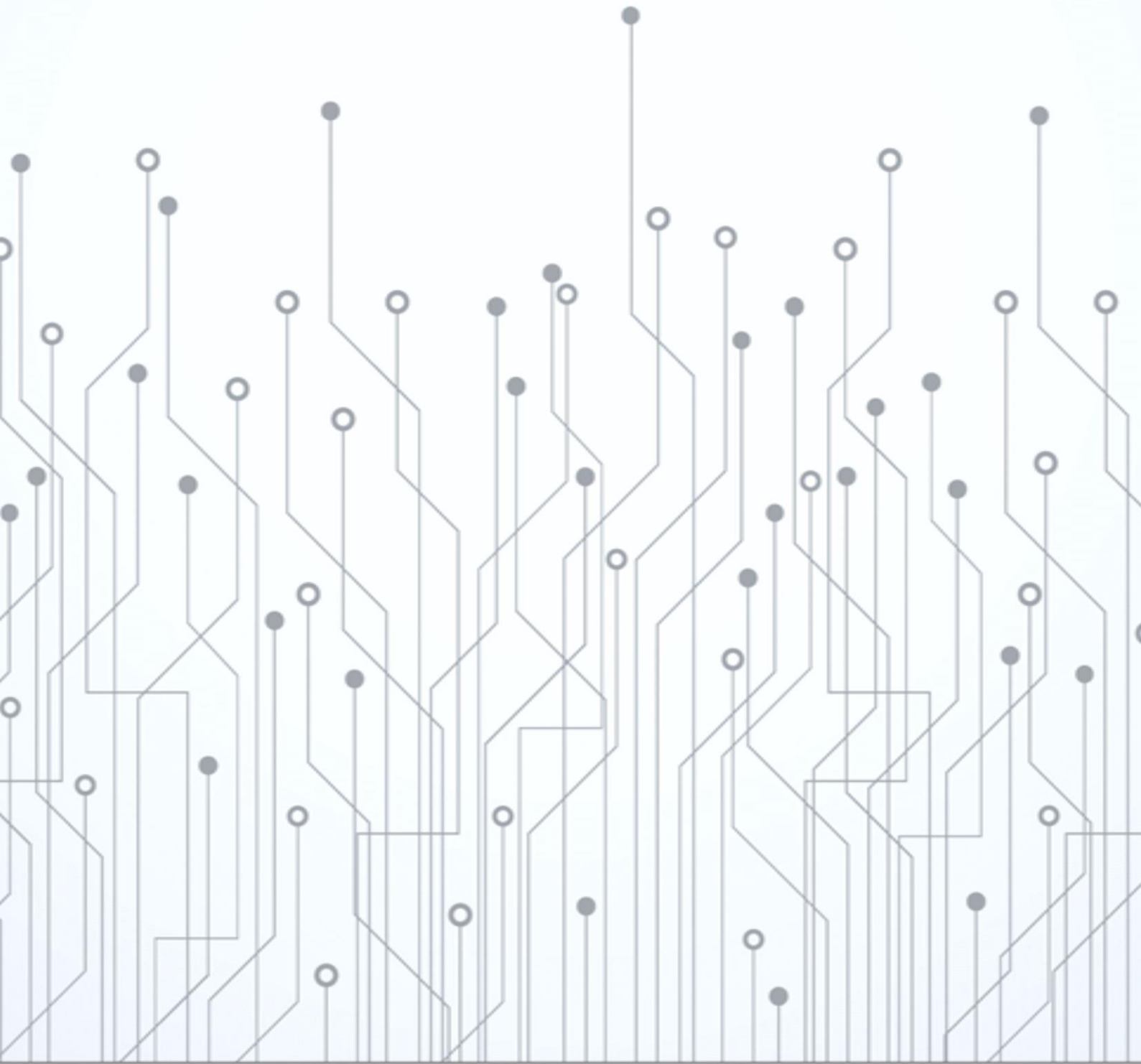




TECHNICAL GUIDELINES FOR REMOTE SENSING

V1.0

General Authority for Survey and Geospatial Information



Disclaimer

This document has been developed by the General Authority for Survey and Geospatial Information (GEOSA). The guidelines have been drafted with reference to various standards and guidelines considered to be international best practices. Any omissions or errors may please be notified.

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Foreword

The General Authority for Survey and Geospatial Information (GEOSA) is the national mapping agency of the Kingdom of Saudi Arabia (KSA). The primary aim of this initiative is to establish the "National Reference Body and Center of Expertise for National Survey & Geospatial Standards."

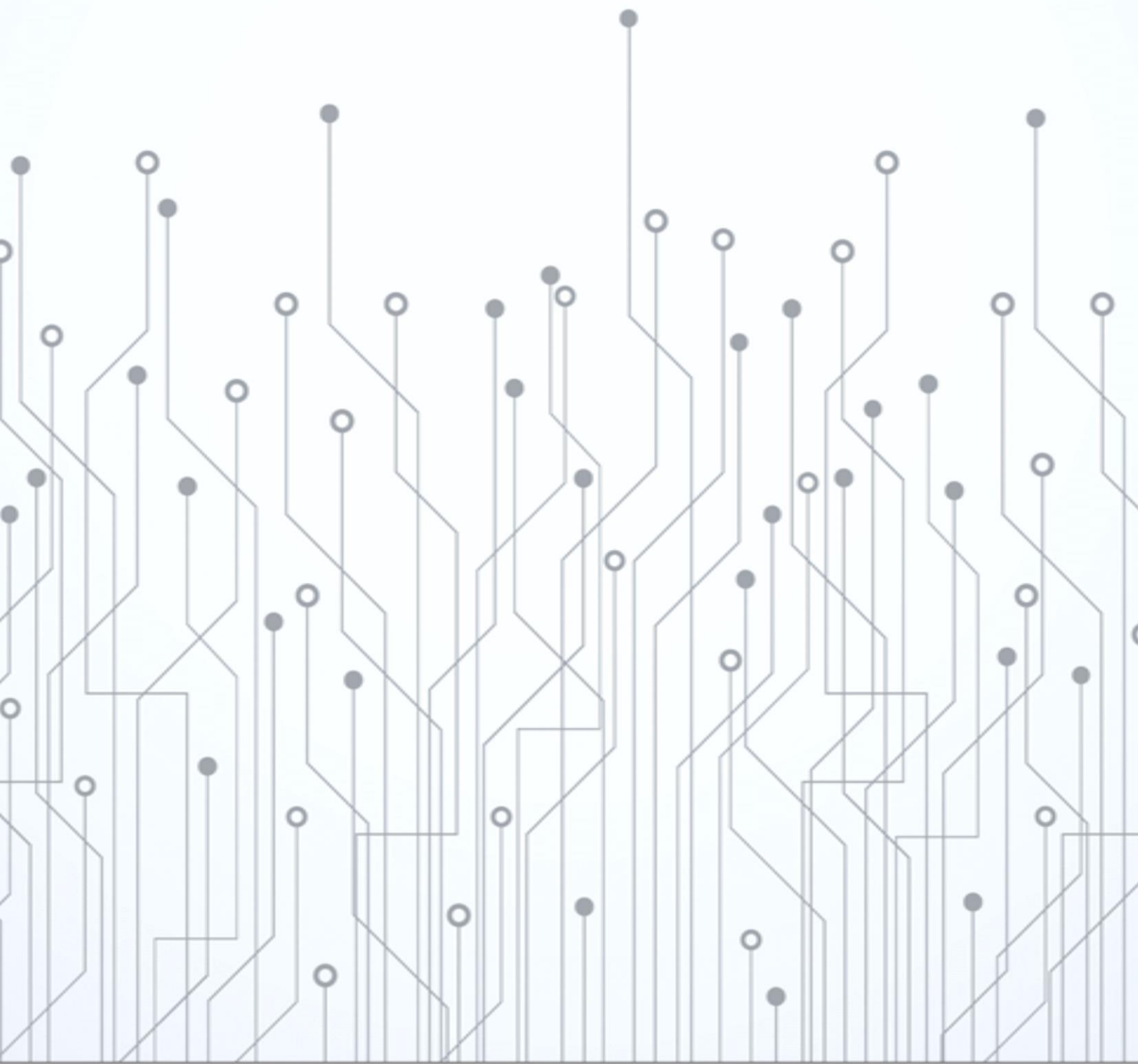
These guidelines provide a vital framework that will assist and align industry, academia, and government bodies in KSA with survey and geospatial data collection and dissemination based on international best practice. These are then applied to develop guidelines and Standard Operating Procedures (SOPs) for various geospatial and remote sensing data forms. This structured approach ensures that geospatial data collected and managed in KSA adheres to international and national standards, leading to data consistency, reliability, and compatibility.

Remotely sensed data provides ever increasing value to a full range of geospatial data users and the geospatial data community. However, data can be highly technical, scientific, and complex and requires scientific knowledge and specialized processing steps before it is in a ready-to-use format.

The concept of **Analysis Ready Data (ARD)** is data that is organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets. The concept of ARD has been championed and adopted by some of the leading satellite remote sensing and other geospatial data providers & agencies internationally.

The ARD criteria provided by the Committee of Earth Observation Satellites (CEOS) has been adopted to create a new guideline framework for the Kingdom of Saudi Arabia termed the KSA Remote Sensing Analysis Ready Data (KSA-RS-ARD) Guidelines.

1. Introduction



Scope and Objectives of the Guideline

The KSA-RS-ARD Guidelines cover two product families, namely:

- Surface Reflectance
- Synthetic Aperture Radar (SAR)

The KSA-RS-ARD Guidelines provide for both mandatory and informative aspects of guidelines for defining ARD for use in the Kingdom of Saudi Arabia.

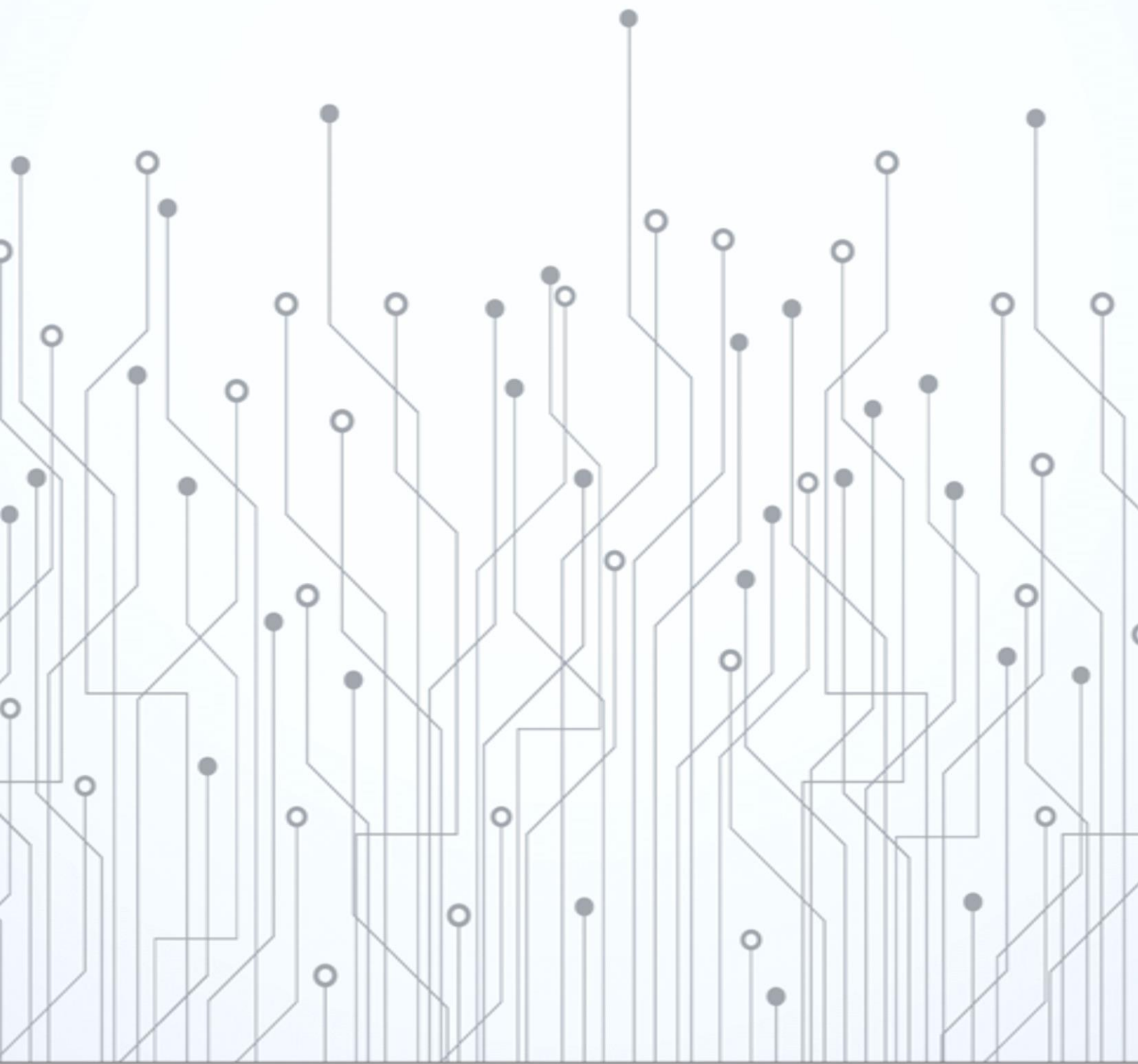
Detailed Technical Guidelines, Guidelines, Standard Operating Procedures (SOP's), Use Cases, and Project Contract needs are often vendor/provider/sensor specific and are not covered by the scope of this guideline.

Terms and Definitions

Term	Definition
KSA-RS-ARD	The short name of the Guidelines described in this document
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.
CEOS-ARD	Committee on Earth Observation Satellites - Analysis Ready Data
CovMat	Normalised Radar Covariance Matrix
Digital Object Identifier (DOI)	Unique set of letters and numbers which gives a persistent link to a resource on the internet.
EMR	Electromagnetic (EM) radiation
EO	Earth Observation
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.
NRB	Normalised Radar Backscatter
ORB	Ocean 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.
Spectral Resolution	Defines the narrowest spectral feature that can be resolved by a spectrometer.
Spectral Sampling Distance	Spectral sampling is the interval, in wavelength units, between discrete data points in the measured spectrum.

2. Normative Elements

DEFINITIONS, GUIDING PRINCIPLES AND FRAMEWORKS
FOR THE ANALYSIS READY DATA



This section provides a detailed description of the guideline for National Earth Observation (EO), Remote Sensing and ARD concepts, activities, and methods; it should give users a better understanding in the following areas:

- Definition of Earth Observation
- Definition of the Electro-Magnetic Spectrum
- Surface Reflectance (SR),
- Synthetic Aperture Radar (SAR).

2.1 Earth Observation (EO) Defined

Gathering information about the Earth using remote sensing technologies is called Earth Observation (EO). Remote sensing refers to making observations of an object using a device that is physically remote from it. The term Earth Observation is most frequently used to describe the utilisation of imagery of the Earth and its atmosphere recorded by airborne and satellite-borne sensors.

Remote sensing devices have been designed to detect various types of energy, including electromagnetic radiation (EMR), radioactivity, magnetism, gravity, and sound and seismic waves. By definition, these sensors generally do not have direct contact with the Earth, so they need to be carried by an elevated platform. Three broad groups of platforms are used to carry EO sensors:

- Spaceborne—satellites, shuttles, or space stations.
- Airborne—manned aircraft, unmanned aerial vehicles, balloons or blimps; and
- Ground-based—in situ, mobile devices, or humans.

2.2 Electro-Magnetic Spectrum Defined

Electromagnetic (EM) radiation (EMR) is the energy form most commonly sensed by Earth remote sensing devices. EM energy is measured in defined regions of the EM spectrum (Figure 1). This energy is either reflected from the Earth's surface or emitted by the Earth.

The small part of the continuous EM spectrum to which the human eye is sensitive is known as 'light'. This visible portion of the spectrum approximately spans the wavelengths from 0.4–0.7 μm .

