# CEOS-ARD - Synthetic Aperture Radar - Polarimetric Radar

## Draft Version

This is a draft version. Please visit the [CEOS-ARD website] for the latest endorsed version of this document.

## Document Status

Product Family Specification, Synthetic Aperture Radar, Polarimetric Radar

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

## Document History

### 2026-07-20 (MINOR)

- The Combined SAR PFS has been split into separate PFS per product type
- Restructured the document; various minor editorial changes; removed empty, irrelevant, or unused parts - many of the changes resulted from the split
- Numerical identifiers were rotated and are deprecated; new textual identifiers have been added
- Moved the Background paragraph about the commonalities and differences in the SAR PFSes to the Introduction
- Requirement “Document identifier”: Removed the trailing “for Synthetic Aperture Radar”
- Requirement “Backscatter Measurement”: Replaced “and/or” with “one of the following types or both”
- Requirement category “CEOS-ARD Product Data Attributes” renamed to “Product Metadata”; Requirement “Source Data Attributes” renamed to “Source Metadata”. Adapted descriptions accordingly.

- Requirement category “Source Data Attributes”: Moved the information about sequential acquisition identifiers to a new threshold requirement “Acquisition ID”. Adapted category description accordingly.
- The subcategories for Source and Product metadata have been flattened into top-level categories
- Annex has been reformatted and updated as required by the split
- Document history has been reset. Check the previous versions for details

**Note:** This document is the successor of the former CEOS-ARD for SAR PFS v1.3.1 for product type **Polarimetric Radar (POL)**.

**Justification:** Migration to building blocks.

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# CEOS Analysis Ready Data Definition

*CEOS Analysis Ready Data (CEOS-ARD) are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets.*

# Description

**Product Family Specification:** Synthetic Aperture Radar, Polarimetric Radar (POL)

**Version:** 3.6.0-draft

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

# Background

This PFS is specifically aimed at users interested in exploring the potential of SAR but who may lack the expertise or facilities for SAR processing.

The CEOS-ARD Polarimetric Radar (POL) product format is an extension of the CEOS-ARD Normalised Radar Backscatter (NRB) format. 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:***

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.

# Definitions and Abbreviations

**ACDD**
: Attribute Convention for Data Discovery as defined by Earth Science Information Partners (ESIP)

**ALE**
: Absolute Geolocation Error

**ATBD**
: Algorithm Theoretical Basis Document

**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, e.g., DEM, aerosols.

**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

**CRS**
: Coordinate Reference System

**DEM**
: Digital Elevation Model

**DOI**
: Digital Object Identifier

**DSM**
: Digital Surface Model

**EGM**
: Earth Gravitational Model

**ENL**
: Equivalent Number of Looks

**EPSG Code**
: An EPSG code is a unique identifier assigned to e.g. a specific coordinate reference system (CRS) by the European Petroleum Survey Group (EPSG).

**GSLC**

Geocoded Single-Look Complex

**ISLR**
Intensity Signal-to-Noise Level Ratio

**LUT**
Look-Up Table

**Metadata**
Structured information that describes other information or information services. With well-defined metadata, users should be able to get basic information about data, without the need to have knowledge about its entire content.

**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

**ORB**
Ocean Radar Backscatter

**PFS**
Product Family Specification

**POL**
Polarimetric Radar

**PRD**
Polarimetric Radar Decomposition

**PSLR**
Polarimetric Signal-to-Noise Level Ratio

**rRMSE**
Radial Root Mean Square Error

**RTC**
Radiometrically Terrain Corrected

**SAR**
Synthetic Aperture Radar

**SI**
International System of Units, internationally known by the abbreviation SI (from French Système international d’unités)

**SLC**
Single-Look Complex

**STAC**
SpatioTemporal Asset Catalog

**UPS**

Universal Polar Stereographic

**URL**
: Uniform Resource Locator, a reference to a web resource that specifies its location on a computer network and a mechanism for retrieving it.

**UTC**
: Coordinated Universal Time

**UTM**
: Universal Transverse Mercator

**WGS84**
: World Geodetic System 1984

**WKT**
: Well-Known Text (WKT) is a text markup language for representing vector geometry objects on a map, spatial reference systems of spatial objects, and transformations between spatial reference systems. The formats were originally defined by the Open Geospatial Consortium (OGC) and described in their Simple Feature Access and Coordinate Transformation Service specifications.

