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|  | **Analysis Ready Data** | **Product Family Specification:**  **Optical Data** |

# Document Status

**Product Family Specification, Optical Data**

Proposed revisions may be provided to: [ard-contact@lists.ceos.org](mailto:ard-contact@lists.ceos.org)

# Document History

| **Version** | **Date** | **Description of change** | **Affected CEOS-ARD product** | **Author** |
| --- | --- | --- | --- | --- |
| 0.1 | 14-06-2024 | Zero Draft based on CEOS-ARD-SR v5.0.1, CARD4L-ST v5.0, CARD4L-AR v1.0, and CARD4L-NLSR v1.0 | - |  |
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# CEOS Analysis Ready Data Definition

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

# Description

**Product Family Specification Title: Optical (CEOS-ARD Optical)**

**Applies to:** Data collected by Optical sensors

# Background to CEOS-ARD for Optical PFS:

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

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

* Surface Reflectance [version 5.0.1]
* Surface Temperature [version 5.0]
* Aquatic Reflectance [version 1.0]
* Nighttime Light Surface Radiance [version 1.0]

The **CEOS-ARD Surface Reflectance [SR]** product specification applies to data collected with multispectral optical sensors operating in the VIS/NIR/SWIR wavelengths at all ground sample distances and resolutions.

The **CEOS-ARD Surface Temperature [ST]** product specification applies to data collected with multispectral sensors operating in the thermal infrared (TIR) wavelengths. These typically operate with ground sample distance and resolution in the order of 10-100m; however, the Specification is not inherently limited to this resolution.

At present, surface temperature measurements tend to be provided as either surface brightness temperature (SBT) or as land surface temperatures (LST) requiring the SBT to be modified according to the emissivity of the target. This specification identifies the Surface Temperature (ST) as being the minimum or Threshold requirement for analysis ready land surface data. Nevertheless, both SBT and LST are land measurements, requiring atmospheric corrections.

The **CEOS-ARD Aquatic Reflectance (AR)** product specification applies to data collected with multispectral and hyperspectral sensors operating in the VIS/NIR/SWIR wavelengths over water bodies. These typically operate with ground sample distance and resolution in the order of 10-1000 m; however, the specification is not inherently limited to this resolution.

The **CEOS-ARD** **Nighttime Light Surface Radiance [NLSR]** product specification applies to data collected with nighttime light sensors operating in the VIS/NIR wavelengths. These typically operate with ground sample distance and resolution in the order of 10-1000m; however, the Specification is not inherently limited to this resolution.

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, in order to optimize their interoperability.

For this generic **CEOS-ARD for Optical** PFS, as for the individual **[SR]**, **[ST]**, **[AR]**, and **[NLSR]** 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 Optical missions and the data provider constraints. Since this document integrates four CEOS-ARD PFSs, it is worth noting that some requirements have been “relaxed” for a few Threshold parameters, depending on the applications/environment of the CEOS-ARD product. Exceptions are identified in the tables by specifying the usage.

# Definitions and Abbreviations

|  |  |
| --- | --- |
| 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. |
| AR | Aquatic Reflectance |
| 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 |
| DOI | Digital Object Identifier |
| LST | Land Surface Temperature |
| 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. |
| MTF | Modulation Transfer Function |
| NIR | Near Infrared |
| NLSR | Nighttime Light Surface Radiance |
| SBT | Surface Brightness Temperature |
| 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. |
| SR | Surface Reflectance |
| ST | Surface Temperature |
| SWIR | Shortwave Infrared |
| TIR | Thermal Infrared |
| VIS | Visible |

