite Quality Map Image		
3	**CEOS-ARD product**	**Radiometrically Corrected Measurements**	**Threshold**	**Goal**
3.1	[ALL]	Backscatter Measurements		
3.2	[ALL]	Scaling Conversion		
3.3	[ALL]	Noise Removal		
3.4	[NRB] [CB] [POL] [GSLC] [InSAR]	Radiometric Terrain Correction Algorithms		

3.5	[ALL]	Radiometric Accuracy		
3.6	[ORB]	Mean Wind-Normalised Backscatter Measurements		
3.7	[NRB] [POL]	Flattened Phase		
3.8	[InSAR]	Coherence Image		
3.9	[InSAR]	Interferogram Image		
3.10	[InSAR]	Unwrapped Interferogram Image		
3.11	[InSAR]	InSAR Displacement Image		
3.12	[InSAR]	InSAR Displacement Residues Image		
3.13	[InSAR]	InSAR Displacement Rate Image		
3.14	[InSAR]	InSAR Displacement Rate Model fit Image		
4	**CEOS-ARD product**	**Geometric Corrections**	**Threshold**	**Goal**
4.1	[ALL]	Geometric Correction Algorithms		
4.2	[ALL]	Digital Elevation Model		
4.3	[ALL]	Geometric Accuracy		
4.4	[ALL]	Geometric Refined Accuracy		
4.5	[ALL]	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).

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?

Threshold (Minimum) 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 (previously referred to as "Target") are the ideal; where we would like to be. Some providers may already meet these.

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.

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

Normalised Radar Backscatter [NRB]

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

Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery, IEEE Transactions on Geoscience and Remote Sensing, vol. 49, no. 8, pp. 3081-3093. doi: 10.1109/TGRS.2011.2120616.

Composite Backscatter [CB]

Small, D., C. Rohner, N. Miranda, M. Rüetschi and M. Schaepman (2022). Wide-Area Analysis-Ready Radar Backscatter Composites, IEEE Transactions on Geoscience and Remote Sensing, vol. 60. doi: 10.1109/TGRS.2021.3055562.

Small, D. (2012). SAR Backscatter Multitemporal Compositing via Local Resolution Weighting, IEEE IGARSS 2012, Munich, Germany, pp. 4521-4524. doi: 10.1109/IGARSS.2012.6350465.

Polarimetric Radar [POL]

Cameron, W.L., N.N. Youssef, and L.K. Leung (1996). Simulated polarimetric signatures of primitive geometrical shapes, IEEE Transactions on Geoscience and Remote Sensing, vol. 34, no. 3, pp. 793–803. doi: 10.1109/36.499784.

Cloude, S.R. and E. Pottier (1996). A review of target decomposition theorems in radar polarimetry, IEEE Transactions on Geoscience and Remote Sensing, vol. 34, no. 2, pp. 498–518. doi: 10.1109/36.485127.

Freeman, A. and S.L. Durden (1998). A three-component scattering model for polarimetric SAR data, IEEE Transactions on Geoscience and Remote Sensing, vol. 36, no. 3, pp. 964–973. doi: 10.1109/36.673687.

Gens, R., D.K. Atwood and E. Pottier (2013). Geocoding of polarimetric processing results: Alternative processing strategies, Remote Sensing Letters, vol. 4, no. 1, pp. 38-44. doi: 10.1080/2150704X.2012.687470.

Krogager, E. (1993) Aspects of polarimetric radar imaging, Ph.D. dissertation, Technical University of Denmark, Electromagnetic 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 Transactions on Geoscience and Remote Sensing, vol. 47, no. 1, pp. 202-213. doi: 10.1109/TGRS.2008.2002881.

Raney, R.K., J.T.S. Cahill, G.W. Patterson and D.B.J. Bussey (2012). The m-chi decomposition of hybrid dual-polarimetric radar data with application to lunar craters. Journal of Geophysical Research: Planets 117(E5). doi: 10.1029/2011JE003986.

Toutin, T., H. Wang, P. Chomaz and E. Pottier (2013). Orthorectification of Full-Polarimetric Radarsat-2 Data Using Accurate LIDAR DSM, IEEE Transactions on Geoscience and Remote Sensing, vol. 51, no. 12, pp. 5252-5258. doi: 10.1109/TGRS.2012.2233206.

Yamaguchi, Y., A. Sato, W.M. Boerner, R. Sato and H. Yamada (2011). Four-Component Scattering Power Decomposition with Rotation of Coherency Matrix, IEEE Transactions on Geoscience and Remote Sensing, vol. 49, no. 6, pp. 2251-2258. doi: 10.1109/TGRS.2010.2099124.

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.

Zebker, H. A. (2017). User-Friendly InSAR Data Products: Fast and Simple Timeseries Processing. IEEE Geoscience and Remote Sensing Letters 14(11): 2122-2126. doi: 10.1109/LGRS.2017.2753580.

Zheng, Y. and H. A. Zebker (2017). Phase Correction of Single-Look Complex Radar Images for User-Friendly Efficient Interferogram Formation. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 10(6): 2694-2701, doi: 10.1109/JSTARS.2017.2697861.

Interferometric Synthetic Aperture Radar [InSAR]

Lanari, R., O. Mora, M. Manunta, J. J. Mallorqui, P. Berardino and E. Sansosti (2004). A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms, IEEE Transactions on Geoscience and Remote Sensing, vol. 42, no. 7, pp. 1377-1386, July 2004, doi: 10.1109/TGRS.2004.828196.

Ferretti, A., A. Fumagalli, F. Novali, C. Prati, F. Rocca and A. Rucci (2011). A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR, IEEE Transactions on Geoscience and Remote Sensing, vol. 49, no. 9, pp. 3460-3470, Sept. 2011, doi: 10.1109/TGRS.2011.2124465.

Annex 1

A1.1: General Processing Roadmap

The radiometric interoperability of CEOS-ARD SAR products is ensured by a common processing chain during production. The recommended processing roadmap involves the following steps:

- Apply the best possible orbit parameters to give the most accurate product possible. These will have been projected to an ellipsoidal model such as WGS84. To achieve the level of geometric accuracy required for the DEM-based correction, precise orbit determination will be required.

- Apply instrument calibration to produce Beta-Nought values with high fidelity.

- Convert Single-Look-Complex (SLC) radiometric channel(s) to intensity **[NRB]**, **[ORB]** and **[POL]** and in addition for **[POL]**, the cross-product element(s) of the covariance as shown in Annex 2.1.

- Perform radiometric terrain correction (gamma backscatter convention terrain-flattening) on the covariance matrix by applying the local surface normalisation factor to each backscatter measurement element (Small, 2011; Shiroma *et al.*, 2022).

- Perform polarimetric speckle filtering (optional for **[NRB]** and **[ORB]**), before geocoding, to optimally preserve the polarimetric information. Most popular polarimetric decomposition methodologies are incoherent in nature, which requires averaging the covariance matrix for stationarity. Depending on the application, a polarimetric filter that preserves local point targets and locally average extended targets may be used, e.g., Sigma Lee filter with 7x7 window and 3-point target (Lee *et al*., 2009). Multi-looking could be performed to meet optimal output sample spacing before the geometric correction step. No speckle filtering or multi-looking is performed for **[GSLC]** products.