# Requirements

**WARNING:** The section numbers in front of the title (e.g. 1.1) are not stable and may change or may be removed at any time. Do **not** use the numbers to refer back to specific requirements! Instead, use the textual identifier that is provided below the title.

## 1. 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.

### 1.1. Traceability

Identifier: `meta-trace-sar`

**Threshold requirements:**

Not required.

**Goal requirements:**

Data must be traceable to SI reference standard.

Notes:

1. Relationship to Radiometrically Corrected Measurements: Radiometric Accuracy. Traceability requires an estimate of measurement uncertainty.
2. Information on traceability should be available in the metadata as a single DOI landing page.

### 1.2. Metadata Machine Readability

Identifier: `meta-memare-sar`

**Threshold 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 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.

## 1.3. Product Type

Identifier: `meta-protype`

**Threshold 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.

**Goal requirements:**

As threshold.

## 1.4. Document Identifier

Identifier: `meta-pfsurl`

**Threshold requirements:**

Reference to CEOS-ARD PFS document as URL.

**Goal requirements:**

As threshold.

## 1.5. Data Collection Time

Identifier: `meta-time-sar`

**Threshold 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 requirements:**

As threshold, but using ISO 8601 time format.

# 2. Source Metadata

Metadata describing (detailing) **each** acquisition used to generate the ARD product.

Source data attribute information can refer to other products for higher level ARD derived from those, under the condition of their availability (Source Metadata: Source Data Access).

## 2.1. Acquisition ID

Identifier: `src-macqid`

**Threshold requirements:**

Source data attribute information are described for each acquisition and sequentially identified e.g. as acqID = 1, 2, 3, …

**Goal requirements:**

As threshold.

## 2.2. Source Data Access

Identifier: `src-daccess-src`

**Threshold requirements:**

The metadata identifies the location from where the source data can be retrieved, expressed as a URL or DOI.

**Goal 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.

## 2.3. Instrument

Identifier: `src-instru-sar`

**Threshold requirements:**

The instrument used to collect the data is identified in the metadata:

- Satellite name
- Instrument name

**Goal requirements:**

As threshold, but using CEOS Mission-Instruments-Measurements (MIM) database as reference.

## 2.4. Source Data Acquisition Time

Identifier: `src-time-src`

**Threshold 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 requirements:**

As threshold.

## 2.5. Source Data Acquisition Parameters

Identifier: `src-acqpar`

**Threshold 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 requirements:**

As threshold.

## 2.6. Source Data Orbit Information

Identifier: `src-orbit`

**Threshold requirements:**

Information related to the platform orbit used for data processing:

- Pass direction (asc/desc), see note
- Orbit data source (e.g., predicted, definite, precise, downlinked, etc.)

Note:

1. 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 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

## 2.7. Source Data Processing Parameters

Identifier: `src-propar`

**Threshold requirements:**

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:

1. Azimuth and Range number of looks are not required when sources are CEOS-ARD or any other geocoded products

**Goal requirements:**

As threshold, plus additional relevant processing parameters, e.g., range- and azimuth look bandwidth and LUT applied.

## 2.8. Source Data Image Attributes

Identifier: `src-imgatt-sar`

**Threshold requirements:**

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:

1. For geocoded sources such as 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.

**Goal requirements:**

Geometry of the image footprint expressed in WGS84 in a standardised format (e.g., WKT).

## 2.9. Sensor Calibration

Identifier: `src-sencal-sar`

**Threshold requirements:**

Not required.

**Goal 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.

## 2.10. Performance Indicators

Identifier: `src-perfind`

**Threshold requirements:**

Provide performance indicators on data intensity noise level ($\mathrm{NE}\sigma^0$ and/or $\mathrm{NE}\beta^0$ and/or $\mathrm{NE}\gamma^0$, i.e., 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 requirements:**

Provide additional relevant performance indicators (e.g., ENL, PSLR, ISLR, and performance reference DOI or URL).

## 2.11. Polarimetric Calibration Matrices

Identifier: `src-polcalm`

**Threshold requirements:**

Not required.

**Goal requirements:**

The complex-valued polarimetric distortion matrices with the channel imbalance and the cross-talk applied for the polarimetric calibration.