# 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 Optical product (SR, ST, AR, NLSR) the parameter refers.*

| **#** | **Parameter** | **CEOS-ARD product** | **Requirements** | **Self-Assessment** |
| --- | --- | --- | --- | --- |
| **1.1** | **Traceability** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Data must be traceable to SI reference standard.  *Note 1: Relationship to 3.2. Traceability requires an estimate of measurement uncertainty.*  *Note 2: Information on traceability should be available in the metadata as a single DOI landing page.* |
| **1.2** | **Metadata Machine Readability** | [SR]  [ST]  [AR]  [NLSR] | **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. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) 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. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  The surface location to which the data relate is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g., WGS84 coordinates). | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  The metadata lists the coordinate reference system that has been used. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **1.6** | **Map Projection** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  The metadata lists the map projection that has been used and any relevant parameters required in relation to use of data in that map projection. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **1.7** | **Geometric Correction Methods** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required.  The user is not explicitly advised of the geometric correction source and methods. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required.  The user is not provided with results of geometric accuracy assessments pertaining to the dataset. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  The instrument used to collect the data is identified in the metadata. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  The central wavelength for each band for which data is included is identified in the metadata, expressed in SI units. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required.  The general metadata does not include sensor calibration details. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **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.  *Note 1: Information on sensor calibration should be available in the metadata as a single DOI landing page.* |
| **1.12** | **Radiometric Accuracy** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required.  The general metadata does not include information on the radiometric accuracy of the data. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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, PICS, Rayleigh, DCC, etc.).  *Note 1: Information on radiometric accuracy should be available in the metadata as a single DOI landing page.* |
| **1.13** | **Algorithms** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold, but only algorithms that have been published in a peer-reviewed journal.  *Note 1: It is possible that high-quality corrections are applied through non-disclosed processes. CARD4L does not per-se require full and open data and methods.*  *Note 2: Information on algorithms should be available in the metadata as a single DOI landing page.* |
| **1.14** | **Auxiliary Data** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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, the organization that performed the processing, the versions of software used, and information on the data collection baseline, giving full transparency to users. |
| **1.16** | **Data Access** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) 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*. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **1.17** | **Overall Data Quality** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not applicable. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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. |

## Per-Pixel Metadata

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

*The column “CEOS-ARD product” indicates to which CEOS-ARD Optical product (SR, ST, AR, NLSR) the parameter refers.*