- For **[GSLC]** products, the topographic phase is estimated relative to a reference orbit and removed from the SLC data (Zebker *et al.*, 2010; Zebker, 2017) (see Annex A1.2)

- Geometric terrain correction (relative to geoid for **[ORB]**) is applied to the normalized backscatter measurement data. For **[POL]**, the resampling methodology should be nearest-neighbour, bilinear or average in order to preserve integrity of the covariance matrix as other resampling functions can introduce artefacts due to the mix of intensity and complex number elements in the matrix. Geocoding to a common grid structure with specified pixel spacings for true data cube format.

- Generate CEOS format metadata to accompany product layers.

- Optionally, a SpatioTemporal Asset Catalog (STAC) file is added to the product.

Table A1.1 lists possible sequential steps and existing software tools (e.g., Gamma software (GAMMA, 2018)) and scripting tasks that can be used to form the CEOS-ARD SAR processing roadmap.

Table A1.1 SAR ARD processing roadmap and software options. RADARSAT-2 Example

Step	**Implementation option**
1. Orbital data refinement	Check xml date and delivered format. RADARSAT-2, pre EDOT (July 2015) replace. Post July 2015, check if 'DEF', otherwise replace. (Gamma - RSAT2_vec)
2. Apply radiometric scaling Look-Up Table (LUT) to Beta-Nought	Specification of LUT on ingest. (Gamma - par_RSAT2_SLC/SG)
3. Generate covariance matrix elements	Gamma – COV_MATRIX
4. Radiometric terrain normalisation	Gamma - geo_radcal2
5. Speckle filtering (Boxcar or Sigma Lee)	Custom scripting
6. Geometric terrain correction/Geocoding	Gamma – gc_map and geocode_back
7. Create metadata	Custom scripting

A1.2: Topographic phase removal

InSAR analysis capabilities from CEOS-ARD SAR products are enabled with **[GSLC]** products, which is also the case when the Flattened Phase per-pixel data (item 3.7) are included in the **[NRB]** or **[POL]** products. This is made possible since the simulated topographic phase relative to a given reference orbit has been subtracted.

From classical approach with SLC data, interferometric phase $\Delta\varphi_{1-2}$ between two SAR acquisitions is composed of a topographic phase $\Delta\varphi_{Topo\_1-2}$, a surface displacement phase $\Delta\varphi_{Disp\_1-2}$ and other noise terms $\Delta\varphi_{Noise\_1-2}$ (Eq. A1.1). The topographic phase consists to the difference in geometrical path length from each of the two antenna positions to the point on the SAR image (φ_{DEM_SLC}) and is a function of their orbital baseline distance (Eq. A1.2). The surface displacement phase is related to the displacement of the surface that occurred in between the two acquisitions. The noise term is the function of the radar signal interaction with the atmosphere and the ionosphere during each acquisition and function of the system noise.

$$\Delta\varphi_{1-2} = \Delta\varphi_{Topo\_1-2} + \Delta\varphi_{Disp\_1-2} + \Delta\varphi_{Noise\_1-2} \quad \textbf{Eq. A1.1}$$

Where

$$\Delta\varphi_{Topo\_1-2} = \varphi_{DEM\_SLC\_1} - \varphi_{DEM\_SLC\_2} \quad \textbf{Eq. A1.2}$$

Since CEOS-ARD products are already geocoded, it is important to remove the wrapped simulated topographic phase φ_{SimDEM_SLC} from the data in slant range (Eq. A1.3) during their production, before the geocoding step. The key here is to simulate the topographic phase relatively to a constant reference orbit, as done in a regular InSAR processing. There are two different ways to simulate the topographic phase:

1- The use of a virtual circular orbit above a nonrotating planet (Zebker *et al.*, 2010)
2- The use of a specific orbit cycle or a simulated orbit of the SAR mission

In both cases, the InSAR topographic phase $\Delta\varphi_{Topo\_OrbRef-2}$ is simulated against the position of a virtual sensor φ_{DEM_OrbRef} lying on a reference orbit, instead of being simulated relatively to an existing reference SAR acquisition ($\varphi_{DEM\_SLC\_1}$). The use of a virtual circular orbit is a more robust approach since the reference orbit is defined at a fixed height above scene nadir and assuming the reference orbital height constant for all CEOS-ARD products. While with the second approach, the CEOS-ARD data producer must select a specific archived orbit cycle of the SAR mission or define a simulated one, from which the relative orbit, matching the one of the SAR acquisitions to be processed (to be converted to CEOS-ARD), is defined as the reference orbit. With this second approach, it is important to always use the same orbit cycle (or simulated orbit) for all the CEOS-ARD produced for a mission, in order to preserve the relevant compensated phase in between them. Providing absolute reference orbit number information in the metadata (item 1.7.15) allows users to validate the InSAR feasibility in between CEOS-ARD products.

$$\varphi_{Flattened\_SLC\_2} = \varphi_{SLC\_2} - \Delta\varphi_{Topo\_OrbRef-2} \quad \textbf{Eq. A1.3}$$

This procedure is equivalent to bring the position of the sensor platform of all the SAR acquisitions at the same orbital position (i.e., zeros baseline distance in between), which results in a Flattened phase $\varphi_{Flattened\_SLC}$, independent of the local topography.

The phase subtraction could be performed by using a motion compensation approach (Zebker *et al*., 2010) or directly on the SLC data. Then the geometrical correction is performed on the Flattened SLC, which results in a **[GSLC]** product.

[GSLC] can also be saved as a **[NRB]** product by including the Flattened Phase per-pixel data (item 3.7) as follows:

$$NRB: \quad \gamma_T^o = |GSLC|^2$$

$$Flattened\ Phase: \ \varphi_{Flattened} = arg\ (GSLC)$$

For the **[POL]** product, the Flattened Phase (item 3.7) is defined for a specific polarisation. Since off-diagonal elements of the covariance matrix contain the relative phase between two polarizations, other polarization(s) Flattened Phase can be estimated by subtracting the complex number phase of the off-diagonal elements from reference polarization Flattened phase. As for example, if the reference Flattened Phase is for HH polarization (φHH), then the Flattened Phase for VV polarization is φVV = φHH - arg(HHVV*). Nonetheless, since the elements of the covariance matrix have been averaged, providing individual polarization Flattened Phase images under 3.7 is more accurate.