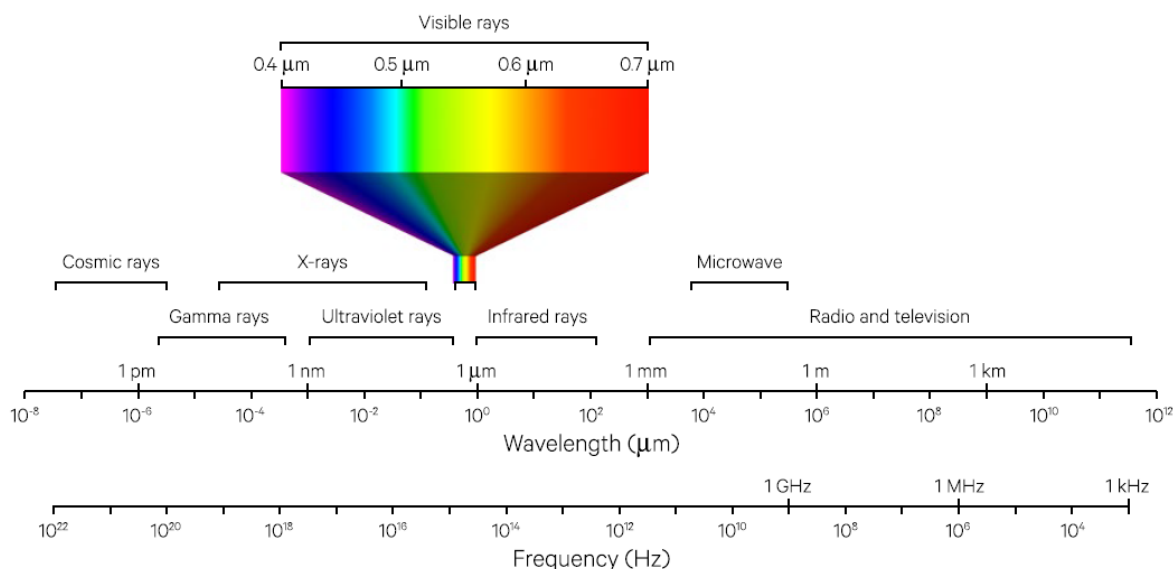
For convenience, names are assigned to the various regions of the spectrum, but there are no precise divisions between them. The regions are generally defined by the sensing method by which they are detected. Commonly accepted ranges for EMR spectral regions are:

- Visible: 0.38–0.7 μm
- Infrared (IR): 0.7–1,000 μm
- Microwave: > 1 mm–1 m

Infrared wavelengths are often sub-divided into the regions:

- Near infrared (NIR): 0.7–1.3 μm
- Short wave infrared (SWIR): 1.3–3 μm
- Middle infrared (MIR) or mid-wavelength (or medium wave) infrared (MWIR): 3–8 μm
- Thermal infrared (TIR) or long wavelength infrared (LWIR): 8–15 μm
- Far infrared (FIR): 15–1,000 μm

In Earth Observation (EO), the shorter wavelengths regions denoted visible, NIR and SWIR are often collectively referenced as 'optical' (or reflective) wavelengths. Longer wavelength energies cannot be seen or photographed but can be sensed with radiometers and scanners.



Adapted from: Harrison and Jupp (1989) Figure 2
Figure 1: The Electromagnetic Spectrum

2.3 Analysis Ready Data (ARD)

In the case of EO and Remote Sensing, ARD refers to EO derived data that has been pre-processed to a certain standard to facilitate analysis and make it readily usable for various applications. The concept of ARD aims to provide data that is consistently processed, calibrated, and corrected, reducing the need for users to perform extensive pre-processing tasks before conducting their analyses for various applications.

2.3.1 Guiding Principles

The Guiding Principles defining the Kingdom of Saudi Arabia (KSA) Guidelines require them to be Discoverable, Accessible, Interoperable, Repeatable, Authoritative, User-centric and Extensible. These guiding principles are comprehensively fulfilled by adopting the concept of ARD.

Discoverable, Accessible, Interoperable & Repeatable are ensured with a focus on metadata and the future trend and benefits of cloud hosted data.

The User-Centric requirement is paramount to ensuring the adoption and use of guidelines that are fit-for-purpose and meet the user needs and use cases that exist within GEOSA and in the wider KSA Geospatial community.

The KSA-RS-ARD Guidelines are assured of being Authoritative and Extensible as they are based on the authoritative work undertaken by international geospatial bodies such as Open Geospatial Consortium (OGC) and the Committee of Earth Observation Satellites (CEOS). This has parallels with the Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia (), adopted from the American Society of Photogrammetry & Remote Sensing (ASPRS), an authoritative international body.

The Guidelines are also authoritative and extensible due to their ultimate publishing and on-going maintenance and extensions by GEOSA as the authoritative national mapping agency for the Kingdom of Saudi Arabia.

2.3.2 Committee on Earth Observation Satellites (CEOS)

Due to diversity in geospatial data types, the methods, and purposes for organizations to collect the data are very diverse in terms of data quality, the pre-processes applied, the data forms (e.g., projection, data organizations, spatial resolutions, etc.), and documentation. A typical geospatial application normally requires obtaining and integrating data from multiple data providers. Because of the diversity in the data contents and forms, application users typically spend up to 80% of their efforts on preparing the acquired data to make the data ready for analysis. Many geospatial data users lack the expertise, infrastructure, and internet bandwidth to access, pre-process, and utilize the growing volume of geospatial data for local, regional, and national decision-making efficiently and effectively. Furthermore, even sophisticated users typically invest a large proportion of their effort into data preparation. This is a major barrier to full and successful utilization of geospatial data. As geospatial applications become more sophisticated and data volumes continue to grow, this barrier only becomes more significant for all users.

ARD is Satellite-derived Data that has 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.
(CEOS definition)

The Committee on Earth Observation Satellites (CEOS) () through working groups, virtual constellations and ad-hoc teams bring together world-leading experts in Earth observation. Over the years these teams have produced numerous best practice and guideline documents for a wide range of topics. CEOS has created a meaningful set of criteria and assessment tools to evaluate data to ensure it meets the requirements of ARD. The criteria provided by CEOS form a useful guideline framework for remotely sensed data that has been adapted and adopted for use in the Kingdom of Saudi Arabia.

Using the CEOS framework, the concept of ARD can be applied to various EO missions and sensor types, including optical and radar sensors. The goal is to create a consistent and standardized data product that enables researchers, scientists, and analysts to focus on their specific applications without the need to spend significant time and resources on data pre-processing. This can be particularly valuable in time-sensitive applications and large-scale analyses. Different EO data providers may have their own ARD guidelines and standards. Some have received CEOS accreditation for their ARD compliance.

The key characteristics of ARD, as per the CEOS Framework, typically include:

- **Radiometric Calibration:** ARD is calibrated to ensure that the pixel values in the imagery represent physical quantities of radiation received by the sensor. This involves correcting for sensor-specific variations, atmospheric effects, and other factors that can affect radiometric accuracy.
- **Geometric Calibration:** ARD ensures that the EO imagery is geometrically accurate by correcting for distortions introduced during image acquisition. This involves accounting for sensor and EO platform characteristics, as well as Earth's topography.
- **Cloud and Shadow Removal:** ARD often involves the removal or masking of clouds, cloud shadows, and other atmospheric artifacts. This is particularly important for applications where a clear view of the Earth's surface is essential.
- **Terrain Correction:** Correction for topographic effects is applied in ARD, especially in regions with significant elevation variations. This correction helps to account for variations in illumination caused by terrain.
- **Standardized Metadata:** ARD includes standardized metadata, making it easier for users to understand the characteristics of the data, such as acquisition date, sensor details, and processing history.

See https://ceos.org/ard/files/CARD4L_Info_Note_Users_v1.0.pdf for further benefits of using ARD.

2.3.3 Open Geospatial Consortium (OGC) ARD SWG

The Open Geospatial Consortium (OGC) Analysis Ready Data Standards Working Group (ARD SWG) has developed multi-part geospatial ARD Standards by working jointly with the International Organization for Standardization Technical Committee (ISO/TC) 211 ARD Standard project team. Through the formal standard development processes of both International Organization for Standardization (ISO) and OGC, this Standards Working Group (SWG) have developed draft geospatial ARD standards by using CEOS-ARD Guidelines as the basis, built on existing OGC and ISO standards where applicable.

The ARD SWG will define standards which specify a set of minimum requirements, including but not limited to, the content, structure, organization, applied preprocessing, metadata, format, and naming conventions, that a type of geospatial data product shall be met in order for the product to be qualified as an ARD product.

The OGC ARD standards are intended to be aligned with some existing OGC standards, which already partially fulfil ARD capability requirements. Some of these are listed below:

- WCS: OGC Web Coverage Service (WCS) can provide on-demand ARD data services for coverage data.
- WFS: OGC Web Feature Service (WFS) can provide on-demand ARD data services for feature data.
- OGC Application Programming Interface (API) – Features can provide on-demand ARD data services for feature data.
- CSW: OGC Catalog Service for Web (CSW) can provide federated discovery of ARD products from multiple data providers.
- Geographic Markup Language (GML): GML is a comprehensive encoding of features, geometry, and topology in Extensible Markup Language (XML). GML can be used to encode the feature ARD.
- Geo-referenced Tag Image File Format (GeoTIFF), Network Common Data Form (NetCDF), and Hierarchical Data Format version 5 (HDF5): These OGC standards are useful for encoding and packing coverage ARD.
- WKT-CRS: The Well-Known Text representation of Coordinate Reference Systems (WKT-CRS) offers a standardized way to describe Coordinate Reference Systems (CRS) for reference by any spatial data set fully.
- Observations and Measurements: this standard defines XML schemas for observations, and for features involved in sampling when making observations. These provide document models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.
- Several evolving OGC Standards are also relevant: OGC API – Tiles, OGC API – Maps, OGC API – Records, OGC API-EDR (Environmental Data Retrieval), and Cloud Optimized GeoTIFF (COG).
- Discrete Global Grid Systems (DGGS) Abstract Guideline: The goal of DGGS is to enable rapid assembly of spatial data without the difficulties of working with projected coordinate reference systems. DGGSs represent the Earth as hierarchical sequences of equal area tessellations, each with global coverage and with progressively finer spatial resolution.

Adopting the CEOS ARD definition as a starting point, the OGC Analysis Ready Data Standards Working Group (OGC ARD SWG) extends the scope of ARD from satellite EO data to all geospatial data. Elements of the OGC ARD Standard will be incorporated into the GEOSA KSA-RS-ARD Guidelines as they become available.

Part-1 Fundamentals and Framework of the OGC Standard: Geospatial Analysis Ready Data are due for release in 2024.

2.3.4 Adoption of ARD as a Framework

The aim is to create guidelines that meet the GEOSA Guidelines Guiding Principles as described in , and specifically the needs of users. It is essential that the guidelines are User-Centric, Interoperable and Accessible at a high level and provide a framework for the success of adoption and use of the guidelines by the Geospatial Users & Community in KSA.

The KSA Remote Sensing KSA-RS-ARD Guidelines aim to meet this high-level requirement.

Detailed Technical Guidelines, Guidelines and Standard Operating Procedures (SoP's) are at a lower (user) level and address the Use Cases or Contract needs and are often vendor/provider or sensor specific and are not covered by the scope of this guideline. However, all deliverables of these use case and contract specific situations are required to meet the KSA-RS-ARD Guidelines.

2.4 ARD Product Family Guidelines (PFSs)

ARD Product Family Guidelines (PFSs) are defined as the core component of the ARD concept. They describe ARD guidelines for remotely sensed measurement types. A PFS details specific requirements that a dataset must satisfy to be identified as ARD compliant at either the minimal (Threshold) and/or desired (Goal) level.

Each PFS has the following Core Requirement Elements:

- **General Metadata:** allow the user to assess overall suitability of the dataset.
- **Per-Pixel Metadata:** allow users to choose which observations (e.g., pixels) to use or discard.
- **Radiometric and Atmospheric Corrections:** specify any corrections that must be made to the data to reach a measurement and accuracy requirements for the data to be analysis ready.
- **Geometric Corrections:** specify geometric corrections that must be made, and geometric accuracy required for the data to be analysis ready.

Each PFS has the core elements mentioned above. However, the exact form of the guideline (i.e., which items / parameters appear in the PFS) differ among PFSs because the measurement, instrumentation, mode of observation, levels of maturity, expectation of the user community, etc., differ among product types.

Two PFSs are provided in this KSA-RS-ARD Guideline. These are for:

- Surface Reflectance (SR),
- Synthetic Aperture Radar (SAR).

2.4.1 Surface Reflectance (SR) PFSs

Surface Reflectance Product Family Guidelines (PFS) refers to data collected with multispectral optical sensors operating in the VIS/NIR/SWIR (Visible/Near Infrared/Short-wave Infrared) wavelengths at all ground sample distances and resolutions.

This is the most common & widely used Product Family that covers the full scope of Land Surface Imaging and other multispectral data. Surface Reflection is the primary PFS for inclusion in the KSA-RS-ARD Guidelines.

Surface Reflectance - High Resolution Imagery (KSA-RS-ARD-HR)

A guideline is provided for High Resolution Surface Reflection. This is widely used for urban applications and use cases. The minimum tile components for delivery of ARD data in the High-Resolution Surface Reflectance category is:

- Multispectral/Hyperspectral Image,
- A Panchromatic Image.

Imagery shall be delivered with levels of pre-processing to meet the needs of ARD and to be optimised for machine learning algorithms. The minimum pre-processing steps required to produce the panchromatic and multispectral ARD tiles are:

- Atmospheric compensation,
- Orthorectification to native resolution, as captured by the sensor.

In addition, an image with visual qualities is generated from the panchromatic and multispectral images, with these minimum additional processing steps:

- Pansharpened,
- Radiometrically balanced per tile,
- Dynamic range adjusted to 8-bit image projection,
- Resampled to a native resolution pixel size and aligned to the ARD grid.

Masks

A set of data masks shall be included with the image tiles. These masks further enable the Ease of Use and Analysis Ready principles of the ARD imagery. Masks shall be to define the following conditions within an Area-of-Interest (AOI):

- Clouds,
- Data/no data,
- Healthy vegetation,
- Multispectral pixel saturation,
- Panchromatic flare,
- Terrain shadows,
- Water.

Bands

The KSA-RS-ARD-HR Guidelines shall cater for imagery collected in either 4 or 8 Spectral Bands. These are defined as:

Table 1: KSA-RS-ARD-HR 4 Spectral Band Definitions

Band Name	Common Name	Description
BAND_B	Blue	Blue
BAND_G	Green	Green
BAND_R	Red	Red
BAND_IR	Nir08	Near Infrared 1

Table 2: KSA-RS-ARD-HR 8 Spectral Band Definitions

Band Name	Common Name	Description
BAND_B	Blue	Blue
BAND_C	Coastal	Coastal Blue
BAND_G	Green	Green
BAND_R	Red	Red
BAND_IR	Nir08	Near Infrared 1
BAND_Y	Yellow	Yellow
BAND_RE	Rededge	Red Edge 1
BAND_N2	Nir09	Near Infrared 2

2.4.2 Synthetic Aperture Radar (SAR) PFSSs

The CEOS Synthetic Aperture Radar Analysis Ready Data (CEOS-ARD-SAR) Product Family Guideline (PFS) () Applies to Data collected by Synthetic Aperture Radar sensors. It is specifically aimed at users interested in exploring the potential of SAR but who may lack the expertise or facilities for SAR processing.

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

- Normalised Radar Backscatter [version 5.5] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Polarimetric Radar [version 3.5] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Ocean Radar Backscatter [version 1.0] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Geocoded Single-Look Complex [version 1.0] ([Committee of Earth Observation Satellites, CEOS, 2021](#)),

2.5 Tiling & Projections

ARD requires data to be available on a tiling structure to ensure ease-of-use and repeatability.

In line with commercial product providers GEOSA has adopted a tiling structure based on a Universal Transverse Mercator (UTM) Grid projection and World Geodetic System 1984 (WGS 84) Datum. For the purposes of this Guideline, this is termed the KSA-RS-ARD Tiling Schema. The schema consists of 5 km x 5 km tiles with a small overlap to ensure seamless mosaicking of tiles. Tiles are supplied as clipped to the 5 km grid and include an additional extent of 512 pixels outside of the grid boundary. This serves as overlapping data so that image analyses do not have to work across seams between adjacent tiles.

The 5 km x 5 km tiles shall be further processed with internal tiling following a quad-key structure where each tile component is successively divided into 4 new quadrants giving levels of zoom. Note that the tiling system is designed for high resolution (25 to 30 cm Ground Sampling Distance (GSD) range) surface reflectance imagery but can be equally suitable for other lower resolution remotely sensed data products.

Due to the physical size of the Kingdom, the tiling shall extend over the following UTM (N) Zones:

- UTM Z36N (small extent),
- UTM Z37N,
- UTM Z38N,
- UTM Z39N,
- UTM Z40N (small extent).

Alternative Map Projections such as Lambert's Conical Conform or Transverse Mercator (TM) may replace the UTM projection to suit the project.