| **#** | **Parameter** | **CEOS-ARD product** | **Requirements** | **Self-Assessment** |
| --- | --- | --- | --- | --- |
| **2.1** | **Metadata Machine Readability** | [SR]  [ST]  [AR]  [NLSR] | **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 part for further use. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.2** | **No Data** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Pixels that do not correspond to an observation (e.g., ‘empty pixels/invalid observation/below noise floor’) are flagged. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.3.1** | **Incomplete Testing** | [SR]  [ST]  [NLSR] | **Threshold (Minimum) 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata identifies which tests have, and have not, been successfully completed for each pixel. |
| **2.3.2** | **Per-Pixel Assessment** | [AR] | **Threshold (Minimum) 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata identifies which tests have, and have not, been successfully completed for each pixel. |
| **2.4.1** | **Saturation** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Metadata indicates where one or more spectral bands are saturated. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Metadata indicates which pixels are saturated for each spectral band. |
| **2.4.2** | **Cloud** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Metadata indicates whether a pixel is assessed as being cloud. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold, information on cloud detection should be available in the metadata as a single DOI landing page. |
| **2.4.3** | **Cloud Shadow** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Metadata indicates whether a pixel is assessed as being cloud shadow. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold, but information on cloud shadow detection should be available in the metadata as a single DOI landing page. |
| **2.4.4** | **Land/Water Mask** | [SR]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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. |
| **2.4.5** | **Snow/Ice Mask** | [SR]  [ST]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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. |
| **2.4.6** | **Terrain Shadow Mask** | [SR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates pixels that are not directly illuminated due to terrain shadowing. |
| **2.4.7** | **Terrain Occlusion** | [SR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates pixels that are not visible to the sensor due to terrain occlusion during off-nadir viewing. |
| **2.4.8** | **Sea/ Lake/River Ice Mask** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel is assessed as being sea/lake/river ice or not. Information on sea/lake/river ice mask should be available in the metadata as a single DOI landing page. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold |
| **2.4.9** | **Sun Glint** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel is assessed as absent or correctable (moderate), or uncorrectable (severe) Sun glint.  *Note 1: Sun glint is deemed uncorrectable if the upper limit of the dynamic range of a sensor is reached (i.e., saturation occurs).* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates the amount of Sun glint for each pixel and band. |
| **2.4.10** | **Sky Glint** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates the amount of sky glint for each pixel and band. |
| **2.4.11** | **Whitecap/ Foam Mask** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel is assessed as affected by whitecaps or foam as a function of the wind speed or other. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.5** | **Solar and Viewing Geometry** | [SR]  [ST]  [AR] | **Threshold (Minimum) Requirements**  Provide average solar and sensor viewing azimuth and zenith angles. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Provide per-pixel solar and sensor viewing azimuth and zenith angles. |
| **2.6** | **Lunar and Viewing Geometry** | [NLSR] | **Threshold (Minimum) Requirements**  Provide average lunar and sensor viewing azimuth and zenith angles. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Provide per-pixel lunar and sensor viewing azimuth and zenith angles. |
| **2.7** | **Terrain Illumination Correction** | [SR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Coefficients used for terrain illumination correction are provided for each pixel. |
| **2.8** | **Adjacency Effects** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata provides the risk of per-pixel adjacency effects contamination, through flagging to denote per-pixel minimum, medium or high adjacency effects contamination.  *Note 1: This effect often occurs in increased turbid or optically shallow waters near shorelines that may confuse this assessment.* |
| **2.9** | **Floating Vegetation/ Surface Scum Mask** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel is assessed as affected by floating vegetation/surface scum. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.10** | **Aerosol Optical Depth Parameters** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates either per-pixel spectral Aerosol Optical Depth (AOD), or per-pixel AOD (550nm) and Angstrom exponent. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.11** | **Deep/Shallow Water** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates where available: the bottom depth referenced to the mean sea level for the oceans and referenced to mean levels for lakes. Information on bathymetry should be available in the metadata as a single DOI landing page. |
| **2.12** | **Optically Deep or Optically Shallow Assessment** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates, based on likelihood (bathymetry maps and average Kd (preferred) or based on turbidity or Secchi disk transparency), whether water pixels may be optically deep or optically shallow. This will most likely be bathymetry map contour based. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Based on an assessment from an inversion algorithm that estimates the optically deep or optically shallow per-pixel status. |
| **2.13** | **Turbid Water Flag** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel is assessed as being turbid or not. Information on turbid water mask should be available in the metadata as a single DOI landing page. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.14** | **Bidirectional Reflectance Distribution Function** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Metadata indicates which pixels are corrected for BRDF effects. |
| **2.15** | **Altitude (ASL)** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates approximate altitude (ASL) of water body pixels is required for atmospheric correction (range = -430 to ~6500m). | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.16** | **Moon Illumination Fraction** | [NLSR] | **Threshold (Minimum) Requirements**  Provide average moon illumination fraction. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Provide per-pixel moon illumination fraction. |
| **2.17** | **Brightness Temperature** | [NLSR] | **Threshold (Minimum) Requirements**  Provide brightness temperature from thermal bands. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **2.18** | **Solar Zenith Angle** | [NLSR] | **Threshold (Minimum) Requirements**  Provide solar zenith angle to support stray-light corrections (see also 3.16). | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |

## Radiometric and Atmospheric Corrections

The 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. Cloud optimized file formats are recommended.