InSAR from [GSLC] Demonstration:

From CEOS-ARD flattened SAR products, InSAR processing can be easily performed without dealing with topographic features and orbital sensor position, as for example with two **[GSLC]** products

$$\begin{aligned}\varphi_{Flattened\_GSLC\_1} &= \varphi_{SLC\_1} - \Delta\varphi_{Topo\_OrbRef-1} = \varphi_{SLC\_1} - \varphi_{DEM\_OrbRef} - \varphi_{DEM\_SLC\_1} \\ \varphi_{Flattened\_GSLC\_2} &= \varphi_{SLC\_2} - \Delta\varphi_{Topo\_OrbRef-2} = \varphi_{SLC\_2} - \varphi_{DEM\_OrbRef} - \varphi_{DEM\_SLC\_2}\end{aligned} \qquad \textbf{Eq. A1.4}$$

The differential phase is

$$\Delta\varphi_{CARD\_1-CARD\_2} = \varphi_{Flattened\_GSLC\_1} - \varphi_{Flattened\_GSLC\_2} \qquad \textbf{Eq. A1.5}$$

Which can be expanded using (Eq. A1.3)

$$\begin{aligned}\Delta\varphi_{CARD\_1-CARD\_2} \\ &= (\varphi_{SLC\_1} - \varphi_{DEM\_OrbRef} - \varphi_{DEM\_SLC\_1}) \\ &- (\varphi_{SLC\_2} - \varphi_{DEM\_OrbRef} - \varphi_{DEM\_SLC\_2})\end{aligned} \qquad \textbf{Eq. A1.6}$$

$$\Delta\varphi_{CARD\_1-CARD\_2} = (\varphi_{SLC\_1} - \varphi_{SLC\_2}) - (\varphi_{DEM\_SLC\_1} - \varphi_{DEM\_SLC\_2}) \qquad \textbf{Eq. A1.7}$$

$$\Delta\varphi_{CARD\_1-CARD\_2} = \Delta\varphi_{SLC\_1-SLC\_2} - \Delta\varphi_{Topo\_1-2} \qquad \textbf{Eq. A1.8}$$

Where $\Delta\varphi_{SLC\_1-SLC\_2}$ can be expressed as Eq. A1.1, which gives

$$\Delta\varphi_{CARD\_1-CARD\_2} = (\Delta\varphi_{Topo\_1-2} + \Delta\varphi_{Disp\_1-2} + \Delta\varphi_{Noise\_1-2}) - \Delta\varphi_{Topo\_1-2} \qquad \textbf{Eq. A1.9}$$

Consequently, the differential phase of two CEOS-_ARD products doesn't contain a topographic phase and is already unwrapped (at least over stable areas). It is only function of the surface displacement and of the noise term. Depending on the reference DEM and the satellite orbital state vector accuracies, some residual topographic phase could be present. Atmospheric (item 2.15) and ionospheric (item 2.16) phase corrections could be performed during the production of CEOS-ARD products, which reduces the differential phase noise in an InSAR analysis.

$$\Delta\varphi_{CARD\_1-CARD\_2} = \Delta\varphi_{Disp\_1-2} + \Delta\varphi_{Noise\_1-2} \qquad \textbf{Eq. A1.10}$$

Annex 2: Polarimetric Radar [POL]

A2.1: Normalised Covariance Matrices (CovMat)

In order to preserve the inter-channel polarimetric phase and thus the full information content of coherent dual-pol and fully polarimetric data, the covariance matrix is proposed as the data storage format. Covariance matrices are generated from the complex cross product of polarimetric channels, as shown in Eq. A2.1 for fully polarimetric data (C3) and in Eq. A2.2 for dual polarization data (C2). Since these matrices are complex symmetrical, only the upper diagonal elements (bold elements) need to be stored in the ARD database.

Fully polarimetric

$$C3 = \begin{bmatrix} |\boldsymbol{HH}|^2 & \sqrt{\boldsymbol{2}} \cdot \boldsymbol{HH} \cdot \boldsymbol{HV}^* & \boldsymbol{HH} \cdot \boldsymbol{VV}^* \\ \sqrt{2} \cdot HV \cdot HH^* & \boldsymbol{2} \cdot |\boldsymbol{HV}|^2 & \sqrt{\boldsymbol{2}} \cdot \boldsymbol{HV} \cdot \boldsymbol{VV}^* \\ VV \cdot HH^* & \sqrt{2} \cdot VV \cdot HV^* & |\boldsymbol{VV}|^2 \end{bmatrix} \qquad \textbf{Eq. A2.1}$$

Where HV = VH, under the reciprocity assumption. | | and * mean respectively complex modulus and the complex conjugate.

Dual polarization

HH-HV

$$C2 = \begin{bmatrix} |\boldsymbol{HH}|^2 & \boldsymbol{HH} \cdot \boldsymbol{HV}^* \\ HV \cdot HH^* & |\boldsymbol{HV}|^2 \end{bmatrix} \quad or$$

VV-VH

$$C2 = \begin{bmatrix} |\boldsymbol{VH}|^2 & \boldsymbol{VH} \cdot \boldsymbol{VH}^* \\ VH \cdot VH^* & |\boldsymbol{VV}|^2 \end{bmatrix} \quad or \qquad \textbf{Eq. A2.2}$$

CH-CV

$$C2 = \begin{bmatrix} |\boldsymbol{CH}|^2 & \boldsymbol{CH} \cdot \boldsymbol{CV}^* \\ CV \cdot CH^* & |\boldsymbol{CV}|^2 \end{bmatrix}$$

Where CH and CV refer to dual polarization transmitting a circular polarized signal. [CH, CV] can be replaced by [LH, LV] or [RH, RV] for left (L) or right (R) hand circular transmission respectively, although RCM will offer only right-hand circular transmission. The coherent HH-VV configuration available on TerraSAR-X could also be represented as C2 format.

Polarimetric decomposition methods like Yamaguchi *et al.* (2011) for fully polarimetric, or m-chi (Raney *et al.*, 2012) for compact polarimetric data, can be applied directly on averaged (speckle filtered) C3 and C2 matrices respectively. These decompositions enhance scattering information, bring it to a more comprehensible level to end-users, and raise the performance of thematic classification methodologies. For SAR products that were acquired with single polarization the use of the covariance matrix does not result in superfluous storage requirements, since only the matrix elements that are populated are retained and the diagonal matrix elements are the backscatter intensities. Thus, a single channel intensity product would yield only one matrix element and the storage needs would not change.

In order to ease the data structure and the metadata in between C3 and C2, Eq. A2.1 should be redefined as Eq. A2.3. Users will have to take care of this non-standard representation when applying their polarimetric analytic tools. “< >” means that ARD matrix elements are speckle filtered. Eq. A2.3 is valid both for dual-linear and fully polarimetric dataquad polarization.

$$C3\ modified\ \ C3m = \begin{bmatrix} \langle|\boldsymbol{HH}|^2\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{HV}^*\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{VV}^*\rangle \\ \langle HV\cdot HH^*\rangle & \langle|\boldsymbol{HV}|^2\rangle & \langle\boldsymbol{HV}\cdot\boldsymbol{VV}^*\rangle \\ \langle VV\cdot HH^*\rangle & \langle VV\cdot HV^*\rangle & \langle|\boldsymbol{VV}|^2\rangle \end{bmatrix}$$ **Eq. A2.3**

Furthermore, for compact polarimetric data, it is recommended to store them, by simple transformation, under the circular-circular basis, since RR and RL polarizations (Eq. A2.4) permit faster and more intuitive RGB visualizations (R=RR, G=RR/(RR+RL), B= RL).