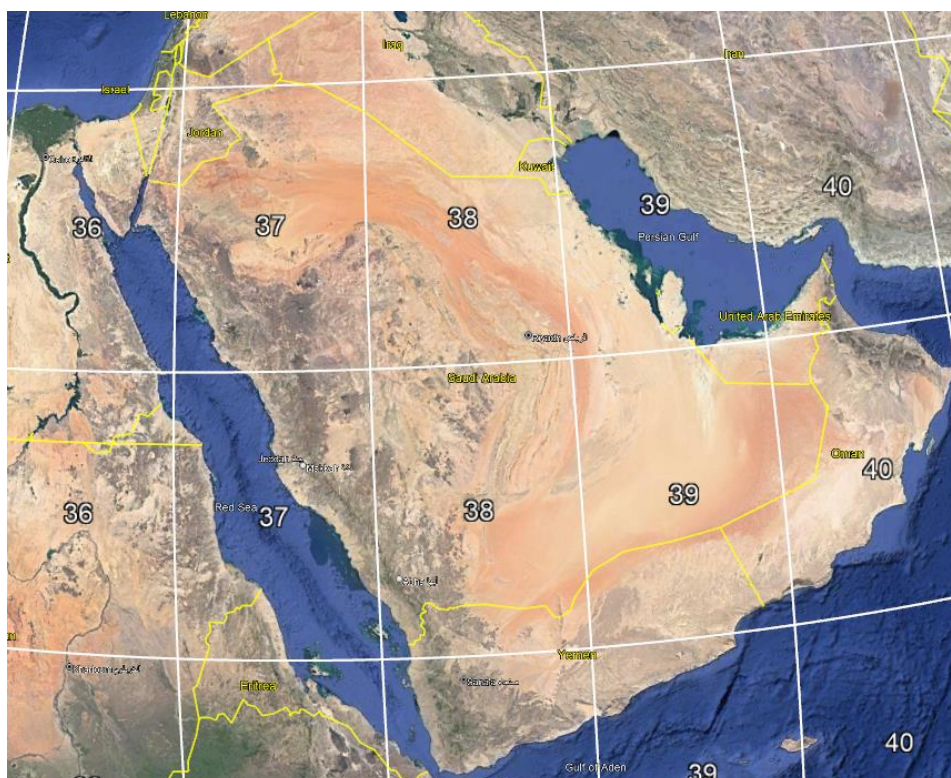


Figure 2: Universal Transverse Mercator Zones for Kingdom of Saudi Arabia

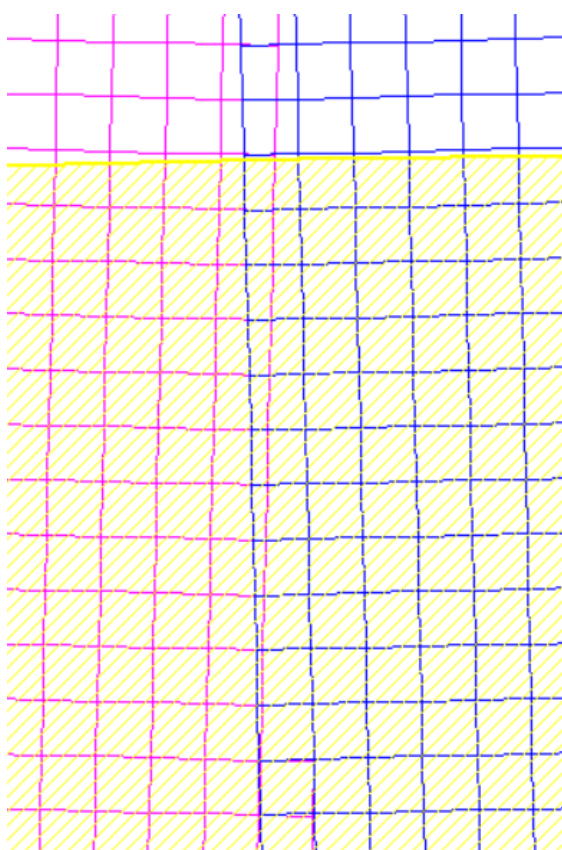


Figure 3: Typical 5 km x 5 km tile detail with overlaps between UTM Zones

2.6 ARD Interoperability

Interoperability and Accessibility are Guiding Principles as described in [section 2.3.1](#). These principles are ensured by following Open Standards, Cloud Native Architecture and by using Accessibility tools such as API's & Software Development Kit (SDKs).

The following KSA-RS-ARD Guideline requirements must be met:

- Data products shall be accessible directly from an approved cloud storage platform.
- The file in any KSA-RS-ARD format shall be accessible to be read directly from the cloud or downloaded to a local directory.
- The image file format shall be:
 - Cloud Optimized GeoTIFF (COG) with overviews and internal tiling using Geospatial Data Abstraction Library (GDAL) (<https://gdal.org/index.html>) COG output format using default settings & DEFLATE compression (Lossless Data Compression File Format),
 - GeoTIFF,
- COG uses additional JPEG (Joint Photographic Experts Group) compression for smaller file sizes.
- File naming shall follow the convention of the provider that includes as a minimum the following:
 - Image ID,
 - Date of acquisition,
 - Image type - pan / ms.
- Metadata shall be provided containing information about the tile (raster & vector), source collection, such as sun elevation, off-nadir angle, and other information needed,
- Metadata files shall be provided in a Spatio-Temporal Asset Catalog (STAC) (<https://stacspec.org/en>) or ISO 19139: Metadata Implementation format.

2.6.1 User Access

ARD compliant data shall be easily searchable using the provider's online tools for submitting AOI's and ordering. In the case of cloud hosted data, the provider shall supply API's SDK's and command line tools to enable accessibility and ease of use.

Providers shall have clear and workable policies and instructions to enable cloud account setup, uploads/downloads, and direct cloud access. Users shall be able to easily query the availability of data and all associated metadata based on the 5 km x 5 km KSA-RS-ARD Tiling Schema.

2.7 ARD Guidelines & Requirements

2.7.1 Surface Reflectance

The tables below provide the list of requirements that pertain to Remote Sensed Data for the category of Surface Reflectance (SR). SR refers to data collected with multispectral optical sensors operating in the VIS/NIR/SWIR wavelengths at all ground sample distances and resolutions.

The requirements and guidelines listed below are to be satisfied for any SR data to be considered ARD. These requirements are an adaptation of the CEOS guideline. Additional notes are provided in cases where a minimum guideline is to be met and in cases where additional requirements are preferred.

2.7.1.1 Glossary of Terms

The general *Category* for each **Term** is added as a prefix.

Table 3: Glossary of Terms for Remote Sensed Data for Surface Reflectance

Category- Term	Description	References/Resources/ Examples
<i>General Metadata</i> - Traceability	The reference standard for the physical measurement. Preferably an SI reference.	e.g., the blackbody methodology for Brightness Temperature calibration of an infrared radiometer.
<i>General Metadata</i> - Metadata Machine Readability	Referring to the file-level or global header metadata model structure, its attributes and readability.	Typical community metadata conventions and standards (e.g., CF , ACDD (Attribute Convention for Data Discovery) , ISO-19115).
<i>General Metadata</i> - Data Collection Time	The temporal bounds of the observations expressed in a community best practice format.	Using well known formats like ISO-8601 .
<i>General Metadata</i> - Geographical Area	The spatial region with bounding coordinates. Can also include vertical dimensions.	Captured in units of the coordinate system.
<i>General Metadata</i> - Coordinate Reference System	Coordinate Reference System (CRS) documented in metadata.	E.g., WGS-84/CF coordinates/WKT/EPSG code.
<i>General Metadata</i> - Instrument	The remote sensing instrument(s) used.	Name derived from a well-known community vocabulary such as the GCMD instrument keywords .
<i>General Metadata</i> - Algorithms	Measurement processing algorithms and their versions.	For example, algorithms published in peer review literature.
<i>General Metadata</i> - Auxiliary	Algorithm and processing inputs from external sources.	For example, data from models and other remote sensing products.
<i>General Metadata</i> - Processing Chain Provenance	Data product provenance information and metadata.	Product provenance including processing systems, and software versions.
<i>General Metadata</i> - Data Access	Data landing page or access location endpoint.	A Digital Object Identifier (DOI) that points to a landing page with further access locations/services/endpoints as URLs.
<i>General Metadata</i> - Geometric Correction Metadata Requirements	Description of geometric correction methodology.	A DOI that points to the geometric correction documentation.
<i>General Metadata</i> - Geometric Accuracy Metadata Requirements	Requirements for metadata on the geometric accuracy.	A DOI that points to geometric accuracy documentation.
<i>Per Pixel</i> - Metadata Machine Readability	Referring to the variable-level metadata model structure, its attributes and readability.	Typical community metadata conventions and standards (e.g., CF, ACDD, ISO-19115/3).
<i>Per Pixel</i> - Quality Tests	A collection of tests (masks) to filter the measurement variable	The exact tests are dependent on the type of remote sensing observation

Category- Term	Description	References/Resources/ Examples
	for missing data, outliers, and other data quality metrics.	and instrument technology. For example, passive optical radiometers will have at least a cloud/land/water mask and others relevant to atmospheric conditions. Active radar will have at least backscattering and saturation masks.
<i>Per Pixel</i> - Quality Tests/No Data	A test for missing values for measurement.	Typically delineated as scalar or bit flag.
<i>Per Pixel</i> - Observation Conditions/	Additional collections of factors to assess the observation conditions affecting the measurement.	The exact tests are dependent on the type of remote sensing observation and instrument technology.
<i>Per Pixel</i> - Additional Correction Parameters/	Additional collections of factors to assess any additional correction affecting the measurement.	The exact tests are dependent on the type of remote sensing observation and instrument technology.
<i>Corrections/Accuracy</i> - Measurement	Bio-geophysical measurement traceable to SI.	Documented with CF Standard Name or Community Surface Dynamics Modelling System (CSDMS) Standard name if possible.
<i>Corrections/Accuracy</i> - Measurement Normalization	Measurements are normalised for solar and viewing conditions.	To be assessed by the user
<i>Corrections/Accuracy</i> - Measurement Uncertainty	Uncertainty expressed as standard deviation, standard error, or Root Mean Square (RMS).	The uncertainty methodology should be detailed in peer reviewed literature. Ground truth reference system should be noted.
<i>Corrections/Accuracy</i> - Corrections Applied	A collection of corrections applied as part of measurement retrieval. The exact corrections are dependent on the measurement and instrument type.	Peer reviewed published methodology. Examples are water vapor, aerosol scattering, ozone, RFI etc.
<i>Geometric Accuracy and Corrections</i> - Geometric Accuracy of Data	The assessed geodetic accuracy of the data. Should be accessible from dataset landing page.	E.g., assessed to 0.5-pixel accuracy.
<i>Geometric Accuracy and Corrections</i> - Geometric Correction Methods	Mandatory geometric correction methods for the data to be considered analysis ready.	A DOI that points to the geometric correction documentation.

2.7.1.2 Requirements - General Metadata

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

Table 4: General Metadata Requirements - Surface Reflectance

#	Item (Term)	Requirements
1.1	Traceability	Data must be traceable to SI reference standard. <i>Note 1: Relationship to 3.2. Traceability (Table 6) requires an estimate of measurement uncertainty.</i> <i>Note 2: Information on traceability should be available in the metadata as a single DOI landing page.</i>
1.2	Metadata Machine Readability	Metadata is provided in a structure that enables a computer algorithm to be used consistently and to automatically identify and extract each component part for further use. Metadata should be provided in a community endorsed standard that facilitates machine-readability. ISO 19115-1:2014 defines the schema required for describing geographic information and services by means of metadata. (International Standardization Organization, ISO, 2014).
1.3	Data Collection Time	The data collection time is identified in the metadata, expressed in date/time, to the second, with the time offset from Coordinated Universal Time (UTC) unambiguously identified. Acquisition time for each pixel is identified (or can be reliably determined) in the metadata, expressed in date/time at UTC, to the second.
1.4	Geographical Area	The surface location to which the data relates is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g., WGS 84). The geographic area covered by the observations is identified specifically, such as through a set of coordinates of a closely bounding polygon. The location to which each pixel refers is identified (or can be reliably determined) with the projection system (if any) and reference datum provided.
1.5	Coordinate Reference System	The metadata lists the coordinate reference system that has been used.
1.6	Map Projection	The metadata lists the map projection that has been used (or geographical coordinates, if applicable) and any relevant parameters required in relation to use of data in that map projection.
1.7	Geometric Correction Methods	The user is not explicitly advised of the geometric correction source and methods.
1.8	Geometric Accuracy of the Data	The user is not provided with results of geometric accuracy assessments pertaining to the dataset.
1.9	Instrument	The instrument used to collect the data is identified in the metadata. but information should be available in the metadata as a single DOI landing page with references to the relevant CEOS Missions, Instruments, and Measurements Database record.
1.10	Spectral Bands	The central wavelength for each band for which data is included is identified in the metadata, expressed in SI units. As threshold, with instrument spectral response details (e.g., full spectral response function) also included or directly accessible using details in the metadata.

#	Item (Term)	Requirements
		Central wavelength and bandwidth at full-width half maximum value of the relative spectral response function are provided at least. <i>Note 1: Information on spectral bands should be available in the metadata as a single DOI landing page.</i>
1.11	Sensor Calibration	The general metadata does not include sensor calibration details. 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. <i>Note 1: Information on sensor calibration should be available in the metadata as a single DOI landing page.</i>
1.12	Radiometric Accuracy	The general metadata does not include information on the radiometric accuracy of the data. The metadata includes metrics describing the assessed absolute radiometric uncertainty of the version of the data or product, expressed as absolute radiometric uncertainty relative to appropriate, known reference sites and standards (for example, pseudo-invariant calibration sites, rigorously collected field spectra, PICS, Rayleigh, DCC, etc.) <i>Note 1: Information on radiometric accuracy should be available in the metadata as a single DOI landing page.</i>
1.13	Algorithms	All algorithms, and the sequence in which they were applied in the generation process, are identified in the metadata. For example, these may be available through Algorithm Theoretical Basis Documents (ATBDs). https://eosps.nasa.gov/content/algorithm-theoretical-basis-documents <i>Note 1: Information on algorithms should be available in the metadata as a single DOI landing page.</i> Ideally only algorithms that have been published in a peer-reviewed journal. <i>Note 1: It is possible that high quality corrections are applied through non-disclosed processes. CEOS-ARD does not per-se require full and open data and methods.</i> <i>Note 2: Information on algorithms should be available in the metadata as a single DOI landing page.</i>
1.14	Auxiliary Data	The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as a single DOI landing page. <i>Note 1: Auxiliary data includes DEMs, aerosols, etc. data sources.</i>
1.15	Processing Chain Provenance	Information on processing chain provenance should be available in the metadata as a single DOI landing page containing detailed description of the processing steps used to generate the product, including the versions of software used, giving full transparency to the users.
1.16	Data Access	Information on data access should be available in the metadata as a single DOI landing page. <i>Note 1: Manual and offline interaction action (e.g., login) may be required.</i>
1.17	Overall Data Quality	Machine-readable metrics describing the overall quality of the data are included in the metadata, at minimum the cloud cover extent, i.e.: Proportion of observations over land (c.f. ocean) affected by non-target phenomena, e.g., cloud and cloud shadows.

2.7.1.3 Requirements - Per Pixel Metadata

The following minimum metadata guidelines applies 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.

Table 5: Per Pixel Metadata Requirements - Surface Reflectance

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
2.1	Metadata Machine Readability	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold.
2.2	No Data	Pixels that do not correspond to an observation ('empty pixels') are flagged.	As threshold.
2.3	Incomplete Testing	The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed. <i>Note 1: This may be the result of missing ancillary data for a subset of the pixels.</i>	The metadata identifies which tests have, and have not, been successfully completed for each pixel.
2.4	Saturation	Metadata indicates where one or more spectral bands are saturated.	Metadata indicates which pixels are saturated for each spectral band.
2.5	Cloud	Metadata indicates whether a pixel is assessed as being cloud.	As threshold, information on cloud detection should be available in the metadata as a single DOI landing page.
2.6	Cloud Shadow	Metadata indicates whether a pixel is assessed as being cloud shadow.	As threshold, but information on cloud shadow detection should be available in the metadata as a single DOI landing page.
2.7	Land/Water Mask	Not required.	The metadata indicates whether a pixel is assessed as being land or water. Information on land/water mask should be available in the metadata as a single DOI landing page.
2.8	Snow/Ice Mask	Not required.	The metadata indicates whether a pixel is assessed as being snow/ice or not. Information on snow/ice mask should be available in the metadata as a single DOI landing page.
2.9	Terrain Shadow Mask	Not required.	The metadata indicates pixels that are not directly illuminated due to terrain shadowing.
2.10	Terrain Occlusion	Not required.	The metadata indicates pixels that are not visible to the sensor due to terrain occlusion during off-nadir viewing.
2.11	Solar and Viewing Geometry	Provide average solar and sensor viewing azimuth and zenith angles.	Provide per-pixel solar and sensor viewing azimuth and zenith angles.
2.12	Terrain Illumination Correction	Not required.	Coefficients used for terrain illumination correction are provided for each pixel.
2.13	Aerosol Optical	Not required.	To be determined.

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
	Depth Parameters		

2.7.1.4 Requirements - Radiometric and Atmospheric Corrections

The following requirements must be met for all pixels in a collection. The requirements indicate both the necessary outcomes (3.1-3.3) and the minimum steps necessary to be deemed to have achieved those outcomes (3.4 onward). Radiometric corrections must lead to a valid measurement of surface reflectance.