*The column “CEOS-ARD product” indicates to which CEOS-ARD Optical product (SR, ST, AR, NLSR) the parameter refers.*

| **#** | **Parameter** | **CEOS-ARD product** | **Requirements** | **Self-Assessment** |
| --- | --- | --- | --- | --- |
| **3.1** | **Measurement** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  SR: Pixel values that are expressed as a measurement of the Surface Reflectance of the land. This is a dimensionless value  ST: Pixel values that are expressed as a measurement of the Surface Temperature of the land, expressed as Kelvin  AR: Pixel values that are expressed as a measurement of the Aquatic Reflectance (AR=pi\*Rrs) or the Remote Sensing Reflectance (sr-1) of the water bodies. This is a dimensionless value  NLSR: Pixel values that are expressed as a measurement of the nighttime light radiance | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Measurements are SI traceable (see also 1.1). |
| **3.2** | **Measurement Uncertainty** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required.  *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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  An estimate of the certainty of the values is provided in measurement units.  *Note 1: This is a requirement for SI traceability. See also 1.1.*  *Note 2: Information on measurement uncertainty should be available in the metadata as a single DOI landing page.* |
| **3.3** | **Measurement Normalisation** | [SR]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Measurements are normalised for solar and viewing conditions (i.e., nadir view angle and average solar angles). This may include terrain illumination, radiative transfer modelling, 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.* |
| **3.4.1** | **Directional Atmospheric Scattering** | [SR] | **Threshold (Minimum) 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.4.2** | **Corrections for Atmosphere and Emissivity** | [ST] | **Threshold (Minimum) Requirements**  Retrieval methods for estimating surface temperature are provided.  *Note 1: The metadata references (may be through a single DOI landing page) a citable peer-reviewed algorithm.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.4.3** | **Atmospheric Reflectance Correction** | [AR] | **Threshold (Minimum) Requirements**  Metadata indicates corrections are applied for molecular (Rayleigh) scattering and aerosol scattering and absorption.  Metadata contains a single DOI landing page with references to a citable peer-reviewed algorithm, technical documentation regarding the implementation of that algorithm and 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.4.4** | **Atmospheric Corrections** | [NLSR] | **Threshold (Minimum) Requirements**  Corrections are applied for atmospheric 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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.5** | **Water Vapour Corrections** | [SR]  [AR] | **Threshold (Minimum) Requirements**  Corrections are applied for water vapour if spectral bands are affected.  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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.6** | **Ozone Corrections** | [SR]  [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Data is corrected for ozone.  Relevant metadata must be provided under 1.8 and 1.9.  Metadata contains a single DOI landing page with references to:   * A citable peer-reviewed algorithm * Technical documentation regarding the implementation of that algorithm |
| **3.7** | **Other Trace Gaseous Absorption Corrections** | [AR] | **Threshold (Minimum) Requirements**  Data is corrected for other trace gaseous absorption if spectral bands are affected.  Relevant metadata must be provided under 1.8 and 1.9.  Metadata contains a single DOI landing page with references to:   * a citable peer-reviewed algorithm * technical documentation regarding the implementation of the other trace gaseous absorption correction algorithm | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.8** | **Sun Glint Correction** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  The metadata indicates the surface contributions from Sun glint removed from the data if a pixel is assessed as being of correctable (moderate) Sun glint. |
| **3.9** | **Sky Glint Correction** | [AR] | **Threshold (Minimum) Requirements**  Sky glint is implicitly corrected for in the atmospheric correction procedure. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Sky glint is separately assessed and corrected for in the data processing. The metadata indicates the surface contributions from sky glint are removed from the data. |
| **3.10** | **Whitecap/ Foam Correction** | [AR] | **Threshold (Minimum) Requirements**  The water-leaving reflectance or radiance is corrected for the contribution from surface whitecaps and foam if a pixel is assessed as affected by whitecaps or foam. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.11** | **Adjacency Effects Correction** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Information on adjacency effects correction (for example, citable peer-reviewed algorithm approach, technical documentation of the implementation, sources of ancillary data) should be available in the metadata as a single DOI landing page. |
| **3.12** | **Floating Vegetation/ Surface Scum Correction** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether a pixel has been corrected for floating vegetation/surface scum or not. In that case information on floating vegetation/surface scum water mask should be available in the metadata as a single DOI landing page. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.13** | **Turbid Water Correction** | [AR] | **Threshold (Minimum) Requirements**  The metadata indicates whether the atmospheric correction accounted for a pixel being turbid or not. In that case information on turbid water mask should be available in the metadata as a single DOI landing page. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.14** | **Bidirectional Reflectance Distribution Function Correction** | [AR] | **Threshold (Minimum) Requirements**  Not required. | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  Data is corrected for BRDF effects (see also 3.3.). |
| **3.15** | **Lunar Radiance Corrections** | [NLSR] | **Threshold (Minimum) Requirements**  Corrections are applied for lunar radiance.  Metadata contains a single DOI landing page with references to:   * A citable peer-reviewed algorithm * Technical documentation regarding the implementation of that algorithm and the lunar model used   *Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |
| **3.16** | **Stray Light Corrections** | [NLSR] | **Threshold (Minimum) Requirements**  Corrections are applied for stray light.  Metadata contains a single DOI landing page with references to:   * A citable peer-reviewed algorithm * Technical documentation regarding the implementation of that algorithm and the lunar model used   *Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) Requirements**  As threshold. |