CH-CV **C2 circular** $$C2c = \begin{bmatrix} \langle|\boldsymbol{RR}|^2\rangle & \langle\boldsymbol{RR}\cdot\boldsymbol{RL}^*\rangle \\ \langle RL\cdot RR^*\rangle & \langle|\boldsymbol{RL}|^2\rangle \end{bmatrix}$$ **Eq. A2.4**

A2.2: Polarimetric Radar Decomposition (PRD)

Different methodologies allow decomposition of coherent dual-polarization data or fully polarimetric data to meaningful components summarizing the scattering processing with the interacting media. Decomposition techniques are divided in two categories: Coherent and incoherent.

1. **Coherent decompositions** express the scattering matrix by the summation of elementary objects of known signature (ex.: a sphere, a diplane, a cylinder, a helix, …). They are used mainly to describe point targets which are coherent. As for examples, coherent PRD could be (but not limited to):

    a. Pauli decomposition (3 layers)

    $|\alpha|^2$: sphere (odd-bounce interaction) [Intensity]

    $|\beta|^2$: 0^o diplane (even-bounce interaction) [Intensity]

    $|\gamma|^2$: 45^o diplane (volumetric interaction) [Intensity]

    b. Krogager decomposition (5 layers) (Krogager, 1993)

    $|\kappa_\sigma|^2$: sphere (odd-bounce interaction) [Intensity]

    $|\kappa_\delta|^2$: diplane (odd-bounce interaction) [Intensity]

    $|\kappa_\eta|^2$: helix [Intensity]

    θ: orientation angle [degrees]

    ϕ_s: sphere to diplane angle [degrees]

    c. Cameron (nine classes) – non-dimensional layers (Cameron *et al.*, 1996)

Table A2.1

Classes	ID
Trihedral	1
Dihedral	2
Narrow Dihedral	3
Dipole	4
Cylinder	5
¼ wave	6
Right Helix	7
Left Helix	8
Asymmetrical	9

2. **Incoherent decompositions** describe distributed targets in terms of scattering mechanisms and their diversity. They are generated from averaged Covariance, Coherence or Kennaugh matrices. As for examples, incoherent PRD could be (but not limited to):

    a. Based and saved on intensity of scattering mechanisms can be (Freeman and Durden, 1998; Yamaguchi *et al.*, 2011; Raney *et al.*, 2012)

Table A2.2

Level 2b - Layers [Intensity]	Incoherent Decompositions		
	Freeman-Durden	Yamaguchi	m-chi
Odd-bounce (surface/trihedral)	X	X	X
Even-bounce (dihedral)	X	X	X
Random (volumetric)	X	X	X
Helix		X	

b. Based on eigenvector-eigenvalue decomposition expressing the diversity of scattering mechanisms (Cloude and Pottier, 1996) and types:

H : Entropy [ ] is the polarization diversity

A : Anisotropy [ ] is weighted difference between the 2nd and 3rd eigenvalues

α : Odd-even bounce angle [Degrees]

β : orientation angle [Degrees]

A2.3: Polarimetric Radar Decomposition Product Examples

From fully polarimetric covariance matrix ARD format **[CovMat]** (Level-2a), it is possible to apply any version of the popular Yamaguchi methodology, which decomposes the polarimetric information under relative intensities of 4 scattering types: Odd bounce, Even bounce, Random (volume) and helix. Figure A2.1b) shows HH intensity of a RADARSAT fully polarimetric acquired over a Spanish area. Decomposition using Yamaguchi methodology (Yamaguchi *et al*., 2011) can be expressed in RGB colour composite (Figure A2.1c) where Red channel refers to even bounce scattering like urban area; Green channel is random scattering like vegetation; and Blue channel is odd bounce scattering like bare soil. Figure A2.1d) is equivalent to c) where radiometric normalisation (terrain flattening) has been applied with the help of the DEM of the scene (Figure A2.1a).

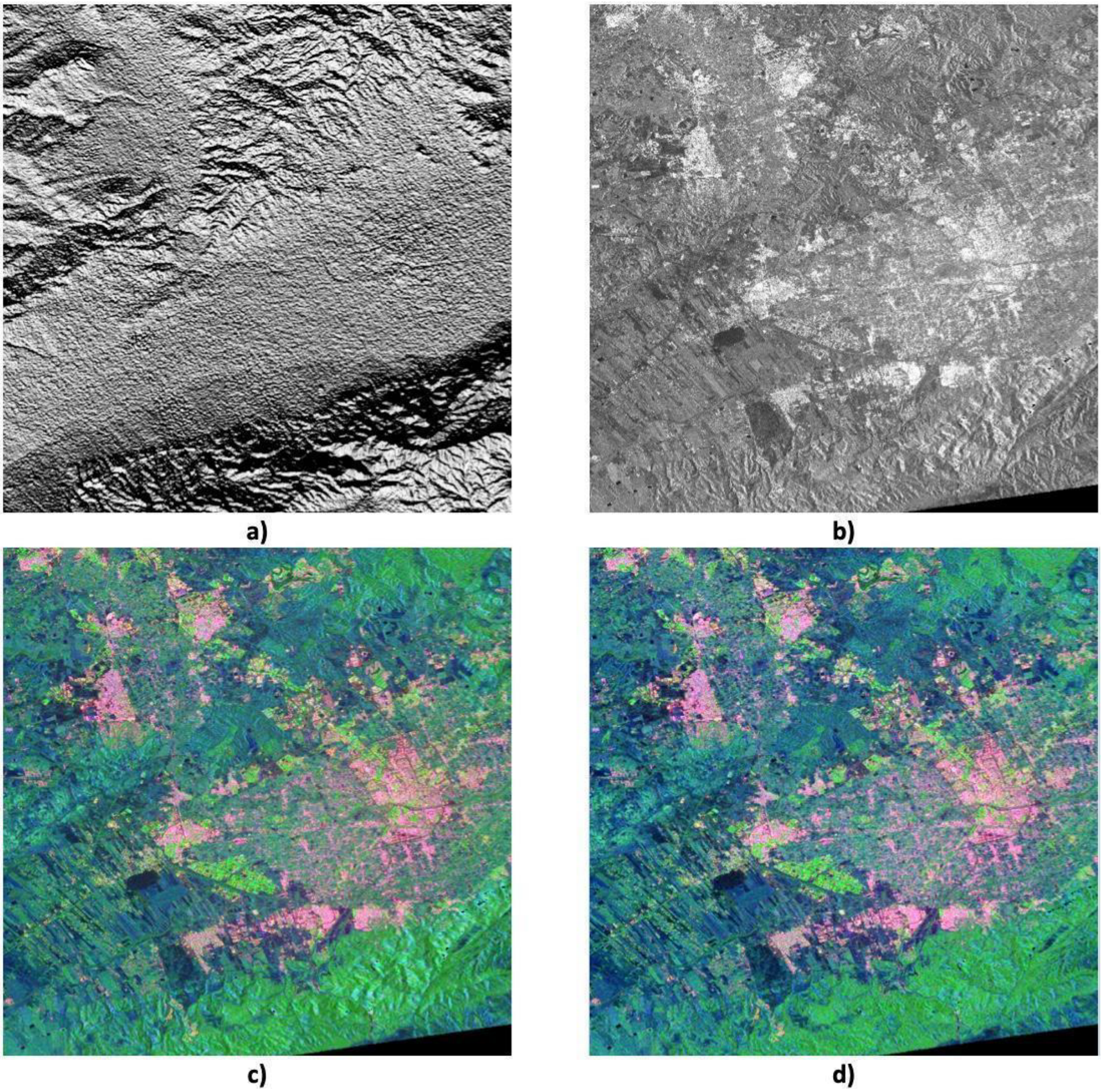
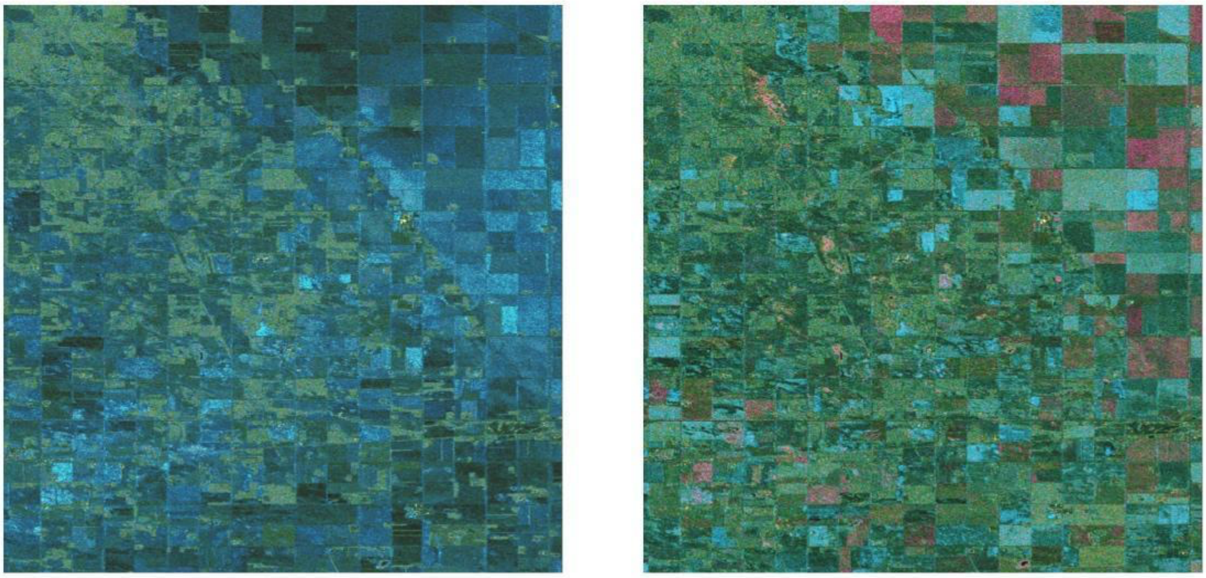