Table 6: Radiometric and Atmospheric Corrections Requirements - Surface Reflectance

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
3.1	Measurement	Pixel values that are expressed as a measurement of the Surface Reflectance of the land. This is a dimensionless value.	Surface Reflectance measurements are SI traceable (see also 1.1 (Table 4)).
3.2	Measurement Uncertainty	Not required. <i>Note 1: In current practice, users determine fitness for purpose based on knowledge of the lineage of the data, rather than on a specific estimate of measurement uncertainty.</i>	An estimate of the certainty of the values is provided in measurement units. <i>Note 1: This is a requirement for SI traceability. See also 1.1 (Table 4).</i> <i>Note 2: Information on measurement uncertainty should be available in the metadata as a single DOI landing page.</i>
3.3	Measurement Normalisation	Not required.	Measurements are normalised for solar and viewing conditions (i.e., nadir view angle and average solar angles). This may include terrain illumination and/or Bi-Directional Reflectance Function (BRDF) correction. <i>Note 1: Information on measurement normalisation should be available in the metadata as a single DOI landing page.</i>
3.4	Directional Atmospheric Scattering	Corrections are applied for aerosols and molecular (Rayleigh) scattering. Metadata contains a single DOI landing page with references to: - a citable peer-reviewed algorithm - technical documentation regarding the implementation of that algorithm - the sources of ancillary data used to make corrections. <i>Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.</i>	As threshold.
3.5	Water Vapour Corrections	Corrections are applied for water vapour.	As threshold.

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
		Metadata contains a single DOI landing page with references to: • a citable peer-reviewed algorithm • technical documentation regarding the implementation of that algorithm <i>Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.</i>	
3.6	Ozone Corrections	Not required.	Data is corrected for ozone. Relevant metadata must be provided under 1.8 and 1.9 (Table 4). Metadata contains a single DOI landing page with references to: • a citable peer-reviewed algorithm, • technical documentation regarding the implementation of that algorithm.

2.7.1.5 Requirements - Geometric Corrections

Geometric corrections must place the measurement accurately on the surface of the Earth (that is, geolocate the measurement) allowing measurements taken through time to be compared.

Table 7: General Corrections Requirements - Surface Reflectance

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
4.1	Geometric Correction	Sub-pixel accuracy is achieved in <u>relative</u> geolocation, that is, the pixels from the same instrument and platform are consistently located, and thus comparable, through time. Sub-pixel accuracy is taken to be less than or equal to 0.5-pixel radial root mean square error (rRMSE) or equivalent in Circular Error Probability (CEP) relative to a defined reference image. A consistent gridding/sampling frame is used, including common cell size, origin, and nominal sample point location within the cell (centre, ll, ur). Relevant metadata must be provided under 1.8 and 1.9 (Table 4). <i>Note 1: The threshold level will not necessarily enable interoperability</i>	Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid). A consistent gridding/sampling frame is necessary to meet this requirement. Relevant metadata must be provided under 1.8 and 1.9 (Table 4). <i>Note 1: This requirement is intended to enable interoperability between imagery from different platforms that meet this level of correction and with non-image spatial data such as GIS layers and terrain models.</i>

#	Item	Threshold (Minimum) Requirements	Goal (Desired) Requirements
		<i>between data from <u>different</u> sources as the geometric corrections for each of the sources may differ.</i>	

2.7.2 Synthetic Aperture Radar (SAR)

2.7.2.1 Synthetic Aperture Radar Defined

Radar is an acronym for Radio Detection and Ranging, that is, using actively transmitted radio waves to detect objects and determine their position or 'range'. Radar signals may be transmitted at a range of wavelengths/frequencies. The standard wavelengths used, and their standard radar frequency letter codes are given in Table 8: SAR Band Definitions.

Synthetic Aperture Radar, or SAR is a type of active data collection where a sensor produces its own energy and then records the amount of that energy reflected back after interacting with the Earth's surface. While optical imagery is similar to interpreting a photograph, SAR data requires a different way of thinking, in that the signal is instead responsive to surface characteristics like structure and moisture.

SAR systems are operated from elevated places on land, from manned and unmanned aircraft and from spacecraft. SAR can provide images on a 24-hour basis and in all kinds of weather as it has the ability to penetrate clouds, fog, and in some cases leaves, snow and sand. The simplest application of SAR data is to produce a panchromatic pseudo image of the earth's surface despite clouds and weather that is obtainable day or night. This has valuable use in areas with constant weather and cloud cover that precludes the use of optical imagery.

The different wavelengths of SAR are often referred to as bands, with letter designations such as X, C, L, and P. The table below notes the band with associated frequency, wavelength, and the application typical for that band. X, C and L bands are most commonly used for EO.

Table 8: SAR Band Definitions

Band	Frequency	Wavelength	Typical Application
Ka	27–40 GHz	1.1–0.8 cm	Rarely used for SAR (airport surveillance)
K	18–27 GHz	1.7–1.1 cm	rarely used (H ₂ O absorption)
Ku	12–18 GHz	2.4–1.7 cm	rarely used for SAR (satellite altimetry)
X	8–12 GHz	3.8–2.4 cm	High resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4–8 GHz	7.5–3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2–4 GHz	15–7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expands C-band applications to higher vegetation density)
L	1–2 GHz	30–15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3–1 GHz	100–30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

One of the limitations of working with SAR data has been the extensive pre-processing steps that SAR data requires. Depending on the type of analyses, these pre-processing steps can include applying the orbit file, radiometric calibration, de-bursting, multilooking, speckle filtering, and terrain correction.

The processing and applications of SAR are complex and require specialist knowledge. This need for pre-processing is removed if the SAR data is supplied as ARD.

2.7.2.2 Background to CEOS-ARD for Synthetic Aperture Radar:

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

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

- Normalised Radar Backscatter [version 5.5] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Polarimetric Radar [version 3.5] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Ocean Radar Backscatter [version 1.0] ([Committee of Earth Observation Satellites, CEOS, 2021](#))
- Geocoded Single-Look Complex [version 1.0] ([Committee of Earth Observation Satellites, CEOS, 2021](#))

CEOS-ARD Normalised Radar Backscatter (NRB)

The CEOS-ARD Normalised Radar Backscatter (NRB) guideline describes products that have been subject to Radiometric Terrain Correction (RTC) and are provided in the Gamma-Nought () backscatter convention (), 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 to Sigma-Nought () 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 Interferometric Synthetic Aperture Radar (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.

CEOS-ARD Polarimetric Radar (POL)

The CEOS-ARD Polarimetric Radar (POL) product format is an extension of the CEOS-ARD Normalised Radar Backscatter format NRB. This extension is required to better support Level-1 SLC (Single-Look Complex) polarimetric data, including full-polarimetric modes (e.g., RADARSAT-2 (Radar Satellite) , ALOS-2/4 (Advanced Land Observing Satellite), SAOCOM-1 (Satélite Argentino de Observación Con Microondas) and future missions), and hybrid or linear dual-polarimetric modes (i.e., Compact Polarimetric mode available on RCM (Radar Satellite Constellation Mission), SAOCOM and the upcoming NISAR (NASA-ISRO Synthetic Aperture Radar) 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 minimize bias in the CEOS-ARD SAR Level-2a covariance matrix product, speckle filtering and averaging of the covariance matrix should be applied in the slant range projection, and geocoding should be

performed using nearest-neighbour resampling. Specifically, nearest-neighbour resampling ensures that the averaged covariance matrix elements in slant range and in geocoded ground projection are exactly the same.

Consequently, the polarimetrically derived parameters are exactly equal in both approaches (assuming that no further averaging is performed on the ARD product for decomposing the polarimetric information). Bilinear and average resampling methods are also suitable for resampling the covariance matrix, but some differences with polarimetric parameters generated in slant range and then resampled (bilinear) might be observed on sloped terrains. Even if 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 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.

CEOS-ARD Ocean Radar Backscatter (ORB)

The CEOS-ARD Ocean Radar Backscatter (ORB) product guideline 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^0_{ell}) or radiometrically terrain corrected (σ^0_{rc}) 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 covariance matrix for enabling advanced polarimetric analysis (similar to the POL product).

CEOS-ARD Geocoded Single-Look Complex (GSLC)

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. Since the GSLC phase is flattened, the phase difference between two GSLC products acquired on a same relative orbit produces an interferogram referring only to surface displacement and noise (i.e., no topographic fringes). The GSLC product may optionally be radiometrically terrain corrected such that the squared amplitude yields γ_T^0 .

As can be seen from the above PFS descriptions, only a few minor details in terms of generated parameters and/or the addition of supplemental data distinguish these CEOS-ARD products. In part, they are to a large extent all backward compatible. For example, POL products implicitly include NRB products, while a coastal NRB or POL product can simply be made compatible with other ORB products by applying gamma-to-sigma conversion. Just

as GSLC can be converted to NRB, the inverse conversion can be made true by including the optional 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, to optimize their interoperability.

For this generic *CEOS-ARD for Synthetic Aperture Radar* PFS ([Committee on Earth Observation Satellites, CEOS, 2023](#)), as for the individual NRB, POL, ORB, and GSLC 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 PFSSs, 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.

The tables below provide the list of requirements that pertain to Remote Sensed Data for the category of Synthetic Aperture Radar (SAR).

2.7.2.3 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.

NRB - Normalised Radar Backscatter

POL - Polarimetric Radar

ORB - Ocean Radar Backscatter

GSLC - Geocoded Single-Look Complex

Table 9: General Metadata Requirements - Synthetic Aperture Radar (SAR)

#	Parameter	CEOS-ARD product	Requirements
1.1	Traceability	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Not required.
			Goal (Desired) Requirements Data must be traceable to SI reference standard. <i>Note 1: Traceability requires an estimate of measurement uncertainty.</i> <i>Note 2: Information on traceability should be available in the metadata as a single DOI landing page.</i>
1.2	Metadata Machine Readability	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Metadata is provided in a structure that enables a computer algorithm to be used consistently and to automatically identify and extract each component part for further use.
			Goal (Desired) Requirements As threshold, but metadata is formatted in accordance with CEOS-ARD SAR Metadata Specifications(Committee on Earth Observation Satellites, CEOS, 2023) , v.1.0, or in a community endorsed standard that facilitates machine-readability, such as ISO 19115-2 (International Standardization

#	Parameter	CEOS-ARD product	Requirements
			Organization, ISO, 2009), CF convention and the Attribute Convention for Data Discovery (ACDD) , etc.
1.3	Product Type	[NRB] [POL] [ORB] [GSLC]	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. Goal (Desired) Requirements As per threshold.
1.4	Document Identifier	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Reference to CEOS-ARD for Synthetic Aperture Radar PFS (Committee on Earth Observation Satellites, CEOS, 2023) document as Uniform Resource Locator (URL). Goal (Desired) Requirements As per threshold.
1.5	Data Collection Time	[NRB] [POL] [ORB] [GSLC]	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 case of composite products, the dates/times of the first and last data takes and the per-pixel metadata 2.8 (Acquisition ID Image) (Table 10) is provided with the product. Goal (Desired) Requirements As per threshold.
1.6	Source Data Attributes		Subsection describing (detailing) each SAR acquisition used to generate the ARD product. <i>Note: Source data attribute information is described for each acquisition and sequentially identified as acqID= 1, 2, 3, ...</i>
1.6.1	Source Data Access	[NRB] [POL] [ORB] [GSLC]	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.
1.6.2	Instrument	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements The instrument used to collect the data is identified in the metadata: - Satellite name, - Instrument name. Goal (Desired) Requirements As per threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.
1.6.3	Source Data Acquisition Time	[NRB] [POL] [ORB] [GSLC]	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.
1.6.4	Source Data Acquisition Parameters	[NRB] [POL] [ORB] [GSLC]	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),

#	Parameter	CEOS-ARD product	Requirements
			- Antenna pointing [Right/Left], - Beam ID (i.e., Beam mode Mnemonic).
			Goal (Desired) Requirements As per threshold.
1.6.5	Source Data Orbit Information	[NRB] [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.] <i>* For source data crossing the North or South Pole, it is recommended to produce two distinct CEOS-ARD products and to use the appropriate "Pass direction" in each.</i>
			Goal (Desired) Requirements As per 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 <i>before</i> start time to 10% of scene length <i>after</i> stop time), - Platform (mean) altitude.
1.6.6	Source Data Processing Parameters	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) 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).
			Goal (Desired) Requirements As per threshold, plus additional relevant processing parameters, e.g., range and azimuth look bandwidth and LUT applied.
1.6.7	Source Data Image Attributes	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Image attributes related to the source data: - Source Data geometry (slant range/ground range), - Azimuth pixel spacing, - Range pixel spacing, - Azimuth resolution, - Range resolution, - Near range incident angle, - Far range incident angle.
			Goal (Desired) Requirements Geometry of the image footprint expressed in WGS 84 in a standardised format (e.g., WKT).
1.6.8	Sensor Calibration	[NRB] [POL]	Threshold (Minimum) Requirements Not required.

#	Parameter	CEOS-ARD product	Requirements
		[ORB] [GSLC]	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.
1.6.9	Performance Indicators	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Provide performance indicators on data intensity noise level ($NE\sigma^0$ and/or $NE\beta^0$ and/or $NE\gamma^0$ (noise equivalent Sigma- and/or Beta- and/or Gamma-Nought)). Provided for each polarization channel when available. Parameter may be expressed as the mean and/or minimum and maximum noise equivalent values of the source data. Values do not need to be estimated individually for each product, but may be estimated once for each acquisition mode, and annotated on all products. Goal (Desired) Requirements Provide additional relevant performance indicators (e.g., ENL, PSLR, ISLR, and performance reference DOI or URL).
1.6.10	Source Data Polarimetric Calibration Matrices	[NRB] [POL] [ORB] [GSLC]	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.
1.6.11	Mean Faraday Rotation Angle	[NRB] [POL] [ORB] [GSLC]	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.
1.6.12	Ionosphere Indicator	[NRB] [POL] [ORB] [GSLC]	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.
1.7	CEOS-ARD Product Attributes		Subsection containing information related to the CEOS-ARD product generation procedure and geographic parameters.
1.7.1	Product Data Access	[NRB] [POL] [ORB] [GSLC]	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.
1.7.2	Auxiliary Data	[NRB] [POL]	Threshold (Minimum) Requirements Not required.

#	Parameter	CEOS-ARD product	Requirements
		[ORB] [GSLC]	<u>Goal (Desired) Requirements</u> The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as DOIs. <i>Note: Auxiliary data includes DEMs, etc., and any additional data sources used in the generation of the product.</i>
1.7.3	Product Sample Spacing	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> CEOS-ARD product processing parameters details: - Pixel (column) spacing, - Line (row) spacing. <u>Goal (Desired) Requirements</u> As per threshold.
1.7.4	Product Equivalent Number of Looks	[NRB] [POL] [ORB]	<u>Threshold (Minimum) Requirements</u> Not required. <u>Goal (Desired) Requirements</u> Equivalent Number of Looks (ENL).
1.7.5	Product Resolution	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required. <u>Goal (Desired) Requirements</u> Average spatial resolution of the CEOS-ARD product along: - Columns, - Rows.
1.7.6	Product Filtering	[NRB] [POL] [ORB]	<u>Threshold (Minimum) Requirements</u> Flag if speckle filter has been applied [true/false]. Metadata should include: - Reference to algorithm as DOI or URL, - Input filtering parameters: - o Type, - o Window size in pixel units, - o Any other parameters defining the speckle filter used. Mandatory for POL: Advanced polarimetric filter preserving covariance matrix properties should be applied. <u>Goal (Desired) Requirements</u> As per threshold.
1.7.7	Product Bounding Box	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Two opposite corners of the product file (bounding box, including any zero-fill values) are identified, expressed in the product coordinate reference system defined in 1.7.11 (in same table - Table 9) Four corners of the product file are recommended for scenes crossing the Antemeridian, or the North or the South Pole. <u>Goal (Desired) Requirements</u> As per threshold.
1.7.8	Product Geographical Extent	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> The geometry of the SAR image footprint expressed in WGS84, in a standardised format (e.g., WKT Polygon). <u>Goal (Desired) Requirements</u> As per threshold.