## 2.12. Mean Faraday Rotation Angle

Identifier: `src-farotan`

**Threshold requirements:**

Not required.

**Goal 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.

## 2.13. Ionosphere Indicator

Identifier: `src-ionind`

**Threshold requirements:**

Not required.

**Goal 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.

# 3. Product Metadata

Information related to the CEOS-ARD product generation procedure and geographic parameters.

## 3.1. Product Data Access

Identifier: `prd-daccess-prod`

**Threshold 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 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.

## 3.2. Auxiliary Data

Identifier: `prd-auxdat-sar`

**Threshold requirements:**

Not required.

**Goal requirements:**

The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as DOIs.

Note:

1. Auxiliary data includes DEMs, etc., and any additional data sources used in the generation of the product.

## 3.3. Product Sample Spacing

Identifier: `prd-samspa`

**Threshold requirements:**

CEOS-ARD product processing parameters details:

- Pixel (column) spacing
- Line (row) spacing

**Goal requirements:**

As threshold.

## 3.4. Product Equivalent Number of Looks

Identifier: `prd-enl`

**Threshold requirements:**

Not required.

**Goal requirements:**

Equivalent Number of Looks (ENL)

## 3.5. Product Resolution

Identifier: `prd-resol`

**Threshold requirements:**

Not required.

**Goal requirements:**

Average spatial resolution of the CEOS-ARD product along:

- Columns
- Rows

## 3.6. Product Filtering

Identifier: `prd-spekfil-pol`

**Threshold 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

Advanced polarimetric filter preserving covariance matrix properties shall be applied.

**Goal requirements:**

As threshold.

## 3.7. Product Bounding Box

Identifier: `prd-geobbox`

**Threshold 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 Product Metadata: Product Coordinate Reference System.

Four corners of the product file are recommended for scenes crossing the Antemeridian, or the North or the South Pole.

**Goal requirements:**

As threshold.

## 3.8. Product Geographical Extent

Identifier: `prd-geoarea-sar`

**Threshold 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 requirements:**

As threshold.

## 3.9. Product Image Size

Identifier: `prd-imgsize`

**Threshold 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 applicable)

**Goal requirements:**

As threshold.

## 3.10. Product Pixel Coordinate Convention

Identifier: `prd-pixcoco`

**Threshold requirements:**

Coordinate referring to the centre, the upper left corner, or the lower left corner of a pixel. Values are pixel centre, pixel ULC or pixel LLC.

**Goal requirements:**

As threshold.

## 3.11. Product Coordinate Reference System

Identifier: `prd-crs-sar`

**Threshold 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 requirements:**

As threshold.

## 3.12. Reference Orbit

Identifier: `prd-reorbit-nrb-pol`

**Usage:** Only when Flattened phase per-pixel metadata (see Radiometrically Corrected Measurements: Flattened Phase) is provided.

**Threshold requirements:**

Not required.

**Goal requirements:**

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.

# 4. Per-Pixel Metadata

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

## 4.1. Metadata Machine Readability

Identifier: `pxl-memare-sar`

**Threshold 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 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.

## 4.2. Data Mask Image

Identifier: `pxl-damaski`

**Threshold requirements:**

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

Notes:

1. All bit value representations included in the Data Mask Image should be indicated in the metadata.
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.

**Goal requirements:**

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)

## 4.3. Scattering Area Image

Identifier: `pxl-piscata`

**Usage:** Recommended for scenes that include land areas.

**Threshold requirements:**

Not required.

**Goal requirements:**

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 $\beta^0$ backscatter. The terrain-flattened $\gamma_T^0$ is best understood as $\beta^0$ 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

Notes:

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.
2. Required for products such as NRB and POL 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.

## 4.4. Local Incident Angle Image

Identifier: `pxl-ploinca`

**Threshold requirements:**

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:

1. 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.

**Goal requirements:**

As threshold.

## 4.5. Ellipsoidal Incident Angle Image

Identifier: `pxl-pelinca`

**Threshold requirements:**

Not required.

**Goal requirements:**

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

Note:

1. 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.

## 4.6. Noise Power Image

Identifier: `pxl-pinopow`

**Threshold requirements:**

Not required.