## 

## 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 Optical product (SR, ST, AR, NLSR) the parameter refers.*

| **#** | **Parameter** | **CEOS-ARD product** | **Requirements** | **Self-Assessment** |
| --- | --- | --- | --- | --- |
| **4.1** | **Geometric Corrections** | [SR]  [ST]  [AR]  [NLSR] | **Threshold (Minimum) Requirements**  Sub-pixel accuracy is achieved in relative 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.  *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.* | Achieved level: Threshold / Goal  Explanation / Justification: …  Other feedback: … |
| **Goal (Desired) 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 1.8 and 1.9.  *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.* |

# Summary Self-Assessment Table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  | **Threshold** | **Goal** |
|  | **CEOS-ARD product** | **General Metadata** |  |  |
| 1.1 | [ALL] | Traceability |  |  |
| 1.2 | [ALL] | Metadata Machine Readability |  |  |
| 1.3 | [ALL] | Data Collection Time |  |  |
| 1.4 | [ALL] | Geographical Area |  |  |
| 1.5 | [ALL] | Coordinate Reference System |  |  |
| 1.6 | [ALL] | Map Projection |  |  |
| 1.7 | [ALL] | Geometric Correction Methods |  |  |
| 1.8 | [ALL] | Geometric Accuracy of the Data |  |  |
| 1.9 | [ALL] | Instrument |  |  |
| 1.10 | [ALL] | Spectral Bands |  |  |
| 1.11 | [ALL] | Sensor Calibration |  |  |
| 1.12 | [ALL] | Radiometric Accuracy |  |  |
| 1.13 | [ALL] | Algorithms |  |  |
| 1.14 | [ALL] | Auxiliary Data |  |  |
| 1.15 | [ALL] | Processing Chain Provenance |  |  |
| 1.16 | [ALL] | Data Access |  |  |
| 1.17 | [ALL] | Overall Data Quality |  |  |
|  |  |  | **Threshold** | **Goal** |
|  | **CEOS-ARD product** | **Per-Pixel Metadata** |  |  |
| 2.1 | [ALL] | Metadata Machine Readability |  |  |
| 2.2 | [ALL] | No Data |  |  |
| 2.3.1 | [SR]  [ST]  [NLSR] | Incomplete Testing |  |  |
| 2.3.2 | [AR] | Per-pixel Assessment |  |  |
| 2.4.1 | [ALL] | Saturation |  |  |
| 2.4.2 | [ALL] | Cloud |  |  |
| 2.4.3 | [ALL] | Cloud Shadow |  |  |
| 2.4.4 | [SR]  [AR]  [NLSR] | Land/Water Mask |  |  |
| 2.4.5 | [SR]  [ST]  [NLSR] | Snow/Ice Mask |  |  |
| 2.4.6 | [SR]  [NLSR] | Terrain Shadow Mask |  |  |
| 2.4.7 | [SR]  [NLSR] | Terrain Occlusion |  |  |
| 2.4.8 | [AR] | Sea/Lake/River Ice Mask |  |  |
| 2.4.9 | [AR] | Sun Glint |  |  |
| 2.4.10 | [AR] | Sky Glint |  |  |
| 2.4.11 | [AR] | Whitecap/Foam Mask |  |  |
| 2.5 | [SR]  [ST]  [AR] | Solar and Viewing Geometry |  |  |
| 2.6 | [NLSR] | Lunar and Viewing Geometry |  |  |
|  |  |  | **Threshold** | **Goal** |
|  | **CEOS-ARD product** | **Per-Pixel Metadata** |  |  |