#	Parameter	CEOS-ARD product	Requirements
1.7.9	Product Image Size	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Image attributes of the CEOS-ARD product: - Number of lines, - Number of pixels/lines, - File header size (if applicable), - Number of no-data border pixels. (if appl.) Goal (Desired) Requirements As per threshold.
1.7.10	Product Pixel Coordinate Convention	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Coordinate referring to the Centre, or the Upper Left Corner (ULC) or the Lower Left Corner (LLC) of a pixel. Values are [pixel centre, pixel ULC or pixel LLC]. Goal (Desired) Requirements As per threshold.
1.7.11	Product Coordinate Reference System	[NRB] [POL] [ORB] [GSLC]	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 European Petroleum Survey Group (EPSG) code, if defined for the CRS. Goal (Desired) Requirements As per threshold.
1.7.12	Look Direction Polynomials	[ORB]	Threshold (Minimum) Requirements In case the per-pixel item 2.11 (Look Direction Image)(Table 10) 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'] <i>* The look direction angle represents the planar angle between north and each range direction. It is not constant in range, especially close to the poles.</i> Goal (Desired) Requirements As per threshold.
1.7.13	Radar Unit Look Vector	[GSLC]	Threshold (Minimum) Requirements 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) (Table 10) is not provided.

#	Parameter	CEOS-ARD product	Requirements
			Goal (Desired) Requirements As per threshold.
1.7.14	Slant Range Sensor to Surface	[GSLC]	Threshold (Minimum) Requirements 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) (Table 10) is not provided.
			Goal (Desired) Requirements As per threshold.
1.7.15	Reference Orbit	[NRB] [POL] [GSLC]	Threshold (Minimum) Requirements Not required.
			Goal (Desired) Requirements Usage: For NRB & POL only when per-pixel metadata 3.7 (Flattened phase in Table 11) is provided. For GSLC when a reference orbit is used instead of a virtual orbit (see Annex 1). Provide the absolute orbit number used as reference for topographic phase flattening. In case a virtual orbit has been used, provide orbit parameters or orbit state vectors as DOI or URL. Provide scene-centred perpendicular baseline for the for the source data relative to the reference orbit used (for approximate use only).

2.7.2.4 Requirements - Per-Pixel Metadata

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

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

Table 10: Per Pixel Metadata Requirements - Synthetic Aperture Radar (SAR)

#	Parameter	CEOS-ARD product	Requirements
2.1	Metadata Machine Readability	[NRB] [POL] [ORB] [GSLC]	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/layer for further use.
			Goal (Desired) Requirements As threshold, but metadata is formatted in accordance with CEOS-ARD SAR Metadata Specifications, v.1.0 (Committee on Earth Observation Satellites, CEOS, 2023).
2.2	Data Mask Image	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Mask image indicating: - Valid data, - Invalid data, - No data.

#	Parameter	CEOS-ARD product	Requirements
			File format specifications/ contents provided in metadata: - Sample Type [Mask], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int, ...], - Bits per Sample, - Byte Order, - Bit Value Representation. Goal (Desired) 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), - Digital Elevation Model (DEM) gap filling (i.e., interpolated DEM over gaps).
2.3	Scattering Area Image	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Not required. 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 [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order.
2.4	Local Incident Angle Image	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements DEM-based Local Incident angle image is provided. File format specifications/ contents provided in metadata: - Sample Type [Angle], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. <i>Note: For maritime ORB scenes when no land areas are covered, a geoid model could be used for the calculation of the local incident angle</i> Goal (Desired) Requirements As threshold.
2.5		[NRB] [POL]	Threshold (Minimum) Requirements Not required.

#	Parameter	CEOS-ARD product	Requirements
	Ellipsoidal Incident Angle Image	[ORB] [GSLC]	Goal (Desired) Requirements Ellipsoidal incident angle is provided. File format specifications/ contents provided in metadata: - Sample Type [Angle], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order, - Reference Ellipsoid Name. <i>Note: For maritime ORB scenes when no land areas are covered, the ellipsoidal incident angle is nearly identical to the geoid based local incident angle.</i>
2.6	Noise Power Image	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements Estimated Noise Equivalent σ^0 (or β^0 or γ^0, as applicable) used for noise removal, if applied, for each channel. $NE\sigma^0$ and $NE\gamma^0$ are both based on a simplified ellipsoid Earth model. File format specifications/ contents provided in metadata: - Sample Type [Gamma-Nought, Sigma-Nought, Beta-Nought], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order.
2.7	Gamma-to-Sigma Ratio Image	[NRB] [POL] [GSLC]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements 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 [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order.
2.8	Acquisition ID Image	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements Note: Required for multi-source product only. Acquisition ID, or acquisition date, for each pixel is identified. In case of multi-temporal image stacks, use source acquisition ID [i.e., 1.6 (in this table) 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 metadata. Pixels not representing a unique date (e.g., pixels averaged in image overlap zones) are flagged with a pre-set pixel value that is provided in the metadata.

#	Parameter	CEOS-ARD product	Requirements
			File format specifications/ contents provided in metadata: - Sample Type [Day, Time, ID], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per sample, - Byte Order. Goal (Desired) Requirements In case of image composites, the sources for each pixel are uniquely identified.
2.9	Per-pixel DEM	[NRB] [POL] [GSLC]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements Provide DEM or Digital Surface Model (DSM) as used during the geometric and radiometric processing of the SAR data, resampled to an exact geometric match in extent and resolution with the CEOS-ARD SAR image product. Can also be provided with ORB products containing land areas. File format specifications/ contents provided in metadata: - Sample Type [Height], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order.
2.10	Per-pixel Geoid	[ORB]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements 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 (Committee on Earth Observation Satellites, CEOS, 2021) image product. File format specifications/ contents provided in metadata: - Sample Type [Height], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order, - Ground Sampling Distance.
2.11	Look Direction Image	[ORB]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements 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 [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order.
2.12	Radar Unit Look Vector Grid Image	[GSLC]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements

#	Parameter	CEOS-ARD product	Requirements
			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). File format specifications/ contents provided in metadata: - Sample Type [3D unit vector], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Float, ...], - Bits per Sample, - Byte Order.
2.13	Slant Range Sensor to Surface Image	[GSLC]	<u>Threshold (Minimum) Requirements</u> Not required. <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. File format specifications/contents provided in metadata: - Sample Type [Distance], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Float, ...], - Bits per Sample, - Byte Order.
2.14	InSAR Phase Uncertainty Image	[GSLC]	<u>Threshold (Minimum) Requirements</u> Not required. <u>Goal (Desired) Requirements</u> Estimate of uncertainty in InSAR phase is provided, such as finite signal to noise ratio, quantization noise, or DEM error. Identification of which error sources are included will be provided as DOI/URL reference or brief description. It represents statistical variation from known noise sources only. File format specifications/contents provided in metadata: - Sample Type [Angle], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Float, ...], - Bits per Sample, - Byte Order.
2.15	Atmospheric Phase Correction Image	[GSLC]	<u>Threshold (Minimum) Requirements</u> Not required. <u>Goal (Desired) Requirements</u> Phase correction value at each pixel, if applied. DOI/URL reference to algorithm or brief description is provided. File format specifications/contents provided in metadata: - Sample Type [Angle], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Float, ...], - Bits per Sample, - Byte Order.
2.16	Ionospheric Phase	[GSLC]	<u>Threshold (Minimum) Requirements</u> Not required. <u>Goal (Desired) Requirements</u>

#	Parameter	CEOS-ARD product	Requirements
	Correction Image		Phase correction value at each pixel, if applied. DOI/URL reference to algorithm or brief description is provided. File format specifications/contents provided in metadata: - Sample Type [Angle], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Float, ...], - Bits per Sample, - Byte Order.

2.7.2.5 Requirements - 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 guideline needs to be provided for each record. The requirements below must be met for all pixels/samples/observations in a collection. Cloud optimized file formats are recommended.

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

Table 11: Radiometrically Corrected Measurements Requirements - Synthetic Aperture Radar (SAR)

#	Parameter	CEOS-ARD product	Requirements
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 [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. <i>*Note: Transformation to the logarithm decibel scale is not required or desired as this step can be completed by the user if necessary.</i>
			<u>Goal (Desired) Requirements</u> As threshold.
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>

#	Parameter	CEOS-ARD product	Requirements
			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, linear power, angle], - Individual covariance matrix element or/and Individual component of the decomposition [C3m11, C3m12, ... or H, A, alpha, or ...], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/ Float/Complex, etc.], - Bits per Sample, - Byte Order. <i>Note: It is recommended to keep CovMat or PRD measurement files separated. Otherwise, specify the multi-channel format order BIP, BIL, BSQ</i> <u>Goal (Desired) Requirements</u> As threshold.
3.1	Backscatter Measurements	[ORB]	<u>Threshold (Minimum) Requirements ORB</u> Geoid-corrected Sigma-Nought backscatter coefficient (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*], - Backscatter Conversion Equation, - Polarization [HH/HV/VV/VH], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. <i>*Note: Transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.</i> <u>Goal (Desired) Requirements</u> Radiometrically Terrain-corrected Sigma-Nought backscatter coefficient (σ_T^0) is provided for each polarization.
3.1	Backscatter Measurements	[GSLC]	<u>Threshold (Minimum) 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). File format specifications/contents provided in metadata: - Measurement Type [Gamma-Nought], - Backscatter Expression Convention [linear amplitude or linear power*], - Polarization [HH/HV/VV/VH], - Data Format [Raw/GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. <i>*Note: Transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.</i> <u>Goal (Desired) Requirements</u>

#	Parameter	CEOS-ARD product	Requirements
			As threshold.
3.2	Scaling Conversion	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) 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 (Desired) Requirements As threshold, but use of float32.
3.3	Noise Removal	[NRB] [POL] [ORB] [GSLC]	Threshold (Minimum) Requirements 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. <i>*Note: Thermal noise removal and image border noise removal to remove overall scene noise and scene edge artefacts, respectively.</i> Goal (Desired) Requirements As threshold.
3.4	Radiometric Terrain Correction Algorithm	[NRB] [POL] [GSLC]	Threshold (Minimum) 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) 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. <i>Note: Examples of technical documentation include an Algorithm, Theoretical Basis Document, product user guide, etc.</i> Goal (Desired) Requirements Goal for GSLC product type Require resolution of DEM better than the output product resolution when applying terrain corrections.
3.5	Radiometric Accuracy	[NRB] [POL] [ORB] [GSLC]	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.
3.6	Mean Wind-Normalised Backscatter Measurements	[ORB]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements Usage: Only for Maritime scene 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],

#	Parameter	CEOS-ARD product	Requirements
			- Backscatter Expression Convention [intensity ratio], - Polarization [HH/HV/VV/VH], - Data Format [GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. <i>Note: Reference wind model, wind speed and direction used for reference backscattering coefficient should be provided.</i>
3.7	Flattened Phase	[NRB] [POL]	Threshold (Minimum) Requirements Not required. Goal (Desired) Requirements 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 3.1.2). The use of the Flattened Phase with the NRB or POL intensity (3.1 Backscatter measurement) provides the GSLC equivalent, as follows: $GSLC = \sqrt{NRB} \times \exp(j \text{ FlattenPhase})$ File format specifications/contents provided in metadata: - Measurement Type [Flattened Phase], - Reference Polarization [HH/HV/VV/VH], - Data Format [GeoTIFF/NetCDF, ...], - Data Type [Int/Float, ...], - Bits per Sample, - Byte Order. In case of polarimetric data, indicate the reference polarization.

2.7.2.6 Requirements - 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 for the data to be analysis ready.

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

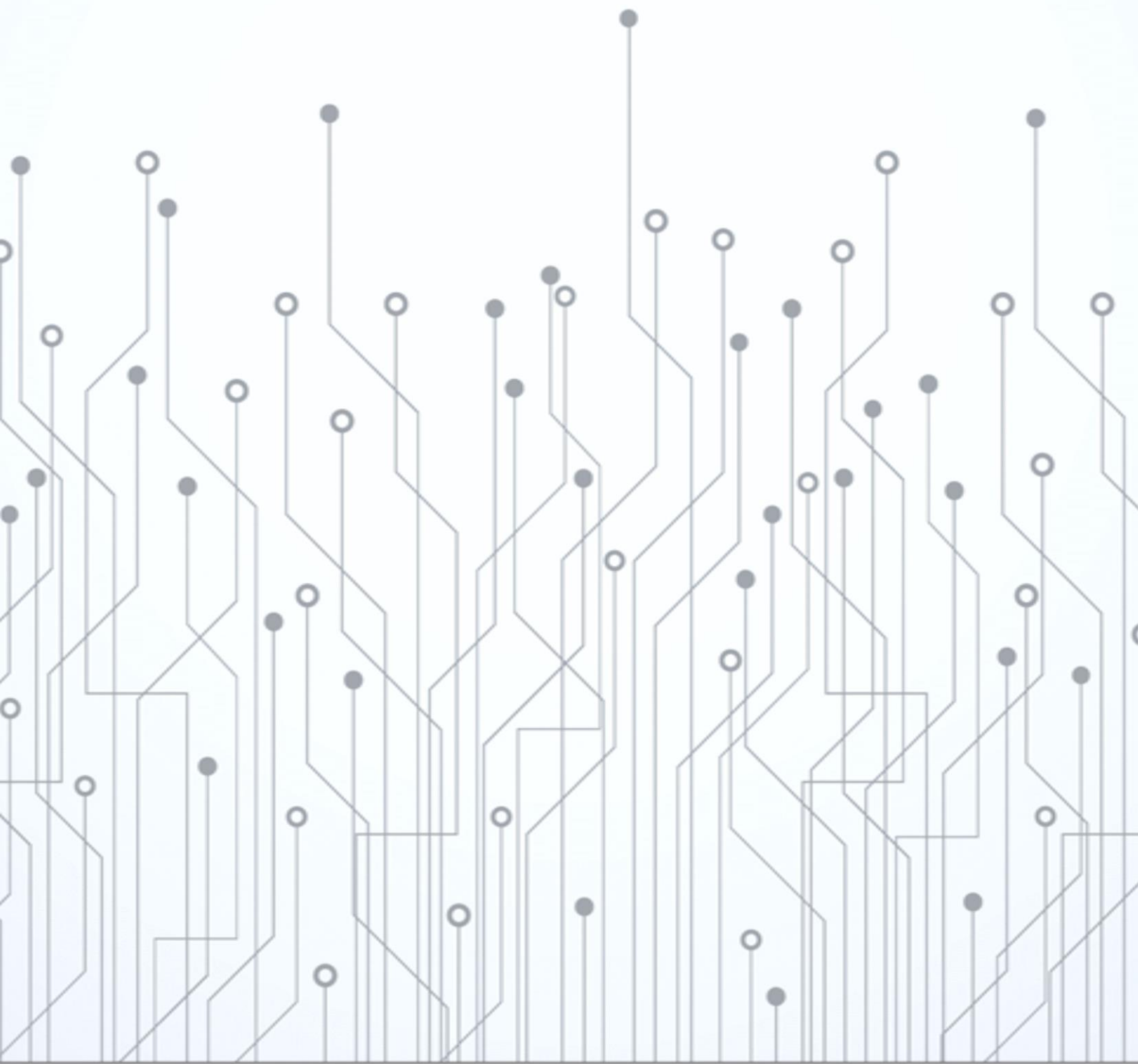
Table 12: Geometric Corrections Requirements - Synthetic Aperture Radar (SAR)

#	Parameter	CEOS-ARD product	Requirements
4.1		[NRB] [POL]	Threshold (Minimum) Requirements Not required.

#	Parameter	CEOS-ARD product	Requirements
	Geometric Correction Algorithm	[ORB] [GSLC]	<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. <i>Note: Examples of technical documentation can include e.g., an Algorithm Theoretical Basis Document (ATBD), a product user guide.</i>
4.2	Digital Elevation Model	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Usage: For products including land areas - 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. - Provide reference to Digital Elevation Model used for geometric terrain correction. - Provide reference to Earth Gravitational Model (EGM) used for geometric correction. <u>Goal (Desired) Requirements</u> - 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. - Resampling method used for preparation of the DEM. - Method used for resampling the EGM.
4.3	Geometric Accuracy	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> 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. <i>Note 1: This assessment is often made through comparison of measured corner reflector positions with their projected location in the imagery. In some cases, other mission calibration/validation results may be used.</i> <i>Note 2: The ALE is not typically assessed for every processed image, but through an ALE assessment by the data processing team characterizing all or (usually a subset) of the generated products.</i> <u>Goal (Desired) Requirements</u>

#	Parameter	CEOS-ARD product	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.
4.4	Geometric Refined Accuracy	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> Not required.
			<u>Goal (Desired) Requirements</u> Values provided under 4.3 Geometric accuracy (Table 12) are provided by the SAR mission Calibration and Validation activities (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.
4.5	Gridding Convention	[NRB] [POL] [ORB] [GSLC]	<u>Threshold (Minimum) Requirements</u> A consistent gridding/sampling frame is used. The origin is chosen to minimize 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. * <i>* If a product hierarchy of resolutions exists (or is planned), the multiple resolutions should nest within each other (e.g., 12.5m, 25m, 50m, 100m, etc.), and not be disjoint.</i>
			<u>Goal (Desired) Requirements</u> 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.

3. Supplementary Informative Elements



3.1 Annex 1 - Normalised Radar Backscatter [NRB]

3.1.1 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](#).
- 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 3.1.2](#))
- 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 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 13 lists possible sequential steps and existing software tools (e.g., Gamma software (<https://www.gamma-rs.ch/software>)) and scripting tasks that can be used to form the CEOS-ARD SAR processing roadmap.