**Goal requirements:**

Estimated Noise Equivalent $\sigma^0$ (or $\beta^0$ or $\gamma^0$, as applicable) used for noise removal, if applied, for each channel. $\mathrm{NE}\sigma^0$ and $\mathrm{NE}\gamma^0$ 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

## 4.7. Gamma-to-Sigma Ratio Image

Identifier: `pxl-gasiri`

**Threshold requirements:**

Not required.

**Goal requirements:**

Ratio of the integrated area in the Gamma projection over the integrated area in the Sigma projection (ground). Multiplying RTC $\gamma^0_T$ by this ratio results in an estimate of RTC $\sigma^0_T$.

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:

1. 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.

## 4.8. Acquisition ID Image

Identifier: `pxl-pacqidm`

**Usage:** Required for mosaic products only.

**Threshold requirements:**

Acquisition ID, or acquisition date, for each pixel is identified.

In case of multi-temporal image stacks, use source acquisition ID (i.e., Source Metadata: Acquisition ID) to list contributing images.

In case of date, data represent (integer or fractional) day offset to reference observation date (in UTC). Date used as reference ("Day 0") is provided in the metadata.

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

**Goal requirements:**

As threshold.

## 4.9. Per-Pixel DEM

Identifier: `pxl-pidem`

**Threshold requirements:**

Not required.

**Goal requirements:**

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:

1. 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.

# 5. 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.

## 5.1. Backscatter Measurements (POL)

Identifier: `rcm-backsca-pol`

**Threshold requirements:**

Measurements can be one of the following types or both:

- **Normalised Radar Covariance Matrix (CovMat)** Diagonal (equivalent to NRB) and upper diagonal elements of the terrain-flattened Gamma-Nought ($\gamma_T^0$) Covariance Matrix are provided for coherent dual (e.g., HH-HV, VV-VH, or …) and fully polarimetric (e.g., HH-HV-VH-VV) acquisitions.
- **Polarimetric Radar Decomposition (PRD)** The individual components of the polarimetric decomposition obtained from the terrain-flattened (Gamma-Nought, $\gamma_T^0$) covariance matrix.

File format specifications/contents provided in metadata:

- Measurement Type (CovMat, PRD)
- Measurement convention unit (linear amplitude, or linear power [see notes], 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, …)
- Bits per Sample
- Byte Order

Notes:

1. Transformation to the logarithm decibel scale is not required or desired as this step can be completed by the user if necessary.
2. It is recommended to keep CovMat or PRD measurement files separated. Else, specify the multi-channel format order [BIP, BIL, BSQ].

**Goal requirements:**

As threshold.

## 5.2. Scaling Conversion

Identifier: `rcm-scaconv`

**Threshold requirements:**

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.

**Goal requirements:**

As threshold, but use of float32.

## 5.3. Noise Removal

Identifier: `rcm-noiser`

**Threshold requirements:**

Flag if noise removal (see note) has been applied (Y/N). Metadata should include the noise removal algorithm and reference to the algorithm as URL or DOI.

Note:

1. Thermal noise removal and image border noise removal to remove overall scene noise and scene edge artefacts, respectively.

**Goal requirements:**

As threshold.

## 5.4. Radiometric Terrain Correction Algorithm

Identifier: `rcm-radtalg-appl`

**Threshold requirements:**

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) $\gamma_T^0$ 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:

1. Examples of technical documentation include an Algorithm, Theoretical Basis Document, product user guide, etc.

**Goal requirements:**

As threshold.

## 5.5. Radiometric Accuracy

Identifier: `rcm-radacc-sar`

**Threshold requirements:**

Not required.

**Goal requirements:**

Uncertainty (e.g., bounds on $\gamma^0$ or $\sigma^0$) information is provided as document referenced as URL or DOI. SI traceability is achieved.

## 5.6. Flattened Phase

Identifier: `rcm-flapha`

**Usage:** Alternative to GSLC product for NRB and POL products

**Threshold requirements:**

Not required.

**Goal requirements:**

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 “Topographic phase removal” in the applicable PFS). The use of the Flattened Phase with the NRB or POL intensity (Radiometrically Corrected Measurements) provides the GSLC equivalent, as follows:

$$\mathrm{GSLC} = \sqrt{NRB} \times \exp(j \cdot \mathrm{FlattenPhase})$$

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.