Figure A2.1 *Example of polarimetric decomposition generated from ARD covariance format.* ***a)*** *Shaded DEM of the area;* ***b)*** *RADARSAT-2 HH intensity;* ***c)*** *Yamaguchi decomposition colour composite (Red: even bounce, Green: random, Blue: odd bounce);* ***d)*** *Same as c) with terrain flattening option. Generated from Radarsat-2 FQ18W acquired over Murcia, Spain on 18 June 2014 ©MDA 2014*

Figure A2.2 is a **[PRD]** compact polarimetric m-chi decomposition (Raney *et al.*, 2012) simulated from two Canadian prairies Radarsat-2 fully polarimetric scenes acquired in May and June 2012. In May, before the growing season (Figure A2.2a), m-chi shows mainly surface scattering from bare soil (blue channel) and vegetation interaction from forested areas (green channel), while in June (Figure A2.2b) growth of vegetation modifies the radar signal with interacting media function of the vegetation density and geometry which increase the amount of even bounce (red channel) and random scattering.



a) b)

Figure A2.2. *m-chi decomposition colour composite of simulated compact polarimetry from Radarsat-2 over an agriculture area. RGB representation: Red: even bounce, Green: random, Blue: odd bounce.* ***a)*** *3 May 2012; and* ***b)*** *18 June 2012. Generated from Radarsat-2 FQ6W acquired over SMAPVEX12 campaign Manitoba, Canada on 3 May and 20 June 2012 ©MDA 2012*

Annex 3: Ocean Radar Backscatter [ORB] example

In contrast to **[NRB]** and **[POL]**, CEOS-ARD Ocean Radar Backscatter **[ORB]** products are geoid corrected and are provided in the Sigma-Nought (σ_E^0) backscatter convention (Figure A3.1a), which is recommended for most ocean applications. In addition, availability of the "Local (or Ellipsoidal) Incidence Angle Image" (Figure A3.1d) and "Look Direction Image" per-pixel metadata are highly recommended (otherwise the general metadata "1.7.12 Look Direction Polynomials") since they required for operational applications like ocean wind field estimates.