Table 13: 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

3.1.2 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 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 $\Delta\phi_{1-2}$ between two SAR acquisitions is composed of a topographic phase $\Delta\phi_{Topo_{1-2}}$, a surface displacement phase $\Delta\phi_{Disp_{1-2}}$ and other noise terms $\Delta\phi_{Noise_{1-2}}$ (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.

$$\Delta\phi_{1-2} = \Delta\phi_{Topo_{1-2}} + \Delta\phi_{Disp_{1-2}} + \Delta\phi_{Noise_{1-2}} \quad \text{Eq. A1.1}$$

Where:

$$\Delta\phi_{Topo_{1-2}} = \phi_{DEM_SLC_1} - \phi_{DEM_SLC_2} \quad \text{Eq. A1.2}$$

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 $\Delta\phi_{Topo_OrbRef-2}$ 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 ($\phi_{DEM_SLC_1}$). 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, to preserve the relevant compensated phase in between them. Providing absolute reference orbit number information in the metadata allows users to validate the InSAR feasibility in between CEOS-ARD products.

$$\phi_{Flattened_SLC_2} = \phi_{SLC_2} - \Delta\phi_{Topo_OrbRef-2} \quad \text{Eq. A1.3}$$

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 $\phi_{Flattened_SLC}$, 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:

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

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

For POL product, the Flattened phase needs also to be subtracted from the complex number phase of the off-diagonal elements of the covariance matrix.

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.

$$\begin{aligned}\varphi_{Flattened_GSLC_1} &= \varphi_{SLC_1} - \Delta\varphi_{Topo_OrbRef-1} = \varphi_{SLC_1} - \varphi_{DEM_OrbRef} - \varphi_{DEM_SLC_1} \\ \varphi_{Flattened_GSLC_2} &= \varphi_{SLC_2} - \Delta\varphi_{Topo_OrbRef-2} = \varphi_{SLC_2} - \varphi_{DEM_OrbRef} - \varphi_{DEM_SLC_2}\end{aligned}\quad \text{Eq. A1.4}$$

The differential phase is:

$$\Delta\varphi_{CARD_1-CARD_2} = \varphi_{Flattened_GSLC_1} - \varphi_{Flattened_GSLC_2} \quad \text{Eq. A1.5}$$

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

$$\Delta\varphi_{CARD_1-CARD_2} = (\varphi_{SLC_1} - \varphi_{DEM_OrbRef} - \varphi_{DEM_SLC_1}) - (\varphi_{SLC_2} - \varphi_{DEM_OrbRef} - \varphi_{DEM_SLC_2}) \quad \text{Eq. A1.6}$$

$$\Delta\varphi_{CARD_1-CARD_2} = (\varphi_{SLC_1} - \varphi_{SLC_2}) - (\varphi_{DEM_SLC_1} - \varphi_{DEM_SLC_2}) \quad \text{Eq. A1.7}$$

$$\Delta\varphi_{CARD_1-CARD_2} = \Delta\varphi_{SLC_1-SLC_2} - \Delta\varphi_{Topo_1-2} \quad \text{Eq. A1.8}$$

Where $\Delta\varphi_{SLC_1-SLC_2}$ can be express as Eq. A1.1, which gives:

$$\Delta\varphi_{CARD_1-CARD_2} = (\Delta\varphi_{Topo_1-2} + \Delta\varphi_{Disp_1-2} + \Delta\varphi_{Noise_1-2}) - \Delta\varphi_{Topo_1-2} \quad \text{Eq. A1.9}$$

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 and ionospheric phase corrections could be performed during the production of CEOS-ARD products, which reduces the differential phase noise in an InSAR analysis.

$$\Delta\varphi_{CARD_1-CARD_2} = \Delta\varphi_{Disp_1-2} + \Delta\varphi_{Noise_1-2} \quad \text{Eq. A1.10}$$

3.2 Annex 2: Polarimetric Radar [POL]

3.2.1 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

$$C3 = \begin{bmatrix} |HH|^2 & \sqrt{2} \cdot HH \cdot HV^* & HH \cdot VV^* \\ \sqrt{2} \cdot HV \cdot HH^* & 2 \cdot |HV|^2 & \sqrt{2} \cdot HV \cdot VV^* \\ VV \cdot HH^* & \sqrt{2} \cdot VV \cdot HV^* & |VV|^2 \end{bmatrix} \quad \begin{matrix} \text{Eq.} \\ \text{A2.1} \end{matrix}$$

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

Dual polarization

HH-HV

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

VV-VH

$$C2 = \begin{bmatrix} |VH|^2 & VH \cdot VH^* \\ VH \cdot VH^* & |VV|^2 \end{bmatrix} \quad or$$

Eq. A2.2

CH-CV

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

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 quad polarization.

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

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).

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

3.2.2 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° diplane (even-bounce interaction) [Intensity],
 $|\gamma|^2$: 45° 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 14: Cameron (nine classes) – non-dimensional layers

Classes	ID
Trihedral	1
Dihedral	2
Narrow Dihedral	3
Dipole	4
Cylinder	5
$\frac{1}{4}$ 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 on intensity of scattering mechanisms. ([Freeman and Durden, 1998](#); [Yamaguchi et al., 2011](#); [Raney et al., 2012](#))

Table 15: Intensity of scattering mechanisms

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].

3.2.3 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 4 b) shows HH intensity of a RADARSAT fully polarimetric imagery acquired over a Spanish area. Decomposition using Yamaguchi methodology ([Yamaguchi et al., 2011](#)) can be expressed in RGB color composite (Figure 4 c) 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 4 d) is equivalent to c) where radiometric normalisation (terrain flattening) has been applied with the help of the DEM of the scene (Figure 4 a).

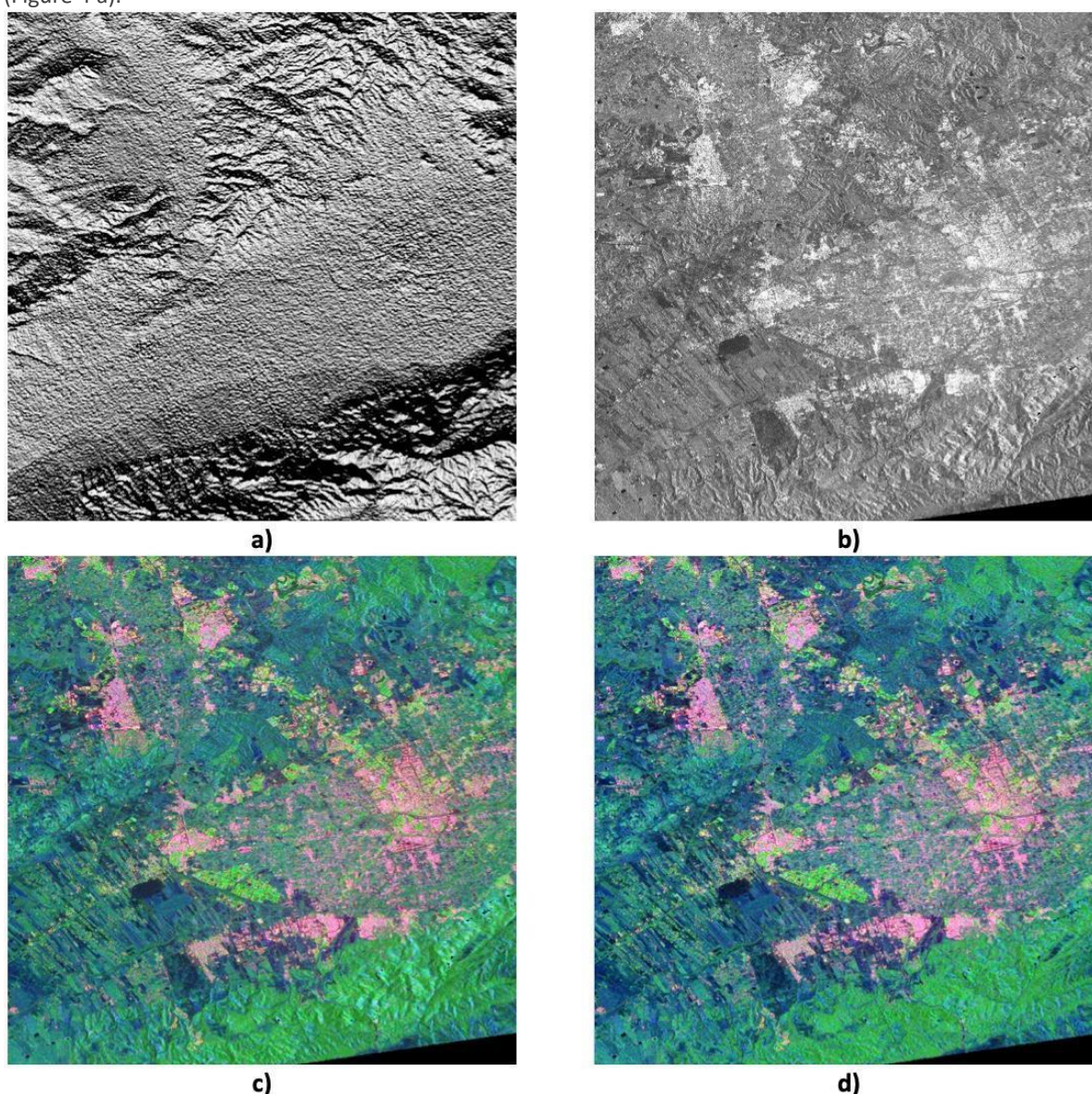


Figure 4: Example of polarimetric decomposition generated from ARD covariance format. a) Shaded DEM of the area; b) RADARSAT-2 HH intensity; c) Yamaguchi decomposition color composite (Red: even bounce, Green: random, Blue: odd bounce); d) Same as c) with terrain flattening option. Generated from Radarsat-2 FQ18W acquired over Murcia, Spain on 18 June 2014 ©MDA 2014

Figure 5 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 5 a), m-chi shows mainly surface scattering from bare soil (blue channel) and vegetation interaction from forested areas (green channel), while in June (Figure 5 b) 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.

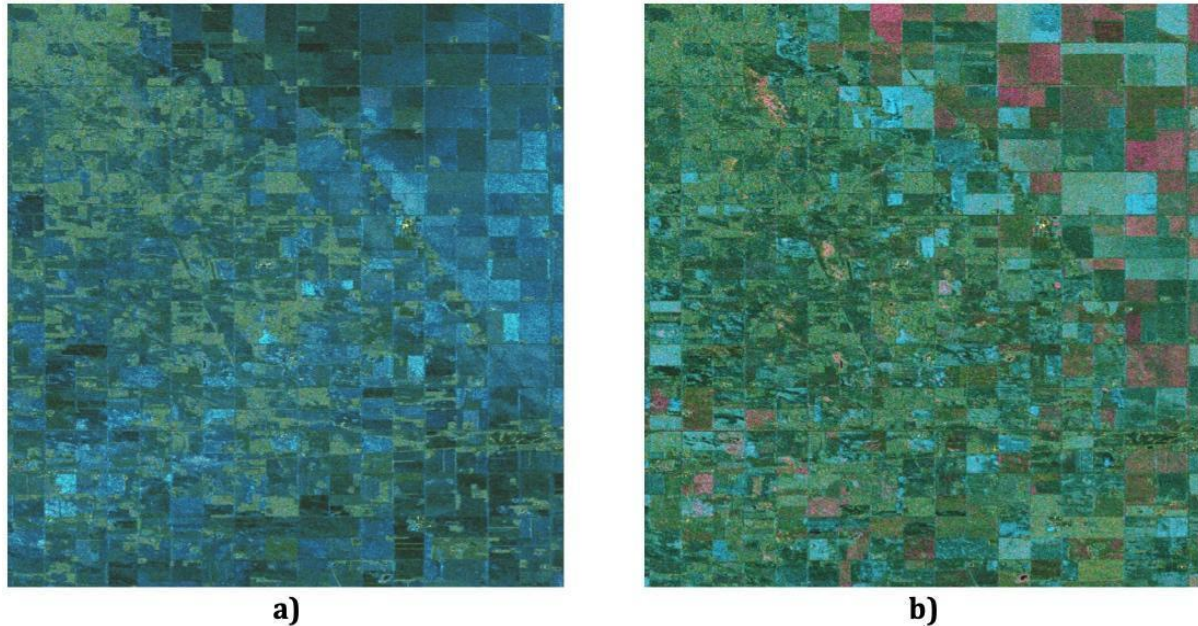


Figure 5: m-chi decomposition color composite of simulated compact polarimetry from Radarsat-2 over an agriculture area. RGB representation: Red: even bounce, Green: random, Blue: odd bounce. a) 3 May 2012; and b) 18 June 2012. Generated from Radarsat-2 FQ6W acquired over SMAPVEX12 campaign Manitoba, Canada on 3 May and 20 June 2012 ©MDA 2012

3.3 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 6 a), which is recommended for most ocean applications. In addition, availability of the “Local (or Ellipsoidal) Incidence Angle Image” (Figure 6 d) and “Look Direction Image” per-pixel metadata are highly recommended since they required for operational applications like ocean wind field estimates.

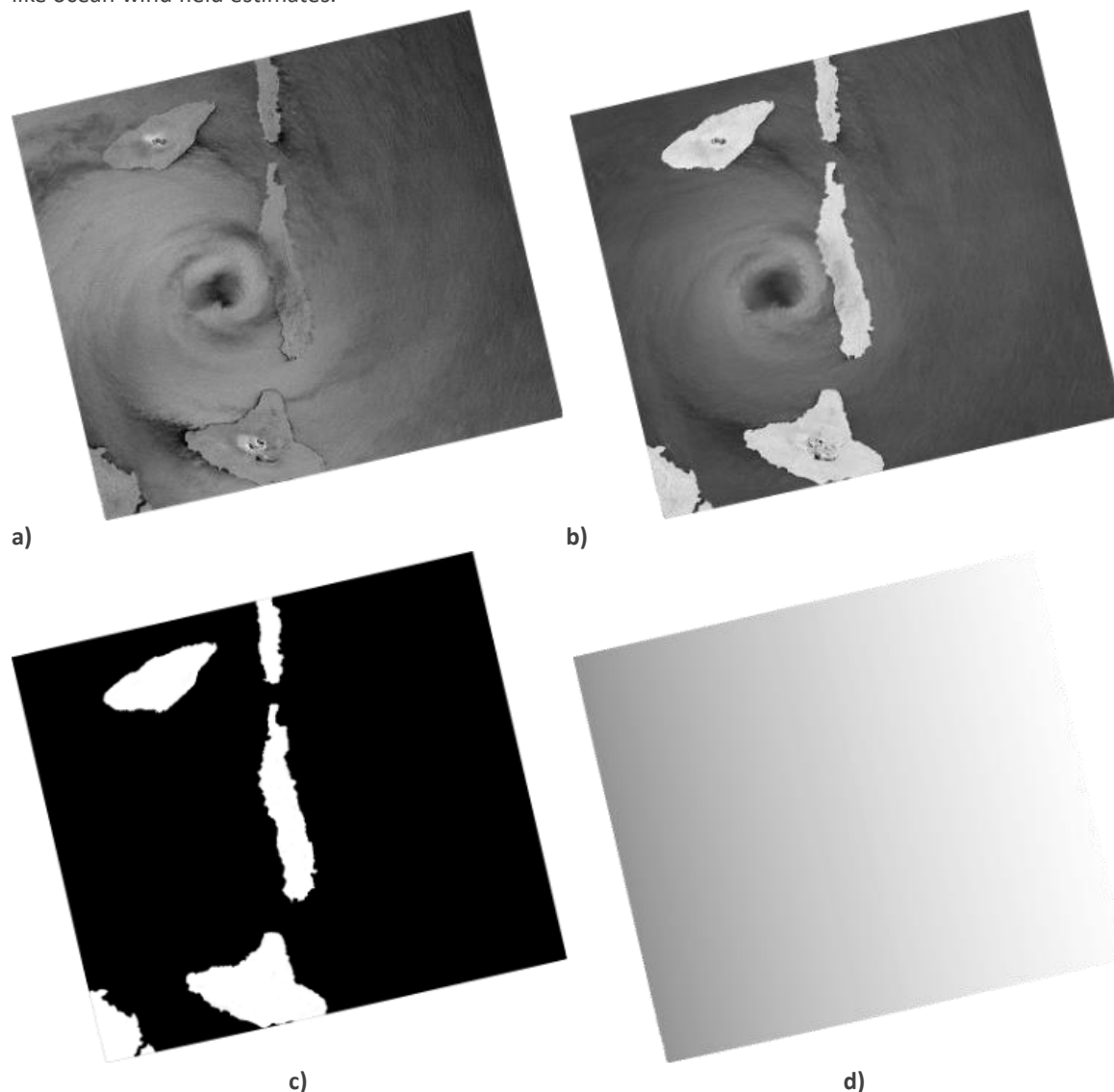


Figure 6: Sentinel-1 ORB product. Tropical Cyclone Harold passing Vanuatu on April 6, 2020. a) VV intensity b) VH intensity c) Data mask image d) Local incident angle. Processing: A. Rosenqvist (soloEO).