# 6. 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.

## 6.1. Geometric Correction Algorithm

Identifier: `gcor-geocalg`

**Threshold requirements:**

Not required.

**Goal requirements:**

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:

1. Examples of technical documentation can include e.g., an Algorithm Theoretical Basis Document (ATBD), or a product user guide.

## 6.2. Digital Elevation Model

Identifier: `gcor-cdem`

**Usage:** For products including land areas.

**Threshold requirements:**

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.

**Goal requirements:**

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.

## 6.3. Geometric Accuracy

Identifier: `gcor-geomacc-sar`

**Threshold 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 composite products, when sources come from different SAR platforms or different beam modes, provide averaged ALE or averaged ARD ALE.

Notes:

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.
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.
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 requirements:**

Output product sub-sample accuracy should be less than or equal to 0.1 (slant range) pixel radial root mean square error (rRMSE).

Provide documentation of estimates of ALE as DOI or URL.

## 6.4. Geometric Refined Accuracy

Identifier: `gcor-georacc`

**Threshold requirements:**

Not required.

**Goal requirements:**

Values provided under Geometric Corrections: 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 composite products, provide averaged ALE or averaged ARD ALE estimated from all sources.

## 6.5. Gridding Convention

Identifier: `gcor-gridconv`

**Threshold 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.

Note:

1. 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.

**Goal 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.

# Introduction

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.

## What is CEOS Analysis Ready Data?

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

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

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

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

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

Agencies or other entities considering undertaking an assessment process should consult the CEOS-ARD Governance Framework.

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

## What is the difference between Threshold and Goal?

**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.

## Compatibility and Interoperability of CEOS-ARD SAR Products

As can be seen from the individual 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.

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# Annexes

## 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 “Normalised Covariance Matrices (CovMat)” of the applicable PFS.
- 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 “Topographic phase removal” in the applicable PFS)
- 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 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 1: SAR ARD processing roadmap and software options. RADARSAT-2 Example

| Step | Implementation option |
|---|---|

| 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 |

## 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. 1 for fully polarimetric data (C3) and in Eq. 3 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**

$$C3 = \left[\begin{array}{ccc} |\mathbf{HH}|^2 & \sqrt{2}\cdot\mathbf{HH}\cdot\mathbf{HV}^* & \mathbf{HH}\cdot\mathbf{VV}^* \\ \sqrt{2}\cdot HV\cdot HH^* & 2\cdot|\mathbf{HV}|^2 & \sqrt{2}\cdot\mathbf{HV}\cdot\mathbf{HV}^* \\ VV\cdot HH^* & \sqrt{2}\cdot VV\cdot HV^* & |\mathbf{VV}|^2 \end{array}\right] \quad (1)$$

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

**Dual polarization**

$$\text{HH-HV:} \quad C2 = \left[\begin{array}{cc} |\mathbf{HH}|^2 & \mathbf{HH}\cdot\mathbf{HV}^* \\ HV\cdot HH^* & |\mathbf{HV}|^2 \end{array}\right] \quad (2)$$

$$\text{VV-VH:} \quad C2 = \left[\begin{array}{cc} |\mathbf{VH}|^2 & \mathbf{VH}\cdot\mathbf{VH}^* \\ VH\cdot VH^* & |\mathbf{VV}|^2 \end{array}\right] \quad (3)$$

$$\text{CH-CV:} \quad C2 = \left[\begin{array}{cc} |\mathbf{CH}|^2 & \mathbf{CH}\cdot\mathbf{CV}^* \\ CV\cdot CH^* & |\mathbf{CV}|^2 \end{array}\right] \quad (4)$$

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. 1 should be redefined as Eq. 5. 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. 5 is valid both for dual-linear and fully polarimetric dataquad polarization.

$$\text{C3 modified:} \quad C3_m = \left[ \begin{matrix} |\langle \mathbf{HH}|^2 \rangle & \langle \mathbf{HH} \cdot \mathbf{HV}^* \rangle & \langle \mathbf{HH} \cdot \mathbf{VV}^* \rangle \\ \langle HV \cdot HH^* \rangle & \langle |\mathbf{HV}|^2 \rangle & \langle \mathbf{HV} \cdot \mathbf{VV}^* \rangle \\ \langle VV \cdot HH^* \rangle & \langle VV \cdot HV^* \rangle & \langle |\mathbf{VV}|^2 \rangle \end{matrix} \right] \tag{5}$$

