CEOS-ARD - Optical - Surface Reflectance

Draft Version

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

Document Status

Product Family Specification, Optical, Surface Reflectance

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

Contributing Authors

- Adam Lewis, Geoscience Australia, Australia
- Jonathon Ross, Geoscience Australia, Australia
- Andreia Siqueira, Geoscience Australia, Australia
- Darcie Bontje, USGS, USA
- Steve Labahn, USGS, USA
- Mary Metzger, USGS, USA
- Matt Steventon, LSI-VC Secretariat

Table of Contents

Draft Version
Document Status
Contributing Authors
CEOS Analysis Ready Data Definition

Description
Definitions and Abbreviations
Requirements
1. General Metadata
1.1. Traceability
1.2. Metadata Machine Readability
1.3. Data Collection Time
1.4. Geographical Area
1.5. Coordinate Reference System
1.6. Map Projection
1.7. Geometric Correction Methods
1.8. Geometric Accuracy of the Data
1.9. Instrument
1.10. Spectral Bands
1.11. Sensor Calibration
1.12. Radiometric Accuracy
1.13. Algorithms
1.14. Auxiliary Data
1.15. Processing Chain Provenance
1.16. Data Access
1.17. Overall Data Quality
2. Per-Pixel Metadata
2.1. Metadata Machine Readability
2.2. No Data
2.3. Incomplete Testing
2.4. Saturation
2.5. Cloud
2.6. Cloud Shadow
2.7. Land/Water Mask
2.8. Snow/Ice Mask
2.9. Terrain Shadow Mask
2.10. Terrain Occlusion
2.11. Solar and Viewing Geometry
2.12. Terrain Illumination Correction
3. Radiometric and Atmospheric Corrections
3.1. Measurement
3.2. Measurement Uncertainty
3.3. Measurement Normalisation
3.4. Directional Atmospheric Scattering
3.5. Water Vapour Corrections
3.6. Ozone Corrections
4. Geometric Corrections
4.1. Geometric Correction
Introduction
What is CEOS Analysis Ready Data?
When can a product be called CEOS-ARD?
What is the difference between Threshold and Goal?
References
Document History
Version 5.0.2 (2026-05-27)

CEOS Analysis Ready Data Definition

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

Description

Product Family Specification: Optical, Surface Reflectance (SR)

Version: 5.0.2-draft

Applies to: Data collected with multispectral optical sensors operating in the VIS/NIR/SWIR wavelengths at all ground sample distances and resolutions.

Definitions and Abbreviations

ATBD
: Algorithm Theoretical Basis Document

Auxiliary Data
: The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources, e.g., DEM, aerosols.

BRDF
: Bi-Directional Reflectance Function

CEOS-ARD
: Committee on Earth Observation Satellites - Analysis Ready Data

CEP
: Circular Error Probability, often provided with an additional percentage (e.g. CEP90 for 90% probability)

DEM
: Digital Elevation Model

DOI
: Digital Object Identifier

GIS
: Geographic Information System

NIR
: Near Infrared

RMSE
: Root Mean Square Error

rRMSE
: Radial Root Mean Square Error

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

SR
: Surface Reflectance

SWIR
: Shortwave Infrared

UTC
: Coordinated Universal Time

VIS
: Visible

WGS84
: World Geodetic System 1984

Requirements

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

1. General Metadata

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

1.1. Traceability

Identifier: `meta-trace-sr`

Threshold requirements:

Not required.

Goal requirements:

Data must be traceable to SI reference standard.

Notes:

1. Relationship to Radiometric and Atmospheric Corrections: Measurement Uncertainty. Traceability requires an estimate of measurement uncertainty.
2. Information on traceability should be available in the metadata as a single DOI landing page.

1.2. Metadata Machine Readability

Identifier: `meta-memare-optical`

Threshold requirements:

Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.

Goal requirements:

As threshold, but metadata should be provided in a community endorsed standard that facilitates machine-readability, such as ISO 19115-2.

1.3. Data Collection Time

Identifier: `meta-time-sr`

Threshold requirements:

The data collection time is identified in the metadata, expressed in date/time, to the second, with the time offset from UTC unambiguously identified.

Goal requirements:

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

Identifier: `meta-geoarea-optical`

Threshold requirements:

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., WGS84).

Goal requirements:

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

Identifier: `meta-crs-optical`

Threshold requirements:

The metadata lists the coordinate reference system that has been used.

Goal requirements:

As threshold.

1.6. Map Projection

Identifier: `meta-mapproj-sr`

Threshold requirements:

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.

Goal requirements:

As threshold.

1.7. Geometric Correction Methods

Identifier: `meta-geocorm-sr`

Threshold requirements:

Not required.

Goal requirements:

Information on geometric correction methods should be available in the metadata as a single DOI landing page, including reference database and auxiliary data such as elevation model(s) and reference chip-sets.