| 2.7 | [SR]  [NLSR] | Terrain Illumination Correction |  |  |
| 2.8 | [AR] | Adjacency Effects |  |  |
| 2.9 | [AR] | Floating Vegetation/Surface Scum Mask |  |  |
| 2.10 | [SR]  [AR]  [NLSR] | Aerosol Optical Depth Parameters |  |  |
| 2.11 | [AR] | Deep/Shallow Water |  |  |
| 2.12 | [AR] | Optically Deep or Optically Shallow Assessment |  |  |
| 2.13 | [AR] | Turbid Water Flag |  |  |
| 2.14 | [AR] | Bidirectional Reflectance Distribution Function |  |  |
| 2.15 | [AR] | Altitude (ASL) |  |  |
| 2.16 | [NLSR] | Moon Illumination Fraction |  |  |
| 2.17 | [NLSR] | Brightness Temperature |  |  |
| 2.18 | [NLSR] | Solar Zenith Angle |  |  |
|  |  |  | **Threshold** | **Goal** |
|  | **CEOS-ARD product** | **Radiometric and Atmospheric Corrections** |  |  |
| 3.1 | [ALL] | Measurement |  |  |
| 3.2 | [ALL] | Measurement Uncertainty |  |  |
| 3.3 | [SR]  [AR]  [NLSR] | Measurement Normalisation |  |  |
| 3.4.1 | [SR] | Directional Atmospheric Scattering |  |  |
| 3.4.2 | [ST] | Corrections for Atmosphere and Emissivity |  |  |
| 3.4.3 | [AR] | Atmospheric Reflectance Correction |  |  |
| 3.4.4 | [NLSR] | Atmospheric Corrections |  |  |
| 3.5 | [SR]  [AR] | Water Vapour Corrections |  |  |
| 3.6 | [SR]  [AR] | Ozone Corrections |  |  |
| 3.7 | [AR] | Other Trace Gaseous Absorption Corrections |  |  |
| 3.8 | [AR] | Sun Glint Correction |  |  |
| 3.9 | [AR] | Sky Glint Correction |  |  |
| 3.10 | [AR] | Whitecap/Foam Correction |  |  |
| 3.11 | [AR] | Adjacency Effects Correction |  |  |
| 3.12 | [AR] | Floating Vegetation/Surface Scum Correction |  |  |
| 3.13 | [AR] | Turbid Water Correction |  |  |
| 3.14 | [AR] | Bidirectional Reflectance Distribution Function Correction |  |  |
| 3.15 | [NLSR] | Lunar Radiance Corrections |  |  |
| 3.16 | [NLSR] | Stray Light Corrections |  |  |
|  |  |  | **Threshold** | **Goal** |
|  | **CEOS-ARD product** | **Geometric Corrections** |  |  |
| 4.1 | [ALL] | Geometric Corrections |  |  |

# Guidance

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

# Introduction to CEOS-ARD

**What is CEOS Analysis Ready Data?**

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

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

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

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

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

Agencies or other entities considering undertaking an assessment process should consult the CEOS-ARD [Governance Framework](https://docs.google.com/document/d/15grQ79D-Ge8PN1_4_XDmci5iezs8HAcOpLcM7d2wmAo/edit?usp=sharing).