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. 6) permit faster and more intuitive RGB visualizations (R=RR, G=RR/(RR+RL), B= RL).

$$\text{CH-CV (C2 circular):} \quad C2_c = \left[ \begin{matrix} \langle |\mathbf{RR}|^2 \rangle & \langle \mathbf{RR} \cdot \mathbf{R}\neg^* \rangle \\ \langle RL \cdot RR^* \rangle & \langle |\mathbf{RL}|^2 \rangle \end{matrix} \right] \tag{6}$$

# 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.

## Coherent decompositions

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):

1. Pauli decomposition (3 layers)

- $|\alpha|^2$ : sphere (odd-bounce interaction) [Intensity]
- $|\beta|^2$ : 0° diplane (even-bounce interaction) [Intensity]
- $|\gamma|^2$ : 45° diplane (volumetric interaction) [Intensity]

2. Krogager decomposition (5 layers) (Krogager et al. 1993)

- $|\kappa_\sigma|^2$ : sphere (odd-bounce interaction) [Intensity]
- $|\kappa_\delta|^2$ : diplane (odd-bounce interaction) [Intensity]
- $|\kappa_\eta|^2$ : helix [Intensity]
- $\theta$: orientation angle [degrees]
- $\Phi_s$ : sphere to diplane angle [degrees]

3. Cameron (nine classes) – non-dimensional layers (Cameron et al. 1996)

Table 2: Elementary objects of known scattering signature

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

## Incoherent decompositions

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):

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

Table 3: Incoherent Decompositions: Freeman-Durden, Yamaguchi, m-chi

| Level 2b - Layers [Intensity] | 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 | |

2. 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 $2^{nd}$ and $3^{rd}$ eigenvalues
- $\alpha$ : Odd-even bounce angle [Degrees]
- $\beta$ : orientation angle [Degrees]

# Polarimetric Radar Decomposition Product Examples

From fully polarimetric covariance matrix ARD format POL (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 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 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 1d is equivalent to c) where radiometric normalisation (terrain flattening) has been applied with the help of the DEM of the scene (Figure 1a).