1.8. Geometric Accuracy of the Data

Identifier: `meta-geoacc-sr`

Threshold requirements:

Not required.

Goal requirements:

The metadata includes metrics describing the assessed geodetic accuracy of the data, expressed units of the coordinate system of the data. Accuracy is assessed by independent verification (as well as internal model-fit where applicable). Uncertainties are expressed quantitatively, for example, as root mean square error (RMSE) or Circular Error Probability (CEP90, CEP95), etc.

Note:

1. Information on geometric accuracy of the data should be available in the metadata as a single DOI landing page.

1.9. Instrument

Identifier: `meta-instru-optical`

Threshold requirements:

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

Goal requirements:

As threshold, 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

Identifier: `meta-specband`

Threshold requirements:

The central wavelength for each band for which data is included is identified in the metadata, expressed in SI units.

Goal requirements:

As threshold, with instrument spectral response details (e.g., full spectral response function) also included or directly accessible using details in the metadata. Central wavelength and bandwidth at full-width half maximum value of the relative spectral response function are provided at least.

Note:

1. Information on spectral bands should be available in the metadata as a single DOI landing page.

1.11. Sensor Calibration

Identifier: `meta-sencal-optical`

Threshold requirements:

Not required.

Goal requirements:

Sensor calibration parameters are identified in the metadata or can be accessed using details included in the metadata. Ideally this would support machine-to-machine access.

Note:

1. Information on sensory calibration should be available in the metadata as a single DOI landing page.

1.12. Radiometric Accuracy

Identifier: `meta-radacc-sr`

Threshold requirements:

Not required.

Goal requirements:

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, Rayleigh, DCC, etc.)

Note:

1. Information on radiometric accuracy should be available in the metadata as a single DOI landing page.

1.13. Algorithms

Identifier: `meta-malgos-sr`

Threshold requirements:

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.

Note:

1. Information on algorithms should be available in the metadata as a single DOI landing page.

Goal requirements:

As threshold, but only algorithms that have been published in a peer-reviewed journal.

Notes:

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.

2. Information on algorithms should be available in the metadata as a single DOI landing page.

1.14. Auxiliary Data

Identifier: `meta-auxdat-optical`

Threshold requirements:

The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as a single DOI landing page.

Note:

1. Auxiliary data includes DEMs, aerosols, etc. data sources.

Goal requirements:

As threshold, but information on auxiliary data should be available in the metadata as a single DOI landing page and is also available for free online download, contemporaneously with the product or through a link to the source.

1.15. Processing Chain Provenance

Identifier: `meta-proprov-sr`

Threshold requirements:

Not required.

Goal requirements:

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

Identifier: `meta-daccess`

Threshold requirements:

Information on data access should be available in the metadata as a single DOI landing page.

Note:

1. Manual and offline interaction action (e.g., login) may be required.

Goal requirements:

As threshold.

1.17. Overall Data Quality

Identifier: `meta-odqual`

Threshold requirements:

Not required.

Goal requirements:

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. Per-Pixel Metadata

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

2.1. Metadata Machine Readability

Identifier: `pxl-pimemare`

Threshold requirements:

Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.

Goal requirements:

As threshold.

2.2. No Data

Identifier: `pxl-pinodat`

Threshold requirements:

Pixels that do not correspond to an observation (‘empty pixels’) are flagged.

Goal requirements:

As threshold.

2.3. Incomplete Testing

Identifier: `pxl-pincot`

Threshold requirements:

The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed.

Note:

1. This may be the result of missing ancillary data for a subset of the pixels.

Goal requirements:

The metadata identifies which tests have, and have not, been successfully completed for each pixel.

2.4. Saturation

Identifier: `pxl-pisatur`

Threshold requirements:

Metadata indicates where one or more pixel in the input spectral bands are saturated.

Goal requirements:

Metadata indicates which pixels are saturated for each spectral band.

2.5. Cloud

Identifier: `pxl-picloud`

Threshold requirements:

Metadata indicates whether a pixel is assessed as being cloud.

Goal requirements:

As threshold, but information on cloud detection should be available in the metadata as a single DOI landing page.

2.6. Cloud Shadow

Identifier: `pxl-picloudsh`

Threshold requirements:

Metadata indicates whether a pixel is assessed as being cloud shadow.

Goal requirements:

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

Identifier: `pxl-lawama-sr`

Threshold requirements:

Not required.

Goal requirements:

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

Identifier: `pxl-snowice-sr`

Threshold requirements:

Not required.

Goal requirements:

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

Identifier: `pxl-tershad`

Threshold requirements:

Not required.

Goal requirements:

The metadata indicates pixels that are not directly illuminated due to terrain shadowing.

2.10. Terrain Occlusion

Identifier: `pxl-terocc`

Threshold requirements:

Not required.