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

**What is the difference between Threshold and Goal?**

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

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

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

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

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

# Reference Papers [CEOS-ARD for Optical Data]

The following papers provide scientific and technical guidance:

## Surface Reflectance [SR]

Li, F., Jupp, D.L.B., Thankappan, M., Lymburner, L., Mueller, N., Lewis, A., Held, A. (2012). A physics-based atmospheric and BRDF correction for Landsat data over mountainous terrain. Remote Sensing of Environment 124 756–770. <https://doi.org/10.1016/j.rse.2012.06.018>

## Surface Temperature [ST]

Cook, M., Schott, J.R, Mandel, J., Raqueno, M. (2014). Development of an Operational   
Calibration Methodology for the Landsat Thermal Data Archive and Initial Testing of the Atmospheric Compensation Component of a Land Surface Temperature (LST) Product from the Archive. Remote Sensing 6 (11244-11266). doi:10.3390/rs61111244 ISSN 2072-4292. [www.mdpi.com/journal/remotesensing](http://www.mdpi.com/journal/remotesensing)

Li et al., (2013) Satellite-derived land surface temperature: Current status and perspectives. Remote Sensing of Environment 131 14–37. <https://doi.org/10.1016/j.rse.2012.12.008>

## Aquatic Reflectance [AR]

Botha, E.J., Brando, V.E., & Dekker, A.G., 2016. Effects of per-pixel variability on uncertainties in bathymetric retrievals from high-resolution satellite images. Remote Sens. 8(6), 459, <https://doi.org/10.3390/rs8060459>.

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Brando, V.E., Anstee, J.M., Wettle, M., Dekker, A.G., Phinn, S.R., & Roelfsema, C., 2009. A physics based retrieval and quality assessment of bathymetry from suboptimal hyperspectral data. Remote Sens. Environ. 113(4), 755-770, <https://doi.org/10.1016/j.rse.2008.12.003>.

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Bulgarelli, B. & Zibordi, G., 2018b. Seasonal impact of adjacency effects in ocean color radiometry at the AAOT validation site. IEEE Geosci. Remote. Sens. Lett. 15(4), 488-492, <https://doi.org/10.1109/LGRS.2017.2781900>.

Bulgarelli, B. & Zibordi, G., 2020. Adjacency radiance around a small island: implications for system vicarious calibration. Appl. Opt. 59(10), C63-C69, <https://doi.org/10.1364/AO.378512>.

C-GLOPS-2, 2018. Lake Ice Extent (LIE) collection 250m Baltic Sea region, Version 1.0.1. Algorithm Theoretical Basis Document CGLOPS2\_QAR\_LIE-250m-V1.0.1, I1.03, Copernicus Global Land Service, 09.11.2018.

Colin F.M., 2014. Glint Avoidance and Removal in the Maritime Environment. Thesis. Rochester Institute of Technology, accessed from <https://scholarworks.rit.edu/theses/8301/> on 27. September 2021.

De Keukelaere, L., Sterckx, S., Adriaensen, S., Knaeps, E., Reusen, I., Giardino, C., Bresciani, M., Hunter, P., Neil, C., Van der Zande, D., & Vaiciute, D., 2018. Atmospheric correction of Landsat-8/OLI and Sentinel-2/MSI data using iCOR algorithm: validation for coastal and inland waters. Eur. J. Remote Sens. 51(1), 525-542, <https://doi.org/10.1080/22797254.2018.1457937>.

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## Nighttime Light Surface Radiance [NLSR]

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