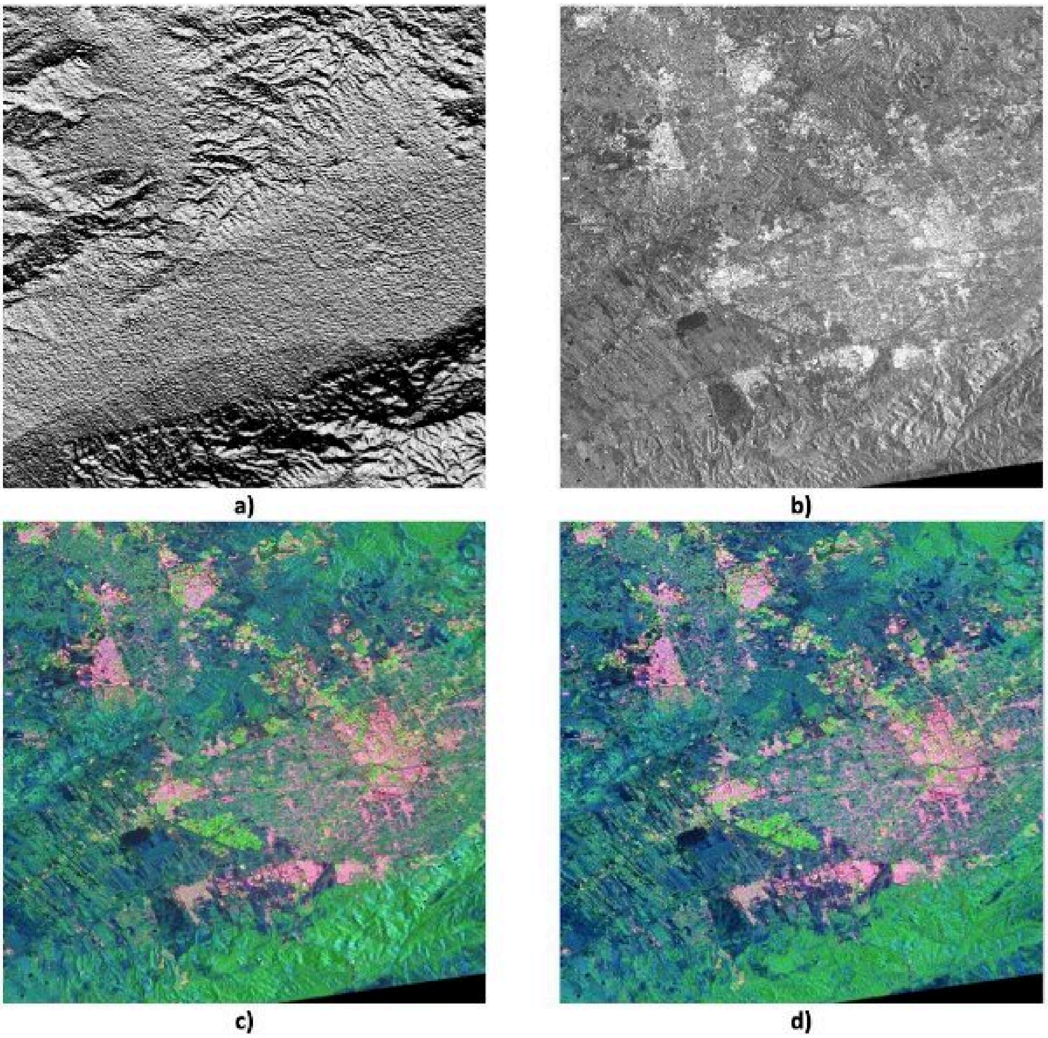

*Figure 1: Example of polarimetric decomposition generated from ARD co-variance format. a) Shaded DEM of the area; b) RADARSAT-2 HH intensity; c) Yamaguchi decomposition colour composite (Red: even bounce, Green: random, Blue: odd bounce); d) Same as c) with terrain flattening option. Generated from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

Figure 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 2a, m-chi shows mainly surface scattering from bare soil (blue channel) and vegetation interaction from forested areas (green channel), while in June Figure 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.

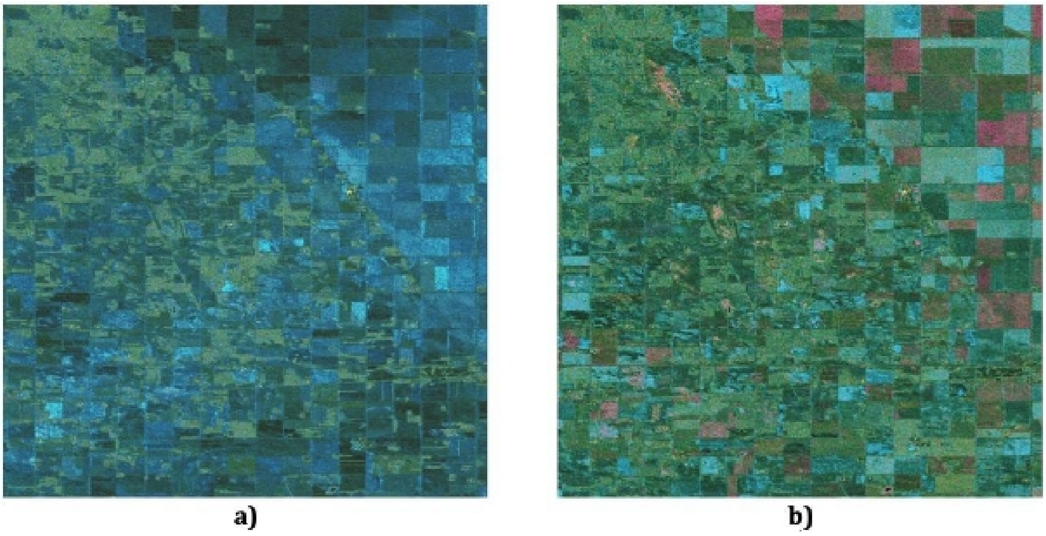


*Figure 2: m-chi decomposition colour composite of simulated compact polarimetry from Radarsat-2 over an agriculture area. RGB representation: Red: even bounce, Green: random, Blue: odd bounce. a) 3 May 2012; and b) 18 June 2012. Generated from Radarsat-2 FQ6W acquired over SMAPVEX12 campaign Manitoba,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