Goal requirements:

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

Identifier: `pxl-vigeso`

Threshold requirements:

Provide average solar and sensor viewing azimuth and zenith angles.

Goal requirements:

Provide per-pixel solar and sensor viewing azimuth and zenith angles.

2.12. Terrain Illumination Correction

Identifier: `pxl-piteric`

Threshold requirements:

Not required.

Goal requirements:

Coefficients used for terrain illumination correction are provided for each pixel.

3. Radiometric and Atmospheric Corrections

The following requirements must be met for all pixels in a collection. The requirements indicate both the necessary outcomes and the minimum steps necessary to be deemed to have achieved those outcomes.

3.1. Measurement

Identifier: `rac-measur-sr`

Threshold requirements:

Pixel values are expressed as a measurement of the Surface Reflectance of the land. This is a dimensionless value.

Note:

1. Radiometric corrections must lead to a valid measurement of surface reflectance.

Goal requirements:

Surface Reflectance measurements are SI traceable (see also General Metadata: Traceability).

3.2. Measurement Uncertainty

Identifier: `rac-muncer-sr`

Note: 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.

Threshold requirements:

Not required.

Goal requirements:

An estimate of the certainty of the values is provided in measurement units.

Notes:

1. This is a requirement for SI traceability. See also General Metadata: Traceability.
2. Information on measurement uncertainty should be available in the metadata as a single DOI landing page.

3.3. Measurement Normalisation

Identifier: `rac-mnormal-sr`

Threshold requirements:

Not required.

Goal requirements:

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.

Note:

1. Information on measurement normalisation should be available in the metadata as a single DOI landing page.

3.4. Directional Atmospheric Scattering

Identifier: `rac-dirats-sr`

Threshold requirements:

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

Note:

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

Goal requirements:

As threshold.

3.5. Water Vapour Corrections

Identifier: `rac-wavap-sr`

Threshold requirements:

Corrections are applied for water vapour. Metadata contains a single DOI landing page with references to:

- a citable peer-reviewed algorithm
- technical documentation regarding the implementation of that algorithm

Note:

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

Goal requirements:

As threshold.

3.6. Ozone Corrections

Identifier: `rac-cozone-sr`

Threshold requirements:

Not required.

Goal requirements:

Data is corrected for ozone.

Relevant metadata must be provided under General Metadata: Geometric Accuracy of the Data and General Metadata: Instrument.

Metadata contains a single DOI landing page with references to:

- a citable peer-reviewed algorithm
- technical documentation regarding the implementation of that algorithm

4. Geometric Corrections

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

4.1. Geometric Correction

Identifier: `gcor-geocorr-sr`

Threshold requirements:

Sub-pixel accuracy is achieved in **relative** geolocation, that is, the pixels from the same instrument and platform are consistently located, and are 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 General Metadata: Geometric Accuracy of the Data and General Metadata: Instrument.

Note:

1. The threshold level will not necessarily enable interoperability between data from **different** sources as the geometric corrections for each of the sources may differ.

Goal requirements:

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 General Metadata: Geometric Accuracy of the Data and General Metadata: Instrument.

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.

Introduction

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

What is CEOS Analysis Ready Data?

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

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

When can a product be called CEOS-ARD?

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

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

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

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

What is the difference between Threshold and Goal?

Threshold (Minimum) requirements are the **minimum** that is needed for the data to be analysis ready. This must be practical and accepted by the data producers.

Goal (Desired) requirements (previously referred to as “Target”) are the ideal; where we would like to be. Some providers may already meet these.

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

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

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

References

International Organization for Standardization. 2009. *Geographic information — Metadata — Part 2: Extensions for imagery and gridded data*. Standard. International Organization for Standardization.

Li, Fuqin, David L. B. Jupp, Medhavy Thankappan, et al. 2012. “A Physics-Based Atmospheric and BRDF Correction for Landsat Data over Mountainous Terrain.” *Remote Sensing of Environment* 124: 756–70. https://doi.org/https://doi.org/10.1016/j.rse.2012.06.018.

Document History

Editorial changes are not listed.

Version 5.0.2 (2026-05-27)

Editors: Matthias Mohr

Building Block	Change	Level
Document	• Renamed CARD4L to CEOS-ARD • Restructured the document; removed empty or unused parts • Document history has been reset. Check the previous versions for details • Numerical identifiers were rotated and are deprecated; new textual identifiers have been added • The requirement “Radiometric corrections must lead to a valid measurement […]” has been moved from the category description to the measurement requirement. • If no threshold requirement applies, the wording has been made consistent (e.g. former req. 1.7 and 1.8). • Former req. 2.13 has been removed as it had neither a threshold nor a goal requirement.	minor

The history of the versions before 5.0.2 is available in the older versions of this document, see the CEOS-ARD website or the GitHub releases.