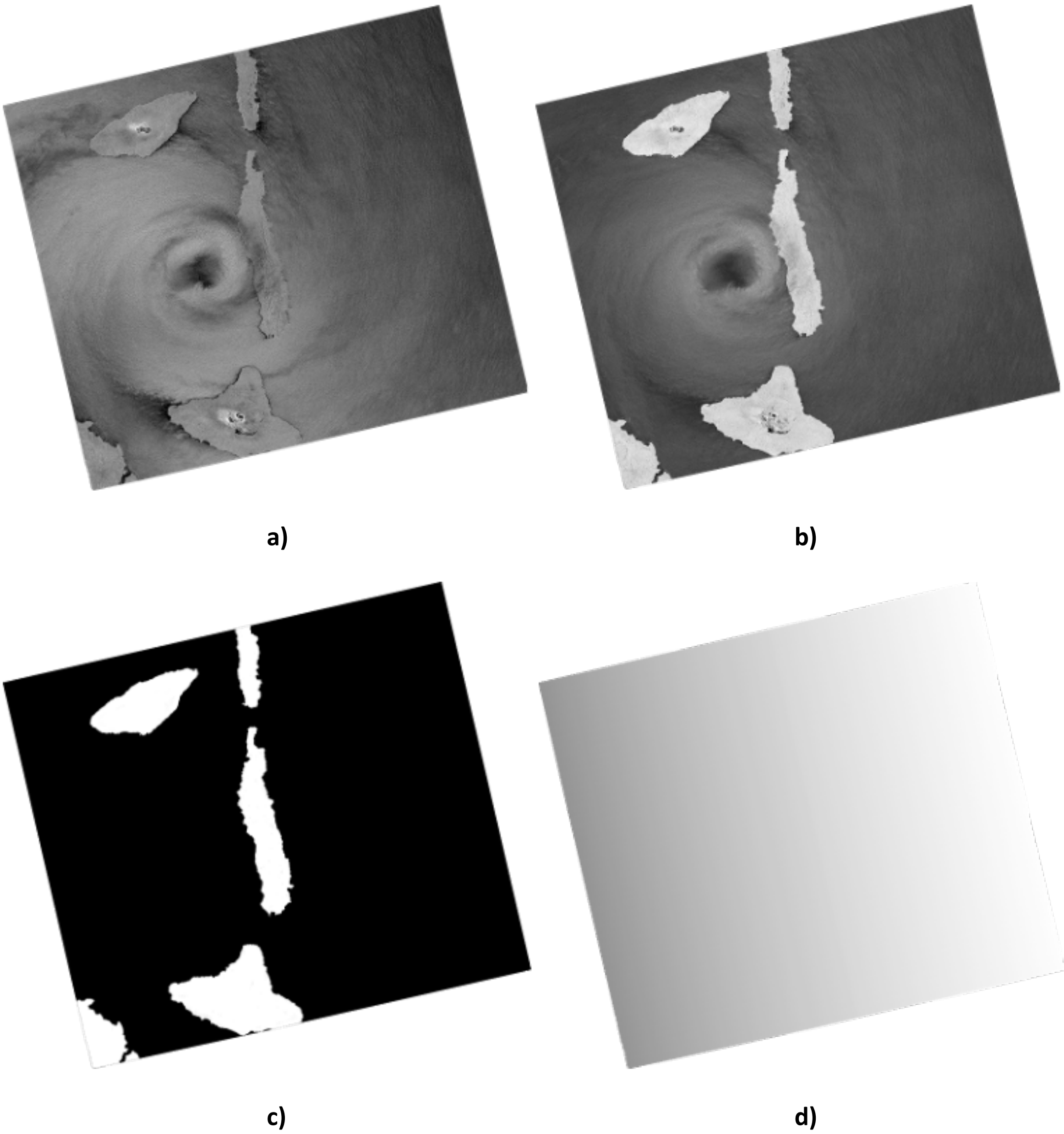
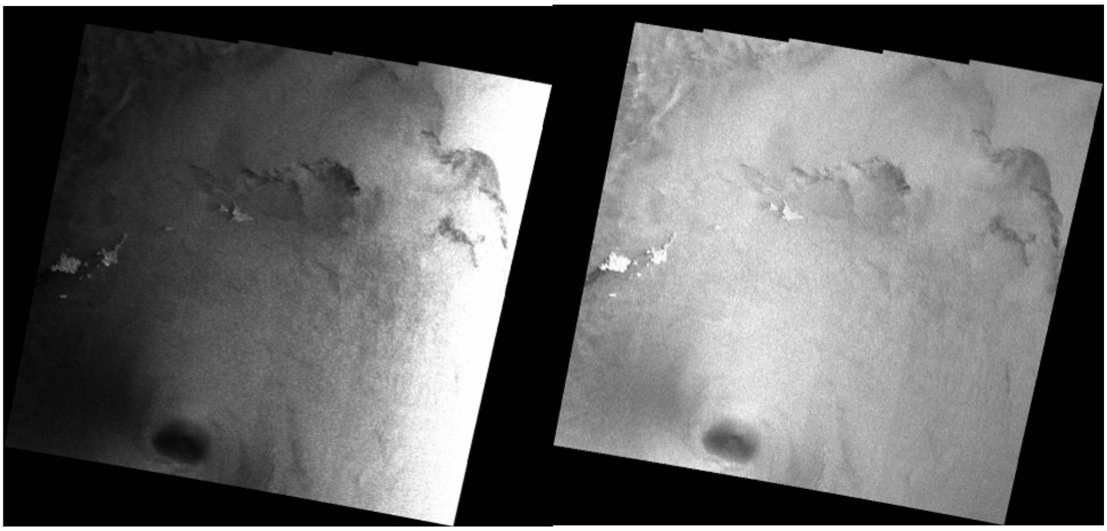


Figure A3.1. *Sentinel-1 [ORB] product. Tropical Cyclone Harold passing Vanuatu on April 6, 2020.* ***a)*** *VV intensity* ***b)*** *VH intensity* ***c)*** *Data mask image* ***d)*** *Local incident angle. Processing: A. Rosenqvist (soloEO).*

Another useful file is the "Mean Wind-Normalised Backscatter Measurements" (Figure A3.2b) which efficiently attenuates intensity variation along range and visually enhances oceanic features. This file is calculated as the ratio between the backscatter intensity and a simulated backscatter intensity image generated using an ocean surface wind model, like CMOD_IRF2 (Quilfen *et al.*, 1998) for VV polarization or CMOD_IRF2K (Vachon and Dobson, 2000) for HH polarization, and the SAR local incidence angle and the look direction information.



a) **b)**

Figure A3.2. *Sentinel-1 EW [ORB] product.* ***a)*** *ORB intensity (Sigma-Nought);* ***b)*** *Intensity compensated with the "Mean Wind-Normalised Backscatter Measurement" (i.e., not Sigma-Nought) and geocoded. Processing: G. Hajduch (CLS).*

Annex 4: Geocoded Single-Look Complex [GSLC] example

In contrast to basic **[NRB]** and **[POL] products**, CEOS-ARD Geocoded SLC **[GSLC]** products are kept close to the native resolution in complex data format for which local topographic InSAR phases, relative to a reference orbit (Zebker *et al.*, 2010; Zebker 2017), have been removed. Having a volume of **[GSLC]** products acquired over repeat cycles, already radiometric and phase terrain corrected and geocoded (Figure A4.1a) and Figure A4.1b), allows user-friendly production of a first iteration of the InSAR coherence (Eq. A4.1 and Figure A4.1c) and differential phases (Eq. A4.2 and Figure A4.1d) in between **[GSLC]** pairs, simply by applying local averaging window over the product of a **[GSLC]** product (GSLC1) with the complex conjugate of a second **[GSLC]** (GSLC2) divided by their local averaged intensities. These intermediate files could be used for coherent change detection analysis and surface displacement monitoring.

Complex coherence:

$$\rho = \frac{\sum[GSLC_1 * conj(GSLC_2)]}{\sqrt{\sum|GSLC_1|^2 * \sum|GSLC_2|^2}}$$

Eq. A4.1

The InSAR differential phase (Eq. A4.2) is the argument of the complex coherence estimated with Eq. A4.1.

InSAR differential phase:

$$\varphi = \arg(\rho)$$

Eq. A4.2

Some advanced [NRB] or [POL] products could include per-pixel “Flattened Phase” data (item 3.7). This “Flattened Phase” enables the possibility to perform InSAR analysis as with two [GSLC] products. As for example, from two different [NRB] products (NRB1) and (NRB2), acquired over repeat cycles (i.e., on the same relative orbit), containing γ_T^0 and their corresponding “Flattened Phase” (FPh1) and (FPh2) per-pixel data, the complex InSAR coherence (Eq. A4.3) can be estimated in the similar manner as Eq. A4.1 for [GSLC] products.