Another useful file is the “Mean Wind-Normalised Backscatter Measurements” (Figure 7 b) 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.

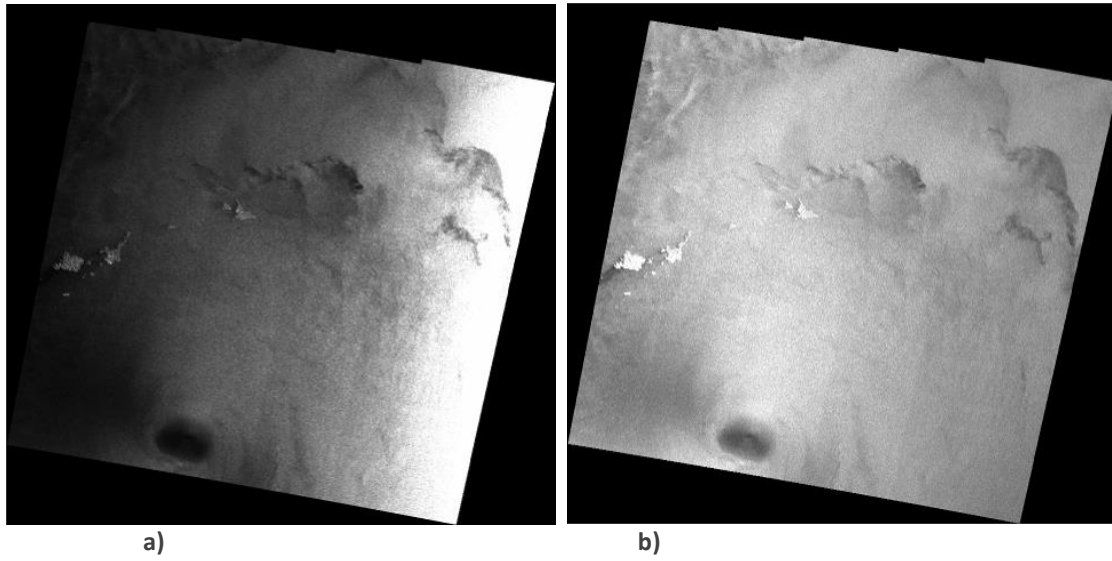


Figure 7: Sentinel-1 EW ORB product. a) ORB intensity (Sigma-Nought); b) Intensity compensated with the “Mean Wind-Normalised Backscatter Measurement” (i.e., not Sigma-Nought) and geocoded. Processing: G. Hajduch (CLS).

3.4 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 8 a) and Figure 8 b), allows user-friendly production of a first iteration of the InSAR coherence (Eq. A4.1 and Figure 8 c) and differential phases (Eq. A4.2 and Figure 8 d) 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. 4.1.

InSAR differential phase:
$$\varphi = \arg(\rho)$$
 Eq. A4.2

Some advanced NRB or POL products could include per-pixel “Flattened Phase” data. 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

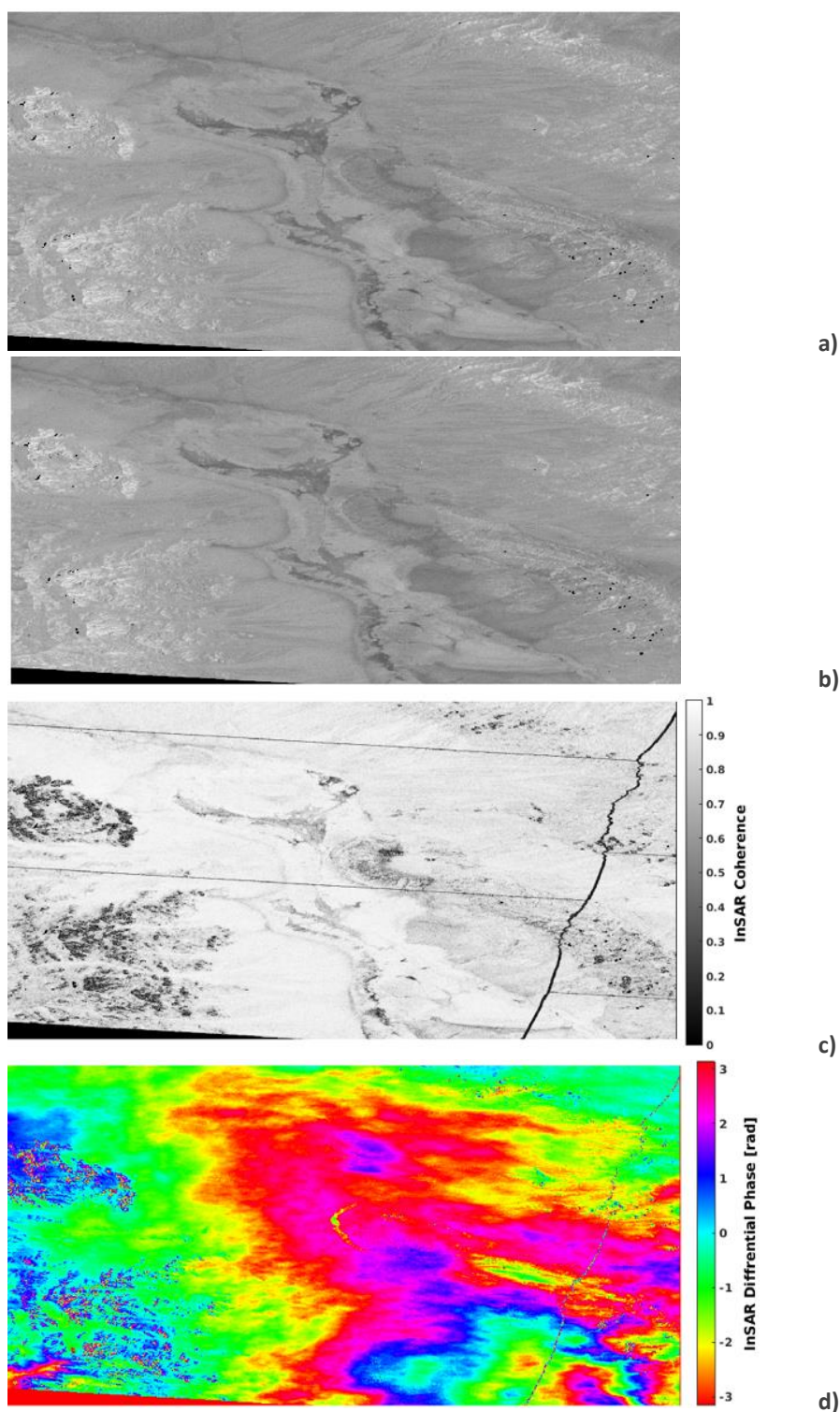


Figure 8: Sentinel-1 [GSLC] products example over Death Valley National Park, California, US. a) GSLC1: Intensity data of the first [GSLC] product (2017-05-27); b) GSLC2: Intensity data of the second [GSLC] product (2017-06-08); c) InSAR coherence map generated directly from A4.1a) and b); d) InSAR differential phase map generated directly from A4.1a) and b).

Some advanced GSLC products can be provided with Radar Unit Look Vector Grid Image per-pixel metadata (Figure 9) 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.

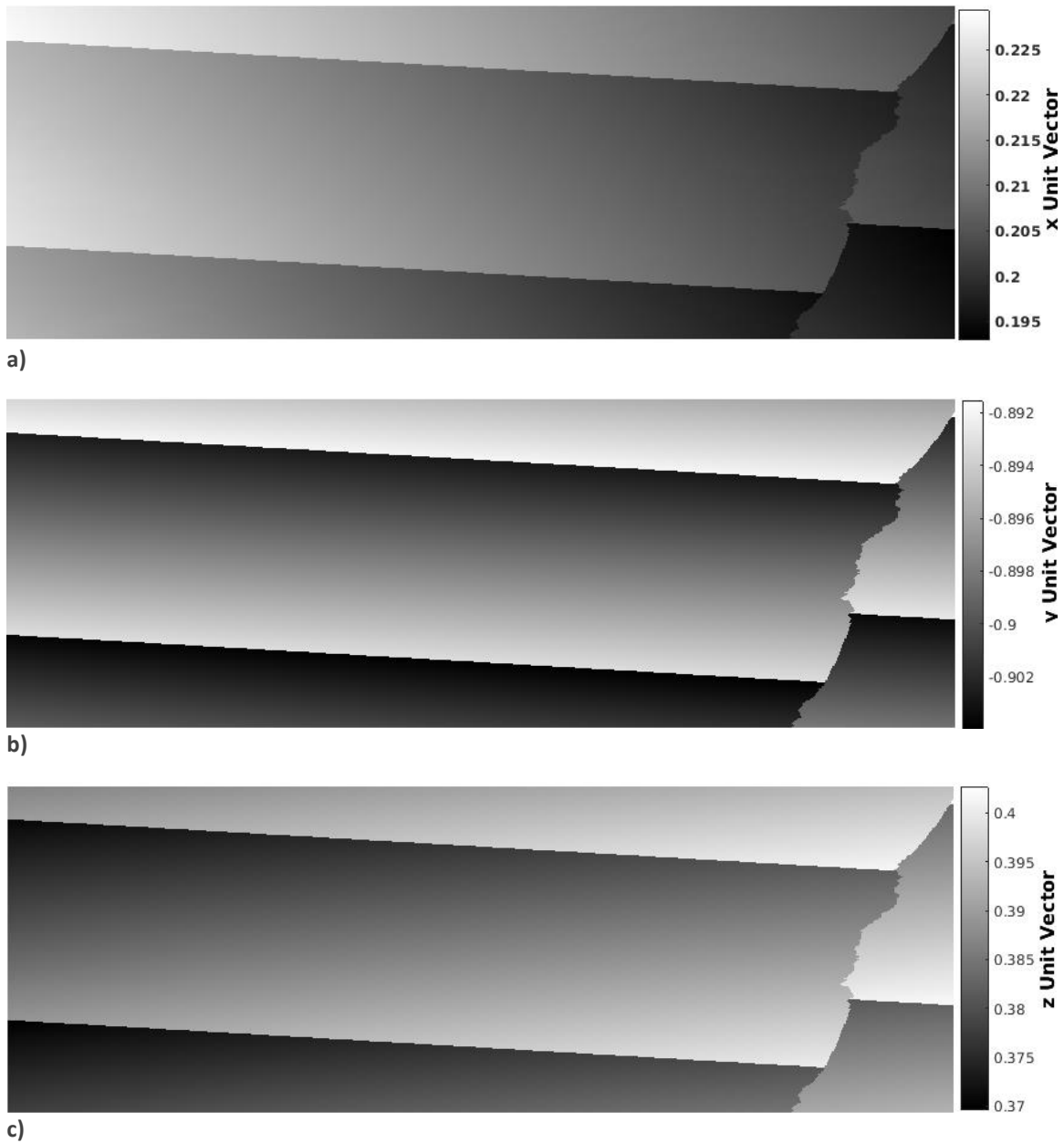


Figure 9: 3-D components radar unit look vector of the [GSLC] product in Figure 5. a) x unit component; b) y unit component; c) z unit component.

3.5 Annex-5 - Guidelines for Geometric Correction of EO Imagery

3.5.1 Introduction

The Kingdom of Saudi Arabia Framework for Analysis Ready Data (KS-RS-ARD) provides the set of criteria and assessment tools to evaluate data to ensure it meets the requirements of ARD.

The aim of ARD is for data providers to deliver data that already have geometric corrections applied. This negates the need for the user to be concerned with the complexities of geometric correction that involves the need for Ground Control Points (GCPs), Digital Elevation Models (DEM's) and Orthorectification, as these are considered pre-processing steps to be undertaken by the provider prior to delivering an ARD product.

However, certain situations exist where users may have a need to undertake their own geometric correction steps. This annex provides further guidelines and guidelines for undertaking geometric correction of EO Imagery. This includes Ground Control Points (GCP's) and Digital Elevation Model (DEM) data required for the orthorectification process required for achieving the desired goals of positional accuracy.

Full guidelines for the requirements relating to Field Surveys, Ground Control, DEM and Positional Accuracies are to be found in:

- Guidelines for Land Surveying for the Kingdom of Saudi Arabia ()
- Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia ()

3.5.2 Application

Surface Reflectance Product Family Guidelines (PFS) refer to data collected with multispectral optical sensors operating in the VIS/NIR/SWIR (Visible/Near Infrared/Short-wave Infrared) wavelengths at all ground sample distances and resolutions.

These additional guidelines are applicable to Earth Observation (EO) satellite remote sensed data in the Surface Reflectance - High Resolution Imagery (KSA-RS-ARD-HR) category, defined as Ground Sample Distances (GSDs) in the range 0.2 to 2m.

As high resolution EO imagery is a logical extension of aerial acquired imagery, the guidelines of accuracies need to meet the standards as provided in the Aerial Survey Guidelines document Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia ()

These high resolution EO imagery guidelines are largely sensor agnostic and equally applicable to data acquired from aerial sensors and high-resolution satellite sensors. Positional Accuracies are not absolute but related to GSD.

This guideline is focused on the use of high resolution EO Imagery where the most accurate data product is required. For this case the use of high accuracy GCP s and Orthorectification is specified.

Other less rigorous correction methods, such as transformations models and the use of lower accuracy GCPs, are possible but are not defined in this guideline.

For EO Imagery of urban areas, additional care is needed when sourcing EO imagery data to minimize distortions resulting from changes in ground elevation and oblique satellite viewing angles.

3.5.3 Ground Control Points (GCPs)

Control points are used to develop a mathematical model between two different coordinate systems, that of the image co-ordinates present in the EO image and a more precise map projection space. GCPs are treated as the precise known co-ordinate values that the EO image must fit to.

The source and accuracy of the GCP has an influence on the ultimate accuracies in the final data product.

Professionals see GCPs as an expensive and time-consuming necessity for image production. The challenge is to find an accurate, consistent, and cost-effective source of GCPs.

Better sensors also cover more land area with lower costs and thus there is larger demand for updated imagery products with higher resolution, improved accuracy and repeatability for monitoring purposes.

The principle of using GCPs relies on obtaining accurate map co-ordinates for points that can be identified in the EO imagery. This accurately positions the EO image. Multiple of such points, when well placed, serve to accurately fix the image at these points. In the case of high-resolution imagery, and in cases of high terrain displacement, a further process of orthorectification is needed to remove distortions from the full EO image extents.

This section provides a brief overview of ground control topics required for geometric correction of EO Imagery. Ground control guidelines applicable to high resolution EO Imagery are similar to those for aerial imagery. For detailed guidelines and guidelines applicable to aerial imagery, including ground control requirements, the reader is referred to Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia ().

The GCPs are applied when using a precise orthorectification model where terrain displacements are removed. Orthorectification is essential for high resolution imagery where terrain displacement is most noticeable and where the use case of the EO data requires the most accurate mapping.

The guidelines for GCPs apply to traditional means of acquiring such points such as field (GNSS) survey techniques.

Surveyors should refer to Guidelines for Land Surveying for the Kingdom of Saudi Arabia () for field surveying techniques.

Alternative methods such as automated point extraction from high resolution-image clips, for example from high resolution stereo radar imagery data, are also applicable. These methods are briefly described below.

3.5.3.1 Field Surveys

The standard and classic approach to survey GCPs is in the field with GNSS equipment. It is the most flexible method since the surveyor can choose the exact feature in the field to be surveyed. Another advantage is the centimeter accuracies achievable.

However, there are disadvantages in that the survey team has to physically reach the location. This may present problems such as distances to travel, security, denied areas, high costs, vast geographical areas that exist.

Most of the points are collected by state-of-the-art GNSS technology in order to ensure the highest accuracy (if required). However, some points are in areas which are difficult to access due to inaccessible terrain, military restrictions or simply the high travel costs. In these cases, points can be derived from other remotely sensed data.

3.5.3.2 Remote Sensed Ground Control Points

Co-ordinates from remotely sensed sources (such as image clips from radar or accepted reference imagery) can be provided with an accuracy better than 1m and can support mapping from scales 1:2,500 to 1:10,000. These derived points provide a cost-effective alternative to field surveyed points.

In the absence of precise field surveyed GCPs, the most reliable approach to orthorectification is to register all images to a single controlled image base - a reference image.

Commercial EO Imagery providers have developed services for providing image clips of identifiable points with known co-ordinate values. These “clips” can be used in place of rigorous field surveyed points provided that the accuracies exceed the accuracies of the final data product being created.

3.5.3.3 Selection of Ground Control Points

There are several aspects that should be considered to ensure the suitability of a GCP's features for orthorectification of EO imagery. For high resolution imagery, the criteria for GCP selection follows the choice of GCPs for aerial photography and use in photogrammetry. These are provided below:

Selection Criteria

- **Suitability** - be a 'suitable' type of feature as described below.
- **Identifiable** – the points selected must be identifiable in the EO image. A surveyor in the field needs to consider if the point chosen is in fact identifiable in the image even though it seems like an obvious choice in the field.
- **Permanent & Repeatable** - control points should define features that will not move or disappear. This is most relevant to multi-image studies since the points can effectively be considered as a 'library' of accurately located features for repeated use.
- **Distribution** - the points need to be well spread over the study area rather than clustered in a few areas. Ideally the points should be chosen to fall outside the polygon extents of the Area of Interest (AOI), well distributed and placed at the extremities of the polygon shape, (in the case of a rectangular block AOI, to fall in the corners of the block). These are more desirable than points only inside the AOI or clustered in only a part of the AOI.
- **Source** - the 'accuracy' of the rectified image is limited by the 'accuracy' of the source of the GCPs. In the case of GCPs sourced from an existing base image / base map, these accuracies can only be as good as the accuracy of the source map/image.
- **Contrast** – the selected feature should have high contrast with its surroundings and have well defined edges to ensure easier identification.
- **Size** – the feature should be scale appropriate and of a suitable size to be clearly identified in the imagery, to suit the resolution of the EO Imagery, preferably in the range 2 to 5 pixels in the shortest dimension. For example, a small feature of less than 2m is not easily identifiable in an image with 2m GSD.
- **Image Overlaps** - where possible, the feature is to be located in the overlap between adjacent image swaths. This effectively serves to tie the swaths together with a common point.
- **Spacing** – for the avoidance in confusion with identification, be at least 250 meters from any other surveyed control point.
- **Elevation values** – The GCP's must include an accurate elevation value for vertical positioning of the geometry relative to the terrain model. For those sites collected by GPS field methods an accurate elevation value is to be observed. In cases of derived GCPs, an elevation value can be extracted from an underlying Lidar-based or other DEM.

Ground features suitable for control points include:

- Narrow roads with intersection angles of at least 50°,
- Centre points of quasi-circular features,
- Road-watercourse junctions.

Examples of unsuitable ground features included:

- Edges of inland waterbodies,
- Edges of roads (especially where the surface changes),
- Coastal features subject to tidal variation,
- Linear features intersecting at an angle of less than 50°,
- Road intersections where the intersection cannot be identified precisely,
- Features larger than about 5 pixels in extent,
- Features that are not clearly identifiable in the supplied EO imagery, or
- Features that appear off nadir (oblique) in the EO Imagery.

3.5.3.4 Premarked GCP

It is not always possible to place control points where they are needed for sound model fitting. Examples are desert areas with very few or no identifiable features in the imagery. In these cases, as in aerial photography it is possible to place pre-marks. These are constructed marks that can be field surveyed and identified in the EO Imagery. The marks need to be of sufficient size and shape to be identifiable and need to be constructed prior to the acquisition of the EO imagery.

The Photo Control Points (PCP) shall be established as high contrast markers by pre-marking of existing geodetic network points or by constructing and pre-marking new ground control point beacons that are clearly visible in the EO Imagery.

Some permanent beacons located in desert areas are constructed with a wide base around the survey beacon, which may be visible in the EO Image or could be pre-marked with paint or other temporary means such as sandbags or plastic sheeting prior to the acquisition of the imagery.

Examples are provided in the Figure 10 photos.

The size of the premarks shall be related to the imagery GSD according to the following rules:

- Premark Leg length – 10x GSD,
- Leg width – 3x GSD.

These are recommended minimum dimensions. The best method of establishing pre-marks to meet the requirements of being well defined, visible in the imagery, easy and safe access for marking and completion of field (GNSS) surveys.



Figure 10: Examples of Premark Ground Control Points

3.5.4 Geometric Correction

Various geometric distortion effects exist in EO imagery. These may be related to characteristics of the sensor and/or the platform used to acquire the imagery, or to the shape or rotation of the earth.

These distortions need to be removed to provide imagery that is fit-for-use in GIS and user applications. To ensure that the geometry of the resulting image is consistent, the EO data is generally resampled to align with a selected map coordinate system.

While models for satellite positioning are increasingly accurate, that accuracy is not yet as high as orthorectification of imagery with precise ground positioning. To accurately rectify an image containing these distortions (or to register an image to another coordinate system) control points are generally used.

Accurate and consistent rectification is essential to ensure that observations are taken at different times, from different sources, and in the field can be compared. Image registration error should ideally be less than the image pixel size because this allows each pixel to be compared 'with itself' through time.

Whilst it is possible to ensure high relative accuracy within a given type of imagery (by co-registration of all images to an initial base image of arbitrary accuracy) this is of limited benefit because it does not allow comparison with different data sources, including field observations. Accurate, repeatable rectification is therefore essential for monitoring, as well as for many other scientific and practical uses of EO data. In particular, the advantages of higher resolution imagery may be lost if accurate rectification is not possible.

Multiple transformation models are needed to proceed from the sensor image geometry to a final map projected geometry. EO data providers provide the first levels of the known nominal models, which account for quantifiable geometric distortions in the EO image and map projection. The first step is to convert both sets of coordinates into model coordinates. The final step consists of a precise orthorectification method.

The general approach in undertaking precise digital orthophoto rectification is to use EO Sensor Ephemeris information as supplied with the EO formatted imagery and a suitable DEM to generate an initial orbit and view geometry model, which is further optimised with multiple GCP's. The orthorectification process uses the DEM to correct the image pixel-by-pixel so that the resulting orthorectified image provides geolocated coordinates for each pixel.

Orthorectification depends on accurate GCPs and an appropriate digital elevation model (DEM), for use with specialised image processing software routines.

3.5.4.1 Source of DEM

To achieve the best positional accuracies in the EO rectified orthoimage, it is essential that a DEM of equivalent accuracy and resolution is used. For urban areas this may exist as a photogrammetry or LiDAR produced DEM. Alternatives sources are high quality DEM products available from the high resolution EO providers. Examples are precision 3D data products from MAXAR, Airbus WorldDEM, and TerraSAR-X and TanDEM-X DATA of the European Space Agency.

A further alternative is to produce derived heighting data from EO imagery stereo pairs. This, however, has a cost overhead as stereo capture seldom exists off-the-shelf and needs to be specially tasked by the EO Imagery data provider.

A special consideration when working with satellite imagery EO Surface Reflectance (SR) data is that often the imagery is acquired from an oblique viewing angle. This off-nadir situation has an adverse effect on accuracies. These are provided in the table from the DEM Sources section of the Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia () document.

3.5.4.2 Orthorectification

The EO imagery shall be orthorectified using suitable ground control data and digital terrain model data appropriate to the accuracy requirements listed. Other, less precise methods of correction such as rubber sheeting are not permitted to achieve the aims of this guideline, namely the precise rectification of EO Imagery in the High-Resolution category.

Resampling (up sampling) of a GSD significantly greater than the desired capture GSD for any of the respective areas is not an accepted methodology.

There must be no distortions in the imagery due to an inadequate Digital Surface Model (DSM). The estimated accuracy of the DSM must be provided.

If pan-sharpening techniques are to be used, based on sensor guidelines, then the methodology for this process needs to be described.

Building displacement is to be minimized. EO Imagery scenes photos must be selected to maximize the nadir position and minimize the effect of building lean.

3.5.5 Mosaicking

Mosaicking is the process of merging adjacent imagery datasets to provide a single continuous resultant image with minimal distortions in the join and with minimal color and appearance variations. Suitable proven software shall be utilized for image mosaicking, to produce continuous seamless imagery.

3.5.5.1 Seamlines

The mosaicking process must ensure seamlines are not visible in the final digital orthophoto product.

Careful planning and some manual editing are expected to ensure that optimal seamlines are used, and occlusions are minimized.

Mosaicking seamlines should run through road reserves or vacant land. In urban areas, no mosaic seam lines should be evident through buildings or elevated features such as bridges and trees.

The mosaicking process must ensure the following:

- The joins between all tiles are to be seamless, with no gaps, overlaps, or visible join lines between adjacent images.
- The pixels on adjacent tiles must align.
- Features at ground level (such as buildings, roads, valleys, ridges) are continuous across mosaic seam lines.
- No duplication of features occurs along seam lines.
- Seamlines shall cross linear features at close to 90 degrees.

A shapefile of the location of the seamlines shall be delivered. The shapefile is to be attributed with the date and time of capture for each image section.

3.5.5.2 Color Balancing, Contrast & Brightness

Color balancing across the whole project area is expected to be consistent and seamless so that no frame differentiation is identifiable.

The contrast and brightness of each image should be adjusted to minimize the color variation between images in adjacent frames. Color balance across the whole mosaic must be optimized to allow quality color discrimination whilst still providing the best possible tonal match across the image.

The mosaicking of images shall:

- Ensure there are no noticeable exposure patches to detract from the photographic image.
- Ensure differences in contrast and brightness between images within a tile are minimized.

- Minimize the difference in contrast and brightness between adjacent tiles.

Suitable frames may need to be selected to ensure bright sunlight reflectance from roofs does not mask detail (e.g. solar panels).

The final orthophoto imagery should be fully color balanced in order to ensure an even colored mosaic.

Detail should not be lost as a result of atmospheric conditions, including clouds, smoke or excessive shadow coverage. Where shadow is present, the dynamic range of the image should be such as to provide the ability to recognize features in the shadow areas. Similarly, the dynamic range of the imagery must ensure images are not over exposed in areas that contain high reflectance.

All Adjustments and color samples shall be approved in a draft form before proceeding with final orthophoto mosaicking.

3.5.6 Digital Orthophoto Deliverables

The Digital Orthophoto product shall be delivered to meet the following requirements:

- Geo-referenced and provided in the following formats:
 - Uncompressed GeoTIFF (.tif) with an associated World file (.tfw),
 - ECW compressed (.ecw) with a maximum compression of 10 times.
- White background color shall apply,
- 1km x 1km tiled imagery covering the AOI extents,
- Positional Accuracy RMSE_x & RMSE_y – 2 pixels
- Agreed file naming convention,
- Orthophoto Mosaics, 3 band and 8-bits per band (channel) for:
 - 3 Band RGB Natural Color (RGB),
 - 3 Band False Color Infrared (NIR, G, B),
 - Alternatively, 4 Band (NIR, R,G,B).
- Imagery and associated data are to be supplied on hard disk or through a cloud based transfer mechanism,
- Digital Orthophoto Processing, Quality & Delivery Reports (PDF format),
- Seamline files (.shp format),
- Metadata (as a PDF document) must be supplied detailing all relevant information, including date of capture, sensor guidelines, accuracy etc.

3.5.7 Positional Accuracies

A specific ARD requirement for SR relating to geometric correction is contained in Table 7: General Corrections Requirements - Surface Reflectance. The ARD Threshold Requirement is that the imagery data shall achieve sub-pixel accuracy in a relative geolocation for the pixels from the same instrument and platform, rendering them consistently located, and thus comparable, through time.

The ARD goal requirement is that the imagery data shall achieve sub-pixel accuracy relative to an identified absolute independent terrestrial referencing system (such as a national map grid). A consistent gridding/sampling frame is necessary to meet this requirement.

Positional accuracies need to meet the standards as provided in the Aerial Survey Guidelines document Guidelines for Aerial Surveying for the Kingdom of Saudi Arabia (). Horizontal, Vertical and Positional Accuracies are presented in the Positional Accuracy Standard for Geospatial Products – General section of that guideline.

The accuracy classes of the ASPRS Guidelines are sensor agnostic and although primarily focused on very high-resolution aerial photogrammetry and aerial LiDAR, these accuracy classes are equally applicable to lower resolution data such as those acquired from satellite sensors.

The resulting orthoimage is assessed for accuracy at a selection of independent GCP across the final rectified data product.

Accuracies shall be determined by measuring plan positions of well-defined features in the final digital orthophoto imagery and comparing these with field surveyed values.

3.6 Symbols, Acronyms and Abbreviations

Symbols, Acronyms and Abbreviations	Definition
ACDD	Attribute Convention for Data Discovery
ALE	Absolute Geolocation Error
ALOS	Advanced Land Observing Satellite
AOI	Area-of-Interest
API	Application Programming Interface
API-EDR	Environmental Data Retrieval API
ARD	Analysis Ready Data
ASPRS	America Society of Photogrammetry & Remote Sensing
ATBD	Algorithm Theoretical Basis Document
BRDF	Bi-Directional Reflectance Function correction
Cal/Val	Calibration and Validation activities
CEOS	Committee of Earth Observation Satellites
CEOS LSI-VC	CEOS Land Surface Imaging-Virtual Constellation
CEOS-ARD-SAR	CEOS Synthetic Aperture Radar Analysis Ready Data
CEP	Circular Error Probability
CF	CF metadata conventions
CMOD	C-band model
COG	Cloud Optimized GeoTIFF
CovMat	Normalized Covariance Matrix
CRS	Coordinate Reference System
CSDMS	Community Surface Dynamics Modelling System
CSW	OGC Catalog Service for Web
DCC	Deep Convective Clouds
DEFLATE	Lossless Data Compression File Format
DEM	Digital Elevation Model
DGGS	Discrete global grid systems
DOI	Digital Object Identifier
DSM	Digital Surface Model
ECEF	Earth-Centred Earth-Fixed coordinate system (also called Earth Centred Rotating – ECR)
ECR	Earth Centred Rotating

Symbols, Acronyms and Abbreviations	Definition
ECW	Enhanced Compression Wavelet format
EDOT	Enhanced Definitive Orbit Tool
EGM	Earth Gravitational Model
EM	Electromagnetic
EMR	Electromagnetic Radiation
ENL	Equivalent Number of Looks
EO	Earth Observation
EPSG	European Petroleum Survey Group
FIR	Far Infrared
GCMD	Global Change Master Directory
GCP	Ground Control Point
GDAL	Geospatial Data Abstraction Library
GEOSA	General Authority for Survey and Geospatial Information, Kingdom of Saudi Arabia
GeoTIFF	Geo-referenced Tag Image File Format
GIS	Geographic Information System
GML	Geographic Markup Language
GNSS	Global Navigation Satellite System
GSD	Ground Sampling Distance
GSLC	CEOS-ARD Geocoded Single-Look Complex
HDF5	Hierarchical Data Format version 5
HH/HV/VV/VH	Polarization
InSAR	Interferometric Synthetic Aperture Radar
IR	Infrared
ISO	International Organization for Standardization
ISO/TC	International Organization for Standardization Technical Committee
JPEG	Joint Photographic Experts Group
KSA	Kingdom of Saudi Arabia
KSA-RS-ARD	Remote Sensing Specifications for the Kingdom of Saudi Arabia - KSA Remote Sensing KSA-RS-ARD Specifications
KSA-RS-ARD-HR	Surface Reflectance – High Resolution Imagery
LLC	Lower Left Corner
LUT	Look-Up Table
LWIR	Long Wavelength Infrared
MIR	Middle Infrared

Symbols, Acronyms and Abbreviations	Definition
MWIR	Mid-Wavelength (or Medium Wave) Infrared
NetCDF	Network Common Data Form
NIR	Near Infrared
NISAR	NASA-ISRO Synthetic Aperture Radar
NRB	CEOS-ARD Normalised Radar Backscatter
OGC	Open Geospatial Consortium
OGC ARD SWG	OGC Analysis Ready Data Standards Working Group
ORB	CEOS-ARD Ocean Radar Backscatter
PCP	Photo Control Point
PFS	Product Family Specification
PICS	Pseudo-Invariant Calibration Sites
POL	CEOS-ARD Polarimetric Radar
PRD	Polarimetric Radar Decomposition
RADARSAT	Radar Satellite
RCM	Radar Satellite Constellation Mission
RFI	Radio Frequency Interference
RMS	Root Mean Square
rRMSE	Radial Root Mean Square Error
RTC	Radiometric Terrain Correction
SAOCOM	Satélite Argentino de Observación Con Microondas
SAR	Synthetic Aperture Radar
SDK	Software Development Kit
SI	The International System of Units
SLC	Single-Look Complex
SOP	Standard Operating Procedure
SR	Surface Reflectance
STAC	Spatio-Temporal Asset Catalog
SWG	Standards Working Group
SWIR	Short-Wave Infrared
TIR	Thermal Infrared
ULC	Upper Left Corner
UPS	Universal Polar Stereographic

Symbols, Acronyms and Abbreviations	Definition
URL	Uniform Resource Locator
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VIS	Visible
WCS	OGC Web Coverage Service
WFS	OGC Web Feature Service
WGS 84	World Geodetic System 1984
WKT-CRS	Well-Known Text representation of Coordinate Reference Systems
XML	Extensible Markup Language

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