Complex coherence:

$$\rho_{NRB} = \frac{\sum[(\sqrt{NRB_1} \cdot e^{i \cdot FPh1}) \cdot conj(\sqrt{NRB_2} \cdot e^{i \cdot FPh2})]}{\sqrt{\sum NRB_1 * \sum NRB_2}}$$

Eq. A4.3

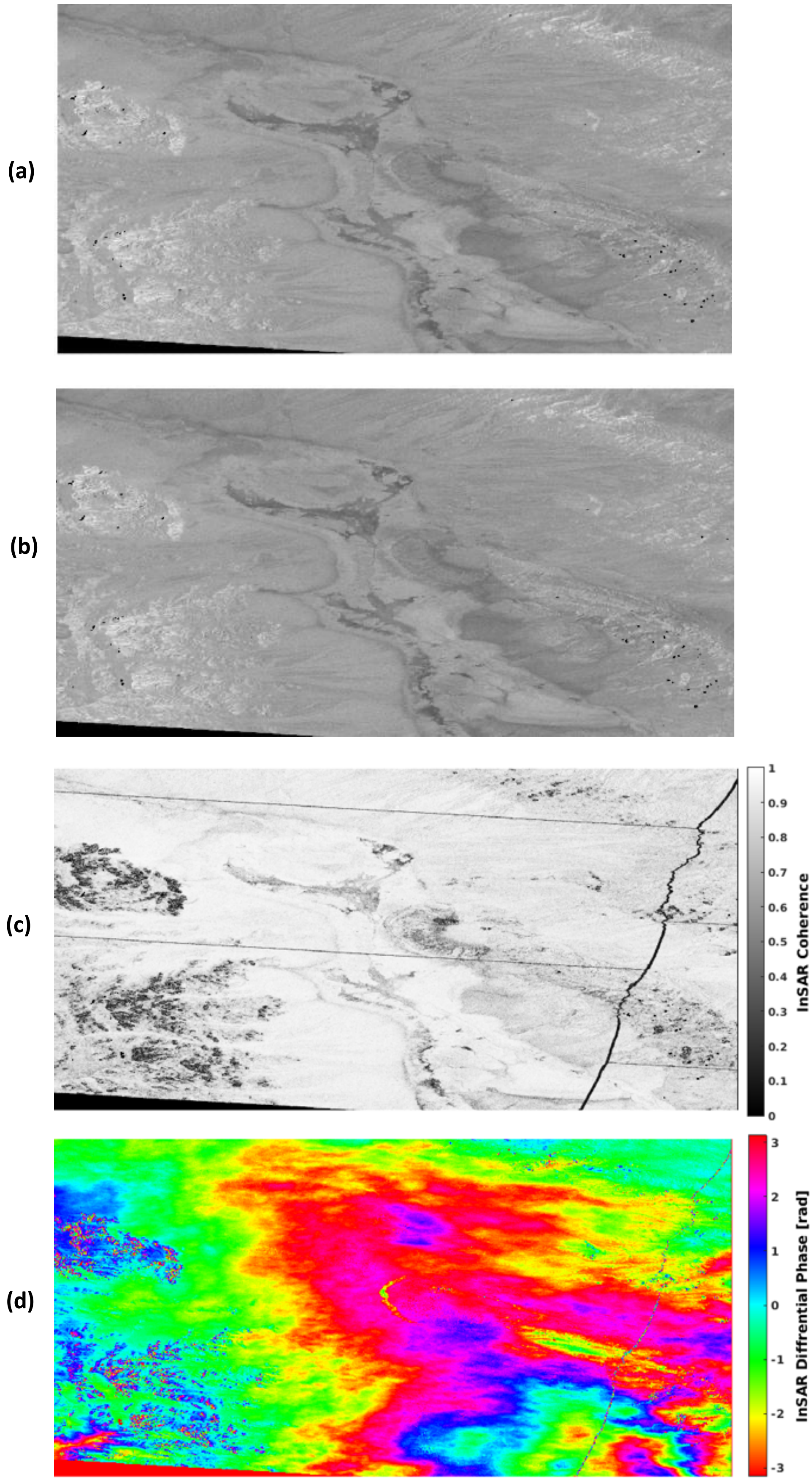


Figure A4.1. *Sentinel-1 [GSLC] products example over Death Valley National Park, California, USA.* ***a)*** *GSLC1: Intensity data of the first [GSLC] product (2017-05-27);* ***b)*** *GSLC2: Intensity data of the second [GSLC] product (2017-06-08);* ***c)*** *InSAR coherence map generated directly from A4.1a) and b);* ***d)*** *InSAR differential phase map generated directly from A4.1a) and b).*

Some advanced [GSLC] product can be provided with “2.12 Radar Unit Look Vector Grid Image” per-pixel metadata (Figure A4.2) which gives the accurate 3-D components radar unit look vector used as for example in decomposing the vertical and horizontal component of an InSAR surface displacement estimate.

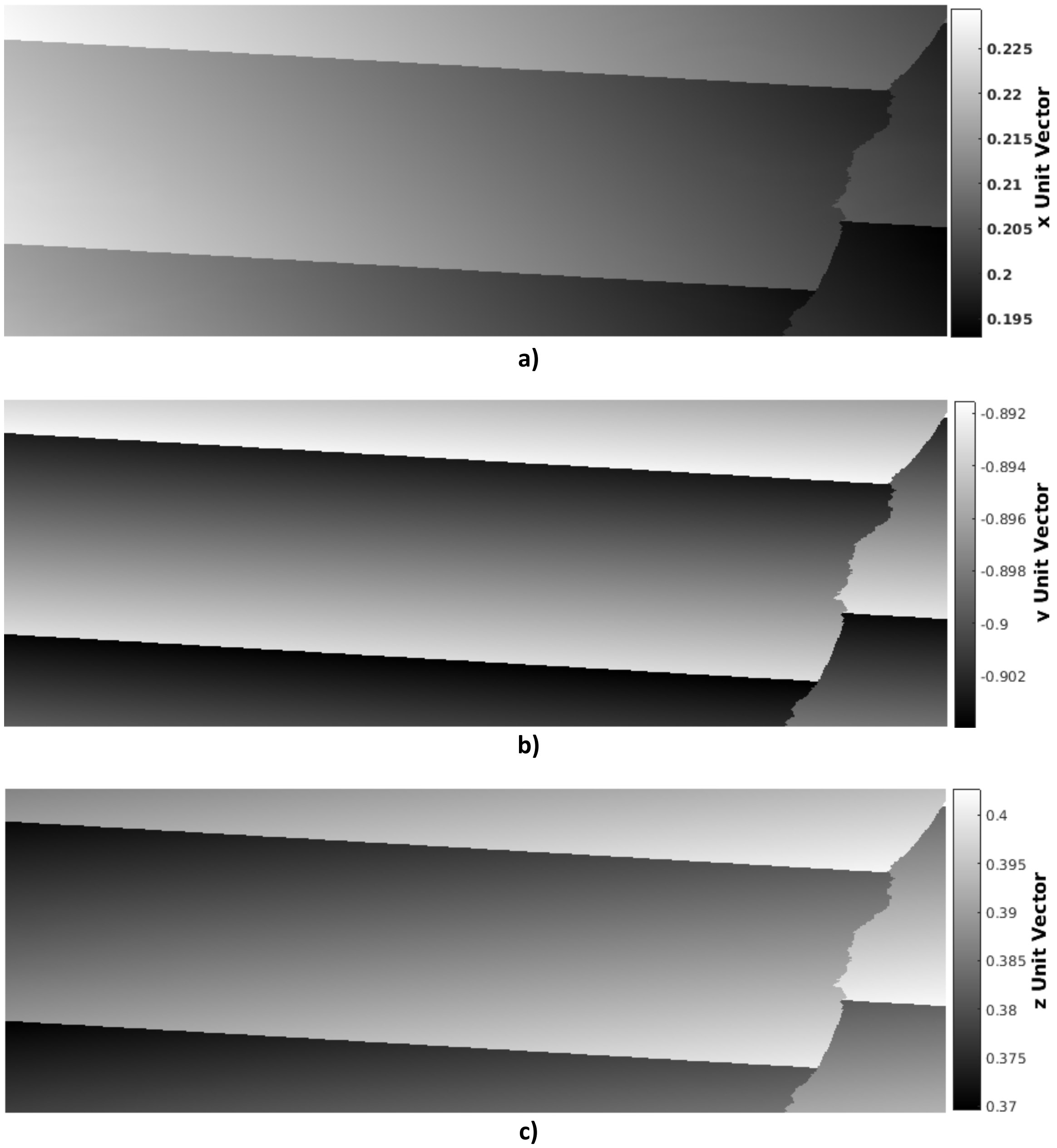


Figure A4.2. *3-D components radar unit look vector of the [GSLC] product in Figure A4.1.* ***a)*** *x unit component;* ***b)*** *y unit component;* ***c)*** *z unit component*.

Annex 5: Composite Backscatter [CB] example

The algorithm for generating a CB product using local resolution weighting is described below.

A temporal window is defined encapsulating all SAR products to be used to generate the CB product. For each pixel *i* in the region to be covered by the CB, all input products are assembled, particularly both the RTC terrain-flattened gamma γ_i^0 (item 3.1) and the local contributing area A_i (item 2.3). That area is the one locally used for terrain flattening during the generation of the RTC product, i.e. the sum of the area expressed in the plane perpendicular to slant range (gamma nought convention) of all terrain facets within the bounds of that pixel [Small et al., IEEE-TGRS, 2022]. The terrain-flattened gamma nought RTC backscatter may or may not have had noise removal applied before proceeding to the composite generation stage. No noise removal step is currently foreseen during the composite generation itself. Given N potential contributing input products, a subset of M is chosen whereby only products with pixel *i* not in shadow are included. Then one proceeds to calculating the composite backscatter for pixel *i*.

First, the sum of the reciprocals S_r of all local contributing areas is calculated:

$$S_r = \sum_{i=1}^{M} \frac{1}{A_i}$$ **Eq. A5.1**

Next, the individual weight W_i for each of the M contributing input images is calculated:

$$W_i = \frac{1}{A_i \cdot S_r}$$ **Eq. A5.2**

Now that the weight of each input image 1…M is ready, calculating the composite backscatter value is a simple matter of applying the weights to the terrain-flattened backscatter values in each input RTC image:

$$\gamma_c = \sum_{i=1}^{M} W_i \cdot \gamma_i^0$$ **Eq. A5.3**

Input images that imaged a mountain slope as a "backslope" (say an ascending image) will have local contributing area values that are relatively small in comparison to descending images covering the same region, as they will locally have been subject to foreshortening or possibly even layover. Low areas in the ascending images will correspond to relatively high weights (higher local resolution), while high areas (e.g. foreshortened) will generally result in relatively low weights. In this way, foreshortening and even layover are not "masked out" in a boolean sense, but their effects are reduced as far with the "fuzzy" weighting pattern. Applying an on or off mask would be an overreaction in some cases to foreshortening/layover, which can each exhibit a large variety of effects on the local backscatter.

One can cycle the set of pixels included e.g. in a standard tile definition to produce a tile-wide composite backscatter image. Multiple tiles can then be concatenated to cover ever larger regions.

One can then generate composites representative of different seasons (e.g. all acquisitions from the first half of January, April, and June). One cycle through multiple CB images to see a "movie" of backscatter over the defined region, or alternatively overlay three CB products as a multi-temporal RGB visualisation. An example of this latter possibility is shown in Fig. A5.1, where the full extent of the European Alps are shown with the red channel from late Feb'25, green from early Apr'25, and blue from early May'25.

Multitemporal backscatter analysis can then be directly applied over large regions (e.g. tracking wet snow at low vs. high elevations through springtime), where that would not be possible for most users given only L1 SLC or L1 GRD products. Such CB products are even more "analysis-ready" than is the set of NRB (RTC) products used to generate them, as no direct analysis over wide regions would be possible on such a heterogeneous dataset. Although not all analytical frameworks will benefit from using CB products, they will be useful for a large subset of backscatter time-series applications, and hopefully ease the initial learning curve for new users of backscatter data.

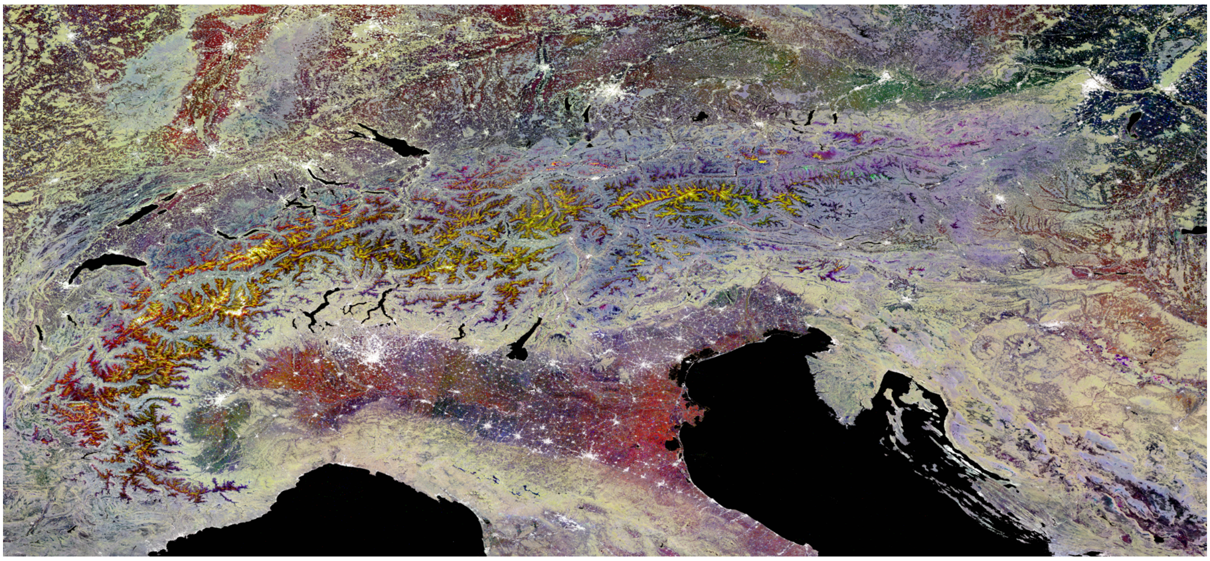


Figure A5.1. *Multitemporal RGB Composite Backscatter image of the European Alps calculated via Local Resolution Weighting (red: late Feb 2025, green: early April 2025, blue: early May 2025), geographic coordinates*.